AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY

1. SUBJECT CLASSIFICATION
A. PRIMARY
Science and Technology
B. SECONDARY
Construction

2. TITLE AND SUBTITLE
Development of low-cost roofing from indigenous materials in developing nations; annual report, 1974/1975

3. AUTHOR(S)
Monsanto Research Corporation, Dayton, Ohio

4. DOCUMENT DATE
1975
5. NUMBER OF PAGES
335 p.
6. ARC NUMBER
ARC
7. REFERENCE ORGANIZATION NAME AND ADDRESS
Monsanto Research Corporation, Dayton Laboratory, Dayton, Ohio 45407
8. SUPPLEMENTARY NOTES (Sponsoring Organization, Publishers, Availability)
(Research summary)

9. ABSTRACT
This report discusses the second phase (May 1974 through September 1975) of a three-phase, 3.5-year research effort to produce improved roofing for developing countries by matching indigenous fibers and fillers with low-cost binders. The ultimate goal of the program is to make available, in at least three countries, one each in Latin America, Asia, and Africa, an economically and technically acceptable roofing system that requires less foreign exchange than existing alternatives. The program objective is to be demonstrated within each of the participating countries through construction of at least four prototype roofs and transfer of the necessary technology to qualified organizations. Current collaborating countries are Jamaica, Philippines, and Ghana. The project emphasis during Phase II was on development of roofing materials and establishing the mechanism for the technology transfer. Primary objectives of the materials development included establishing a generalized set of criteria for roofing; defining composite material ingredients; determining the most promising sets of materials, processes, and products; and analyzing the cost and practicality of the candidate systems. Four candidate composite roofing material systems were defined that use from 70 to 100% indigenous material. Outstanding as a filler is the sugar cane residue, bagasse. The primary candidate binders include natural rubber, phenolic, and commercial thermoplastic resins. Accelerated and outdoor aging are demonstrating the viability of the candidate systems. The objectives of the technology transfer aspects included defining potential collaborative institutions and individuals in Jamaica, the Philippines, and Ghana; forming Advisory and Technical Working Committees in each of these countries that would participate in the roofing development program; and locating qualified organizations interested in future commercial production of the roofing. Those institutions, committees, and working groups were defined in the three countries and

10. CONTROL NUMBER
PN-AAB-674
11. PRICE OF DOCUMENT

12. DESCRIPTORS

13. PROJECT NUMBER

14. CONTRACT NUMBER
AID/CM/ta-C-73-12 Res.
15. TYPE OF DOCUMENT

AID 590-1 (4-74)

are functioning to various degrees, with Jamaica taking the lead. Private industry organizations that may become future manufacturers of the roofing have been located in each of the three countries. During Phase III, October 1975 through December 1976, the program will be brought to completion through material optimization, design, fabrication, testing, and evaluation of prototype roofing; and field manufacture, installation, and evaluation of full-scale roofing.

MRC-DA-517

DEVELOPMENT OF LOW-COST ROOFING FROM INDIGENOUS MATERIALS IN DEVELOPING NATIONS

Contract No. AID/CM/ta-C-73-12

SECOND ANNUAL REPORT

Period Covered: May 1974 through September 1975

For

Agency for International Development
Department of State
Washington, D.C. 20523

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18 December 1975

 This annual report incorporates the substance of the required eighth and ninth quarterly reports.

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ABSTRACT

This report covers Phase II (May 1974 through September 1975) of a 3-1/2 year research effort to match indigenous fibers and fillers with low cost binders to produce improved roofing for developing countries. The ultimate goal of the program is to make available, in at least three countries, one each in Latin America, Asia, and Africa, an economically and technically acceptable roofing system requiring less foreign exchange than existing alternatives.

Achieving the program objective is to be demonstrated within each of the participating countries through (a) the construction of at least four prototype roofs and (b) transfer of the necessary technology to qualified organizations. The current collaborating countries are Jamaica, Philippines and Ghana.

The project emphasis during Phase II was on roofing materials development; and establishing the mechanism for the transfer of the technology .

The primary objectives of the materials development included establishing a generalized criteria for roofing; defining composite material ingredients, determining the most promising sets of materials, processes and products; and analyzing the cost and practicality of the candidate systems.

Four candidate composite roofing material systems were defined that utilize between 70 and 100% indigenous material. Outstanding as a filler is the sugar cane residue, bagasse. The primary candidate binders include natural rubber, phenolic, and commercial thermoplastic resins. Accelerated and outdoor aging are demonstrating the viability of the candidate systems.

The objectives of the technology transfer aspects included defining potential collaborative institutions and individuals in Jamaica, the Philippines, and Ghana; forming Advisory and Technical Working Committees in each of these countries that would participate in the roofing development program; and locating qualified organizations interested in future commercial production of the roofing.

The collaborative institutions, Advisory Committees and Working Groups were defined in Jamaica, Philippines, and Ghana. These are functioning to various degrees, with Jamaica taking the lead. Private industry organizations that may become future manufacturers of the roofing have been located in each of the three countries.

During the third phase, October 1975 through December 1976, the program will be brought to completion through material optimization, design, fabrication, testing and evaluation of prototype roofing; and field manufacture, installation and evaluation of full-scale roofing.

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NOTE

All cost information is given in equivalent United States dollars ($) or cents (¢) unless otherwise indicated.

All data was generated and is reported in English scientific units.

1. INTRODUCTION

Adequate housing of citizens is essential in all developing countries. However, before houses of the desired quality and quantity can be made available within the framework of the limited economies of these countries, it is necessary to reduce material and construction costs, especially those requiring foreign exchange. A roof is one of the key and more costly elements of construction. Thus it is a prime target for cost reduction and performance upgrading.

The United Nations has appealed for research and development to provide improvements in roofing. A special study conducted by the U. S. National Academy of Sciences and Engineering also recommended the implementation of specific roofing research projects, particularly on composites incorporating indigenous fillers and polymeric binders.

In response to these appeals, the U. S. Agency for International Development has sponsored a research and development effort with Monsanto Research Corporation to match indigenous fillers with low cost binders, to produce roofing with a wide range of applicability in the developing countries. The research results were to be directed toward meeting low cost housing needs, improving the foreign exchange position of the countries involved, and developing products that may be the basis of a local industry.

The ultimate goal of the research and development program is to make available, in at least three countries (one each in Africa, Asia, and Latin America) an economically and technically acceptable alternative roofing system requiring little foreign exchange.

The means of achieving this ultimate goal are to be demonstrated within each of the three participating countries through: (a) the construction of at least four prototype roofs, and (b) transfer of the necessary technology to qualified organizations. It is important that this technology be known and well understood by individuals in these organizations in order to assure the future utilization of the technology and its intrinsic value to the construction industry.

The roofing development program will emphasize:

- competitive costs,
- minimum foreign currency requirements,
- competitive performance,
- durability,
- acceptability,
- competitive installation methods,
- low-capital manufacturing,
- renewable or under-utilized ingredients, and
- applicability in other developing countries.

Foreign currency requirements are to be minimized through the development of a composite material that requires only a minor amount of imported binder and/or additives. The roofing must be processable locally with indigenous materials, and abundant manpower; i.e., the value added is to be maximized for the participating countries. Performance and durability are to include resistance to static loading, impact, solar radiation, heat, rain, humidity, wind, fire, sound transmission, insects, pests, and fungus. Acceptability is to include such factors as appearance shape, form, and prestige. Manufacturing, ideally, will be cost competitive in either small-scale (rural villages) or large-scale (urban) operations.

The program is divided into three phases:

- Phase I (May 1973-May 1974) Problem Definition and Country Selection
- Phase II (May 1974-May 1975) Roof Definition, Ingredient Selection, Laboratory Composite Material and Process Development, and Collaborative Institution Definition
- Phase III (May 1975-December 1976) Material Optimization, Design, Fabrication, Testing and Evaluation of Prototype Roofing: Field Manufacture, Installation and Evaluation of Full-Scale Roofing

Phase I was completed in May 1974. The specific results included:

- The selection of the Philippines, Zambia, and Jamaica as participating countries.
- The definition of a host of institutions and individuals with expertise in the required scientific areas who agreed to participate if called upon.

- The collection and assimilation of information, literature and representative samples of potentially valuable indigenous binders and fillers.

- The initiation of a screening effort to determine the applicability of the indigenous raw materials to a composite roofing system. Numerous, obviously less appropriate materials were eliminated from further consideration.

The specific objectives for Phase II (May 1974-May 1975) were to:

- Define potential collaborative institutions and individuals in the selected countries,

- Form an advisory committee of experts in each selected country,

- Form a working group in each selected country to implement an advanced roofing development program,

- Establish generalized criteria for roofing,

- Define candidate composite material ingredients,

- Optimize and select the most promising sets of materials and processes based on performance, and

- Conduct an initial cost and practicality analysis.

The contents of this report encompass Phase II (through May 1975) and an additional four months work (through September 1975).

This 3-1/2 year program is being administered under the direction of the Agency for International Development, Department of State, Washington, D. C. The AID project manager is Mr. William H. Littlewood, Associate Director, Office of Science and Technology (TA/OST), Agency for International Development. Support, especially in monitoring the technical aspects of the program, is provided by the Materials and Safety Division, Center for Building Technology, National Bureau of Standards, Department of Commerce, headed by Dr. Edward O. Pfrang, Chief, Structures.

The program manager for Monsanto Research Corporation is Ival O. Salyer, Manager, Polymer Physics and Applications. George L. Ball III, Polymer Applications Research Group Leader, is project leader. Technical assistance is provided by Arthur M. Usmani, Dennis W. Werkmeister, and Robert D. Myers.

Under subcontract, the Center for Development Technology, Washington University, St. Louis, Mo., provides architectural, sociological, and economic input to the program. Professor J.P.R. Falconer, Associate Director, heads this effort in St. Louis and in the field.

Valuable assistance in agricultural fiber utilization is being provided on a consulting basis by Dr. Ben S. Bryant, Professor, Wood Utilization Technology, Wood and Paper Division, College of Forest Resources, University of Washington, Seattle, Washington.

2. SUMMARY

This roofing development program has two aspects. The first involves the actual development of roofing materials. The second involves the transfer of the developed technology through collaboration and demonstration in three participating countries. The development was started in a research program at Monsanto Research Corporation's Dayton Laboratory and will expand through experimental work to be conducted at qualified institutions in the participating countries. During Phase II about equal effort went into each of these two aspects.

2.1 COLLABORATION, DEMONSTRATION AND TRANSFER OF TECHNOLOGY

The primary objectives of the technology transfer aspects of Phase II were achieved. These included: (a) defining potential collaborative institutions and individuals in three developing nations, (b) forming advisory committees with expertise in each of these countries, and (c) forming working groups in each of these countries that would participate in an advanced roofing development program.

Three countries, one each in Latin America, Asia and Africa, were selected at the end of Phase I. These included: Jamaica, the Philippines, and Zambia. Zambia continued to be the participating country in Africa throughout Phase II; however, progress in negotiating a working agreement was slow. During the writing of this report, it was made known that Zambia could not commit the necessary resources to allow participation. Accordingly, the appropriate officials in Ghana were approached to determine if their interest in participation still existed, and if so, whether or not they would participate. All parties were in accord and Ghana has now been designated the participating country in Africa. Because of this chain of events, Phase II work conducted in Africa was done in the context of Zambia.

2.1.1 Defining Collaborative Institutions and Individuals

The purpose of this task was to obtain the information needed to rationally select members of advisory committees and working groups. It was initiated in Phase I, however, participating countries were not defined and the composite materials experimental program had not evolved sufficiently at that time to describe the specific types of participation required. Information was available only in general terms, but was adequate to guide the selection of the participating countries.

Definition of potential collaborators was conducted in Phase II, after the three participating countries had been selected and the materials research had progressed sufficiently to define areas of expertise to be required.

The search for qualified collaborators included the various sectors of government, industry, academic institutions, and individuals. Expertise in the areas of housing, roofing, engineering, specifications, research and development, materials, economics, agricultural residues, minerals, testing, composites, importing, processing, outdoor exposure, and urban development was defined. This was done initially in order to select the appropriate institutions, and then the individuals within them who could directly contribute and participate.

2.1.2 Forming Advisory Committees

The approach being taken in the program is to form technical advisory committees in each of the participating countries. They are to provide for bilateral communication, exchange of information, and control of the program results. The detailed local requirements of the participating countries is most accurately known by them. Monsanto Research Corporation's primary role is to contribute its extensive background in materials and composites research and development.

Advisory committees were formed in Jamaica and the Philippines and staffed with representatives of various government, industry, and academic agencies. A typical advisory committee is that for Jamaica shown in Table 1.

Table 1

IMPROVED ROOFING MATERIALS WITH ECONOMIC TRADE BENEFITS TO JAMAICA; ADVISORY COMMITTEE

ADVISORY COMMITTEE MEMBERS

Organization	Representative	Title
Douet Brown Adams and Partners (DBAP) 7 Lismore Avenue Kingston 5 Phone: 926-3485	Alfrico D. Adams	Chartered Engineer and Roof Program Coordinator
Ministry of Housing (MH) 2 Hagley Park Road Kingston 10 Phone: 936-1590, Ext. 330	Rev. G. L. McLaughlin Ms. Nadine Isaacs	Special Advisor to the Minister Architect
Scientific Research Council (SRC) Old Hope Road, P.O. Box 350 Kingston 6 Phone: 937-9931 (32,22)	Dr. K. E. Magnus Mr. Fred Campbell	Technical Director Senior Principal Scientific Officer
National Housing Corp (NHC) 6a Oxford Road, P.O. Box 48 Kingston 6 Phone: 926-5854 (55,56)	Ms. T. Nelson	Research Officer Science and Technology
Bureau of Standards (JBS) 6 Winchester Road Kingston 10, Phone: 926-3140	Dr. A. S. Henry Mr. Campbell Mr. A. K. Elliott	Director Head, Materials Administrative Secretary
U. of West Indies (UWI) Mona Road Kingston 7 Phone: 927-0751	Dr. Thomas Hughes	Prof. of Material Science
Jamaica Industrial Development Corp (JIDC) 4 Winchester Road, P.O. Box 505 Kingston 10 Phone: 936-3130		
Urban Development Corp (UDC) 40 Harbour Street Kingston Phone: 929-2240	Mr. David Gregory-Jones	Chief Architect and Planner
Knox Development Foundation (KDF) P.O. Box 45 Spaldings Phone: 964-2359	Mr. Lewis Davidson	Director
Standard Building Products (Jamaica) Ltd. (SBP) P.O. Box 29 66 Corletts Road Spanish Town Phone: 984-2295 (96)	Mr. Douglas Wynter Mr. M.K.S. Biersay	Technical Director Vice President for Sales and Marketing
Berger Paints (BP) 256 Spanish Town Road Kingston 11 Phone: 923-6226 (30)	Mr. M. S. Fennel Mr. Dervin R. Brown	General Manager Technical Manager
Thermoset Ltd. (TS) Office - 14 Dominica Drive Kingston 5 Plant - Naggo Head Phone: 936-5920 936-6394	Dr. Lester A.D. Chin Mr. James A. Blackwood	Technical Director Managing Director
Plastic Products Ltd. (PPL) 2 Jones Avenue Kingston 11 Phone: 933-6379 923-6450	Mr. Stanley L. Borland Mr. Jerry E. Burwell	Managing Director Technical Director
Goodyear Jamaica Ltd (GY) Office - 29 Tobago Avenue Kingston 10 Plant - Morant Bay Phone: 926-8018 982-2353	Mr. T. S. Elliott Mr. Helmut Schueller	Manager, GMMC Technical Superintendent
Thermo-Plastics (Jamaica) Ltd. (TP) 45 Elma Crescent Boulevard P.A. Phone: 935-2390 925-1050	Mr. Desulme Mr. Yvon T. Desulme Mr. Ludwig Reisinger	President Purchasing Manager Manufacturing Manager
A. F. Pattinson Co. (PAT) 2 Marcus Garvey Drive Kingston Phone: 932-0365	Mr. A. F. Pattinson	Manufacturer's Representative
U.S. A.I.D. Mission (AID) to Jamaica Duke Street Kingston Phone: 932-6340	Mr. Peter Kolar	Program Officer

A chairman for each of the advisory committees was designated. The chairman is to see that the committee meets, functions, and achieves the objectives of the program. He is to form a working group that is to implement an advanced roofing development effort. The chairman is the primary contact in each of the participating countries and will coordinate their efforts with the Monsanto Research Corporation program in Dayton. Initially, contacts between these chairmen will be made through the MRC project leader. However, it is anticipated that eventually direct communication will be introduced between advisory committees and the working groups.

The chairman of the advisory committee in Jamaica is Alfrico D. Adams, a chartered engineer with the firm of Douet Brown Adams and Partners, 7 Lismore Avenue, Kingston 5, Jamaica, West Indies. The chairman of the advisory committee in the Philippines is Florencio A. Medina, chairman of the National Science Development Board. Formation of the advisory committee in Ghana has not yet been completed, but it is expected that the primary contact will be through the Director of the Building and Roads Research Institute (Dr. Joe DeGraft-Johnson), Council for Scientific and Industrial Research, Kumasi, Ghana.

These advisory committees will provide advice and consent to the various developments carried out by Monsanto Research Corporation and the participating institutions. This is to assure the validity of the work being done and the viability of any roofing product eventually developed. The existence of these advisory committees also assures that a large number of individuals and several institutions will be aware of the work going on and will be able to take advantage of it at the earliest possible time.

2.1.3 Forming Advanced Roofing Development Working Groups

The formation of working groups to expand on the MRC research and development program is a critical task of the project. A group of individuals and institutions is required that can take the existing information, assimilate it, and conduct experimental efforts to optimize and refine the various candidate roofing materials specific to their local areas. It is important that the materials aspects of the completed work be understood, but it is also important that the program move rapidly through the materials development stage to design, actual fabrication, and installation of roofing.

Working groups were defined and formed in Jamaica and the Philippines. The efforts of the working committee in Jamaica will be coordinated by Alfrico D. Adams (who is also chairman of the advisory committee) and in the Philippines by Miss Lydia G. Tansinsin, of the National Science Development Board. The primary experimental effort on materials in Jamaica will be conducted at the Scientific Research Council with Mr. Fred Campbell, a senior principal scientific officer, acting as the project leader.

Members of the working group in Jamaica are shown in Table 2, and illustrated in Figure 1, typifying the range of institutions and individuals that are involved, ranging from materials through housing capabilities.

The experimental work in the Philippines will be coordinated through the National Science Development Board. Research will be conducted by the Forest Products Research and Industries Development Commission and the National Institute of Science and Technology. Design will be provided by the University of the Philippines Building Research Center and the Philippine Institute for Civil Engineering. Construction will involve the National Housing Corporation and the Peoples Homesite and Housing Corporation.

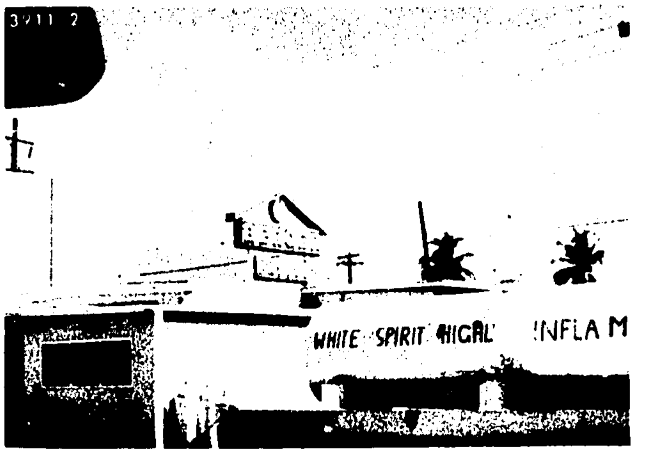
During Phase II the working groups were shown the latest developments in the experimental program by the MRC project coordinators. It is expected that experimental work will be implemented early in Phase III in both Jamaica and the Philippines and early in 1976 in Ghana. Their initial task will consist of duplicating the results achieved in MRC's Dayton Laboratory on the materials systems that appear to be more promising for the local situation. Establishing criteria for roofs will also be conducted early in that effort.

Table 2

IMPROVED ROOFING MATERIALS WITH ECONOMIC TRADE BENEFITS TO JAMAICA; WORKING GROUP

Organization	Representative	Title	Role
JAMAICA			
Douet Brown Adams and Partners 7 Lismore Avenue Kingston 5 Phone: 926-3485	Alfrico D. Adams	Chartered Engineer and Roof Program Coordinator for MRC	Coordination and Engineering
Ministry of Housing 2 Hagley Park Road Kingston 10 Phone: 936-1590	Ms. Nadine Isaacs	Architect	Architectural support
Scientific Research Council Old Hope Road, P. O. Box 350 Kingston 6 Phone: 937-9931	Mr. Fred Campbell	Senior Principal Scientific Officer	Materials and Design Research
University of West Indies Mona Road Kingston 7 Phone: 927-0751	Dr. Thomas Hughes	Professor of Material Science	Composite Materials and Testing Consultant
Berger Paints 256 Spanish Town Road Kingston 11 Phone: 923-6226	Mr. Dervin R. Brown	Technical Manager	Outdoor Exposure

(a) Scientific Research Council
(Research and Development)



(b) Berger Paints
(Outdoor Exposure)

(c) Thermo-Plastics Group Ltd.
(Plastic Processing)

(d) Thermoset Ltd.
(Plastic Laminating)

Figure 1. Organizations in Jamaica that Typify Working Group Participants.

2.2 ROOFING MATERIALS DEVELOPMENT

The primary objectives of the materials development facet of Phase II were achieved. These included (a) establishing generalized criteria for roofing, (b) defining composite material ingredients through a screening process, (c) defining the most promising sets of materials and processes based on the performance of the products generated, and (d) analyzing on a preliminary basis the cost and practicality of the more promising products.

2.2.1 Roof Criteria

A set of criteria for roofs was established that included generalized requirements and also those necessary due to the specific objectives of AID. Three categories of criteria were used. These included: Requirements (must be achieved); Desirable Characteristics (desirable but not necessary); and Highly Desirable Characteristics (to be emphasized due to specific USAID objectives).

It was found necessary to establish criteria for a roof, rather than just for a roofing material. Taken into consideration were the roofing material itself, architectural design, contruction and detailing, economics, and sociological factors. Additionally, only roofing for residential, single-story, moderately sized houses was considered.

The "required" and "highly desirable" characteristics determined are listed in Table 3. The "required" characteristics are not weighted, since they are necessary conditions. Further definition of these characteristics, however, is necessary to establish the specific degrees of performance needed to meet these requirements. These definitions are given in the text, section 4.2.1.

The "highly desirable" characteristics are weighted based on criticality of performance, the degree of emphasis suggested by AID personnel, and the consequences of achieving these characteristics based on the designated approach, e.g. disadvantages of organic binders.

Numerous additional desirable characteristics were also selected, in terms of mechanical, environmental and life, optical, social, thermal, and acoustic properties or characteristics. These were weighted in a manner similar to the highly desirable characteristics.

These roof criteria are being reviewed by our collaborators in participating countries to assure that the classifications and weightings coincide with local needs and desires.

Table 3

CRITERIA FOR ROOF

Requirements
Keep off rain
Not leak
Water resistant
Wind resistant
Adequate Strength
Keep out direct sun
Adequate life (3 years)
Available

Highly Desirable Characteristics	Weight
Low cost	9
Indigenous Material (>50%)	9
Acceptability	
User	8
Government	8
Fire resistance	5
Easy installation	5
Labor intensive mfg.	6
Reasonable life (5 years)	6

2.2.2 Screening of Material Ingredients

Material ingredients were selected through a screening process to provide the basis for composite material and process development. The screening was achieved through (a) determining a set of criteria, (b) determining techniques for conformance to these criteria, and (c) test and analysis.

The criteria for selection of materials included seven categories: source, availability, form, cost, mechanical performance, life and compatibility. In the first year of the program (Phase I) the screening was conducted using source, availability, form, and cost as criteria. A host of fillers passed this initial screening, but just a few indigenous binders were deemed worthy of more detailed analysis. About 20 fillers were examined in Phase II that were considered representative of those found or available in participating countries (see Figure 2). These included such materials as bagasse (residue from sugar cane) sawdust, wood shavings, bamboo, coconut husks, rice straw, ore tailings, clay, water and air.

These fillers were all examined as a primary constituent (70 vol %) of a composite with a polystyrene thermoplastic binder. All were prepared identically in a melt process using an intensive shear mixer (Banbury). Characterization included measurement of flexural and tensile strength and modulus initially, and following 1000-hour exposure in a carbon-arc weatherometer (with cyclic water, humidity, and temperature).

(a) Bagasse (sugar cane) in Jamaica, Ghana and Philippines

(c) Natural rubber (tree) in Ghana and Philippines

(b) Wood shavings in Ghana and Philippines

Figure 2. Typical Candidate Fillers and Binder Abundantly Available in Participating Countries

The results of this initial examination are listed in Table 4 in terms of initial and retained tensile strength. Bagasse and sawdust performed the best, as illustrated by their retention of initial properties (relative to the unfilled polystyrene) and after 1000-hour weatherometer exposure. The relatively low retained strengths indicated in the table are partially attributable to the use of unstabilized polystyrene for accelerated screening. These results are not indicative of the true properties of the materials as discussed later.

Importantly, in the screening, it was noted that the humidity and thermal cycling conditions caused the most rapid degradation of the highly filled composites. The ability of bagasse and sawdust to resist degradation was impressive. The rapid temperature/humidity degradation is in contrast to the milder effects of ultraviolet radiation, elevated temperatures, or just constant high humidities.

Bagasse was selected as the best candidate filler, with saw dust providing a good alternative, when available. It was significant that whole bagasse, which included at least 20% pith, was used in this evaluation.

Binders were placed in three categories: (a) thermoplastics, (b) thermosets, and (c) others. Like the fillers, significant screening had been conducted in Phase I based on binder source, availability, form, and cost. Additional study in Phase II

Table 4

SUMMARY OF TYPICAL RESULTS OF EFFECT OF FILLER ON TENSILE STRENGTH OF COMPOSITE PANELS[a]

Filler[b]	Tensile Strength, psi[c] Initial	After 1000 hr Exposure[d]	Strength Retained %
Bagasse	3400	1650	49
Sawdust	3700	1400	38
Bamboo	2000	0	0
Coconut Husks	3050	250	8
Rice Straw	2250	250	11
None	3450	1000	29

(a) Based on 70 vol % filler in polystyrene. Processed in Banbury using whole filler. Compression molded panels ∿9 in. x 9 in. x 1/8 in. Specimens milled from panel.
(b) Only processing of filler was Banbury mixing in presence of polystyrene, except for drying of green plants.
(c) ASTM D638 - tensile, rate 0.05 in./min.
(d) Tensile strength following 1000 hour exposure in Atlas weatherometer with cyclic UV, water spray, temperature, humidity.

included screening for mechanical performance, life, and compatibility. The binders examined are listed in Table 5. Thermoplastics included styrenics, olefins and PVC. Thermosets comprised polyesters, phenolics, and melamine/formaldehyde. The "other" binders encompassed natural rubber, polyelectrolytes, water-glass (sodium silicate), and naturally occurring aldehyde monomers (derived from pentosans in bagasse).

The screening process was severely complicated by the dynamic economic situation and its effect on synthetic binders during 1974-1975. Reconsideration of cost analyses conducted in Phase I was necessary. The general effect introduced was that the very low cost resins containing minor amounts of expensive modifiers increased in price to a much greater extent than the higher cost engineering plastics.

The binders were screened quantitatively through measurement of their initial and retained physical properties, and qualitatively through their processability and compatibility. Typical performance of the binders in combination with bagasse is illustrated in Table 6 for the styrenics and a sulfur-cured natural rubber. The relative performance of these binders is best illustrated by their retention of strength following 1000 hours exposure in a weatherometer (see Figure 3). The excellent performance of the styrene/acrylonitrile (SAN), acrylonitrile/butadiene/styrene (ABS) and the cured, stabilized natural rubber was shown relative to

Table 5

BINDERS EXAMINED IN PHASE II

Binders
THERMOPLASTIC
Styrene Acrylonitrile (SAN)
Acrylonitrile Butadiene Styrene (ABS)
Polystyrene (PS)
Polyvinyl Chloride (PVC)
Polyethylene (PE)
Polypropylene (PP)
THERMOSET
Phenol Formaldehyde (P/F)
Melamine Formaldehyde (U/F)
Polyester, General Purpose
Polyester, Water Extended (WEP)
OTHERS
Polyelectrolytes
Sodium Silicate
Natural Rubber
Furfural aldehyde derived from pentosan in bagasse-then reacted with phenol or melamine

Table 6

SUMMARY OF TENSILE STRENGTH PROPERTIES OF VARIOUS THERMOPLASTIC BINDERS AND NATURAL RUBBER FILLED WITH WHOLE BAGASSE

Binder[a]	Tensile Strength, psi: Initial	Tensile Strength, psi: Following 1000 hr Accelerated Exposure[b]	Percent Strength Retention
Styrene Acrylonitrile (SAN)	4000	3900	98
Acrylonitrile Butadiene Styrene (ABS)	4200	4200	100
General Purpose Polystyrene	3400	1650	49
Cured Natural Rubber	3000	2950	98

(a) 70 vol % bagasse filler; no stabilizers or pigments added except in the natural rubber formulation (Flectol H and Mapico #477)

(b) Cycle: 1 hr water spray, 3.8 hr carbon arc UV

(a) Tensile specimens exposed to accelerated conditions in Weather-ometer

(b) 9 in. x 9 in. panels on exposure rack outdoors at Berger Paints in Kingston, Jamaica

Figure 3. Illustration of Durability Analysis Through Environmental Exposure of Samples

the poor properties of polystyrene. Polystyrene durability could be improved, however, by the addition of stabilizers, UV screeners, etc, when economical.

The binders selected from the screening were SAN, ABS, polyvinyl chloride (PVC), phenol/formaldehyde (P/F), polyelectrolytes, and natural rubber. The olefins, polystyrene, polyesters, sodium silicate, and *in-situ* generated furfuraldehyde monomer were all deemed inadequate for a variety of reasons.

The best three binders were SAN, P/F, and natural rubber. The SAN was highly attractive from its well-known stability characteristics and its demonstrated mechanical performance in conjunction with bagasse. In this highly filled system it lacked sufficient toughness for nailability, but this was deemed to have a lower priority than other factors.

A specially plasticized and stabilized, PVC formulation was also included in this category late in Phase II. This synthetic resin is manufactured locally in the Philippines and thus could be considered "indigenous" in that country. For the Philippines at least, this modified PVC bagasse composition may offer an attractive combination of toughness, fire resistance and good outdoor aging.

Phenol/formaldehyde has been used successfully for many years as a resin binder in a variety of exterior applications. This combined with its performance in combination with bagasse, and its very low cost, contributed most to this resins acceptability.

Natural rubber (available in the Philippines) was highly attractive since it offered the potential of providing the base for a 100% indigenous roof. Natural rubber is not usually well-known for its long-term stability, but this can be improved with stabilizers and fillers. It has remained low in cost during the last few years, especially in the Philippines, giving it an unexpected cost advantage.

The other binders probably would be viable in developing a composite roofing material, but they were considered to be less effective. They may need to be examined in the future by the participating countries. This is expecially true of the *in-situ*-generated furfuraldehyde monomer from bagasse that could be substituted to further reduce cost once a phenol/formaldehyde based roofing system is developed.

Considerable attention was given to the use of polyelectrolytes in bonding clay. Water-proofing, a required characteristic, was approached through heating or chemical reaction to insolubilize the polyelectrolyte or by incorporation of wax. It was demonstrated that addition of as little as 0.05 part per hundred of polyelectrolyte could significantly enhance the compressive strength of clay, but attempts at adequately improving resistance to water immersion were not totally successful. It is suggested that consideration be given to these materials for the fabrication of construction members that are protected from water and used in compression, i.e. bricks, blocks, flooring, foundations, etc.

2.2.3 Primary Candidate Composite Materials and Processes for Roofing

Using the ingredients selected through the screening process, sets of composite materials were optimized with respect to process and formulation. Four categories of materials were defined, having as a prime distinction the nature of the process and secondarily the binder or the filler. In all cases, bagasse was considered as the primary filler, but sawdust could be substituted. Each category of material was processable with given equipment with latitude available for alternative binders.

The four categories of materials are:

I Melt-compounded, resin-bonded, bagasse-fiber-reinforced composites,

II Wet or dry-blended, thermoset resin-bonded, bagasse fiber-reinforced composites,

III Wet-process, thermoset resin-bonded, depithed-fibrillated-oriented-bagasse fiber-reinforced composites, and

IV Wet or dry-blended, resin-bonded, unfired clay tiles.

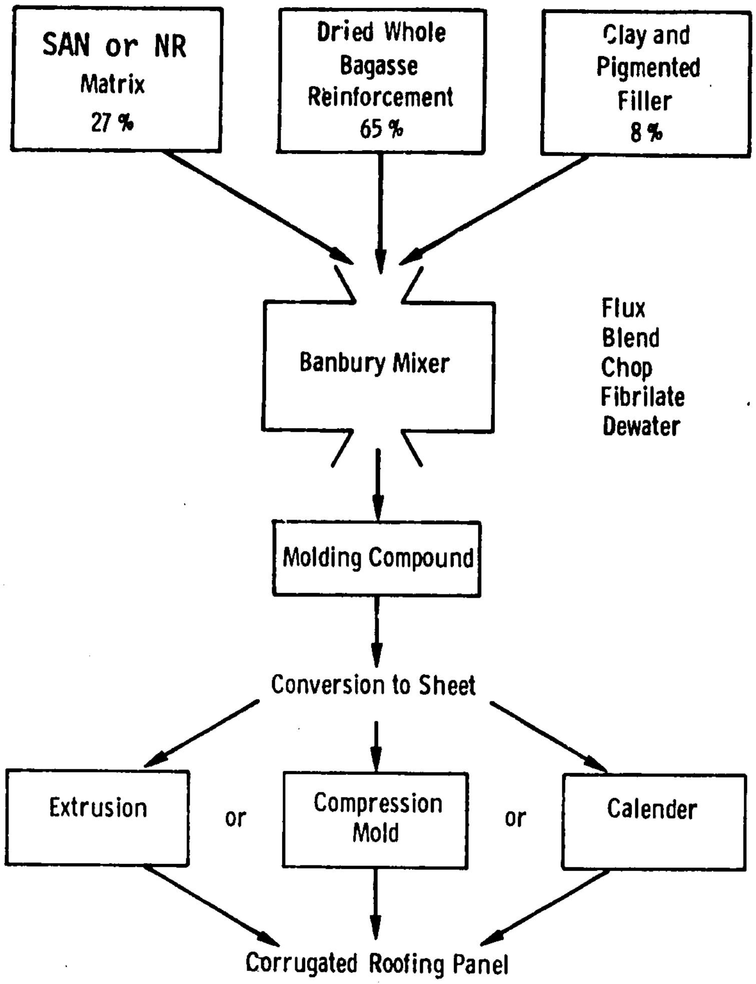
All the roofing materials would be applicable to thin corrugated roofing panel designs. The nature of the four categories of materials can best be illustrated by schematics of the processes for making them (also indicating ingredients) and listings of their mechanical properties, initially and following exposure in either a weatherometer or complete immersion in water. This information is contained in Tables 7 through 10.

Category I materials are highly attractive because of their excellent initial and retained properties, their ready formability into a variety of shapes, and the simplicity of the manufacturing process, which requires no pretreatment of whole bagasse (as received from a sugar mill), illustrated in Figure 4. The only disadvantage is the need for a specific type of intensive shear mixer (e.g. Banbury), which requires significant capital. Importantly, however, the only necessary equipment is this mixer and a sheet-forming apparatus (the sheet forming requirement is inherent in all categories of materials).

The primary advantage of the Category II materials is the simplicity of the process both in terms of equipment requirements and number of operations. Grinding of bagasse and separation (not removal) of pith is first necessary. Then, the bagasse is simply wet or dry blended with a thermosetting resin, and compression molded into a sheet. This process is by far the simplest of all the four systems. The fact that a thermosetting resin is used limits reprocessability of the material, but this is not a major

Table 7

SCHEMATIC PROCESS DESCRIPTION AND MECHANICAL PROPERTIES OF MELT-COMPOUNDED, RESIN-BONDED, BAGASSE-FIBER REINFORCED COMPOSITES (CATEGORY I)



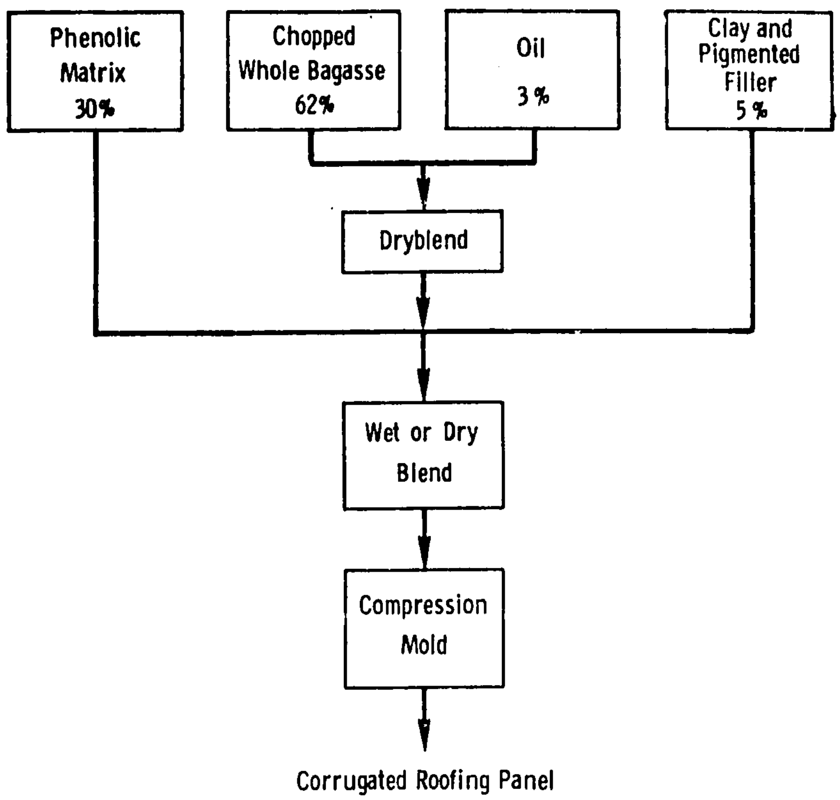
MECHANICAL CHARACTERISTICS

Binder	Initial Flexural Str. (psi)	Initial Flexural Mod. (10^3 psi)	Initial Tensile Str. (psi)	Initial Tensile Mod. (10^3 psi)	Tensile Following Exposure: Weatherometer (1000 hr) Str. (psi)	Tensile Following Exposure: Weatherometer (1000 hr) Mod. (10^3 psi)	Tensile Following Exposure: High UV (430 hr) Str. (psi)	Tensile Following Exposure: High UV (430 hr) Mod. (10^3 psi)
Styrene Acrylonitrile (SAN)	6400	1230	400	960	3900	942	3900	930
Acrylonitrile Butadiene Styrene (ABS)	5400	1110	4200	970	4200	940	4600	960
Natural Rubber (NR)	5000	3000	3000	--	2950	--	--	--

Table 8

SCHEMATIC PROCESS DESCRIPTION AND MECHANICAL PROPERTIES OF WET OR DRY BLENDED, THERMOSET-RESIN-BONDED, BAGASSE-FIBER REINFORCED COMPOSITES

(Category II)



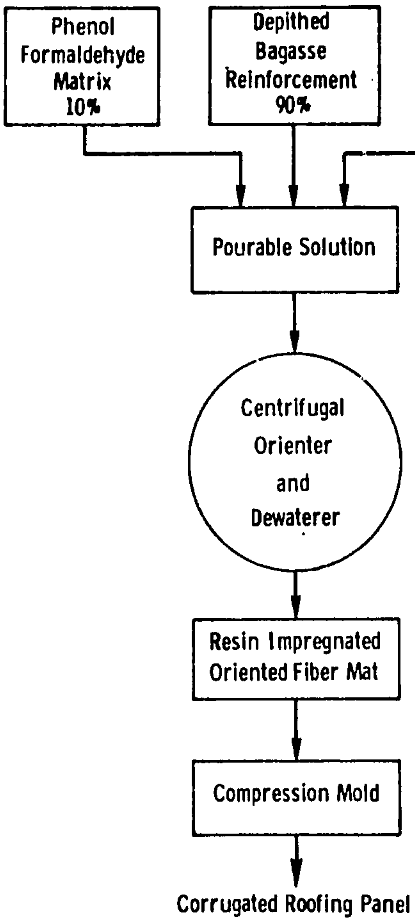
MECHANICAL PROPERTIES OF DRY BLENDED, PHENOLIC BONDED, BAGASSE FIBER REINFORCED COMPOSITE

Flexural Strength (psi)	
Dry	7200
Wet	5500
Flexural Modulus (psi, 10^3)	
Dry	710
Wet	510
Tensile Strength (psi)	
Dry	4130
Wet	3600
Tensile Modulus (psi, 10^3)	
Dry	830
Wet	680
Water Pickup (%)	1.9

Table 9

SCHEMATIC PROCESS DESCRIPTION AND MECHANICAL PROPERTIES OF WET-PROCESS, THERMOSET-RESIN-BONDED, DEPITHED-FIBRILLATED ORIENTED-BAGASSE-FIBER REINFORCED COMPOSITES

(Category III)

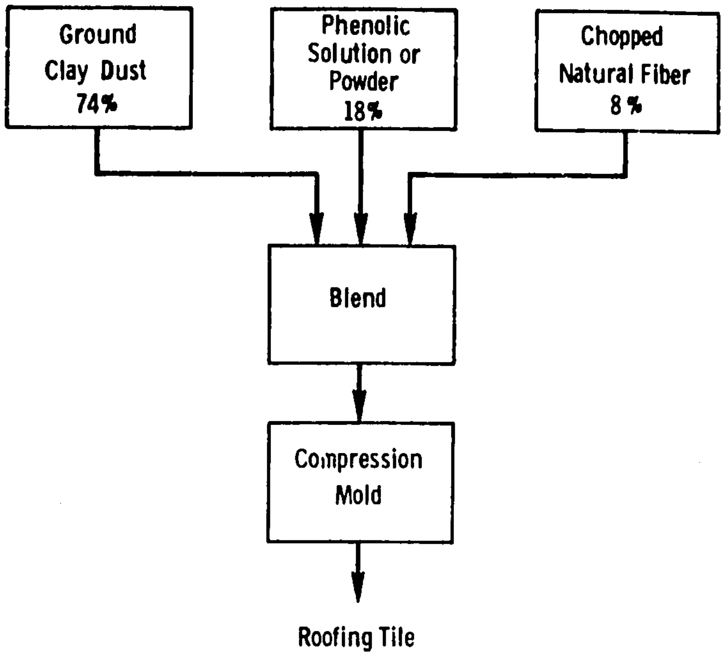


MECHANICAL PROPERTIES OF WET PROCESS PHENOLIC BONDED (3-10%) ORIENTED BAGASSE FIBER REINFORCED COMPOSITES

	Fiber Direction	
	=	⊥
Flexural Strength (psi)		
Dry	4700	1740
Wet	1990	520
Flexural Modulus (psi, 10^3)		
Dry	600	250
Wet	330	95
Tensile Strength (psi)		
Dry	5410	1130
Wet	1700	510
Tensile Modulus (psi, 10^3)		
Dry	910	365
Wet	290	100
Water Pickup (%)	33	34

Table 10

SCHEMATIC PROCESS DESCRIPTION AND MECHANICAL PROPERTIES OF WET OR DRY BLENDED, RESIN-BONDED, UNFIRED CLAY TILES
(Category IV)



MECHANICAL PROPERTIES OF WET BLENDED, PHENOLIC BONDED, UNFIRED CLAY

	% Resin				
	2.5	5.0	7.5	20	18*
Flexural Strength (psi)					
Dry	2160	1980	2020	5200	1900
Wet	-	-	-	2300	1700
Flexural Modulus (psi, 10^6)					
Dry	1.17	0.85	1.04	1.84	0.36
Wet	-	-	-	0.8	0.30
Compressive Strength (psi)					
Dry	3960	6300	8030	11,300	-
Wet	470	1800	2260	-	-
Compressive Modulus (psi, 10^3)					
Dry	53	75	78	55	-
Wet	-	40	45	-	-

* with Bagasse

(a) Natural Rubber

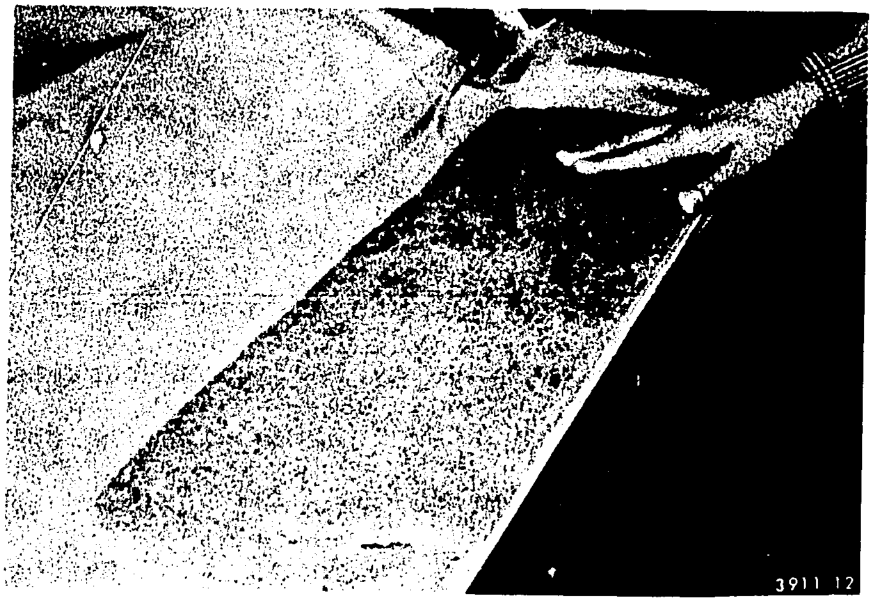
(b) Compounded Natural Rubber, Bagasse and Additives ready for molding into panel

Figure 4. Completely Indigenous Candidate Roofing Material Ingredients Based on Natural Rubber Binder and Bagasse Filler.

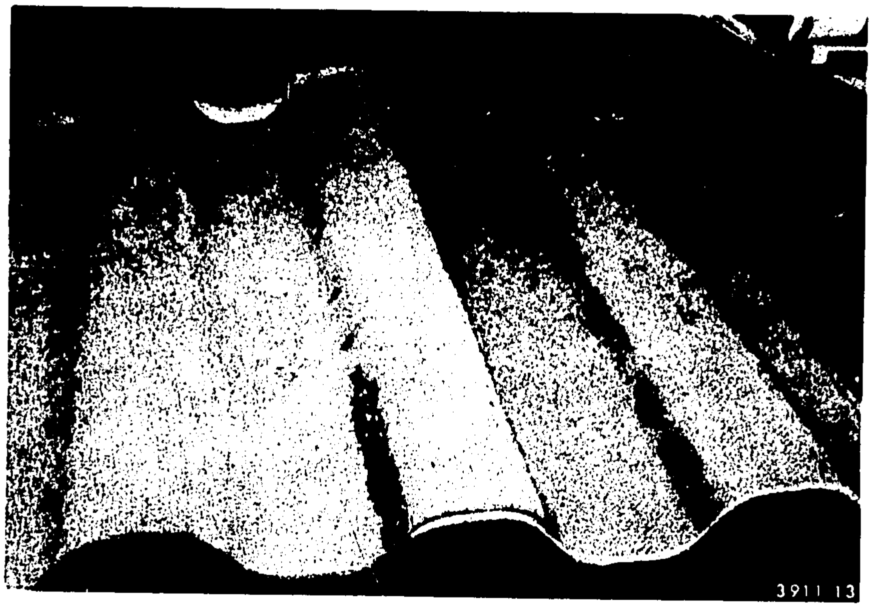
detriment. As with the other processes, compression molding at temperatures around 300°F and pressures of 500 psi is required.

The Category III product probably has the greatest potential since the binder requirement is the lowest of any of the four systems. The resin requirement is less than 10% (potentially 3-5%) of the composite system. This results in at least 90% of the composite, by either volume or weight, being indigenous bagasse. The properties of this system are outstanding, considering that it is primarily bagasse. These properties are achieved by using highly processed bagasse fibers (from which all pith has been removed), orienting these fibers into a mat, and binding them with a thermosetting resin as shown in Figure 5. Advantageously, the process is applicable to both very small and large scale manufacturing while maintaining reasonable economics. The disadvantages of the process are the requirements for significant processing of the bagasse, large volumes of process water, and associated capital equipment.

Category IV materials include a large amount of clay. Their advantage is in geographic areas where clay is readily available and where technology for working with clay exists. The toughness of the product is less than that of the other three categories of materials, which contain a large amount of bagasse, but this limitation can be overcome through panel and roof design. The process involves very simple wet or dry blending much like that



(a) Oriented preformed bagasse mat



(c) Corrugated panel

Figure 5. Candidate Roofing Material Based on >90% Oriented Bagasse Fiber Bonded with a Synthetic (phenolic) Resin.

presently used in making clay bricks or cement. An advantage is that no firing is required, although heating to around 300°F at pressures of 500 psi is necessary.

2.2.4 Cost and Practicality of the Primary Roofing Material Candidates

The cost and practicality of the four categories of materials hinge upon the ingredients and the nature of the processes used to make them. These were briefly discussed in the previous section, and are given in detail in section 4.2.3.

The material costs for the four categories of composites are shown in Table 11 (based on 1975 material costs in the developing countries). Illustrated is the fact that the category I, II, and III materials all met the target of less than 10¢/sq ft (for materials alone). What is of very great significance is the Category III material, which contains only 3¢/sq ft of ingredients. It is expected that up to 5¢/sq ft needs to be added to this material to provide waterproofing, but the good economics of this system will be retained if processing costs can be kept under 10¢ per square foot.

All material cost data (¢/sq ft) are based on an anticipated panel-type roofing material that is expected to have a thickness of about 0.1 inch. This can be expected from the mechanical properties defined.

Table 11

SUMMARY OF INGREDIENT COSTS FOR THE CANDIDATE ROOFING MATERIALS

Category	Title	Material Cost[a] U.S. ¢/lb	Material Cost[a] U.S. ¢/sq ft
I	Melt-Compounded, Resin-Bonded, Bagasse-Fiber Reinforced Composites	12-18	8-12
II	Wet or Dry Blended, Thermoset-Resin Bonded, Bagasse-Fiber Reinforced Composites	14	10
III	Wet Process, TS Resin Bonded, Depithed Fibrillated Oriented Bagasse Fiber Reinforced Composites	4	3
IV	Wet or Dry Blended, Resin Bonded, Unfired Clay Tiles	8	12
-	Target Properties 1975[b]	-	<11

(a) Includes no processing, handling, administrative, or profit costs. Best estimate of ingredient costs in participating countries (U.S. $).

(b) Adjusted from 1974 figure of $8¢/ft^2$ which was based on 1/3 the cost of corrugated galvanized iron sheet.

The capital requirements for the Category I and III materials are about the same and provide for the necessary high degree of processing of the bagasse fiber. The capital requirements for Category II and IV materials would be identical and relatively low. At this point, only these qualitative statements may be made about the processes, all of which are quite practical for a variety of sizes of manufacturing operations, including village-level industries. Their actual cost will be explored further in Phase III.

3. FUTURE PLANS (PHASE III)

Phase III is the final stage of the program and will be conducted from May 1975 through December 1976. This phase will encompass material optimization, design, fabrication, field manufacture, installation, and evaluation of both prototype and full-scale roofing. In this phase demonstration and transfer of technology will be completed.

The approach being taken is illustrated in Table 12, showing two interrelated aspects. These include (a) collaboration, demonstration and transfer of technology, and (b) materials development. The various functions include the operation of a working and advisory group to provide expansion of the seed program (conducted primarily in MRC's Dayton Laboratory) within each of the selected institutions in the three participating countries.

The approach includes the functioning of three regional interrelated programs. The specific tasks to be conducted by each of the participating countries are outlined in the program work statement, illustrated in Table 13. The first two tasks, that entail the setting up of advisory and working groups, were completed to various degrees in Phase II. The additional tasks will be continued in sequence, respectively, in Jamaica, the Philippines, and Ghana.

Table 12

SCHEMATICS OF PROGRAMATIC APPROACHES

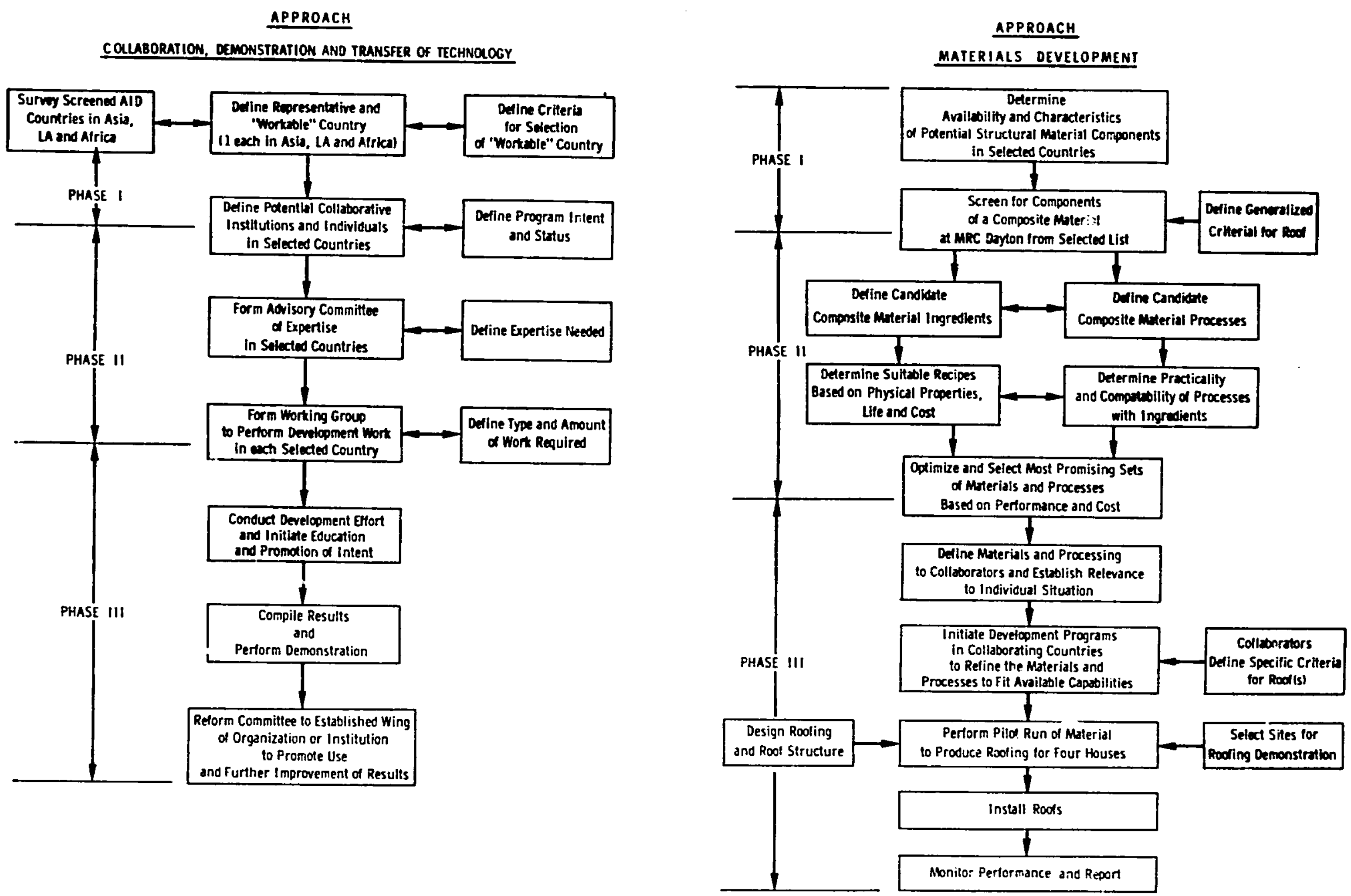


Table 13

PROGRAM WORK STATEMENT FOR PARTICIPATING COUNTRIES (JAMAICA EXAMPLE)

IMPROVED ROOFING MATERIALS WITH ECONOMIC TRADE BENEFITS TO JAMAICA

PROGRAM WORK STATEMENT

OBJECTIVE: To develop, define and demonstrate economically viable roof material candidates in Jamaica.

TASKS

1. Set up an advisory committee to provide advice, communication, coordination and planning.
2. Set up a working group to provide for performing the following tasks.
3. Review composite materials R&D work done by MRC and determine relevance to Jamaican situation.
4. Conduct cost analyses on the candidate material systems to determine their degree of viability with respect to other available roofing.
5. Assist MRC in determining functional life of candidate composite materials by providing proper exposure (environmental), testing and analysis of MRC and eventually Jamaican produced panels.
6. Conduct R&D program to optimize, upgrade, refine, etc. the composite materials systems using the MRC recipes (ingredients and lab process) as starting points.
7. Determine processing techniques and conditions for the more attractive material systems:
   (a) laboratory scale process
   (b) large scale factory process
   (c) low capitol-labor intensive process
8. Determine both necessary and desired criteria for a roof and a roofing material for low-cost housing in Jamaica.
9. Design roof and/or roofing product (panel, tile, etc.) based on the criteria in 7, the properties of the materials resulting from 4 and 5, the processability from 6, and knowledge of factors determining general acceptability, i.e. shape, color, size, strength, etc.
10. Define roof construction details, i.e. substructure, method of attachment, etc.
11. Determine criteria for and select site for at least four (4) demonstration roofs. Include visibility to public and decision makers, convenience to laboratory and project participants with respect to time and cost, availability of materials and necessary skills to make and install the roof, future acceptability, etc.
12. Fabricate sufficient roofing product for 5 roofs. Set up quality control and preliminary specifications.
13. Install roofs on at least 4 houses. Provide architectural supervision, record the installation process, record problem areas, submit data and analyses to the committee and MRC for review.
14. Monitor performance and user response of roofs with time (at least 6 months).
15. Write and submit final report covering all aspects of work. Monthly summary and detailed quarterlies are also required.

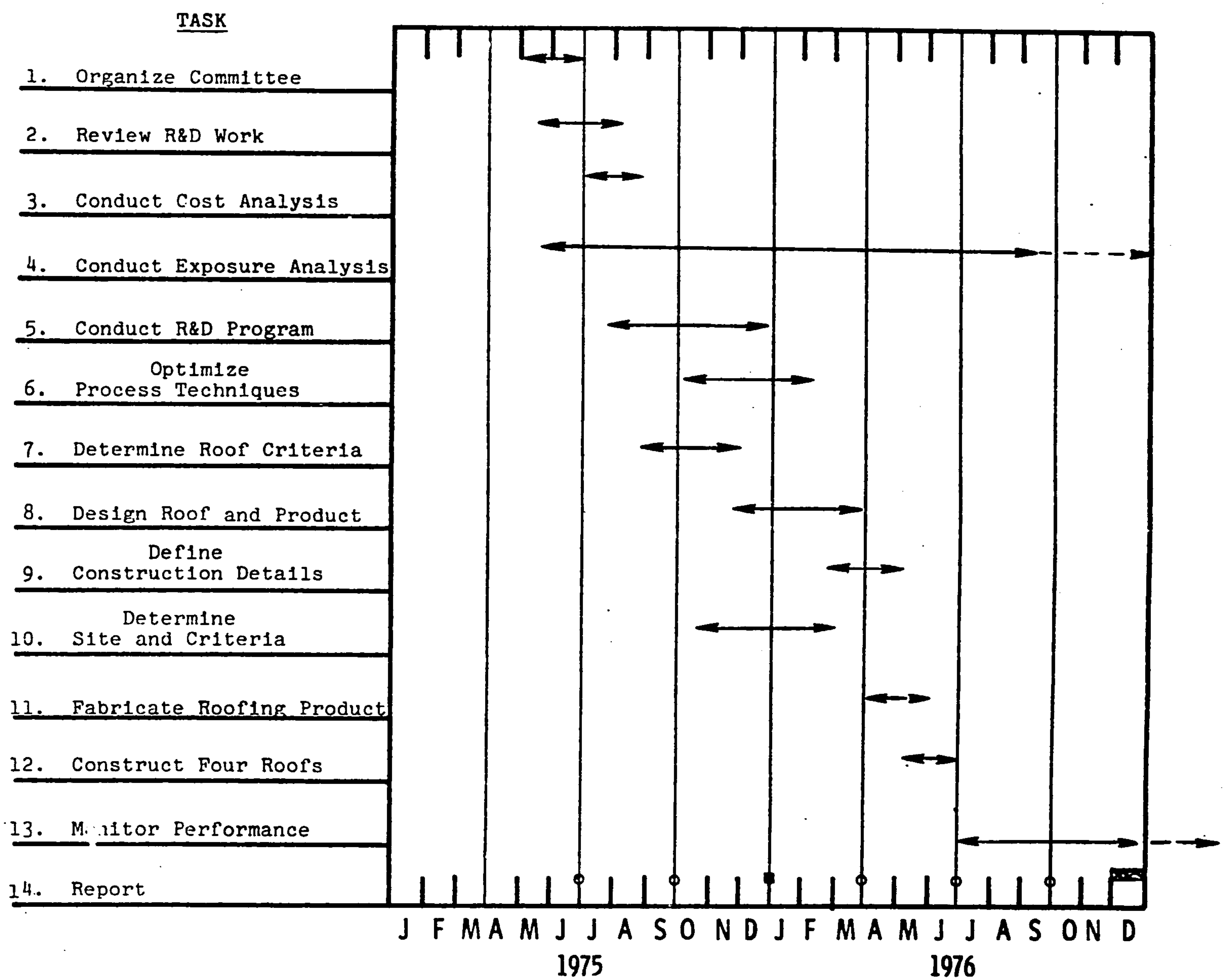
A typical time schedule for the program tasks is shown in Table 14. This time schedule roughly illustrates the degree of effort anticipated for each of the tasks and the time frame during which it is to be performed. The lead program will be conducted in Jamaica, with the Philippine and Ghana programs lagging by 2-3 months.

