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9. ABSTRACT

This report covers the first year (May 1973-May 1974) of a three-and one half year research effort to match indigenous fibers and fillers with low-cost binders to produce improved roofing for developing countries. A new roofing system is urgently needed to replace currently used corrugated galvanized iron, which has undesirably high foreign exchange costs, insufficiently utilizes indigenous materials and manpower, and has poor thermal insulation and durability characteristics (for use in tropic climates).

A survey conducted in twelve countries in three different geographical areas (Asia, Africa and Latin America) resulted in selection of the Philippines, Zambia and Jamaica for collaborative activities and as roofing demonstration sites. Samples of low-cost fiber, filler and binder materials were collected from these and other developing countries. These materials are now being evaluated as components of roofing composites, with consideration of socio-economic and architectural aspects.

Composite materials development for roofs was initiated, stressing low-cost binders and fillers (including representative indigenous particulate and fibrous materials, as well as universally available air and water). The feasibility of preparing clay roofing tiles which would not require firing was explored using minor amounts of a synthetic polyelectrolyte as a binder.

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

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

FIRST ANNUAL REPORT

30 July 1974

For

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

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 This annual report incorporates the substance of the required fourth quarterly report.

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This report covers the first year (May 1973-May 1974) of a three-and one half year research effort to match indigenous fibers and fillers with low-cost binders to produce improved roofing for developing countries. A new roofing system is urgently needed to replace currently used corrugated galvanized iron, which has undesirably high foreign exchange costs, insufficiently utilizes indigenous materials and manpower, and has poor thermal insulation and durability characteristics (for use in tropic climates).

One objective of the project is to construct at least four demonstration roofs in three developing tropical countries -- one each in Asia, Africa and Latin America. Another objective is to adequately transfer the new technology and implement the research results in each participating developing country.

A survey conducted in twelve countries in three different geographical areas (Asia, Africa and Latin America) resulted in selection of the Philippines, Zambia and Jamaica for collaborative activities and as roofing demonstration sites. Samples of low-cost fiber, filler and binder materials were collected from these and other developing countries. These materials are now being evaluated as components of roofing composites, with consideration of socio-economic and architectural aspects.

Composite materials development for roofs was intiated, stressing low-cost binders and fillers (including representative indigenous particulate and fibrous materials, as well as universally available air and water). The feasibility of preparing clay roofing tiles which would not require firing was explored using minor amounts of a synthetic polyelectrolyte as a binder.

In the second phase, May 1974 to May 1975, in-depth studies of the cost and availability of indigenous fillers and binders, as well as detailed socio-economic studies, will be conducted. Laboratory materials development will be continued and intensified so as to have one or more candidate roofing systems defined for each of the three countries by the end of the year.

During the third phase, May 1975 to December 1976, the project will be concerned with the design, manufacture, testing and evaluation of prototype roofing, and the manufacture and field evaluation of full-scale roofing.

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1. INTRODUCTION

1.1 PROJECT BACKGROUND

Adequate housing is a critical requirement in all developing countries. A Roof is one of the key and most costly elements in basic human shelter. There is a great need in developing countries 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. In these respects, it must be better than corrugated galvanized iron, which is commonly used in these countries despite its high foreign currency cost and poor thermal characteristics.

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

In response to these appeals, the U.S. Agency for International Development has sponsored a three-and one half year research and development effort with Monsanto Research Corporation to match indigenous fibers and fillers with low-cost binders to produce roofing with a wide range of applicability in the developing countries.

"Roofing in Developing Countries, Research for New Technologies," National Academy of Sciences, National Research Council, Washington, D.C., 1974.

The research is directed toward use in low-cost housing and is aimed primarily at village-level industry and self-help projects, but does not exclude surburban and urban applications.

1.2 PROGRAM ORGANIZATION

This three-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. Dr. Edward O. Pfrang, Chief, Structures, Materials and Safety Division, Center for Building Technology, National Bureau of Standards, Department of Commerce, provides support, especially in monitoring the technical aspects of the program.

The Program Manager for Monsanto Research Corporation is Ival O. Salyer, Manager, Polymer Physics and Applications. George L. Ball III is Project Leader. The Principal Investigator is Arthur M. Usmani, who replaced Robert A. Cass in the eleventh month of Phase I. He is assisted by other technical personnel, including Dennis W. Werkmeister, as required for completion of specified tasks.

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. He is assisted by G. N. Coleman, a research architect and Donald C. Royse, Associate Professor in the School of Architecture.

2. SUMMARY

2.1 PROGRAM OBJECTIVES

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, a roofing system which is an economically and technically acceptable alternative for the extensively used corrugated galvanized iron (CGI).

One specific objective of this project is to construct at least four demonstration roofs in three developing countries. A second objective is to adequately transfer and implement the research results in each participating developing country. The new roofing system should emphasize:

- 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,
- labor-intensiveness in manufacture,
- widespread production by local government, private enterprise and rural industry, and
- technological transfer to other developing countries.

Appendix A provides details of the complete contract Statement of Work.

Figure 1 shows examples of the use of CGI, and the poor aging resistance of this roofing material in the tropics.

To achieve the above project objectives and goals, the program has been divided into the following three phases:

• Phase I	(May 1973-May 1974)	Problem Analysis and Country Selection
• Phase II	(May 1974-May 1975)	Composite Material Development and Socio-Economic Definition of Roofing
• Phase III	(May 1974-Dec 1976)	Design, Fabrication, Testing and Evaluation of Prototype Roofing Field Manufacture, Installation and Evaluation of Full-Scale Roofing

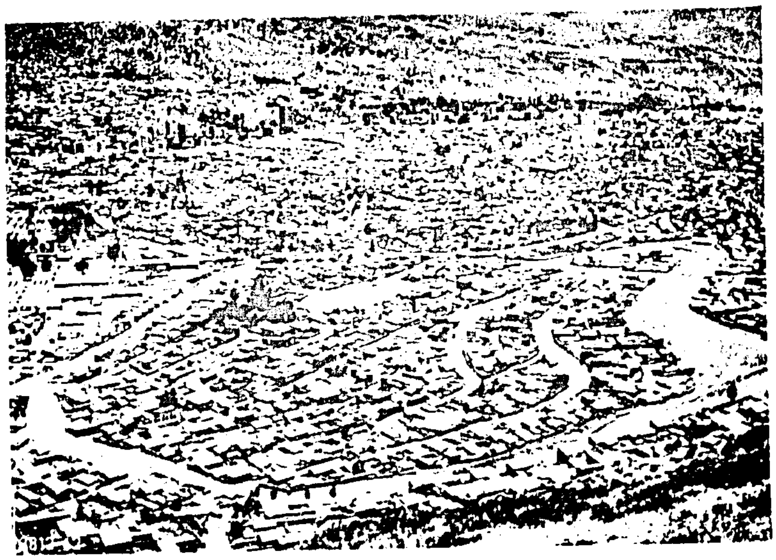
Phase I was completed during the first year's effort Phase II is scheduled for one additional year's effort. Phase III will encompass 18 to 21 months.

The specific goals for the Phase I effort were to:

- Conduct field surveys in candidate countries in Asia, Africa, and Latin America to determine their relative potential as sites for the roofing development.
- Make preliminary contacts with knowledgeable individuals in the candidate countries who might become collaborators in the subsequent phases of the program.

(a) Asia

(b) Africa



(c) Latin America

Figure 1. Examples of Use of Corrugated Galvanized Iron Roofing in Asia, Africa and Latin America. Severe rusting is shown. Useful roof lives from 2 to 20 years were indicated.

- Select one country in each geographical area where, on an overall basis, the program is most likely to be successful.

- Obtain information and representative samples of low-cost indigenous binders and fillers.

- In the fourth quarter, begin laboratory research and development of composite roofing materials using raw materials potentially indigenous to the selected countries.

- Collect, review, and index pertinent literature on low-cost housing and roofing.

These Phase I goals were achieved and are summarized in the following sections (2.2-2.7). Additional details are contained in the Appendices, as follows:

Appendix A - Contract Statement of Work.

Appendix B - Field Surveys of Countries in Southeast Asia, Africa and Latin America.

Appendix C - Establish Contacts with Knowledgeable Individuals, Etc.

Appendix D - Selection of One Country Each in Southeast Asia, Africa and Latin America.

Appendix E - Materials Development and Definition.

Appendix F - Collection, Review and Indexing of Current Relevent Literature

Appendix G - Work Plan Phase II

2.2 COUNTRY SURVEYS

The first year entailed acquiring the information needed for the selection of three countries as sites for field collaboration and for demonstration of the roofing system to be developed in the later phases of the program. The information was to be obtained through comparative field surveys of 12 countries (in Asia, Africa and Latin America), consultation with experts, and analysis of available literature. Samples of indigenous fibers and fillers were also to be obtained for subsequent evaluation.

The initial selection of the 12 countries was made from a larger list of 40 USAID recipient countries through discussions and consultations by the project team members with the AID program manager, and other AID representatives of the developing countries.