The materials development seed program in Dayton will continue but at a much lower rate. Its objectives will be to assist in optimization; further refine the processes; assist in solving problems, as they come up in the participating countries; and detail the work in written form so that it can be properly utilized. Emphasis will be on evaluation of the defined materials and their exposure to accelerated aging and the environments of the participating countries. Adjustments in formulation and processes will be made as these analyses dictate.

Monitoring and analysis of performance through December 1976 will complete MRC's participation in the program. It is expected that studies will continue, however, both internally and between the participating countries through their own interaction and through regional interest groups. Additional USAID funding will be necessary to demonstrate the viability of the research results. The results would also definitely be amplified through expanded development programs that show the applicability of the material systems to other construction requirements such as walls, fencing, floors, furniture, etc.

Table 14

PROGRAM TASK TIME SCHEDULE FOR PARTICIPATING COUNTRIES (JAMAICA EXAMPLE)



4. DISCUSSION

4.1 PROGRAM STATUS IN COLLABORATING COUNTRIES

During Phase II, from May 1974 through September 1975, most or all of the program goals in the three selected countries (Philippines, Zambia-Ghana, and Jamaica) were achieved. These goals included:

- Defining potential collaborative institutions and individuals,
- Establishing the degree to which the necessary processing facilities for larger scale pilot plant production are on hand in the three selected countries,
- Forming advisory committees with expertise in building materials and low cost housing,
- Selecting working groups in each of the three countries that would participate in the roofing research and development program, and
- Determining the availability and cost of the candidate resin binders and fillers.

A change of the African collaborating country from Zambia to Ghana took place in mid-1975 and is reported herein for completeness, even though timewise it is part of Phase III.

Members of the roofing project technical team from both Monsanto Research Corporation and Washington University participated directly in the selected countries on the time schedule shown in Table 15.

The specific siutuation in each of the three collaborating countries is discussed separately in the following subsections.

Table 15

PROJECT PARTICIPANTS IN COLLABORATING COUNTRIES IN PHASE II

I. PHILIPPINES

1.	I. O. Salyer	Jan 16 - Feb 7 1975
2.	J. P. R. Falconer	Jan 26 - Feb 15 1975
3.	I. O. Salyer	Aug 23 - Sep 14 1975

II. ZAMBIA

1.	I. O. Salyer	Jun 30 - Jul 5 1974
	G. L. Ball	Jun 30 - Jul 5 1974
2.	A. M. Usmani	Nov 9 - Dec 2 1974
	J. P. R. Falconer	Nov 21 - Nov 28 1974
3.	I. O. Salyer	Feb 8 - Feb 15 1975

III. GHANA

1.	I. O. Salyer	Jun 23 - Jun 30 1974
	G. L. Ball	Jun 23 - Jun 30 1974
2.	I. O. Salyer	Sep 15 - Sep 25 1975
	J. P. R. Falconer	Sep 15 - Sep 25 1975

IV. JAMAICA

1.	I. O. Salyer	Apr 17 - Apr 20 1974
	A. M. Usmani	Apr 17 - Apr 20 1974
	J. P. R. Falconer	Apr 17 - Apr 21 1974
2.	J. P. R. Falconer	Jun 12 - Jun 18 1974
3.	A. M. Usmani	Aug 16 - Aug 31 1974
4.	G. L. Ball	May 12 - May 21 1975
5.	G. L. Ball	Jul 23 - Aug 1 1975

4.1.1 Jamaica

4.1.1.1 Summary

A good overview of the housing situation in urban and rural Jamaica has been achieved. Government and international agency (e.g., World Bank) approaches to low cost housing, designs, and construction were reviewed first hand. Organizations were called on in both the government and the private sector that had a potential interest in the AID roofing program and an ability to contribute to its implementation in Jamaica.

The availability of processing facilities which might be used for R&D, pilot, and/or larger-scale plant production was determined. Firms in the private sector, having facilities and/or market position, were defined that might have an interest in future commercial manufacture of a roofing material (e.g., Standard Building Products, Thermoset Ltd., Thermoplastic Group Ltd.).

An Advisory Committee and Working Group were formed (Tables 1 and 2), and a Chairman (Mr. Alfrico Adams) was selected to coördinate a Jamaican effort. Considerable technical information on the four candidate roofing materials, associated formulations, raw material costs, product properties and aging characteristics was presented to the Advisory Committee by the MRC team.

Limited experimental work and practical outdoor aging studies were started by the Working Group, but this was slowed due to funding limitations. The general availability and cost range of the primary Jamaican candidate resin binders (SAN, PVC, natural rubber, and phenol/formaldehyde), and fillers (bagasse, sawdust, red mud, clay) were determined. Specific costs are presently being determined by the Working Group.

Details of the key in-country organizations, information relating to low cost housing, and information on raw materials in Jamaica follows.

4.1.1.2 Potential Collaborating Government Organizations and Institutions

a. Ministry of Housing, 2 Hagley Park Road, Kingston, Jamaica, Phone 936-1590

The Ministry of Housing is a principal source of information regarding housing needs and government policy and programs for housing. The functional organization of this ministry is given in Table 16. The Acting Permanent Secretary is Mr. Clovis McLean. Mr. MacDonald is ex-Permanent Secretary and now Consultant.

Rev. Gerald L. McLaughlin is a Special Advisor to the Minister and was our initial principal contact on matters relating to housing and the placement of our roofing project in Jamaica. Nadine Isaacs, an Architect assigned to the World Bank Site and Service Program, was assigned by the Ministry to participate in the roofing project. She has been very helpful in arranging visits to housing projects and defining criteria for roofs, especially in the low cost category.

The Ministry of Housing would likely be directly responsible for assisting in task 7 (see Objectives and Tasks, Table 13) to determine both necessary and desired criteria for a roof, and a roofing material in Jamaica, and to select sites for demonstration.

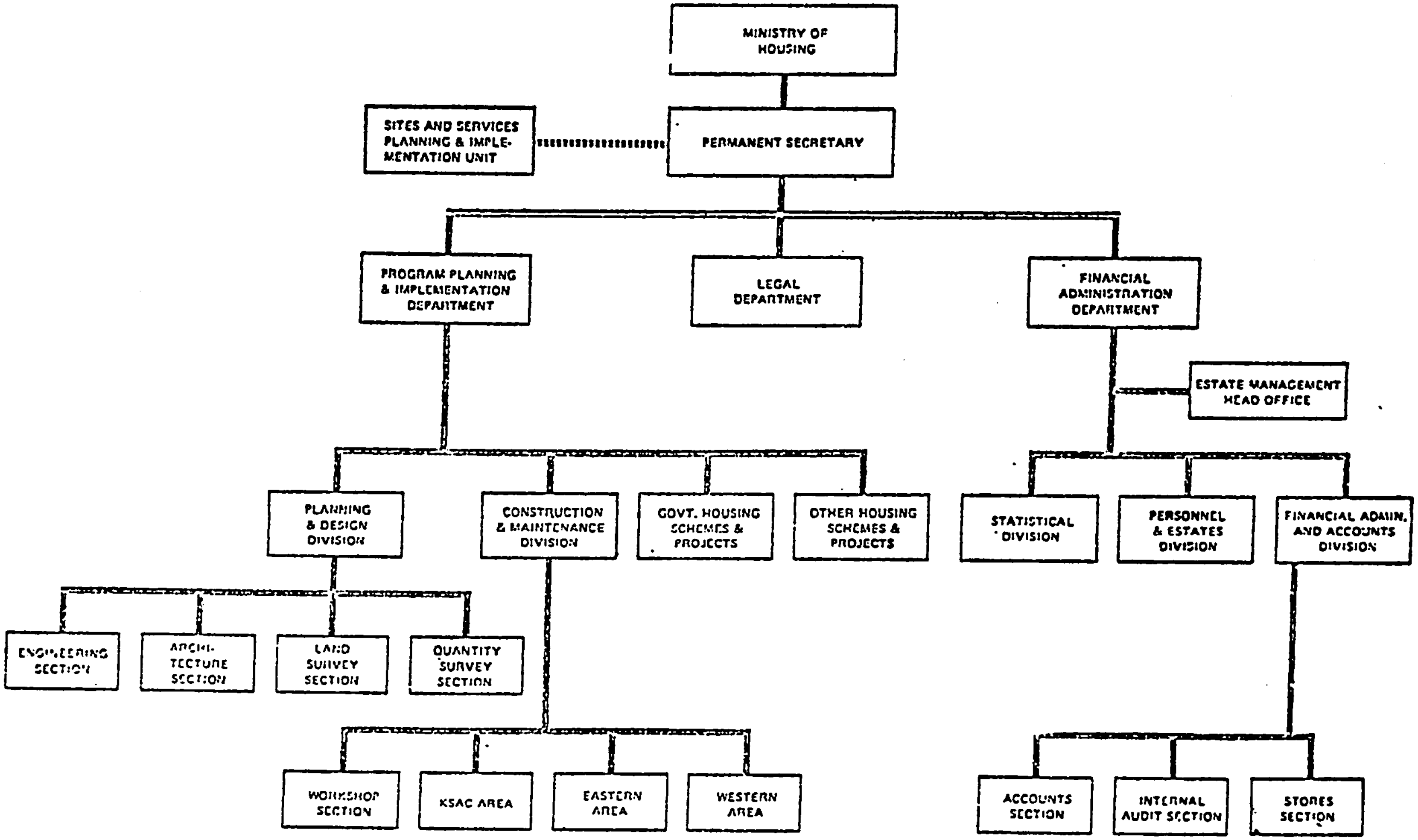
b. Scientific Research Council (SRC), Old Hope Rd., P.O. Box 350, Kingston 6, Phone 937-9931

SRC is a government laboratory that is to interface new technology with Jamaican needs. The Director is Dr. Ken E. Magnus (through August 1975) and the particular Senior Principal Scientific Officer to be assigned to support the roofing project is Mr. Fred Campbell.

Table 16

ORGANIZATION OF THE MINISTRY OF HOUSING

Source: IBRD Report No. 294a-JM, April 12, 1974



SRC is expected to perform a major and leading role in the roofing materials development in Jamaica. Specific tasks from Table 13 which they indicated might be performed by them included 4,5,6 and 12 as follows.

(a) Assist MRC and Berger Paints in determining functional life of candidate composite materials by providing proper exposure (environmental), testing and analysis.

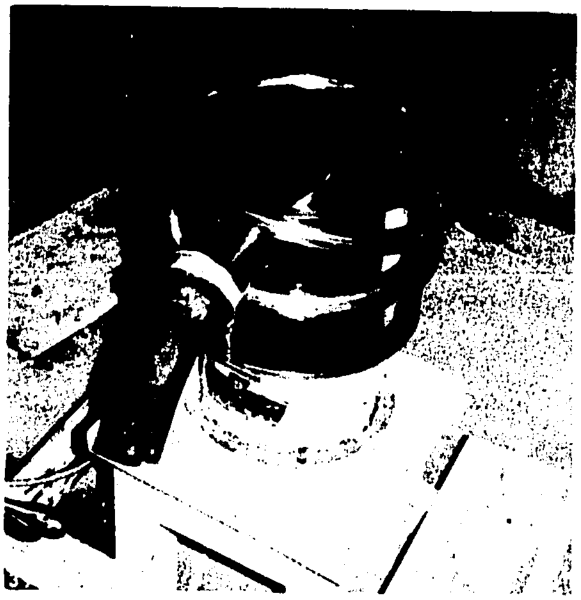
(b) Conduct R&D program to optimize, upgrade, refine, etc. the composite materials systems using the MRC recipies (i.e., ingredients and laboratory process) as starting points.

(c) Determine processing techniques and conditions for the more attractive material systems. First, experimentally on a laboratory scale, then to estimate a large scale factory process, and finally to consider the potential for a low-capital, labor-intensive process.

(d) Monitor performance and user response of the developed and fabricated roofs with time for a minimum of six months. (Assistance in the fabrication of roofing panels and roofs prior to construction also will be required.)

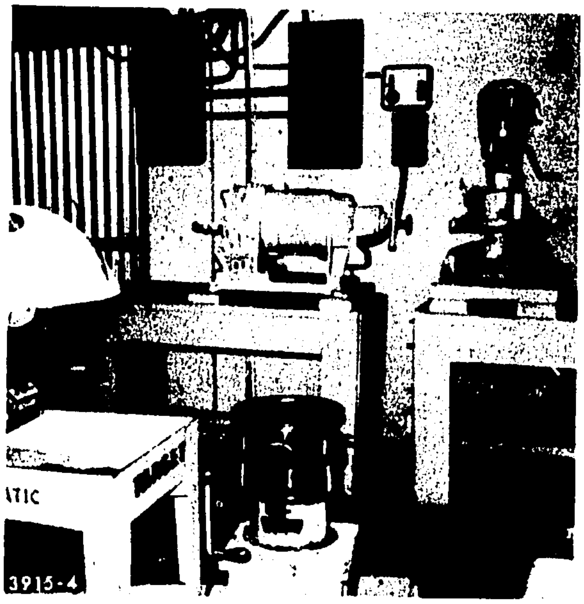
SRC has the skilled manpower and good laboratory facilities to conduct research programs of the type envisioned. Some additional equipment or modifications will be required to handle plastic binders on existing facilities. Some of these facilities are shown in Figure 6.

(a) 5 in. x 5 in. mold
in mechanical press



(b) Sieving apparatus

(c) Roll grinding apparatus
(fibrillator)



(d) blending and cutting
equipment

Figure 6. Views of Various of the Compounding and Molding Facilities at the Scientific Research Council, Kingston, Jamaica.

c. <u>Bureau of Standards (JBS), 6 Winchester Road Kingston 10, Phone 926-3140</u>

The Director of the Bureau is Dr. A. S. Henry, the Administrative Secretary Mr. A. K. Elliott, and Head of Materials Testing, Mr. James Campbell.

The Bureau has an excellent reputation and a relatively new or remodeled facility which is in excellent condition. Mr. James Campbell's laboratory is actually set up for measuring the properties of concrete blocks, bricks, aggregates, etc. and thus is less well equipped for measuring properties of metal panels (e.g., CGI) or plastic composites.

They run compressive and flexural strength tests routinely. Load is applied thru hydraulic pressure and measured with a dial gage, inside a proving ring (no electronics). A means for measuring elongation (or deflection) is not provided and thus modulus cannot be determined.

d. <u>University of West Indies, Kingston Campus (UWI), Mona Road, Kingston 7, Phone 927-0751</u>

Dr. Tom Hughes is Professor of Materials Science, Dr. Chan of Chemistry, and Dr. Kent of Physics. Materials Science is in the Physics Dept.

From the standpoint of our roofing program, the most important section of the University is Materials Science. Dr. Tom Hughes, who is head of this section, has completed 1/2 year of a 3-year contract at the University. Accordingly, he will be available in Jamaica for a period of at least 1 year beyond our December 1976 contract completion date. Dr. Hughes is technically well informed and experienced in composite materials.

The Material Science Laboratory at the University is equipped with some very basic and good apparatus. Included is a set up to measure flexural strength of glass-reinforced concrete and composite materials. They have a very novel and low cost method for measuring the tensile strength of fibers. [Strain is measured with a torsion-type galvanometer, using a mirror as an amplifier (spot galvanometer approach). They were installing (May 1975) a strain gauge which will be hooked into the system to provide output for strain curves.] Also on hand is a Monsanto tensiometer which can be used to measure various strengths of specimens having small cross sectional areas. Some investigation into bagasse fibers was already underway.

Because of the facilities and his directly related experience, Dr. Hughes can make a valuable contribution to the roofing materials development program - especially during the experimental research stage. His role is seen as an active consultant to the SRC group.

e. Urban Development Corporation (UDC), 40 Harbour St., Kingston, Jamaica, Phone 929-2240

The Urban Development Corporation is a Jamaican Government enterprise that is engaged in coordinating efforts and resources between the public and private housing sectors. It designs housing and plans communities.

Mr. David Gregory Jones is Chief Archetect-Planner. Other persons contacted at UDC included Karl Thorne, Senior Architect-Planner and Gloria Knight, Manager.

UDC is involved in some of the World Bank-sponsored housing developments such as the Montego Bay and Catherine Hall sites and service projects. In one case (Montego Bay, West Green)

UDC has constructed several prototype houses and thus has up-to-date cost data (which was made available to us).

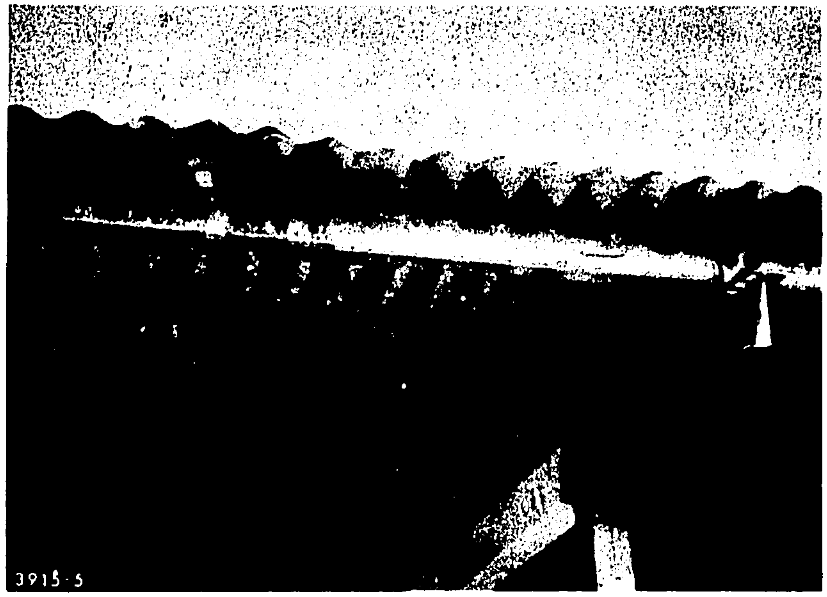
UDC could contribute strongly in site selection and in making a house "available" for installation of the new roofing, when that phase of the program is reached.

f. Government of Jamaica/World Bank Site and Service Projects (IBRD)

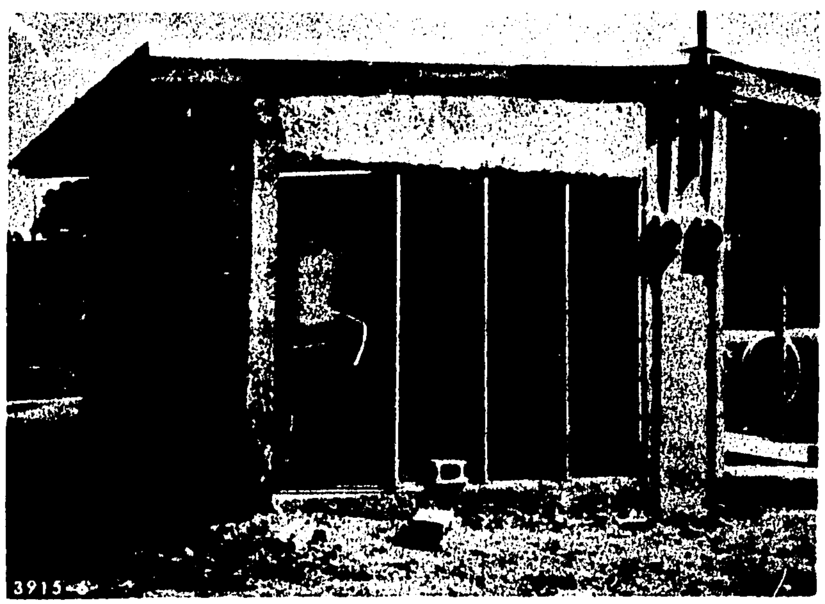
An agreement has been reached between the International Bank for Reconstruction and Development (IBRD = World Bank), and the Jamaican Government for financing and implementing of site and service, self-help, low income housing which will eventually provide some 6000 serviced lots in the four largest Jamaican cities. Included are Kingston-St. Andrews area (3940 lots), Spanish Town (560 lots), May Pen (840 lots), and Montego Bay (660 lots).

In addition, the GOJ-IBRD agreement includes three squatter upgrading projects which will eventually affect some 2750 households in the Kingston-St. Andrews and Montego Bay areas.

Visits to one of the Sites and Service projects, located at Spanish Town, revealed that the core units were designed around welded light gauge steel I and box beams for studding and purlins. The foundation is a concrete slab. Curtain and separating walls were constructed of concrete block, and roofing of currugated aluminum (insulated with bead foam polystyrene). This type of construction, shown in Figure 7, which involves extensive use of imported steel was interesting, but in Jamaica requires extensive foreign exchange.



(a) Corrugated aluminum roofing
and steel purlin details



(b) Roughed in, steel-framed
200 square foot core

Figure 7. World Bank Sponsored Site and Service Core Housing at Spanish Town, Jamaica Indicating One Construction Materials Approach.

Mr. Fitz Ford, head of the "Sites and Service Planning and Implementation," within the Ministry of Housing, was originally cautiously optimistic about the possibility of aligning our roofing demonstration with one or more of the Sites and Service projects. However, more recent discussions with Nadine Isaacs (see Ministry of Housing) were more positive, especially since more specific details could be discussed.

4.1.1.3 Potential Private Industry Collaborators

a. Douet, Brown, Adams, and Partners
7 Lismore Avenue, Kingston 5, Phone 926-3485

Douet, Brown, Adams and Partners is a consulting engineering firm. Mr. Alfrico Adams, engineer and partner in the firm, has previously participated in a project and prepared a report for USAID having to do with housing, "Low Cost Housing and Extreme Wind-Related Problems in Jamaica". This report is a useful summary of common low cost housing systems in Jamaica, It also discusses socio-economic conditions relating to housing, user preferences, and cultural considerations.

A very considerable amount of information on available raw materials for possible use in roofing systems to be developed under the project was also supplied by Mr. Adams. This and other information on raw materials in Jamaica are discussed in Section 4.1.1.5.

Mr. Alfrico Adams has extensive background in materials of construction and the design and building of houses. This, along with his ability to communicate, and high credibility with leaders of Jamaican government and industry, made Mr. Adams an excellent candidate to head (and coordinate) the activities of an Advisory Committee and the Working Technical Group in Jamaica.

This coordinator assignment was discussed with Mr. Adams at the time of the May 12-16 visit of G. L. Ball and J.P.R. Falconer. Mr. Adams agreed that he would accept the position of Chairman and could make a total of about 500 hours available through December 1976. Since this is a significant fraction of his time, it was stipulated that an appropriate consulting fee would be required.

b. Standard Building Products (SBP), 66 Corletta Road, Spanish Town, Jamaica, Phone 984-2295.

Ralph Corning is President; Mr. Douglas Wynter, Technical Director; Mr. Kenneth S. Biersay, Marketing Director; and Mr. Joe Williams, Manufacturing Director. Barclay Ewart will be taking over the company late in 1975.

SBP makes mainly a relatively low density urea/formaldehyde-bonded bagasse board, from chopped, screened depithed bagasse raw material. When costs allow (not very often) they use phenol/formaldehyde binder, to obtain better water resistance. The product as currently manufactured is sold in the form of 4 ft x 8 ft panels (@25 U.S. ¢/ft^2). The market is in furniture (60%), and wall panels (40%).

Mr. Biersay agreed that the bagasse board as made now would not perform as a roofing material, or any other outdoor application. For this reason, he was strongly interested in the bagasse reinforced composite materials, which potentially can withstand outdoor exposure. The apparent performance of those made using natural rubber or ABS binders seemed most interesting.

SBP has on hand several items of equipment (e.g., compression molding presses, depithers, etc.) which could be used in pilot or commercial production of a bagasse-based roofing material. SBP also has marketing outlets established; and accordingly, could get into the roofing business if potentially profitable (after the development and demonstration phases of our project have been completed).

c. Berger Paints (BP), 256 Spanish Town Road, Kingston 11, Phone 923-6226

Berger Paints is a German-owned company. Contacts at BP were Mr. M. S. Fennel, General Manager, and Mr. Derwin R. Brown, Technical Manager.

Berger Paints makes and sells paints in Jamaica and elsewhere. They have outdoor exposure tests constantly in progress on various paint samples. Accordingly, they have several appropriately oriented (with respect to the sun) exposure racks already installed.

Our interest in Berger Paints was to provide some polymer expertise to the project and to have available a collaborator experienced in outdoor exposure tests on various compositions. They readily agreed to provide the exposure space. Our needs were for periodic visual observations of specimen change in color, surface texture, etc. with time and, on a prearranged time schedule, removal and mailing of specimens to Dayton for physical testing.

Additionally, it is highly likely that one of the developed roofing products (the oriented bagasse fiber board) will require a surface coating of paint for added weather resistance and/or decorative effects. In this case, Berger Paints could recommend coatings, available in Jamaica with established good resistance to outdoor exposure.

d. <u>Goodyear Jamaica Ltd., 29 Tobago Avenue, Kingston 10, Jamaica, Phone 926-8018 Plant Morant Bay, Phone 982-2353</u>

Mr. T. S. Elliott, Manager, GMMC, and Mr. Helmet Schueller, Technical Superintendent, were the persons contacted at the Morant Bay factory.

One of the four processes developed utilizes an intensive mixer (e.g., Banbury) to compound large (70% vol) quantities of bagasse into a resin binder. Since intensive mixers are used in the compounding of rubber, it was anticipated that Goodyear would have this type of equipment. This turned out to be the case. Goodyear has a 450-lb capacity mixer, along with accessory mill rolls, extruders, and calenders. This equipment is used by Goodyear exclusively for compounding natural rubber to make auto tires.

Goodyear had been previously solicited by others for the use of their equipment to make various special rubber compounds. Goodyear's management has consistently decided against working in such specialty areas because of the potential problem of contaminating their equipment; resulting in off-grade tire production. For this reason, Mr. Schueller thought Goodyear would probably not be interested in getting into the compounding business at this plant. He did not, however, rule out the possibility, and stated their interest in helping in the project in any way possible. Importantly, Goodyear has extruders which can provide 20 in. wide sheets, and calenders with capability up to 50 in. widths.

At Goodyear there was little or no small scale laboratory size equipment; such as would be necessary in the research (implementation) phase in Jamaica.

e. <u>Thermo-Plastics Group of Companies, Ltd. Thermo-Plastics (Jamaica) Ltd., 45 Elms Crescent Blvd., P.A. , Kingston, Phone 935-2390</u>

The existence of facilities, equipment, and interest in the AID roofing program were discussed with Mr. Thomas Desulme, President; Mr. Yvon T. Desulme, Purchasing Manager; and Mr. Ludwig Reisinger, Manufacturing Manager.

The company operates two plants. An older one is located in Northwest Kingston, where PVC hose and small water pipe are extruded. At the newer and larger plant, located just east of Spanish Town, there is a most impressive modern injection molding, pipe extrusion, compression molding, and mold making facility. They do not have dies or take-off equipment for extruding sheet products that would be desired for continuous production of our roofing material, but that is a minor part of the required facilities.

Mr. Reisinger thought that, if necessary, they could handle pilot production runs of 2 ft x 2 ft panels by injection or compression molding. Their ability to make "pilot" quantities of roofing (2 ft x 2 ft) could be a valuable asset in the development phase of the project in Jamaica.

f. <u>Thermoset Ltd. Offices, 14 Dominica Drive, Kingston 5, Jamaica, Phone 936-5920 Plant - Naggo Head, Phone 936-6394</u>

Principal contacts were Dr. Lester A.D. Chin, Technical Director; Mr. James A. Blackwood, Managing Director; and Mr. T. W. Walker, Plant Manager.

Thermoset Ltd.'s prime business is high pressure melamine/phenolic laminates for table tops, wall panels, etc. They also thermoform sinks, etc. to complement the counter tops. When visited in May they were manufacturing the sinks and table tops for a housing development near the Bernard Lodge sugar estate.

Of interest to the roofing program, Thermoset Ltd. has a high temperature and pressure, multiple opening, compression molding facility. Laminates or panels of 50 in. x 90 in. can routinely be prepared. They could mold corrugated panels (for roofing) also, if a corrugated die was provided. They also have a ∿12 in. x 12 in. laboratory press usable at high temperature and pressures, that could be used for laboratory work.

Mr. Blackwood was quite interested in processing possible future pilot or production quantities of roofing panels if compatible with their facilities.

g. Knox Development Foundation - Spaldings, near Mandeville

Dr. Lewis Davidson is the Director of the Knox Development Foundation.

The Knox operation includes Knox College, a private secondary boarding school, and Knox Development Foundation, a non-profit community development organization. Operations are sponsored by the Church of Scotland, with staff drawn from Jamaica, Europe, the United States, Canada, and elsewhere. The Development Foundation has established a number of rural community industries, which now include farming, animal husbandry, food processing and packaging, and a print shop which produces educational materials for the Jamaican school system. Students in the college are encouraged to prepare for rural development work by participation in current community projects in the Spaldings area.

Dr. Davidson, his wife and colleagues are most knowledgeable about rural housing needs and problems, and are currently carrying out a series of experiments in building methods and technology. Their objectives are to develop better, faster, and cheaper building methods and materials for the rural areas. Dr. Davidson is especially interested in developing housing which, by using various intermediate technologies, can provide for the rural family a degree of autonomy which can make up for the lack of services and amenities available only in the towns, in this way helping to reduce some of the stresses that make it difficult for the rural family to stay and work their land. This concern has led them to investigate the potential for low-technology applications and the use of solar energy, wind power, and methane gas generation, in addition to a number of prototype building methods.

Dr. Davidson indicated his interest in the roofing project, and his willingness to help in trial and demonstration phases. Considering this interest, and the Knox history of innovative experimentation in using intermediate technology to benefit the ultimate user, the field team felt that cooperation and collaboration with Knox in later phases would make a strong contribution to the ultimate success of the project, especially with respect to labor intensive process compatability.

4.1.1.4 Forming an Advisory Committee and Technical Working Group

In Jamaica, with its small size and population, it was felt that a completely separate Advisory Committee and Technical Working Group were not necessary. An Advisory Committee assisting a much smaller working group was more appropriate. After discussions with a variety of individuals in several agencies and organizations, it was decided that the program could best be conducted through a Program Coordinator, with the support of an Advisory Committee.

Mr. Alfrico D. Adams, a chartered engineer and partner in the consulting engineering firm of Douet, Brown, Adams and Partners, agreed to take on the task of Program Coordinator, with the support of an Advisory Committee. It was suggested and agreed that the Advisory Committee consist of individuals who could make a technical contribution, as well as those who could make commitments for an organization.

It was left up to Mr. Adams to form the Advisory Committee (based on a list started by MRC), cause it to meet periodically, provide for communications internally and externally, and to solicit advice, support, technology, etc., from members of the committee. It was also hoped that various of the committee members could represent two or more organizations or agencies, in order to minimize the size of the Advisory Committee. For example, societies such as the Jamaican Society of Architects should be represented on the Advisory Committee, but the representative could also be an individual on the committee who is a representative of some other organization.

It was agreed that the task of Program Coordinator would require about 500 hours of Mr. Adams' time over an 18-month period, lasting until the end of the program, December 31, 1976.

It is expected that the amount of actual time of Mr. Adams' required will initially be quite low and will increase as the active experimental program gets underway. The highest level of participation will be required during the demonstration phase, when the roofing materials are being manufactured and installed on the four houses.

Technical information given to the various Jamaican organizations, and the members of the Advisory Committee during the past phase is summarized in two documents contained in Appendix B. entitled, "Improved Roofing Materials with Economic Trade Benefits to Jamaica." There are two parts (a) Advisory Committee Information, and (b) Working Group Technical Information.

In summary form, these two technical brochures contain:

- A list of the tasks to be performed,
- A time schedule for completing each task, and
- Technical information outlining the process, recipes, properties, and raw material costs of the candidate roofing materials.

A cumulative list of all the people contacted in the several visits to Jamaica, their official position and organization, address, and phone number is contained in Appendix E.

4.1.1.5 Resin Binder and Filler Cost and Availability

4.1.1.5.1 Resin Binders

Candidate binders during Phase II included several synthetic thermoplastic resins, thermosetting phenol/formaldehyde and natural rubber. Neither the thermoplastic resins nor natural rubber could be considered indigenous in Jamaica, since neither is made or grown there.

Urea/formaldehyde (U/F) thermosetting resin is made by Standard Building Products. Phenol/formaldehyde (P/F) resin could presumably be made in the same plant equipment, from imported phenol and paraformaldehyde. Import duties in Jamaica are relatively low, thus stable P/F could be imported without much penalty, in contrast to the situation in the Philippines.

In general, the price of the resin binders can be said to be ~5¢/lb higher than U.S. costs. Some specific cost data, obtained from Standard Building Products, Berger Paints, and Goodyear are shown in Table 17.

4.1.1.5.2 Fillers

From its extensive sugar cane cultivation, Jamaica produces 1.2 million tons of bagasse annually. Raw, whole, bagasse was reported by Dr. Lester A.D. Chin to be worth $14/ton with water content of up to 50%. Thus, the price can be as much as $28/ton based on dry weight. This is still a very low price for such an excellent filler material. In contrast to its worth (based on fuel value) it is traded for as low as $14/dry ton.

Clay is available at many locations in Jamaica at very low but undetermined cost. "Red mud" from bauxite ore processing is available at refining sites as an unwanted residue. It thus could be had for shipping and handling costs.

Table 17

RESIN BINDER AND FILLER COST[a] IN JAMAICA

	US¢/lb
Urea/formaldehyde	24
Phenol/formaldehyde	34
Natural rubber	45
Styrene/acrylonitrile copolymer (SAN)	47 [b]
Acrylonitrile/butadiene/styrene (ABS)	47 [b]
Polyvinyl chloride (PVC)	32 [b]
Crystal polystyrene	27
Paraffin wax	15
PE wax	57
Bagasse, whole (dry weight)	1.4
Sulfur	17
Clay	0.044
Iron oxide pigment	18-39

(a) Truck load volumes
(b) U. S. price + 5¢/lb

4.1.1.5.3 Roofing and Other Building Materials

Corrugated galvanized iron sheets of 28 gauge cost the Jamaican equivalent of 38¢/ft^2 (May 1975). Corrugated aluminum runs approximately 50% higher than CGI in price. Both these figures are roughly world prices.

The bagasse board from Standard Building Products sells for about 25¢/sq ft. It is not manufactured for outdoor use or roofing.

4.1.2 Philippines

4.1.2.1 Summary

Two visits were made to the Philippines during Phase II. During the visit made by I. O. Salyer and J. P. R. Falconer in January-February 1975, a National Advisory Coordinating Committee for roofing was formed. All of the government agencies critically concerned with housing were represented in the most recent visit to the Philippines, August 23 to September 14, 1975 by I. O. Salyer.

A cumulative list of all personnel and organizations contacted in the Philippines has been prepared and is contained in Appendix F. The task of organizing a technical working group was completed. A detailed experimental program was drawn up to guide the different groups who would be performing various parts of the investigation. The experimental program was designed to provide allocation of specific work tasks to the best qualified organization.

Two technical bulletins prepared by MRC were given to the technical working group. These contained detailed information on program tasks as well as specific information on candidate roofing material, formulations, cost (per pound and per square foot), and physical properties. Copies of the two MRC bulletins on "Advisory Committee Information", and "Working Technical Group Information" are shown in Appendix C.

A proposed memorandum of understanding or agreement was prepared for submission to the AID-Washington office for review and future implementation (Appendix D). Importantly, the proposed agreement provided for ~$100,000 of total effort for the experimental program. Approximately equal amounts of funds are to be supplied by AID-Washington, and PL-480 funds available in the Philippines.

Contact was made with Philippine manufacturing companies having an interest in the future manufacture and marketing of roofing products of the type to be developed in the program. These included Jardine Davies Company, A Soriano Corporation and Structures and Systems, Inc. Jardine Davies has an unusually attractive position since they are large-scale producers of sugar (and thus have large quantities of excess bagasse), and are already marketing Eternit, an imported roofing product. The A. Soriano Corporation is one of the largest in the Philippines and reportedly has a very strong position in materials for the construction industry.

A considerable body of quantitative information on the cost and availability of candidate fillers and resin binder systems was also obtained. Representative samples of the candidate filler raw materials (e.g., bagasse, sawdust, rice husks, coconut husks, bamboo mats, etc.) were obtained and shipped to the Dayton Laboratory for the laboratory program. The cost and availability of specific phenol/formaldehyde resins was determined. Additionally, the availability of potentially useful processing equipment (Banbury mixers, multiple opening compression molding presses, etc.) was ascertained.

4.1.2.2 Identification of Collaborating Government Organizations and Institutions

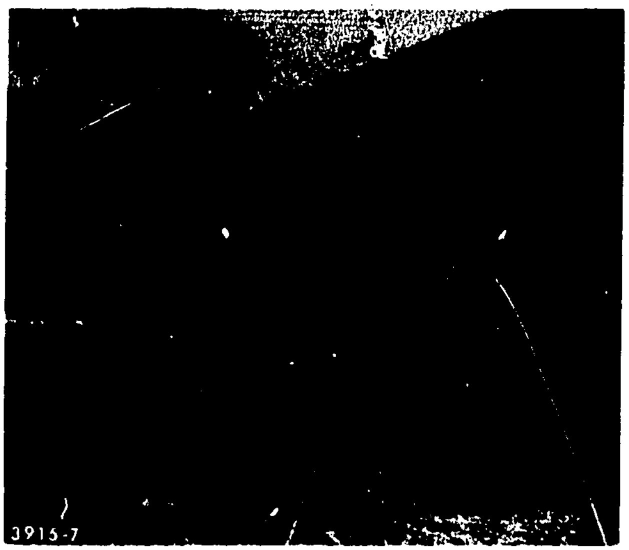
a. National Economic and Development Authority (NEDA) Downtown Manila, near the U.S. Embassy, on Padre Faura, Phone 50-38-77

NEDA is the principal economic planning agency of the Philippines. Under the present President Marcos government, NEDA is also responsible for preparing the annual budget for the country. In terms of housing, and housing needs, NEDA is responsible for planning both short- and long-range solutions. The head of NEDA, Dr. Sicat, has also been responsible for originating a series of plans to mitigate and ultimately eliminate the housing shortage in the Philippines. Typical housing is shown in Figure 8. Our principal contact at NEDA has been Dr. Josephina M. Ramos.

Insofar as the AID roofing program specifically is concerned, the approval of NEDA would be necessary for any Philippine counterpart funds to be made available to support the development program (whether the counterpart funds derive from PL-480 or totally internal sources).

b. National Science Development Board (NSDB), Bicutan, Taguig, Rizal, Philippines (on the outskirts of Manila), Phone 83-99-34

There are several agencies organized under the National Science Development Board. These include the National Institute of Science and Technology (NIST), the Atomic Energy Commission, the



(a) Hollow block construction with CGI roof at Das Morinas

(b) Large-scale, low-cost housing project at La Mesa Dam

(c) Experimental low-cost house at FORPRIDECOM

Figure 8. Examples of Low Cost Housing in the Philippines.

Forest Products Research and Industries Development Commission (FORPRIDECOM), the Textiles Research Institute, and the Coconut Research Institute. Our principal contacts at NSDB have been General Florencio A. Medina, Chairman; Mr. Pedro Afable, Vice Chairman; and Ms. Lydia G. Tansinsin.

NSDB, and it associated agencies (especially NIST and FORPRIDECOM), is certainly the principal government scientific agency in the Philippines. Accordingly, they are the logical choice to carry out any experimental development work on roofing in the Philippines, and have been so designed by NEDA. The chairman of NSDB, General Medina, has accepted this responsibility. He also agreed to take on the chairmanship of our AID-Roofing Advisory Committee in the Philippines. General Medina has selected Ms. Lydia G. Tansinsin to act for him, and to head up the technical working group.

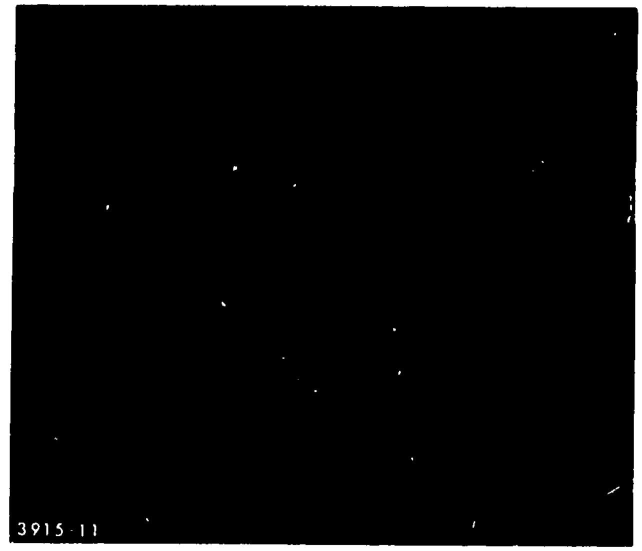
The make-up of the Advisory Committee and the Technical Working Group is discussed in a later section.

c. Forest Products Research and Industries Development Commission (FORPRIDECOM), 872 Isabel Building, Isabel St., Espana, Manila, Phone 48-44-95

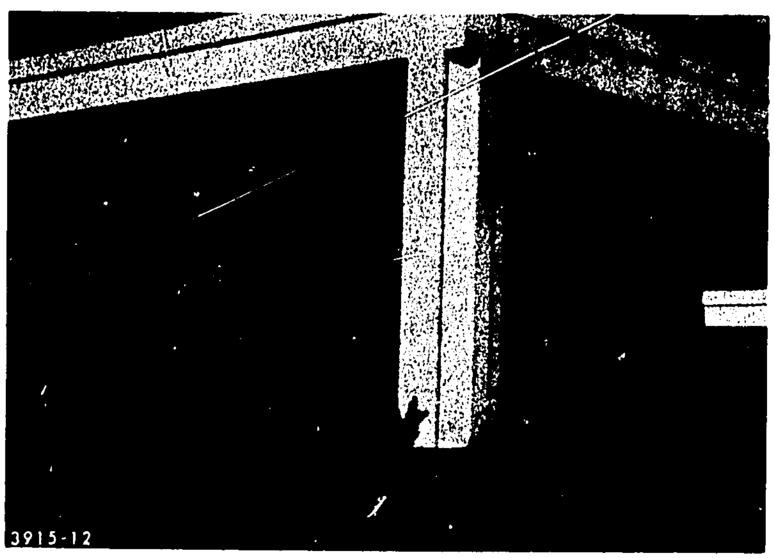
Our principal contacts at FORPRIDECOM have been Dr. Francisco U. Tamolang, Commissioner; Dr. Filiberto S. Pollisco, Director, Philippine Council for Forest Research Division; Dr. Mario Eusebia, Associate Commissioner for Research; and Joaquin O. Siopongco, Engineer.

The FORPRIDECOM laboratories (Figure 9) perform a number of functions. They do testing in the timber engineering, and research in wood technology and wood chemistry. They have considerable interest and experience in wood waste utilization and have become involved in plant fiber utilization for building products. They

(a) National Science Development Board



(b) FORPRIDECOM



(c) Development Academy of the Philippines

Figure 9. Organizations in the Philippines that Typify Working Group Participants.

have produced a series of experimental building block units, which utilize wood wastes as fillers (sawdust, wood chips, rice hulls, etc.), and they have constructed several demonstration houses at their laboratories using some of these materials.

Specialized facilities, pertinent to the roofing development program at FORPRIDECOM, includes equipment for treating and fibrillating wood; and for processing fibers into paper. Hydraulically operated compression molds, with heated platens, are reportedly available. Centrifuges such as would be required for the phenolic-resin-bonded, oriented bagasse fiber board are not available. However, a small-scale processing unit of this type can be extemporized from a commercially available washing machine having the spin-drying feature. Intensive mixers of the Banbury or Stewart Bolling type, were not available at the time of our visit.

Thus, FORPRIDECOM certainly has personnel with directly related experience, and some of the basic facilities and equipment, required to carry out experimental roofing process and product development. They have a keen interest in performing a major part of this research at their installation, since it fits with their own concepts of greater utilization of forest and agricultural waste products. As is pointed out in Section 4.2 it is also possible to use wood fibers or sawdust to replace the equivalent raw materials from bagasse.

FORPRIDECOM lacks large centrifuges, compression molding presses, and intensive mixers such as would be required for the "pilot plant" production of roofing material for the demonstration houses. Fortunately, this large-scale equipment is available elsewhere in the Philippines (e.g., National Housing Corporation, Manila Rubber) and it is likely that these facilities could be leased or borrowed by FORPRIDECOM.

d. National Institute of Science and Technology (NIST), Herran St., Ermita, Manila

Our contacts at NIST included Dr. Vedasto Jose, Director, and Mrs. Guillerminia C. Manalac.

The Ceramics Department at NIST had extensive experience and interest in further utilization of clay, which is relatively plentiful at several locations in the Philippines. NIST is interested in the possibility of utilizing phenol/formaldehyde resins or polyelectrolyte-bonded clay, to make composite bricks which "do not have to be fired." They envision possible utility of these resin-bonded clay products in interior walls and partitions, outside walls (protected by overhang), and roof tiles.

NIST forwarded to MRC in Dayton, samples of "representative" clay from four different locations in the Philippines for evaluation in roofing composite materials.

NIST appears to be both well equipped and interested in carrying out the small-scale research to evaluate the merit of the various clay-bonded products.

e. National Housing Corporation (NHC), Tala, Calocan City (on the outskirts of Metropolitan Manila, Phone 90-10-08 and 90-16-36, 37 and 38

Our principal contact at NHC has been General Guadencio V. Tobias, Executive Vice President.

The National Housing Corporation was organized in 1968 by four government financing institutions (The Government Service Insurance System, The Bank of Philippines and the National Investment and Development Corporation). Capitalized at

P100,000,000, its main objective is to assist in carrying out "the coordinated mass housing program of the government" by engaging in the mass production of component parts, and mass erection of prefabricated housing units.

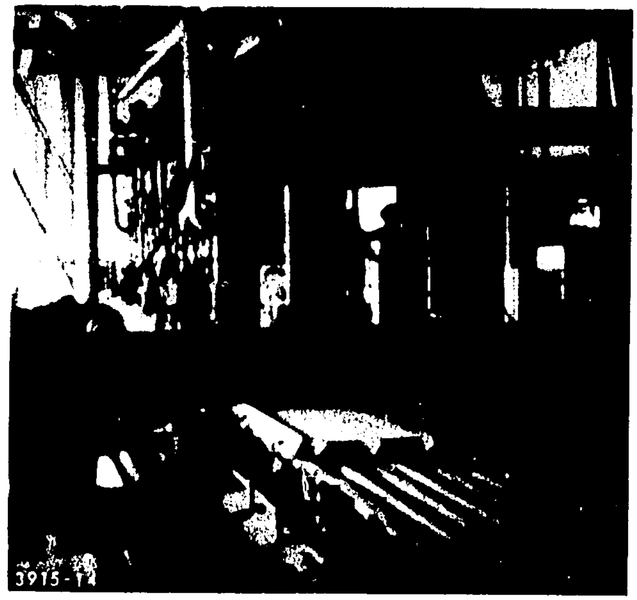
To carry out its main objective the NHC, through a German company, built a factory complex composed of a polyvinyl chloride plant (floor tiles), a chip board plant (wall and ceiling panels), an asbestos-glazed tiles plant (bathroom tiles), a woodworking plant (manufactured wood components), and a porous cement and concrete plant (slabs of different sizes for walls). The complex (Figure 10) is designed to produce at least 12,000 housing units per year. However, for various reasons, the plant has only operated at a fraction of its rated capacity.

Pertinent to our roofing development program, the chip board plant in the Calocan factory has a large automated steam-heated compression molding press, now used for producing 4 ft x 8 ft urea-bonded interior wall panels. General Tobias stated that when we reach the "pilot plant" production phase of our program, these compression molding facilities could be made available on a short-term basis, even though it would interrupt their ongoing chip board production.

They have two 2-1/2 in. extruders, and accessory mixing equipment, now used for the production of PVC floor tile. This equipment could also be used for the production of extruded roofing panels, provided a suitable die is made available.

General Tobias and his co-workers at the National Housing Corporation, exhibited a strong interest in assisting in any way in the production of new lower cost materials in the Philippines. He also was of the opinion that two of the four processes, described in Section 4.2 could readily be adapted into their production operation if the demonstration program illustrates their value.

(a) Particle board plant



(b) Portion of particle board manufacturing line

(c) Extruder and accessory equipment for manufacture of vinyl (PVC) floor tile

Figure 10. Views of Factory Complex Generated by Philippine National Housing Corporation to Produce Housing Components.

f. <u>University of Philippines (UP), Diliman, Quezon City near Manila</u>

Our principal contacts have been Dr. Aurelio T. Juguilon, Dean, College of Architecture; Dr. Ernesto G. Tabujara, Associate Professor of Civil Engineering; and Dr. Geronimo Manahan, Associate Professor of Architecture and Planning.

It is expected that the colleges of civil engineering and mechanical engineering at the University of Philippines could supply a considerable amount of the specialized equipment needed for determining the physical properties of the roofing composite (e.g., tensile, flexural, compressive strength and modulus).

It is anticipated that in collaboration with Professors Manahan and Tabujara, that the University of the Philippines could also be involved in architectural activities related to demonstration of the roofing system on four houses, including:

- site selection (establishment of criteria for site selection)
- design (preliminary roof design, design development, construction detailing)
- construction (architectural, supervison and recording of roof installation process)
- follow-up (observing and recording performance of installed roofs, recording user response to installed roofs, and contributing to final report).

g. Mindanao State University (MSU), Marawi City, Offices in the L&S Building, 1414 Roxas Blvd., Ermita, Manila, Phone 58-91-03 and 50-23-79

Until recently, our principal contact has been Dr. Rufino Ignacio, Dean, College of Engineering. Within the last six months, Dean Ignacio has left to take other employment. It is not known who his successor will be. Other contacts at MSU, in the Manila office, include Dr. Alexander Lucman, Assistant Vice President for Planning and Development; Attorney Edwin Acoba; and Dr. Eric S. Casino, Mindanao Executive Development Academy.

At Mindanao State University, some considerable research has been done on the use of various soil (clay)/cement compositions to make blocks and bricks for use in housing, roads, and other construction. Several soil/cement houses have been built on the campus for students, in an area designated as Goodman Village (in honor of Dr. Louis S. Goodman of the East-West Research Center in Hawaii, Figure 11). They also have at MSU a section devoted to ceramics for art objects.

The combination of research on soil/cement compositions for housing, along with accumulated experience and technology in ceramics, could make MSU an excellent site for some of the research on roofing materials involving "unfired clay" composites.

h. Other Philippine Government Agencies Concerned with Housing (Listing Only)

Peoples Homesite and Housing Corporation (PHHC)

Home Financing Commission (HFC)

Presidential Assistant on Housing and Resettlement Agency (PAHRA)

(a) Soil-cement (9/1 ratio) blocks being placed

(b) Completed soil-cement houses with CGI roof

(c) Dr. Louis S. Goodman (left) at project named for him.

Figure 11. Mindanao State University (Philippines) Experimental Housing Project Emphasizing Soil-Cement Construction.

Government Service Insurance System (GSIS)

Social Security System (SSS)

Development Bank of the Philippines (DBP)

Department of Public Works and Communications (DPWC)

Department of Social Welfare (DSW)

4.1.2.3 Private Industry Organizations with Facilities and Interests in Roofing Development

a. Jardine Davies, Inc., Jardine Davies Building, 222 Bundia Avenue, Makati, Phone 89-30-61

Our principal contacts there have been Mr. A. G. Westly, Vice President; Mr. A. W. Russell, Manager; and Mr. Sergio Y. Hilado, Manager, Technical Services.

Jardine Davies operates four large sugar mills in the Philippines: two in Negros, one in Sabu, and one in Pane. At all of their plants, a major portion of the bagasse (about 80%) is used for fuel to run the boilers. This use, they say, is to a considerable extent defensive. Otherwise the plant and the surroundings would be buried under mountains of bagasse refuse. The raw bagasse, when produced and baled, ordinarily contains approximately 50% water; but, the water content goes down to lower levels of ∿20% during storage.

At the largest plant on Negros, 12,000 metric tons/year of excess bagasse are produced which could be made available for use in roofing. This excess bagasse is now disposed of by landfill in swampy areas, and by stocking along the banks of the river. Accordingly, the excess bagasse has a negative commercial value to Jardine Davies, since significant costs are involved in disposing of it.

The cane is harvested and milled for about 8 months of the year. Thus production of bagasse would have to be for this period, or baling and storage facilities equivalent to 4 months production would have to be provided.

Jardine Davies said they would be strongly interested in going into the production of roofing from bagasse. They now make and market cement/asbestos siding and roofing (Eternit) under a Belgium technology licensing agreement. Thus, they are already in the roofing business, have marketing outlets, etc. Vice President Westly said: "If anyone is going to bring out a roofing material utilizing bagasse, Jardine Davies should be at least as well equipped to enter this market as others; and we would like an alternate to our present Eternit products."

The combination of strong interest, raw materials availability, and established market outlets in roofing make Jardine Davies an excellent prospect for private enterprise production of the roofing material in the Philippines after the demonstration program is completed. On the most recent trip to the Philippines (August-September 1975), Jardine Davies reaffirmed their interest in possible future commercialization. This time, they were given a technical bulletin which provided information on raw material costs, formulations, process outline and product properties.

Jardine Davies agreed to place several of our candidate roofing composite materials on their outdoor exposure racks for aging studies. After 6 months outdoor aging, they will cut these samples in half, send one-half back to MRC-Daytin, and reinstall the other half on the exposure rack for an additional 6 months, after which it will also be returned to Dayton. Jardine Davies also air-shipped, at their expense, one bale of bagasse from their plant on Negros to MRC-Dayton. This sample of bagasse will be tested to confirm whether filled composites made from it are identical to that made from samples obtained elsewhere.

b. A. Soriano Corporation, Ayala Avenue, Corner Paseo and Roxas, Phone 88-10-11

Systems and Structures, Inc., Zaragoza Building, 102 Gamboa St., Legaspi Village, Makati, Rizal, Phone 88-14-84

Soriano is reported to be one of the largest private enterprises in the Philippines, with very broad interests in many areas including construction materials, San Miguel Beer, etc. Our contact with Soriano is Mr. Ramon A. Pedrosa, Vice President. Mr. Pedrosa is also a director of the Philippine Business for Social Progress (PBSP) which has been instrumental in low-cost housing projects in the Manila area, including the Mandaluyong Condominium.

Our contact with Systems and Structures, Inc., is Mr. Jose R. Zaragoza, Jr., Vice President Engineering/Sales. As the name indicates, Systems and Structures makes components for buildings and houses.

The AID roofing program in the Philippines was discussed with Mr. Pedrosa and Mr. Zaragoza, at a meeting held at USAID, Magsaysay Building in Manila. Both of them indicated a keen interest in the development, and a possible interest in future commercial production, after the development program has been completed. Messrs. Pedrosa and Zaragosa were both given copies of the AID technical bulletin describing the processes, formulations, costs and properties of the various candidates now being considered for roofing applications in the Philippines.

c. Philippines Rubber Project Company, Inc. (Goodyear), Goodyear Building, Corner of Pasong, Tamo, and Pasay Road, Makati, Rizal, Phone 89-20-41

Our contact at Goodyear is Mr. Alfonso Penares, Liaison Officer, who contributed much valuable information on cost and availability of natural rubber.

Production of natural rubber, by Goodyear alone, is about 8 million pounds annually. Goodrich and Firestone each produce nearly equal amounts of rubber, as does Menzi. All of the rubber production for Goodyear, Goodrich and Firestone is on the island of Mindanao. The rubber processing plants are in the Manila area on Luzon. The current excess of natural rubber production by Goodyear alone, over their usage in tires, is 675 metric tons/year or 1.5 million pounds annually. This excess, and the accompanying pressure to lower prices, should make natural rubber an excellent candidate resin binder for low cost roofing.

Price data for three grades of Goodyear natural rubber range from 16 to 22¢/lb, depending on the grade quality. These data are summarized in Table 18 along with comparable data on other resin binders discussed later. Sample quantities of Goodyear block rubber were also obtained and air-shipped to MRC-Dayton. Technical bulletins on the composition and properties of Goodyear block rubber were also obtained.

Table 18

RESIN BINDER COSTS IN THE PHILIPPINES

		P/lb	¢/lb
I.	NATURAL RUBBER		
1.	SMR-5 Crumb (locally grown)	1.45-1.50	22
2.	2X Brown (locally grown)	1.15-1.20	18
3.	3X Brown (locally grown)	1.10	16.5
II.	SYNTHETIC THERMOPLASTIC RESINS		
4.	Styrene/Acrylonitrile Copolymer (SAN) + ∿30% import duty	3.87-4.06	55.7-58.4
5.	Acrylonitrile/Butadiene/Styrene (ABS) + ∿30% import duty	4.06	58.4
6.	Polystyrene + 50% import duty	3.12	44.96
7.	Polystyrene $ + 0% (local mfg)	2.60-3.00	37.4-43.2
8.	Expandable Polystyrene (local mfg)	5.00	71.94
9.	Polyvinyl chloride (PVC) P5250/MT-P4500/MT (local mfg)	2.39-2.45	34.3-35.3
10.	Dioctylphthalate Plasticizer for PVC (local mfg)	3.24	47
III.	SYNTHETIC THERMOSETTING RESIN		
11.	Phenol/formaldehyde, 45% solids, P2.27 (local mfg)	5.04	72.58
12.	Urea/formaldehyde, 65% solids, P1.09 (local mfg)	1.68	24.17
13.	Melamine/formaldehyde - none made in Philippines		
14.	Polyester, styrenated rigid (local mfg)	5.39	77.56
15.	Polyester, styrenated flexible (local mfg)	5.71	82.41

Mr. Penares has confirmed that Goodyear, Goodrich and Firestone have Banbury type mixers, which are widely used everywhere in compounding rubber. They have other rubber processing equipment, including mill rolls, calenders, extruders, etc. They are mainly committed to making of rubber tires and related rubber goods. However, Mr. Penares said that in view of their excess rubber (especially the low quality grades), they would not be adverse to a new product, such as our roofing material, which could create a profitable new market for natural rubber, and take advantage of their considerable accumulated technology and facilities for rubber processing.

Rubber processing equipment, including Banbury intensive mixers, are all on hand at the three major rubber producers (Goodyear, Goodrich, and Firestone). Potentially, the equipment could be made available for pilot plant and/or commercial production of natural rubber bonded/bagasse-filled roofing composites.

Additionally, Manila Rubber Company also has a complete rubber compounding line. In a telephone contact, their management indicated that they would be willing to rent or lease the use of a rubber production line in order to make pilot plant quantities of rubber bonded bagasse roofing composite panels.

d. Borden Internationale Philippines, Inc., Ayala Avenue, Makati, Rizal, Philippines, Phone 89-45-26

Our principal contact at Borden is Vice President, Reynaldo A. Adriano.

Borden is one of the two major producers of phenol/formaldehyde and related thermosetting resins in the Philippines. They have three plants in the Philippines, one near Manila; a second at Davao City, Mindanao; and the third at Zamboanga City, Mindanao. All the plants produce their own formaldehyde from methanol. They also have spray-dryers for producing phenolic resin in powder form. The selling price for the 45% solution is about 33¢/lb, or 73¢/lb on a 100% resin solids basis. The spray-dried phenolic powders are sold at a slightly higher price, 85¢/lb, on a 100% solids basis.