Visits to four or more countries in each geographical area were scheduled, with the assistance and participation of the AID program manager. The African countries of Ghana, Zambia, Malawi, Kenya, Ethiopia and Sudan were visited by the project team during August through October 1973. The Latin American countries Peru, Bolivia, Honduras, and Jamaica were surveyed in November-December 1973. The Philippines, Thailand and Bangladesh in Southeast Asia were surveyed during February-March 1974.

It was originally planned to include Indonesia as one of the candidate countries to be surveyed in Southeast Asia. However, at the time of the scheduled visit, problems developed, and with USAID concurrence, Indonesia was dropped and Thailand substituted.

It was also planned that Ghana would be one of the prime candidate countries in Africa because it offered a variety of climates (within a single small country). and one of the project team members, Professor J.P.R. Falconer, Washington University, had extensive background experience resulting from his residence and teaching assignment in that country. Mr. G. N. Coleman, a member of the subcontractors' roofing project team, visited Ghana in August 1973 on personal business, and made some preliminary contacts with government and private sector officials concerned with housing. However, it was believed by the USAID mission in Ghana that the MRC roofing program paralleled and might conflict with a related project being conducted for USAID by A. D. Little on "Cost Reduction in Public Construction." As a result, Ghana was, for the time being, dropped from consideration. However, this country fits the program design criteria well, and further discussions were held in June 1974. When the present project is completed, the feasibility of transferring and adapting the research results to Ghana will be examined.

The field surveys required about 50 man-weeks of on site examination of housing, interviews with government and other knowledgeable personnel, etc. Additional details concerning the field surveys are contained in Appendix B. The information obtained in the surveys of each candidate country is summarized under six subject headings: (1) Geographic Location, Climate and Language, (2) Housing Trends, the Economy and Urbanization Degree, (3) Need for Low-Cost Housing and Roofing (4) Interest and Attitudes of the People and Government Officials, (5) Existing Institutional and Technology Base and (6) Indigenous Resources for Use as Binders and Fillers.

2.3 CONTACTS WITH KNOWLEDGEABLE INDIVIDUALS

A second important objective in the surveys of prospective countries was to contact individuals knowledgeable about the housing problem in the government, institutional, and private sectors. Establishing these contacts was important both to obtain reliable information concerning housing in the countries, and to identify potential collaborators. These knowledgeable individuals might form part of a committee to assist in carrying out the project and the subsequent transfer of the technology to local entrepeneurs.

Appendix C lists the people contacted in each of the developing countries during the entire survey, along with their official title or position (when known).

During the country surveys, contacts were also established with people in educational and other research institutions concerned with housing.

A brief stopover was made at the East-West Technology and Development Institute, at the East-West Center in Honolulu, Hawaii. Personnel interviewed at this institute included Dr. Manuel S. Alba, Director (a Filipino); Dr. Louis J. Goodman, Assistant Director for education and training; Frederich Burian, Senior Program Officer; and Professor Paul Hubert, Vice President Research and Development, University of the Philippines, Manila.

The East-West Center is a point for technology exchange between the East and West. They have a strong interest in low-cost housing. Visiting professors from both the developed and developing nations often come to the East-West Center for one year of teaching and/or research.

In the Philippines the Forest Products Research Industrial Development Commission, located at Los Banos College Laguna, about 50 miles out of Manila, was visited. Dr. Mario Eusebia, Associate Commissioner for research, and several of his co-workers were interviewed regarding the considerable amount of research and development underway at this location on low-cost housing concepts, based on more extensive utilization of wood and wood by-products in building materials.

At the University of the Philippines, Quezon City, discussions were held with Dr. Ernesto G. Tabujara, Associate Professor of Civil Engineering; Aurelio T. Jugilion, Architect and Civil Engineer; and Dr. Eugene Juinio, Dean of Civil Engineering.

In Malaysia, a visit was made to the Rubber Research Institute at Kaula Lumpur. At this institute, discussions were held with Dr. Wong Niap Poh and other personnel at his laboratory. There is continuing and extensive work at this laboratory to further develop and improve the production and utilization of natural rubber. In our roofing program, natural rubber is important as a possible binder resin, since it is available indigenously in the Philippines, and possibly could be cultivated in other tropical developing countries.

In Thailand, the Asian Institute of Technology at Bangkok was visited. At this institute some outstanding examples of low-cost housing, grain storage bins, canal locks, and other structures are being fabricated from ferro cement by Dr. Seng-Lip-Lee and his co-workers. Some significant work on materials development is also being done at the Applied Scientific Corporation of Thailand under the direction of Dr. Kasem Balajiva. Emphasis there is on a wider utilization of clay and cement, both of which are available in Thailand.

In Bangladesh, the University of Engineering and Technology at Dacca was visited. Dr. Jamilur R. Choudhury and his co-workers at this university are exploring the "shell-house" approach to low-cost housing. They are also considering corrugated rigid vinyl as a possible roof paneling material. At the Building Research Institute in Dacca, development work is being done on more extensive utilization of clay, and conversion of the water-hyacinth into a useful building material. Mr. William Woudenberg of CARE in Bangladesh is also developing shell houses based on composites of jute cloth and imported polyester binder.

In India, a wide variety of research on low-cost housing and low-cost building materials is being done by Dr. Dinesh Mohan and his co-workers at the Central Building Research Institute, Roorkee, India.

In a similar way, contacts were also made with educational and other institutions engaged in research on low-cost housing in Africa and in Latin America.

In Africa, the University of Zambia and the National Council for Scientific Research, both located in Lusaka were visited. In Ghana, the Buildings and Roads Research Institute at Kumasi was visited.

In Latin America, in Jamaica, in addition to official government sector contacts, visits were made with Mr. Noel E. Foster, Manager Coconut Industry Board, Kingston; Alfrico D. Adams, Douet, Brown, Adams and Associates, Consulting Engineers, Kingston; and Mr. Lewis Davidson, the Knox Development Foundation at Spaldings. All three of these organizations are engaged in developments relating directly to low-cost housing and/or building materials.

To a significant, but to a lesser degree, contacts were also made with individuals in the private sector in all the countries surveyed. Appendix C contains a complete list of people and organizations contacted.

2.4 COUNTRY SELECTION

Following the country survey, members of the project team reviewed the information and data obtained. Criteria used in the country selection process included:

- Interst (of country, of AID Mission)
- Need (roofing problems, housing problems, unemployment)
- Resources (labor, filler, reinforcement, matrix, raw mate-ials market, housing subcontractors, materials, manufacturing).
- Existing Technology Base
- Existing Institutional Base (research, materials testing housing authorities)
- Language
- Economy (foreign exchange position, ability to purchase)
- Attitudes (social, cultural, economic)
- Housing Trends (local, government)
- Climate (absolute and relative)
- Geographic Location (absolute and relative)
- Urban-Rural Mix
- Probability for Program Success

These criteria were weighted in what was believed to be the relative importance of each to the program. The selection was quantified using a Kepner-Tregoe analysis (see Appendix D).

The survey team placed numerical values on the degree of conformance of the country to each criteria. The value of this Kepner-Tregoe analysis derives from the fact that it enables each member of the project team to independently evaluate each of the candidate countries in terms of the selected criteria on a semi-quantitative basis.

In Asia, the countries of Bangladesh, the Philippines and Thailand were surveyed, studied and analyzed. The rating for the Philippines was highest of the three nations considered, Thailand second and Bangladesh third. Although the need for housing and roofing is admittedly greater there, Bangladesh did not have sufficient resources and other pro-factors to make it even the second candidate. In the case of the Philippines, a very strong institutional and technology base exists, there are many potentially usable resources, and the interest of collaborative personnel and institutions is high.

In Africa the rating for Zambia was easily the highest of the African countries considered in the analysis, which included Ethiopia, Kenya, Malawi, and the Sudan. The primary factor in Zambia's achieving the highest rating was the intensely strong interest in the program on the part of the Ministry of Local Government and Housing there. It was believed that this interest would help to insure cooperation of the government in setting up and following up with the demonstration project in Zambia. Ethiopia suffered from other more pressing needs (food) and considerable political problems.

In Latin America, Jamaica recieved a significantly higher rating than the other countries, Honduras, Peru and Bolivia. This was based to a great extent on expressed government interest, a pronounced need, a balanced urban and rural situation, a convenient geographical location, and the absence of a language barrier. The warm, moist climate of the island also presented a much greater challenge to materials than the cooler, dryer climate in most of Bolivia and Peru.

In all three of the selected countries (Philippines, Zambia and Jamaica) galvanized iron is used extensively for roofing despite the high cost of the material in foreign exchange. Thus, the original objectives of the program to develop an alternate to corrugated galvanized iron can be realized in each of these three countries.

2.5 SAMPLING OF LOW-COST INDIGENOUS BINDERS AND FILLERS

In the survey of available materials in the developing countries, it quickly became clear that there was less waste material from agriculture and industry than had been expected. Other than grass, sand, water and air, the desired fiber or filler resources were found only as under-utilized materials. Accordingly, utilization of these indigenous fibers and fillers in roofing should upgrade their value, but may require replacing them in their current applications.

For example, bagasse is a by-product of sugar refining and is available in all three of the selected countries (Philippines, Zambia, Jamaica). Since the bagasse is produced at the sugar mill, it is often used as fuel to provide energy for the sugar-making process. Upgrading the utility of bagasse into a roofing material should be highly desirable, but will require the use of another fuel by the sugar manufacturing plant.

Additionally, some agricultural by-products are produced at widely separate locations, and collecting them for fabrication into roofing might involve undesirably high costs. Rice hulls, and rice straw are examples of under-utilized agricultural residues of this type. Rice, for the most part, is produced on small individual farms where it is also harvested and threshed. Thus, although rice hulls and rice straw may indeed be a valuable filler component for a roofing composite, the collection costs versus utility will have to be carefully analyzed in the continuing work.

As predicted, in the original study conducted by the U.S. National Academy of Sciences and Engineering, low-cost binder resins were not found to be readily available in two of the three selected countries and may have to be imported.

In the Philippines, natural rubber is produced on the island of Mindanao in quantities sufficient for all local use, and reportedly some will soon be available for export. Thus,, natural rubber should be considered as a binder resin in the Philippines. Two thermoplastic synthetic resins, polystyrene and polyvinyl chloride, are also produced in the Philippines in commercial quantities from imported monomers. Additionally, there is some production of urea/formaldehyde and phenol/formaldehyde thermosetting resins. Samples of natural rubber latex, and crumb rubber were obtained during the field surveys in Southeast Asia. Samples of the synthetic resins were not obtained since it was assumed that their equivalents in terms of composition and properties were available in the United States and could be used in the development work.

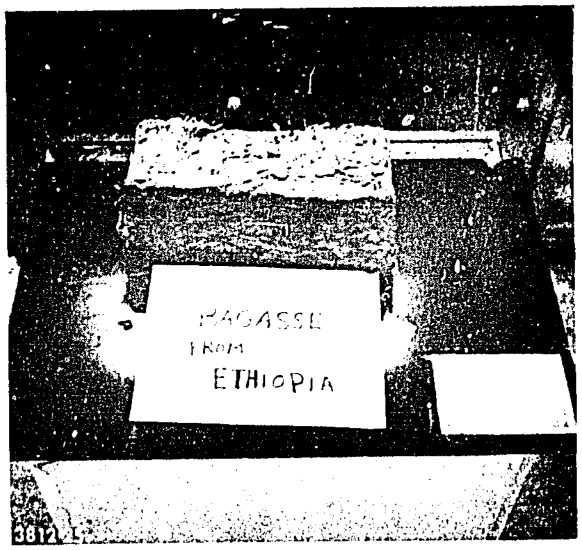
In Zambia, there was no readily identifiable indigenous resin binder available. Thermoplastic and thermosetting monomers and resins, including polystyrene, polyurethanes, polyesters, urea/formaldehyde, and phenol/formaldehde are imported.

In Jamaica, the situation with respect to resin binders is much the same as in Zambia; that is, synthetic monomers and/or polymers are imported. However, there is large scale production of asphalt in nearby Trinadad and, accordingly, asphalt could be considered an available binder. Samples of asphalts were not obtained, since their equivalents are also available in the U.S. and could be used in the experimental program.

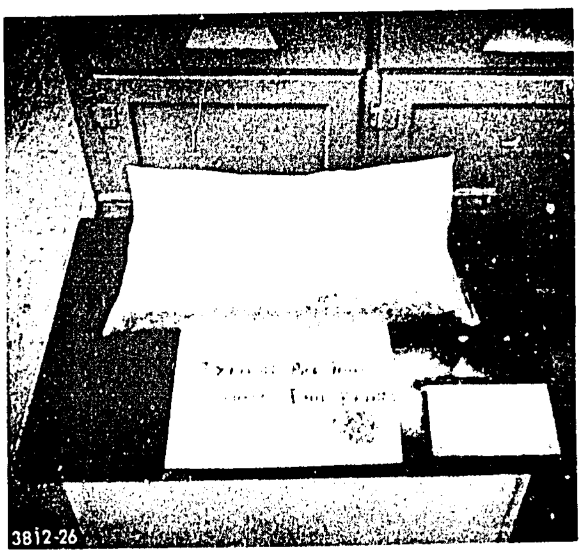
Samples of clay were obtained from several of the countries surveyed. Clays suitable for brick making are available in each of the three selected countries. However, other than in the soil-cement compositions (CINVARAM) there are no indigenous binders for clays, other than the reaction caused by firing at high temperature. Although not indigenously available in any of the three countries, small amounts of specific polymer electrolytes might be used to bond clay so as to make tiles or other structural components which do not require firing. This technology is further discussed in section 2.6.

Products obtained from the field trips also included some basic raw materials, and items which were being investigated, or used in construction as well. These materials have been catalogued (Appendix E) and several have received preliminary evaluation. Filler materials collected included bagasse, rice hulls, rice straw, coconut husks, coconut fiber (coir), jute fiber and cloth, jute sticks, asbestos fiber, and smelter slag. These are represented by illustration in Figure 2.

(a) Gum Rubber - Malaysia



(b) Bagasse - Ethiopia



(c) Rice Hulls - Philippines

(d) Smelter Slag - Zambia

Figure 2. Typical Indigenous Materials Collected on Field Trip to Africa, Asia, and Latin America.

2.6 ROOFING COMPOSITE DEVELOPMENT

As stated in earlier sections of this report, it is believed that the most likely solution to the problem of a low-cost roofing to replace corrugated galvanized iron will be through a combination of indigenous fibers or fillers with minor quantities of low-cost binders in the form of a "composite". Composite technology is well advanced in the United States and takes several forms in order to achieve maximum strength and performance properties with least weight and/or cost. Structures of high strength fibers and synthetic resin binders are widely used in the aircraft and aerospace industry to obtain higher levels of performance and/or lower weight. Composites of high strength fiber-reinforced skins with a foam core are also utilized for the same purposes.

From the country survey, 15 low-cost available fillers, and 7 types of binders were selected for initial screening evaluation. These 15 fillers, and 7 binders are listed in Table 1 below. Three materials--clay, cement and gypsum--appear both as filler and binder because they may be used in both ways. Air and water are of course universally available filler materials.

Table 1

CANDIDATE FILLERS AND BINDERS FOR ROOFING COMPOSITES FROM SURVEY OF THE COUNTRIES DURING THE FIRST YEAR

Fillers	Binders
1. Bagasse	1. Synthetic Thermoplastics
2. Bamboo	2. Synthetic Thermosets
3. Abaca (hemp)	3. Natural Rubber
4. Jute	4. Asphalt
5. Rice Straw	5. Other Indigenous Resin (e.g. copal, rosin, etc.)
6. Rice Hulls	6. Water Glass
7. Nipa Palm	7. Cement
8. Grasses (e.g. Cogan)	8. Clay + Polyelectrolyte
9. Coconut Husk	9. Gypsum
10. Wood Chips	
11. Sand	
12. Ore Tailings	
13. Air	
14. Water	
15. Cement	
16. Clay	
17. Gypsum	

Recently, in the United States, methods have been found in which water can be dispersed and encapsulated permanently as spherical droplets, in certain specially tailored polyester resin binders in order to extend the resin with this low-cost readily available "indigenous filler".

By no means were all of the combinations of binders and fillers evaluated. The specific fillers studied preliminarily to date in the composites have included air, water, jute cloth, bagasse, and rice straw. Both thermoplastic and thermosetting binders were considered. The thermoplastic binders were polystyrene, polyethylene, polyvinylchloride, and polypropylene. The thermosetting binders included the styrenated polyesters (including water-extended polyesters), urea/formaldehyde, and phenol/formaldehyde. Most of these low-cost synthetic resins are manufactured locally in the Philippines and, to a lesser extent, in Jamaica and Zambia.

Composite panels utilizing "indigenous" fillers were prepared and are awaiting tests. One model structure was made from an air-filled (foamed) epoxy both plain and containing rice straw filler; in flat and corrugated configurations; with and without jute cloth skins. Test panels were also prepared from urea/formaldehyde and polyester foams, with jute cloth skins; polyester foam core with reinforced polyester skins; water-filled polyesters with bagasse or jute fiber reinforcement; and jute fabric reinforced polyesters. Figure 3 shows examples of some of these model roof panel composites.

The investigation of polyelectrolytes as binders for clays was started. Clay containing 0.5% to 5% by weight of a synthetic polyelectrolyte, plus a waterproofing agent, with and without fibrous reinforcement, have been molded into test specimens having fair-to-good strength properties and resistance to water. The primary objective of this work was to make available a ceramic tile-like material that would not require firing.

The preliminary evaluation of candidate fibers and fillers and the composite panels described above is detailed in Appendix F.