Dr. Adriano showed a keen interest in the AID roofing program as a possible route to expanded sales of their phenolic resins in the Philippines. He further stated that if there was a specific type of phenolic resin desired as the binder for the roofing material, they would make every attempt to match it, and would manufacture the resin in the Philippines on whatever scale would be required. He also offered to furnish sample quantities for the experimental phase of the roofing development in the Philippines, free of charge.

e. Resins, Incorporated
Office: 610 Tanduay, Manila D-405, Phone 40-57-26 to -29
Plant: Bario, Ugong, Pasig, Rizal, Phone 692-51-33 to -37

Resins Inc. is the older major indigenous producer of phenolic resins in the Philippines. Contacts made at Resins, Inc. included Mr. Ernesto Lichauco, Vice President, and Benjamin M. Misa, Engineer.

Resins, Inc. has a production capacity of 45,000 metric tons per year of liquid phenolic, and a much smaller production capacity of 3000 metric tons per year of phenolic powder. Resins, Inc. imports their phenol and methanol from Japan, Taiwan and Australia. However, they have a methanol plant going onstream now with a capacity of 2000 tons/day.

Not surprisingly, the price quoted for liquid phenolic resin (on a 100% solids basis) was 73¢/lb; that for the dry phenolic resin powder was 86¢/lb, identical to Borden's pricing.

Resins, Inc. also has a production capacity of 9000 tons/year of the phthalate ester-type plasticizers used in vinyl resins. The dioctyl phthalate plasticizer sells for the equivalent of 47¢/lb in the Philippines.

The availability, from local manufacture of phthalate ester plasticizers for vinyls is important to our roofing program, since vinyl resins are also indigenously produced in the Philippines, and are therefore possible candidate binders for use in the roofing composite.

f. Mabuhay Vinyl Corporation, Phone 88-66-91 to -93

Both Mabuhay Vinyl Corporation and Philippines Vinyl Consortium produce polyvinyl chloride resin, and polyvinyl chloride copolymers, in the Philippines. Mabuhay Vinyl Corporation has a production capacity of 16,400 metric tons per year and the Philippines Vinyl Consortium produces 20,000 metric tons per year. Until recently (1974), all of this production utilized imported vinyl chloride monomer. However, according to the Board of Investments, vinyl chloride monomer is now made from locally available carbide and chlorine.

A phone contact was made with Mr. Fernando Vincente, Vice President, Mabuhay Vinyl Corporation. He quoted a current price for PVC resin equivalent to 36¢/lb. This price places PVC in the same price range as the lowest cost polystyrene resin (also produced locally in the Philippines).

4.1.2.4 Forming an Advisory Committee and Technical Working Group in the Philippines

In the Philippines, which currently has a population of more than 40 million (more than 10 times that of Jamaica), it was believed that the in-country roofing development program needed both an Advisory Committee, and a Technical Working Group. The function of the Advisory Committee was to be principally one of coordinating the various aspects of the program, as well as to obtain credability and acceptance of the results. The Technical Working Group, on the other hand, is a much smaller group having one representative from each of the organizations carrying out the various parts of the program. The Chairman of this Technical Working Group Subcommittee, in turn, reports to the Chairman of the Advisory Committee.

At the suggestion of the National Economic Development Authority (NEDA), the National Science Development Board (NSDB) was selected as the scientific agency in the Philippines to carry out the in-country development of the AID roofing project. General Florencio A. Medina, Chairman, National Science Development Board, was asked, and agreed, to head the National Advisory Coordinating Committee. The committee was formally constituted at a meeting at NSDB on February 12, 1975 and has representatives of all of the government agencies critically concerned with housing. A membership of the National Advisory Coordinating Committee is listed in Table 19.

Table 19

LOW-COST ROOFING NATIONAL COMMITTEE (PHILIPPINES)

Country Coordinator:

1. General Florencio A. Medina
   Chairman
   National Science Development Board
   Bicutan, Taguig, Rizal

Members:

2. Dr. Jose R. Velasco
   Commissioner
   National Institute of Science and Technology
   National Science Development Board
   Bicutan, Taguig, Rizal

3. Dr. Francisco U. Tamolang
   Commissioner
   Forest Products Research and Industries Development Commission
   872 Isabel Bldg., Isabel St., España, Manila

4. Dr. Ernesto Tabujara (represented by G. Hanahan)
   Officer-in-Charge
   Building Research Service
   University of the Phil ppines
   Diliman, Quezon City

5. Dean Aurelio T. Juguilon
   College of Architecture
   University of the Philippines
   Diliman, Quezon City

6. Dean Rufino Ignacio
   College of Engineering
   Mindanao State University
   L and S Bldg., Roxas Blvd., Manila

7. Gen. Gaudencio V. Tobias
   Executive Vice-President
   National Housing Corporation
   Tala, Caloocan City

   Executive Director
   Tondo Foreshore Development Authority
   Tondo, Manila

8. Mr. Sebastian B. Santiago
   General Manager
   People's Homesite and Housing Corporation
   Elliptical Road, Quezon City

9. Col. Jaime A. Venago
   Officer-in-Charge
   Presidential Assistant on Housing and Resettlement Agency
   Quezon Blvd., Extension, Quezon City

10. Dean Cesar H. Concio
    Chairman
    National Building Code Committee and
    President, Philippine Institute of Environmental Planners
    Sikatuna Bldg., Ayala Avenue
    Makati, Rizal

11. Mr. Cesar A. Caliwara
    President
    Philippine Institute of Civil Engineers
    Delta Motor Sales Corporation Bldg.
    Quezon Blvd., Extension, Quezon City

12. Mr. Joseph Whelton
    Assistant Director
    Humanitarian and Private Assistance
    United States Agency for International Development
    Ramon Magsaysay Center, Roxas Blvd.
    Manila

Subsequent to the formation of the National Advisory Coordinating Committee, Chairman Medina designated a "Technical Working Group," consisting of members who would carry out the actual experimental work. The makeup of this committee is listed in Table 20.

A meeting of the entire Technical Working Group was held at NSDB on August 29, 1975.

The results obtained in the materials development to date by MRC were presented. At this meeting the decision to go ahead with the implementation of the roofing program in the Philippines was confirmed. Additionally, however, Chairman Medina stated that it would be necessary to have some sort of written understanding or agreement, which would be approved and signed by all of the organizations involved (NEDA, NSDB, USAID-Philippines and AID-Washington).

Following the meeting, a proposed "Memorandum of Agreement" was prepared by NEDA attorneys and has been submitted to AID-Washington for review and possible implementation. Importantly, the proposed agreement provides for a total research effort of approximately $100,000. for the experimental program, with one-half of the funds to be supplied by AID-Washington and the other half from PL-480 Peso equivalent available in the Philippines.

At the request of NEDA, a detailed experimental program was drawn up as a guide to the different groups who would be performing various parts of the investigation. Technical bulletins or brochures were also given to the Technical Working Group which contain detailed information on program tasks and schedule, process outlines, formulations for the candidate roofing materials, the cost per pound (and per sq ft), and the physical properties and aging characteristics of the resulting products.

Table 20

TECHNICAL WORKING GROUP FOR THE DEVELOPMENT OF A LOW-COST ROOFING (PHILIPPINES)

1. Ms. Lydia G. Tansinsin
   Chairman
   National Science Development Board
   Bicutan, Taguig, Rizal

2. Dr. Vedasto R. Jose
   Vice Chairman
   National Institute of Science and Technology
   Bicutan, Taguig, Rizal

3. Engr. Joaquin Siopongco
   Member
   Forest Products Research and Industries Development Board
   Industries Development Commission
   872 Isabel Bldg., Isabel St., Espana, Manila

4. Prof. Geronimo Manahan
   Member
   University of the Philippines
   Building Research Service
   Diliman, Quezon City

5. Dean Auerlio T. Jugilon
   Member
   University of the Philippines
   College of Architecture
   Diliman, Quezon City

6. Dean Rufino Ignacio
   Member
   Mindanao State University
   L and S Building, Roxas Blvd., Manila

7. Col. Alejandro R. Kabiling
   Member
   National Housing Corporation
   Tala, Caloocan City

8. Engr. Ramon R. Veto
   Member
   People's Homesite and Housing Corp.
   Elliptical Road, Quezon City

9. Dr. Carlos Javier
   Member
   Presidential Assistant on Housing and Resettlement Agency
   Quezon Blvd., Extension, Quezon City

10. Dean Cesar H. Concio
    Member
    National Building Code
    Sikatuna Bldg., Ayala Avenue
    Makati, Rizal

11. Engr. Sangel Lazaro, Jr.
    Member
    Philippine Institute of Civil Engineers
    Sikatuna Bldg., Ayala Avenue
    Makati, Rizal

12. Mr. Robert Halligan
    Assistant Program Officer
    US-AID

    Mr. Albert S. Fraleigh
    Assistant Director
    Food for Peace, US-AID
    Ramon Magsaysay Center, Roxas Blvd., Manila

13. Mr. Jose O. Jaug
    Member-Secretary
    National Science Development Board
    Bicutan, Taguig, Rizal

A copy of the proposed "Memorandum of Agreement" and the two MRC bulletins on "Advisory Committee Information" and "Working Technical Group Information" are attached in Appendix D and C.

A cumulative list of personnel field contacts in the Philippines is included in Appendix F.

4.1.2.5 Resin Binders and Filler Cost and Availability in the Philippines

a. Resin Binders

As previously stated, the candidate binders for the AID roofing composites include natural rubber, three synthetic thermoplastic resins, and thermosetting phenol/formaldehyde. Natural rubber is grown and processed on a large scale in the Philippines. Synthetic resins, including most of the thermoplastic resins and thermosetting phenol/formaldehyde, and polyesters, are all produced locally in the Philippines. The synthetic resins are "indigenous" to varying degrees, since in some cases the monomer, or monomer precursors are imported.

The Philippine government imposes a 30% duty on imported resins not manufactured in the Philippines, and a 50% duty on those that are. The selling price of the locally produced synthetic resins is only slightly lower than that of imported equivalents, despite the considerable shipping costs and import duties on the latter.

As already discussed in the preceding section, concerning Goodyear, natural rubber is grown on a sufficient scale (e.g., 32,000,000 lb/year) to supply all the local needs for tires and rubber goods, and there is a substantial quantity available for other uses and for export.

The selling price for natural rubber ranges from 16.5 to 22¢/lb depending on quality grade, as shown in Table 18. At this price, natural rubber, especially in the lower quality grades, is easily the lowest cost of our candidate resin binders in the Philippines. Naturally, the Filipinos are much interested in broader utilization of this available indigenous resource.

The synthetic thermoplastic resin binders of established interest for the AID roofing composites include styrene/acrylonitrile/ butadiene/styrene graft copolymer polyblends (ABS), and polyvinyl chloride (PVC). Neither SAN or ABS is manufactured in the Philippines, if used, they would have to be imported (and the import duty paid). Polystyrene hompolymer is manufactured locally by two companies: Philippine Petrochemical Products, Inc., and Polystyrene Manufacturing Company, using imported technology and monomer. However, our research indicates that polystyrene is not as compatible with bagasse filler, and is significantly inferior in aging characteristics to the SAN and ABS. In view of the direct relationship of the already available technology to manufacture polystyrene, it is possible that SAN copolymers could be produced in the Philippines in the immediate future.

Polyvinyl chloride is truly indigenous in the Philippines, since both monomer and polymer are locally produced from basic starting raw materials. Despite being entirely indigenous, PVC at 35¢/lb is significantly higher in cost than equivalent product from Japan.

Thermosetting resins, e.g., urea/formaldehyde, phenol/formaldehyde, and polyesters, are all made locally in the Philippines by at least two producers (Borden and Resins, Inc.). The thermosetting resins are "indigenous" to varying degrees. Formaldehyde (for P/F and U/F resins) is manufactured in the

Philippines by oxidation of imported methanol precursors. How, ever, Resins, Inc. currently has a plant scheduled to go onstream which will synthesize methanol from basic available raw materials. Phenol is imported, as is urea.

Phenol/formaldehyde resins are available from both the major producers in 45% aqueous solutions at 73¢/lb (at 100% solids basis) and spray-dried powders at 85¢/lb (100% solids basis).

Polyester resins are also manufactured in the Philippines at current costs ranging from 77 to 82¢/lb.

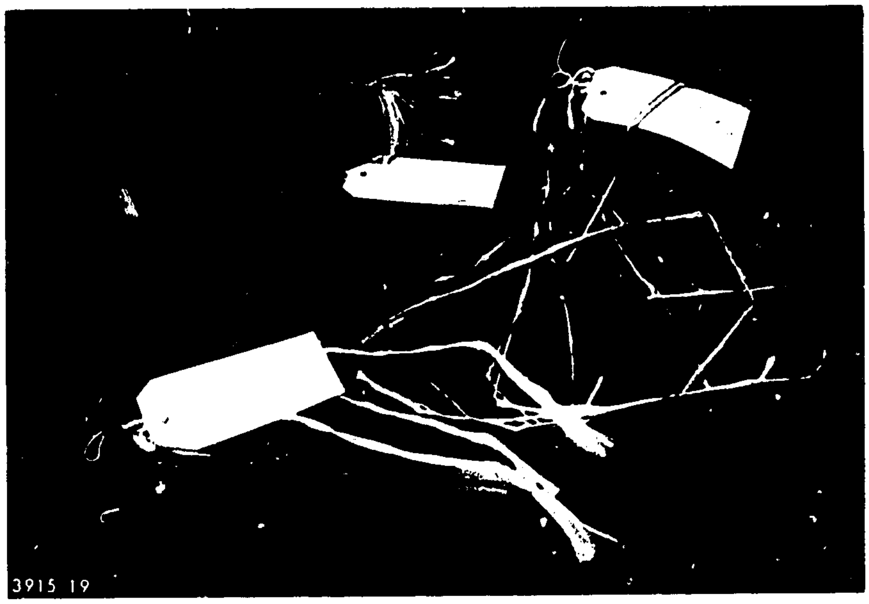
Asphalt is produced in the Philippines as a by-product of their petroleum refining operations. Depending on the grade, the selling price of asphalt ranges from 5 to 15¢/lb.

Sulfur, being investigated by Southwest Research as a "binder", has a selling price in the Philippines of about 12¢/lb.

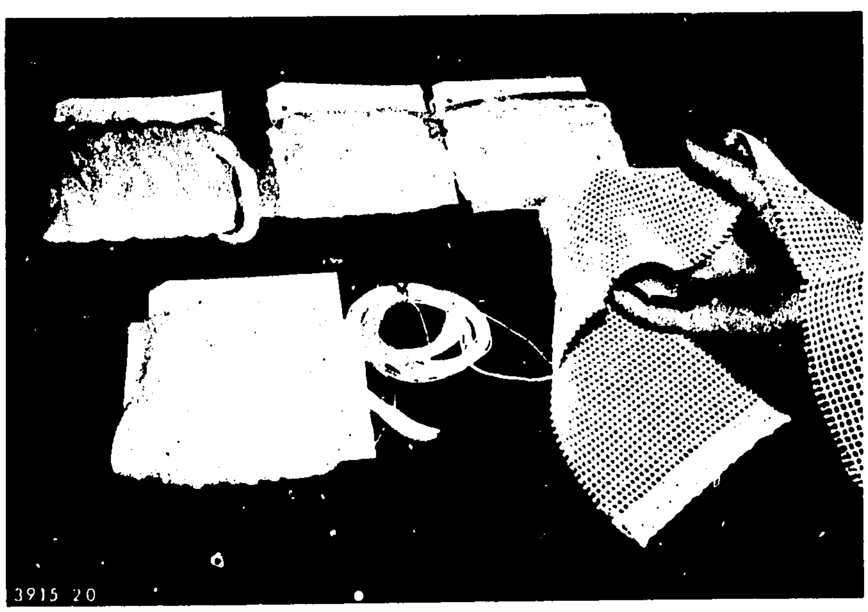
The selling prices in the Philippines of the various grades and types of binder resins are summarized in Table 18.

b. Fillers

The principal indigenous fillers of interest for possible use in the AID roofing composites included bagasse, sawdust and clay. Information on the cost and availability of these primary fillers was obtained. However, there is also interest in other low-cost forest or agricultural residues which might be alternate fillers in the Philippines. For this reason, some data were also collected on the various grades of abaca, and ramie. (See Figure 12).



(a) Raw and partially
processed ramie stalks



(b) Ramie fiber staple and
woven products

Figure 12. Various Forms of Ramie Plant and Fiber Grown, Processed, and Marketed in the Philippines.

Sugar cane is extensively grown in the Philippines, especially on the islands in the south, including Negros, Sabu, and Panay. The amount of sugar produced from sugar cane in the Philippines is enormous (e.g., 1974 - 3.7 million tons). Thus, sugar is not only sufficient for all local consumption, but also is a major export product of the Philippines, and earner of foreign exchange. On the island of Negros alone there are 17 sugar mills accounting for approximately 75% of the Philippines produce in raw sugar, molasses. and other by-products.

Since the concurrent production of bagasse is ∿3 times the weight of the refined sugar, it follows that the supply of bagasse in the Philippines is also enormous, especially on the island of Negros, where two of the Jardine Davies sugar mills are located. Although the bagasse is used as fuel for firing the boilers at the sugar mill, there is, as reported by Mr. Gordon Westly, Vice President of Jardine Davies, always an excess amounting to about 20% of the total amount of bagasse generated at the sugar mill. This excess bagasse constitutes a real disposition problem at the sugar mills, where it is used for landfill, and stored on the banks of rivers to be carried away during the flood season. For this reason, the sugar mill operators (especially those like Jardine Davies who are already marketing roofing), would be very happy to find some profitable use for their excess bagasse. Accordingly, Mr. Westly stated that in roofing manufacture, they would charge-in bagasse at zero, or negative (disposition) value.

At the largest Jardine Davies plant in Negros, 12,000 metric tons/year of excess bagasse could be made available for use in roofing. This quantity (26,400,000 lb/year) from a single mill is probably sufficient to supply a considerable fraction of the contemplated usage of bagasse in composite roofing materials. Certainly, the amount of excess bagasse available on the total island of Negros could supply filler for all of the contemplated usage in roofing material composites, as well as in building materials for the walls, ceilings, and other portions of the house.

Sawdust for use as a filler in a roofing composite is also plentifully available in the Philippines from some 374 saw mills in the country, with a total rated capacity of 2.3 billion board feet per year. Sawdust also presents a disposition problem at the saw mills, where it accumulates and frequently must be burned to dispose of it. There are some sales of sawdust for fuel at 2P/bag of 50 lb for about 0.6¢/lb. The sawdust is of two types, that from the older circular saws (larger chips) and that from the newer bandsaws (smaller chips).

Wood chips from saw mill waste slabs cost only about P70/ton or 0.5¢/lb.

Accordingly, sawdust is certainly available on a large scale in the Philippines wherever there are lumbering operations, and at a very low cost (0.6¢/lb).

Another possible fibrous agricultural filler is abaca (used to make Manila hemp) which is also produced on a very large scale (90,000 metric tons/year) in the Philippines. Most of the production is on the island of Mindanao. Due to the increasing usage of abaca in pulp and paper, as well as cordage, the 1975 demand is predicted to equal or exceed total available supply. However, production of abaca is being encouraged by the government and thus there should, in the future, be excess abaca available which could be used in the roofing composite.

There are many grades of abaca, defined by fineness (size), lint, and color of the fibers. There are three established grades with prices ranging from 17 to 46¢/lb. In addition to these three grades that are harvested, there is an equal production not harvested of pith and short fiber that is useless for the current abaca applications, and is "left in the fields to rot." This plantation grade reportedly would be available at a price substantially below that of the lowest commercial grade.

The P and $ equivalent price of the various grades of abaca is shown on Table 21.

Ramie fiber, in several grades, is also produced in the Philippines on a limited but growing scale. Current production, all in Mindanao, is estimated at 4-1/2 million pounds/year. However, the crop can be harvested every 2 or 3 months, and requires replanting only after about 6 years growth in one location.

The ramie plant is unusual, in that all of the plant stem consists of useful fiber bundles; only the bark and leaves need to be removed, and the fiber decorticated. Thus, approximately 90% of the stem of the ramie plant can be recovered as useful fiber. Depending on grade, the selling price ranges from 16-32¢/lb.

Because of the high quality of the fiber that is produced, the high percentage of fiber recovered from the plant, and the rapidity of growth, the production of ramie in the Philippines is likely to be increased rapidly over the next few years. Although there is no surplus of ramie, of any variety at the present (production equals demand), this may very well change in the future with increasing cultivation of the plant and production of the fiber. Accordingly, ramie should also be

Table 21

AVAILABILITY AND "COST" OF INDIGENOUS FILLERS IN THE PHILIPPINES

I. BAGASSE

A. Production 1974 - 11,000,000 metric tons
B. Selling Price - No market value for the 20% excess

II. SAWDUST AND WASTE WOOD PRODUCTS

A. Production 1974 - >1,000,000 metric tons (estimated)
B. Selling Price

1.	Wood chips	P70/ton	0.5¢/lb
2.	Sawdust	P2/50 lb	0.6¢/lb

III. ABACA

A. Production 109,000 metric tons
B. Selling Price

1.	Best, whitest	P6-8/kilo	46¢/lb
2.	Medium coarse	P3-5/kilo	27¢/lb
3.	"Y" lowest grade	P2-3 kilo	17¢/lb
4.	Plantation waste (not harvested)	P1-2/kilo	7-13¢/lb

IV. RAMIE

A. Production 1974 2500 metric tons
B. Selling Price

1.	Best, highest grade	P2.2/lb	32¢/lb
2.	Lowest grade	P1.1/lb	16¢/lb

V. CLAY

A. Production 1974 - "Plentiful" at several locations.
B. Selling Price - No established price for raw clay.

considered as a possible future renewable, indigenous source of fibrous fillers for roofing composites. The current selling price of the decorticated fiber in the Philippines is also listed on Table 21, along with similar data on abaca. It is possible that the raw, whole ramie plant could be used directly as a filler in the Banbury melt compounding process, as already developed for whole, dry bagasse.

Clay deposits, suitable for making brick, was located in many places in the Philippines including the major islands of Luzon and Mindanao. As already noted, there has been considerable research at Mindanao University on the use of clay-soil/cement composites to make blocks, bricks, and other items for use in low-cost housing, roads, etc. There is also research done on clay for use in bricks and ceramics at the National Institute of Science and Technology in Manila. Four samples of representative Luzon clays were obtained and sent to MRC-Dayton, along with analysis of their composition and other properties as raw materials for fired clay brick manufacture. Despite some fairly significant differences in composition, water plasticity, etc., all of these clays appear to be suitable for use with phenolic or polyelectrolyte binders for making "bricks that do not have to be fired."

Provided that the clays do not have to be of any specific chemical composition, as is currently believed, these fillers would indeed be very low in cost in the Philippines. If compositions similar to those required for fired clay bricks were necessary, the cost would be higher but still probably less than 1¢/lb.

4.1.3 Zambia

In common with many other developing countries, Zambia has a pronounced need for new and lower cost building materials requiring less foreign exchange and derived largely from indigenous resources, to provide urgently needed housing for their increasing population. Additionally, Zambia has also experienced, in recent years, a pronounced rural-to-urban migration. This has resulted in build-up of squatter settlements, and other areas of inadequate housing, in the principal cities of the country, and especially in the capitol, Lusaka. The Honorable Peter Matoka, Minister of Local Government and Housing, expressed a strong interest in having Zambia participate in the AID-sponsored roofing materials development program. This and other favorable factors, noted in the "country survey" completed in Phase I, led to the selection of Zambia as the African country for development and demonstration of new low cost roofing concepts.

During Phase II, a total of three separate visits were made to Zambia by individuals or teams of MRC-Washington University personnel in attempts to initiate the AID roofing development there.

In the three visits, government and private industry approaches to low cost housing, housing designs, and construction were reviewed.

Government and private organization having an interest in housing, and the potential ability to contribute to the roofing implementation in Zambia were contacted.

The availability of processing facilities, for both small-scale experimental work, as well as later pilot plant production, was determined.

Firms in the private sector having facilities and/or market position which might make them future commercial manufacturers of the roofing material (e.g., Turner Asbestos Products Company) were also located. Since the building industry has been largely centralized in the government-controlled Industrial Development Company (INDECO), there is only limited opportunity in Zambia to obtain private enterprise participation.

An Advisory Committee was formed in Zambia centered around the National Council for Scientific Research, with Dr. D. S. Nkunika, Secretary General, as Chairman.

The cost and availability of the candidate resin binders (SAN, PVC, natural rubber, and phenol/formaldehyde); and fillers (bagasse, sawdust, ore tailings and clay) in Zambia was also determined.

As in the other two selected countries, it was deemed essential to have in-country participation and involvement for the roofing development program to be successful. For this participation, some allocation of funds, or equivalent in services and facilities was necessary.

During Phase I and until July 1974, it appeared that the necessary technical support in Zambia could be made available. However, it was later stipulated (during the November visit of Dr. Usmani) that a formal agreement would have to be negotiated between the Government of the United States (AID) and the Government of Zambia. Additionally, they attached several conditions to the agreement, including the right to designate who in Zambia would manufacture the materials, exclusive rights to the technology developed, and any patents. Some of these conditions were not entirely acceptable to AID which has, from the start, held that the results of the roofing development work, wherever and however done, should be made freely available to the world community.

Unsuccessful attempts were made, by personnel of the U. S. Embassy, to persuade the Government of Zambia to accept an informal "Memorandum of Understanding" as a substitute for a formal agreement (which could take up to one year to negotiate).

The difficulties of completing the negotiation of a formal agreement, a decrease in the price of copper (and a consequent worsening of Zambia's foreign exchange position), and a lack of established facilities for carrying out the experimental program, led the Government of Zambia (GOZ) in July 1975, to withdraw from the program and recommend "that Monsanto should seek collaboration with Ghana where there are already facilities." This decision by GOZ was accepted with regret by AID, and the roofing development activities in Zambia were terminated. However, Zambia was assured that the research results obtained in the roofing program would be made available to them via the Annual and Final Reports. Thus, they would be able to take advantage of the roofing developments at a future time if they so elected.

Contacts are listed in Appendix G.

4.1.4 Ghana

4.1.4.1 Summary

It was originally anticipated that Ghana would be one of the prime candidate countries in Africa. It offered a variety of climates, pronounced housing needs, material resources, and appropriate collaborating institutions (e.g., Building and Roads Research Institute) with a demonstrated background in research on materials of construction. However, at that time, it was believed by the USAID Mission in Ghana, that the AID roofing program paralleled and might conflict with a related project then being conducted in Ghana for USAID, by

A. D. Little, on "Achievement of Cost Reduction in Public Construction". As a result, Ghana was, for the time being, dropped from consideration.

When Zambia officially withdrew from the project in June 1975, it was decided to reopen the question of participation by Ghana in order to have an African country in the program.

Accordingly, contacts were made with Mr. Haven North, Director USAID Mission, Ghana. Mr. North, in turn, contacted various officials of the Government of Ghana concerned with housing, as well as with Dr. J. W. S. DeGraft-Johnson, Director of the Building and Roads Research Institute at Kumasi. Since no current conflict was seen between the now completed A. D. Little study and the proposed AID-sponsored roofing program, approval was given to initiate the project in Ghana.

During Phase II, two visits were made to Ghana. The first by I. O. Salyer and G. L. Ball (June 30 to July 5, 1974) was a preliminary "get-acquainted and resource study", conducted before Ghana was officially brought into the program. The second visit to Ghana was made by I. O. Salyer and J. P. R. Falconer (September 15-September 25, 1975).

The general objective of the second visit was to initiate the roofing development program, and to take other steps which would quickly bring the project in Ghana up to the same stage as the other two countries. The specific objectives were to define potential collaborative institutions and individuals, establish the degree to which processing facilities were available, form an Advisory Committee (if necessary), select a Technical Working Group, and determine the availability and cost of the candidate resin binders and fillers in Ghana.

A cumulative list of people and organizations contacted, relative to the roofing program in Ghana, is summarized on Appendix H.

4.1.4.2 Identification of Collaborating Government Organizations and Institutions in Ghana

Mr. G. N. Coleman, a native of Ghana who is on the staff of Washington University, made a trip to Ghana on personal business during Phase I (August 10-28, 1973). Mr. Coleman made contacts with a number of government and private industry agencies to determine their interest in having the AID roofing development program brought to Ghana. Those indicating a positive interest and desire to cooperate at that time were: The Building and Roads Research Institute, the Forest Products Research Institute, and the Crops Research Institute, of the Council for Scientific and Industrial Research; the Department of Housing and Planning Research; the Ministry of Lands and Mineral Resources; the Ministry of Agriculture; the Ghana Housing Corporation; TEMA Development Corporation; the Ghana Industrial Holding Corporation; and the Ghana Geological Survey.

Copies of letters from these organizations confirming their interest are contained in Appendix I.

During the Phase II visits, these initial contacts were renewed, and others established as discussed below.

a. Bank of Ghana, Downtown Accra,
P.O. Box 2674, Phone 66902 and 62930

Contacts at the Bank of Ghana include Mr. M. F. Owierdu, Executive Director; and H. N. O. Quao, Deputy Chief, Development Fianance Department.

Mr. Owierdu said that the construction industry in Ghana was underdeveloped, but important. They now use 70-80% imported materials and are restricted by foreign exchange availability. Cement (now widely used in building) is imported as clinker from Norway, with freight charges amounting to 70% of the value. Unfortunately, there are no established sources of limestone in Ghana for cement manufacture, but further surveys are in progress in an attempt to locate practical sources.

They have a major interest in developing indigenous building materials. They are now building several brick factories, a few large ones first in major cities, then smaller ones in towns, villages, etc. Production of fired clay roof tiles is not planned at present; however, there are facilities for extruding clay tiles at Kumasi.

Production of asbestos/cement sheets for roof panels is also planned, but both components have high foreign exchange requirements.

They now import both aluminum and galvanized iron sheets, which are cut and corrugated in Ghana.

Mr. Owierdu further stated that the banks (e.g., Bank of Ghana) have excess money (Cedi's) on hand which could be used to finance viable development projects which have low or no risk. How to get to that stage is the problem. He said the Bank of Ghana could make available new Cedi's in the amount of 50,000 to Building and Roads Research Institute as counterpart funds for the development stage of the roofing program.

Ghana produces sugar on a scale sufficient to fill 30% of present requirements, but have a program planned to be self-sufficient in sugar in 5 years. He stated that bagasse is now used to fire the boilers at the sugar mills, but that a changeover to firing with low cost "residual oil" (available in 70,000,000 gallons/year quantities from their petroleum refining operations) could be done if bagasse proved to be a useful material for roofing.

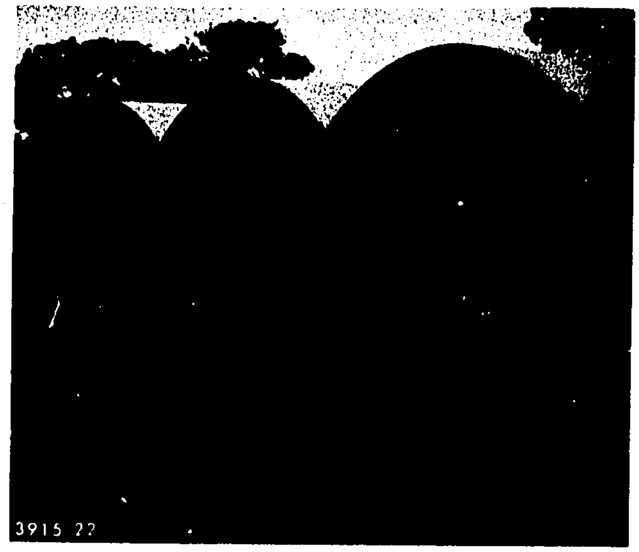
Natural rubber is produced in Ghana on a scale sufficient for their internal use in tires and rubber goods, and production is increasing as new plantations mature.

b. <u>Building and Roads Research Institute (BRRI), Campus of University of Science and Technology, P.O. Box 40, Kumasi, Ghana, Phone 4221, 4222</u>

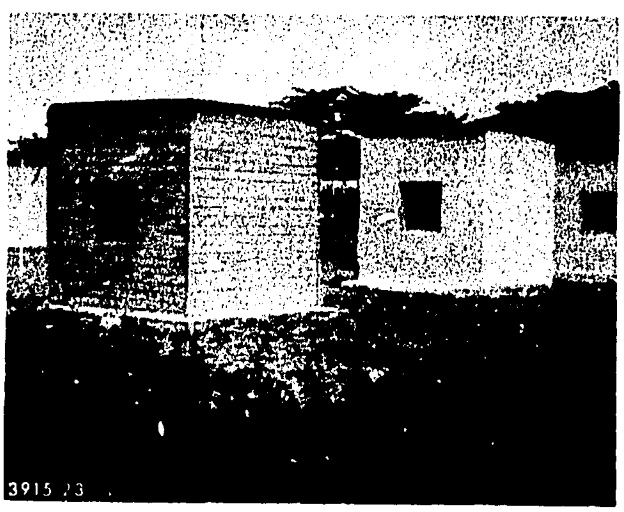
Our principal contacts at BRRI are Dr. J. W. S. DeGraft-Johnson, Director, and Mr. Kwesi A. Manuel, Chief Administrative officer. BRRI is now building new and more adequate facilities for Research and Development a short distance away from the University on the Kumasi-Accra Road (Figure 13). These facilities are expected to be completed and occupied in 1976-77. As the name indicates the Building and Roads Research Institute has broad technical responsibilities and considerable prestige in Ghana. The Director, Dr. J. W. S. DeGraft-Johnon is also well-known and respected in the international scientific community. Thus, it appears that BRRI should, in Ghana, be uniquely equipped to carry out the experimental and/or implementation phases of the roofing development program in that country.

Although they are well-equipped for research and development in ceramics, brick, cement, concrete, etc (Figures 14), they have little experience or equipment at BRRI of the type required (Banbury mixer, steam-heated compression-mold, centrifuge-orienter) for the AID roofing project. Consequently, this type of small-scale processing equipment would have to be imported from the U.S., or elsewhere, and would require a significant amount of scarce foreign exchange.

(a) Portion of present physical facility



(b) New physical facility under construction due to be functional in 1976



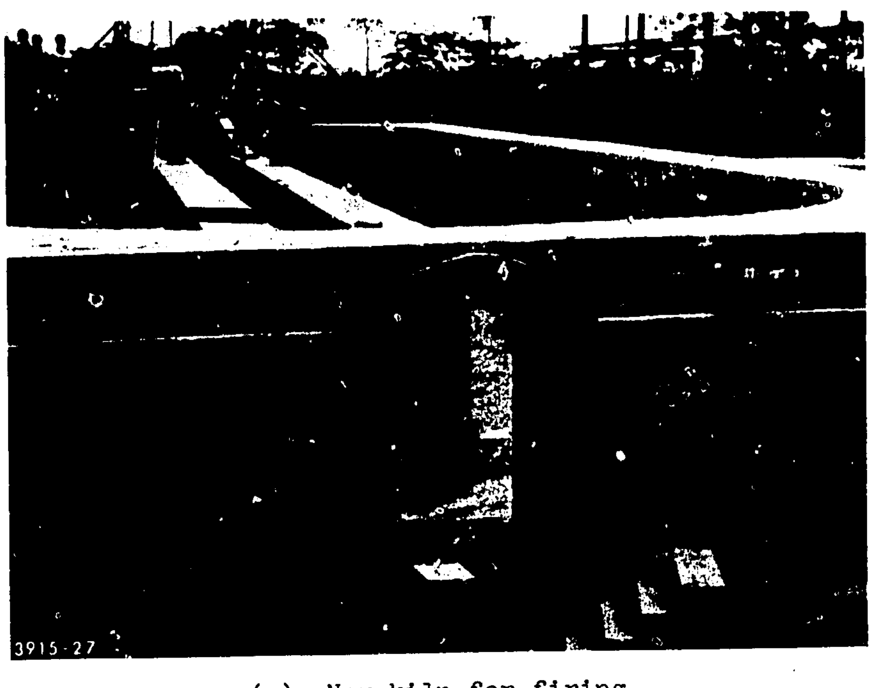
(c) Instrumented buildings for evaluation of insulating characteristics

(d) Prototype walls under outdoor exposure tests

Figure 13. Views of Building and Roads Research Institute, Kumasi, Ghana Indicating Their Background in Materials of Construction.

(a) Manual block press (UST)

(b) Block press in operation to compress clay (UST)



(c) New kiln for firing bricks (BRRI)

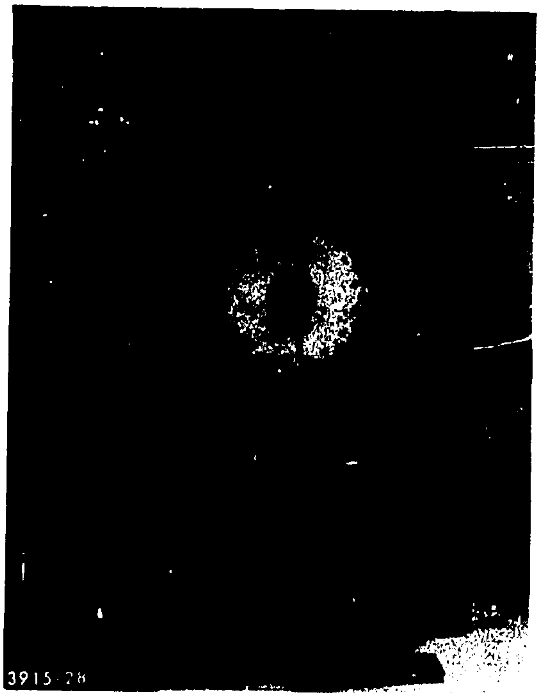
Figure 14. Facilities and Work in Progress on Soil-Cement and Fired Bricks at Building and Roads Research Institute, and the University of Science and Technology, Kumasi, Ghana.

Larger scale processing facilities, as would be needed in the pilot plant production phase of the program in Ghana, are probably available in Ghana, and this will be discussed later.

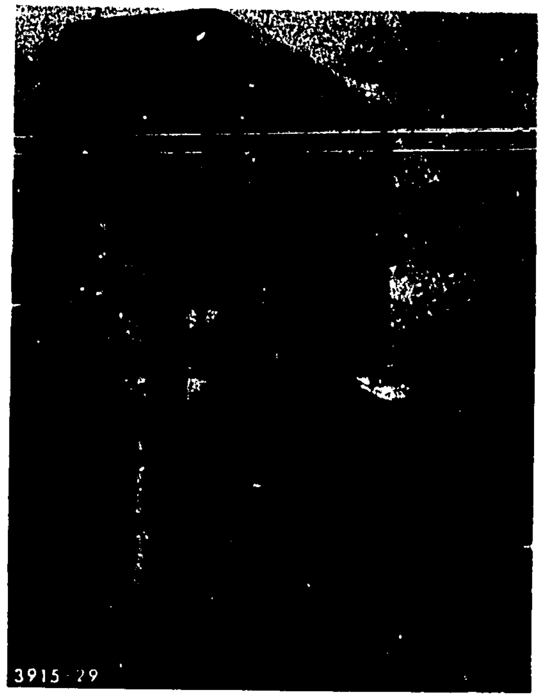
Instruments and equipment for determining the physical strength properties of the composites, outdoor aging characteristics, and termite resistance, are already on hand at BRRI. The equipment for physical testing could, if necessary, be supplemented by additional facilities existing within the engineering department at the nearby University of Science and Technology (Figure 15).

At BRRI, it was pointed out by Mr. Alex Schienesson, Sr. Project Advisor, Technology Consultancy Centre, University of Science and Technology, that a type of wild rubber, *Funtumia elastica* is grown in Ghana, which might be equally usable for the program, and available at lower cost than *Hevea brazilensis* (cultivated on plantations and used for tires and rubber goods). Mr. Scheinesson obtained for us, samples of *Funtumia elastica,* in both latex and dry form for evaluation as the indigenous rubber binder in the roofing composites.

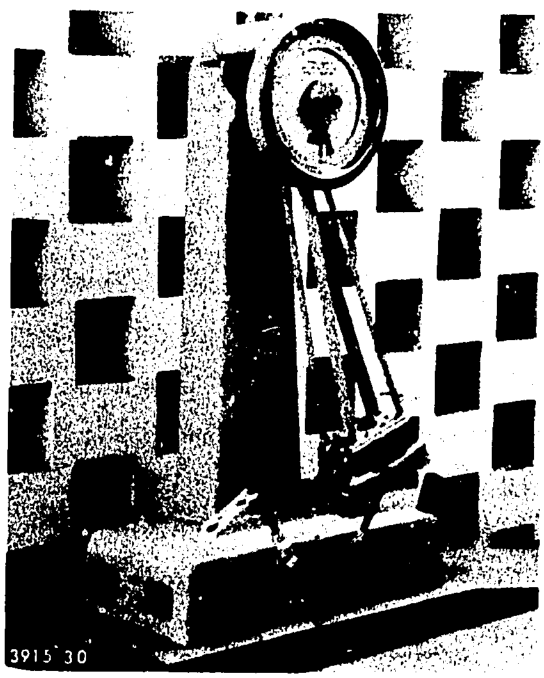
Dr. DeGraft-Johnson seems genuinely interested and enthusiastic about the potential of the AID roofing program for Ghana. He stated that they would have no difficulty with the Cedi requirements for the research phase. If the Bank of Ghana provided these funds, that would be fine. However, if the Bank of Ghana did not furnish the Cedi requirements, Dr. DeGraft-Johnon stated that BRRI would absorb the cost of this program in their normal operating budget. Any foreign exchange requirements for equipment or otherwise would, however, have to be furnished by AID.



(a) Universal tester for tension testing



(b) Universal tester for compression testing



(c) Impact tester

Figure 15. Mechanical Test Equipment at the University of Science and Technology, Faculty of Engineering, Kumasi, Ghana.

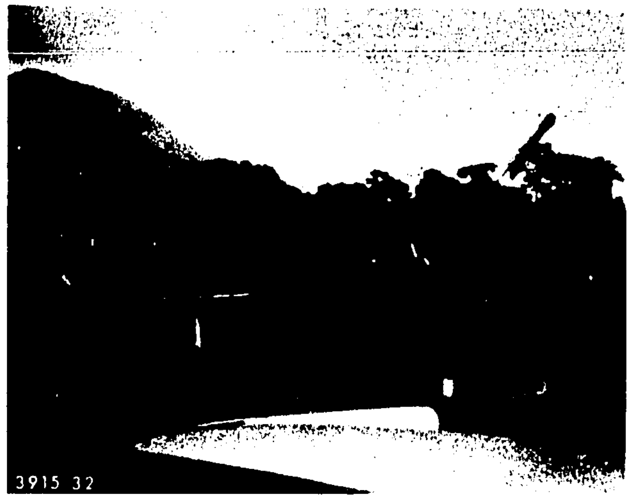
c. University of Science and Technology (UST), Located on the Outskirts of Kumasi, Kumasi-Accra Rd., P.O. Box 3408, Phone 5351

The University of Science and Technology is one of the three largest universities in Ghana; and, pertinent to our roofing program, has a well-equipped School of Architecture and School of Engineering. Principal contacts there include: Dr. F. A. Abloh, Associate Professor on the Faculty of Architecture, Department of Housing and Planning Research; Dr. B. Biswas, Associate Professor of Chemistry; and Dr. J. Powwell, Head of the Technology Consultancy Centre.

The Department of Housing and Planning Research, and the School of Architecture, have significant work underway, at the University and nearby, on various concepts of low cost housing. They are stressing wider utilization of the relatively plentiful wood and lumber resources of Ghana (Figure 16). In the wood utilization area, the developments by UST closely parallel and, in some cases, overlap that being done by the Forest Products Research Institute, which is a part of the Council for Scientific and Industrial Research (CSIR).

In Ghana, wood in the form of lumber or plywood, is an important export commodity and earner of foreign exchange. However, wood is under-utilized in local housing, for either roofs or other parts of a house, because of a strong feeling that wood has inadequate resistance to fire and termites. The work at UST, as well as in BRRI, is aimed at encouraging wider utilization of the indigenous wood resources of Ghana.

(a) Logs representing plentiful quality lumber



(b) Lumber mill showing sawdust residue

(c) Wood shingles for walls or roofs that have had trouble gaining general acceptability

Figure 16. Illustration of the Plentiful Wood and Lumber Resources in Ghana.

d. <u>Forest Products Research Institute (FPRI), Campus of University of Science and Technology, P.O. Box 63, Kumasi, Phone 5770</u>

Our main contacts at FPRI are Mr. F. W. Addo-Ashong, Director; and William K. Ashiabor, Research Scientist.

FPRI has a strong interest in wider utilization of Ghana's extensive forest resources, and the by-products (sawdust, wood chips, trim, etc.). FPRI has sponsored and initiated a program of reforestation of Ghana's forest with more desirable species (e.g., for lumber) and with more rapid growing species such as pine.

FPRI would be strongly interested in any research program which would turn some of the current sawdust waste into a useful material for construction purposes. FPRI agreed to supply samples of various types of sawdust, and other wood waste products, as needed for the AID roofing program.

e. <u>Crops Research Institute (CRI), Kwadaso, About 20 Miles North of Kumasi, Phone 6221, 6222</u>

Contacts at CRI include Dr. Accrey, Director and Mr. Knight, Chief Administrative Officer.

A new development in Ghana is the apparently successful and increasing cultivation of rice. Rice cultivation has developed rapidly in the last three years. They expect, in a few years, to be self-sufficient in rice and to have some available for export as well. Along with the production of rice, there is the concurrent production of increasing quantities of rice hulls, rice straw, etc., which they would like to see utilized profitably (e.g., filler for roofing composite).

f. Bast Fibers Development Board (BFDB),
Outskirts of Kumasi,
P.O. Box 1992, Phone 6573

Discussions were held at the Bast Fibers Development Board with Dr. J. W. Twum, Executive Director.

Bast fibers, or kenaf, cultivation in Ghana is another new crop being encouraged by the government. In the growing and processing of kenaf, fibers, are following closely the technology developed in Bangladesh for jute. Production of kenaf for the current year will fill only 5-7% of the market and is expected to be about 250 tons. This is not sufficient to supply their present fiber processing plants and jute is imported from Bangladesh to make up the difference.

Of possible interest to the AID roofing program is the potential future availability of kenaf fiber intermediate in ribbon form at about 0.12 Cedi/lb, or 11¢/lb. Of even greater interest, provided it could be used, would be the whole kenaf plant harvested but unretted, at a price of about 2¢/lb. However, for either the ribbon or the unretted whole stalk to be available for use in the rocfing, the planned increases in kenaf production to supply both the present and anticipated market for the material in fiber form would first have to be realized and exceeded. This increased production is not likely to materialize in the immediate future.

4.1.4.3 Private Industry Organizations with Facilities and Interests in Roofing Development

a. Firestone-Ghana, Ltd., Ghana Rubber Estates, Ltd., Accra, P.O. Box 5758, Phone 28414

Our principal contact at Firestone is C. E. (Chet) Hoyt, Comptroler. Mr. Hoyt provided a considerable amount of valuable information on production and selling price of natural rubber in Ghana.

The government is a majority stockholder in rubber operations in Ghana. Current production is from 7400 acres, and there are 20,000 additional acres already planted but not yet producing. The 1975 estimated production of raw rubber is 4,500,000 (pounds) with production doubling by 1980 as additional trees mature. This year, Ghana can more than supply local needs for tires, tubes, etc. Firestone is now selling 100 tons/month to two companies who make shoes rainwear, etc. In addition to supplying total local needs, they expect to have significant quantities available for export or other use starting next year.

The selling price of block rubber in Ghana is based on distance from Malaysia (basing point system), and ranges from 0.30-0.40 Cedi/lb, or 0.33-0.44 $/lb. The lower grades have darker color and/or odor, but are reported to give equivalent or even superior physical properties.

As elsewhere, block rubber is cheaper than latex (on a solids basis). The latex must be cleaned, centrifuged, and stabilized (principally to kill bacteria which otherwise cause putrefication). These steps increase costs and cause the latex to sell for 0.50-0.65 $/lb dry basis.

Firestone has one large Banbury mixer in operation which processes more than 4,000,000 lb of rubber compound annually. They have a second Banbury mixer on order to handle increasing capacity.

Mr. Hoyt stated that Firestone would not be adverse to producing other rubber compounds in their equipment (e.g., natural rubber bonded/bagasse-filled roofing material). He expressed concern about possible problems of contamination of tire compounds, if the roofing material did not dump cleanly from the Banbury.

Firestone also produces about 20,000 lb/year of uncured scrap rubber tires. This scrap contains nylon tire cord, but no steel wire from the tire bead. Mr. Hoyt said that this scrap rubber could be made available at a fraction of the cost of the pure block rubber, if we could use it in our roofing composite. This point will be investigated later in the program as a possible means of obtaining a significant quantity of natural rubber binder at a substantially reduced price.

H. O. Wilson, Inc., is also a major producer of natural rubber in Ghana and makes high quality smoked sheet. This company, in fact, started the Firestone plantations. Although their main plants are located in the Takoradi area, they also have an Accra office, Phone 24209.

b. <u>Ghana Rubber Company, Accra</u>

The Ghana Rubber Company has its main offices and factories in Accra. Principal contacts were Mr. Kalil Farhyr, Managing Director, and Mr. Philip Westray, General Manager.

Ghana Rubber has two Banbury mixers with capacities of about 125, and 175 lb, respectively. Using a mixing cycle of 6 minutes overall, they process 10 batches or 1200 lb/hr of rubber compound. Even this smaller machine would provide more than ample capacity for the "pilot plant" production of rubber-bonded roofing composite material, for the demonstration houses in Ghana.

Ghana Rubber Company also has all the necessary associated rubber processing equipment including calenders, extruders, and multiple daylight-opening steam-heated compression molds (which can handle sheets 30 in. x 40 in.). With their calenders they can process continuous sheets up to 39 in. in width, which can be cut to any length desired.

Mr. Westray stated that Ghana Rubber Company would produce any foreseeable quantity of rubber/bagasse compound needed for the demonstration roofing in Ghana. He added that they would also have a potential future interest in producing the roofing in Ghana, especially if it is natural rubber bonded (since they are "always looking for new areas"). They have considered roads, floor tiles, etc. but up to now no good uses have materialized.

Ghana Rubber also produces a large amount of trim and scrap foam rubber, of assorted colors. This by-product can be ground to size, and contains only a small amount of clay (kaolin) and whiting fillers. They would like to find a large-scale commercial application for this waste by-product. They supplied a 5-lb sample of the ground rubber foam for our evaluation in roofing composites.

Ghana Rubber Company wants to be kept advised of the progress of the AID roofing program throughout the implementation and demonstration stages.

There are two other rubber processors in Ghana which also have Banbury mixers and other rubber processing equipment. These are Ghana Industries, Shoe Manufacturing Division in Accra; and Freedom Chemical Industries, Kumasi.

c. Ghana Sugar Estates - Swan Mill Building, Liberty Avenue, Phone 63424

Our contact at Ghana Sugar Estates was Mr. H. Gormans, Managing Director.

Ghana Sugar Estates have two sugar mills, one at Akasombo near the hydroelectric dam, and the second at Komenda near Cape Coast. In Ghana they harvest only one crop a year during the months from December through April. They cannot get necessary machinery into the fields after the rainy season starts in May. They are now producing 16,000 tons/year of sugar. The total Ghana market is estimated to be 70,000 tons/year, which Ghana Sugar Estates has programmed to reach before 1980. Their top milling capacity at the present plant is 40,000 tons/year; thus the milling facilities are only about 40% utilized.

They process about 250,000 tons/year of cane to get 16,000 tons of sugar. This results in the concurrent production of 40,000 tons/year of bagasse. At present, all the bagasse is used as fuel to power the mills. The reasons for the current complete utilization of the bagasse in Ghana have to do with fiber content of the bagasse, under-capacity operation of the current plant, and inefficiency of burning, heat transfer, etc. Mr. Gormans predicts that there will be a surplus of bagasse as full plant capacity is reached, through increased sugar cane cultivation (2-3 years).

Mr. Gormans stated that Ghana Sugar Estates is not opposed to converting the burners to the use of "residual oil", if it can be made available to them at an economic price. The present price of the residual oil in Ghana, he reports, is 0.50 Cedi's/gallon or about $0.45/gallon. This compares with gasoline at 1.60 Cedi/gal or $1.45/gallon. Mr. Gormans figures that the selling price of the bagasse should be one-sixth of whatever they would have to pay for residual oil. This would make the bagasse cost ∿1¢/lb.

d. Logs Lumber, Ltd. Outskirts of Kumasi, P.O. Box 3344, Phone 5227

Logs Lumber, Ltd. produces and exports logs, lumber and plywood. The AID-sponsored roofing program was discussed with Mr. Nadim R. Bitar, Owner-Manager.

Mr. Bitar has a keen interest in expanding his business by better utilizing a current waste product, sawdust, which presents a disposal problem. Mr. Bitar was given copies of the technical data on formulations, costs, and properties of the composites currently envisioned for use in roofing. In sawdust-filled roofing composite he thinks there is an opportunity to utilize his waste sawdust and simultaneously expand his business in a directly related area of construction materials for use in housing.

Mr. Bitar also supplied some information on the delivered cost in Ghana of stabilized phenol/formaldehyde resins, which he uses as plywood adhesives.

4.1.4.4 Forming an Advisory Committee and Technical Working Group in Ghana

There has been only one official visit to Ghana, September 15-September 27, 1975, since the decision was reached for Ghanian participtation in the roofing program there. It was found that it will not be necessary to form a separate "Advisory Committee" and "Technical Working Group", since all of the laboratory work can be handled by a single organization, namely, the Building and Roads Research Institute. Instead, a single, combined advisory/technical working group operating under the leadership of Chairman Dr. J. W. S. DeGraft-Johnson, who is also the Director of BRRI, was recommended and formed. Although the makeup of this combined committee has not been finalized, it is expected that it will contain representatives from UST (School of Architecture and School of Engineering), and other parts of the Council for Scientific and Industrial Research (the Forest Products Research Institute and the Crops Research Institute).

One meeting of Dr. DeGraft-Johnson's committee was held at BRRI on Wednesday, September 24. At this meeting, the current status of the process and product development on the AID roofing materials development was presented. The committee members were given copies of two technical brochures, "Advisory Committee Information" and "Working Technical Group Information", Appendix C.

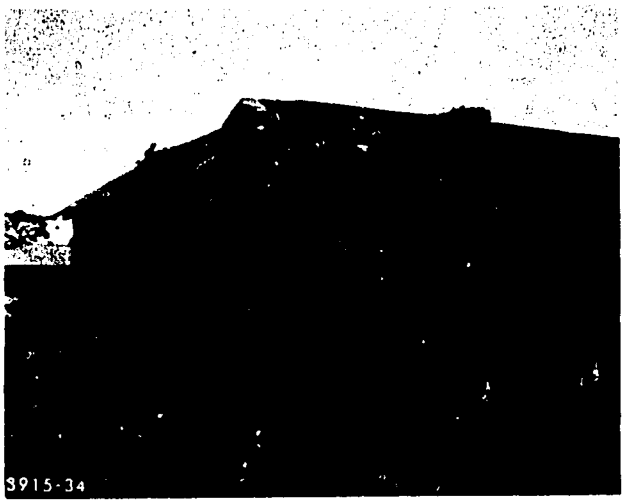
The first of these two brochures suggests tasks for the Advisory Committee, and a time schedule on which various parts of the program needs to be accomplished. The second brochure contains outlines of the four processes developed at Dayton, formulations, physical properties and aging characteristics, and raw material costs. Additionally, the committee members were also given a written description of a suggested experimental program to further develop and optimize the AID roofing processes and products.

In the discussions following the meeting, Dr. DeGraft-Johnson said that the main objective of their program at BRRI would be to obtain enough data to verify the processes, properties and costs of the AID roofing materials. Such data, obtained locally at BRRI would, he said, be sufficient to convince the Government of Ghana that these roofing products should be adopted and used for typical housing (Figure 17).

Dr. DeGraft-Johnson pointed out clearly that for the roofing program to be carried out in Ghana, it would be absolutely essential for the foreign exchange requirements to be supplied by AID. There would be no problem he said with internal Cedi funds, whether the Bank of Ghana wished to supply them or not. If the Bank of Ghana supplied the funds, these would be welcome; but, if not, the research could be performed as a part of the normal budget of BRRI. On the other hand, he emphasized that unless the foreign exchange requirements could be supplied by AID, there could be no program.

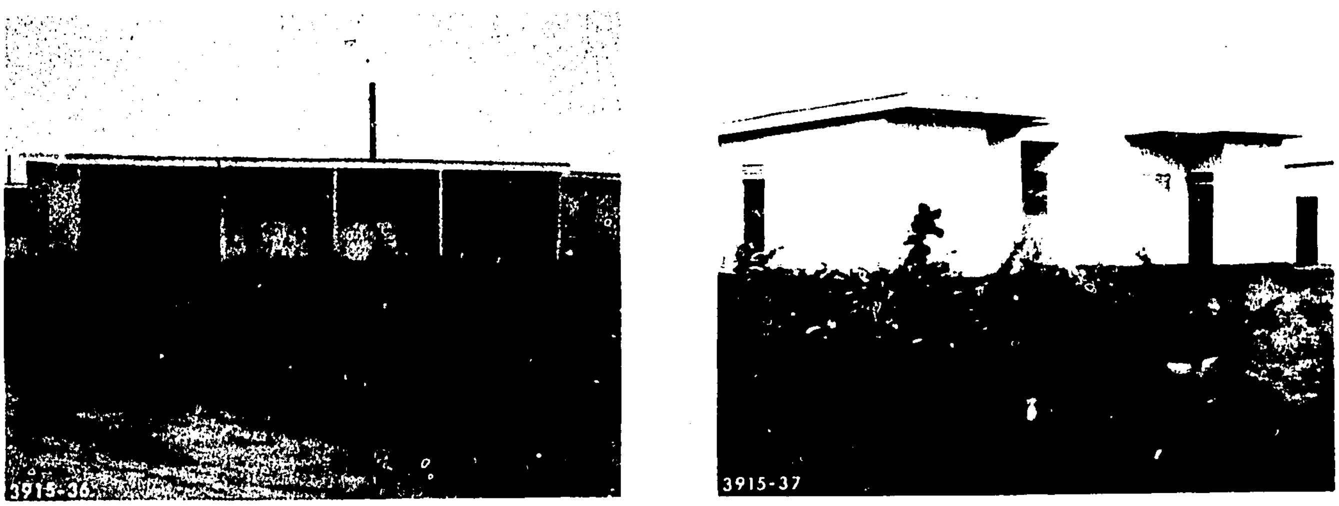
Finally, an approximate budget for the Cedi funds, and the AID counterpart funds was prepared. This budget is only approximate, since the prices of processing equipment requiring the foreign exchange funds are not yet known.

In view of the acceptance of the program by BRRI, on the funding basis as outlined above, Dr. DeGraft-Johnson throught it would not be necessary to have a formal "agreement" between the Government of Ghana and the United States (AID). However, he does believe that an informal program plan or "Memorandum of Understanding" will have to be prepared.



(a) Older mud wall construction with CGI roof

(b) Experimental house at BRRI, Kumasi with CGI roof



(c) More recent construction at TEMA where CGI and cement-asbestos roofing is used

Figure 17. Typical Housing Situations in Ghana Illustrating Problems, Proposed Solutions, and General Use of Corrugated Galvanized Iron Roofing.

4.1.4.5 Resin Binders and Filler Costs and Availability in Ghana

a. Resin Binders

Of the candidate resin binders for the AID roofing, only natural rubber is indigenous to Ghana. There is currently no production of synthetic resins either thermoplastic (ABS, SAN, PVC), or thermosetting resins (phenol/formaldehyde) in Ghana at present. However, one company is "considering" setting up a small phenol/formaldehyde resin manufacturing operation, to supply adhesive for the large and growing plywood industry.

As discussed separately in Section 4.1.4.3 (Firestone-Ghana, Ltd.), the 1975 production of raw block rubber is estimated to be 4,500,000 lb with the production doubling by 1980 as additional trees mature. In addition to supplying total local needs, they expect to have significant quantities available for uses other than tires and rubber goods, and for export.

The selling price of block rubber in Ghana is based on distance from Malaysia (basing point system), and ranges from 0.30-0.40 Cedi/lb or 0.27-0.36 $/lb. The lower priced grades have darker color and/or odor, but are reported to give eqivalent or even superior physical properties.