2.7 COLLECTION, REVIEW AND INDEXING OF CURRENT LITERATURE

The collection, review, and indexing of the current literature was started in Phase I and will continue throughout the program. This is not an attempt to review the voluminous past literature on low-cost housing and roofing, nor is it planned to make a separate report on this collected literature. Rather the objective is to review the current literature, use it where applicable, and file it systematically by a method which will

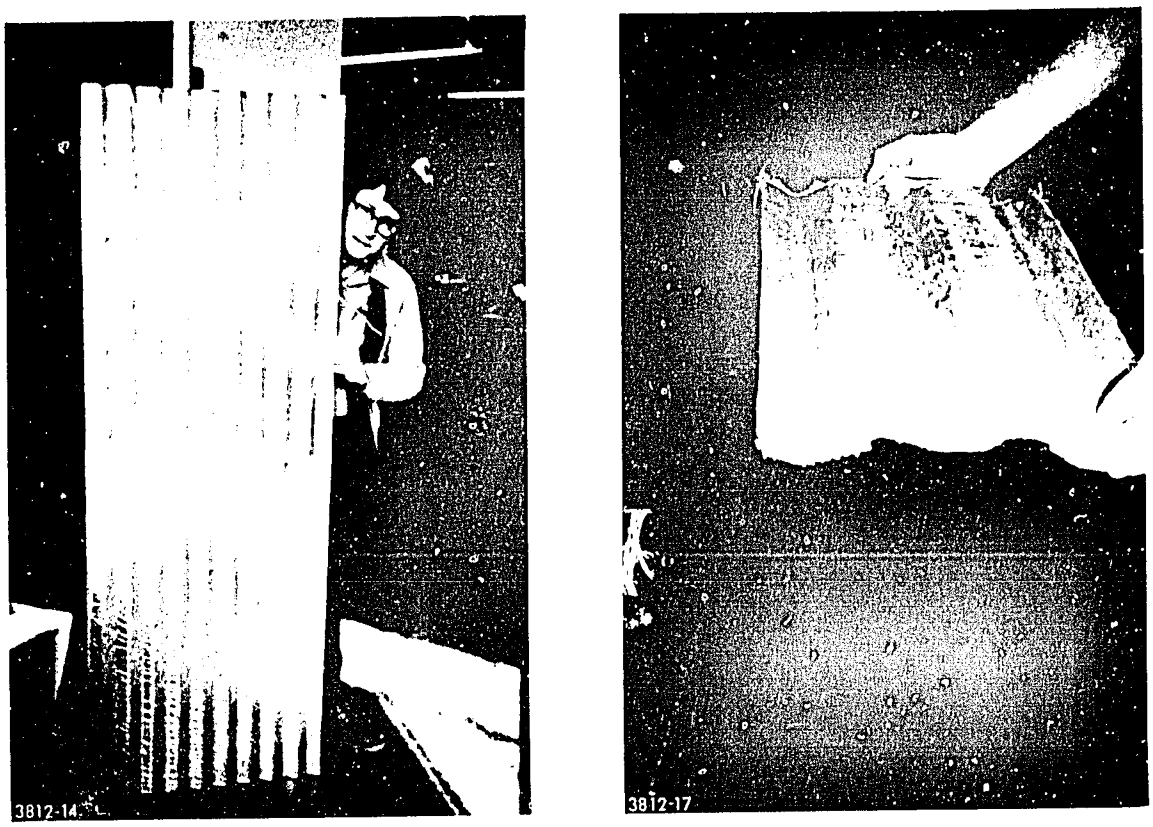


Figure 3. Prototype Corrugated Panels Containing Indigenous Air, Rice Straw, Potentially Indigenous Jute and Low-Cost Polyester Resin

permit ready retrieval by the project team at any time desired during the program. This indexing and retrieval is being accomplished by the use of a "Keyword in Context" index (KWIC), which is done by listing the subject, authors, titles and sources on computer cards. Every significant word in the title is indexed. Thus, all of the literature articles which contain "housing" as a significant word in the title would be found by looking in the index under housing. If the article concerned housing in Ghana, it would also be indexed under the word Ghana.

It is also expected that the KWIC index will be useful to readers of this report in developing nations who can readily determine thereby where some significant article of interest to them can be found. Conversely, if readers of this report are aware of other current articles which should be added to this literature review, it would be greatly appreciated if they would send a copy of the article to the attention of I. O. Salyer at Monsanto Research Corpporation, Dayton Laboratory, P.O. Box 8, Station B, Dayton, Ohio 45407, USA.

It was possible to carry out this computer indexing of the accumulated information since the necessary software and program for this purpose was already available in our laboratory.

The collection of the literature accumulated, reviewed and indexed (KWIC) in Phase I is contained in Appendix F.

3. WORK PLAN FOR PHASE II AND PHASE III

The program for the development of low-cost roofing systems from indigenous materials for the developing countries has three phases, as outlined in Section 2.1, Program Objectives. The remaining two phases are envisioned as taking place over the next 2-1/2 years, as shown in the Program Schedule, Figure 4. This schedule shows Phase III being completed in 18 months instead of the 12 months originally planned. This additional time in the program is necessary so as to be able to complete six month's observation of the installed roofs before the end of the program.

In Figure 4, the 13 activities listed in the Contract Statement of Work (Appendix A) are tabulated for each of the three selected countries, Jamaica, Zambia and the Philippines. The time in months for the remainder of the contract is indicated at the top of the chart. A diagonal cross-hatched bar is used to indicate the time period in which each activity will take place in the three countries. The last activity, Literature Survey and Analysis, will be done throughout the program as described in Appendix F.

The emphasis in Phase II will be on the detailed analyses of the three selected countries, Jamaica, Zambia and the Philippines, and on composite materials and process development. As outlined

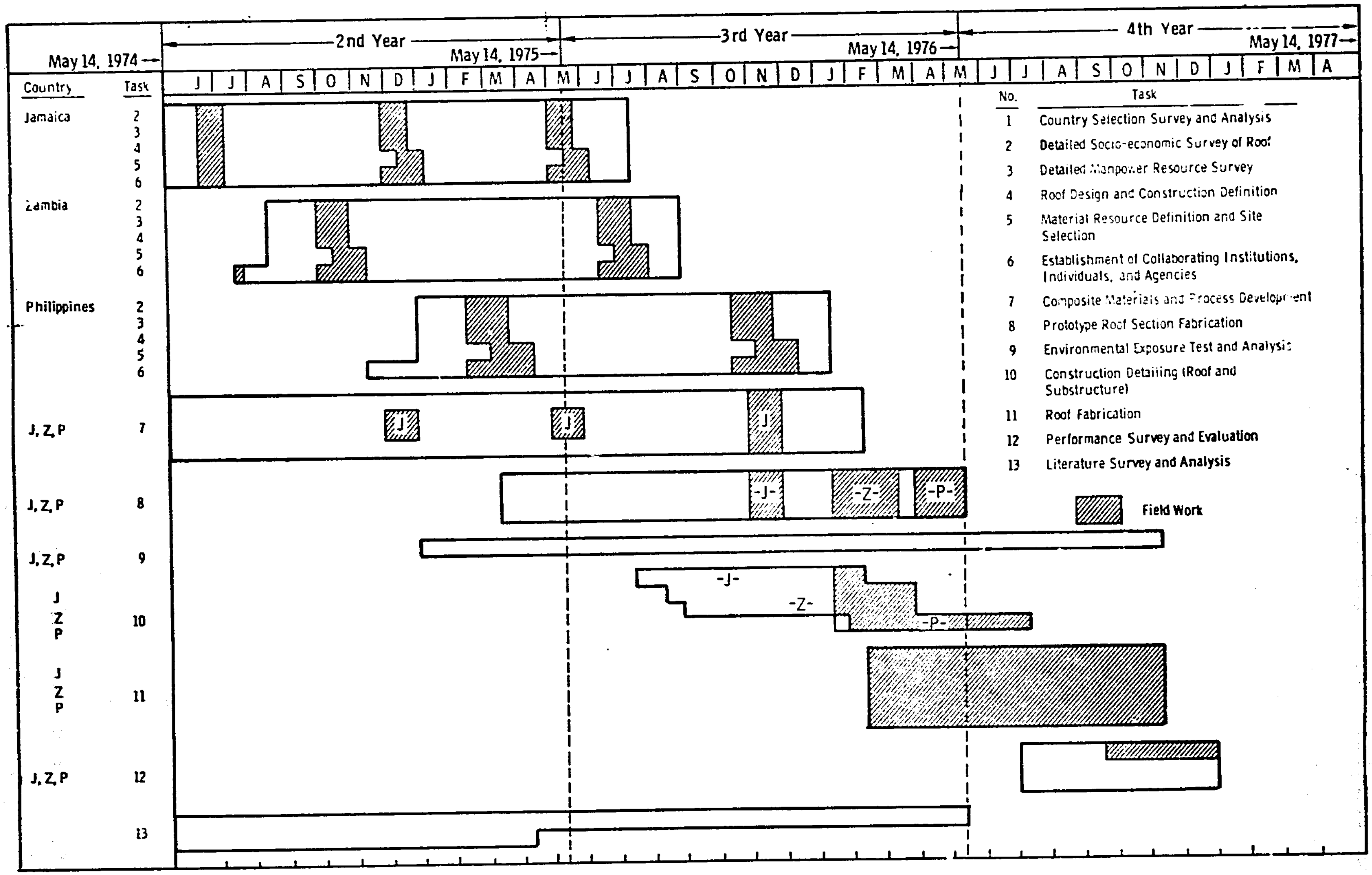


Figure 4. Program Schedule for Additional Three Phases Indicating Tasks, Their Timing and the Scheduling for the Efforts in the Three Selected Countries

on the program schedule, the socio-economic survey in each of these countries will be performed by Washington University personnel. The program is detailed in Appendix G.

At least one visit will be made to each of the demonstration countries in Phase II, and two or three to Jamaica. While the field work is detailed on the program schedule, we propose to retain a relatively flexible schedule which will allow us to interact most advantageously with the institutions and individuals who will become involved.

The field work in Jamaica shown in the composite materials and process development area (Task 7) is separate from the survey work (Tasks 2 and 3). This is to allow utilization of Jamaica as a remote environmental test site, to provide an extension of our Dayton Laboratory. The environmental exposure tests and analyses (Task 9) shown in Phase II will be conducted partly in Jamaica and partly with accelerated aging equipment at the Dayton Laboratory. Use of Jamaica as a "nearby" tropic test site has the added advantage that it helps to develop Jamaican's indigenous capability and their interest and participation in the program.

Literature survey and analysis will continue throughout the total program. We will attend pertinent meetings involving housing, indigenous materials, construction materials, etc.

Additionally, periodic information consultations and discussions will be held, as feasible, with knowledgeable experts in appropriate offices and institutions worldwide.

The work is staged so that Tasks 2 through 6 will be completed at different times (in Phase III) in each of the three countries, Jamaica first, Zambia second, and the Philippines last. This staging provides a combination of benefits. First, what is learned in one country can be used in the other two, thus reducing some of the learning process and providing added confidence in our technical approach. Second, it permits use of a single field team, which will minimize costs and communications problems.

It is very important that the composite materials development (Task 7) be well underway in Phase II. Otherwise it would be difficult to meet the objective of fabricating roofs at the required time late in Phase III.

It is expected that the technical evaluations in Phase III, to be held 3-6 months after the roofs are constructed, will represent the end point of the program. Hopefully, through the collaboration process, techniques for further study, evaluation and feedback will have been set up internally with the DC's. The applicability of the roofing elements for other uses, such as sidewalls or fencing, could then be considered.

APPENDIX A

CONTRACT STATEMENT OF WORK

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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 LDC 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 LDC 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-help methodology.

Phase I - Material & 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, and the organization and infrastructure controlling new low-cost housing construction, 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.

<u>Phase II - Design, Manufacture, Testing and Evaluation of Prototype Roofing</u>

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.

<u>Phase III - Manufacture and Field Testing of Full-Scale Roofing</u>

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.

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APPENDIX B

FIELD SURVEYS OF COUNTRIES IN SOUTHEAST ASIA, AFRICA AND LATIN AMERICA

APPENDIX B

FIELD SURVEYS OF HOUSING IN ASIA, AFRICA AND LATIN AMERICA

Our primary effort during the first year was in conducting field surveys of portions of Asia, Africa and Latin America, to define the roofing problem, provide the basis for selecting demonstration sites, and acquire preliminary information on resources, housing trends, and potential collaborators.

The countries surveyed were categorized as primary or secondary. The primary countries were those considered to be potential collaborators, and information confirming the suitability of each country as a test site was to be accumulated. The secondary countries were visited to provide our team with a more complete picture of the roofing problem and the ongoing development of new building materials and low-cost housing. These secondary countries were also considered to be the back-up sites should a primary country be ruled out for any reason.

The African countries were surveyed in August and October 1973, the Latin American countries in late November to early December 1973, and the Asian countries during mid-February through mid-March 1974. These surveys were all scheduled to be accomplished within the first nine months of the program, at the direction of the AID Project Manager. This required that part of the Latin American trip (Jamaica) be conducted during the December 1973 holiday season, which precluded some official contacts. Jamaica was therefore briefly revisited in April to complete the survey.

The field surveys encompassed about 50 man weeks of on-site inspections and interviews. The trip reports contain detailed information beyond that needed to communicate the conclusions of the field surveys. These surveys are thus summarized here, and two copies of the trip reports are being delivered to the AID Project Manager along with this annual report.

The field surveys are discussed in terms of each country's (1) interest, (2) need, (3) housing trends, economy and degree of urbanization, (4) resources, (5) existing institutional base, and (6) geographic location, climate and language.

1. SOUTHEAST ASIA

The Southeast Asian countries surveyed were the Philippines, Thailand and Bangladesh (primary candidates), and Singapore, Malaysia and India (secondary candidates). The primary countries were thoroughly compared with each other in order to select the best candidate for a roofing demonstration. The secondary countries were visited to obtain general information regarding their approaches to low-cost housing, to visit building research institutes, etc.

The Rubber Research Institute at Kuala Lumpur in Malaysia was visited because rubber latex is being considered as a binder resin for the roofing. Also, Malaysia has a strong interest in developing a capacity for resin-bonded chipboard, which could be used in roofing. Several other interesting approaches to low-cost building materials are also being investigated there.

It was originally planned to include Indonesia as one of the primary countries in this area. However, problems developed and, with AID's concurrence, Thailand was substituted for Indonesia.

Surveys of the Southeast Asian countries were concentrated in and around the capital cities. However, in the primary countries, cities and villages outside of the capital areas were also visited briefly in order to observe their housing, and as well rural housing along the way. Cities visited in Southeast Asia included Manila, Los Banos College-Laguna, Quezon City, and Makati in the Philippines; Singapore in Singapore; Kuala Lumpur in Malaysia; Bangkok and Si Ayutthaya in Thailand; Dacca, Barisol and Chittagong in Bangladesh; and Delhi and Roorkee in India.

1.1 Philippines

1.1.1 Geographic Location, Climate and Language

The Philippines lies just north of the equator, and has a tropical climate with two seasons: wet from May to October, and dry the rest of the year. Temperature differences are slight, varying only a few degrees from 27°C. Rainfall varies considerably by region due to topography and direction of the air stream. The Philippines has the greatest annual frequency of tropical cyclones in the world. Earthquakes are also frequent.

The Philippine archipelago consists of 11 major islands and over 7000 small islets. The major islands contain 90% of the total land area of about 300,000 square kilometers, which is divided into three main regions: Luzon, 140,000 square kilometers; Visayan, 65,000 square kilometers; and Mindanao, 95,000 square kilometers.

There are 87 native languages or dialects. The three principal ones are Cebuano (spoken on the Visayas), Tagalog (in the area around Manila), and Ilocano (on Northern Luzon). Filipino (based on Tagalog), English, and Spanish are the official languages. Filipino is taught in all the schools. English is the most important non-native language in the Philippines. It is the second language of 40% of the population, and is the universal language of professional academies and governmental people.

1.1.2 Interest and Attitudes

There was a strong interest on the part of the government officials and other Filipinos interviewed in having the roofing program brought to the Philippines. This interest was expressed by such key individuals as Cesar H. Concio, Architect and Chairman of the National Building Code Committee, Makati; Col. Manuel R. Rebueno, Head of Engineering, Planning Survey Department, Peoples Homesite and Housing Corporation, Quezon City; General G. V. Tobias, Executive Vice President, National Housing Corporation; Dr. Josefina M. Ramos, National Economic and Development Authority; and others.

This interest was also endorsed by personnel in the university and/or research institutes, including Ernesto G. Tabujara, Professor of Civil Engineering, University of the Philippines; Alfredo L. Juinio, Dean of College of Engineering, University of the Philippines; Aurelio I. Juguilon, Dean of the School of Architecture, University of the Philippines; and Mario Eusebia, Associate Commissioner for Research at the Forest Products Research Industries Development Commission (FORPRIDECOM), Los Baños, College Laguna.

All of these people agreed that better housing was a prime need of the Philippine people in order to upgrade their living standard to an acceptable level. They were thus very eager to have the program brought to the Philippines, and stated that they would cooperate in every way possible to insure its successful operation.

It is beneficial if the AID Mission in the candidate country be in favor of the program and assist as appropriate and feasible. AID personnel with whom the program was discussed, including William Larson, P. M. Groves, Allen C. Hankins and others, agreed that roofing was an urgent local need, and stated that they would be pleased to see the Philippines selected for the Asian aspects of the project.

More recently (May 20, 1974), the proposed program for the Philippines was also discussed with Mr. Larson's replacement at the Mission, Mr. Richard Dangler from AID Washington, D.C.