A type of wild rubber (*Funtumia elastica)*, grown in Ghana, might be equally usable for the roofing composites, and available at lower cost than the natural rubber *(Hevea brazilensis)*. Samples of *Funtumia* elastica in both latex and dry rubber form have been obtained for evaluation as the indigenous rubber binder in the roofing composites.

Any of the thermoplastic (ABS, SAN, and PVC) or thermosetting resins (phenol/formaldehyde) can be imported into Ghana at a cost approximately 37% higher than the export selling price in western Europe or the United States. This 37% includes the standard import duty of 30% plus other charges for insurance, transport, clearing, etc. Thus, the cost in Ghana for the resin binders of interest would be as shown on Table 22.

On a comparative basis, the cost of the three thermoplastic resins in Ghana is intermediate between that encountered in Jamaica and in the Philippines. In Ghana, natural rubber at 0.27-0.36 $/lb is the lowest cost binder resin, followed by the imported thermoplastics (0.37-0.57 $/lb) and the thermosetting phenol/formaldehyde (0.48-0.63 $/lb).

The higher price of the phenol/formaldehyde resin can be partially attributed to the fact that a higher-cost, special storage-stable grade has to be imported (because of the time involved in sea shipment from Europe).

b. Fillers

The principal indigenous fillers in Ghana of interest for the AID roofing composites include bagasse, sawdust, rice hulls, rice straw, and clay. As compared to the Philippines and Jamaica, the production of sugar and bagasse in Ghana is still small (40,000 tons bagasse/year). However, the production of bagasse (and sugar) in Ghana is programmed to more than double (100,000 tons bagasse/year) by 1980. Thus, an expected surplus of 20% over fuel requirements (as in the Philippines) could provide as much as 20,000 tons of bagasse annually for use in roofing composites. This amount of bagasse is certainly more than sufficient to supply any anticipated future uses of bagasse for the AID roofing composite.

Table 22

AVAILABILITY AND COST OF RESIN BINDERS AND INDIGENOUS FILLERS IN GHANA

	Pesswas/lb	US¢/lb
I. NATURAL RUBBER		
Indigenous		
A. *Hevea Brasilensis*	30-40	27.3-36.4
B. *Funtumia Elastica*	No established price	
II. SYNTHETIC THERMOPLASTIC RESINS		
Imported at US or European Selling Price +37% duty, etc.		
A. Styrene/Acrylonitrile Copolymer (SAN)	44	40
B. Acrylonitrile/Butadiene/Styrene (ABS)	46.2	42
C. Polyvinyl Chloride (PVC)	40.7	37.0
D. Dioctylphthalate Plasticizer (DOP)	-	-
III. SYNTHETIC THERMOSETTING RESINS		
Imported at US or European Selling Price +37% duty, etc.		
A. Phenol/Formaldehyde 1974 storage-stable formulation	68.9	62.6
B. Phenol/Formaldehyde 1975 storage-stable formulation	53.5	48.6

IV. BAGASSE

A. Production 1974 40,000 tons/year
1980 100,000 tons/uear

	Pesswas/lb	US¢/lb
B. Selling Price at 1/6 cost of residual oil	1.04	0.95

V. SAWDUST

A. Production - no accurate figures available, but "large"

B. Selling Price - no commercial value at present.

VI. KENAF

A. Production of fiber in 1974 - 500,000 pounds

	Pesswas/lb	US¢/lb
B. Selling price of hand-retted "ribbon"	12.0	9.1

VII. RICE STRAW, RICE HULLS

A. Production - just starting but increasing rapidly

B. No commercial value at present

VIII. CLAY

A. Reported to be "plentiful" at many locations

B. No established commercial price

If so decided by the Government of Ghana, the firing of the boilers at the sugar mills could be changed to "residual oil" (which is produced in 70 million gallons/year quantities in Ghana from its petroleum refining operations, and is under-utilized). If we use 45¢/gallon selling price in Ghana of residual fuel oil (5.6¢/lb) and an equivalent heating value of one-sixth on a per pound basis, the price of bagasse filler in Ghana should be approximately 1¢/lb, an attractive price for this excellent filler material.

Sawdust, the second candidate filler of interest for the roofing composites, is certainly plentifully available in Ghana as a residue from the extensive lumber and plywood manufacturing operations. Although no quantitative data have yet been obtained, sawdust of various types (circular saw and band saw) as well as wood chips and trim, are produced on a large scale in Ghana. The annual production is reported to be "several times that of the bagasse from the sugar cane industry", and thus more than sufficient for any anticipated needs for roofing.

Although there is some utilization of sawdust as fuel, the major portion present a waste disposal problem which is frequently handled by burning at the saw mill.

The cultivation of rice, and the concurrent production of rice hull and rice straw residues, is still small but increasing rapidly in Ghana. Again, quantitative data are not available, but future production is anticipated to be "very large," in order to supply rice both for local consumption and for export.

Kenaf (jute) fibers are just beginning to be grown in Ghana, and production for 1975 is expected to be about 250 tons. Since production of kenaf in Ghana is programmed to increase more than ten fold, within the next 5 years, it follows that the kenaf fiber in unretted form at a low cost of 13¢/lb may be of future interest as a filler material for the roofing composite. Of even greater interest, provided it could be used, would be the unretted whole kenaf plant at a price of about 2¢/lb. Samples of both the unretted kenaf ribbon and the whole kenaf stalks have been obtained for us by our co-workers in Ghana, and are being shipped to MRC-Dayton Laboratory for evaluation as a "future" filler in the roofing composite.

Clay, suitable for making bricks, and for use as a filler in one of the types of roofing composites is plentifully available at many locations throughout Ghana. Since clay is not only beginning to be utilized for production of bricks, there is no established price for clay in Ghana. Furthermore, the requirements for clay to be used in the roofing composites are not as stringent as those for clay to be used for making bricks. Thus in Ghana, clay should be available at a price that is even less than that for bagasse.

The cost and availability of these fillers in Ghana is summarized on Table 22.

4.2 ROOFING DEVELOPMENT

The roofing material development performed constituted the second phase of a three-phase program. In the first phase of this effort, the availability and known characteristics of potential structural material components were defined for candidate participating countries. These materials were screened in our laboratory for their utility in a composite roofing material.

In the second phase of the work, three participating countries having been defined, a more detailed and intensified evaluation of candidate structural material components was performed. These candidates were narrowed by their availability in the three countries. Emphasis was primarily on indigenous fillers and reinforcements for composites. When available, indigenous binders were also evaluated.

The second phase involved four primary tasks. These were:

- Defining generalized criteria for a roof,
- Defining candidate composite material ingredients,
- Development of candidate roofing materials and associated laboratory processes, and
- Analysis of cost and practicality for the materials and processes.

The overall materials development approach is illustrated graphically in Table 12. Also outlined are the follow-on tasks to be conducted in Phase III to complete the program. (It is expected, however, that Phase III will encompass a period of 18 months, whereas the first two phases each encompassed 12 months).

4.2.1 Generalized Criteria for Roofs in Developing Countries in the Context of US-AID Requirements

It is most important in a roofing material development that a set of criteria be established both to define the performance of the roof and to illustrate the objectives of the development work to be undertaken. Towards illustrating these criteria the standard problem analysis parameters of "requirements", indicating the results that must be achieved, and of "desirable characteristics", which are appropriate, but not necessary, are used. The desirable characteristics are weighted to indicate the degree of desirability.

In this analysis an additional term, a "highly desirable characteristic", was included. These are factors that reflect conditions to be emphasized (due to specific USAID objectives).

It is important that the various criteria designated as criteria per se be mutually exclusive. It is very easy to have in mind a given model that, by its nature (materials, design, etc), forces the criteria to be interrelated. The dependence of various criteria on each other must be initially ignored, otherwise a solution may be forced that is little different from those that exist. For instance, given all of the physical parameters for corrugated galvanized iron sheet, there will be no other material that can match it on a point-by-point basis. In contrast, it is obvious that good alternative roofing materials do exist.

The criteria for a roof, put together by our research team, are outlined in Tables 23 and 24. Illustrated by the diagram at the top of Table 23 is that the criteria are for a roof rather than for a roofing material, for it is the roof that must provide the desired performance. Inherent in the roofing system are the roofing material itself, architectural design, construction and detailing, economics, and sociological factors.

It would have been preferable to have selected criteria for the roofing material itself. This was not possible as may be illustrated by corrugated galvanized iron roofing material. It can be used to make a roof which performs very well, but also can be used to make an unsuitable roof. Typically, leaks in roofs very seldom occur through the roofing material but rather at improper seals between pieces. It is, in fact, difficult to consider a roofing system separate from the rest of a building. We attempted to do this, however, to maximize the effectiveness of our efforts in solving the roofing problem, independent of those associated with housing in general.

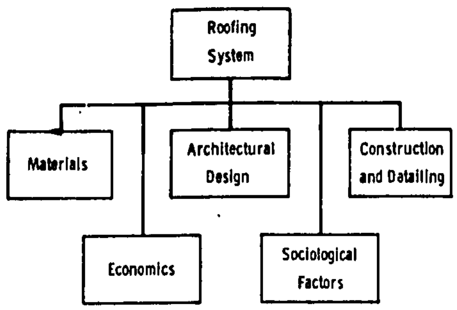
In determining the criteria, only roofing for residential, single-story, moderately sized houses that are detached, semi-detached, or combined into multiple dwelling units was considered.

Finally, weighting can be controlled by any number of considerations. Whereas major emphasis was placed on what a roof needs to do, the consequences of achieving these criteria must be considered, especially in the context of the objectives of this specific program.

Those who weighted these criteria introduced known consequences based on their extensive materials background.

Table 23

ROOF SYSTEM OUTLINED AND PRIMARY CRITERIA



PRIMARY CRITERIA FOR ROOF

Requirements
Keep off rain
Not leak
Water resistant
Wind resistant
Adequate Strength
Keep out direct sun
Adequate level of life (3 years)
Available

Highly Desirable Characteristics[a]	Weight[b]
Low cost	9
Indigenous Material (>50%)	9
Acceptability	
User	8
Government	8
Fire resistance	5
Easy installation	5
Labor intensive mfg.	6
Reasonable life (5 years)	6

(a) Areas of emphasis due to USAID objectives.
(b) Weighting determined by MRC research team with consequences on the approach factored in. Most desirable weighting is 10, over a range 1 to 10.

Table 24

DESIRABLE CHARACTERISTICS FOR ROOF[a]

Mechanical

Weight[b]	Item
8	Resist impact
4	Resist hurricanes
6	Not increase truss or Purlin requirement
3	Support a person
2	Resist earthquakes
2	Resist abrasion
1	Hold house together
1	Be strong
1	Be rigid
2	Provide security and protection

Environmental and Life

Weight	Item
	Maintenance
8	None (5 yr)
9	Easy
9	Ability to nail, seal, cut
6	Lightweight
6	No vapor or toxic fumes from material or process
5	Life - 10 years
7	Simple tools and equipment to handle
3	Resistant to insects, water, UV
1	Vapor impermeable
1	Reusable
3	Available

Optical

Weight	Item
9	Keep out sun
9	Opaqueness
8	Attractive
1	Shine (gloss)
2	Color

Social

Weight	Item
9	Status (image)
9	Contour
6	Smell
9	Overhang Capability
4	Material (image)
1	Texture

Thermal

Weight	Item
9	Keep off sun
9	Resist heat
6	Ventilation
5	Thermal control retain heat reflect heat keep in heat keep out heat keep out cold keep in cold

Acoustic

Weight	Item
3	Not noisey in wind or rain
1	Sound absorbing
1	Poor sound transmission
1	Damping

(a) Based on Developing Nation housing requirements.
(b) Weighting detrmined by MRC research team with consequences of the approach factored in. Most desirable weighting is 10, over a range 1 to 10.

The weights given for the various desirable characteristics ranged from 0 to 10, with 10 being the most desirable. A few items were given 0 to indicate that they were considered and found to be unnecessary, although they had generally been expected to be desirable.

We are now in the process of determining if our participants in the three collaborating countries agree with these weightings. This is being done to help reflect local conditions or prejudices that could be a major factor in the functioning or acceptability of the roofing. and to prevent missing some "very obvious" requirement or shortcoming.

4.2.1.1 Requirements

The requirements designated for a roof are summarized in Table 23. Some additional information, however, is required to specify limits and deviations around these requirements.

Examining the requirements, one by one, consider first that the roof must keep off rain. That is to say that during the period when rain is falling, the roof must protect the portions of the house covered by it from direct impingement. This protection must be provided, independent of the type, extent or nature of the rain that may exist in the geographic regions where the roofs are to be used.

The requirement that the roof not leak is inherent in keeping off rain. However, beyond this is the need for eliminating the penetration of water even when it is not raining. This introduces a time-dependent factor into water penetration. Water-resistance introduces the factor of durability in the presence of water and high humidity. (A material, with poor water resistance, could still prevent the penetration of rain and might not leak due to its own water absorption characteristics, but in time it might lose physical integrity. Thus, water-resistance is related to the useful life of the material.)

Resistance to wind concerns the ability of the roof to perform its protective function under a variety of wind conditions (depending on the climatic area). That is, it must have sufficient integrity to withstand the physical force of the wind itself and to remain in place. Some minimum level of strength will be necessary to provide this wind-resistance (this strength may be much less than that required for other desirable characteristics such as carrying the weight of someone walking on the roof, but indeed is all that is actually needed).

The roof must at least diffuse direct sunlight and its various spectral elements including visible, ultraviolet, and infrared radiation. A roof can in fact be transparent or translucent, but there are both beneficial and adverse consequences, as discussed below.

One of the most important criteria for a roof is that it provide its basic functions over some minimum time, which we term life. This requires resisting the various elements to which it will be exposed under the climatic, geographic and even sociological conditions that prevail where it is used. A three-year life was specified as an absolute minimum. Longer life is, of course, desirable.

Finally, the components for the roof must be available. This may seem obvious, but in fact it is not. The essence of this criterion lies in the existence of alternatives. Importantly, the extensive use of corrugated galvanized iron sheet hinges to a great extent on its availability (even independent of its performance) in the developing countries, and the lack of suitable alternatives.

The limit set on cost involves meeting the competition, but both the absolute cost and the cost-performance must be considered. For the purpose of this program low cost on an absolute basis has been defined as that of the most price-competitive alternative roofing. This, in most cases, has been corrugated galvanized iron which ranges in price from 25 to 30 U.S.¢/sq ft. Cost effectiveness involves normalizing the price of the material per year. (For example, if the corrugated galvanized iron functions for a period of 10 years, its value would be 2.5 to 3 U.S.¢/sq ft/per year.)

Acceptability to the user is important from the standpoint that even if a roof has all of the other desirable or mandatory attributes, it will not be used if the potential user does not like it for some reason.

The health and safety aspects of roofing have become increasingly important. One safety factor is fire-resistance. The extent to which this does or can exist is highly variable. A roof with acceptable fire-resistance is defined as one having burning characteristics (including rate, ignitability, fuel content and burning residues) no worse than that of wood commonly used in roof substructures.

Ease of installation is important to minimize skilled labor requirements, cost, and variability in the performance of roofing (due to improper construction). "Easy installation" is defined as the skill required for installing corrugated galvanized iron sheet, which is nailed directly in large panels to fabricate a roof.

A reasonable life is defined as 5 years performance without major maintenance.

That roofing be made from indigenous materials is important from the standpoint of reducing the absolute import requirements in developing countries. The minimum is defined as ≥50 volume percent of the roof material being indigenous to the area. It is not realistic to consider this percentage on a cost or weight basis, since the material could be acceptable even if the percentage of imported material is high (due to the relative low cost of the indigenous material). A standard of comparison is the absolute value of the foreign exchange inherent in existing imported roofing materials.

The roofing system should involve labor-intensive manufacture to maximize use of available under-utilized manpower and also to improve the balance of payments by minimizing the need for capital equipment.

Acceptability to the government encompasses improvements in economic conditions, and also the general health, safety and well-being of the citizens of the country. Endorsement by the government of a country for a given roofing system is highly desirable, but general acceptability is satisfactory. Building codes, of course, represent minimum acceptability legally.

4.2.1. Desirable Characteristics

The desirable characteristics are separated into the categories shown in Table 24. These include mechanical, environmental and life, optical, social, thermal, and acoustic.

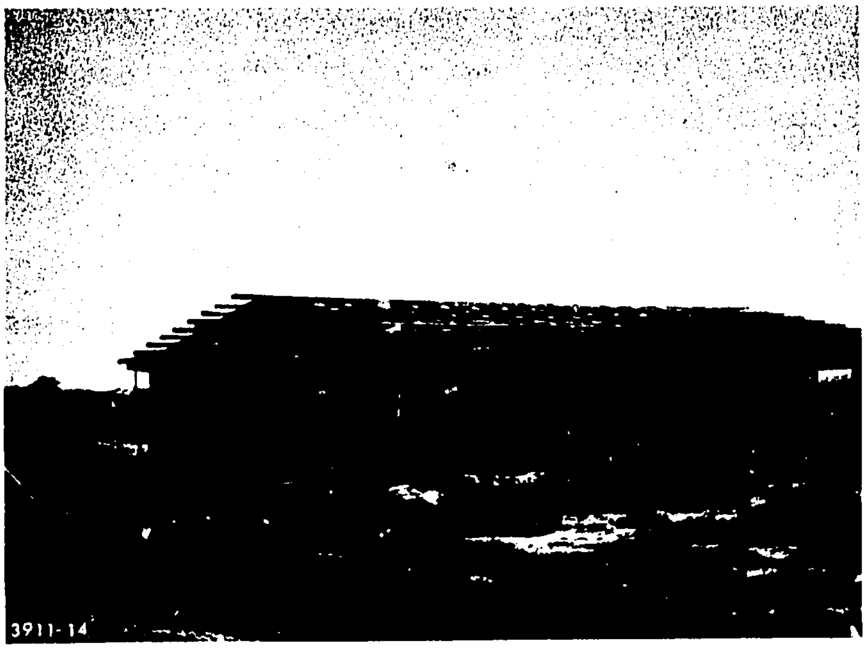
It is desirable that the roof survive impacts by a variety of objects (flying stones, dropping coconuts, hail, etc). These impacts should have no deleterious effect on the roofing. However, various degrees of impact resistance would be allowable provided the integrity of the roof is not impaired.

In areas where a high probability of hurricanes or typhoons exist (e.g. Philippines and Jamaica), it is desirable that the roof withstand the associated rain and high winds. There is also a secondary factor. Should the roofing material become detached from the roof it is desirable that it be less lethal than say a flying piece of corrugated galvanized iron.

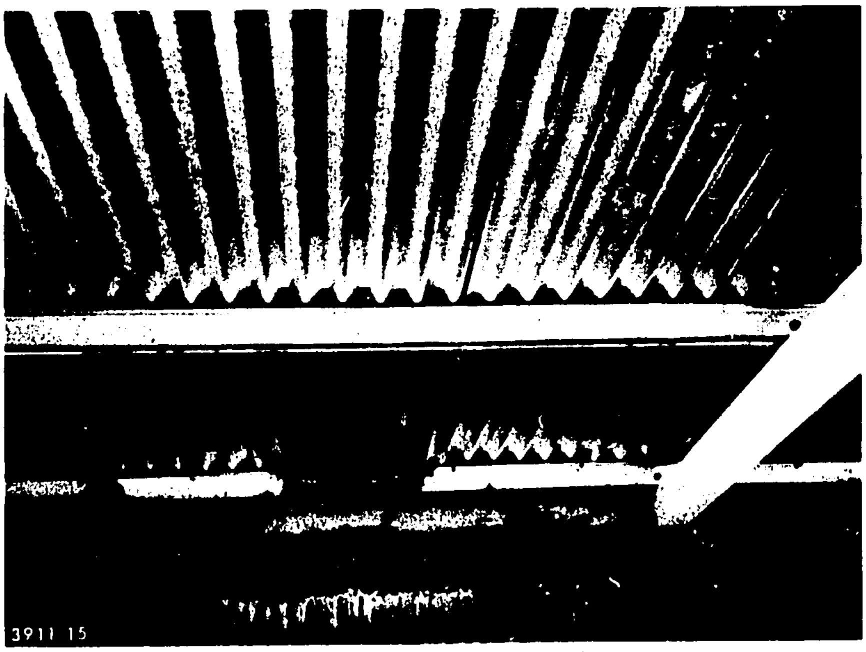
The net effect of the roof on its substructure and the supporting members of the building must be considered. It is desirable that the truss or purlin requirement not be increased due to significant increases in weight, etc. of the roof itself compared to alternative roofing. Some substructures are shown in Figure 18.

Mechanical strength and rigidity sufficient to support a person for the installation and repair of a roof is desirable. It is more desirable that an individual be able to walk unimpaired over an entire roof. However, for the purpose of this program, the simple support of a person for installation is regarded as the minimum. This may be achieved by some added load distributing element. It is desirable that the roof resist the effects of an earthquake, however, the need for the roof to help hold the house together (as a shear panel, etc.) was minimized in the analysis.

Resistance to abrasion is desirable, but if this does not affect life, is less important. The need for the roof to provide security and protection from invasion by intruders was also minimized. The roof need not be strong or rigid except as these characteristics affect some other performance of the roof (indeed, a roof may be quite flexible and still perform its necessary functions).



(a) Most typical wood type



(b) Steel I-beams at World Bank Site and Service project, Spanish Town, Jamaica

Figure 18. Roof Substructures Used in Residential Housing.

In the area of environmental factors and life, freedom from maintenance, and the ability to be repaired are most important. The conditions given for the desirable roof are that it have a life of at least 10 years, that it require no maintenance of any significance for 5 years, and that it be repairable.

Ease of installation is important. It is desirable that the material be readily nailed and/or cut. Many roofing systems exist, however, that require predrilled or preformed holes for attachment. Therefore this is not a mandatory consideration. The ability to fabricate and repair a roof with simple tools and equipment coincides somewhat with the workability of the roofing material itself.

The weight of a roof is important with respect to the requirement for the substructure, and also with respect to availability and transportability. Obviously, compromises can be made toward reducing the weight of a given piece of roofing material by merely reducing the panel size for the heavier materials. This adds to the degree and number of overlaps of panels, however, reducing the overall efficiency of the roof.

The roof must have some degree of resistance to insects, water, UV, fungus, etc. first with respect to the effects of these on the roof itself and second with respect to their presence in the house. It is desirable that no toxic vapors or fumes that would compromise either the safety or health of the occupants emanate from the roof during its manufacture or use. Reusability is important where it is commonplace to tear down, transport, and reinstall roofing materials, because of their high contribution to the cost of a house. Naturally, providing for reusability does allow for such roofing to be stolen.

Various degrees of availability can exist, the most desirable being individual supplies of panels, tiles, etc. at local stores. This feature is weighted below the requirement that the components to manufacture the roofing be available, however.

Optical characteristics can provide a variety of desirable effects. First of all, the more opaque the roof is, the better it will filter out of sun. Opaqueness is also a factor in providing security in a psychological sense. It has been shown that transparent or translucent houses impart a feeling of insecurity to those living within them. Therefore, opaque walls and roofs are preferred. Other optical properties include general attractiveness, shine (i.e., glossy or flat character) and color. Generally, roofing has been metallic (CGI or aluminum), white, black, or shades in between, with the exception of clay tiles. Interestingly, however, roofs of various colors are gaining more acceptance and are, in fact, being selected over "shiny tin" roofs. The preferred colors are primarily greens, blues, and reds.

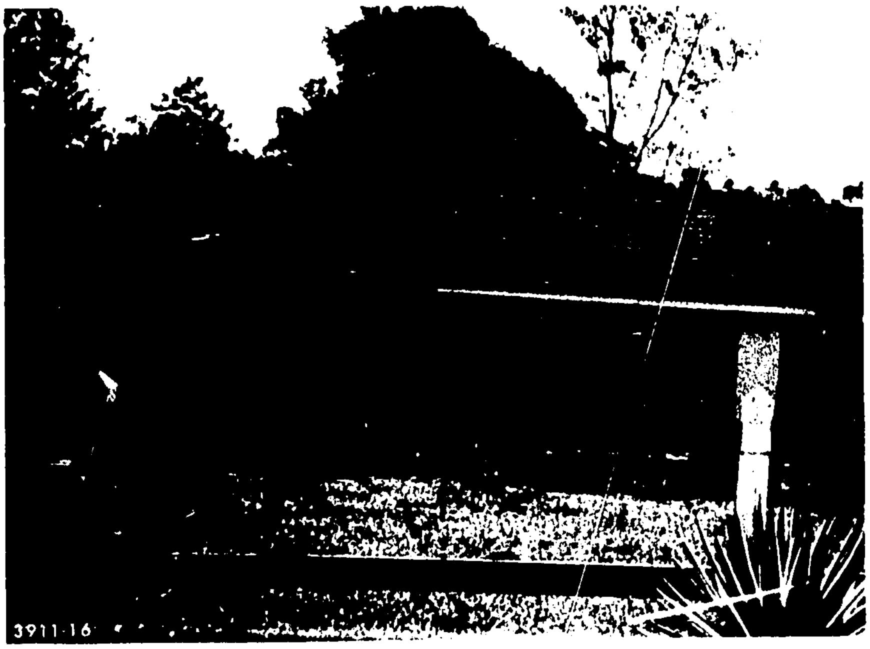
The social implications of a roof must be considered. In many areas of the world corrugated galvanized iron represents a step up from other roofing. In a similar manner, clay tile and cement asbestos roofs have gained acceptance. What is important is that the roofing be considered by the user to be an improvement over what he has used before. In the context of the developmental program underway, it is important that any system developed be thought of, and in fact be, a suitable alternative for existing roofing systems and not just be a "cheap substitute for whose who cannot afford anything better". Status in this context will be affected by the actual performance of the roof, but also can be controlled to a great extent by the marketing techniques used in its promotion and sale.

The contour of a roof can have a major effect on both its technical and social acceptability. Specifically, contours which may be the more desirable are those that may be indistinguishable from generally encountered roofing such as corrugated galvanized iron, corrugated aluminum, clay or asphalt tiles. A good example of the use of socially acceptable appearance exists in Jamaica where concrete roofs are built in the same shape as tile roofs, as shown in Figure 19. A generally less-acceptable countour is a "Quonset hut" type of structure.

It is important that the roof have little odor, either undesirable or desirable, which in time may introduce discomfort to the inhabitants. Survivability of a roof is therefore measured not only by mechanical performance but also by its lack of odor with time, which might, for example, be produced by decay.

A roof material should have a good performance image. This is one advantage that metals such as steel and aluminum have because they are known to "wear like iron". Likewise, assuming that the performance of the roof has been demonstrated, the name given to the materials may affect its general acceptability. Nomenclature as "plastic", "improved bagasse board", etc, have a negative connotation.

The technical requirements of the roof will vary throughout the world. One major consideration is the intensive use of cantievered roof overhangs in tropical countries to provide a variety of functions which include acting as sun awnings over windows and doors, covering cooking areas, and extending the boundaries of the "formal house".



(a) Fired clay tile roof

(b) Simulated tile roof of cast concrete

Figure 19. Typical Acceptable Roof Contours in Jamaica

The roof can be a major factor in controlling the thermal characteristics of a house. First, it must itself be able to withstand anticipated temperature/time cycles. Thermal control is then provided by keeping direct sun out of the house, through ventilation, and through use of the roofing material mass, thermal conductivity, reflectivity, and emissivity. What is required of the roof varies from area to area so that it is desirable that the thermal characteristics be controllable. In areas with high radiation cooling, high mass and thermal capacity may be desirable so heat can be accumulated during the day and re-radiated at night (within the home to keep it warm).

The acoustic characteristics of a roof are usually not placed high on a priority list for residential housing. However, they have become more important as external noises have increased in amplitude and frequency range. One function of the roof is to separate the exterior from the interior of the house. The extent to which this is accomplished acoustically may psychologically affect the inhabitants and thus cause them to reject the material. It is therefore desirable that a roof not generate much noise due to the wind, impacts, or rain. Either poor transmission or internal damping characteristics may be used to minimize external noise. Sound absorbing properties are also important inside the house, i.e., its ability to reduce echoes, etc would be a benefit.

4.2.1. Existing Alternative Roofing Systems

The types of roofing in common use are summarized in Table 25. and are shown in Figure 20. Those generally accepted and used in the participating countries are corrugated galvanized iron (zinc sheet), corrugated aluminum, clay tiles, concrete, cement asbestos, wood shingles, and thatch. Thatch is a material that is 100% indigenous and is very low in cost. In the developmental work there is no attempt being made to replace, or provide any low cost competition for thatch.

Table 25

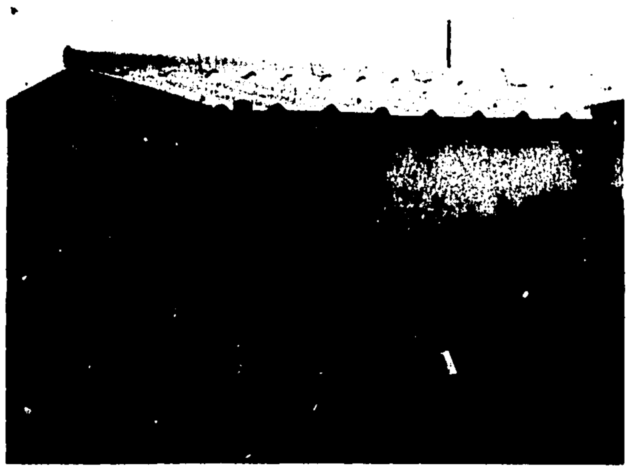
TYPES OF ROOFING IN COMMON USE

Galvanized Iron Corrugated Flat	Asphalt Plain Shingle (aggregate) Tar Paper
Corrugated Aluminum	Particle Board
Cement Asbestos Flat Corrugated	Thatch Grass Bamboo Leaves Reeds
Tile Clay, Fired Cement CA Mud	Corrugated Vinyl
Wood Shingle Plain	Corrugated Reinforced Polyester
	Plastic Film

(a) Corrugated iron
(Zinc sheet)

(b) Aluminum panels

(c) Wood shingles



(d) Cement-Asbestos

Figure 20. Typical Existing Alternative Roofing Systems

Examination of these types of roofing has generally showed the corrugated galvanized iron to be the most reliable alternative. Very high import costs are associated with its use, however. Its advantages and disadvantages are listed in Table 26. It suffers mainly from its range of quality, poor thermal characteristics, high import costs, and noisiness.

4.2.2 Materials Selection and Characterization

In this section the basis for selecting materials, the materials selected, and the techniques used in characterization are discussed. The materials selected provide the basis for the composite material and process development discussed in Section 4.2.3. The discussion of characterization includes the methods used in the screening and the types of techniques to be used as the composite systems are examined and finally evaluated as roofing.

4.2.2.1 Selection Criteria

Selection of materials was initiated in Phase I of the program, but was not conducted in detail until the participating countries were defined. The criteria used as a basis for selection included seven categories. These were:

- Source,
- Availability,
- Form,
- Cost,
- Mechanical performance,
- Life, and
- Compatability

Table 26

CORRUGATED GALVANIZED IRON ROOFING
ADVANTAGES AND DISADVANTAGES

Advantages	Disadvantages
Low cost	Rusting
Low weight	Poor thermal barrier
Low volume for shipping and joining	Low mass
Life - 2 to 40 years	Tendency to fly
Able to nail	Range of quality
Paintable	Contaminates water
Keeps off sun and rain	Over-acceptance
Provides heat in cooler periods	High import costs
Easy to install - low skill required	Noisy
Available	Removable
Good status	
Collects rain water - no mold problem	
Resists wind	
Tough	
Fire resistant	
Vapor barrier	
Maintenance free	
Reusable	

The _source_ of the material refers to its origin geographically. Specifically, it is important that the material be indigenous to the country for which the roofing is proposed. If the material is not actually indigenous, then it should at least be available nearby.

Availability refers to the presence of the material, the ease with which it can be utilized, the existing volume, and its renewability. Important here is the present (not planned) existence of the material in the country with established collection and distribution sources. It is desirable that there be an abundance of material and preferably that it be a renewable resource such as an agricultural product.

The criterion of _form_ was designated somewhat arbitrarily, but nevertheless was deemed to be highly important for the developmental effort. Form was defined as the condition in which the material is normally collected, thus implying that it is desirable to utilize the entire material as collected without additional processing. For example, in the case of coconuts it is desirable to use the entire husk and not just the coir, etc. Although form was used as a criterion in the initial screening, it was later found that there were considerable advantages to processing the selected fillers. Therefore, this criterion was deemphasized as the experimental work evolved.

Cost was a major consideration, especially based on volume. It was found that materials that had an established price were already being used for some purpose, which made them more readily available. Such materials were looked upon as potentially being under-utilized. If used in roofing their value could be significantly enhanced. The foreign exchange component of cost was considered a negative factor to be minimized.

Mechanical performance refers to the type of contribution that the material may make to a composite structure. In the case of fillers, this mechanical performance may be separated into two categories: (1) those that just extend the material, and (2) those that contribute some added strength, rigidity, or toughness. In the case of binders, mechanical performance as related to cost was much more important than absolute performance (although these were never found to be too far apart).

Life refers to the time over which the material can perform its function in composite roofing, under a variety of climatic conditions. It is a major factor in determining the acceptability and final cost of the better systems.

Compatibility refers to the mutual compatibility of the materials. This criterion was selected due to the anticipated composite nature of the roofing, which requires the parts of the composite not only provide mechanical contributions themselves, but also when combined with others. In essence, the combination of two strong but incompatible materials would tend only to detract from the desirable properties of the better one. An important consideration here was the ability of various binders and resins to wet hydrophillic surfaces, since agricultural residues (normally highly polar) were considered to be of primary interest.

The above criteria were used in selecting the various binders and fillers for the composite materials. In the case of fillers it was imperative that they be indigenous to the country and be under-utilized (low in cost). Limitations in form, mechanical performance, compatibility, and life were expected to be resolvable through the proper selection of the binder system. Fillers that could provide a greater latitude in binder selection, of course, were deemed more desirable.

4.2.2.2 Fillers and Binders Examined

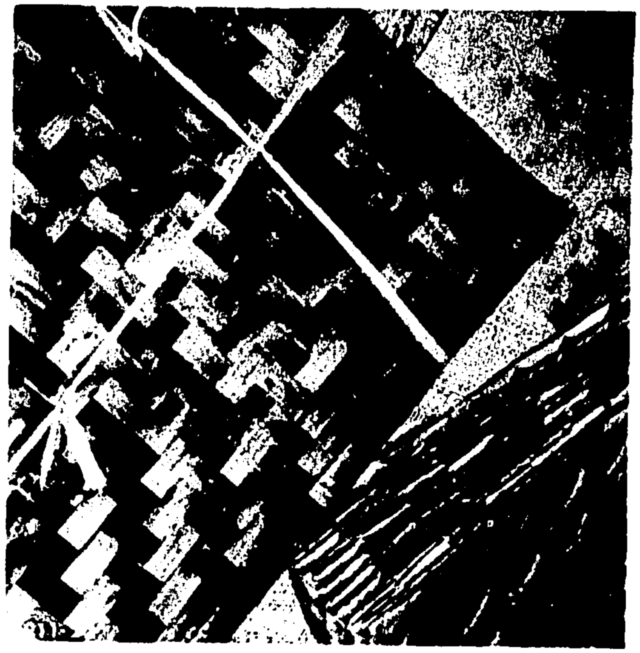
The initial screening of binders and fillers was conducted in Phase I, with emphasis on the criteria categories of source, availability, form, and cost. As had been expected, a host of fillers passed the initial screening, whereas just a few "indigenous" binders were deemed worthy of more detailed analysis.

4.2.2.2.1 Fillers

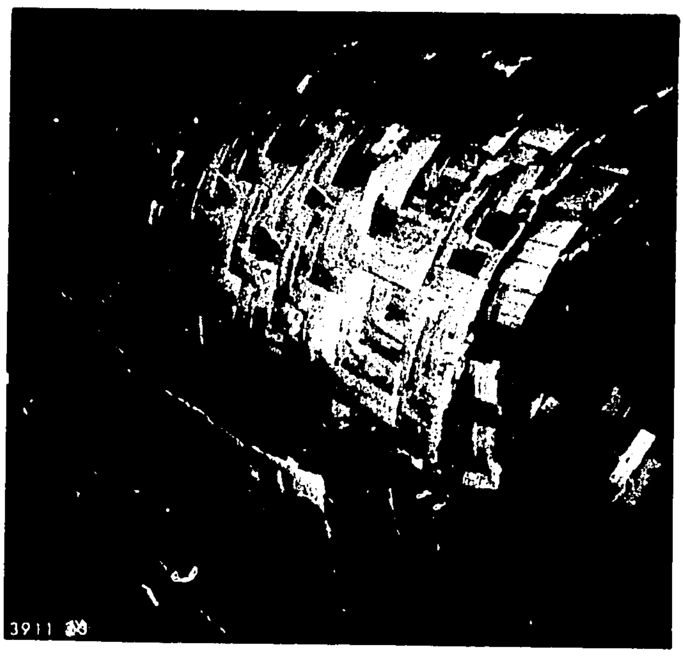
The fillers that passed the initial screening were, for the most part, agricultural and mineral residues. Some primary agricultural products having a fibrous nature were initially considered, but it was found that they were utilized and thus already had a relatively high value. These materials, such as ramie, abaca, kenaf, jute, woven fabrics and mats, shown in Figure 21, were therefore not considered further. However, it was anticipated that, as the particular material systems were refined, some of these relatively expensive materials could perform in a very cost efficient manner. (Such reconsideration would be conducted in Phase III of the program.)

The actual fillers considered are listed in Table 27 and a few are shown in Figure 22. It should be re-emphasized that these materials were considered in their "as available" form, i.e., bagasse, as it lies outside the sugar mill; wood shavings and sawdust, as they lie outside the lumber mill; coconut husks, in their entirety; and ore tailings, from mineral processing sites.

(a) Giant Kenaf fibers



(b) Woven bamboo mats



(c) Woven bamboo fabric

Figure 21. Typical Primary Agricultural Products with Existing Commercial Value and Usage

Table 27

FILLERS AND BINDERS EXAMINED IN PHASE II

Fillers[a]	Binders
Bagasse	**THERMOPLASTIC**
Rice Straw	Styrene Acrylonitrile (SAN)
Balsa Wood	Acrylonitrile Butadiene Styrene (ABS)
Wood Shavings	Polystyrene (PS)
Sawdust	Polyvinyl Chloride (PVC)
Iron Oxide Pigment	Polyethylene (PE)
Rice Hulls	Polypropylene (PP)
Ore Tailing	
Water	**THERMOSET**
Palm Fronds	Phenol Formaldehyde (P/F)
Water Hyacinths	Melamine Formaldehyde (M/F)
Coconut Husks	Polyester, General Purpose
Bamboo	Polyester, Water Extended (WEP)
Excelsior	
Zirconium Dioxide	**OTHERS**
Clay	Polyelectrolytes
Sand	Sodium Silicate
Air	Natural Rubber
	Furfural aldehyde derived from pentosan in bagasse, reacted with phenol or melamine

(a) Fillers examined as received with no individual processing per se.

(a) Coconuts

(b) Palm fronds

(c) Red mud from Bauxite

Figure 22. Typical Agricultural and Mineral Residues Considered as Fillers

The fillers were obtained from a variety of sources, both domestically and from the participating countries. It was much more economical, practical, and timely to obtain the agricultural resides domestically. It was expected that the domestic agricultural residues would adequately represent those available in the participating countries.

Using the same rationale, the primary clay examined was obtained from a specific pit in Columbus, Ohio. The representativeness of the ore tailings, was considered to be less well defined. Therefore, ore tailings from copper were obtained from Zambia and those from bauxite (red mud) from Jamaica.

4.2.2.2.1.1 Experimental

Those fillers listed in Table 27, having passed screening in Phase I, were then screened based on the criteria of mechanical performance, compatibility, and life. Again, some judgement was required to set up a reasonable experimental program that would provide for separating the various candidates. In setting up any experimental matrix, short of doing any and all tests on all candidates, there is a risk of screening out a material that actually could provide the desired performance. Using the experience of those setting up the experimental matrix, however, minimizes the chances for missing some good material and, most importantly, maximizes the chances of defining a system that will work.

One of the most important criteria for a roof is that it have some reasonable life, measured in years. This poses a major problem since testing can not go on for years and still provide timely results. Accordingly, the experimental program for evaluating the fillers was set up to provide accelerated exposure. This involved the use of a carbon arc weatherometer, which is a standard apparatus for accelerating cyclic outdoor exposure conditions of ultraviolet light, moisture, humidity, temperature and drying.

The exposure studies also involved the use of an unstabilized thermoplastic binder (polystyrene) with the various fillers. It was expected that some degradation of the polystyrene could be observed within one month, thus more rapidly exposing the effect of the filler and binder/filler interface. (This indeed turned out to be the case, even more so than had been expected.)

Experimental samples all consisted of 70 vol % of filler compounded into 30 vol % of the polystyrene. The compounding was done using a standard thermoplastic technique of blending and fluxing in a Banbury intensive mixer. Following preparation of the compounds, 9 in. x 9 in. x 1/8 in. thick plates were prepared by compression molding. During the compounding and molding, filler/binder compatibility and flow characteristics were estimated qualitatively.

Sufficient flexural and tensile specimens were machined from the compression molded plates for the determination of initial mechanical properties and those after at least 1000 hours exposure in a weatherometer. The test specimens were intentionally machined to introduce the factor of a cut surface into the experimental matrix. Such a surface is considered to be much more vulnerable to the accelerated exposure than molded surfaces, which usually contain a higher level of plastic binder and totally surround the filler. Where water-sensitive fillers are used, this plastic surface protects the filler by lengthening the time required for moisture to get to it.

4.2.2.2.1.2 Results

The results of the mechanical and exposure screening tests are shown in Table 28. The initial flexural strength and modulus, the initial tensile strength and modulus, and the tensile strength after 1000 hours exposure in the weatherometer are listed. This specific weatherometer cycle is described later in Section 4.2.2.3. Data on the polystyrene alone, with no filler, are shown for reference and to illustrate the effect of the fillers.

The data first showed that all the fillers examined increased both the flexural and tensile modulus significantly, with the higher values being slightly more than double the modulus of the polystyrene alone. However, for the most part, flexural and tensile strengths were reduced below that of the unmodified polystyrene. Only sawdust provided increased strength, and bagasse about the same strength, compared with the unmodified polystyrene. In terms of initial properties, the wood shavings and coconut husks provided the next highest levels of performance, even though their strengths were lower than that of the thermoplastic binder. Any filler was considered reinforcing that allowed the flexural and tensile strength to be near that of the unmodified polystyrene while, at the same time, significantly improving its rigidity (modulus). Bagasse and sawdust fit into this category.

More important than the initial mechanical properties for the filled systems was their performance after 1000-hour exposure in the weatherometer. The initial tensile strengths and the percentage loss in tensile strength after exposure are given in

Table 28

EFFECT OF FILLER ON MECHANICAL PROPERTIES OF THERMOPLASTIC PANELS[(a)]

Filler[(b)]	Flexural[(c)]		Tensile[(c)]		1000 Hr Weatherometer Exposure[(d)]	
	Strength (psi)	Modulus (10^3 psi)	Strength (psi)	Modulus (10^3 psi)	Tensile Strength (psi)	Strength Loss %
Bagasse	5650	1260	3400	1070	1650	51
Sawdust	6600	1280	3700	1200	1400	62
Excelsior	4850	1260	2950	1360	250	91
Wood Shavings	5250	1240	3100	995	<50	98
Bamboo	4300	1070	2000	750	0	100
Balsa Wood	3550	1050	1900	925	500	74
Coconut Husks	5200	950	3050	750	250	92
Rice Straw	3350	940	2250	920	250	84
Palm Fronds	4650	825	2050	545	0	100
None	6350	580	3450	475	1000	71

(a) Based on 70 vol. % filler in polystyrene. Processed in Banbury using whole filler. Compression molded panels ~9 in. x 9 in. x 1/8 in. Specimens milled from panel.

(b) Only processing of filler due to Banbury in presence of polystyrene, except for drying of green plants.

(c) ASTM D790 - Flexural, D638 - tensile, rate 0.05 in./min.

(d) Tensile strength following 1000-hour exposure in Atlas weatherometer with cyclic UV, water spray, temperature, and humidity.

Table 28. The results of these tests are most interesting and were not entirely expected.

It was found that bagasse- and sawdust-filled specimens, which performed the best initially, also lost the least amount of strength (on a percentage basis) and the tensile strengths after exposure were still high. These specimens lost less strength than the unmodified polystyrene. This was expected because the filler hid the polymer from ultraviolet radiation. The moisture and humidity cycling, on the other hand, were much more detrimental than either the ultraviolet radiation or thermocycling. The real difference appeared to be that water was not absorbed nearly as readily by the bagasse and sawdust specimens as by the others. Apparently, the swelling and shrinking of fibers did the most damage in the case of these later hydrophillic fillers.

4.2.2.2.1.3 Conclusions

The data illustrated in Table 28 clearly demonstrated that bagasse was the best filler and that sawdust was a good alternative. No other alternatives were demonstrated. It is empasized that whole bagasse was used, which included at least 20% pith.

4.2.2.2.2 Binders

Initial screening of binders was conducted in Phase I, with emphasis on their source, availability, form, and cost. Few of these binders could be classified as indigenous, as expected. Unexpectedly, however, very significant increases and wide fluctuations in the prices of anticipated potentially useful binders occurred after the start of the program (May 1973).

The proposed approach had been based to a great extent on using the very lowest cost synthetic resin binders. It was this category of material that suffered most severely from the energy and inflationary pressures, which increased costs two to four-fold over those in effect at the origin of the program. Although resin prices have since moderated and stabilized somewhat (June 1975), a return to 1973 prices is very unlikely. The result was that some of the binders that had passed the Phase I screening were considered only to a minor extent in Phase II.

The binders examined are listed in Table 27, in three categories: thermoplastic, thermoset, and others. All of these include some chemical or physical reaction that provides the physical integrity of the composite.

Binders that were screened in Phase I included engineering thermoplastics such as nylon, polycarbonate, thermoplastic polyesters, and polysulfone. All of these, however, are too expensive and have a variety of limiting performance features, such as the water-sensitivity of nylon, and the poor craze resistance of polycarbonate. Similarly, thermosetting resins such as the epoxies, polyurethanes, and silicones were screened. Urea/formaldehyde, while very low in cost, is highly sensitive to water. Furthermore, urea/formaldehyde was one of the resins that increased most (>500%) after the onset of the energy crisis.

As with the fillers, more significance was given to binder mechanical performance, compatibility, and life in Phase II. At that time, also, bagasse filler appeared to have reasonable efficacy, so was used in combination with the various binders for secondary screening and to optimize the more desirable recipes. The binder systems were evaluated in the same manner as the fillers through measurement of initial physical properties and those following accelerated exposure in a weatherometer.

4.2.2.2.2.1 Thermoplastic Binders

Data on the thermoplastic binders are shown in Table 29. Polystyrene (PS), styrene/acrylonitrile (SAN), and acrylonitrile/butadiene/styrene (ABS) exhibited reasonably adequate mechanical properties, whereas those of polyethylene and polypropylene were substantially lower. The SAN, ABS and low density polyethylene exhibited very good retention of mechanical properties following accelerated exposure, whereas the polystyrene and high density polyethylene degraded rapidly. Additionally, both the low and high density polyethylene had a limited degree of compatability with the bagasse, which rendered the PE less appropriate. Thus, SAN and ABS emerged as the best candidates.

An important factor in the selection of binders was the requirement that the bagasse not be heated much above 425°F during processing. This limitation was necessary to minimize the risk of scorching or burning. Plasticized PVC, while not examined early in Phase II, was also considered to have some potential if rigidity could be maintained and processing temperatures reduced. PVC, therefore, was considered a potential candidate.

4.2.2.2.2.2 Thermoset Binders

The selection of the thermosetting binders was made, to a great extent, based on our extensive background in these lower cost resins. As mentioned above, urea/formaldehyde (U/F) was initially outstanding with respect to its low cost (8¢/lb) but the cost increased significantly and fluctuated widely during the past two years. U/F was thus eliminated because of this loss of cost advantage and because of its known poor water, moisture, and outdoor aging resistance.

Table 29

TENSILE STRENGTH PROPERTIES OF BAGASSE FILLED THERMOPLASTICS[a]

Binder[b]	Initial[c] (psi)	Following Exposure[d] 300 hr UV (psi)	Following Exposure[d] 1000 hr weaterometer (psi)
Polystyrene	3400	3100	1650
Styrene Acrylonitrile	4000	3900	3900
Acrylonitrile Butadiene Styrene	4200	4600	4200
Low Density Polyethylene	750	800	700
High Density Polyethylene	1550	1300	800

(a) 70 vol.% whole bagasse Banburyed into binder, specimens milled from compression molded panels.

(b) commercial grade resins

(c) ASTM D638 - tensile, rate 0.05 in/min

(d) Tensile strength following either 300 hours of intense UV or 1000 hours of weatherometer exposure with cyclic UV (carbon arc), water spray, temperature, humidity.

Use of U/F to extend either the more stable phenol or melamine/formaldehyde was also considered. Unfortunately, the water sensitivity of the U/F is so great that even minor substitutions of it into phenol/formaldehyde (P/F) introduced severe water sensitivity. Since the P/F did not increase in price to the extent the U/F did, the cost differential also minimized the effectiveness of this approach.

Phenol and melamine/formaldehyde (M/F) binders were selected, based on their well established utility in exterior coatings and binders. M/F is usually the preferred resin for outdoor performance but suffers from a slightly higher cost than P/F. The utility of both P/F and M/F resins was confirmed qualitatively in combination with bagasse filler. As expected, their compatibility with this cellulosic material was excellent.

These types of resins readily wet cellulosic materials (such as wood), providing extensive, intimate chemical bonding. Their efficacy is well demonstrated in particle board where only 3% resin is required to establish a reasonable level of mechanical strength. Waterproofing is provided by binder contents greater than 3%, or by adding waxes. Cellulosic materials normally are not water-resistant and thus need waterproofing.

The P/F resin is highly attractive also, since it is available in three forms: latex, water-soluble resin, or dry powder. This allows it to be used in a variety of processes, particularly in combination with water. Cure temperatures ranging from ambient up to 350°F can be accomodated. The disadvantage of the P/F liquid resin is its poor shelf life, which limits shipping distances. In its favor, however, is the relative ease of preparation from stable ingredients. P/F resin is manufactured in Jamaica and the Philippines.

General-purpose (GP) polyester was initially considered because of its relatively low cost, low cure temperature, and good performance in combination with many inorganic (e.g., glass) and organic fillers. GP polyester, contains a significant amount of styrene monomer. This material also has increased and fluctuated in price drastically during the past two years and has suffered from poor availability due to the "oil shortage". The GP polyester was expected to show some reasonable performance in combination with the bagasse fibers, but initial qualitative examination proved differently. Degradation of bagasse-filled polyester panels occurred rapidly in a weatherometer (see Sec. 4.2.5). This degradation was attributed to the wetting of fibers and the wicking of this water throughout the composite, causing it to swell and lose mechanical integrity. The resin was thus incompatible with the bagasse fiber. The present higher price of the GP polyester, its sensitivity to water during curing, and the complexitites of curing the polyester made it less attractive (than the phenol or melamine/ formaldehyde resins).

Specific polyesters can be filled to levels of 50-80% with water, producing "water-extended polyester (WEP). This provides an excellent way of reducing the cost of a given volume of polyester. Unfortunately, the water does not contribute to the strength of the system (acting only as an extender). It was shown that the WEP could be used as a binder for bagasse filler, but the processability of the mixture was such that only low volumes (less than 30%) of bagasse could be added. Thus, at least 35% polyester was still required (50% of the remaining 70% of the volume). This lack of significant compatability with the bagasse fiber and complexities required for curing of the polyester (albeit at room temperature) made it less desirable.

4.2.2.2.2.3 Others

The other binders examined included the polyelectolytes, sodium silicate (water glass), natural rubber, furfural aldehyde, sulfur, and clay.

A number of polyelectrolytes were examined as binders for clay. It was demonstrated that as little as 0.05 part per hundred parts of polyelectrolyte would significantly enhance the compressive strength of clay. However, the polyelectrolyte composites all remained water-sensitive. Numerous attempts were made towards insolubilizing the polyelectrolytes, but none were adequate enough to produce a bonded clay system for roofing. The experiments and results are discussed later to make them available for possible use in foundation stabilization or the preparation of house walls (see Section 4.2.5).

Sodium silicate was examined in the same manner as the polyelectrolytes, i.e., as a binder for clay with, unfortunately, similar results. Significant improvements in the dry strength of molded clay were achieved, but adequate wet strength was never introduced. These data are also presented in Section 4.2.5.

Natural rubber originally was considered because it represented an available indigenous binder in the Philippines and Ghana. At the start of the program, natural rubber had no expected cost or performance advantages over other low cost binders. The cost advantage of the natural rubber, however, improved very significantly during the past two years, since it was not a product of oil. Natural rubber also somehow survived much of the inflationary price increases which affected all synthetic resins.

Accordingly, while natural rubber passed the initial screening in Phase I only because of its indigenous character, it became of much more interest in Phase II because of its low cost, as well.

Natural rubber could act as a binder for a roofing product, providing the required initial mechanical performance. The primary concern with natural rubber was durability, but it was expected that its life could be enhanced considerably through the addition of stabilizers. When there was no real cost advantage to the natural rubber, salvaging it through the addition of relatively expensive stabilizers made little sense. However, as the cost picture changed, the addition of relative minor amounts of expensive stabilizers made it viable.

Initial qualitative mechanical screening showed that bagasse could be used to fill and reinforce natural rubber and that suc a composite could be cured into a relatively strong, rigid product. Sulfur, in excess of that used for normal vulcanizati was used to convert the gum to a hard rubber. In this manner, rigidity was substantially increased without loss of toughness.

Bagasse contains one of the monomer precursors for a thermosett resin. Utilization of this compound was considered to be attractive because of its availability and low cost, and becaus it is contained in the bagasse fiber itself. It was demonstrat that furfural aldehyde could be derived from the pentosans in bagasse by relatively simple processing (hydrolysis). This furfural aldehyde was then reacted with phenol or melamine to form a binder for the bagasse. This process is attractive in terms of maximizing indigenous materials. However, it suffers from the fact that the furfural aldehyde is not the expensive portion of a phenol/formaldehyde resin, and the resin must be generated *in situ* by reaction with an appropriate amount of phenol.

Additionally, control of the procedure to make the product binder requires considerable technology. It was demonstrated that such a binder system could be prepared and useful products made, but it was not emphasized in the experimental program. However, it is proposed that this approach be examined further in the future by the developing countries toward optimizing their roofing products.

Clay is considered a binder in the sense that it can be made to react with various chemicals such as polyelectrolytes and sodium silicate. This is in addition to its action as a filler. That information concerning compressive strength improvement was discussed above and will not be further discussed here.

Sulfur is widely available and can be used as a binder in a variety of ways, many of which are being examined by Southwest Research Institute. Sulfur has not been examined extensively in this program, but it has not been ignored as a potential binder either. Attempts to use it alone to bind clays, especially with respect to reducing water-sensitivity, were unsuccessful.

4.2.2.3 Characterization

Characterization can be categorized into two interdependent categories: (a) mechanical, and (b) environmental. The nature and types of tests comprising these two categories will be altered throughout the program as it moves from the initial screening, through materials development, into roof panel simulation, and finally to evaluation of a completed roof. The roof panel simulation and the full roof evaluation will take place in Phase III. Such evaluation will go beyond strictly materials properties into design, geometry, and functional utility considerations.

The types of characterizations used in the initial screening and the development of the more promising candidate composites are indicated in Table 30. Especially in the initial screening, qualitative observations were employed to eliminate obviously less promising systems. Such qualitative observations included filler/binder compatibility, processability, obvious low strengths, and obviously poor environmental resistance (judged from water resistance).

All testing was conducted according to ASTM methods for plastics, plastic composites, rubber or structural sandwich constructions, when possible. Due to limited sample availability, however, test specimen size was altered at times, but size was held constant during evaluation of any given set of specimens.

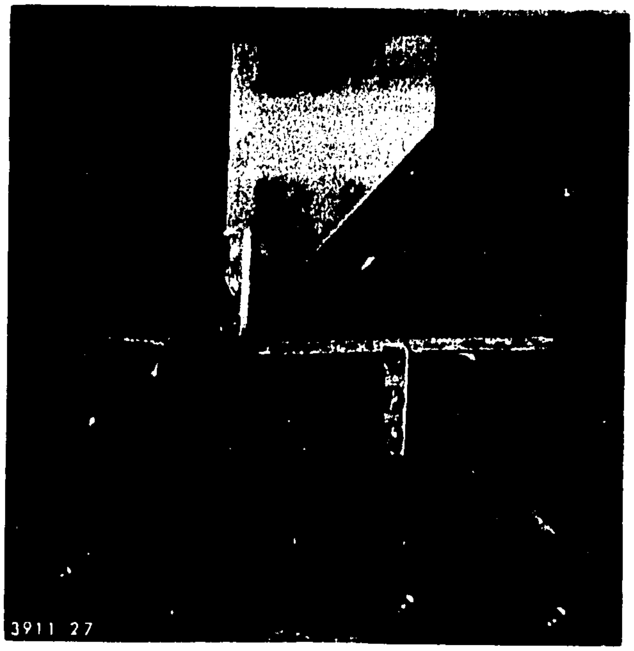
The primary mechanical screening was based on measurements of flexural modulus and strength. Tests were conducted on specimens usually measuring 5 in. long x 1 in. wide by approximately 1/8 in. thick. Heavy clay specimens were 7.5 in. long x 1.5 in. wide by 0.25 in. thick. Three-point loading was used in all cases, with the span being adjusted to approximately 80% of specimen length, as shown in Figure 23. Strength indicated the highest load sustained by the specimen (in psi) just prior to or at failure. Deflection was determined from crosshead movement, and modulus was calculated from the primary slope of the stress/strain curve. Only elastic responses were considered, except where this did not reflect the real efficacy of the specimen being tested.

Compressive testing was utilized for systems such as bonded clay, especially in the initial screening, where the preparation of more sophisticated specimens would have been inefficient.

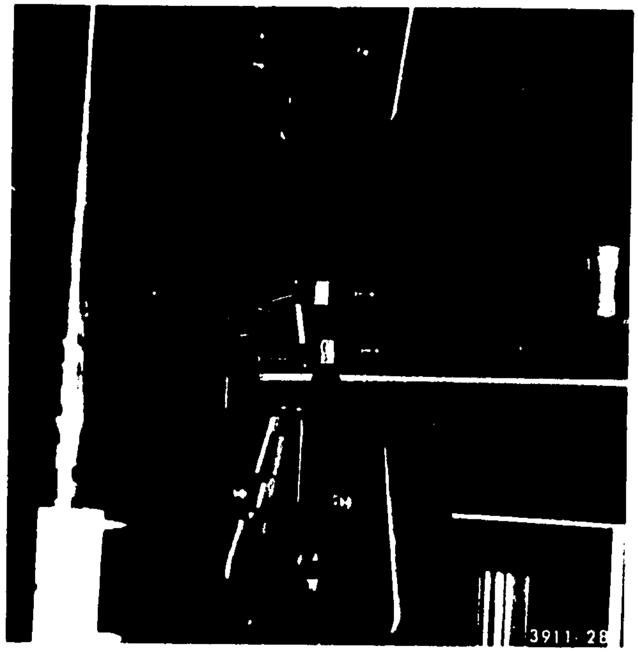
Table 30

TYPES OF CHARACTERIZATION USED IN SCREENING

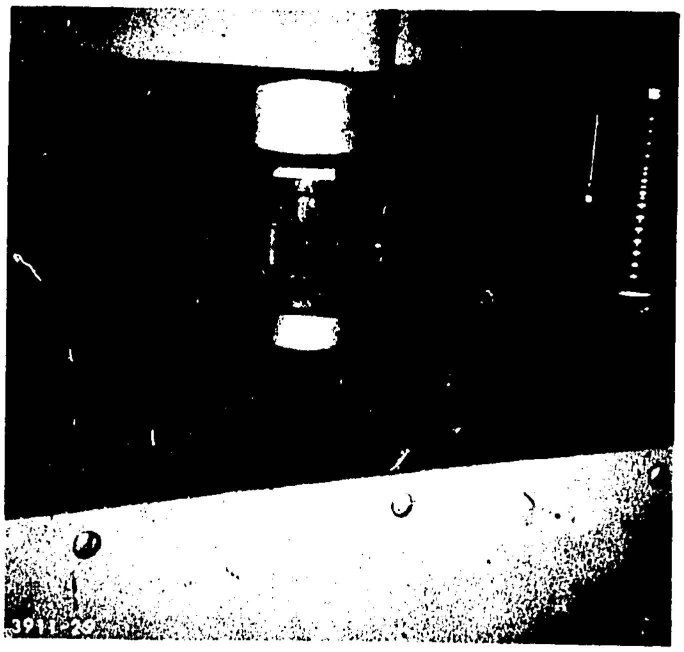
Mechanical	Environmental
Tensile	Cyclic UV, Water, Temperature, Humidity
Flexural	Accelerated UV
Compression	Water Immersion
Impact Izod Indent	Outdoor Exposure (Dayton, Jamaica)
Hardness (scratch and nail)	Fire Resistance
Qualitative Feel	Thermal Deflection
Static Load (creep)	Processability Ingredient Compatibility Ability to mold
	Qualitative Durability



(a) Flexural (3 point)



(b) Tensile



(c) Compressive

Figure 23. Mechanical Test Fixtures Used to Evaluate Candidate Composite Materials

Tensile tests were conducted using dog bone type specimens, when practical. Rectangular specimens also were utilized, but data were recorded only when failure occurred in the region between the supporting grips. Tensile tests were used in particular to determine the contribution and effects of various environments on fibrous fillers.