1.1.3 Need for Low-Cost Housing and Roofing

The need for low-cost housing and roofing in the Philippines is acute. In common with many other developing nations, the Philippines has both a high annual rate of population increase and a continuing movement of people from the rural to the urban environment. These factors tend to produce a proliferation of squatter and other unsatisfactory types of housing in areas immediately adjacent to the capital and other principal cities.

Based on the 1970 housing census, there is an estimated nation-wide housing need of 10,448,880 dwellings projected for the period 1970 to 2000[1]. Urban areas will require 3,615,700 housing units and rural areas 6,833,180 units to meet the backlog housing deficit, to reduce overcrowding, to replace substandard housing and that lost through deterioration and natural disasters, and to supply the need caused by population growth. Over one-half of the total need is caused by population increase. However, Philippine housing analysts now calculate the actual rural-to-urban housing need to be in the ratio of 85% to 15%.

[1]Housing Needs Up to the Year 2000 and Its Financial Implications, Jacob S. De Vera, Peoples Homesite and Housing Corporation.

Of the total urban housing need, that which is substandard and overcrowded constitutes by far the largest component. Slums and squatter settlements have been growing at the rate of 12% per year, as a combined result of rural-to-urban migration and new household formation (which occurs at the rate of about 4% per year).

Conditions in most of the squatter areas are extremely bad. Typically, there is little or no drainage and houses are built over stagnant pools of water, with access through narrow passage-ways and over plank bridges. Overcrowding results from two or three families living in one-room shacks. Few houses have toilets or piped water. The houses are generally built of second hand "found" materials, usually wood or woven split bamboo for walls, and combinations of CGI sheet and thatching for roofs. Some examples of this type of substandard housing are shown in Figures 5 and 6.

Although it requires a high component of foreign exchange, CGI is the most extensively used roofing in low-cost housing. It is estimated that current non-thatched roofing in the Philippines is 90% CGI sheet, 5-8% asbestos-cement and 1-2% ceramic tiles.

The CGI sheets are used in low-cost housing for several reasons. First, they are easily transported, even in rural areas where roads are poor. Second, if properly nailed down, the CGI sheets will also resist the high wind velocities which prevail in the Philippines. To quote one Philippine building contractor, "The whole roof or building may blow away, but the CGI sheets will remain fastened to the roof." In contrast, aluminum roof sheeting will literally peel off the roof, even in winds which are short of hurricane force. Third, the CGI sheets require less supporting roof substructure. Fourth, the CGI sheets are suitable for catching rain water in rural areas, whereas asbestos-cement tiles permit mold growth and transmit moisture.

Figure 5. Typical Inadequate and Squatter Housing in the Philippines is Shown and the Utilization of All Types of Materials for Roofing. In particular, note the extensive use of corrugated galvanized iron in combination with thatch.

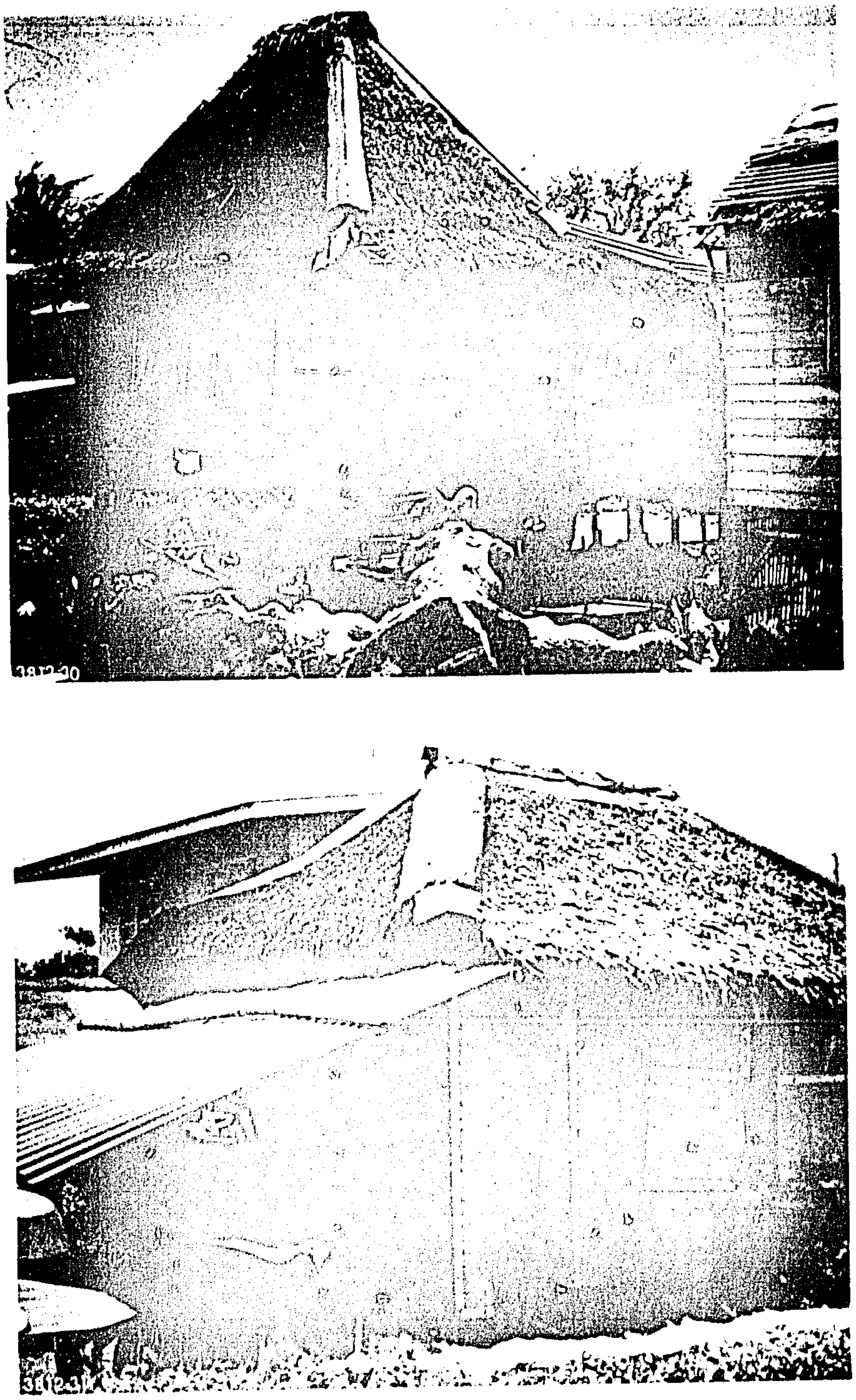


Figure 6. Typical Substandard Housing in the Philippines (Manila Metropolitan Area) Built from Second-Hand "Found" Materials - Usually Wood or Woven Split Bamboo for Walls and Combinations of Corrugated Galvanized Iron Sheet and Thatching for Roofs.

Thus, despite its shortcomings in foreign exchange costs and poor thermal properties, the CGI sheeting is a cost-effective roofing material. However, roofing with a lower foreign exchange component and better thermal characteristics and rust resistance is urgently desired.

Thatched roofs of grass and nipa palm leaves are found in many rural areas. In terms of both foreign exchange and absolute cost, the thatch roofing is significantly lower in cost than the CGI sheeting. Thatched roofs are certainly better thermal and sound insulators than the CGI sheets, but they are reported to be decreasing in popularity and use for several reasons. They are not very resistant to high winds and ordinarily do not last longer than two or three seasons in the rigorous climate areas of the Philippines. Nipa palm and thatched roofs are also highly flammable, and are prohibited by law in urban areas because of the risk of large-scale fires. More importantly, perhaps the nipa palm and thatched roofs also harbor insects and rodents which may carry diseases. Mrs. Ofelia V. Bulaong stated, "The nipa palm house is a home for insects."

Prior to World War II, clay tiles were used in the Philippines to a significant degree. Tiles have since become less popular because of their relatively high cost, as compared to CGI sheeting, and the higher cost of the roof supports required to carry their greater weight. Further, tile roofs are reported to "ravel" in high winds. Finally, it is difficult to transport clay tiles over any distance without extensive breakage. Although the clay tiles could be made from entirely indigenous material (clay), their manufacture requires imported petroleum or other fuel for firing, and thus the foreign exchange component may not be zero.

Asbestos-cement roof tiles or sheets are also used in the Philippines on a small scale. The objections to this type of roofing material are identical to those for clay tiles, with the additional disadvantage that they do require foreign exchange for the asbestos component. Asbestos-cement supports mold growth in moist tropic climates and this makes the material unsuitable for catching rain water in rural areas.

As stated by Mr. Cesar H. Concio, Architect and President and Chairman of the National Building Code Committee, a replacement for the widely used corrugated metal roofing is urgently needed in the Philippines to obtain improved thermal and sound insulation quality, as well as reduced high foreign exchange costs. Mr. Concio does not think that this replacement can come from the present clay tiles or cement asbestos.