Impact and hardness determinations were done qualitatively to establish toughness and nailability of the various composite materials.

Nailability was determined by driving a round 1 mm diameter nail through an ~1/8 in. thick specimen that was backed with at least a 2 in. x 4 in. piece of wood. The evaluation was based on the ability to get the nail into the specimen, the integrity of the sample with the nail in it, and the visability of crazing or cracking marks. The specimens that visually passed the insertion of the first nail were then considered further by driving two additional nails approximately 1 inch from the first hole, and at least 1 inch from each other (and no closer than 1 inch to an edge when practical). Cracking between holes or between a hole and an edge were noted. Any results deemed a deviation from the norm were also recorded.

Hardness and scratch resistance were determined initially by resistance to scratching or penetration with a steel nail. The type and nature of the scratch was recorded.

Durability (life in specific environments) is a major factor in the acceptability of the roofing material. While no set of artificial conditions has ever been shown to adequately simulate final outdoor exposure, various exposure environments have been accepted as being the most desirable alternatives. These include the use of weatherometers, high-intensity ultraviolet lights, and water immersion.

In this program major emphasis was placed on 1000-3000 hours exposure in the weatherometer. The weatherometer used was a carbon arc type that has available programmed high intensity UV (but with a more limited UV spectrum) water spray, high and low humidity, and elevated temperature. The specific weatherometer cycle used is shown in Table 31.

Because of the limited spectrum of the ultraviolet in the weatherometer, additional exposure was achieved in a solar chamber containing a bank of high intensity UV lights at moderately elevated temperatures. One hour in this apparatus is equivalent to about 10 hours of full sunlight in the tropics.

Resistance to total immersion in water at elevated temperatures (100°C) or times longer than 72 hours was considered to be an accelerated condition (see Figure 24). However, resistance to total immersion at ambient temperature for periods of up to 72 hours (usually 24 hours) was considered to be a desirable characteristic. The degree of this resistance, of course, could vary. The retention of initial dry mechanical properties following drying of wetted specimens was also important.

Outdoor exposure in the field will be initiated in Phase III, first in Jamaica and then in the Philippines and Ghana. Quantitatively, fire resistance and thermal deflection will also be determined in Phase III, although some very qualitative measurements of fire resistance were made in Phase II using small propane torches.

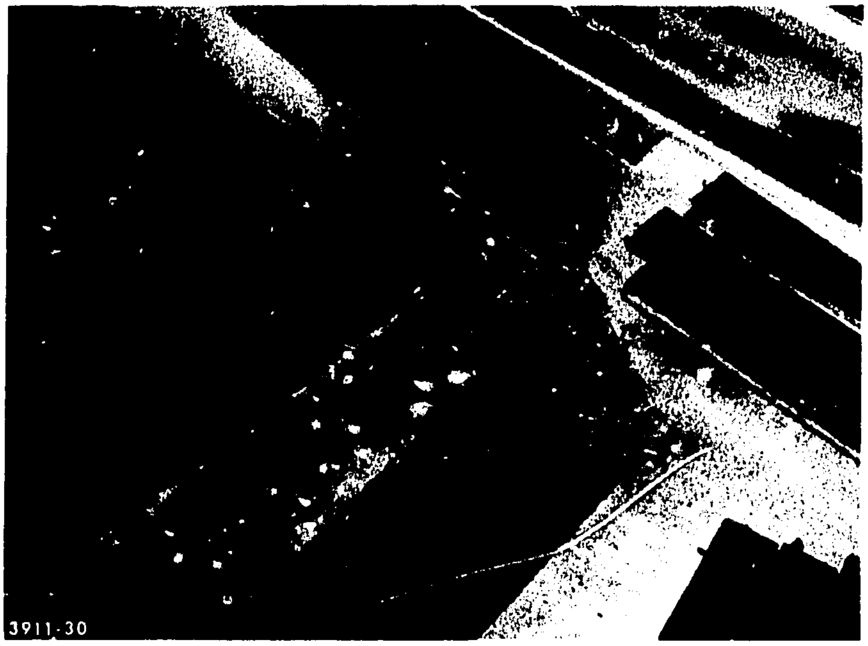
Table 31

WEATHEROMETER CYCLE[a,b]

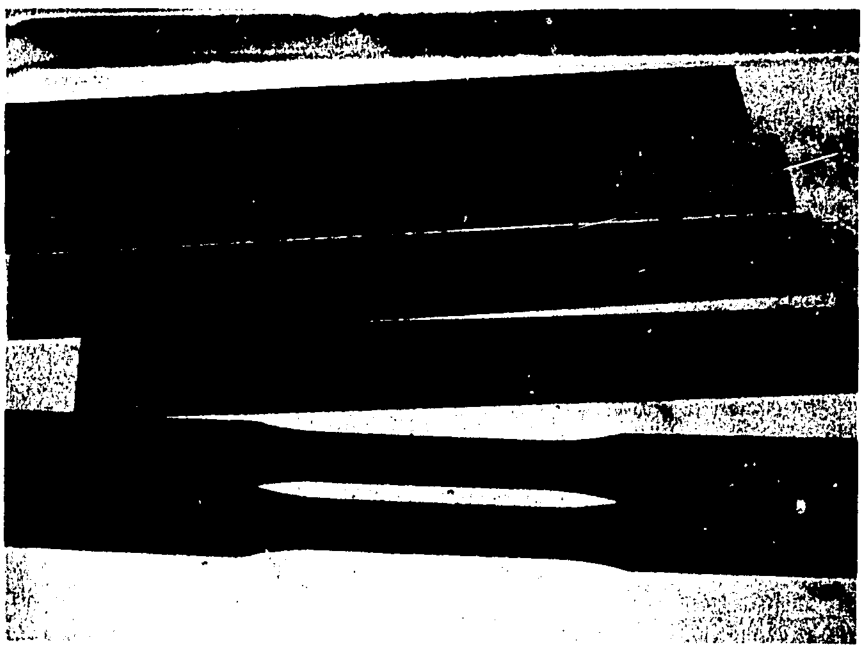
Time Period		
minutes	hr	Condition
0-60	1	water spray on[c]
61-288	3.8	water spray off, dual carbon arc lamps on[d], heating to 145°F, temperature control and humidity lowering by drafting of air
Total Cycle Time -		4.8 hr, 5 cycles per 24-hour period 19 hr of light and 5 hr of water per day

(a) Atlas Weatherometer Model DMC-H, Serial Number WO-1266, Atlas Electric Devices Co.
(b) ASTM D-1494, "Operating Light and Water Exposure Apparatus (Carbon Arc Type) for exposure of plastics
(c) Deionized water
(d) Spectral distribution of Atlas twin enclosed carbon arc lamp

Spectral Range (nm)		Energy ($\mu W/cm^2$)
<340		112
340 - 400		10,000
400 - 750		20,900
>750		28,500
	TOTAL	59,512



(a) Type III Composite flexural



(b) Type I Composite flexural
and tensile

Figure 24. Physical Test Specimens Immersed in Water to be Used in Determining Water Resistance (accelerated).

4.2.3 Material and Process Development

The experimental effort can be categorized in a variety of ways, to illustrate results. Earlier discussions were categorized by the type of binder. Processing categories now best illustrate the roofing distinctions. Indicating process distinctions also set the scene for Phase III, wherein participating countries will expand upon and refine the work done in the MRC laboratories. All formulations within a category are manageable on a given set of facilities.

The experimental work encompassed four general categories of materials. Their titles, below, indicate the types of process, binder, and filler.

Category	Description
I	Melt-compounded, resin-bonded, bagasse fiber-reinforced composites.
II	Wet- or dry-blended, thermoset resin-bonded, bagasse fiber-reinforced composites.
III	Wet-process; Thermoset resin-bonded; depithed, fibrillated, oriented, bagasse fiber-reinforced composites.
IV	Wet- or dry-blended, resin-bonded, unfired clay tiles.

Each of these four categories of candidate roofing material systems will be discussed in turn, with descriptions of (a) the process involved, (b) the ingredients used, and (c) the product. These four categories comprise materials that have shown the better results to date. Data on approaches taken that were not sufficiently promising, especially with respect to technical performance, are detailed in Section 4.25. These latter concepts may still be useful for expansion or optimization of any of the four major categories, or for developing materials of construction other than roofing.

The general objective of this program is to provide a good alternative roofing system in at least Jamaica, the Philippines, and Ghana. It is also desirable that this alternative be useful and available to all of the developing countries. The reason that four candidate roofing systems are still under consideration is due partly to dissimilarities in materials and facilities in the three participating countries, and partly to provide alternatives that may be required in Phase III due to the widely fluctuating world economics.

4.2.3.1 Category I: Melt-Compounded, Resin-Bonded, Bagasse Fiber-Reinforced Composites

4.2.3.1.1 Process

The key to production of this candidate roofing material is the efficacy of the melt-compounding process, and specifically, intensive shear mixing.

The term melt-compounding refers to the state of the binder (matrix) during the process. Because of the large amount of energy introduced, the binder forms a very high viscosity melt. This melt may be achieved by increasing temperature (in the case of most thermoplastics) or it may exist in elastomeric or rubber-like materials that have glass transitions below room temperature. Intensive mixers (see Figure 25) are sturdy enough that they can blend these high viscosity melts, and, through the melt, transmit energy (work) to the other ingredients as well. A number of processes can thus occur simultaneously. Taking the example of melt-compounding whole bagasse

(a) View of bagasse being loaded into hopper that is forced down into the mix chamber

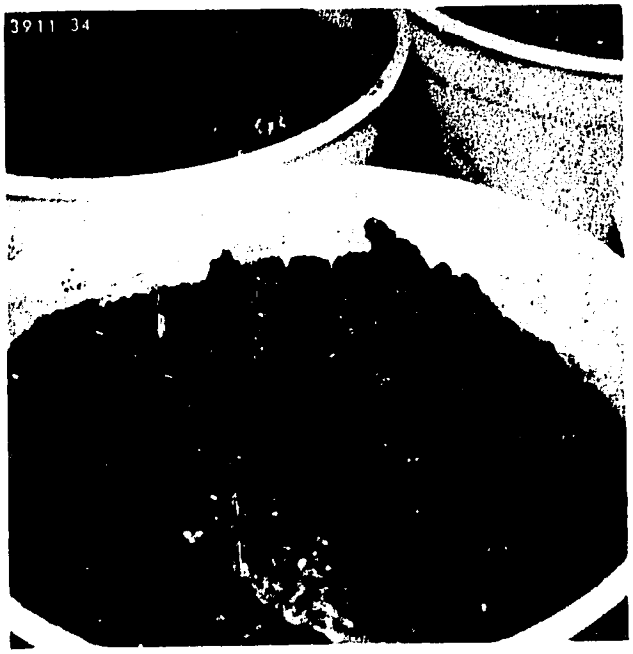
(b) General view with mix chamber, motor and controls

Figure 25. Views of a Banbury Type Intensive Shear Mixer for Melt Compounding Thermoplastics and Rubbers (Category I composites)

into a thermoplastic binder, the following processes occur: (a) fluxing, (b) blending, (c) chopping, (d) fibrillating, and (e) dewatering.

Fluxing involves raising the temperature of the binder to above its glass transition temperature to render it a viscous fluid (not required of rubber). Blending involves separating and distributing the ingredients intimately with each other. Chopping involves reducing the size of the fillers (in this case the bagasse). Fibrillation involves further separation of the fibrous filler into individual fibers by physical breakdown of the material holding these fibers together (pith). Dewatering involves the boiling out of residual moisture by the application of relatively high temperatures in combination with the re-exposure of melted surfaces. There is also the possibility, not proven, that chemical conversion (hydrolysis) of the bagasse may occur due to exposure to water at elevated temperatures and pressures.

The importance of melt-compounding, then, is that one piece of equipment can be used to process all of the ingredients of a formulation. The result is a material (molding compound) that can be melt-formed after grinding as shown in Figure 26, into a variety of sizes and shapes by standard processing techniques. The simplest of these forming techniques for the laboratory is compression molding as shown in Figure 27. Here the molding compound is literally squashed between two platens at an elevated temperature to form a homogeneous mass that is stable when cooled. With a thermoplastic binder, this operation can be done repeatedly on the same material to provide a variety of sizes and shapes. Similarly, standard extrusion or calendering techniques may be utilized to form sheets in a variety of configurations.

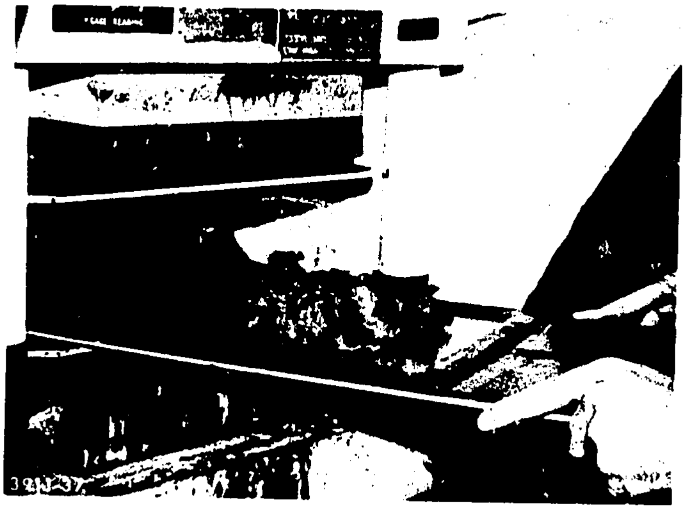


(a) Compounded chunks from
intensive shear mixer

(b) Plastic granulator

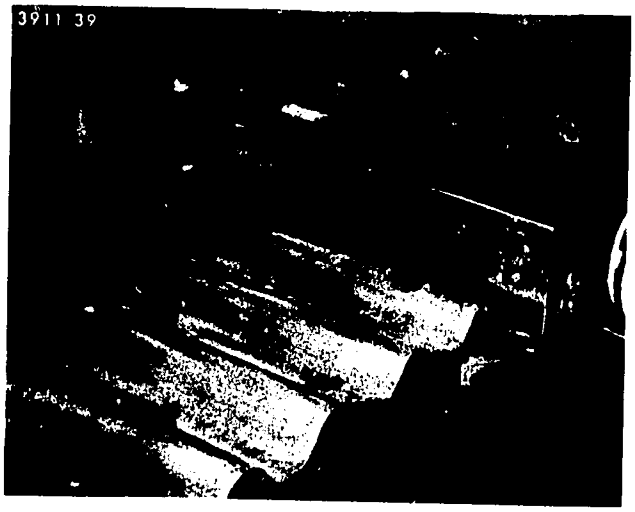
(c) Granulated molding
compound

Figure 26. Secondary Stage of Process to Produce
Category I Composite



(a) Compound in sample mold going into preheated hydraulic press

(b) Molded panel and unmolded material in mold



(c) corrugated electrically heated mold

Figure 27. Molding of Category I Composites

Extrusion and calendering are continuous processes and thus are desirable for production. They circumvent the disadvantage of compression molding, which is the long time required to both heat and cool a mold. In the case of a crosslinkable rubber, this thermocycling is not required, thus improving the efficiency of the process. Proper control of conditions for crosslinking in either the extrusion or calendering process, however, introduces additional complications.

The disadvantage of the intensive mixer is its relatively high initial capital cost. Given a reasonable amount of time, however, these high capital costs are readily offset by the multiplicity of functions performed by the apparatus. Further, these mixers (Banburys) are always "available" in countries where rubber is processed on any scale (e.g., Philippines, Ghana, and Jamaica).

Compression molding equipment is required for all processes under investigation and therefore is not a unique disadvantage for the melt-compounding approach.

4.2.3.1.2 Ingredients

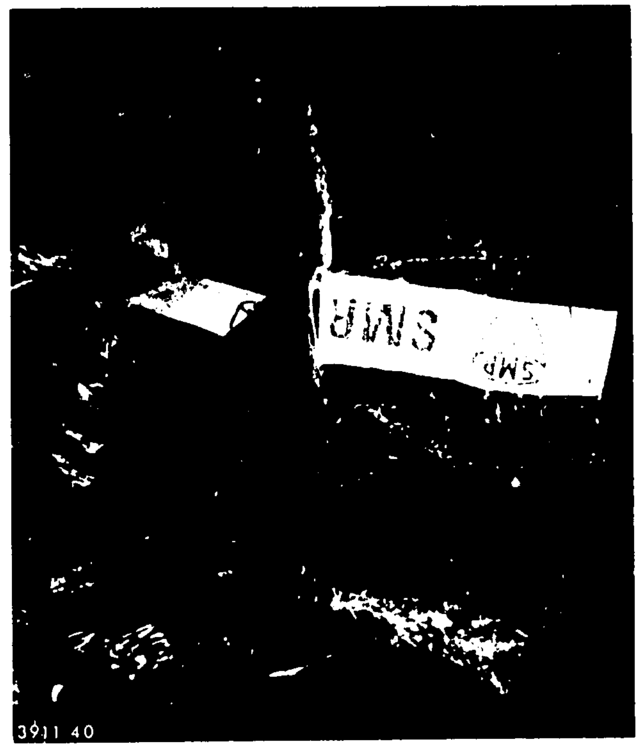
One basic formulation has been developed for use in the melt-compounding process. However, on the surface two variations of this appear different because of the conditions necessary for processing, the number of ingredients, and the nature of the product.

Basically, these systems are bagasse fiber-reinforced composites, in which the fiber is randomly oriented. Because of this random orientation, the space between the fibers represents approximately 25 vol % of the composite. This entire free space must be filled with binder to provide sufficient flow for processing and water-resistance. For strength purposes, the binder could be present at much lower levels, but for all practical purposes the material would not be processable.

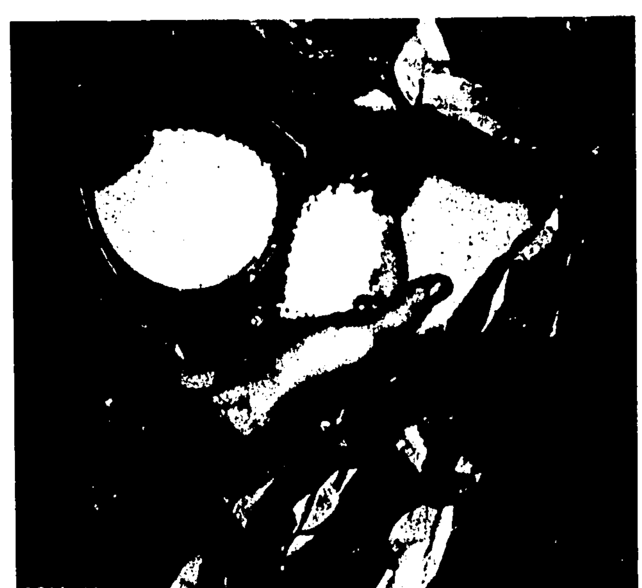
A difference between the two formulations is in the binder. One uses a thermoplastic binder [styrene/acrylonitrile copolymer (SAN) or acrylonitrile/butadiene/styrene graft copolymer (ABS)]. The other uses natural rubber, extended with a low cost oil and crosslinked with sulfur shown in Figure 28. The formulations for these two types of materials are given in Table 32. (Both weight and volume percents are given since the processability and properties depend on material volume, but the materials are usually purchased and measured on a weight basis.)

The SAN and ABS thermoplastic binders have an inherent stability and are commercially available in grades that contain additional stabilizers to protect against exterior environments. Natural rubber is available in pure form without any stabilizers added. In this form, and with a sulfur cure, it is not well-known for its good exterior resistance. However, stabilizers can be added to enhance durability. Initially, it was considered that a similar case would exist for the thermoplastic binder, i.e., low cost polystyrene could be combined with a minor amount of relatively expensive stabilizer. The escalating price of polystyrene ruled this out. In contrast, natural rubber did not increase greatly in cost in the past two years and thus became more desirable in this application.

In the recipe, the whole bagasse is multifunctional. First of all, it replaces 50-60 vol % of the binder, thus increasing the relative amount of both indigenous and low-cost materials. A good question is "why not just use the binder itself as the roofing, which is now done with thermoplastic resins such as PVC." The answer lies in the desire to improve the balance of



(a) Natural rubber



(b) ABS pellets

Figure 28. Binders used in Category I Composites

Table 32

TYPICAL FORMULATIONS FOR MELT COMPOUNDED CATEGORY I MATERIALS[a]

Ingredient[b]	Thermoplastic Binder % Volume[c]	Thermoplastic Binder % Weight	Rubber Binder % Volume[c]	Rubber Binder % Weight
SAN binder	35	26.7	-	-
Natural rubber	-	-	30	20.5
Sulfur	-	-	5.5	8.2
Whole bagasse	60	63.2	52	54
Dry ground clay	3	4.9	-	-
Extender oil	-	-	10	7.4
Iron oxide pigment	2	5.2	1.5	5.6
Additives	-	-	1.0	4.3

(a) Melt-compounded, resin-bonded, bagasse-fiber reinforced composite. Process: Banbury melt blending, grinding to molding compound, compression molding at ∿500 psi. Molding temperature 400°F for SAN and 325°F for rubber.

(b) SAN - Monsanto LNA 21 or equivalent.
Whole bagasse - dried to ∿20% moisture, but weights based on dry material.
Clay - brick grade ground to ≤20 mesh.
Extender oil - Sundex 790 or equivalent.
Pigment - Mapico red #477, Cities Service Co.
Additives - In natural rubber 2 parts Flectol H, 1.5 parts Monsanto A-100 per 100 parts rubber.

(c) Determined experimentally from specific gravities of: SAN - 1.02, NR ∿1.0, sulfur ∿2, bagasse ∿1.4, clay ∿2, oil ∿0.9, iron oxide ∿5.

payments for developing countries (most of which do not manufacture or have the resources for producing synthetic resins).

Beyond just replacing 50-60% of the binder, the bagasse has the advantage that a large portion (60-80%) of it is a reinforcing fiber. This reinforcement is reflected in retention of rigidity, improvement in impact resistance, and minimal loss of strength in tension or flexure. The remaining portion (20-40%) of the bagasse is pith, which takes up space but, also detracts from mechanical properties (extender). The pith, however, contributes by providing improved melt flow and by filling in spaces between the fibers that otherwise require binder. Pith does not make any major contribution to the physical properties of the composite, but its removal would add to both material and process cost.

Incorporation of clay into the composite (shown in Figure 29) expands upon the beneficial function of the pith in processing. The clay performs much like the pith, filling the space between the randomly oriented fibers and providing "ball bearings" internally that aid in the processability of the composite. Possibly if more pith were present in the bagasse, the ground clay would not be necessary, nor desired.

The iron oxide is a pigment that is important first because it is compatible with the given binder system, second because it provides color and, third because it "hides" the binder from the external environment, especially the ultraviolet component of the sunlight. The clay and pith also provide this "hiding" effect.

(a) Sulfur

(b) Baled whole bagasse

(c) Ground clay

(d) Iron oxide pigment

Figure 29. Fillers Used in Category I Composites

In the case of the natural rubber formulation, the sulfur is used to crosslink the rubber into a rigid form. This is done at a temperature of ~300°F under pressure. The oil is a low-cost material that is an extender and a processing aid for the natural rubber system. It enhances the flow of this highly-filled composite and also provides additional compatibility between the natural rubber and the bagasse.

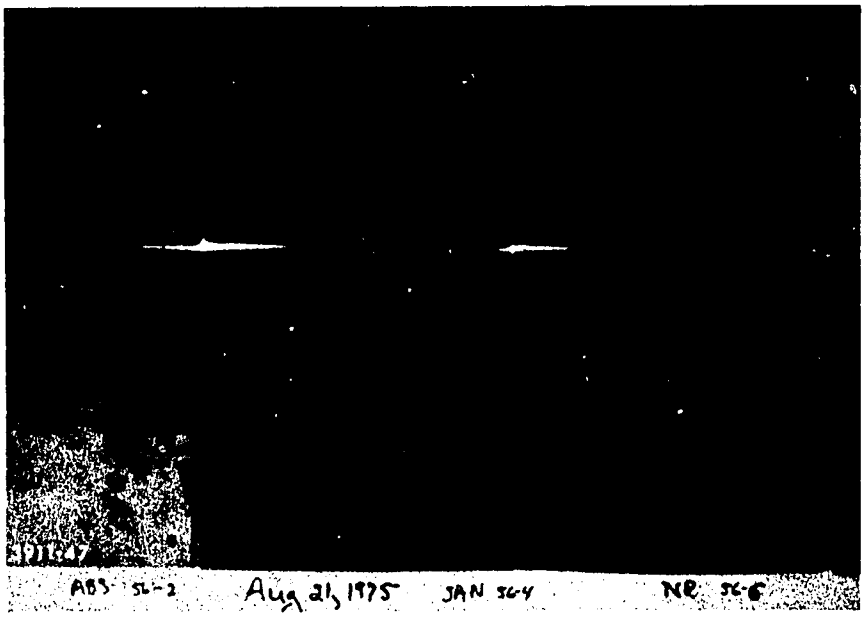
4.2.3.1.3 Product

The product in the case of the melt-compounded, resin-bonded, bagasse-fiber reinforced composite is a panel material with good strength and modulus. This system can be made a variety of colors, but the present one is red (maroon). Interestingly, the panel does not have the appearance of being highly filled as shown in Figure 30.

The mechanical properties of these products are shown in Table 33, compared to polystyrene. This table lists the initial flexural and tensile strength and moduli, and tensile properties following 1000-hour weatherometer exposure or 340 hours of intense UV. For all practical purposes, these data show that composites made with binders of SAN, ABS, or natural rubber did not significantly change in mechanical performance following these exposures. As expected, this was not true of the system with commercial unstabilized polystyrene binder.

The ABS binder was considered because it offered the potential for nailability that was not present in the composite with SAN. This was achieved with the high rubber grade of ABS. However, the higher temperatures required for processing ABS, its expected shorter life, and its slightly higher cost rendered it a less attractive alternative to SAN. Natural rubber as a binder, of course, is most valuable where that material is indigenous. The composite based on rubber is tough, nailable, and rigid and can be processed at lower temperatures.

(a) With ABS (top) and natural rubber (bottom) binders on outdoor rack in Jamaica after 3 months exposure



(b) With binders of ABS, SAN and Natural Rubber (left to right).

Figure 30. Category I Panels (9 in. x 9 in.)

Table 33

MECHANICAL CHARACTERISTICS AND DURABILITY OF MELT-COMPOUNDED CATEGORY I MATERIALS WITH VARIOUS BINDERS[a]

	Initial				Following Exposure[d]			
	Flexural[c]		Tensile[d]		Tensile (1000 hr)		Tensile (430 hr)	
Binder[b]	Str. (psi)	Mod. (10^3 psi)	Str. (psi)	Mod. (10^3 psi)	Str. (psi)	Mod. (10^3 psi)	Str. (psi)	Mod. (10^3 psi)
SAN	6400	1230	4000	960	3900	942	3900	930
NR	5000	3000	3000	-	2950	-	-	-
ABS	5400	1110	4200	970	4200	940	4600	960
PS	5650	1265	3400	1067	1650	500	3100	1000

(a) Melt-compounded, resin-bonded, bagasse-reinforced composite. Process: Banbury melt blending, grinding to molding compound, compression molding at ∿500 psi. Molding temperature 400°F for SAN and 325°F for rubber.

(b) SAN - styrene acrylonitrile.
NR - natural rubber, sulfur cured.
ABS - acrylonitrile butadiene styrene.
PS - polystyrene

(c) ASTM D790 - flexural, D638 - tensile, rate 0.05 in./min.

(d) Tensile strength following either 430 hours of intense UV or 1000 hours of weatherometer exposure with cyclic UV (carbon arc), water spray, temperature, humidity.

4.2.3.2 Category II: Wet-or Dry-Blended, Thermoset Resin-Bonded Bagasse Fiber-Reinforced Composites

4.2.3.2.1 Process

The primary advantages of this type of material are the simplicity and relatively low capital requirement of the manufacturing process. Only a series of simple blendings with mechanical devices followed by compression molding are required.

Processing of the fibers alone is required. First, baled whole bagasse, if used, must be mechanically chopped into a manageable form. The preferred form consists of pieces of ∿1 inch length that have pith separated (but not removed).

Second, this chopping is followed by a "dry fibrillation". This "dry fibrillation" turned out to be a necessary part of the total process. This uniqueness encompassed use of a minor amount of oil (the low cost extender type used in natural rubber), and use of an intensive shear mixer (Banbury). The oil was considered originally to provide improved processing flow characteristics, better compatability between the filler and the binder, and additional water-proofing.

The oil was added to the whole bagasse in a Banbury mixer, initially as a convenience. Unexpectely, the combination of the small amount of oil and the intensive mixing action of the Banbury not only caused an excellent distribution of the oil onto the bagasse fibers, but also caused separation of the fibers from the pith, as shown in Figure 31. It provided an ideal filler material to which pigments and binders could readily be added, using very simple mixing techniques (spatula and bucket).

(a) Oil depithed bagasse

(b) Phenolic binder

(c) Molding compound containing bagasse, phenolic powder, oil and pigment

Figure 31. Ingredients Used in Category II Composites

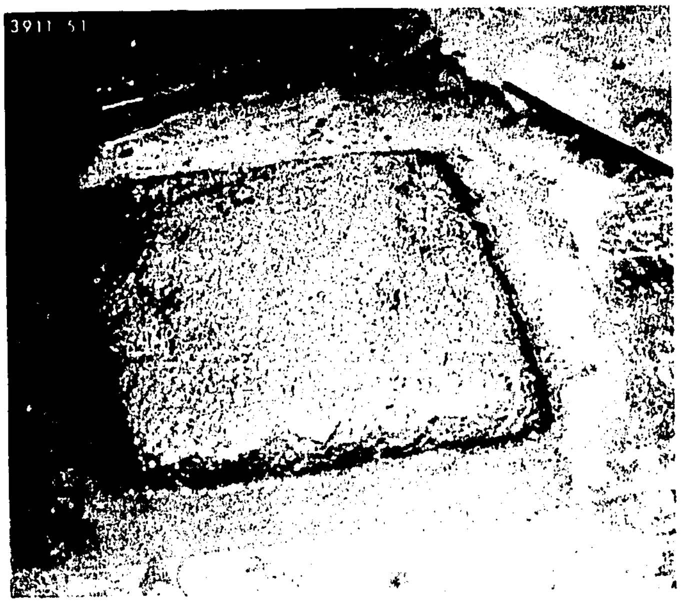
Attempts were made to duplicate this separation of fiber using other types of mixers. This was important because the Banbury intensive mixer represents a relatively high capital requirement that, if needed, would reduce the attractiveness of this material category.

Mixers, including planetary and high intensity shear types, were considered. While some degree of mixing and fibrillation was observed when using a high speed shear mixer (Waring Blendor), the resultant product was never as good as that processed with the Banbury intensive mixer. Future work must definitely concentrate on duplicating this effect in lower cost equipment.

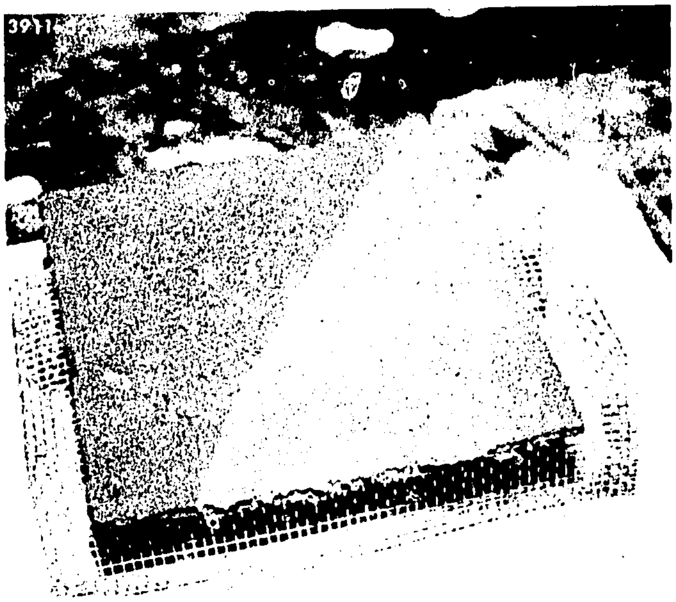
The fibrillation and mixing can be duplicated in a wet process where caustic is used to break down the pith; less intensive mixing can then separate the pith from the fiber. This approach is used in Category III materials and will be discussed in more detail there. This wet process has the disadvantage that large amounts of water must be used and then removed, thus adding to its complexity, energy consumption, and cost.

Having the oiled, fibrillated fibers, the process then only requires simple blending with a thermosetting resin, a minor amount of clay, and a pigment. This can be done in either a dry or wet condition. The dry blended material can easily be preformed to a shape. About 20 wt % water was shown to be useful for giving this material a degree of formability and green strength (shown in Figure 32). The choice of wet versus dry blending will also be dictated by the binder form selected (see the next section).

Following the simple mixing of the ingredients, they are compression molded (as a thermoset) as shown in Figure 33, using a

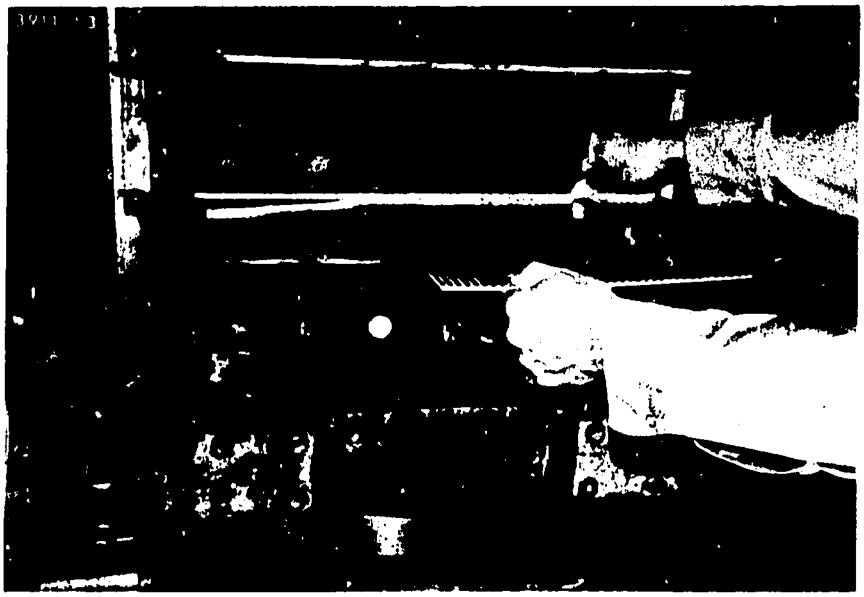


(a) Wet trowelled preform

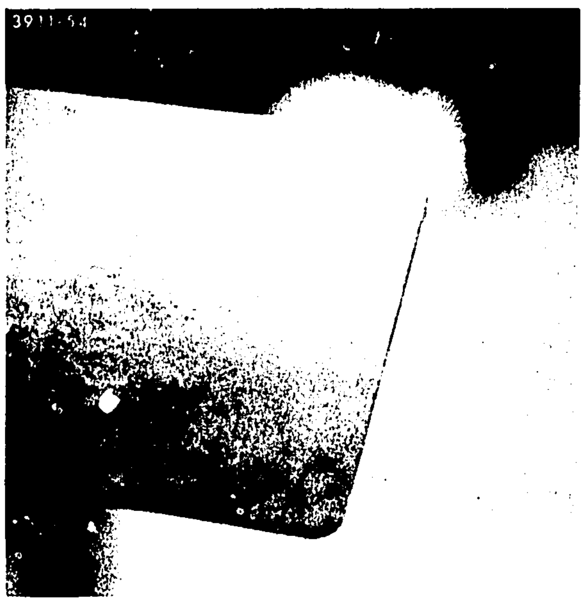


(b) Dry molding preform

Figure 32. Wet Blended Category II Molding Compound



(a) Elevated temperature compression molding



(b) Molded panel from phenolic dry blend

Figure 33. Molding of Category II Composites

pressure of ~500 psi at a temperature of ~325°F. Molding times can be as low as 30 seconds, if proper equipment is available. In the laboratory, cure cycles of 10 to 15 minutes were used for convenience.

4.2.3.2.2 Ingredients

A formula for the wet- or dry-blended composite is shown in Table 34. As might be expected, this formulation is similar to that for Category I materials. The primary difference is that there is less volume of phenolic binder and a minor amount of oil (the purpose of which was discussed in the previous section). The higher density of the phenolic resin (approximately 1.35) causes the seemingly higher weight ratio of the binder in this case.

There are a host of phenolic (phenol/formaldehyde) binders available as either dry powders, liquids, or latices. The liquids are the lowest in cost, function well, and are easy to work with; therefore, they are normally the most desired. However, the shelf life of phenolic liquids and latices are poor, thus they ordinarily can not be stored for prolonged times or shipped any distance. Ideally, phenol/formaldehyde liquid resins should be manufactured within 100 miles of where they are used. Nonetheless, P/F resins for plywood manufacture are imported from the United Kingdom to Ghana.

The dry powder phenolics have the disadvantage of higher cost, but are stable for many months. It is because of this stability that dry powder resins were used for most of the experimental work. Thus the resins could be shipped anywhere in the world and results duplicated, an important factor in assisting the transfer of this technology to our participating countries. Fortunately, water can be added to the formulation even with dry powder to gain some pre-moldability.

Table 34

TYPICAL FORMULATION FOR DRY BLENDED CATEGORY II MATERIAL[(a)]

Ingredient[(b)]	Volume[(c)] %	Weight %
Phenolic binder	32	30
Dry fibrillated bagasse	61	62
Dry ground clay	1	2
Iron oxide pigment	2	3
Oil	4	3

(a) Wet or dry blended, thermoset-resin-bonded, bagasse fiber reinforced, dense composite. Process: bagasse fibrillated with oil in Banbury (no separation of pith), dry blend of ingredients, compression molding at ∿500 psi.

(b) Phenolic - phenol formaldehyde resin, Monsanto PR 736 dry powder;
Whole bagasse - dried to ∿20% moisture, but weights based on dry material.
Clay - brick grade ground to ≤20 mesh.
Extender oil - Sundex 790 or equivalent.

(c) Determined experimentally from specific gravities: phenolic - 1.35, bagasse ∿1.4, clay ∿2, oil ∿0.9, iron oxide ∿5.

The purpose of the oil as a processing agent has been discussed. Because of the processing advantages, it is important that it be retained in the formulation even though its contribution to polymer/filler compatibility and water-proofing were not quantified.

The chopped-whole-bagasse, ground clay, and iron oxide perform the same functions in this system as in the Category I materials. Importantly, even though some processing is done on the bagasse, it is used in its entirety.

4.2.3.2.3 Product

The product of the above process is a rigid red panel, that can be visually distinguished from Category I materials only through its slightly darker color (shown in Figure 33). Its mechanical properties are given in Table 35, which lists the tensile and flexural properties initially, and after complete immersion in water for 48 hours.

The initial tensile strength and modulus of this phenolic-bonded randomly-oriented bagasse composite are about equivalent to those of any of the Category I materials using a thermoplastic binder, and the wet strength and modulus are approximately 80% of these values. Upon drying of the originally wet specimens, most of this loss was recovered.

The flexural strength, even when wet, is very close to that of the Category I materials, but the flexural modulus is about half (500,000 psi). Flexural properties also recover upon drying.

The 15-25% decrease in flexural and tensile properties, due to direct immersion in water, was much more than anticipated, taking into consideration the relatively high volume percent binder.

Table 35

MECHANICAL PROPERTIES OF DRY BLENDED CATEGORY II MATERIAL INITIALLY AND FOLLOWING IMMERSION IN WATER[(a,b,c)]

Flexural Strength (psi)	
Dry	7200
Wet	5500
Flexural Modulus (psi, 10^3)	
Dry	710
Wet	510
Tensile Strength (psi)	
Dry	4130
Wet	3600
Tensile Modulus (psi, 10^3)	
Dry	830
Wet	680
Water Pickup (%)	1.9

(a) Wet or dry blended, thermoset-resin-bonded, bagasse fiber reinforced, dense composite. Process: bagasse fibrillated with oil in Banbury (no separation of pith), dry blend of ingredients, compression molding at ∿500 psi.
(b) Immersion in water for 48 hours. Tested wet.
(c) ASTM D790 - flexural, D638 - tensile, rate 0.05 in./min.

Much of this can be attributed to the relatively high surface area of the cut edge of the specimens tested. This decrease in mechanical performance, due to immersion, is not desirable, but it is not expected to be a major problem with respect to this composite material functioning in a roofing situation.

4.2.3.3 Category III: Wet-Process, Thermoset Resin-Bonded, Depithed-Fibrillated-Oriented, Bagasse Fiber-Reinforced Composites

4.2.3.3.1 Process

The primary advantages of this type of material hinge around a highly effective process in which individual bagasse fibers are first prepared and then oriented into mats. This process provides for nearly complete removal of pith from bagasse, making available individual short bagasse fibers, which because of the orientation process, can be packed to a higher density. This reduces the free volume and the amount of resin required to bond the structure together (less than 15%).

The fiber-orienting and mat-forming technique is attractive because it has been demonstrated on a small laboratory batch scale and on a moderately sized batch pilot (1 ft x 3 ft), and can be projected for development into a continuous manufacturing process. Importantly, reasonable economics could be anticipated for any of these levels of manufacture (assuming that reasonably-priced labor can be utilized in the batch processes). Some capital equipment is required, but the primary disadvantage is the large quantity of water needed. This dictates that water be available initially and that there be a means for filtering it and removing the waste from it. For every pound of bagasse used, approximately 50 pounds of water would be required, even if some recycling is accomodated.

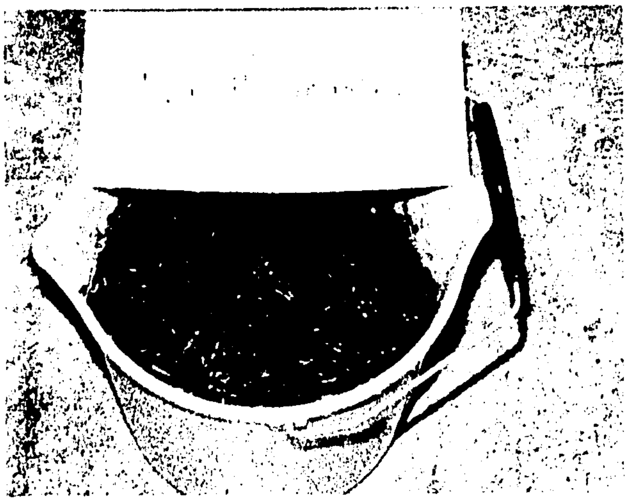
The best method to prepare bagasse fibers for this process involves, first, a dry, mechanical depithing of bagasse, followed by further degradation of the pith with a caustic treatment, and then a final wet fibrillation (by mechanical beating of pith from fiber). This is shown in Figure 34.

The process is designed to separate and remove all the pith (see Figure 35) so that only strong individual bagasse fibers remain. The reason for this is that, in the next step of the process, these fibers are oriented and laid down into a mat. Since pith has no fiber-like geometrical character, it cannot be oriented.

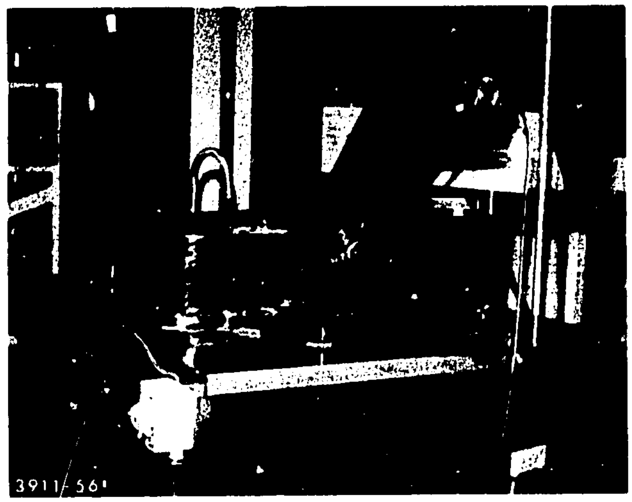
Addition of binder and a water-proofing wax is the next step in the process, as shown in Figure 36. Water-compatible resins are necessary and, so far, liquids rather than latices have been considered. The cleaned, depithed fibers are added to water at a level of about 2% by weight. Simple agitation of this slurry is initiated and then the binder (5% by weight based on dry fiber) and wax emulsion (2% by weight based on dry fiber) are added.

The binder is then precipitated out of solution, hopefully onto the fiber itself. With phenolic resins this is usually done by adjusting the pH of the solution to 4.5 by the addition of paper-maker's alum and sulfuric acid. The slurry is mixed for about 15 minutes and then transferred to a easily handleable container (e.g. a 30-gallon plastic waste can), and diluted with equal parts of water. At that point there is one part of fiber, based on initial dry weight, per hundred parts of water.

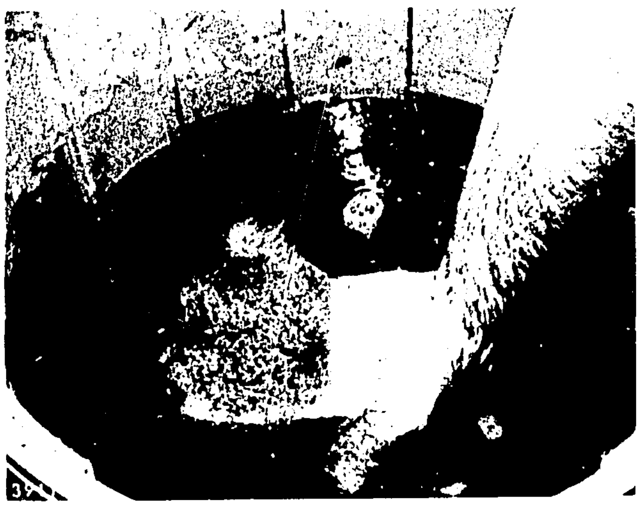
Dilution of the slurry is required to introduce maximum separation between fibers. This minimizes the effect that one fiber has on the other, allowing outside forces to have a major impact on them.



(a) Caustic soak to weaken pith/fiber bond



(b) Beater to fibrillate the fibers from the pith



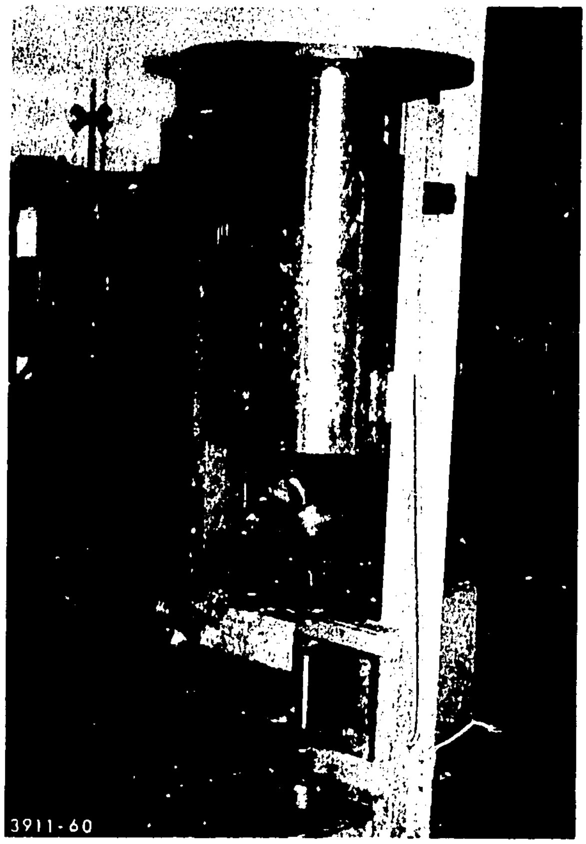
(c) Fibrillate, washed bagasse fibers

Figure 34. Illustration of Bagasse Fiber Wet Preparation Required for Category III Process

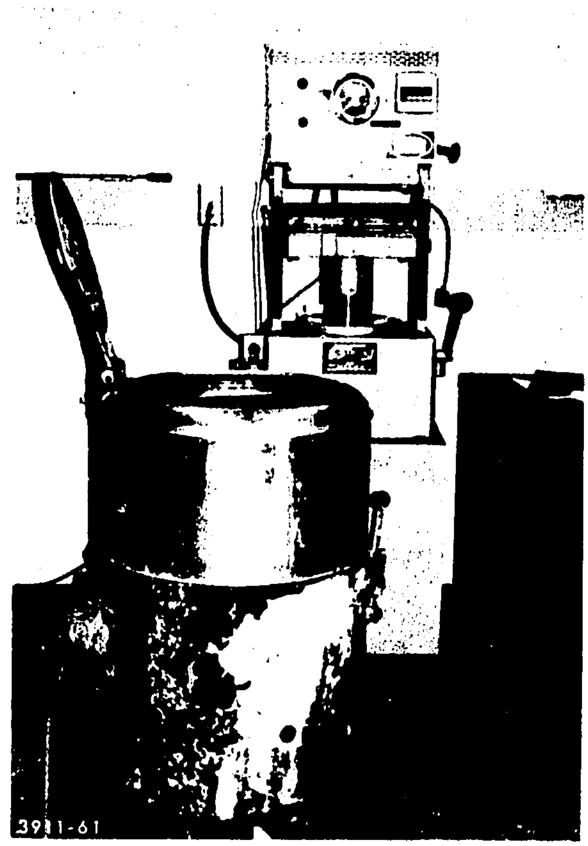
(a) With pith

(b) Fibers with pith washed out

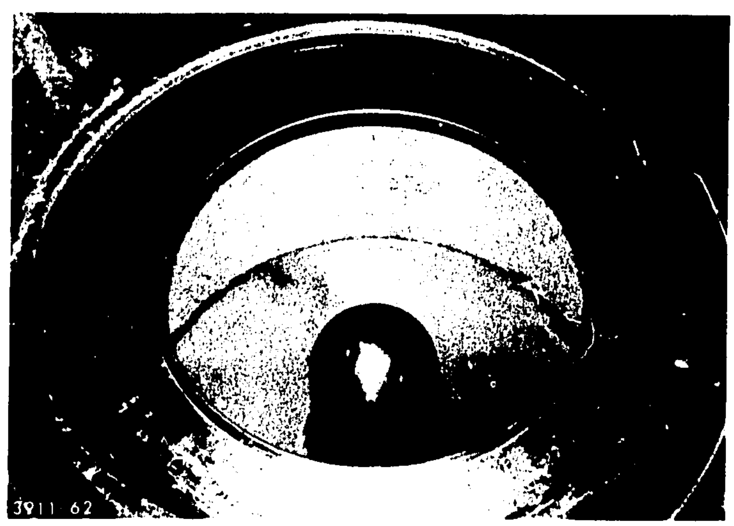
Figure 35. Illustration of Fibrillated Bagasse Fiber Depithing by Wet Process



(a) Mix tank for blending binder and wax with bagasse in water



(b) General view of "spin dryer" orienting centrifuge



(c) Inside of "spin dryer" centrifuge with screen on wall

Figure 36. Equipment Used in Mixing and Orienting Bagasse Fibers and Binder in Category III Process

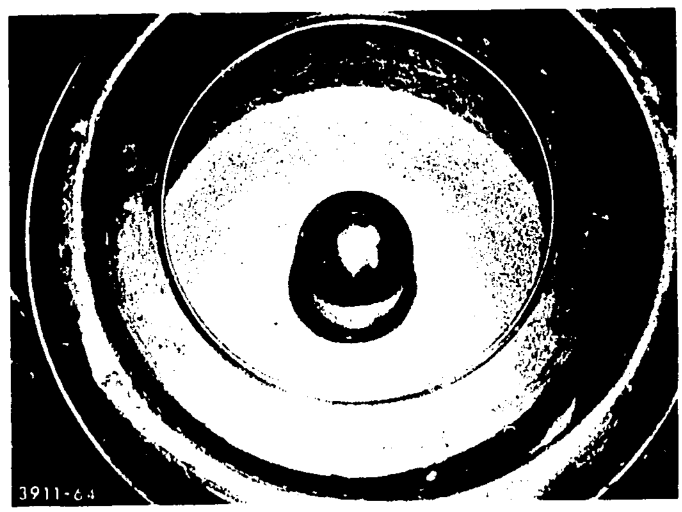
The next step is the heart of the Category III process. This portion of the procedure involves both orientation of the fiber and mat formation. This is done using a centrifuge, or squirrel-cage fan. A preferred type of centrifuge is a commercial laundry-type spin dryer (shown in Figure 36). The preparation of smaller mats can be done equally well using squirrel cage fans of any desired depth and diameter.

The only modification required of a commercial laundry centrifuge is wiring around the safety switch so that the lid can be opened while the centrifuge is spinning Two screens, one on top of the other, are placed around the inside of the centrifuge drum. These screens are important, since the fiber mat will be laid down on them. The screen is also needed to allow the discharge of water from the mat during its formation, and as a support to lift the mat out of the centrifuge.

The fiber mat formation is initiated by placing the two screens into the centrifuge, turning the centrifuge on and letting it come up to full speed, usually 1720 rpm. The fiber/binder/wax slurry, in a large plastic container, is first stirred to suspend the slurry and then <u>dumped</u> rapidly into the centrifuge until a thick cylinder of fiber and water is formed on the wall, as shown in Figure 37. The rate of pouring is then decreased so that excess slurry is not thrown out the top of the centrifuge. The initial dumping is most important to provide a uniformly thick mat the full height of the centrifuge. Slow pouring would cause a triangular-shaped mat of little value to form.

It is the rotation and the differential shear that causes the fibers to be aligned. The mat forms due to the centrifugal action of the slurry being pushed against the drum wall. After all the slurry is dumped into the centrifuge, it is allowed to run until water ceases to be extracted. At this point, the moisture in the mat should be 200-250%.

(a) Dumping dilute resin coated fibers into spinning centrifuge



(b) View of oriented mat on wall of centrifuge

(c) Unmolded oriented bagasse mat

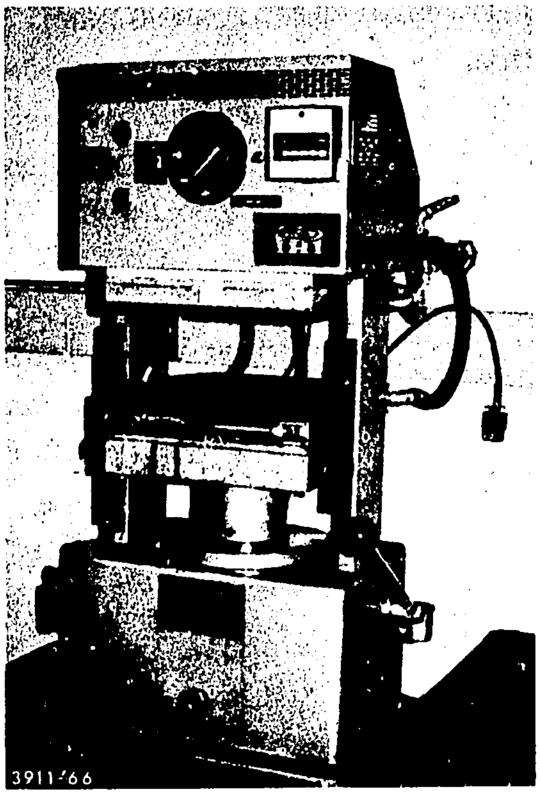
Figure 37. Illustration of the Fiber Orienting Process Used for Category III Materials

The centrifuge is stopped and the mat removed (see Figure 37). This is done by tearing the mat apart where the supporting screen overlaps itself. The mat, and the screen can then be turned in upon themselves and lifted vertically from the drum. the mat is not strong enough to support itself. This mat is transferred to a mold and the screen removed from the back. Retention of this or a similar screen may be desirable to assist in expelled water during molding.

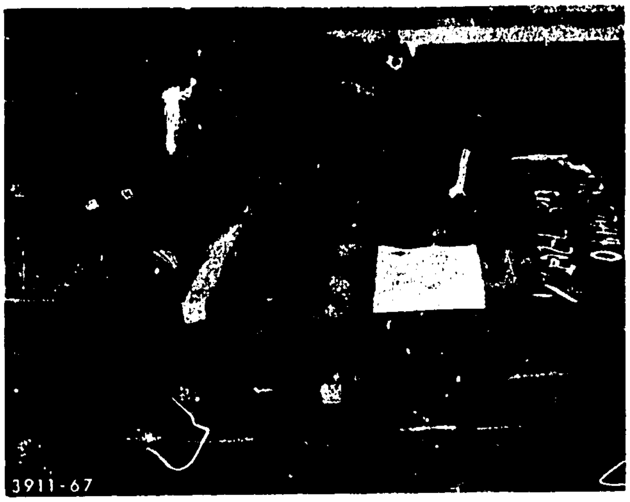
Mats generated in this way, when processed further, result in a panel having a thickness of only 1/16 of an inch. Accordingly, it is usually desirable to ply mats together making sure that the direction of orientation is matched. At some point later in the program, the efficacy of cross-plying of these mats should be explored.

The plied mat is then ready for the application of pressure and temperature to densify it and cure the binder. For convenience, the mat is first placed between a caul sheet and very fine screen. These are needed to prevent bonding of the binder to the press platens, and to accomodate removal of water during initial pressing. Typical pressing equipment and molds are shown in Figure 38.

Molding consists of heating the press (to 350°F for phenol/formaldehyde resin) and conducting a pressure/time cycle similar to the following: a) increase the pressure to 400 psi over a period of 60 seconds, b) hold at 400 psi for no more than 10 seconds, c) lower pressure to 150 psi rapidly, d) hold at 150 psi for 6 minutes, and e) gradually reduce the pressure to zero over a period of 60 seconds. The molded specimen, Figure 38, can then be trimmed and used as desired.



(a) Typical heated laboratory press



(b) Typical full scale (~50 in.) corrugated mold

(c) Molded and painted flat panels

Figure 38. Molding Equipment for Category III Panels

It is expected that some sort of surface treatment will be required to completely water-proof this panel. The most effective way of doing this is being explored and will be completed in Phase III. This includes examining higher concentrations of resins, the application of tempering oil, painting, etc.

4.2.3.3.2 Ingredients

Ingredients for the bonded, oriented-fiberboard are shown in Table 36. This board is basically bagasse bonded with only 3% phenol/formaldehyde binder and 3% water-proofing wax. The properties discussed in the following section are based on this formula and those with slightly higher resin contents.

The resin content of the molded panels was not always known due to the nature of its addition and undetermined losses. Even though up to 10% resin was added to the initial slurries and precipitated, it is expected that not all of this resin actually precipitated onto the fibers and thus was carried through in the process. The remainder would have been precipitated as a fine powder, passed through the screen, and flushed down the drain with the water. Resin losses in the process and the actual resin on the mats will need to be determined.

Unoriented mats were prepared in a slightly different manner for comparison. The resin contents could be as high as 10% in these.

The 3% phenolic resin is sufficient to give the oriented panels the desired mechanical strength. The 3% wax content provides some waterproofing. It is expected that either wax and/or resin may need to be increased to where their combination totals approximately 15% (by volume) to render a waterproof, mechanically sound panel. Importantly, this is 10% less resin than that required for any of the other category of materials.

Table 36

TYPICAL FORMULATION FOR WET PROCESS CATEGORY III MATERIAL[a]

Ingredient[b]	Volume %	Weight %
Phenolic binder	3	3
Wax emulsion	3	3
Depithed, fibrillated bagasse fibers	94	94

(a) Wet process, thermoset resin bonded, depithed fibrillated oriented bagasse fiber reinforced composite. Process: bagasse fibers prepared with wet caustic treatment to depith and beating to fibrillated fibers oriented in centrifuge, wet resin precipitated onto fibers, compression molding in pressure cycle at 350°F.