1.1.4 Housing Trends, The Economy and Urbanization Degree

Since Independence, there have been several (17) successive plans (Hibben, Vula Marcos, etc.) for economic and social development, including housing. Government policy on housing has also shifted dramatically. The recent Sicat Plan is only the latest of these plans which have been identified by the name of the sponsoring government official, for four year development (1971-1974) and includes a much larger social role by the Government in housing in general.

Section d.3 on specific policies for beneficiaries of housing programs provides that: "The National Housing Program will maintain a judicious balance between the subsidized and non-subsidized sectors. The government will promote and finance, through the SSS, GSIS and DEP, economic housing for those with annual earnings of about P. 2,500-12,500, at reasonable prices over a long period of repayment and, subsidized with public funds, establish dwelling for those whose income level is below P. 1,800 per annum." Section d.4, a specific policy on urban lands, provides further: "There should be simultaneous government effort to strengthen government control over private urban land; to acquire urban lands for housing needs and to exclude government urban lands in financing schemes connected with agricultural land reform and/or other uses."

The Sicat four year plan has recently been modified and extended to cover the period 1972-1975. This modification further increases the role of the government in housing. Section b. provides that the National Housing Program, according to the plan, covers (1) social housing financed and built by the government, (2) economic housing financed and built by the government, and (3) privately-owned housing financed by the government. Additional provisions of this modified plan provide specifically for resettlement of squatter families on public land, as well as construction of extensive tenement housing in one or more locations.

Housing trends in the Philippines incorporate, to a considerable extent, the problem of roofing materials already outlined. The principal house building methods practiced in the Philippines are conventional, on-site construction and prefabrication of components.

As far as could be determined, prefabrication of modular components is practiced by only two companies; the National Housing Corporation and Panelock Homes. The latter produces modular wall panels and roof trusses, using components from other fabricators.

There is a very definite preference by the Filipinos for individual unit housing. This is well illustrated by several low-cost housing projects now under construction, such as that at LaMesa, on the outskirts of Quezon City, where 700 units are being sponsored by the Government Service Insurance System (GSIS) The government plans to make each of these sites an integrated unit having its own waste disposal system, shopping centers, schools, and churches. They expect to run railroad or other mass transit systems to surburban developments of this type to enable workers to be transported into the city at minimal cost.

Under martial law, the economy of the Philippines can be said to be directly controlled, to a large extent, by the government and specifically by presidential decree. Despite this control, there has been the same type of spiraling inflation as encountered elsewhere, and the official exchange rate for the peso is not the same as can be obtained on the free market. Because the Philippines possess considerable natural resources (including rubber, timber and a strong agricultural economy), the inflation has not been as pronounced here as in many other developing nations. However, it is rising rapidly. Provided the rapidly increasing rate of population can be brought under control, the Philippine economy should be sufficient to supply food for both the present and the immediate future population. However, continued industrialization and the development of a largely lacking petrochemical industry is needed in order for the Philippines to become self-sufficient in many basic raw materials.

Prior to World War II it is estimated that 80-90% of the Philippine population lived in rural areas and small villages and towns. Currently, less than 70% of the people still live in the rural areas and this percentage is steadily decreasing as more people move to the urban centers for employment. This causes a high congestion of population around a few major population centers with resulting squatter settlements and substandard housing.

1.1.5 Resources

Several indigenous materials that could be used in the fabrication of low-cost roofing are available in the Philippines. There is an infant steel rolling mill industry which could manufacture corrugated sheeting for roofing. However, the cost is often higher than for the imported Japanese product. Thus, almost all of the CGI sheeting is imported.

Cement is produced in sufficient quantity that some is available for export. However, there is a law requiring that the industry first satisfy the demand for home use before any is exported.

Some low-quality asbestos is found in the Philippines, but the asbestos used for cement-asbestos roof sheets or tiles is imported.

Clay of the necessary quality for making good bricks or tiles is available in quantity. However, the difficulties with respect to breakage in transport, greater cost of roofing substructure and raveling in the high winds, and perhaps local custom, causes it to be little used.

There are several agricultural or forest products which have potential for use in making roofing. Since 130,000,000 bags of rice at 44 kg/bag were produced in the Philippines in 1974, it follows that rice hulls of approximately the same weight were also produced.

Another attractive agricultural by-product for possible use in roofing is abaca, a secondary product from Manila hemp production. It is estimated that 500,000 bales per year at 125 kilos per bale are now left in the hemp fields to ruin. However, for both hemp and rice hulls, which are produced on widely scattered small farms, the collection costs may make the material uneconomical.

Bamboo grows plentifully in the Philippines and is used both for floors and walls, in strips about 1/2 inch wide. Bamboo rods or canes could be considered for use as reinforcing substrate in a roofing composite.

Nipa palm is also widely available at low cost, and thus might be considered as a component in low-cost roofing.

Sugar cane is produced on a relatively large scale and thus the by-product, bagasse, might be considered as a filler. Currently, some of the bagasse is used for firing boilers to generate power in the sugar mills, although most of the sugar mills are reported to be fired with petroleum products.

Lumber is produced on a large scale and a considerable amount is exported to Japan in the form of logs. A new law was recently passed which will allow only export of lumber and/or plywood. Concurrent with the production of lumber and plywood, there is considerable waste sawdust and by-product small branches, bark, etc., which could be used for production of particle board. This is already being done on a limited (or experimental) scale using urea/formaldehyde resin binder. The urea/formaldehyde bonded particle board is somewhat moisture-sensitive, and this limits its utility. Additionally, the cost of urea/formaldehyde resin has dramatically increased recently.

Although some urea is produced in the Philippines, there is only experimental production of urea/formaldehyde resin. Almost all of the urea/formaldehyde resin used in making chipboard, etc. is imported from Japan and the United States.

There are several naturally occurring resins as well as synthetic ones which could be considered as binders in a roofing composite.

Lumbang oil from the nut of a tree is beginning to be produced in small quantity in the Philippines. The chemical composition has not been exactly determined, but the oil contains unsaturated and other functional groups which could permit it to be used as a polymerizable drying oil.

Copal is another forest product from the sap of the tree, which is used to make a varnish. It is a rosin-like resinous product. Gum rosin is available from pine trees grown in northern Luzon.

Rubber in sufficient quantity to supply the needs of the Philippines is produced on the island of Mindanao. Firestone, Goodyear and Goodrich have plantations there. Automobile tires for use in the Philippines are made from this rubber. There is no export of rubber crumb at present, but this may come with increasing production.

Polyester resins are produced in quantities of hundreds of tons per year by two companies, Resins, Inc. and Addo Resins, Inc. This small scale production is expected to increase.

A polystyrene bead foam plant has just started production in the Philippines using styrene monomer imported from Japan. The current capacity of the plant is estimated at 6600 metric tons per year, with 7000 tons additional capacity scheduled to be added in the near future. Since polystyrene is one of the lowest cost synthetic resins, the availability of this material in the bead foam formulation makes it possible to consider this resin (in either dense or foam form) as a roofing raw material.

Certainly, it could be concluded that the Philippines has available a variety of low-cost fibrous fillers, and potential resin binders, which should greatly facilitate the development of a low-cost roofing composite to replace the widely used corrugated iron. It is naturally expected that in a more detailed study of the Philippines, additional indigenous raw materials, for use as binders or fillers, will be uncovered.

In terms of manpower resources, the Philippines appears to possess an adequate supply of both unskilled and skilled labor for use in the construction of houses and roofing. In marked contrast to the situation in the United States, the cost of labor in building a house is only about 20% of the total construction cost. In 1971, common laborers engaged in construction in the greater Manila area earned 9.34 pesos ($1.40) per day. The rates for more skilled workers were: masons P. 11.59, electricians P. 13.31, and foremen P. 17.50. The wages of these workers are increasing at varying rates averaging about 6% annually. The wages paid to the construction workers are not substantially lower than those paid to workers in other industries. Accordingly, the requisite skilled labor is expected to be readily available at near these rates.

1.1.6 Existing Institutional and Technology Base

The institutional and technical support for the roofing program in the Philippines should be good. There are several agencies organized under the National Science Development Board (NSDB). These include the National Institute of Science and Technology (plans and implements research on agriculture, biology, food and nutrition, industry, medicine, tests and standards, evaluation and documentation), the Atomic Energy Commission, the Forest Products Research and Industries Development Commission (FORPRIDECOM), the Textiles Research Institute, and the Coconut Research Institute.

FORPRIDECOM was visited by our roofing team to discuss their specific research interest and capability. They have considerable interest and experience in wood waste utilization, and have been investigating the use of plant fibers for building products. They have produced a series of experimental building block units using various forest products as fillers: sawdust, woodchips, rice hulls, coconut husk fibers, banana stalk fibers, etc.