(b) Phenolic - phenol formaldehyde resin; liquid resin wax, standard waterproofing emulsion.

4.2.3.3.3 Product

The product of the wet process, thermoset resin-bonded, depithed, fibrillated, oriented, bagasse is a panel material with excellent directional strength and modulus characteristics. Since surface coating or painting has not been used, it has the appearance of a composition board. Fiber orientation is obvious visually and mechanically (by bending). Qualitatively, it has a tough, rigid feel. Importantly, the panel does not look or feel like bagasse board, which is used extensively in developing countries as the structural element in bookshelves, counter tops, etc. Bagasse board has a poor reputation in construction, an application for which it has been used but for which it was never intended.

The ingredients appear to be those for existing bagasse board. This, in fact, is so when examined on a weight basis, and no distinction as to type of bagasse is made. However, there are three distinctions that result in this product being completely different from bagasse board. The first is density. When examined on a volume basis, ordinary bagasse board will have up to 50 volume percent of air (implying that it is very porous), whereas this Category III-type material, has less than 10% free space. It is anticipated that this free space can eventually be reduced to less than 5%. The density of bagasse board is ~35 lb/cu ft, whereas the Category III material is ~70 lb/cu ft.

The second factor distinguishing the Category III material from bagasse board is the absence of pith, which assures the availability of individual bagasse fibers for bonding. Pith is a very low strength, non-fibrous material that contributes nothing to the mechanical performance of a board. Pith also attracts and soaks up binders, thus causing the binder to be concentrated on the low strength pith, rather than around high strength fibers.

The third factor distinguishing the two materials is the orientation of the bagasse fibers. This significantly increases the strength and modulus in a given direction. It also produces better packing of fibers, and is the basis for the higher densities indicated above. This close packing minimizes free space within the composite, reducing porosity and the amount of resin required to completely bind all the fibers together.

The mechanical properties of these Category III materials are shown in Table 37. A comparison is made to a randomly oriented, phenolic-bonded, bagasse fiber composite. That the fibers are oriented, and improved strength and modulus are actually achieved is illustrated best by the tensile strength and modulus characteristics. The strength is improved nearly five-fold and the modulus 2.5-fold when measured in a direction parallel to the fibers versus the perpendicular direction. These properties are, respectively, 3 and 1.5 times those of a randomly-oriented panel.

The flexural strength and modulus are affected by the orientation significantly, but to a slightly lesser degree.

The wet strength and modulus, following direct immersion in water for 48 hours, retain the directional distinction of the oriented-fiber system. It was also demonstrated that all properties were nearly completely recovered following drying of the wetted panels.

The water pickup appears to be high relative to the other category of materials, but is very low compared to bagasse board. It is necessary that this be improved. This water pickup was not reflected in any significant dimensional changes in the oriented boards that would make them appear to be less structurally valuable. Panels of the oriented boards were boiled in water

Table 37

MECHANICAL PROPERTIES OF WET PROCESS CATEGORY III MATERIAL[a,b,c]

	*(d)	=(d)	⊥(d)
Flexural Strength (psi)			
Dry	3100	4700	1740
Wet	1500	1900	520
Flexural Modulus (psi, 10^3)			
Dry	480	600	250
Wet	200	330	95
Tensile Strength (psi)			
Dry	1780	5410	1130
Wet	600	1700	510
Tensile Modulus (psi, 10^3)			
Dry	650	910	365
Wet	240	290	100
Water Pickup (%)	40	33	34

(a) Wet process, thermoset resin bonded, depithed fibrillated oriented bagasse fiber reinforced composite. Process: bagasse fibers prepared with wet caustic treatment to depith and beating to fibrillate, fibers oriented in centrifuge, wet resin precipitated to fibers, compression molding in pressure cycle at 350°F.

(b) Immersion in water for 48 hours. Tested wet.

(c) ASTM D790 - flexural, D638 - tensile, rate 0.05 in./min.

(d) * unoriented bagasse fiber for reference.
= properties measured with load parallel to fiber direction.
⊥ properties measured with load perpendicular to fiber direction

for periods of up to 24 hours. These panels remained dimensionally stable, visually showed no degradation, and lost no more than 5% of their mechanical strength upon drying.

While good mechanical performance, and reasonable water-resistance has been demonstrated for this particular type of material, it is expected that additional work will be required to stabilize the system completely against water, fungus, bacteria, etc. The fact that it requires so little resin obviously makes it a very strong candidate with respect to low cost and make its pursuit mandatory.

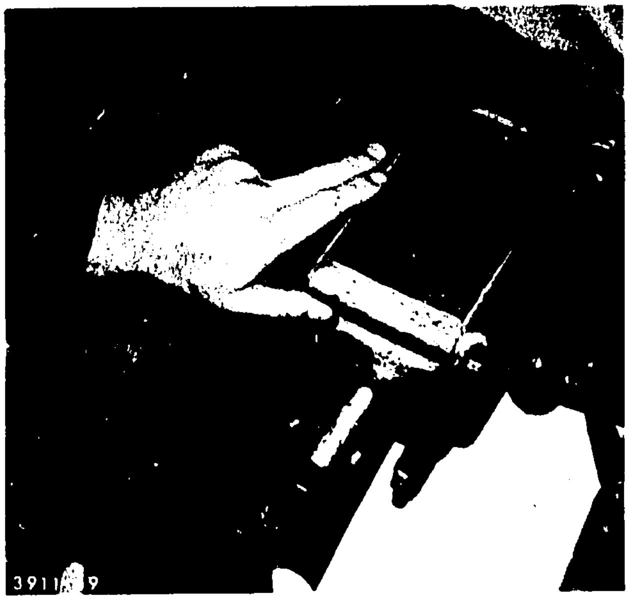
4.2.3.4 Category IV: Wet- or Dry-Blended, Resin-Bonded, Unfired Clay Tiles

4.2.3.4.1 Process

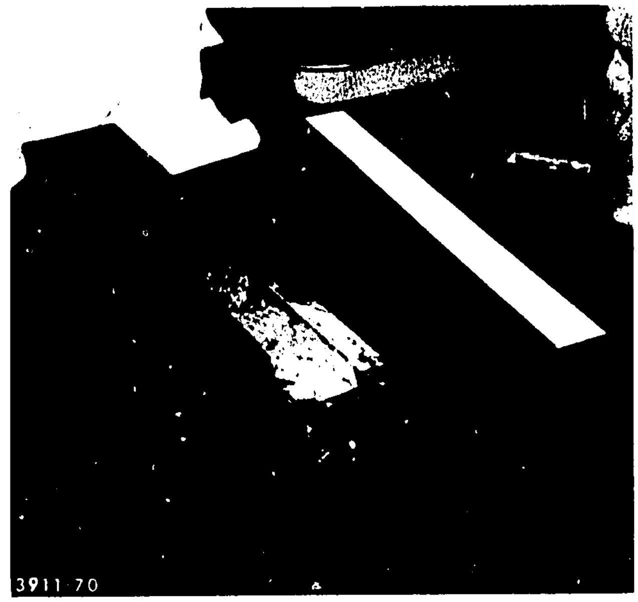
The process for Category IV-type materials is very similar to those of Category II, except that fiber is not necessary, and when used, need only be chopped into a handleable form. However, future experiments may show added treatment of the fibers to be desirable.

Compounding of Category IV materials requires only a good, sturdy mixer for wet, heavy, mixtures (ordinary cement mixers would be quite usable). Simple air-drying is then used, and finally compression molding at elevated pressures and temperatures is required.

The actual process is very similar to mixing concrete. It consists of first mixing ground clay dust with water until all agglomerates are broken, then adding a dry or wet binder and mixing until the two ingredients are well blended, as shown in Figure 39. This composition should be only wet enough to allow



(a) Wet blending



(b) Wet compound in compressed mold

(c) Mold in hydraulic press. Fabric is to allow bleeding of water while retaining binder.

(d) Molded phenolic bonded clay bar

Figure 39. Category IV Wet Blending Process, Molding and Product

easy mixing; it should not be soupy. If addition of fibers is desired, these should first be chopped into a reasonable size (approximately 1 in. length) and then dumped into the wet clay/binder mixer and agitation continued until a good distribution of fiber is evident. Pigments and/or dyes can be added at this stage.

Forming of the molding compound is done by introducing the entire wet blend into a mold (Figure 39), first applying pressure to extract gross water, and then applying additional pressure and temperature to melt, fuse, and react the binder. The mold for such an operation requires paths for expelling the gross water. This can be achieved by rough texturing, and use of screens or bleeder cloths.

Removal of gross water can also be achieved through simple air-drying, prior to elevated temperature molding. Doing this should reduce energy requirements for the process. However, this drying should be conducted on compression molded preforms that have nearly the dimensions of the desired final panel. It is important that the initial pressing be conducted with water present to accomodate flow of the clay. In the subsequent elevated temperature/compression molding, then minor flow will be accomodated by the presence of melted binder. The time period over which the binder has an adequate low viscosity to provide this flow, however, is very short (seconds); this is why the preform must be very close to the final desired shape and size.

The elevated temperature/compression molding is usually conducted at pressures of approximately 600 psi and a temperature of 325°F. Laboratory molding times were usually 10-15 minutes, but this can be reduced significantly in pilot or production manufacturing.

The binders used in this process, as well as in the other categories, usually have a great affinity for metals, ceramics, etc., and therefore release agents MUST be used. Suitable release agents include waxes, silicones, rigid plastic films (that will not melt at the molding temperatures), and very tightly woven fabrics. One disadvantage of the clay system is the abrasiveness of the clay that scrapes release agents from mold surfaces.

4.2.3.4.2 Ingredients

A typical formulation for a wet-blended, phenolic-bonded bagasse fiber-reinforced clay composition is shown in Table 38. The similarity of this formulation to that shown in Table 34 for a category-type II material should be examined. In essence, these two compositions are identical, except that the portions of clay and bagasse are reversed. The reason that these materials have been separated into two categories involves differences in the processing, processability, and the product.

Bagasse may be eliminated from the formulation shown in Table 38. thus providing a phenolic-bonded clay with good strength and very high rigidity. However, such a composition would be brittle, and (because of its relatively high density) suffer from low impact resistance. Addition of the bagasse fiber significantly improves the impact resistance, but strength and rigidity are severely reduced.

The phenolic resin can be a liquid, emulsion, or dry powder. Dry powders were used, for the most part, in the experimental work and perform well. Since liquid phenolic resins require control of pH to impart initial stability and then for precipitation, less success was achieved in using them in the presence of the usually basic clay. Further development work can probably be used to remedy this situation and take advantage of the lower cost liquid phenolic.

Table 38

TYPICAL FORMULATION FOR WET BLENDED CATEGORY IV MATERIAL[a,b,c]

Ingredient	Weight %
Dry ground clay	70
Phenolic resin	18
Pigment iron oxide	4
Chopped screened bagasse	8

(a) Wet or dry blended, resin bonded, bagasse reinforced, unfired clay tile. Process: bagasse (if used) ground and screened for cut between 2 mm and 0.5 mm, ~20% water, partial air dry, compression mold at ~500 psi and 325°F.

(b) Phenolic - phenol formaldehyde resin, Monsanto PR 736 dry powder.
Clay - brick grade ground to ≤20 mesh.
Pigment - Mapico red #477, Cities Service Co.
Bagasse - whole, dried to ~20% moisture, weights based on dry material.

(c) Determined experimentally from specific gravities: phenolic - 1.35, bagasse ~1.4, clay ~2, iron oxide ~5.

The bagasse used in these formulations was baled, whole bagasse that was ground and then screened to eliminate coarse fibers and pith. The fibers used were those that passed through a 2 mm screen and were retained on a 0.5 mm screen. This minimizes undesirable low strength, water-sensitive pith and large groups of fibers that cannot be wetted well with the binder.

The iron oxide pigment was used for coloring and to screen the solar radiation from the phenolic binder, similarly to Category I, II and III materials.

4.2.3.4.3 Product

The product in the case of the wet-blended, phenolic-bonded clay is a panel material with good strength and very high modulus. Added toughness can be achieved by the inclusion of the bagasse fibers, but with some compromise in strength and rigidity. The system can be made in a variety of colors and is not visually distinguishable from Category I and II materials. A panel of this material, however, is much heavier than those in any other category and is not nailable. Because of its lower strength and higher weight, panels would need to be smaller but need not be tiles. Thicknesses of 1/8 to 1/4 inch would probably be usable.

The mechanical properties of wet-blended, phenolic-bonded clay as a function of resin content and bagasse fiber addition are given in Table 39. Illustrated are flexural and compressive strength and moduli, initially and following 24-hour immersion in water.

A number of relationships are illustrated by the data in Table 39. First, among the specimens having resin contents from 2.5 to 7.5%, it is illustrated that 2.5% resin is sufficient to

Table 39

MECHANICAL PROPERTIES OF WET BLENDED CATEGORY IV MATERIAL AS A FUNCTION OF RESIN CONTENT AND WATER IMMERSION[a,b,c]

	Weight %, Resin					
	2.5	5.0	7.5	20	50	18[d]
Flexural Strength (psi						
Dry	2160	1980	2020	5200	12,000	1900
Wet	-	-	-	2300	13,000	1700
Flexural Modulus (psi, 10^6)						
Dry	1.17	0.85	1.04	1.84	3.0	0.36
Wet	-	-	-	0.8	3.5	0.30
Compressive Strength (psi)						
Dry	3960	6300	8030	11,300	-	-
Wet	470	1800	2260	-	-	-
Compressive Modulus (psi, 10^3)						
Dry	53	75	78	55	-	-
Wet	-	40	45	-	-	-

(a) Wet or dry blended, resin bonded, bagasse reinforced, unfired clay tile. Process: bagasse (if used) ground and screened for cut between 2 mm and 0.5 mm ∿20% water, partial air dry, compression mold at ∿500 psi and 325°F.
(b) Immersion in water for 48 hours. Tested wet.
(c) ASTM D790 - flexural, D695 compressive, rate 0.05 in./min.
(d) Also includes 8% by weight of chopped screened bagasse.

provide minimum strengths, which are dependent upon the properties of the clay (assuming some reasonable degree of bonding with the phenolic resin). Resin contents above 2.5% (but below 20%) contribute only to water-proofing by filling in the free space. It is expected, then, that reasonable flexural strength and moduli can be achieved with as little as 2.5% resin, and water-proof panels can be prepared by completely impregnating with wax, etc., or by the addition of surface coatings.

The data on composites containing 20 and 50% resin illustrate the crossover from clay-dominated characteristics to those of the very high strength binder. Both of these compositions have a continuous matrix of the phenolic binder extended with clay. The composite containing 50% binder was not deemed to be viable because of cost, but was prepared to illustrate this crossover effect from filler to binder dominance. The composition containing 20% resin is very similar to a Category II type material except the clay is substituted for bagasse.

Compared with the Category II products the modulus of the clay system is much higher, even when wet, but is slightly lower in initial flexural strength and much lower in wet strength. Superficially, these compositions may seem somewhat comparable. What is not illustrated is the relatively poor impact resistance of the clay system. Additionally, the flexural strength and modulus decrease significantly upon immersion in water to below usable levels. These results confirmed earlier data on the efficacy of the bagasse fiber with respect to contributions towards water resistance.

The outstanding composite illustrated in Table 39 is the clay system bonded with 18% phenolic and reinforced with bagasse. The strength and modulus in flexure is no better than any of the other compositions in the table, but the retention of these properties following direct immersion in water is superseded only by the composite with 50% resin. Not shown is the toughness and impact resistance of this composition. The toughness was illustrated in the stress/strain curve (flexural), which, instead of being linear up to a sharp break, was rounded. Significant strength was maintained with additional deflection after this peak strength was achieved. Qualitatively it may be said that (except the composite containing 50% resin) 9 in. x 9 in. x 1/8 in. panels containing no bagasse if dropped from a distance of 3 ft would probably break in two. The bagasse-reinforced panel probably would not.

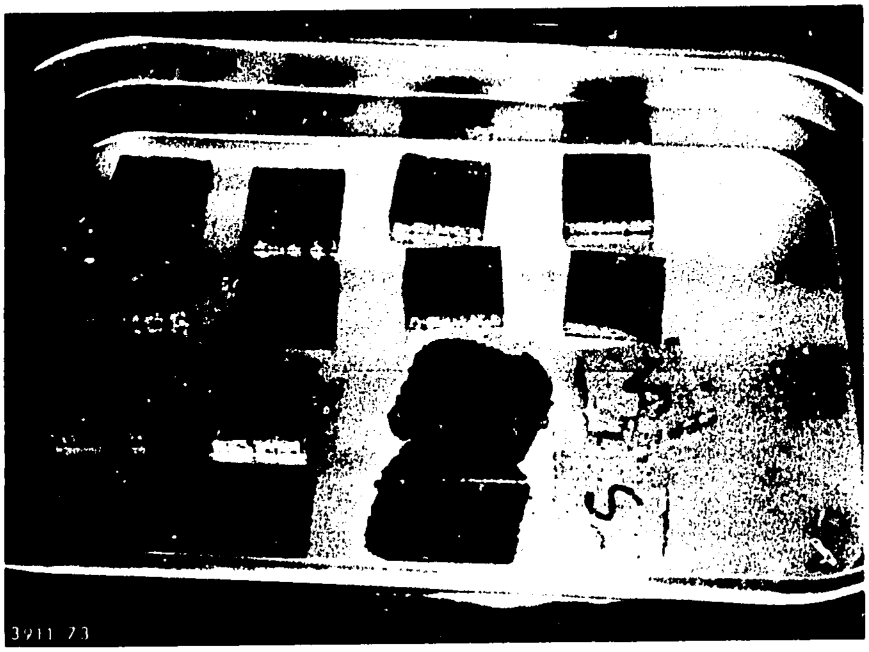
The toughening of a clay composition is the most significant characteristic of this Category IV product, since it allows panels shown in Figure 40 prepared by this process to be shipped and handled with less risk of breakage. This is in contrast to fired-clay tiles, where only 80% of those manufactured usually survive to become a part of a roof.

Significant additional development of the Category IV materials will be required to better optimize strength, modulus, toughness, weight, resin content, and cost. The product is probably less desirable than those of either Categories I, II, or III, but the simplicity of the process and ingredients, render it viable where clay is readily available.

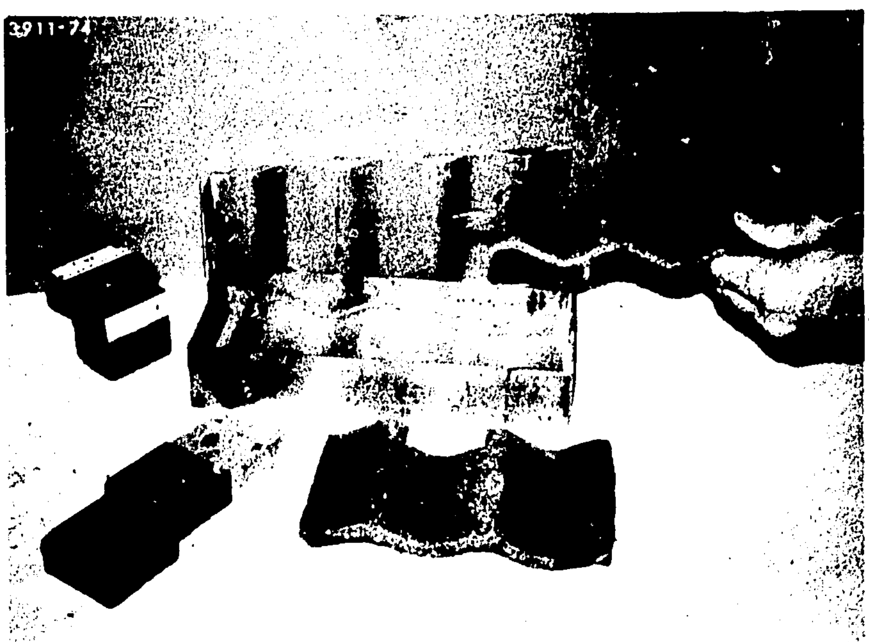
4.2.4 Analysis of Cost and Practicality

The cost of the four candidate systems was estimated to illustrate their viability. Costs were not discussed in the previous section with the performance of materials, but this was always a factor in the selection of the various ingredients and processes.

It had been expected that ingredient costs could be fairly well defined, while those for processing, administration, overhead,



(a) Immersed in water, samples in lower right are unbonded controls



(b) Corrugated bagasse reinforced panels

Figure 40. Category IV Clay Composites

profit, etc. would be more difficult to determine in the earlier development stages. However, the dynamic economic conditions of 1974-75 made even the specification of ingredient costs difficult.

It was necessary that some sort of criteria or reference from which to judge the economic viability of the various candidate systems be set up. Corrugated galvanized iron (CGI) costs were used for this purpose. The cost of CGI was determined in 1974 to be 25¢/sq ft, later ranging up to 32¢/sq ft. Thus, initially, a product cost of from 25¢ to 32¢ per square foot was considered to be required to be competitive. Because of foreign currency demands, and limited availability of CGI, the actual selling price for CGI and other imported roofing will frequently be much higher than these world market prices.

Since only ingredient costs could be determined for the experimental systems, those for CGI were extracted from the selling price by dividing the latter by three. This multiplication factor of three was assumed to adequately reflect the cost of manufacturing, distribution, marketing, profit, etc. This mark up is a debatable number that could range as high as 6 and as low as 2. However, on this basis, the materials cost for CGI was assumed to be in the range of 8-11¢ per square foot. Production with labor intensive processes and very low cost labor are required to achieve the mark up of 2.

The ingredient costs for the four candidate systems are shown in Table 40. All categories of materials nearly met the designated cost criteria of 11¢ per square foot or less, although Category IA and IV materials were slightly high. Category IB is useful in the Philippines where natural rubber is available at about 17¢/lb and is indigenous.

Table 40

MATERIALS COST FOR THE FOUR CANDIDATE SYSTEMS[a]

	Ingredient[b] Cost $/lb	Component Cost, $/lb of Product for Categories[c] IA	IB	II	III	IV
SAN Binder	0.05	(27) 0.135	--	--	--	--
Natural Rubber	0.20	--	(20.5) 0.041	--	--	--
Phenolic Binder	0.35	--	--	(30) 0.105	(3) 0.01	(18) 0.063
Bagasse						
Whole	0.014	(63) 0.009	(54) 0.007	--	--	--
Chopped	0.02	--	--	(62) 0.012	--	(8) 0.002
Depith-Defib.	0.03	--	--	--	(94) 0.028	--
Sieved Ground Clay	0.001	(5) 0.001	--	(2) 0.001	--	(70) 0.0007
Iron Oxide Pigment	0.5	(5) 0.025	(5.6) 0.028	(3) 0.015	--	(4) 0.016
Sulfur	0.02	--	(8.2) 0.0016	--	--	--
Oil	0.15	--	(7.4) 0.011	(3) 0.005	--	--
Wax Emulsion	0.15	--	--	--	(3) 0.005	--
Additives	0.80	--	(4.3) 0.034	--	--	--
TOTAL, $/lb		0.170	0.123	0.138	0.043[f]	0.082
$/sq. ft.[d]		0.114	0.083	0.097	0.031[f]	0.123
Processing Factor[e]		3.1	3.3	2.8	6.0	2.6

(a) Includes only cost of ingredients in volume (1974-1975). Cost of processing of ingredients or combination, handling, overheads, etc not included.
(b) Best estimate of material cost in participating countries, includes shipping and taxes to port of entry. Significant variations exist. Price for natural rubber is from Philippines, cost is $0.40 in Jamaica. Bagasse based on fuel value is 0.014 $/lb, higher costs reflect losses due only to partial use of whole bagasse and not processing.
(c) Component cost = cost/lb x wt % shown in parenthesis (--).
(d) Based on panel thickness of 0.1 inch for Categories I, II and II and 0.15 inch for IV. Aerial densities of products are correspondingly (in. lb/ sq ft) are: IA-0.67, IB-0.68, II-0.7, III-0.7, IV-1.5.
(e) Range 2 to 6, qualitatively estimated based on expected scale-up of laboratory process. PFX material cost equals sales price.
(f) Is not waterproof in this form. Added binder or coating may double cost.

The Category III material exhibited the most outstanding cost picture. In its present form, the Category III material is not completely stabilized against water, so additional binder or coatings must be utilized. This could double the cost of materials, but the economics would still be highly attractive.

The cost of materials shown is the total cost, including the price of indigenous materials. Accordingly, import requirements would be slightly lower. The indigenous material cost is so low that it has little effect on the price of the material. Importantly, over 55% of each of the products on a weight basis is indigenous. Thus, except for capital needs, these figures represent the total import requirements. They are 1/2 to 1/3 of the estimated 20-30¢ per square foot import costs for CGI.

Natural rubber, polystyrene, PVC and phenol/formaldehyde (P/F) resins are all available or manufactured in the Philippines, thus they should be considered "indigenous". Natural rubber is available and P/F manufacture is planned for Ghana. In Jamaica only P/F resin can be manufactured locally. In these cases, the foreign components of cost would be minimal.

Processing factors were determined qualitatively based on the nature of the expected scale-up of the laboratory processes including its capital, energy, material, time, and man-power requirements. This processing factor, when multiplied by the material cost per square foot, should give the sales price. It is emphasized that these estimates are highly speculative and should be used only in a very general manner until values are verified.

The processing factors determined for the five types of materials are also shown in Table 40. These reflect, respectively, a typical thermoplastic processing condition for the products in

Category IA; a similar situation in Category IB except that forming is probably done in batch; the simple blending technique of Category II materials; the high degree of fiber processing, the large use of water and energy, and the batch nature for Category III materials,; and finally the very simple blending technique for Category IV materials. Multiplying these processing factors by the cost per square foot provides corresponding projected sales prices of 35, 27, 27, 19 and 32¢ per square foot. Rating of the four categories of materials, based on cost results in Category III being number 1, Category II and IB number 2, and Category IV and IA number 3.

The larger the operation, the more the Category IA processing factor could be reduced, but even limited processing requires significant capital. Even though the Category III material requires capital equipment, it can be sized to the desired scale. This makes it attractive for either small rural village or large scale industries.

A more quantitative and detailed analysis of costs, especially processing, will be conducted in Phase III. The above information is only tentative and was used to guide the developmental work. The viability of any of the four systems will also depend on the existence of the required processing equipment in the participating countries or the ease with which it could be installed there. Fortunately, technology for working with thermoplastic, thermosetting, and rubber binder systems exists in all of the participating countries; and a degree of large scale processing facilities also exist.

4.2.5 Detailed Experimental Results in Tabular Form

The most significant results indicating the rationale for the selection of the various binders and fillers and the four most promising candidate systems were discussed in the previous three sections. Considerable additional work was done to provide background and support for the conclusions made. That information has been tabulated and is presented here without discussion; the titles of the tabulations indicate the rationale behind the data presented. (See Tables 41 through 57).

The nature of the screening process required that other approaches be investigated during Phase II. These approaches, which appeared less promising and therefore were not pursued to the extent of four primary categories, are also indicated through tabular results. These tables (58 through 64) show the extensive, but less promising, data accumulated in attempts to bond clay with polyelectrolytes, jute with polyester, various natural fibers with bead polystyrene foam, and clay with water glass. The data obtained during examination of the *in situ* generation of the phenol/formaldehyde resin in bagasse is also illustrated. This may be of value in further reducing phenolic binder costs in the future.

Table #1

EFFECT OF AGRICULTURAL FILLERS ON THE MECHANICAL PROPERTIES AND DURABILITY OF POLYSTYRENE PANELS

Sample ID MRC	Prime Filler[a,b] Type	Prime Filler[a,b] Origin	Secondary Filler[c] Type	Secondary Filler[c] Amt (phr)	Initial Flexural Strength (psi)	Tensile Strength (psi): Initial at no Exposure	Tensile Strength (psi): After 300 Hr Weatherometer Exposure	Tensile Strength (psi): After 1000 Hr Weatherometer Exposure	After 1000 Hr[d] Percent Retention
168833-9	Bagasse	USA	ZrO_2	5	5750	3000	2000	700	23.4
168833-3	Sawdust	USA	ZrO_2	5	6600	3700	2800	1400	37.8
168854-2	Coconut Husk	Jamaica	ZrO_2	5	5200	3050	1800	250	8.2
168832-3	Rice Straw	Philippines	ZrO_2 PE	5 3	4000	2550	900	50	2.0
168833-5	Excelsior	Ghana	PE ZrO_2	1 5	4350	2800	1700	100	3.6
168832-8	Balsa Wood	USA	ZrO_2	5	3550	1900	1200	500	26.3
168849-1	Palm Frond	Jamaica	ZrO_2	5	4650	2050	627	500	24.4
168833-1	Wood Shavings	Ghana	ZrO_2	5	5250	3100	1000	50	1.6
168833-9	Bagasse	USA	Fe2O3 ZrO2	12 4	7400	4400	4000	1700	38.6
168831-16	None	-	-	-	6350	3400	1800	000	29.4

(a) Binder is Lustrex HF-77, 30% by weight, processed by melt compounding in Banbury.
(b) 7 by weight of composition (ca. 70% by volume).
(c) Stabilizing or processing aids; ZrO - Zirconium Dioxide,
PE - polyethylene powder, Fe2O3 Mapico #477 Iron Oxide pigment.

(d) Percent Tensile Strength Retention = $\frac{\text{Final Strength}}{\text{Initial Strength}}$ x 100.

Table 42

EFFECT OF BINDER TYPE ON THE MECHANICAL PROPERTIES AND DURABILITY OF BAGASSE-REINFORCED COMPOSITES

Sample ID MRC-DA	Binder Type[a]	Secondary Filler Type	Secondary Filler Amount phr	Initial Flexural Strength (psi)	Tensile Strength (psi) After Hours Exposed in Weatherometer 0	300	1000	Percent Tensile Retention[b] After 1000 hr Exposure
168339-5	Polystyrene (Lustrex HF-77)	Mapico 477 iron oxide Zirconium dioxide (ZrO_2) Zinc stearate (Z S)	12 4 1	4950	2700	2700	1900	70.3
168339-1	Polystyrene (Lustrex HF-77)	477 iron oxide ZrO_2	12 4	5450	2900	3000	1800	36.8
168333-9	Polystyrene (Lustrex HF-77)	ZrO_2	5	5750	3000	2000	700	23.3
168333-8	Polystyrene (Lustrex HF-77)	477 iron oxide ZrO_2	12 4	7400	4400	4000	1700	38.6
168333-13	Low Density Polyethylene (Tenite)	ZrO_2	5	1250	750	800	50	6.6
168333-14	High Density Polyethylene	ZrO_2	5	3250	1550	1300	50	3.2
168339-2	SAN (Lustran LNA-21)	477 iron oxide ZrO_2	12 4	6400	3700	2800	3250	87.8
168339-3	SAN (Lustran LNA-21)	477 iron oxide ZrO_2 Z S	12 4 1	6400	4000	3900	3900	97.5
168339-4	SAN (Lustran LNA-21)	477 iron oxide	16	5800	3550	4700	3600	--

(a) Binder 30% by weight, whole bagasse 70% by weight (dry basis)

(b) $\text{Percent Tensile Strength Retention} = \frac{\text{Final Strength After Exposure}}{\text{Initial Strength}} \times 100$

Table 43

EFFECT OF FILLER TO BINDER RATIO ON
WEATHERING PROPERTIES OF BAGASSE - POLYSTYRENE COMPOSITES

Sample ID MRC-DA	Composition: Polystyrene[a] (%)	Composition: Bagasse[b] (%)	Composition: Additives[c] (phr)	Initial Flexural Strength (psi)	Tensile Strength (psi), After Weatherometer Exposure (hrs): None	300	1000
168831-16	100	0	0	6350	3400	1800	1000
168832-6	100	0	ZrO_2 5 PE 0.5	5800	3050	2000	1500
168831-13	100		ZrO_2 5	4200	2400	1300	950
168831-1	50	50	TiO_2 5	3750	2350	1900	900
168833-9	30	70	ZrO_2 5	5750	3000	2000	700
168831-11	25	75	ZrO_2 1	5650	3400	3100	1650
168831-14	25	75	ZrO_2 5 ZnSt 5	3050	1700	900	--

(a) Lustrex HF-77 (Source: Monsanto)

(b) Whole at ∿20% moisture content; percent shown is on dry basis

(c) ZrO_2 = Zirconium dioxide, ZnSt = Zinc Stearate, phr = parts hundred resin
PE = low density polyethylene powder, TiO_2 = Titanium dioxide

Table 44

EFFECT OF RESIN AND CLAY CONTENT ON FLEXURAL PROPERTIES OF ABS-BONDED BAGASSE PANELS

Sample ID MRC-DA	Composition by Weight Percent				Composition by Volume Percent				Flexural	
	ABS[a]	Whole Bagasse	Iron Oxide[b]	Clay[c]	ABS[a]	Whole Bagasse	Iron Oxide[b]	Clay[c]	Strength psi	Modulus 10^3 psi
184101-1	26.7	63.2	5.2	4.9	35.0	60.3	1.4	3.3	5640	5500
184101-2	31.1	59.3	5.0	4.6	40.0	55.9	[illegible]	[illegible]	6500	4650
184101-3	40.3	51.4	4.3	4.0	50.0	46.[illegible]	1.1	2.5	6500	5250
168898-5	21.5	54.2	5.3	19.0	30.0	55.0	1.5	13.5	5400	6600
168899-1	22.0	60.4	5.4	12.2	30.0	60.0	1.5	8.5	5000	5800
168899-2	22.5	66.9	5.5	5.1	30.0	65.0	1.5	3.5	6000	6200
168899-3	22.8	71.6	5.6	-	30.0	68.5	1.5	-	6150	5800

(a) LNI-780 Acrylonitrile Butadiene Styrene, Monsanto Co.
Processing by melt compounding in Banbury

(b) Mapico #477 red pigment, Cities Service Co.

(c) Bedford Shale, Columbus, Ohio

Table 45

DURABILITY OF MELT-COMPOUNDED SAN BONDED COMPOSITES

Sample ID MRC	Prime Filler	Processing and Functional Additives Type	Additives Amt (phr)	Tensile Properties After Exposure in Weatherometer: Initial Strength (psi)	Initial Modulus (10^3 psi)	324 hours Strength (psi)	324 hours Modulus (10^3 psi)	1017 hours Strength (psi)	1017 hours Modulus (10^3 psi)	2766 hours Strength (psi)	2766 hours (10^3 psi)
168874-2[a]	Hemp (Philippines)	Mapico 477 iron oxide (Cities Service)	12	2660	1160	1460	460	450	44	40	12[e]
168878-2[a]	Hemp (Philippines)	Mapico 477 iron oxide Sundex Oil 790 (Sun Oil)	10 30	1750	-	815	202	75	-	20	23[e]
168887[a]	Depithed Bagasse (Jamaica)	Mapico 477 iron oxide	10	2950	1130	27[illegible]0[c]	720[c]	1850	1 660	35[d]	- [e]
168878-1[a]	Whole Bagasse (Jamaica)	Mapico 477 iron oxide Sundex Oil 790	10 30	3450	815	2410	590	1400	570	210	152[e]
168873[b]	Whole Bagasse (Jamaica)	Mapico 477 iron oxide	12	3600	1150	3400	890	3400	660	1550	480[f]

(a) Based on Monsanto's LNA-21, a SAN resin; 25 wt %.
(b) Based on Monsanto's P-100, HC-20, a SAN resin at 25 wt %.
(c) 363 instead of 324 hours.
(d) 2,630 instead of 2,766 hours
(e) Severe cracking and chalking noted.
(f) Surface crazing and slight chalking noted.

Table 46

COMPARISON OF THE DURABILITY OF SAN VERSUS ABS BINDERS WITH BAGASSE FILLER

		Tensile Properties After Exposure in Weatherometer							
		Initial		298 hrs		1065 hrs		3592 hrs	
Sample ID MRC-DA	Binder	Strength (psi)	Modulus (10^3 psi)	Strength (psi)	Modulus (10^3 psi)	Strength (psi)	Modulus (10^3 psi)	Strength (psi)	Modulus (10^3 psi)
168831-10	SAN[(a)]	4000	800	3830	1000	3200	800	780[(c)]	950
168831-12	ABS[(b)]	4600	975	4550	910	4200	815	700[(c)]	340

(a) Lustran LNA-21 (Monsanto), 25 wt %, 1.9% Zirconium Dioxide

(b) Lustran LNI-780 (Monsanto), 25 wt %, 1.9% Zirconium Dioxide

(c) Surface and internal crazing with some swelling after 3592 hours exposure in Weatherometer

Table 47

EFFECT OF PIGMENTARY STABILIZER(S) ON A SAN-BONDED BAGASSE COMPOSITE

Sample ID MRC-DA	Pigmentary Stabilizers[a]	Amt (phr)	Initial Strength (psi)	Initial Modulus (10^3 psi)	308 Hours Strength (psi)	308 Hours Modulus (10^3 psi)	1010 Hours Strength (psi)	1010 Hours Modulus (10^3 psi)	3496[b] Hours Strength (psi)	3496[b] Hours Modulus (10^3 psi)
			Tensile Properties After Exposure in Weatherometer							
168839-4	Mapico 477 iron oxide	20	3550	1000	4700	925	3600	980	4000	970
168839-2	Mapico 477 Zirconium Dioxide	16 4	3550	960	2800	920	3600	1000	3900	1000
168839-3	Mapico 477 Zirconium Dioxide Zinc Stearate	16 4 1	4000	970	3900	815	3900	665	1450	560

(a) Binder was Lustran LNA-21 (Monsanto), a S/AN resin at 30 weight %.
(b) All samples chalk with internal cracking after 3496 hours of exposure.

Table 48

PRELIMINARY HARD RUBBER COMPOSITIONS AND TEST DATA TO DETERMINE FEASIBILITY OF RUBBER AS A BONDING RESIN FOR BAGASSE

Sample Number MRC-DA	Composition, parts by weight[a] Natural Rubber	Sulfur	Whole Bagasse	Sundex 790 Oil	Iron Oxide #477	Zinc Oxide	Stearic Acid	A-100 Accelerator	Additives	Curing[e] Minutes	°F	Remarks	Flexural Strength (psi)	Initial Strength (psi)	Initial Modulus (10^3 psi)	330 hours exposure Strength (psi)	330 hours exposure Modulus (10^3 psi)	1000 hours exposure Strength (psi)	1000 hours exposure Modulus (10^3 psi)
168868-1	400 100	180 45	1392 348	348 87	50 12.5	-	-	6 1.5	-	7	350	Partial vulcanization; panel is flexible.	-	-	-	-	-	-	-
168868-2	544.8 100	244.8 45	1640 301	245.6 45	64.8 12	-	-	8.2 1.5	-	35	290	Panel extremely flexible.	-	-	-	-	-	-	-
168874-1	544.8 100	244.8 45	1640 301	245.6 45	64.8 12	5.5 1	5.5 1	8.2 1.5	-	60	325	Rigid panel	30	3050	-	2240	-	2940	-
168875	227 100	227 100	1816 800	272 119.8	55 24.5	4.5 2	4.5 2	6.8 3.0	- -	45	325	Good surface characteristics, but brittle and breaks easy.	2840	1520	-	1410	-	1370	-
168876	-	408	1634	245	50	4	4	6.1	-	30	325	No strength and poor flow	-	-	-	-	-	-	-
168877	200 100	90 45	2000 1000	240 120	50 25	4 2	4 2	6 3.0	200[b] 100	45	325	Good flow and look; slightly flexible.	1400	1080	210	1180	200	996	266
168879A	250 100	125 50	1816 726.4		55 22	2.5 1	2.5 1	3.8 1.5	5[c] 2	45	325	-	-	1430	220	1730	-	1670	310
168879B	250 100	125 50	1816 726.4		55 22	2.5 1	2.5 1	3.8 1.5	5[c] 2	15/60	225/ 325	-	-	1570	235	1820	-	1840	314
16884	430 100	220 45	1476 301.7		58 11.3	5 1	5 1	7.5 1.53	[illegible][d] 75	45	325	-	3960	1640	-	1900	273	-	-

LEGEND:

(a) Upper number in formula - actual charge in grams.
Lower number in formula - based on parts hundred rubber.
Raw Material Manufacturer:
Natural rubber, MR-5 (Malaysian origin) - Firestone
Sundex 790 Oil - Sun Oil
Mapico #477 iron oxide - Cities Service
Flectol H and A-100 Accelerator - Monsanto

(b) Asphalt
(c) Flectol H stabilizer
(d) Rubber dust
(e) Pressure 600 psi

Table 49

FLEXURAL STRENGTH AND MODULUS OF VULCANIZED RUBBER BAGASSE COMPOSITE AS A FUNCTION OF SULFUR CONTENT

Sample ID MRC-DA	Composition (a) By Weight Percent					Composition (a) By Volume					Flexural Strength (psi)	Deflection At Break (inch)
	Natural Rubber (b)	Sulfur	Sundex 790 Oil (c)	Bagasse (d)	Iron Oxide #477 (e)	Natural Rubber (b)	Sulfur	Sundex 790 Oil (c)	Bagasse (d)	Iron Oxide #477 (e)		
184102-5	18.2	3.5	4.0	71.9	2.4	25.0	2.2	5.0	65.0	0.6	1700	0.29
184102-4	18.8	4.4	0.0	74.3	2.5	25.0	2.7	0.0	65.0	0.6	2900	0.14
184102-3	18.1	4.2	3.9	71.4	2.4	25.0	2.7	5.0	65.0	0.6	2500	0.22
184102-1	18.0	8.3	7.8	63.6	2.3	25.0	5.3	10.0	58.0	0.6	5000	0.10
184102-2	24.0	8.5	7.3	58.0	2.2	30.0	5.4	8.5	49.0	0.5	7000	0.20

(a) Stearic acid 1 part per hundred rubber (phr), and A-100 accelerator (Monsanto) 1.5 phr used in all compositions. Panels pressed at 325°F for 60 minutes under 615 psi pressure. Processed in Banbury.

(b) MR-5 of Malysian origin (Source: Firestone Rubber and Chemical Company).

(c) Aromatic petroleum oil from Sun Oil.

(d) Whole and dried

(e) Source: Cities service

Table 50

EFFECT OF CURE TIME ON DEVELOPMENT OF FLEXURAL STRENGTH IN A RUBBER COMPOSITE

Sample ID MRC-DA	Curing Time[a,b] (min)	Flexural Strength (psi)	Deflection at Break (inch)
184104-1	15	1750	0.4
184104-2	30	2700	0.3
184104-3	30 (presheeted & under no pressure)	1200	0.4
184104-4	60	1400	0.4

(a) Hard Rubber Formulation:

Ingredient	Weight Percent	Volume Percent	Parts Hundred Rubber
MR-5 Natural Rubber (Firestone)	17.7	25.0	100
Sulfur	4.2	2.7	24
Sundex Oil 790 (Sun Oil)	7.7	10.0	44
Whole Dried Bagasse	64.6	60.8	365
Mapico 477 Iron Oxide (Cities Service)	5.8	1.5	33
Stearic Acid			1
A-100 Accelerator (Monsanto)			1.5
	100.0	100.0	

(b) Panels vulcanized at 325°C under 615 psi

Table 51

EFFECT OF CURE TIME AND FILLER TYPE ON DEVELOPMENT OF HARDNESS IN A RUBBER FORMULATION

	Bagasse Composite[a,b]			Sawdust Composite[a,b]		
Curing Time (min)	Shore Hardness	Color of Sample[c]	Remarks	Shore Hardness	Color of Sample[c]	Remarks
15	40	3	flexible	52	3	flexible
30	52	5	flexible	63	5	flexible
45	53	7	hard	81	7	hard
60	109	9	hard	110	8	hard
75	106	10	hard	116	9	hard
90	106	10	hard	118	10	hard

(a) Hard Rubber Formulation:

Ingredient	Percent	Parts Hundred Rubber
MR-5 Natural Rubber	20.0	100.0
Sulfur	9.0	45.0
Sawdust or whole bagasse	58.5	292.5
Sundex Oil 790	9.0	45.0
Mapico 477 iron oxide	1.4	12.0
Zinc Oxide	0.2	1.0
Stearic Acid	0.2	1.0
A-100 Accelerator	0.3	1.5
Flectol H	0.4	2.0

(b) Curing Conditions: Prepress test samples cold and cure at 350°F in an oven under ambient pressure.

(c) Color Rating 1-10; 1 = light red, 5 = dirty red, 10 = black.

References: MRC-DA 175463 and 175469.

Table 52

EFFECT OF CURING SCHEDULE ON ARTIFICIAL WEATHERING PROPERTIES OF A VULCANIZED NATURAL RUBBER-BAGASSE COMPOSITE

Sample[a] ID MRC-DA	Flexural Properties, Exposure in Weatherometer							
	Initial		331 Hours		1000 Hours		2440 Hours	
	Strength (psi)	Modulus (10^3 psi)	Strength (psi)	Modulus (10^3 psi)	Strength (psi)	Modulus (10^3 psi)	Strength (psi)	Modulus (10^3 psi)
168879-A[b]	1400	200	1730	-	1670	310	890	470
168879-B[c]	1550	235	1920	-	1840	314	400	143

(a) Hard Rubber Formulation:

Ingredient	Percent	Parts Hundred Rubber
Natural Rubber MR-5	11.1	100
Whole Bagasse	80.4	726.4
	2.4	22
Zinc Oxide	0.1	1
Stearic Acid	0.1	1
Flectol H Stabilizer	0.2	2
A-100 Accelerator	0.2	2
Sulfur	5.5	
	100.0	

(b) Panel pressed at 325°F for 45 min. under 615 psi pressure.
(c) Panel pressed at 225°F for 15 min. followed by 60 min. at 325°F both under 615 psi pressure.

Table 53

EFFECT OF FIBER ORIENTATION AND WATER IMMERSION ON PROPERTIES OF PHENOLIC BONDED DEFIBRILLATED BAGASSE COMPOSITES

Sample ID MRC-DA	Composite Composition: Resin[a] (%)	Composite Composition: Bagasse Type[c]	Composite Composition: Bagasse Weight (%)	Composite Composition: Montan Wax (%)	Process[d]	Orientation[e]	Flexural[f] Strength Dry (psi)	Flexural[f] Strength Wet (psi)	Flexural[f] Strength W/D (psi)	Flexural[f] Modulus, 10^3 Dry (psi)	Flexural[f] Modulus, 10^3 Wet (psi)	Flexural[f] Modulus, 10^3 W/D (psi)	Tensile[f] Strength Dry (psi)	Tensile[f] Strength Wet (psi)	Tensile[f] Strength W/D (psi)	Tensile[f] Modulus, 10^3 Dry (psi)	Tensile[f] Modulus, 10^3 Wet (psi)	Tensile[f] Modulus, 10^3 W/D (psi)	Water Pickup (%)
184129-6	0.0	UCW	100	-	We	*	2500	Fa	Fa	402	-	-	690	Fa	Fa	1030	-	-	Fa
184129-5	0.0	ScDp	100	-	We	*	1500	Fa	Fa	254	-	-	810	Fa	Fa	1040	-	-	Fa
184129-4	10.0	UCW	90	-	We	*	3700	1400	3400	498	193	460	1520	540	1200	610	140	300	40.0
184129-3	10.0	UCDp	90	-	We	*	3400	850	2400	460	130	300	850	260	470	310	82	560	44.0
184129-2	10.0	SCDp	90	-	We	*	3000	2000	2300	510	250	380	2130	540	1400	710	230	1000	37.0
184129-1	10.0	SCDp	90	-	We	*	2600	1000	3500	430	160	590	1700	710	1400	630	340	540	40.0
184123	10.0[b]	Dp	87.5	2.5[g]	CO	=	4700	1990	5600	600	330	320	5410	1700	3050	910	290	910	33.0
184123	10.0[b]	Dp	87.5	2.5	CO	⊥	1740	520	2020	250	95	170	1130	510	890	365	100	430	34.0

(a) Monsanto PF-588 liquid phenolic resin.
(b) R-7248 (Rheichhold Chemicals) phenolic resin substituted for PF-588 (Monsanto).
(c) Bagasse and process type identification:
    UCW - unscreened, chopped, dry, mechanically whole bagasse.
    SC - sieve cut between 10 and 32 mesh of UCW.
    UCDp - Unscreened, chopped, depithed by 2% NaOH solution and wash.
    SCDp - Screen of 10-32 mesh, mechanically chop, caustic 2% NaOH depith and wash.
    (Dp) - Screening type depithing.
(d) CO - Centrifugally oriented.
    We - Wet process during molding.
(e) * - Random fiber orientation.
    = - Properties measured parallel to the fiber orientation.
    ⊥ - Properties measured perpendicular to the fiber orientation.
(f) Wet - represents total immersion in water for 72 hours.
    W/D - Wet/Dry - represents total immersion in water for 72 hours, followed by 24 hours drying under ambient conditions.
    Fa - represents falls apart - meaning no integrity.
(g) Montan (ester type wax) and paraffin wax in a 3:1 ratio; M.P. 69°C.

Table 54

STRENGTH AND DURABILITY OF CHEMICALLY DEPITHED BAGASSE FIBERS WITH PHENOLIC RESIN

Sample ID MRC-DA	Composition[a] Bagasse[b] Fiber (Wt %)	Phenolic[c] Binder (Wt %)	Wax[d] (Wt %)	Tensile Strength (psi)	Tensile Modulus (psi, 10^3)	Water[e] Absorption	Flexural Test Data in psi: Dry Panels Strength (psi)	Dry Panels Modulus (psi, 10^3)	Soaked Panels[f] Strength (psi)	Soaked Panels[f] Modulus (psi, 10^3)	Wet/Dry Panels[g] Strength (psi)	Wet/Dry Panels[g] Modulus, (psi, 10^3)
175482-1	90.0	10.0	-	1170	481	24.0	2500	312	1230	113	1800	218
175482-2	85.0	10.0	5.0	1630	992	19.0	5150	489	3680	229	5610	423
175482-3	90.0	5.0	5.0	2040	654	16.0	5820	517	4280	285	5100	492
175482-4	92.5	5.0	2.5	2690	851	17.0	6990	629	3140	286	5400	536

(a) Molding and Curing Conditions: Cured for 20 minutes under pressure at 350°F.
(b) Fiber prepared by soaking whole bagasse with 2% sodium hydroxide and 800% water for 2 hours, wet blending, washing three times with water, and finally drying in a circulating oven, i.e, pith removed.
(c) PF-588 liquid phenolic resin, Monsanto.
(d) Cascowax E402 EW Emulsion, Borden.
(e) Following immersion in water for 24 hours.
(f) Soaking Time = 24 hours immersion in water.
(g) Wet/Dry Specimens dried in air for 24 hours after 24 hours immersion in water.

Table 55

QUALITATIVE EVALUATION OF BONDING CLAY WITH PHENOL/FORMALDEHYDE EMULSION

Sample ID MRC-DA	P/F Binder[(a)] (Wt.%)	Color of the Finished Composite	Sample Rating[(c)] Initial	After Six Days of Total Immersion in Water
175472-1	5.0	beige	8	7
175472-2	7.5	beige	9	8
175472-3	10.0	light brown	10	9
175472-4	15.0	dark brown	10	10
175472-5	20.0	dark brown	10	10
175472-6	5.0[(b)]	beige	8	7
175472-7	10.0[(b)]	beige	8	8
175472-8	0.0	reddish ash	2	1

(a) Resinox RI-2279 phenol/formaldehyde resin (weight based on solids) as binder for clay. Clay: Dried, ground and sieved to 8 mesh size (Source: Claycraft Co., Columbus, Ohio Clay-emulsion compounded and processed through a mini-extruder to give 1" x 1" tablets. Tablets were cured at 125°C for 60 minutes prior to rating and testing.

(b) Resinox RI-4031, a developmental phenol/formaldehyde emulsion of Monsanto

(c) Rating Scale = 1-10; 10 = excellent, 7 = very good, 5 = good, 1 = poor. Rating based on qualitative measures of density, scratch resistance, impact resistance, and surface characteristics.

Table 56

STRENGTH AND DURABILITY OF PHENOLIC BONDED CLAY AS A FUNCTION OF BINDER CONTENT

Sample ID MRC-DA	Sample Composition[a] Clay[b]	Binder[c]	Wax[d]	Flexural[e] Strength (psi)	Flexural[e] Modulus (10^3 psi)	Initial Compressive Strength (psi)	Initial Compressive Modulus (10^3 psi)	Compressive After 24 Hour Soak[f] Strength (psi)	Compressive After 24 Hour Soak[f] Modulus (10^3 psi)	Compressive[g], Dried Strength (psi)	Compressive[g], Dried Modulus (10^3 psi)	Water[f] Pickup (%)
175477-1	97.5	2.5	0.0	2160	1170	3960	53	470	-	1400	26	15.0
175477-2	95.0	5.0	0.0	1980	847	6300	76	1800	40	3340	53	11.0
175477-3	92.7	7.5	0.0	2020	1040	8030	78	2260	45	2680	47	8.9
175477-4	90.0	10.0	0.0	2080	1007	6000	69	1860	34	2300	34	9.3
175477-5	92.5	5.0	2.5	1310	715	5140	62	1470	32	3560	47	4.2
175477-6	85.0	5.0	10.0[h]	1220	398	compacts	21	compacts		compacts	25	5.4

(a) Percent solids on weight basis; sample cured at 125°C for 60 minutes.
(b) Dried, ground and sieved to 8 mesh size (Source: Claycraft Company, Columbus, Ohio).
(c) Product of Monsanto Polymers and Petrochemical Company - PF-2279 phenolic emulsion.
(d) Product of Broden Company - Cascowax emulsion E402 EW.
(e) Flexural test specimen size 3/8 in. x 1-1/2 in. x 5 in.
(f) Property measured on wet specimen after 24 hour total immersion in water.
(g) Property measured on dried specimen after 24 hour total immersion in water followed by 24 hour drying.
(h) Whole chopped bagasse used in place of wax.

Table 57

WATER RESISTANCE OF PHENOLIC BONDED CLAY COMPOSITES[(a)]

Days Sample Immersed in Water	Wet Properties[(b)]			Dry Properties[(c)]		
	Water Absorption (%)	Compressive Strength (psi)	Compressive Modulus (psi, 10^3)	Water Retention (%)	Compressive Strength (psi)	Compressive Modulus (psi, 10^3)
0	0.0	4070	65	-	-	-
1	8.0	2220	47	0.5	4810	66
2	9.3	2360	51	0.5	4240	69
3	9.5	2330	45	1.5	4980	62
4	10.0	1850	46	1.3	3300	60
5	9.0	1910	45	0.0	3880	59
6	9.9	2100	47	0.9	4200	58

(a) 5% by weight Resinox RI-2279 (Source: Monsanto) binder with clay: dried, ground and sieved to 8 mesh size (Source: Claycraft Company, Columbus, Ohio), MRC-DA 175486

(b) Properties measured on wet specimen following immersion time in the table.

(c) Properties measured on dry specimen soaked in water for the time shown, followed by 72 hour drying in air.

Table 58

STRENGTH OF POLYELECTROLYTE BONDED CLAY COMPOSITES - INITIAL EVALUATION

Sample ID MRC-DA	Composition[a], Percent Weight						Compressive	
	Clay[b]	Binder[c]	Calcium Oxide	Sand	Other	Wax[f]	Strength (psi)	Modulus (10^3 psi)
175424-10	98.5	1.0[d]	0.5	-	-	-	2500	58
175424-15-2	85.0	5.0	-	-	10.0 (slag)	-	3100	67
175426-16	64.9	5.0	0.1	30.0	-	-	2850	96
175426-24	98.9	1.0	0.1	-	-	-	2840	-
175426-25	89.9	10.0	0.1	-	-	-	3360	67
175427-30	90.0	10.0[e]	-	-	-	-	1950	22
175427-31	95.0	5.0[e]	-	-	-	-	2000	21
175427-34	60.0	10.0[e]	-	20.0	10.0 (Rice Husk)	-	2800	52
175427-37	88.0	2.0[e]	-	-	10.0 (Bagasse)	-	3600	44
175427-39	82.5	1.0	0.5	15.0	1.0 (Abaca)	-	5600	62
175430-40	87.0	2.0	0.5	10.0	0.5 (Jute Fiber)	-	4000	38
175436-1	95.5	1.0	-	-	1.5 (Abaca)	2.0	4,100	68

(a) Amount of coloring pigment and processing water are not indicated in the formulation.
(b) Origin: Miami Valley; sample dried, ground and sieved to 4-8 mesh size.
(c) Lytron 898 used as a solution, in water, at 20% concentration. Lytron 898 is a product of Monsanto Company.
(d) Lytron 897 (Source: Monsanto Company) used instead of Lytron 898 at 20% concentration.
(e) Hydrolyzed polyacrylonitrile used instead of Lytron 898 at 5% concentration in water.
(f) Montan:Paraffin: 75:25 - M.P. 69°C; Montan is an ester-type wax.

Table 59

STRENGTH AND DURABILITY OF POLYELECTROLYTE AND WATER GLASS BONDED CLAY COMPOSITES - INTERMEDIATE EVALUATION

Sample ID MRC-DA	Composition, Percent Weight[a]					Initial Flexural[e]		Compressive					
								Initial		Wet[f]		Wet/Dry[g]	
	Clay[b]	Poly-electrolyte[c]	Sodium Silicate	Wax[d]	Calcium Oxide	Strength (psi)	Modulus (psi, 10^3)	Strength (psi)	Modulus (psi, 10^3)	Strength (psi)	Modulus (psi, 10^3)	Strength (psi)	Modulus (psi, 10^3)
184113-1	94.6	0.25	-	5.15		825	870	2180	36	79	-	2180	26
184113-2	99.7	0.30	-	-		531	726	2320	28	------ fell apart -----			
184113-3	92.5	-	-	7.5		976	984	2600	42	1070	23	2130	38
184113-4	94.6	0.25[h]	-	5.15		908	848	2080	42	582	11	793	18
184113-5	99.9	0.10	-	-		306	508	1610	23	------ fell apart -----			
184113-6	92.0	0.30	-	7.7		1044	1100	2180	42	370	7	1970	39
184113-7	99.6	0.30	-	-		452	662	2120	34	------ fell apart -----			
184113-8	94.6	0.25	-	5.15		920	939	2700	40	265	-	1180	21
184113-9	75.0	-	20.0	5.0	5.0	85	—	1770	14	------ fell apart -----			
184113-10	87.5	-	10.0	2.5	2.5	216	421	2770	22	------ fell apart -----			
184113-11	94.6	0.25[i]		5.15		452	738	2160	33	412	-	2250	28
184113-12	97.0	0.30		2.7		921	793	2800	38	213	-	1520	25

(a) 3/8 in. x 1.5 in. x 15 in. bar pressed at 625 psi; heat condition at 70±2°C for 3 hours.
(b) Bedford shale dried, ground and sieved to 8 mesh (source: Claycraft Company).
(c) Used as 10% solution in water; Lytron 898 is a product of Monsanto.
(d) A mixture of montan, an ester type wax, and paraffin wax in 3 to 1 ratio; m.p. 69°C and 20 mesh size.
(e) Test specimen 3/8 in. x 1.5 in. x 5 in.
(f) Immersed in water for 24 hours and test run immediately on wet specimen.
(g) Immersed in water for 24 hours followed by drying in air for 24 hours.
(h) Lytron 810 (Monsanto), a styrene/maleic anhydride polymer used in the form of an ammonium salt at 10% solution in water.
(i) Ethylene-maleic anhydride (EMA 64K), a product of Monsanto used as a 10% solution in water.

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Table 60

DRY STRENGTH OF CLAY AND COPPER TAILING BONDED WITH A POLYELECTROLYTE OR LATEX

Sample Identification MRC-DA	Composition, Weight Percent								Compressive		Flexural	
	Clay[a]	Copper Tailing[b]	Poly-electro-lyte[c]	Fibrous Filler	Coloring Pigment	Cement	Latex	Wax Additive[d]	Strength (psi)	Modulus (10^3 psi)	Strength (psi)	Modulus (10^3 psi)
175444-18	-	81.0	1.0	15.0 (bagasse)	1.0	-	-	2.0	1740	-	144	28
175444-19	92.0	-	1.0	5.0 (bagasse)	1.0	-	-	1.0	2780	29	512	78
175444-20	92.0	-	1.0	5.0 (bagasse)	1.0	-	-	1.0	2430	35	461	35
175442-12	36.0	60.0	0.2	-	1.0	-	1.8 (Dow 460)	1.0	1240	43	46	37
175443-13	-	95.0	0.2	-	1.0	-	1.8 (Dow 460)	2.0	1670	46	122	55
175450-42	-	92.0	5.0	-	1.0	-	-	2.0 (zinc stearate)	1040	51	127	126
175451-43	97.0	-	1.0	-	1.0	-	-	1.0 (zinc stearate)	2570	92	463	284
175448-33	88.0	-	1.0	-	1.0	10.0	-	-	-	-	202	201
175449-35	88.0	-	1.0	-	1.0	10.0	-	-	2970	101	195	179
175440-2	-	90.0	2.0	8.0 (rice straw)	-	-	-	-	2480			
175441-6	98.0	-	0.2	-	-	-	1.8 (natural rubber)	-	1770	58	569	327
175441-7	-	98.0	0.2	-	-	-	1.8 (Dow 460)	-	3800	91	1050	263
175452-47	97.0	-	1.0	-	1.0	-	-	1.0 (calcium stearate)	3670	-	52[illegible]	405
175452-48	-	97.0	1.0	-	1.0	-	-	1.0 (calcium stearate)	2000	-	166	254

(a)Origin Miami Valley; sample dried, ground and sieved to 4-8 mesh size.
(b)From Zambia, Africa - powder size 40-80 mesh.
(c)Lytron 898 (Monsanto) exptessed as solid, and used in the form of a 5% solution in water.
(d)Montan: Paraffin:: 75:25 - M.P. 69°C. Others specified in parentheses.

Physicals of Latorex brick of Drästhold Products A/S.

Compressive Strength, psi	4,200
Elastic Modulus, psi	88,500
Flexural Strength, psi	743
Elastic Modulus, psi	337,000

Table 61

STRENGTH AND DURABILITY OF CLAY BONDED WITH CALCIUM SALT OF STYRENE/MALEIC ANHYDRIDE COPOLYMER

Formula and Test Data	Sample Number MRC-DA 175479-1	MRC-DA 175479-2	MRC-DA 175479-3
Formula (weight percent)[(a)]			
Clay	94.6	94.2	91.7
Lytron 810 (styrene/maleic anhydride copolymer of Monsanto)	2.5	2.5	5.0
Cascowax EW-402E (Borden)	2.5	2.5	2.5
Calcium oxide	0.4[(b)]	0.8[(c)]	0.8[(b)]
Flexural of Dry Sample			
Strength (psi)	519	391	482
Modulus (psi, 10^3)	471	325	420
Compressive Strength (psi)			
Dry	3300	3640	4460
Wet[(d)]	944	600	1100
Wet/Dry[(e)]	2120	2754	3060
Compressive Modulus (psi, 10^3)			
Dry	26.9	27.0	23.8
Wet[(d)]	8.9	6.1	8.2
Wet/Dry[(e)]	25.5	22.4	19.3

(a) All samples cured at 200°C for 60 minutes.

(b) Quantitative amount to make calcium salt of Lytron 810.

(c) 100 percent excess over stoichiometry for making calcium salt.

(d) Following immersion in water for 24 hours.

(e) Following drying for 24 hours after immersion in water for 24 hours.

WET PROCESS, *IN SITU* GENERATED RESIN BONDED BAGASSE PANELS

QUALITATIVE EVALUATION OF THE CONCEPT

Sample ID MRC-DA	Composition(a,b)		General Remarks Pertaining to Cooking, Panel Preparation, and Testing
167286-2	Bagasse	200 g	Liquor and bagasse separate after cooking. Panel pressed from dried composition.
	H_3PO_4	25 g	
	H_2O	1.5 l	
	Aniline	20 ml	
167287-1	Bagasse	200 g	Liquor and bagasse look separated after cooking.
	H_3PO_4	25 ml	
	Urea	25 g	
	H_2O	1.5 l	
	CaO	2 g	
167287-2	Bagasse	200 g	Pressed and cured panel swells in water and therefore no good.
	H_3PO_4	10 ml	
	H_2O	1.5 l	
	Melamine	20 g	
	CaO	12 g	
167287-3	Bagasse	200 g	Pressed and cured panel swells in water and therefore no good.
	H_3PO_4	10 ml	
	H_2O	1.5 l	
	Aniline	20 ml	
167288-1	Bagasse	200 g	Pressed and cured panel swells in water and therefore no good.
	H_3PO_4	10 ml	
	H_2O	1.5 l	
	Phenol	15 g	
	CaO	12 g	
167288-2	Bagasse	200 g	Partial resinification takes place.
	H_3PO_4	25 ml	
	H_2O	1.5 l	
	Melamine	20 g	
	CaO	25 g	
167288-3	Bagasse	200 g	Tensile strength of dry panel - 1000 psi.
	H_2SO_4	10 ml	
	H_2O	1.5 l	
	Melamine	20 g	
	CaO	10 g	
167289-1	Bagasse	200 g	Overnight reflux to achieve resinification
	H_2SO_4	10 ml	
	H_2O	1.5 l	
	Phenol	20 g	
	CaO	12 g	
167289-2	Bagasse	200 g	After six weeks immersion in water, this sample is rated better than 167289-1.
	H_2SO_4	10 ml	
	H_2O	1.5 l	
	Phenol	20 g	
	CaO	12 g	
167290-1	Bagasse (H_2O, 1.5l)	200 g	Monflex 4530 does not seem to contribute to properties.
	H_2SO_4	10 ml	
	Melamine	15 g	
	Monflex 4530	15 ml	
	CaO	12 g	

Sample No. MRC-DA	Composition(a,b)		General Remarks Pertaining to Cooking, Panel Preparation, and Testing
167790-2	Bagasse	200 g	Control sample without phenol or melamine; after 6 weeks immersion; this sample is highly swollen.
	H_2SO_4	10 ml	
	H_2O	1.5 l	
	CaO	12 g	
167291-1	Bagasse	200 g	Sample looks O.K. after 6 weeks immersion in water
	H_2SO_4	10 ml	
	H_2O	1.5 l	
	Monflex 4530	15 ml	
	Hexamethylene-	1 g	
	tetramine	12 g	
	CaO		
167291-2	Bagasse	200 g	Swollen and almost no strength after 6 weeks immersion in water.
	H_2SO_4	10 g	
	H_2O	1.5 l	
	CaO	12 g	
	Hexamethylene-tetramine	1 g	
167292-1	Bagasse	200 g	Sample looks O.K. after 6 weeks immersion in water.
	H_2SO_4	10 g	
	H_2O	1.5 l	
	Melamine	15 g	
	Hexamethylene-tetramine	1 g	
	Monflex 4530	15 ml	
	CaO	12 g	
167292-2	Bagasse	200 g	Better than 167291-2 indicating melamine enters into resinification.
	H_2SO_4	10 ml	
	H_2O	1.5 l	
	Melamine	15 g	
	Hexamethylene-tetramine	1 g	
	CaO	12 g	
167294-1	Bagasse	200 g	Santicizer plasticizer does not improve properties.
	H_2SO_4	10 ml	
	H_2O	1.5 l	
	Melamine	15 g	
	Hexamethylene-tetramine	1 g	
	Santicizer 150	10 g	
	CaO	12 g	
167294-2	Bagasse	200 g	No resinification; sample disintegrates after 2 hours immersion.
	H_2SO_4	10 ml	
	H_2O	1.5 l	
	Hexamethylene-triamine	1 g	
	CaO	9 g	
167295-1	Bagasse	200 g	No resinification; sample disintegrates after 2 hours immersion.
	H_2SO_4	10 ml	
	H_2O	1.5 l	
	Hexamethylene-tetramine	15 g	
	CaO	7 g	

Sample No. MRC-DA	Composition(a,b)		General Remarks Pertaining to Cooking, Panel Preparation, and Testing
167295-2	Bagasse	200 g	Panel O.K. in water for 4 weeks.
	H_2SO_4	10 ml	
	H_2O	1.5 l	
	Melamine	15 g	
	CaO	10 g	
167296-1	Bagasse	200 g	Slightly better than 167295-2
	H_2SO_4	10 ml	
	H_2O	1.5 l	
	Melamine	20 g	
	CaO	12 g	
167296-2	Bagasse	200 g	Panel cracks during molding. No water immersion test carried out.
	H_2SO_4	10 ml	
	H_2O	1.5 l	
	Phenol	20 g	
	CaO	12 g	
167297-1	Bagasse	200 g	Phenol added after CaO (pH 10) Poor panel - no water immersion test done.
	H_2SO_4	10 ml	
	H_2O	1.5 l	
	Phenol	20 g	
	CaO	14 g	
167297-2	Bagasse	200 g	Panel was very water sensitive - easily disintegrates in water.
	H_2SO_4	10 ml	
	H_2O	1.5 l	
	Sulfur	200 g	
	Hexal	5 g	
	L-546	3 g	
	Silicon		
	Extra H_2O	200 ml	
	CaO	12 g	
168841-1	Bagasse	200 g	No inorganic filler and therefore the silane does not couple; surface characteristics not improved.
	H_3PO_4	25 ml	
	H_2O	1.5 l	
	Melamine	20 g	
	CaO	20 g	
	Z6020 Silane	1 ml	
168841-2	Bagasse	200 g	Tensile strength of the dry panel is 1300 psi
	HNO_3	10 ml	
	H_2SO_4	5 ml	
	H_2O	1.5 ml	
	Phenol	20 g	
	CaO	8 g	
	Z6020 Silane	1 ml	
168842-1	Rice Hulls	127 g	Panel is extremely water-sensitive and disintegrated rapidly.
	H_2SO_4	4 ml	
	HNO_3	15 ml	
	H_2O	950 ml	
	Phenol	20 g	
	CaO	10 g	
	Camphor	1 g	
	Z6020 Silane	1 g	
168842-2	Bagasse	200 g	First panel pressing at 225°F was flexible. Repressed same panel at 390°F. Good panel but surface cracks apparent.
	HNO_3	20 ml	
	H_2SO_4	5 ml	
	H_2O	2.0 l	
	Phenol	20 g	
	CaO	12 g	
	Camphor	1 g	
	Z6020 Silane	1 g	

Table 62

Sample No. MRC-DA	Composition(a,b)		General Remarks Pertaining to Cooking, Panel Preparations, and Testing
168844	Pine Needles	140 g	Somewhat water-sensitive and "non-compacted".
	HNO_3	20 ml	
	H_2SO_4	5 ml	
	H_2O	25 ml	
	Phenol	15 g	
	CaO	8 g	
168845-1	Corn cobs	250 g	Panel does not look strong; corn cobs are good source of furfuraldehyde but are not good filler.
	H_2SO_4	10 ml	
	H_2O	1.5 l	
	Phenol	20 g	
	CaO	13 g	
	Cunilate 2440	10 g	
168845-2	Pine needles	100 g	Panel is not completely rigid.
	Bagasse	100 g	
	H_2SO_4	10 ml	
	H_2O	2.5 l	
	CaO	15 g	
168846-1	Water Hyacinth	200 g	Panel is rigid.
	H_2SO_4	10 ml	
	H_2O	1.5 l	
	Phenol	20 g	
	CaO	10 g	
168846-2	Pine needles	100 g	Poor resin flow in mold. Considerable swelling after 2 days soaking in water.
	Bagasse	100 g	
	H_2SO_4	10 ml	
	H_2O	2.5 l	
	Hexamethylene-tetramine	10 g	
	CaO	10 g	
168282-1	Bagasse	200 g	Panel O.K. in water for 6 eeks.
	H_3PO_4	50 g	
	H_2O	2 l	
	Phenol	10 g	
	CaO	45 g	
	Monflex 4530	10 ml	
168282-2	Bagasse	200 g	Good water resistance
	H_3PO_4	50 g	
	H_2O	15 l	
	Phenol	10 g	
	CaO	55 g	
	Monflex 4530	10 ml	
167283-1	Bagasse	200 g	Cf. 168282-1
	H_3PO_4	50 g	
	H_2O	1.5 l	
	Phenol	15 g	
	CaO	21 g	
	Monflex 4530	15 ml	
167283-2	Bagasse	150 g	Resinfication occurs with urea but panel is more water sensitive when compared with the phenol counterpart.
	H_3PO_4	30 g	
	H_2O	1125 ml	
	Urea	15 g	
	CaO	16 g	
	Monflex 4530	10 ml	

Sample No. MRC-DA	Composition(a,b)		General Remarks Pertaining to Cooking, Panel Preparations, and Testing
167284	Bagasse	200 g	Sample looks O.K.
	H_3PO_4	20 ml	
	H_2O	1.5 l	
	Phenol	15	
	CaO	15 g	
	Monflex 4530	15 ml	
167284-2	Bagasse	150 g	Composition attacks the mold because of highly acidic condition.
	HCl	30 ml	
	Phenol	12 g	
	H_2O	1225 ml	
	Monflex 4530	10 ml	
	No neutralization	15 ml	
167284-3	Bagasse	200 g	Sample looks O.K.
	H_3PO_4	25 g	
	H_2O	1.5 l	
	Melamine	15 g	
	Monflex 4530	15 ml	
	CaO	20 g	
167285-1	Bagasse	150 g	Slightly better than 167283-2 because of higher resin content.
	H_3PO_4	15 g	
	H_2O	1.2 l	
	Urea	25 g	
	CaO	10 g	
167285-2	Bagasse	200 g	Compares with 167284-3 in overall panel evaluation.
	H_3PO_4	10 g	
	H_2O	1.5 l	
	Phenol	15 g	
	CaO	10 g	
	Monflex 4530	15 ml	

(a) Legend

H_3PO_4	85% phosphoric acid
H_2O	Water
CaO	Calcium oxide
H_2SO_4	98% sulfuric acid
Monflex 4530	Ethylene vinyl chloride emulsion (Monsanto)
Santicizer 160	Plasticizer (Monsanto)
Z6020	Coupler (Dow Corning)
L-546	Silicone-type surfactant (Dow Corning).
Cunilate 2419	Fungistat (Venton Corporation, Beverly, Mass.)

(b) Process

Bagasse, acid and water refluxed overnight to produce furfuraldehyde; add phenol, melamine or urea and condense at reflux temperature for 4 hours. Remove water from the mass in an oven at 50°C.

Press and cure for 20 minutes at 390°C under 625 psi.

Table 63

STRENGTH AND DURABILITY OF POLYESTER BONDED JUTE COMPOSITES

Sample ID MRC-DA	Basic Formula: Binder[a] Type	Binder Amount (Wt.%)	Reinforcement Type	Reinforcement Amount (Wt.%)	Initial Flexural Strength (psi)	Tensile Strength (psi) Exposure in Weatherometer: 0 Hrs	300 Hrs	1000 Hrs
168833-12	General Purpose (GP) Polyester	100	-	-	10,600	8350	4000	3000
168834-2	G.P. Polyester	30	jute fabric (3 plys)	70	5900	4450	1700	1500
168833-11	Water Extended Polyester	100	-	-	2150	800	800	0
168834-1	Water Extended Polyester	50	jute fabric (3 plys)	50	1800	1000	800	800

(a) For curing G.P. polyester, 3.0 percent methyl ethyl ketone (MEK) peroxide catalyst used based on resin; water to resin ratio in formulation 1:1.

For curing water extended polyester, 1.0 percent each of hydrogen peroxide (30% concentration) and MEK peroxide used based on resin.

GP polyester - Plast. #79, styrenic type, (Source: Fiber-Glast, Inc., Dayton, Ohio).
Water extended polyester - WEP 661P (Source: Ashland).

Table 64

NATURAL FIBER REINFORCED POLYSTYRENE FOAM COMPOSITES - COMPOSITION AND PROPERTIES

Sample ID MRC-DA	Filler Type and Description	Filler (wt %)	Polystyrene[a] (wt %)	Remarks	Flexural Strength (psi)	Flexural Modulus (psi)
175456-7-2	None	-	100.0	Coloration by dry pigment(s) is possible	46	2380
175455-2	Ground whole bagasse	23.3	76.7	Sample looks attractive	93	2470
175455-3	Coarse jute fabric used as outer skins	31.0	69.0	Fabric remains bonded	91	1220
175455-4	Fine jute fabric used as outer skins	31.0	69.0	Sample looks attractive	104	1430
175456-7	Straw from the Philippines	31.0	69.0	-	141	1350
175456-8	Coarse jute fabric - three plys; two outside skins	34.0	64.0	-	89	2910
175456-9	Rice Husk from the Philippines	35.0	65.0	-	85	1430
175456-10	Grass from Zambia	35.0	65.0	-	67	1440
175457-11	Tightly woven jute fabric used as outer skins	40.0	60.0	Skin peels off after two days under ambient condition	44	841

(a) Represents pre-expanded beads containing 6.5 percent *n*-pentane; beads prepared from Dylite C, (Source: Sinclair-Koppers). All samples fabricated in corrugated mold by 100°C steam for 3 minutes.

APPENDIX A

CONTRACT STATEMENT OF WORK

APPENDIX A

CONTRACT STATEMENT OF WORK

The Contractor shall make available and employ its research and development facilities and personnel to carry out a three-year research and development program directed toward developing, testing, and evaluating low-cost binders applicable in meeting DC roofing needs. The experimental program will be conducted in three twelve-month phases as described below.

The binders developed shall be low in cost--particularly in foreign exchange costs, broadly applicable to a variety of locally available cheap fibers and fillers, easy to handle and apply, resistant to wear, and with thermal and other properties suitable to the tropics and socio-economic constraints of developing countries.

Although it is recognized that the bulk of the research will likely be in the field of plastics and resins, the project is also to explore other binding materials, such as rubber, asphalt and cement (especially "ferro-cement"), pursuing them if they appear more advantageous than polymers, etc.

The objective is to provide a key ingredient for DC roofing that can maximize utilization of local natural resources, surplus manpower, and limited manufacturing capabilities, in producing a cheaper and better product than is now available. Targets are DC low-cost housing projects and development of village level industry or self-held methodology.

Phase I - Material and Process Development; and Socio-Economic Base Study

The initial phase will:

(a) involve the selection of three developing countries, one each in Africa, Asia and Latin America (with disparate climatic and roofing problem characteristics), as geographical sites for demonstration purposes;

(b) selection of local personnel and institutions for collaboration;

(c) collection for analytical testing of commonly available native fibers, fillers, or other plentiful and cheap materials, including agricultural wastes, which may be used as a resin source or as fibers, etc.;

(d) collection and study of pertinent literature on DC roofing needs, on existing roofing materials and types in both developed and developing countries, on related projects, experiments and potentials, to avoid duplication and to utilize earlier experience;

(e) study of the building styles, trends, codes, structural characteristics, total costs, foreign currency costs, <u>and</u> the organization and infrastructure controlling new low-cost housing ocnstruction, both in larger housing projects and in self-help or village and town-level local construction;

(f) study of the social, cultural, marketing and economic constraints and characteristics which would inhibit or enhance acceptance of new roofing materials and styles;

(g) study of the local labor market pertinent to roofing manufacture, distribution, self-help processes, etc., including quality and trends, and

(h) initiation of processing techniques, testing and preliminary design.

Phase II - Design, Manufacture, Testing and Evaluation of Prototype Roofing

Phase II will incorporate the most promising materials into prototype roofing panels, provide for scaled-up evaluation, testing and environmental exposure, incorporate advanced architectural design responding to strength, longevity, cost, labor and acceptability, and lay the ground work for full-scale construction and demonstration activities in the developing nations.

Phase III - Manufacture and Field Testing of Full-Scale Roofing

Upon acceptance by AID of fully tested and successful prototype(s), in Phase III construct a total of at least 12 full-scale roofs with local manpower, and evaluate in company with local officials. Particular attention will be placed on socio-economic factors in terms of acceptability of the new roofing system, the lack of foreign currency requirements, the total cost, the level of involvement of unskilled and semi-skilled labor, the expected performance characteristics (thermal, acoustic, durability, strength, longevity, etc.), the encouragement of development of local industry, the utilization of cheap and plentiful fibers and fillers, or other local material resources, and the transferability aspects.

APPENDIX B

WORKING DOCUMENTS FOR PARTICIPATING COMMITTEES MAY 1975 COMMITTEE NOTES FOR INFORMAL DISCUSSION OF PROJECT IN JAMAICA

IMPROVED ROOFING MATERIALS WITH ECONOMIC TRADE BENEFITS TO JAMAICA

COMMITTEE NOTES

Kingston, Jamaica
May, 1975

Notice

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750505-1 (19 ppg)

OBJECTIVE AND TASKS

THE COMMITTEE TO MAKE AVAILABLE IMPROVED ROOFING MATERIALS WITH ECONOMIC TRADE BENEFITS TO JAMAICA

OBJECTIVE: To develop, define and demonstrate economically viable roof material candidates in Jamaica.

TASKS

1. Set up organization (committee and subcommittees) to provide communication, coordination and planning, and to define the roles of the subcommittees with respect to the tasks.

2. Review composite materials R&D work done by MRC and determine relevance to Jamaican situation.

3. Conduct cost analyses on the candidate materials systems to determine their degree of viability with respect to other available roofing.

4. Assist MRC in determining functional life of candidate composite materials by providing proper exposure (environmental), testing and analysis of MRC and eventually Jamaican produced panels.

5. Conduct R&D program to optimize, upgrade, refine, etc. the composite materials systems using the MRC recipes (ingredients and lab process) as starting points.

6. Determine processing techniques and conditions for the more attractive material systems:

   (a) laboratory scale process

   (b) large scale factory process

   (c) low capitol-labor intensive process

7. Determine both necessary and desired criteria for a roof and a roofing material for low-cost housing in Jamaica.

750429-2a

8. Design roof and/or roofing product (panel, tile etc.) based on the criteria in 7., the properties of the materials resulting from 4 and 5, the processability from 6, and knowledge of factors determining general acceptability, i.e. shape, color, size, strength, etc.

9. Define roof construction details, i.e. substructure, method of attachment, etc.

10. Determine criteria for and select site for at least four (4) demonstration roofs. Include visibility to public and decision makers, convenience to laboratory and project participants with respect to time and cost, availability of materials and necessary skills to make and install the roof, future acceptability, etc.

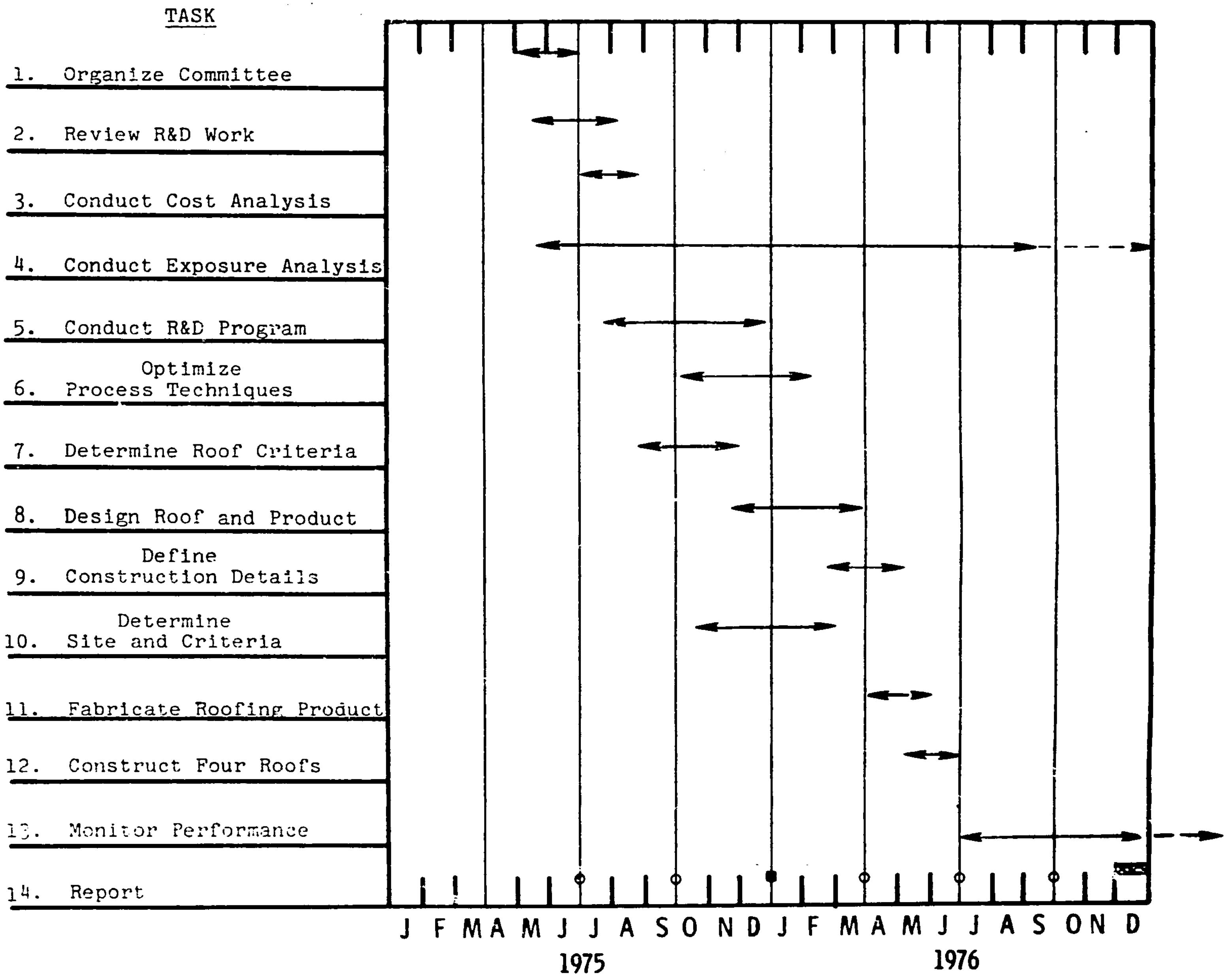
11. Fabricate sufficient roofing product for 5 roofs. Set up quality control and preliminary specifications.

12. Install roofs on at least 4 houses. Provide architectural supervision, record the installation process, record problem areas, submit data and analyses to the committee and MRC for review.

13. Monitor performance and user response of roofs with time (at least 6 months).

14. Write and submit final report covering all aspects of work. Monthly summary and detailed quarterlies are also required.

750429-2b



740429-3 ROOFING DEVELOPMENT PROGRAM TASK TIME SCHEDULE

PROPOSED MEMBERS
THE COMMITTEE TO MAKE AVAILABLE IMPROVED
ROOFING MATERIALS WITH ECONOMIC TRADE BENEFITS TO JAMAICA

Organization	Representative	Title
Ministry of Housing (MH)	Rev. G. L. McLaughlin	Special Advisor to the Minister
Scientific Research Council (SRC)	Dr. K. E. Magnus Dr. C. E. Davis	Technical Director Senior Principal Scientific Officer
National Housing Corp (NHC)	Miss T. Nelson	Research Officer
Bureau of Standards (JBS)	Mr. Cambell A. K. Elliot	Science and Technology Head, Materials
U. of West India (UWI)	Dr. T. Hughes	Prof. of Material Science
Jamaica Industrial Development Corp (JIDC)	Mrs. Carmen Cambell	Acting Special Project Director
Urban Development Corp (UDC)	Mr. David Gregory Jones	Chief Architect
Douet Brown Adams and Associates (DBAA)	A. D. Adams	Consulting Engineer
Knox Development Found. (KDF)	Mr. Lewis Davidson	Director
Standard Building Products (Jamaica) Ltd.	Mr. Douglas Wynter Mr. M.K.S. Biersay	Technical Director Vice President for Sales and Marketing
Berger Paints	Mr. Dervin R. Brown	Technical Manager
Thermoset Ltd.	Dr. Lester A. D. Chin	Director
Monsanto Research Corp. Dayton Laboratories	Mr. George L. Ball Mr. Ival O. Salyer Dr. A. M. Usmani	Research Group Leader Research Manager Research Chemist
Washington University	Mr. J.P. Rudd Falconer	Professor and Sub-contract Manager
U.S. A.I.D. Mission to Jamaica	Mr. Peter Kolar	Program Officer

750429-1

ROLE OF THE CHAIRMAN

The Committee To Make Available Improved Roofing Materials With Economic Trade Benefits To Jamaica

To cause a committee to be formed through selection of individuals appropriate to the objectives of the committee.

To define and form subcommittees based on the various needs defined by the tasks, and to appoint their chairman with the approval of the committee.

To cause the committee to meet as a whole, at least once quarterly, and at other times as deemed appropriate.

To designate a secretary and provide for internal and external communication of the committee.

To coordinate the total effort as described in the tasks, and to keep the committee headed towards the primary objective with enthusiasm.

To provide liaison of the committee with the Monsanto Research Corporation project team.

To promote the continued existence of the committee to maximize its effectiveness in Jamaica with time.

750429-5

Monsanto Research Corporation

and

Washington University

for

USAID

Problem

Ineffective roofing with heavy
burden on economic trade balance

Objective

Provide good alternative roofing
from indigenous materials having
little effect on balance of trade.

Experimental Program

Phase I - Problem Definition and Country Selection

Phase II - Material Development and Socio-Economic Study on Roofs

Phase III - Design, Manufacture and Testing of Prototype Roofing
Manufacture and Field Testing of Full Scale Roofs

PHASE I

Problem Definition and Country Selection

- Field Surveys
  - Africa
  - Latin America
  - Asia
- Country Selection
- Literature Survey
- Materials Survey

Phase II

Material and Process Development

- Region Analysis
- Site Selection
- Roof System Analysis
- Resource Definition
- Material Selection
- Material Development
- Initial Roof Detailing
- Testing
- Collaborator Definition
- Exposure Studies

PHASE III

Design, Manufacture, and Testing of Prototype Roofing

- Scale Up
- Designing
- Practicality
- Economics
- Testing
- Info Transfer

Manufacture and Field Testing of Full-Scale Roofing

- Final Design and Detailing
- Environmental Testing
- On Site Construction
- Field Evaluation
- Technology Transfer
- Financial Acessment

Selection Criteria For Demonstration Sites

- Interest
- Need
- Existing Institutional Base
- Existing Technology Base
- Resources
- Climate
- Attitudes
- Geographic Location
- Economy
- Urban - Rural Mix
- Language
- Housing Trends
- Ability to succeed

Surveyed Potential Demonstration Sites

Africa (1)

Zambia, Ethiopia, Ghana
Malawi, Sudan

Latin America (1)

Bolivia, Peru, Honduras,
Jamaica

Asia (1)

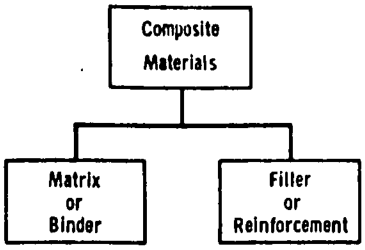
Philippines, Indonesia,
Bangladesh, Thialand

Countries Selected

Jamaica
Zambia
Philippines

COMPOSITES R&D

- Materials
- Processes
- Structures
- Characterization
- Economics
- Literature



FILLERS EXAMINED

•Bagasse
Rice Straw
Balsa Wood
Wood Shavings
† Sawdust
•Iron Oxide Pigment
Rice Hulls
Ore Tailings
Water

Palm Fronds
Water Hyacinths
Coconut Husks
Bamboo
Excelsior
ZrO_2
•Clay
Sand
Air

BINDERS EXAMINED

Thermoplastic

SAN, ABS, PS
PVC, PE, PP
Asphalt

Thermoset

GP Polyester
WE Polyester
Melamine Formaldehyde

Natural

Furfural aldehyde derived from pentosan in bagasse - reacted with phenol or melamine

Clay - with polyelectrolyte and water proofer

Rubber + Rubber Latex

CHARACTERIZATION
(Initial Qualification)

Mechanical

Tensile
Flexural
Compression
Impact
  Izod
  Indent
Hardness
Roof Panel Simulation

Environmental

UV, Water, Temperature
Accelerated UV
Water Soak
Outdoor (Dayton, Jamaica)
Fire
Thermal Deflection
Humidity

EFFECT OF FILLER ON MECHANICAL PROPERTIES OF THERMOPLASTIC PANELS

	Flexural		Tensile		1000hr
	Str. (psi)	Mod. (10^3psi)	Str. (psi)	Mod. (10^3psi)	Ten.Str. (psi)
Bagasse (W)	5650	1260	3400	1070	1650 (-51%)
Sawdust	6600	1280	3700	1200	1400 (-62%)
Excelsior	4850	1260	2950	1360	250 (-91%)
Wood Shavings	5250	1240	3100	995	<50 (-98%)
Bamboo	4300	1070	2000	750	0 (-100%)
Balsa Wood	3550	1050	1900	925	500 (-74%)
Coconut Husks (W)	5200	950	3050	750	250 (-92%)
Water Hyacinths	4900	850	3050	610	1600 (-48%)
Palm Fronds	4650	825	2050	545	0 (-100%)
None	6350	580	3450	475	1000 (-71%)
Rice Straw	3350	940	2250	920	250 (-89%)

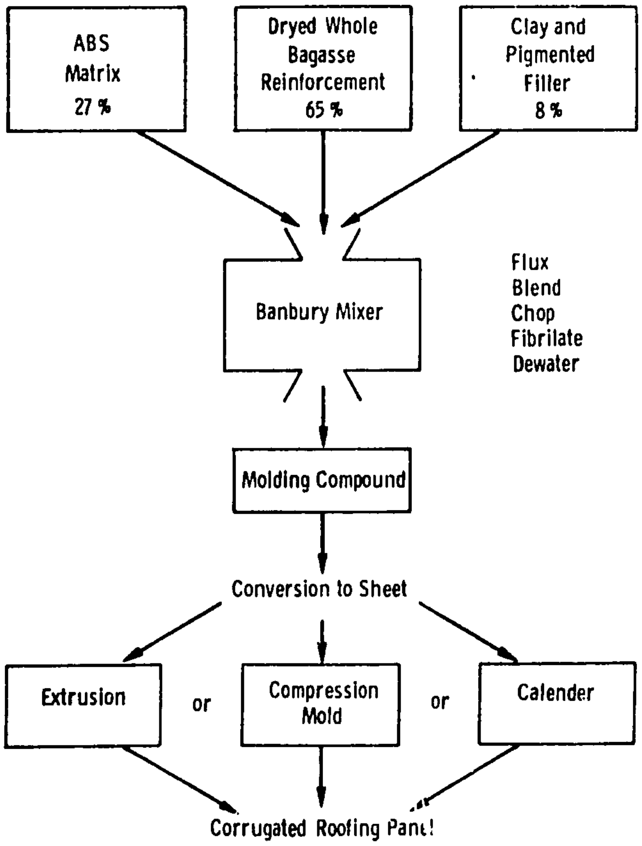
MECHANICAL CHARACTERISTICS OF BAGASSE FILLED THERMOPLASTICS

	Initial				Following Exposure			
	Flexural		Tensile		Tensile (1000hr)		Tensile (430)	
Binder	Str. (psi)	Mod. (10^3psi)	Str. (psi)	Mod. (10^3psi)	Str. (psi)	Mod. (10^3psi)	Str. (psi)	Mod. (10^3psi)
SAN	6400	1230	4000	960	3900	942	3900	930
PS	5650	1265	3400	1067	1650	--	3100	--
ABS	5400	1110	4200	970	4200	--	4600	--

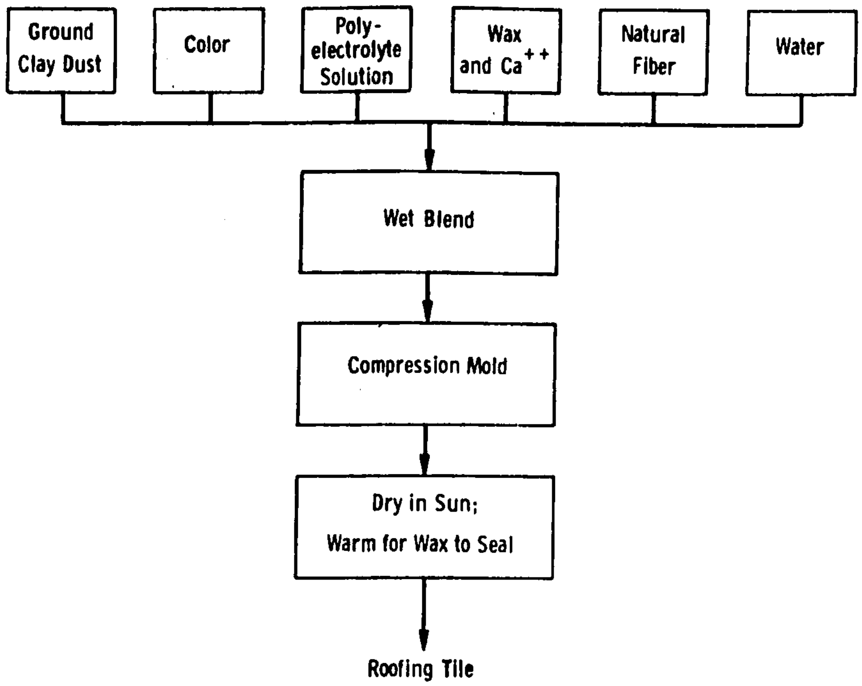
PROCESSES EXAMINED

- Thermoplastic (Banbury)
- Thermoset (Centrifugal lay up)
- Thermoset (Dry Molding Compound)
- Natural (Dry Molding Compound)
- Natural (Wet blend + Comp. Mold)
- Thermoplastic Solution
- Thermoplastic Latex

REINFORCED THERMOPLASTIC MANUFACTURING PROCESS



UNFIRED CLAY TILE MANUFACTURING PROCESS

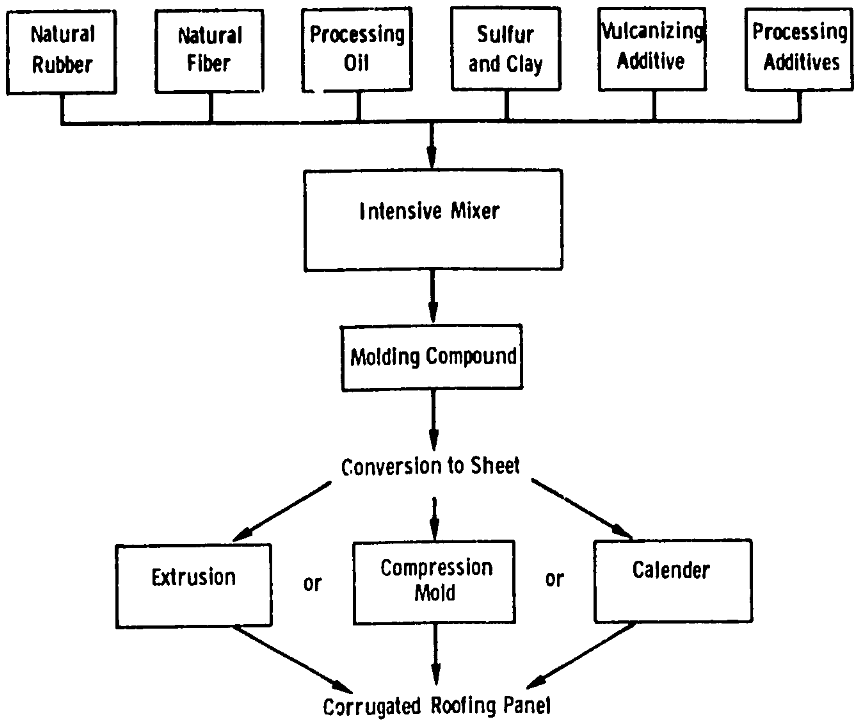


CHARACTERISTICS OF STABILIZED, WATER RESISTANT, REINFORCED CLAYS

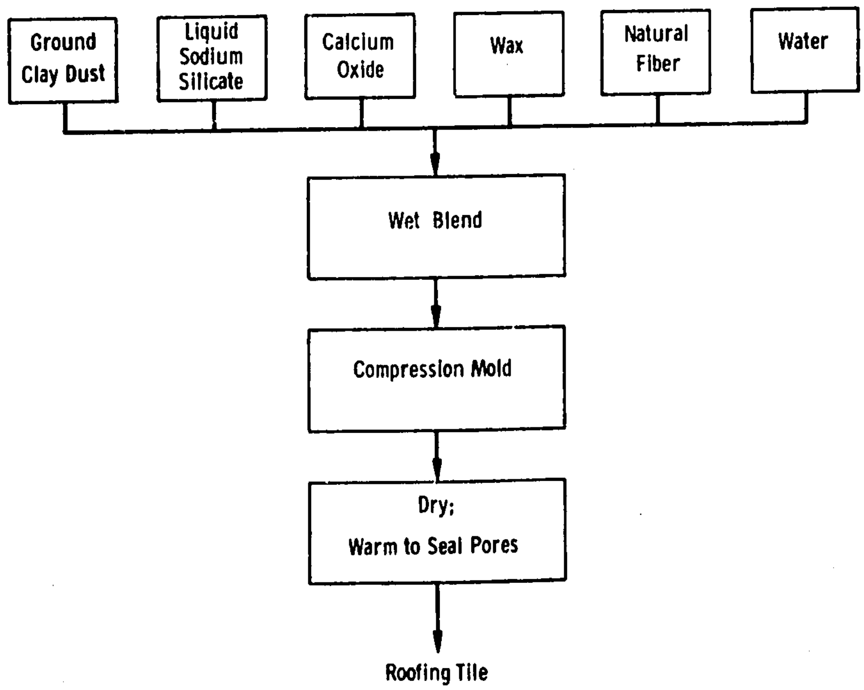
Composition, Wt%							Unconstrained Compressive Properties		
		Filler			Reinforcement				
Clay	Poly-electro-lyte	Sand	Slag	Wax	CaO	Abaca	Str. psi	Defl. %	Mod. psi
95.5*	1.0	---	---	2.0	---	1.5	4100	12	68,000
82.5	1.0	15	---	---	0.5	1.0	5600	11	62,000
100	---	---	---	---	---	---	Broke before test		
98.5	1.0	---	---	---	0.5	---	2500	8	58,000
89.9	10.0	---	---	---	0.1	---	3360	---	67,000
85	5.0	---	10	---	---	---	3100	4	67,000
64.9	5.0	30	---	---	0.1	---	2850	4	96,000
Latorex	———						4200	---	88,500

* Water absorption in 24 hr = 7.7% (specimen dryed before test)

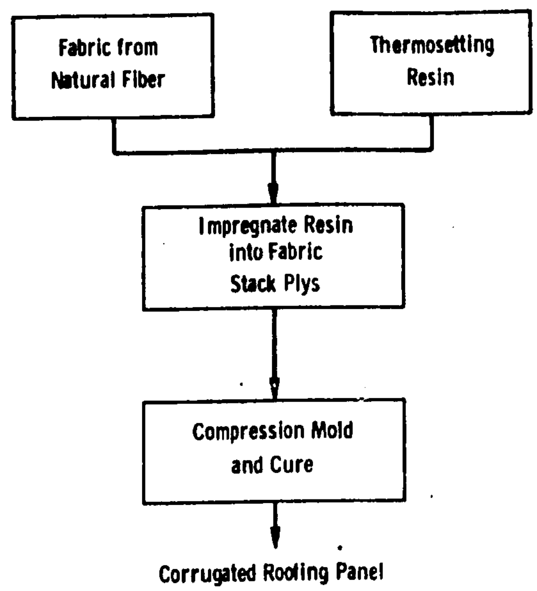
NATURAL RUBBER BINDER MANUFACTURING PROCESS



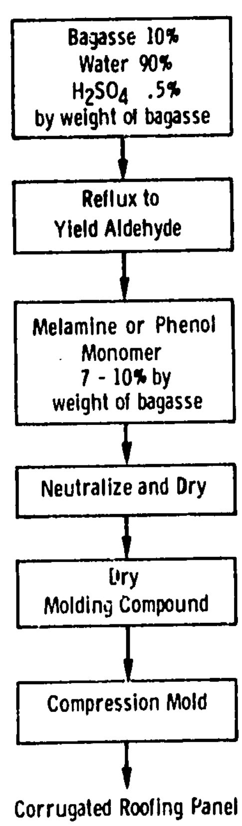
UNFIRED CLAY TILE MANUFACTURING PROCESS



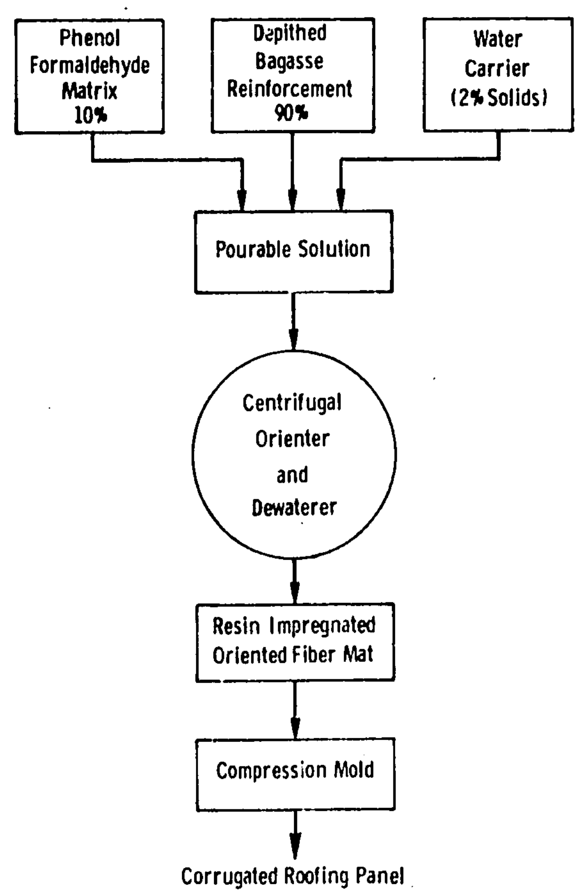
FABRIC REINFORCED THERMOSET MANUFACTURING PROCESS



NATURAL BINDER MANUFACTURING PROCESS



REINFORCED THERMOSET MANUFACTURING PROCESS



NATURAL FIBER REINFORCED THERMOPLASTIC

Ingredient	% (Vol)	% (Wt)	Material Cost ($/lb)	Component Cost ($/lb of product)
ABS Binder	35	27	0.60	0.162
Whole Bagasse	60	63	0.005	0.003
Ground Clay	3	5	0.005	0.001
Iron Oxide	2	5	0.40	0.02

Material Cost
per lb $0.186
per sq.ft. $0.125

Panel t = 0.1 inch Wt. = 0.67 lb/sq.ft.

NATURAL FIBER REINFORCED NATURAL RUBBER

Ingredient	% (Vol)	% (Wt)	Material Cost ($/lb)	Component Cost ($/lb of product)
Natural Rubber	30	20.5	0.20	0.041
Sulfur	5.5	8.2	0.02	0.0016
Bagasse	52	54	0.005	0.0027
Oil	10	7.4	0.15	0.011
Iron Oxide	1.5	5.6	0.5	0.028
Additives	1.0	4.3	0.8	0.034

Material Cost
per lb $0.118
per sq.ft. $0.08

Panel t = 0.1 inch Wt. = 0.68 lb/sq.ft.

FIBER REINFORCED UNFIRED CLAY TILE

Ingredient	%	Material Cost ($/lb)	Component Cost ($/lb of product)
Clay	73	0.001	0.0007
Water Glass	8	0.05	0.004
CaO	2	0.10	0.002
Bagasse	17	0.005	0.0009

Material Cost
per lb $0.0076
per sq.ft. 0.028

Tile t = 3/8 inch Wt = 3.7 lb/sq.ft.

CONCLUSIONS

- Best Thermoplastic Binder System

  ABS - Whole Bagasse - Iron Oxide
  Banbury Process

- Best Natural Binder Systems

  Phenol formaldehyde - Whole Bagasse
  Dry Molding Compound Process

  Clay - Polyelectrolyte - Wax
  Compression Molding Process

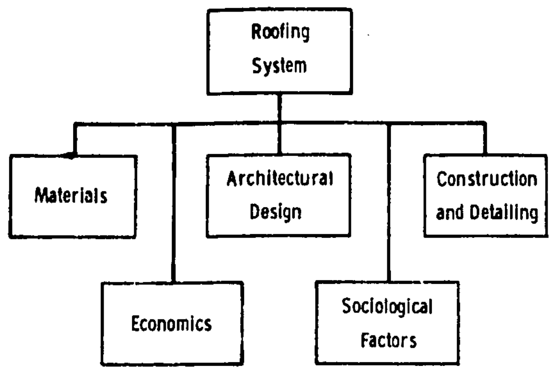
- Best Thermoset Binder System

  Phenol formaldehyde - Depithed Bagasse
  Centrifugal Lay-up Process

- Best Filler - Bagasse

  Sawdust Backup
  No Other Good Candidates

- Whole Bagasse can be used as filler
- SAN is good backup for ABS binder
- Moisture more detrimental than UV to stability of panel
- Properties of reinforced SAN in flexure:
  - 5000 psi strength
  - 1.1×10^6 psi modulus
- Multipurpose processes available:
  - Banbury
  - Centrifugal lay-up
- Other binders potentially available:
  - Asphalt
  - Rubber



CRITERIA FOR ROOF

Requirements	Highly Desirable Characteristics	Wt.
• Keep Off Rain	• Low Cost	9
• Not Leak	• Indigenous Material (>50%)	9
• Water Resistant	• Acceptability	
• Wind Resistant	User	8
• Minimum Strength	Government	8
• Keep Out Direct Sun	• Fire Resistance	5
• Minimum Life (Resist Elements)	• Easy Installation	5
• Available	• Labor Intensive Mfg.	6
	• Reasonable Life	6

TYPES OF ROOFING IN COMMON USE

- Galvanized Iron
  - Corrugated
  - Flat
- Corrugated Aluminum
- Cement Abestos
  - Flat
  - Corrugated
- Tile
  - Clay, Fired
  - Cement
  - CA
  - Mud
- Wood
  - Shingle
  - Plank
- Asphalt
  - Plain
  - Shingle (aggregate)
  - Tar Paper
- Particle Board
- Thatch
  - Grass
  - Bamboo
  - Leaves
  - Reeds
- Corrugated Vinyl
- Corrugated Reinforced Polyester
- Plastic Film

WHY CORRUGATED GALVANIZED IRON ROOFING IS USED

- Low Cost
- Low Weight
- Low Volume - 30 gage
  Shipping & Joining
- Life - 2 to 40 Years
- Able to Nail
- Paintable
- Keeps Off Sun and Rain
- Provides Heat in Cooler Periods
- Easy to Install - Low Skill Required
- Available !
- Status
- Collect Rain Water -
  No Mold Problen
- Resists Wind
- Tough
- Fire Resistant
- Vapor Barrier
- Maintenance Free

DESIRABLE CHARACTERISTICS FOR ROOF

Mechanical

Wt.	Item
(8)	Resist Projectiles
(4-JP)	Resist Hurricanes
(6)	Not Increase Truss or Perling Requirement
(3)	Support a Person
(2-P)	Resist Earthquakes
(2)	Resist Abrasion
(1)	Hold House Together
(-)	Be Strong
(-)	Be Rigid
(2)	Security & Protection

Environmental and Life

Wt.	Item
	Maintenance
(8)	None (5yr)
(9)	Easy
(9)	Ability to Nail, Seal, Cut
(6)	Lightweight
(6)	No Vapor or Toxic Fumes on M or P
(5)	Life - 10 years
(7)	Simple Tools and Equipment
(3)	Resistant to Insects, Water, UV
(1)	Vapor Impermeable
(1)	Reusable
(3)	Availability

Optical

Wt.	Item
(9)	Keep Out Sun
(9)	Opaque
(8)	Attractive
(1)	Shine
(2)	Color

Social

Wt.	Item
(9)	Status
(9)	Contour
(6)	Smell
(9)	Overhang
(4)	Material
(1)	Texture

Thermal

Wt.	Item
(9)	Keep Off Sun
(9)	Resist Heat
(6)	Ventilation
(5)	Thermal Control retain heat reflect heat keep in heat keep out heat keep out cold keep in cold

Acoustic

Wt.	Item
(3)	Not Noisey in Wind or Rain
(1)	Sound Absorbing
(1)	Poor Sound Transmission
(-)	Damping

APPENDIX C

WORKING DOCUMENTS FOR PARTICIPATING COMMITTEES

JULY-AUGUST, 1975 COMMITTEE NOTES FOR INFORMAL DISCUSSION OF PROJECT IN PARTICIPATING COUNTRIES

(Revised and updated from May 1975 version)

IMPROVED ROOFING MATERIALS WITH ECONOMIC TRADE BENEFITS TO DEVELOPING COUNTRIES

ADVISORY COMMITTEE INFORMATION

August, 1975

<u>Notice</u>

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750815-1 - 4 pages

• MONSANTO RESEARCH CORPORATION •

IMPROVED ROOFING MATERIALS WITH
ECONOMIC TRADE BENEFITS TO DEVELOPING COUNTRIES

PROGRAM WORK STATEMENT

OBJECTIVE: To develop, define and demonstrate economically viable roof material candidates.

TASKS

1. Set up an advisory committee to provide advice, communication, coordination and planning.

2. Set up a working group to provide for performing the following tasks.

3. Review composite materials R&D work done by MRC and determine relevance to local situation.

4. Conduct cost analyses on the candidate material systems to determine their degree of viability with respect to other available roofing.

5. Assist MRC in determining functional life of candidate composite materials by providing proper exposure (environmental), testing and analysis of MRC and eventually local produced panels.

6. Conduct R&D program to optimize, upgrade, refine, etc. the composite materials systems using the MRC recipes (ingredients and lab process) as starting points.

7. Determine processing techniques and conditions for the more attractive material systems:

   (a) laboratory scale process

   (b) large scale factory process

   (c) low capital-labor intensive process

8. Determine both necessary and desired criteria for a roof and a roofing material for low-cost housing.

8. Design roof and/or roofing product (panel, tile etc.) based on the criteria in 7., the properties of the materials resulting from 4 and 5, the processability from 6, and knowledge of factors determining general acceptability, i.e. shape, color, size, strength, etc.

9. Define roof construction details, i.e. substructure, method of attachment, etc.

10. Determine criteria for and select site for at least four (4) demonstration roofs. Include visibility to public and decision makers, convenience to laboratory and project participants with respect to time and cost, availability of materials and necessary skills to make and install the roof, future acceptability, etc.

11. Fabricate sufficient roofing product for 5 roofs. Set up quality control and preliminary specifications.

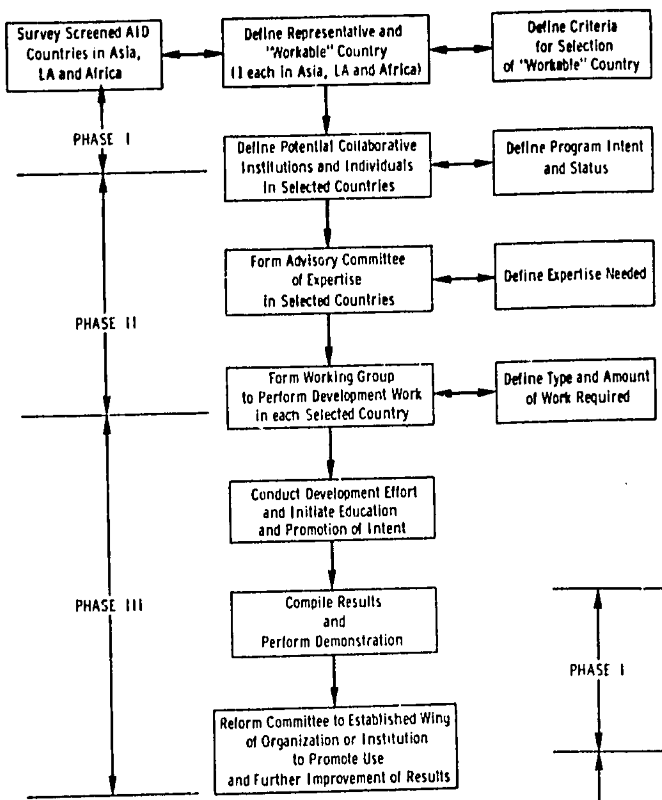
12. Install roofs on at least 4 houses. Provide architectural supervision, record the installation process, record problem areas, submit data and analyses to the committee and MRC for review.

13. Monitor performance and user response of roofs with time (at least 6 months).

14. Write and submit final report covering all aspects of work. Monthly summary and detailed quarterlies are also required.

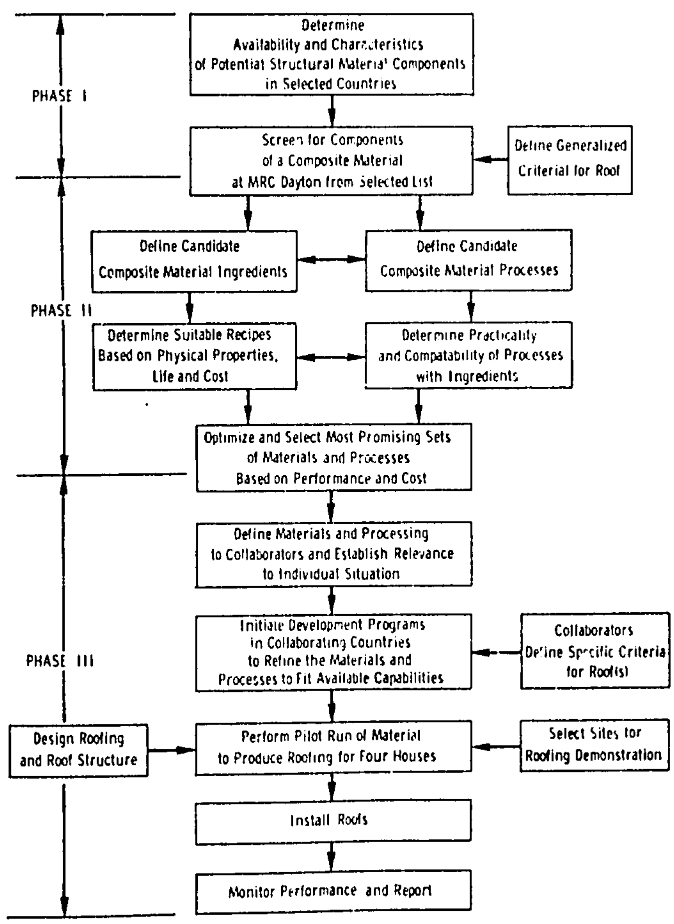
APPROACH

COLLABORATION, DEMONSTRATION AND TRANSFER OF TECHNOLOGY

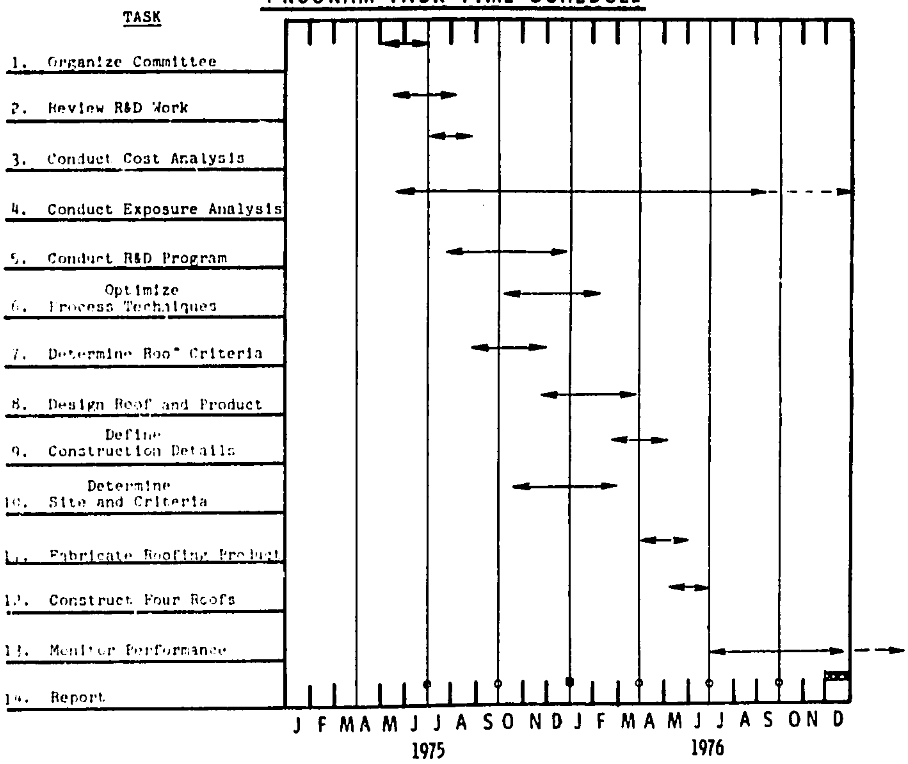


APPROACH

MATERIALS DEVELOPMENT



PROGRAM TASK TIME SCHEDULE



IMPROVED ROOFING MATERIALS WITH ECONOMIC TRADE BENEFITS TO DEVELOPING COUNTRIES

WORKING GROUP TECHNICAL INFORMATION

August, 1975

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• MONSANTO RESEARCH CORPORATION •

COLLABORATORS

- Government and Industry
- Monsanto Research Corporation
- Washington University
- US Agency for International Development

Problem

Ineffective roofing with heavy burden on economic trade balance

OBJECTIVE

Provide good alternative roofing having a beneficial effect on import requirements

Experimental Program

Phase I - Problem Definition and Country Selection

Phase II - Material Development and Socio-Economic Study on Roofs

Phase III - Design, Manufacture and Testing of Prototype Roofing
Manufacture and Field Testing of Full Scale Roofs

PHASE I

Problem Definition and Country Selection

- Field Surveys
  - Africa
  - Latin America
  - Asia
- Country Selection
- Literature Survey
- Materials Survey

Phase II

Material and Process Development

- Region Analysis
- Site Selection
- Roof System Analysis
- Resource Definition
- Material Selection
- Material Development
- Initial Roof Detailing
- Testing
- Collaborator Definition
- Exposure Studies

PHASE III

Design, Manufacture, and Testing of Prototype Roofing

- Scale Up
- Designing
- Practicality
- Economics
- Testing
- Info Transfer

Manufacture and Field Testing of Full-Scale Roofing

- Final Design and Detailing
- Environmental Testing
- On Site Construction
- Field Evaluation
- Technology Transfer
- Financial Acessment

Selection Criteria For Demonstration Sites

- Interest
- Need
- Existing Institutional Base
- Existing Technology Base
- Resources
- Climate
- Attitudes
- Geographic Location
- Economy
- Urban - Rural Mix
- Language
- Housing Trends
- Ability to succeed

Surveyed Potential Demonstration Sites

Africa (1)

Zambia, Ethiopia, Ghana
Malawi, Sudan

Latin America (1)

Bolivia, Peru, Honduras,
Jamaica

Asia (1)

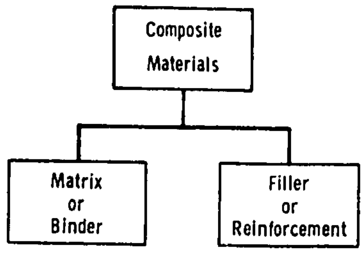
Philippines, Indonesia,
Bangladesh, Thialand

Countries Selected

Jamaica
Ghana
Philippines

ROOFING MATERIAL DEVELOPMENT

- Roof Criteria
- Material Selection
- Material and Process Development
- Process and Cost Analysis



COMPOSITES R&D

- Materials
- Processes
- Structures
- Characterization
- Economics
- Literature

CRITERIA FOR FILLERS AND BINDERS SELECTION

- Source
- Availability
- Form
- Cost
- Mechanical Performance
- Life
- Compatability

CHARACTERIZATION
(Initial Qualification)

Mechanical	Environmental
Tensile	UV, Water, Temperature
Flexural	Accelerated UV
Compression	Water Soak
Impact Izod Indent	Outdoor (Dayton, Jamaica)
	Fire
Hardness	Thermal Deflection
Roof Panel Simulation	Humidity

BINDERS EXAMINED

Thermoplastic

ABS, SAN, PS
PVC, PE, PP
Asphalt
foam PS

Thermoset

Phenol Formaldehyde
Melamine Formaldehyde
GP Polyester
WE Polyester

Others

Polyelectrolytes
Sodium Silicate

Natural Rubber

furfural aldehyde
derived from pentosan
in bagasse-reacted with
phenol or melamine

Sulfur

FILLERS EXAMINED

- •Bagasse
- Rice Straw
- Balsa Wood
- Wood Shavings
- † Sawdust
- • Iron Oxide Pigment
- Rice Hulls
- Ore Tailings
- Water
- Palm Fronds
- Water Hyacinths
- Coconut Husks
- Bamboo
- Excelsior
- ZrO_2
- •Clay
- Sand
- Air

EFFECT OF FILLER ON MECHANICAL PROPERTIES OF THERMOPLASTIC PANELS

	Flexural		Tensile		1000hr
	Str. (psi)	Mod. (10^3psi)	Str. (psi)	Mod. (10^3psi)	Ten.Str. (psi)
Bagasse (W)	5650	1260	3400	1070	1650 (-51%)
Sawdust	6600	1280	3700	1200	1400 (-62%)
Excelsior	4850	1260	2950	1360	250 (-91%)
Wood Shavings	5250	1240	3100	995	<50 (-98%)
Bamboo	4300	1070	2000	750	0 (-100%)
Balsa Wood	3550	1050	1900	925	500 (-74%)
Coconut Husks (W)	5200	950	3050	750	250 (-92%)
Rice Straw	3350	940	2250	920	250 (-89%)
Palm Fronds	4650	825	2050	545	0 (-100%)
None	6350	580	3450	475	1000 (-71%)

ROOFING MATERIAL TYPES

- Melt-Compounded, Resin-Bonded, Bagasse-Fiber Reinforced Composites
- Wet of Dry Blended, Thermoset-Resin Bonded, Bagasse-Fiber Reinforced Composites
- Wet Process, TS Resin Bonded, Depithed Fibrilated Oriented Bagasse Fiber Reinforced Composites
- Wet of Dry Blended, Resin Bonded, Unfired Clay Tiles

COMPOSITE CONCEPTS

- Binder Content
  25 vol % - dense
- Fillers
  Reinforcing
  Filling
  Extending
- Binder Type
  TP vs TS
  Wet vs Dry
- Additives
  Stabilizers
  Hiding
  Curing

PROCESS EMPHASIS

- Low capital
- Labor intensive
- Minimal skills
- Local industry

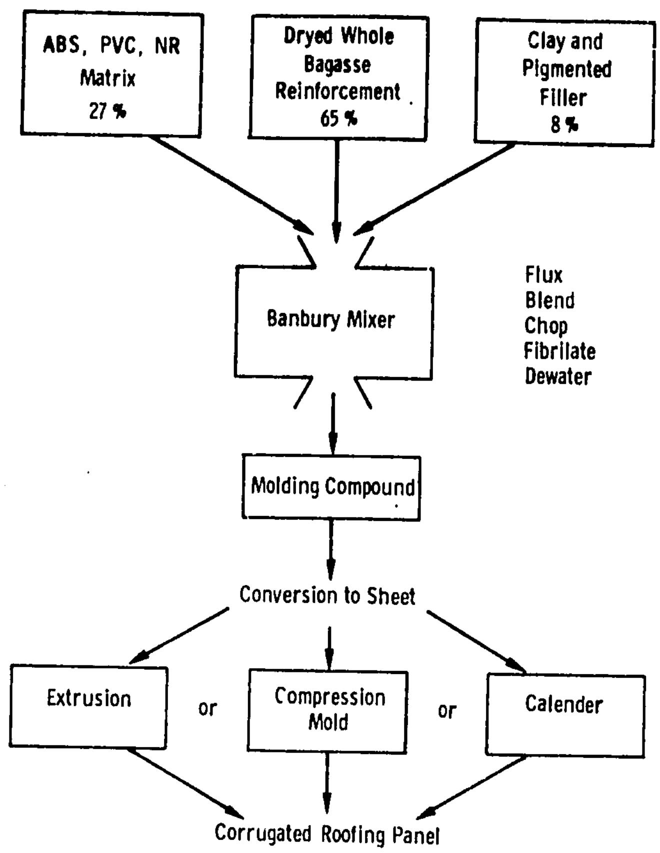
ARCHITECTURAL RESPONSIBILITIES

- Site Selection
- Design
- Construction
- Performance Analysis

PHILIPPINES MATERIALS

	Cost U.S. ¢/lb
Binders	
ABS	58
Polystyrene	37-45
Natural Rubber	16-22
PVC	35
Phenol Formaldehyde	53
Melamine Formaldehyde	--
Fillers	
Bagasse	1.4
Sawdust	0.6
Coconut Husks	--
Abaca	7-46
Ramie	16-32
Clay	--
Sulfur	11-12

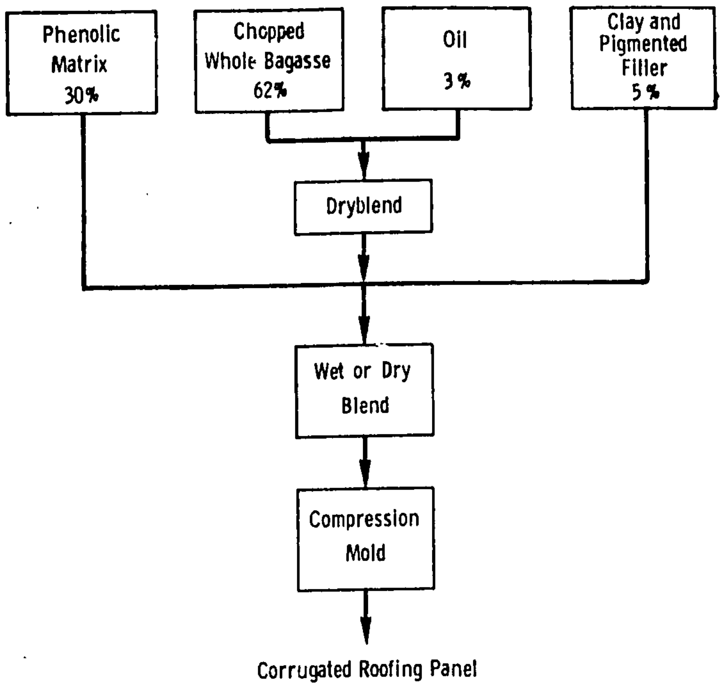
MELT-COMPOUNDED, RESIN-BONDED, BAGASSE-FIBER REINFORCED DENSE COMPOSITES



MECHANICAL CHARACTERISITCS OF MELT-COMPOUNDED, RESIN-BONDED, BAGASSE-REINFORCED COMPOSITES

	Initial				Following Exposure			
	Flexural		Tensile		Tensile (1000hr)		Tensile (430hr)	
Binder	Str. (psi)	Mod. (10^3psi)	Str. (psi)	Mod. (10^3psi)	Str. (psi)	Mod. (10^3psi)	Str. (psi)	Mod. (10^3psi)
SAN	6400	1230	4000	960	3900	942	3900	930
PS	5650	1265	3400	1067	1650	500	3100	1000
ABS	5400	1110	4200	970	4200	940	4600	960
NR	5000	3000	3000	--	2950	--	--	--

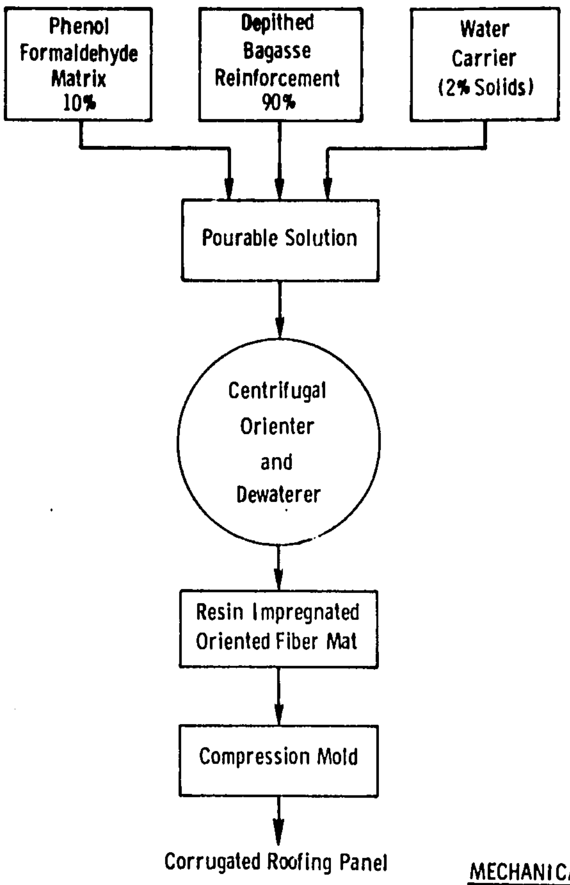
WET OR DRY BLENDED, THERMOSET-RESIN BONDED, BAGASSE-FIBER REINFORCED, DENSE COMPOSITES



MECHANICAL PROPERTIES OF DRY BLENDED, PHENOLIC BONDED, BAGASSE FIBER REINFORCED COMPOSITE

Flexural Strength (psi)	
Dry	7200
Wet	5500
Flexural Modulus (psi, 10^3)	
Dry	710
Wet	510
Tensile Strength (psi)	
Dry	4130
Wet	3600
Tensile Modulus (psi, 10^3)	
Dry	830
Wet	680
Water Pickup (%)	1.9

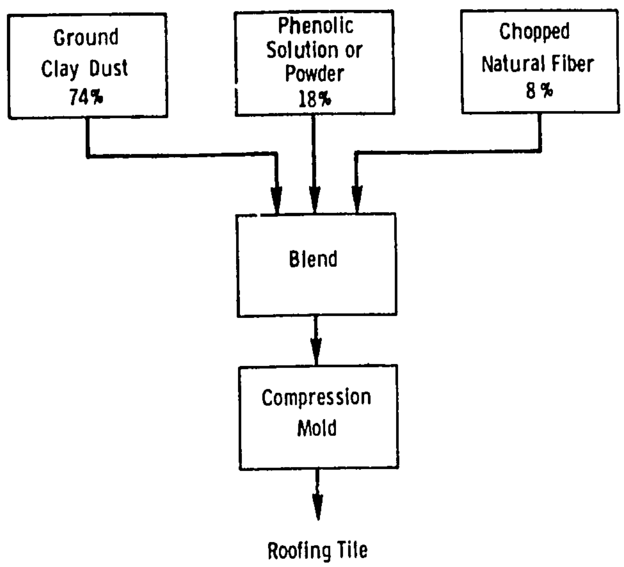
WET PROCESS, TS RESIN BONDED, DEPITHED FIBRILATED ORIENTED BAGASSE FIBER REINFORCED COMPOSITES



MECHANICAL PROPERTIES OF WET PROCESS PHENOLIC BONDED (3-10%) ORIENTED BAGASSE FIBER REINFORCED COMPOSITES

	*	=	⊥
Flexural Strength (psi)			
Dry	3100	4700	1740
Wet	1500	1990	520
Flexural Modulus (psi, 10^3)			
Dry	480	600	250
Wet	200	330	95
Tensile Strength (psi)			
Dry	1780	5410	1130
Wet	600	1700	510
Tentile Modulus (psi, 10^3)			
Dry	650	910	365
Wet	240	290	100
Water Pickup (%)	40	33	34

WET OR DRY BLENDED, RESIN BONDED, UNFIRED CLAY TILE



MECHANICAL PROPERTIES OF WET AND DRY BLENDED, PHENOLIC BONDED, UNFIRED CLAY

	% Resin					
	2.5	5.0	7.5	20	50	18*
Flexural Strength (psi)						
Dry	2160	1980	2020	5200	12,000	1900
Wet	-	-	-	2300	13,000	1700
Flexural Modulus (psi, 10^6)						
Dry	1.17	0.85	1.04	1.84	3.0	0.36
Wet	-	-	-	0.8	3.5	0.30
Compressive Strength (psi)						
Dry	3960	6300	8030	11,300	-	-
Wet	470	1800	2260	-	-	-
Compressive Modulus (psi, 10^3)						
Dry	53	75	78	55	-	-
Wet	-	40	45	-	-	-

* with Bagasse

NATURAL FIBER REINFORCED THERMOPLASTIC

Ingredient	% (Vol)	% (Wt)	Material Cost ($/lb)	Component Cost ($/lb of product)
SAN Binder	35	27	0.50	0.135
Whole Bagasse	60	63	0.014	0.009
Ground Clay	3	5	0.005	0.001
Iron Oxide	2	5	0.40	0.02

Material Cost
per lb 0.165
per sq.ft. 0.111

Panel t = 0.1 inch Wt. = 0.67 lb/sq.ft.

NATURAL FIBER REINFORCED NATURAL RUBBER

Ingredient	% (Vol)	% (Wt)	Material Cost ($/lb)	Component Cost ($/lb of product)
Natural Rubber	30	20.5	0.20	0.041
Sulfur	5.5	8.2	0.02	0.0016
Bagasse	52	54	0.005	0.0027
Oil	10	7.4	0.15	0.011
Iron Oxide	1.5	5.6	0.5	0.028
Additives	1.0	4.3	0.8	0.034

Material Cost
per lb $0.118
per sq.ft. $0.08

Panel t = 0.1 inch Wt. = 0.68 lb/sq.ft.

NATURAL FIBER REINFORCED THERMOSET (Dry Blend)

Ingredient	% (Vol)	% (Wt)	Material Cost ($/lb)	Component Cost ($/lb of product)
Phenolic Binder	32	30	0.35	0.105
Chopped Bagasse	61	62	0.02	0.012
Ground Clay	1	2	0.001	0.001
Iron Oxide	2	3	0.50	0.015
Oil	4	3	0.15	0.005

Material Cost
per lb $0.138
per sq.ft. $0.097

Panel t - 0.1 inch Wt - 0.7 lb/sq.ft.

FIBER REINFORCED UNFIRED CLAY TILE

Ingredient	%	Material Cost ($/lb)	Component Cost ($/lb of product)
Clay	70	0.001	0.0007
Phenolic	18	0.35	0.063
Iron Oxide	4	0.40	0.016
Bagasse	8	0.014	0.001

Material Cost
per lb $0.081
per sq.ft. $0.122

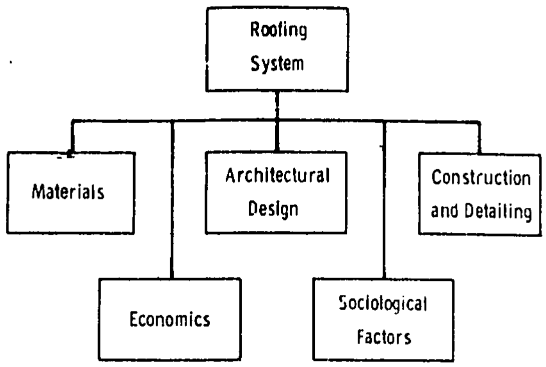
Tile t - 0.15 inch Wt - 1.5 lb/sq.ft.

ECONOMICS OF ORIENTED BAGASSE PHENOLIC BONDED PANEL

Ingredient	Wt (%)	Material Cost ($/lb)	Component Cost ($/lb of product)
Phenolic	3	0.35	0.01
Wax	3	0.15	0.005
Bagasse	94	0.014	0.013

Panel Specifications
Density 75/lbcu.ft.
Thickness - 0.10 in.
Weight - 0.7 lb/sq.ft.

Material Cost
per lb $0.028
per sq. ft. $0.02



CRITERIA FOR ROOF

Requirements	Highly Desirable Characteristics	Wt.
• Keep Off Rain	• Low Cost	—
• Not Leak	• Indigenous Material (>50%)	—
• Water Resistant	• Acceptability	
• Wind Resistant	User	—
• Minimum Strength	Government	—
• Keep Out Direct Sun	• Fire Resistance	—
• Minimum Life (Resist Elements)	• Easy Installation	—
• Available	• Labor Intensive Mfg.	—
	• Reasonable Life (5 yr)	—

DESIRABLE CHARACTERISTICS FOR ROOF

Mechanical

Wt.	Item
___	Impact Resistance
___	Resist Hurricanes
___	Not Increase Truss or Purlin Requirement
___	Support a Person
___	Resist Earthquakes
___	Resist Abrasion
___	Hold House Together
___	Be Strong
___	Be Rigid
___	Security & Protection

Environmental and Life

Wt.	Item
	Maintenance
___	None (5 yr)
___	Easy
___	Ability to Nail, Seal, Cut
___	Lightweight
___	No Vapor or Toxic Fumes on M or P
___	Life - 10 years
___	Simple Tools and Equipment
___	Resistant to Insects, Water, UV
___	Vapor Impermeable
___	Reusable
___	Availability

Optical

Wt.	Item
___	Keep Out Sun
___	Opaque
___	Attractive
___	Shine
___	Color

Social

Wt.	Item
___	Status
___	Contour
___	Smell
___	Overhang
___	Material
___	Texture

Thermal

Wt.	Item
___	Keep Off Sun
___	Resist Heat
___	Ventilation
___	Thermal Control retain heat reflect heat keep in heat keep out heat keep out cold keep in cold

Acoustic

Wt.	Item
___	Not Noisey in Wind or Rain
___	Sound Absorbing
___	Poor Sound Transmission
___	Damping

TYPES OF ROOFING IN COMMON USE

- Galvanized Iron
  - Corrugated
  - Flat
- Corrugated Aluminum
- Cement Abestos
  - Flat
  - Corrugated
- Tile
  - Clay, Fired
  - Cement
  - CA
  - Mud
- Wood
  - Shingle
  - Plank
- Asphalt
  - Plain
  - Shingle (aggregate)
  - Tar Paper
- Particle Board
- Thatch
  - Grass
  - Bamboo
  - Leaves
  - Reeds
- Corrugated Vinyl
- Corrugated Reinforced Polyester
- Plastic Film

WHY CORRUGATED GALVANIZED IRON ROOFING IS USED

- Low Cost
- Low Weight
- Low Volume - 30 gage
  Shipping & Joining
- Life - 2 to 40 Years
- Able to Nail
- Paintable
- Keeps Off Sun and Rain
- Provides Heat in Cooler Periods
- Easy to Install - Low Skill Required
- Available !
- Status
- Collect Rain Water -
  No Mold Problen
- Resists Wind
- Tough
- Fire Resistant
- Vapor Barrier
- Maintenance Free

PROBLEMS OF CORRUGATED GALVANIZED IRON ROOFING

- Rusting
- Poor Thermal Barrier
- Low Mass
- Tendency to Fly
- Range of Quality
- Contaminate Water
- Over Acceptance
- High Import Costs
- Noisey
- Removable

APPENDIX D

PROPOSED "MEMORANDUM OF AGREEMENT" PHILIPPINES

D R A F T

MEMORANDUM OF AGREEMENT

THE UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT (USAID)
THE NATIONAL ECONOMIC AND DEVELOPMENT AUTHORITY (NEDA), AND
THE NATIONAL SCIENCE DEVELOPMENT BOARD (NSDS)

Recognizing that adequate housing is one of the critical requirements of the Philippines;

Aware that a roof is one of the key and most costly elements in basic human shelter; and

Realizing that there is a great need for improved roofing that is low in cost, has a low foreign exchange component, has improved thermal insulation properties, and utilizes abundant indigenous materials and manpower;

Have agreed to undertake a cooperative research project entitled "ROOFING MATERIALS DEVELOPMENT IN THE PHILIPPINES," hereinafter called the "Project," which shall be implemented in accordance with the following provisions:

A R T I C L E I

OVERALL TECHNICAL OBJECTIVE

The overall technical objective of the project is to:

1) Further develop and optimize the processes for manufacturing the roofs on a small scale; and

2) Evaluate the physical properties, durability, acceptability and costs of several roofing compositions or composites which have been developed in laboratory research by Monsanto Research Corporation, U.S.A.,

With emphasis on: low cost (particularly foreign currency costs); strength, fire resistance and longevity; resistance to solar radiation, heat, rain, wind, sound transmission; insects and other vermin; local acceptability of its appearance and form; utilization of abundant and cheap local materials such as agricultural residues; and labor intensiveness in manufacture.

A R T I C L E I I

DURATION

The project shall be undertaken for a period of one and one half (1-1/2) years, effective from the day the document has been signed.

A R T I C L E I I I

METHODS AND STRATEGY

1) The USAID, through Monsanto Research Corporation, shall introduce four (4) processes that will produce four (4) types of roofing materials, namely:

a. Melt-Compounds, Resin-Bonded, Bagasse-Fiber REinforced Composites;

b. Wet or Dry-Blended, Thermoset-Resin Bonded, Bagasse-Fiber Reinforced Composites;

c. Wet Process, TS Resin Bonded, Depithed Fibrillated Oriented Bagasse Fiber Reinforced Composites; and

d. Wet or Dry Blended, Resin Bonded, Unfired Clay Tiles

2) The NSDB, through the implementing agencies whose respective authorities and reponsibilities are indicated in Appendix "A" hereto attached and made integral part hereof, shall undertake the following activities, including cost analysis to determine the economic feasibility:

a. Production of samples using five (5) systems

b. Testing and evaluation

c. Modification and optimization

d. Testing and evaluation

e. Selection of samples and roofing design

f. Production of roof panels enough for four (4) houses
and for further testing

g. Testing and evaluation

3) The aforesaid activities shall observe and be guided by the time table (Appendix "B") hereto attached and made integral part hereof.

4) Thereafter, there shall be a ranking of the candidate roofing materials in the order of overall merit, and then a selection of no more than two for larger scale production and evaluation.

5) The selected roofings shall be manufactured locally in cooperation with the Monsanto Research Corporation and Washington University representatives on a scale sufficient to demonstrate the practicality of the process; and to supply materials for four (4) houses. The manufactured roofing will then be installed on a minimum of four (4) houses built on a site selected by the NSDB.

6) USAID and NSDS shall monitor the installed roofings for a period of six (6) months to determine whether there are any signs of early deterioration.

A R T I C L E I V

PERIODIC REPORTS

The NSDS shall submit to USAID brief quarterly reports on the progress and technical aspects of the project as well as quarterly reports of expenditures of project funds.

A R T I C L E V

FUNDING

1) The funding of the project shall consist of the contribution of the USAID in the total amount of $50,000.00 in cash to defray the salaries of at least two (2) professional engineers ane two (2) technicians; the costs of necessary supplies, raw materials and specialized equipment; and the expenses for the training of two (2) members of the Technical Committee of the NSDB at the MRC Dayton Laboratories for a period of 2 to 4 weeks during the early part of the implementation of the project. Said amount shall be released to the NSDB in two (2) equal parts - the first half upon the signing of this Memorandum

of Agreement, and the second half on or before ____________________.

2) The NSDB shall put up a matching or counterpart contribution in the form of salaries of additional personnel, facilities, equipment, laboratory space wherein small scale experiments can be carried out under controlled conditions, and other miscellaneous items, with a total value of $350,000.00 equivalent to $50,000.

A R T I C L E V I

OWNERSHIP OF PATENTS

Any patents obtained from the project shall be jointly owned by the USAID and the Philippine Government (through the NSDB) but neither of them shall derive any royalty for the use of said patents as the same shall be made freely available to the world community. Likewise, neither of them shall restrict the other from mass producing the product within respective countries in commercial quantity either by local consumption or for export or both

A R T I C L E V I I

AMENDMENT

Amendments to this agreement may be proposed by any of the parties and shall be adopted by their unanimous consent expressed in writing.

A R T I C L E V I I I

EFFECTIVITY

This Agreement shall take effect immediately.

Done at Manila, Philippines, on this ____ day of September 1975.

FOR THE UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT.

____

FOR THE NATIONAL ECONOMIC AND DEVELOPMENT AUTHORITY:

____

FOR THE NATIONAL SCIENCE DEVELOPMENT BOARD:

FLORENCIO A. MEDINA
Chairman

CONFORME:

FOR THE MONSANTO RESEARCH CORPORATION

IVAL O. SALYER

APPENDIX E

CUMULATIVE LIST OF JAMAICAN CONTACTS

APPENDIX E

CUMULATIVE LIST OF JAMAICAN CONTACTS

Organization	Representative	Title
Douet Brown Adams and Partners 7 Lismore Avenue Kingston 5 Phone: 926-3485	Mr. Alfrico D. Adams Mr. Raymond Brown	Chartered Engineer and Partner Partner
Ministry of Housing 2 Hagley Park Road Kingston 10 Phone: 936-1590, Ext. 330	Rev. Gerald L. McLaughlin Ms. Nadine Isaacs Mr. Roydell E. Kinghorn Mr. Fitz Ford Mr. Clovis McLean Mr. Angus W. McDonald Mr. Reggie Cardosa	Special Advisor to the Minister Architect Sr. Executive Engineer Head, Technical Service Section Acting Permanent Secretary Ex-Permanent Secretary Sites and Services Group
Ministry of Works 140 Maxfield Avenue Kingston Phone: 936-3110	Mr. L. A. Dixon	Architect
Scientific Research Council Old Hope Road, P.O. Box 350 Kington 6 Phone: 937-9931 (32,22)	Dr. Ken E. Magnus (to 9/75) Mr. Fred Campbell	Technical Director Senior Principal Scientific Officer
National Housing Corp. 6a Oxford Road, P.O. Box 4B Kingston 6 Phone: 926-5854 (55,56)	Ms. T. Nelson Ms. Porene Williams	Research Office, Science and Technology Sociologist, Marketing Analyst
Bureau of Standards 6 Winchester Road Kingston 10, Phone: 926-3140	Dr. A. S. Henry Mr. Campbell Mr. Alroy K. Elliott Mr. W. Nembhard	Director Head, Materials Manager, Administrative Secretary Standards Scientific Officer
University of West Indies Mona Road Kingston 7 Phone: 927-0751	Dr. Thomas Hughes Dr. Marshall Hall	Professor of Material Science Economist, Dept. of Management Studies
Jamaica Industrial Development Corp. 4 Winchester Road, P.O. Box 505 Kingston 10 Phone: 936-3130		
Urban Development Corp. 40 Harbour Street Kingston Phone: 929-2240	Mr. David Gregory Jones Mrs. Gloria Knight Mr. Karl Thorne	Chief Architect/Planner General Manager Sr. Architect/Planner
Knox Development Foundation P.O. Box 45 Spaldings Phone: 964-2359	Mr. Lewis Davidson	Director
Standard Building Products (Jamaica) Ltd. P.O. Box 29 66 Corletts Road Spanish Town Phone: 984-2295	Mr. Douglas Wynter Mr. M. K. S. Biersay	Technical Director Vice President for Sales and Marketing
Berger Paints 256 Spanish Town Road Kingston 11 Phone: 923-6226	Mr. M. S. Fennel Mr. Dervin R. Brown	General Manager Technical Manager
Thermoset Ltd. Office - 14 Dominica Drive Kingston 5, Jamaica Plant - Naggo Head Phone: 936-5920 936-6394	Dr. Lester A. D. Chin Mr. James A. Blackwood	Technical Director Managing Director
Plastics Products Ltd. 2 Jones Avenue Kingston 11 Phone: 933-6379 923-6450	Mr. Stanely L. Borland Mr. Jerry E. Burwell	Managing Director Technical Director
Goodyear Jamaica Ltd Office - 29 Tobago Avenue Kingston Plant - Morant Bay Phone: 926-8018 982-2353	Mr. T. S. Elliott Mr. Helmut Schueller	Manager, GMMC Technical Superintendent
Thermo-Plastics (Jamaica) Ltd. 45 Elma Crescent Boulevard P.A. Phone: 935-2390 925-1050	Mr. Desulme Mr. Yvon T. Desulme Mr. Ludwig Reisinger	President Purchasing Manager Manufacturing Manager
A. P. Pattinson Co. 2 Marcus Garvey Drive Kingston Phone: 932:0365	Mr. A. P. Pattinson	Manufacturer's Representative
U.S. A.I.D. Mission to Jamaica Duke Street Kingston Phone: 932-6340	Mr. Peter Kolar Mr. Edilberto Alarcar Mr. Curry Brookshire	Program Officer Engineering Agriculture

Organization	Representative	Title
Jamaica Manufacturers Assn. 85a Duke Street Kingston. Phone: --9-5515	Mr. Douglas Vay	President
Coconut Industry Board 18 Waterloo Road Kingston, 10 Phone: --6-1770	Mr. Nel E. Poster Mr. David Romney	Manager Director of Research
Banana Board 10 South Avenue Kingston, 4 Phone: --2-5490	Mr. David Lord Mr. Trevor Donaldson Dr. D. Fixley	Managing Director Chairman Member
Systems Building Co., Ltd. 42a Upper Waterloo Road Kingston, 8 Phone: --4-5429	Mr. Dennis Simmons	Quantity Surveyor
Space Utilization Group Ltd. Apt. 6, St. James Court 7 Kingsway, Kingston 10 Phone: --6-9845 (pay)	Mr. Angus W. MacDonald	Architect
Jamaica Master Builders 4 Ballater Avenue Kingston 10 Phone: --6-4588	Mr. Ruddy Austin	Member
Mutual Housing Service 9 Tangerine Place Kingston Phone: --6-4766	Paul Thompson	Director (?)
Design Collaborative 3 Dunfries Rd Kingston 10 Phone: --6-4288	Patrick Stanigar	Architect
Rutkowski Bradford & Partners Architects 7 Cecelio Avenue Kingston, 10 Phone --6-3150	Mr. Herb Bradford	Architect and Principal
Architects	Ted Warmington	Architect/Builers/Developer

APPENDIX F

CUMULATIVE LIST OF PHILIPPINE CONTACTS

APPENDIX F

CUMULATIVE LIST OF PHILIPPINE PERSONNEL CONTACTED ON LOW COST ROOFING PROGRAM

	Name	Organization	Position
1.	Mr. Garnett Zimmerly	USAID	Mission Director
2.	Mr. Robert Halligan	USAID	Assistant Program Officer
3.	Mr. P. M. Groves	USAID	Agriculture
4.	Mr. Allen C. Hankins	USAID	Agriculture
5.	Mr. Albert S. Fraleigh	USAID	Food-For-Peace
6.	Mr. Ruben C. Delgado	USAID	Food-For-Peace
7.	Mr. Richard M. Dangler	USAID	Capitol Development
8.	Mr. Thomas E. Johnson	USAID	Deputy Assistant Director, Capitol Division
9.	Dr. Josefina M. Ramos	National Economic Development Authority (NEDA)	City Planner
10.	Miss Nuna Almanzar	National Science Development Board (NSDB)	
11.	Mrs. Bonita Serrano	National Science Development Board (NSDB)	
12.	Gen. Florencio A. Medina	National Science Development Board (NSDB)	Chairman
13.	Mr. Pedro Afable	National Science Development Board (NSDB)	Vice Chairman
14.	Ms. Lydia G. Tansinsin	National Science Development Board (NSDB)	Assistant to Chairman
15.	Mr. Jose O. Jaug	National Science Development Board (NSDB)	
16.	Dr. Francisco Tamalong	Forest Products Research and Industries Development Commission (FORPRIDECOM)	Commissioner
17.	Dr. Filiberto S. Pollisco	FORPRIDECOM (Forest Research Division)	Director
18.	Dr. Mario Eusebia	FORPRIDECOM	Associate Commissioner for Research Research
19.	Mr. Joaquin O. Siopongco	FORPRIDECOM	Engineer
20.	Dr. Vedesto R. Jose	National Inst. Science and Technology	Director
21.	Mr. Severino Bernardo	National Inst. Science and Technology	Scientist
22.	Mrs. Guillermina G. Mañalac	National Inst. Science and Technology	Scientist
23.	Gen. Gaudencio V. Tobias	National Housing Corporation	Executive Vice President
24.	Colonel Alejandro R. Kabiling	National Housing Corporation	-
25.	Mr. F. C. Pamatruat	National Housing Corporation	-
26.	Col. Manuel R. Rebueno	Peoples Homesite and Housing Corporation	-
27.	Mr. Ramon R. Veto	Peoples Homesite and Housing Corporation	Engineer
28.	Mr. Sebastian B. Santiago	Peoples Homesite and Housing Corporation	General Manager
29.	Dr. Carlos A. Javier	Presidential Assistant on Housing and Resettlement Agency	Executive Director
30.	Mr. J. P. Cabazar	Presidential Task Force on Human Settlements	Coordinator
31.	Dr. Angel Lazaro, Jr.	Philippines Institute of Civil Engineers	
32.	Dr. Aurelio T. Juguilon	University of Philippines, College of Architecture	Dean, College of Architecture
33.	Dr. Alfredo L. Junio	University of Philippines, College of Architecture	Dean, College
34.	Dr. Gironimo Manahan	University of Philippines Building Research Service	Professor
35.	Dr. Ernesto G. Tabujara	University of Philippines College of Engineering	Associate Professor
36.	Dr. Rufino Ignacio	Mindanao State University	Dean
37.	Dr. Eric S. Casino	Mindanao State University	Mindanao Executive Development Academy
38.	Atty. Edwin F. Acoba	Mindanao State University	Vice President
39.	Mr. Simplicio Endaya	Special Task Force, Office of the President	New City Planner
40.	Dean Cesar H. Concio	National Housing Code	Cesar H. Concio and Associates
41.	Mrs. Ofelia V. Bulaong	Board of Investments	Chief Analyst
42.	Col. A. Fernando	National Housing Council	-
43.	Mr. W. Encarnation	National Housing Council	-
44.	Mr. Perlito C. Reyes	DCCD Engineering Corporation	Vice President
45.	Mr. A. G. Westly	Jardine Davies, Inc.	Manager
46.	Mr. A. W. Russell	Jardine Davies, Inc.	Manager
47.	Mr. Sergio Y. Hilado	Jardine Davies, Inc.	Manager, Technical Services
48.	Mr. Ramon A. Pedrosa	.A. Soriano Corporation	Vice President
49.	Mr. Jose R. Zaragoza, Jr.	Systems and Structures	Vice President Engineering and Sales
50.	Mr. Alfonso P. Panares	Philippine Rubber Project Co.	Liaison Officer
51.	Dr. Reynaldo A. Adriano	Borden International-Philippines	Vice President
52.	Mr. Ernesto Echauco	Resins, Inc.	Vice President
53.	Mr. Benjamin M. Misa	Resins, Inc.	Engineer
54.	Mr. Maneleo J. Carlos, Jr.	Resins, Inc.	Engineer
55.	Mr. Aristo T. Yeasiano	Ramie Textiles, Inc.	Vice President
56.	Herman M. Montenegro	Pacific Activated Carbon, Inc.	President

APPENDIX G

CUMULATIVE LIST OF ZAMBIAN CONTACTS

APPENDIX G

CUMULATIVE LIST OF ZAMBIAN CONTACTS

Organization	Representative	Title
Ministry of Local Government and Housing	Mr. Aldrich Adamson	Permanent Secretary
Steelbuild Holdings, Ltd.	Mr. R. S. K. Chiluwe	Managing Director
	Mr. Brian Moyo	
Zambesi Saw Mills	Mr. Dockrell	
Roan Mining Company	Mr. Eastwood	
Lusaka City Council	Mr. A. D. C. Godavitarna	City Engineer
Ministry of Land and Natural Resources	Mr. Greenwood	Forest Products Research Officer
	Mr. A. D. K. Hardie	Forest Products Research Officer
Government of the Republic of Zambia	Honorable Peter Matoka	Minister of Local Government and Housing
	Honorable Siteke Mwale	Ambassador to the USA
National Council for Scientific Research	Dr. D. S. Nkunika	Secretary-General
	Dr. Silangua	Deputy Section Gen
	Mr. O. Sodie	Farm Building Engineer
	Mr. Simon Zukas	Chairman Engineering and Construction Committee
National Housing Authorty	Dr. Durk Jol	Architect
	Mr. Richard Martin	Senior Architect
	Mr. Mutale	Managing Director
	Mr. J. T. Robertson	Financial and Administrative Mgr.
Ministry of Local Government and Housing	Mr. A. Mbanga	Under Secretary Housing
	Mr. K. S. Yowamu	Assistant Secretary Housing
University of Zambia	Mr. Don Anderson	Physics Department
	Mrs. Don Anderson	Physics Department
	Mr. S. Uzsoy	Professor, Civil Engineering
Vitafoam Ltd.	Mr. J. Ndhlovire	
Polyproducts, Ltd.		
TAP Building Products Ltd.	Mr. Barrie D. McCurdy	General Manager
	Mr. Bill Young	Sales Manager
Intercontinental Hotel	Mr. Tabri	
U. S. Embassy	Mr. Bobat	Cashier
	Mr. Ray Jorgensen	Economic Commercial Officer, AID Operations Officer
	Mr. Harvey Nelson	Deputy Chief Mission
	Mr. Charles Sten	Counselor Officer
	Mr. Aurthur Wilson	Public Relations Officer

APPENDIX H

CUMULATIVE LIST OF GHANA CONTACTS

APPENDIX H

CUMULATIVE LIST OF PERSONNEL IN GHANA RELATING TO AID ROOFING PROGRAM

Name	Organization	Position
1. Mr. Haven North	USAID - Accra	Mission Director
2. Mr. David Dibble	USAID - Accra	Private Enterprise Officer
3. Mr. Alan W. Sudhott	USAID - Accra	Agricultural Advisor
4. Ms. Lou Anne Daures	USAID - Accra	Intern
5. Ms. Judy Bryson	USAID - Accra	Women's Programs
6. Mr. M. F. Owierdu	Bank of Ghana	Executive Director
7. Mr. H.N.O. Quao	Bank of Ghana	Deputy Chief, Development Finance
8. Mr. G. O. Kesse	Geological Survey Dept.	Acting Director
9. Mr. H. K. Quartey-Papafio	Ministry of Agriculture	-
10. Mr. S.D.K. Kaportufe	Ministry of Lands and Mineral Resources	-
11. Mrs. Sarah Samuel	League of Insured Savings	-
12. Mr. I. M. K. Lartey	Ghana Housing Corporation	-
13. Mr. Vik Adegbite	TEMA Development Corporation	Chief Development Officer
14. Mr. Mirtneh Tirgie	Bol Housing Project	Site Agent
15. Dr. J.W.S. DeGraft-Johnson	Building and Roads Research Institute	Director
16. Mr. Kwesi Manuel	Building and Roads Research Institute	Chief Adm. Officer
17. Mr. John Nutsugah	Building and Roads Research Institute	Research Officer, Architecture Div.
18. Mr. A. K. Chatterjee	Building and Roads Research Institute	Chief Research Officer (Materials)
19. Dr. M. D. Gidigasu	Building and Roads Research Institute	Chief Research Officer (Soils)
20. Dr. K. Amonoo-Neizer	Building and Roads Research Institute	Chief Research Officer (Structures)
21. Mr. F. W. Addo-Ashong	Forest Products Research Institute	Director
22. Mr. W. K. Ashiabor	Forest Products Research Institute	Research Officer
23. Dr. Accrey	Crops Research Institute	Director
24. Mr. Knight	Crops Research Institute	Administrative Officer
25. Dr. G. K. Buahin	Crops Research Institute	Senior Research Officer
26. Dr. P. A. Biaku	Crops Research Institute	Director
27. Dr. B. Biswas	University of Science and Technology	Sr. Associate Professor, Dept. of Chemistry
28. Prof. Robert Chapman	University of Science and Technology	Professor, Engineering
29. Dr. J. Powell	University of Science and Technology	Head, Technology Consultancy Centre
30. Dr. Alex Scheinesson	University of Science and Technology	Sr. Project Advisor, Technology Consultancy Centre
21. Dr. P. Austin-Tetteh	University of Science and Technology	Dean, Faculty of Architecture
22. Dr. F. A. Abloh	University of Science and Technology	Head, Dept. of Housing and Planning Research, Faculty of Architecture
23. Mr. Victor Bartels	University of Science and Technology	Sr. Research Fellow, DHPR, Faculty of Architecture
24. Mr. A. Gbeckor-Kove	University of Science and Technology	Senior Technician, DHPR, Faculty of Architecture
25. Mr. Sam Spencer	University of Science and Technology	Senior Lecturer, Dept. of Building Technology, Faculty of Architecture
26. Mr. Francois Pfister	University of Science and Technology	Senior Research Fellow, DHPR, Faculty of Architecture
27. Mr. John Dye	University of Science and Technology	Peace Corps Assignee to DHPR, Faculty of Architecture
28. Mr. J. W. Twum	Bast Fibers Development Board	Executive Director
29. Mr. C. C. Hoyt	Fireston-Ghana, Ltd.	Comptroller
30. Mr. Kalil Farhry	Ghana Rubber Company	Managing Director
31. Mr. Phillip Westray	Ghana Rubber Company	General Manager
32. Mr. H. Gormans	Ghana Sugar Estates	Managing Director
33. Mr. Nadim Bitar	Logs and Lumber Limited	Owner-Manager
34. Mr. N.B.X.P.M. Meijer	Reiss and Company (Ghana) Ltd.	Technical Sales Representative

APPENDIX I

CORRESPONDENCE FROM FIELD TRIP (GHANA)

Cables and Telegrams: MINERALS
Telephone: 65421
In reply please quote
LMR.35/2

REPUBLIC OF GHANA

MINISTRY OF LANDS AND
MINERAL RESOURCES
P.O. BOX M.212
ACCRA

24th August, 1973.

Dear Sir,

USAID CONTRACT AID/CM/ta-C-73-12:
LOW-COST ROOFING MATERIALS

I write to inform you that Mr. G.N. Coleman has called at this Ministry on Wednesday, 22nd August, 1973.

2. Together, Mr. Coleman and the under-signed had some useful discussions on your programme. The programme as conceived falls perfectly in line with Government's own priorities with special reference to the provision of low-cost houses for the workers of this country.

3. Obviously, this Ministry will like to see the programme through within the shortest possible time in view of the urgency Ghana, like other developing countries, attaches to measures aimed at minimising housing costs.

4. The Ag. Director of Geological Surveys has been informed to offer any help that your preliminery studies may require.

5. It is hoped that this Ministry will hear from you again on the matter.

Yours faithfully,

for: PRINCIPAL SECRETARY
(S.D.K. KPORTUFE)

J.P.R. FALCONER ESQ.,
(ASSOCIATE DIRECTOR)
CENTRE FOR DEVELOPMENT TECHNOLOGY,
BOX 1106,
WASHINGTON UNIVERSITY,
ST. LOUIS,
MISSOURI 63130.

In case of reply the number and date of this letter should be quoted.

My Ref. No. M/A.13/19/21

Your Ref. No.___

REPUBLIC OF GHANA

M.A. Form 7
MINISTRY OF AGRICULTURE
P.O. BOX M.37
ACCRA

28th August, 1973.

Dear Sir,

USAID CONTRACT AID/CI1TA-C.73-12
LOW COST ROOFING MATERIAL

On 22nd August, 1973 Mr. Coleman, Research Architect, Centre for Development Technology of Washington University of which you are an Associate Professor visited my office and had very interesting discussion with me about the above research contract.

He made me to understand that your University is holding a sub-contract for developming locally availacle roofing materials to cut down the cost of housing projects in industrialising areas of the world and that it is intended to select among others certain countries in Africa, where this research would be conducted.

The provision of low cost houses for the people of this country is receiving the serious attention of the Government and any contribution from your institution in finding out how to reduce the cost of housing through the use of as much local material as possible would be welcome. This Ministry would therefore support this project and intends to co-operate with the research team when they visit the country.

It is hoped that Ghana will provide the necessary condition which will favour its selection as one of the African countries, for the execution of this research project.

Yours Sincerely,

J.K. Quartey-Papafio

for: AG. DIRECTOR OF AGRICULTURE
(H.K. QUARTEY-PAPAFIO)

PROF. J.P.R. FALCONER,
ASSOCIATE DIRECTOR,
CENTRE FOR DEVELOPMENT TECHNOLOGY,
P. C. BOX 1106,
WASHINGTON UNIVERSITY,
ST. LOIUS, MISSOURI 63130

-3

TEMA DEVELOPMENT CORPORATION

TELEPHONE: TEMA 2781-4 (4 Lines)
TELEGRAPHIC ADDRESS: "TEDICO"

P.O. Box 46,
TEMA.
Ghana.

Our Ref. CDO/GEN/36.

Your Ref.

August 24, 1973.

Dear Sir,

COLLABORATION WITH THE CENTRE FOR DEVELOPMENT TECHNOLOGY, WASHINGTON UNIVERSITY, SAINT LOUIS, MISSOURI 63130 IN THE RESEARCH, DEVELOPMENT, PROTOTYPE CONSTRUCTION AND EVALUATION OF LOW-COST ROOFING MATERIALS IN INDUSTRIALIZING WORLD AREAS.

Reference Mr. George N. Coleman, Research Architect's visit to our office in respect of the above, we have much pleasure to state that we are very interested in the project, and that we are willing to collaborate with you. It might interest you to know also that we have a modest Research Unit in our Development Department which has been carrying-out quite a few operational research projects into the design materials, and construction techniques in low-cost housing with a view to reducing costs while at the same time providing functional, structurally sound and aesthetically pleasing housing units utilizing as much local materials as possible.

We enclose a copy of our Tema Development Corporation Magazine in which one would find at pages 26 - 32 the methodology of our Unit.

We are looking forward to a fruitful collaboration.

Very truly yours,

CHIEF DEVELOPMENT OFFICER.
(VIK. ADEGBITE)

Mr. J.P.R. Falconer,
Associate Director,
Centre for Development Technology,
P. O. Box 1106,
Washington University,
St. Louis,
MISSOURI 63130.
U. S. A.

Encl.

CROPS RESEARCH INSTITUTE

DIRECTOR
Dr. W. K. AGBLE, B.Sc., M.Sc., Ph.D.
P.O. Box 3785
KUMASI, GHANA
Telephone KUMASI 6221
Telegraphic Address "CROPSEARCH"

P.O. Box No. 3785,
Kumasi,
Ghana.

Our Ref. No. CVG/2/V.4/160

Your Ref. No. -

20th August, 1973.

COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

Dear Sir,

USAID CONTRACT AID CM/ta-C-73-12:
Low-Cost Roofing Materials

I refer to your letter dated 9th August, 1973, and would like to inform you that Mr. G.N. Coleman, Research Architect, Center for Development Technology, Washington University, called at the Crops Research Institute on the 20th of August, 1973 and had discussions with Dr. G.K. Buahin, Senior Research Officer and the Acting Director of this Institute. This Institute will be pleased to co-operate in the above project when called upon to do so. We would also be prepared to provide any information that will be related to the Institute's field of research.

Many thanks.

Yours faithfully,

(P.A. Biaku)
for: DIRECTOR

Mr. J.P.R. Falconer,
Associate Director,
Center for Development Technology,
Washington University,
P. O. Box 1106,
Saint Louis,
Missouri 63130, U.S.A.

PAB/JBD:

FOREST PRODUCTS RESEARCH INSTITUTE
(C.S.I.R.)

Telephone
Kumasi 3301, ext. 400
Kumasi 5873
Telegraphic Address
"FORMARCH"

University P.O. Box 63
Kumasi
Ghana

21st August 1973

Our Ref. FPL/149/Vol.2/ 824

Mr. J.P.R. Falconer,
Associate Director,
Center for Development Technology,
Washington University,
P.O. Box 1106,
Saint Louis,
Missouri 63130,
U. S. A.

Dear Sir,

USAID CONTRACT AID CM/ta-C-73-12:
DEVELOPMENT OF LOW COST ROOFING MATERIALS

Your letter on the above subject has been received with thanks. In addition, Mr. G.M. Coleman, Research Architect, Center for Development Technology, Washington University, has called on me at at the F.P.R.I. on both 20th and 21st of August, 1973, and has explained to me the purpose of his visit to Ghana. I told Mr. Coleman all about the work we have been doing on Wood wool for Low Cost Housing and the possibility of using Wood wool for roofing purposes.

It is a fact that wood wool has been used in Ghana for the roofs of certain houses with variable successes and it is our intention to develop this further with other materials to improve its purpose as a roofing material. I was therefore highly interested in the project outlined in your letter referred to above and this Institute will be very willing to co-operate with you in finding solution to the problem of roofing in Low Cost Houses in Tropical areas. I hope that you will keep in touch so that we pull our resources together for a possible solution of the problem.

Our Mr. W.K. Ashiabor is working on Wood wool full time and we have recently been receiving some support from the IDRC of Canada for the purpose. It is expected that something substantial will come out of the project and if your agency will co-operate with us, I am sure our efforts will not be vain.

I look forward to hearing from you in due course.

Yours sincerely,

(F.W. ADDO-ASHONG)
DIRECTOR

Department of Housing & Planning Research

Faculty of Architecture · University of Science and Technology Kumasi Ghana

Telephone: Kumasi 4361, 5351
Cables: Housing Kumasitech

Our Ref. RD.107/Proj.11/Vol.4
Date 21st August, 1973.

Mr. J.P.R. Falconer,
Associate Director,
Center for Development Technology,
Washington University,
P. O. Box 1106,
Saint Louis,
Missouri 63130
U. S. A.

Dear Sir,

USAID CONTRACT AID/CM/TA-C-73-12
LOW-COST ROOFING MATERIALS

Thank you very much for your letter on the above subject.

I wish to inform you that Mr. G.N. Coleman, your Research Architect, called on me at the Department both yesterday August, 20th and today 21st August, 1973, and explained to me the purpose of his visit, and aims and objectives of the forth-coming Research Project.

He sought, among other things, the Department's interest and willingness to co-operate in the Project should Ghana be selected as one of the countries where the work will be done.

I mentioned briefly to Mr. Coleman, some of our efforts in the area of Roof Material and Roof System Development i

(1) Lamella Roof Truss
(2) Cement Screed on Wood frame
(this is just starting, as such there is no written material available)

We are therefore, very much interested in the project as described in your letter, and will be very willing to co-operate with you fully during the various stages of work.

We look forward to hearing from you again soon.

Yours sincerely,

Fred Abloh

FAA/MAA+

(Assoc.Prof. F.A. Abloh)
HEAD OF DEPARTMENT

-7

In case of reply the number and date of this letter should be quoted

My Ref. No. T.70/4

Your Ref. No.

Telephone ACCRA: 28093

REPUBLIC OF GHANA

Geological Survey Department
Ministry Branch Post Office
P.O. Box M.80
Accra, Ghana

22nd August, 1973

Dear Sir,

USAID CONTRACT AID CM/ta-C-73-12:
DEVELOPMENT OF LOW COST ROOFING MATERIALS

This is to inform you that Mr. G.N. Coleman Research Architect, Center for Development Technology visited the Ghana Geological Survey Department on Wednesday, August 15th 1973 and on Wednesday August 22nd 1973 in connection with the above Research Project.

Mr. Coleman explained to me the purpose of his visit the nature and objectives of the research contract. He sought the interest of this Department in co-operating with the above research effort, by way of making available any information about the availability of natural resources which might be utilized in roofing materials.

He explained also that if Ghana be selected as one of the countries in which the research will be performed, a research team will visit the country sometime in October this year to gather detailed and relevant information, pertaining to the above project.

We wish, very much to assure you of our interest and full co-operation with you during all stages of this research work, and look forward to seeing you soon.

Yours sincerely,

G. O. Kesse

ACTING DIRECTOR, GEOLOGICAL SURVEY
(G. O. KESSE)

MR. J.P.R. FALCONER,
ASSOCIATE DIRECTOR,
CENTER FOR DEVELOPMENT TECHNOLOGY,
WASHINGTON UNIVERSITY,
P.O. BOX 1106,
SAINT LOUIS,
M I S S O U R I 63130,
U. S. A.

/LKS

-8

GHANA HOUSING CORPORATION

CONSTITUTED BY ORDINANCE No. 31 of 1955

P. O. Box 2753, ACCRA, Telephone No. 21422 (4 Lines)

● In case of reply the number and date of this letter should be quoted.

My Ref. No. ADM/209/VOL.II

Your Ref. No.

24th August, 1973

Dear Sir,

RESEARCH INTO LOW COST ROOFING MATERIALS BY MONSANTO RESEARCH CP DAYTON U. S. A.

We were very pleased to receive your Research Architect Mr. G. N. Coleman at our office during his visit to Ghana. The officers in our Planning and Development Division had the opportunity of a lively discussion with Mr. Coleman who actually explained into details, the object of this research. He was able to arouse our interest and willingness to participate in the project should Ghana be selected as one of the countries.

We could foresee how we would benefit from the research to the extent for example, that our main difficulty of roofing estate houses with cheap and durable local roofing materials could be resolved in the near future.

As a start, we mentioned to Mr. Coleman during our discussions, some local materials like straws and saw dust which are now a waste product and which can be used as fillers for roofing composites.

During the visit of the research team to Ghana, we hope they will call on us for further discussions.

Yours faithfully,
STATE HOUSING CORPORATION

For: MANAGING DIRECTOR
(I. H. K. LARTEY)

THE ASSOCIATE DIRECTOR,
CENTER FOR DEVELOPMENT TECHNOLOGY,
P. O. BOX 1106,
WASHINGTON UNIVERSITY,
ST. LOUIS, MISSOURI, 63130,
U. S. A.

cc: Chief Development Officer,
The Architect.

IHKL/MA'

BUILDING AND ROAD RESEARCH INSTITUTE
(COUNCIL FOR SCIENTIFIC & INDUSTRIAL RESEARCH)
UNIVERSITY P. O. BOX 40, KUMASI-GHANA. Telephone: 4221/2

CABLES : BRIGA

Our Ref.............................

Your Ref.............................

Address your reply to 'The Director'

22nd August, 1973

Dear Sir,

I have been given a copy of your letter of introduction that you gave to Mr.Coleman and I have had a lengthy discussion with him regarding the research project that you are being required to undertake on the development, prototype construction and evaluation of low cost roofing materials.

I have given Mr. Coleman a copy of the Project Statement for a research project we ourselves are undertaking on construction cost reduction. One of the subject programmes under the study relates to Construction Alternatives for building roofs. This project is being undertaken with the support of USAID, Washington and we have been selected by the Ghana Government to undertake it in collaboration with Arthur D. Little Inc. I gave this report to Mr. Coleman to indicate to him our interest in the problems relating to low cost roofing materials. At the same time to point out to him the work being done at our Institute on the subject.

I am happy to note that following our meeting in Washington on the same subject that you are also actively engaged in further work on low cost roofing materials. Naturally, we will be pleased to collaborate with you in seeking a solution to the problems relating to low cost roofing materials. I would like to say that I am particularly pleased that Mr. Coleman is working with you on this programme.

I hope to see you in Ghana in due course.

Yours sincerely,

(J.W.S. DEGRAFT-JOHNSON)
DIRECTOR

Mr. J.P.R. Falconer,
Assoc. Director,
Washington University,
Saint Louis, Missouri 63130.

Thro'
Mr. G.N. Coleman,
U.S.T. Guest House,
ACCRA.

APPENDIX J

MATERIAL IDENTIFICATION AND COSTS

Jamaica Price J¢/lb	US¢/lb	Materials
	1.4	Bagasse - whole from Sugar Mill, water content 10% (cost based on dry weight). (Source: South Coast Corp., Franklin, La.)
		Clay - ground brick grade, Bedford Shale, 8 mesh size. (Source: Claycrafts, Columbus, Ohio)
		Iron Oxide Pigment - Mapico #447 (Source: Cities Service Co., Columbian Div. Monmouth Junction, N.J.)
17		Sulfur - 794 COND Sulfur (Source: Harwick, Akron, Ohio)
		ABS (Acrylonitrile Butadiene Styrene) - Lustran I-780-1000 (Source: Monsanto Polymers & Petrochemicals Company, St. Louis, Mo.)
47		Natural Rubber - gum from Malaysia MR-5 (Source: Firestone) - latex from Malaysia Hartex S-4, 62.4% solid (Source: Firestone Tire & Rubber Co., Akron, Ohio)
		Extender oil - Sundex 790, Aromatic Petroleum Oil (Source: Sun Oil, Philadelphia, Pa.
		Sodium Silicate (water glass) - Type N, 38% solid in water (Source: Philadelphia Quartz Company, Philadelphia, Pa.)
		Calcium Oxide (CaO) - rough ground, purified (Source: J. T. Baker Chemical Co., Phillipsburg, N.J.)
		Sawdust - (Source: Philippines)
		Zinc Oxide (ZnO) - analytical grade (Source: Fischer Scientific Co., or equivalent supply house)

Jamaica Price J¢/lb	Jamaica Price US¢/lb	Materials
		Stearic Acid analytical grade (Source: Mo[illegible]anto Industrial Chemicals Co., St. Louis, Mo.)
		Phenolic Resin - PRF M-4-29 with Hardener M-4-28, Cure Room Temperature (Source: Monsanto Polymers and Petrochemicals Company, St. Louis, Mo.)
		PR-736-7720, Cure at 350°F, powder (Source: Monsanto Polymers and Petrochemicals Company, St. Louis, Mo.)
		PF-588, liquid, elevated temperature cure, ~300°F. (Source: Monsanto Polymers and Petrochemicals Company, St. Louis, Mo.)
		Woven Fabric - abaca (Source: Philippines) - ramie (Source: Philippines)
		Glass Scrim, 42-560-560 (Source: Bay Mills Ltd., St. Catharines, Ontario, Canada)
		Sulfuric Acid (H_2SO_4) (98%) (Source: Allied Chemicals, Morristown, N.J.)
		Phenol (98%) (Source: MCB or equivalent chemical supply house)
		Polyelectrolyte - Lytron 898 VA/MA (100% solid) (Source: Monsanto Polymers and Petrochemicals Company, St. Louis, Mo.)
		Lytron S/MA
		Wax - 75% Montan/25% paraffin in small spheres (Source: Interpace, P.O. Box 785, Ione, CA)
		Factowax R-143 (Source: Boron Oil Company, Cleveland, Ohio)
	15.4	Paraffin Wax
	34.4	Phenol/Formaldehyde Resin @Bagasse Board Plant
	24.0	Urea/Formaldehyde Resin @Bagasse Board Plant
		Polystyrene
	31.5	-expandable [3.15 FF/kilo] (1FF=20J¢=22 US¢)
	27	-crystal [2.70 FF/kilo]
	57	AC PE Wax