FORPRIDECOM has constructed several experimental demonstration houses at their laboratories using some of these materials. Figure 7 shows such a demonstration house under construction. This is a multi-family unit employing soil cement blocks on the first floor, and making extensive use of chipboard for the upper walls and roof. The roof is coated with asphalt to protect the water-sensitive urea/formaldehyde bonded chipboard from the weather. Figure 7 also shows a display rack at the FORPRIDECOM building site, with a variety of the waste product blocks, pipes, etc., which have been produced. Studies on the economic feasibility of these experiments were not yet available, although physical testing has been carried out with good results. For example, a standard core hollow block using coconut fiber and

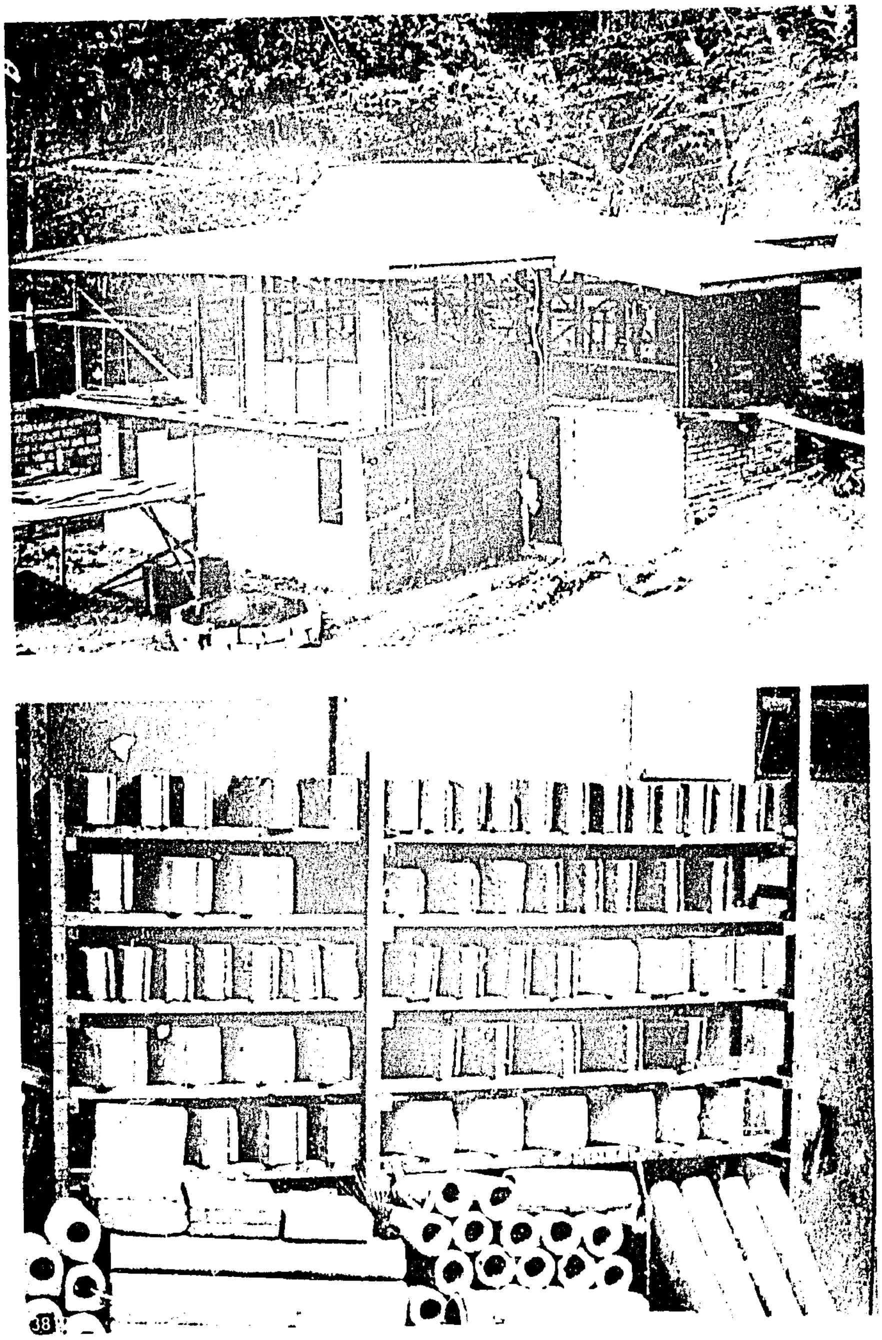


Figure 7. Experimental Demonstration of House of FORPRIDECOM and Newly Developed Materials. The building blocks shown at the bottom utilize wood wastes and fillers such as: saw dust, chips, rice hulls, etc., and are used in the first floor of this house. The strength of these building blocks is shown to be good, but economic viability is yet to be determined.

Portland cement binder was found to be stronger than many locally produced standard cement blocks now in use for housing.

FORPRIDECOM expressed considerable interest in cooperating in the roofing project.

Other institutions visited included the National Housing Corporation, The Peoples' Housing and Homesite Corporation and the University of the Philippines.

The National Housing Corporation (NHC) is a government enterprise incorporated in June 1968 for the purpose of mass production of prefabricated low-cost housing units. Its authorized capitalization of one hundred million pesos is financed equally by the Government Service Insurance System (GSIS), Social Security System (SSS), Development Bank of the Philippines (DBP), and the Philippine National Bank (PNB). The National Housing Corporation's integrated factory complex is located at Tala, Calocan City, Metropolitan Manila. There are several different processing plants at this site, including a porous concrete plant, a woodworking plant, a particle board plant, a polyvinyl chloride plant (to produce plastic tiles), and an asbestos-cement coating sub-plant (to coat walls of toilets and bathrooms with asbestos as a substitute for ceramic tiles).

The field team visited the National Housing Corporation Headquarters and interviewed the Executive Vice President, General Gaudencio Tobias. Plant capacity was stated to be 1000 houses per month, with the current production level at 135 houses per month. The high cost of production appears to be the biggest obstacle to NHC's meeting their demand. NHC expressed considerable interest in the roofing project, and in cooperating in the research. They thought it possible that the roofing product developed in the program could be produced in their plant. They were also interested in upgrading the quality and lowering the costs of the urea/formaldehyde binder now used in the production of chipboard.

At the University of the Philippines, personnel interviewed included: Alfredo L. Juinio, Dean of the College of Engineering, Aurelio T. Juguilon, Dean of the School of Architecture, and Ernesto G. Tabujara. Some materials research was being done at the University of the Philippines, though not on the scale of that underway at FORPRIDECOM. Among the individuals interviewed, Dr. Tabujara's energy, enthusiasm and ability make him an excellent candidate to head up a coordinating committee for the roofing program in the Philippines, provided he can make the necessary time available in his already crowded schedule.

Another institution active in low-cost housing development is the College of Engineering and Campus Development, Mindanao State University, Marawi City. They are developing a 45 square meter house consisting of a living room, dining room, kitchen, bath and bedroom, from a combination of soil cement blocks and CGI sheet roofing for about $600. This university could also be a good collaborator.

1.2 Singapore

Singapore currently has 2,500,000 inhabitants in a 220 square mile area; a population density greater than 10,000 per square mile.

The new government housing is all high rise, including higher cost executive housing and apartments. There are many squatters living on the land in very temporary housing, who are gradually being forced into the high rise apartments. A typical 18 ft x 10 ft one-room flat rents for $30.00/month and cannot be purchased. Two-room apartments sell for $5,000, three-room for $9,000 and four-room for $17,000. These apartments will eventually serve all of the low-income 70% of the population. The other 30% can afford private construction.

In Singapore, reinforced concrete is now exclusivly used for both individual dwellings and apartments "because that is what we have." "Even sand is becoming difficult to obtain anymore and, therefore, expensive." The Singapore Institute of Standards and Industrial Research has had samples of low density concrete from both Japan and the Swedish firm of Ytong, but do not intend to manufacture it at this time. In the high rise apartments, reinforced concrete is used for the roof. However, there are some roof tiles used in medium- and high-income residential dwellings.

Singapore has few natural resources. Some rubber is still being grown on the island, but the plantations are rapidly decreasing in size. No petroleum has been found on Singapore, although a refinery processes petroleum from Indonesia and elsewhere.

1.3 Malaysia - Kuala Lumpur

Kuala Lumpur was visited for two reasons: (1) to investigate the nature of a large, indigenously-based chipboard manufacturing operation expected to be established there, and (2) to update the team on the current technology and price of rubber through a visit to the Malaysia Rubber Research Institute.

Kuala Lumpur presented an interesting contrast to the other Southeast Asian capitals visited, excepting Singapore. The airport is large, and the terminal is modernistic in design, and beautiful. Streets are well paved and wide, and office buildings, stores and individual dwellings approach or equal western standards in quality and cleanliness. Very few squatter or slum dwellings were noted, although travel around the city was limited during the short stop. With its natural resources of rubber, wood, tin and petroleum, Malaysia has relatively few problems with foreign currency shortages, and its well-developed agricultural lands make it self-sufficient in food.

The unusually high level of development apparently prevailing in Malaysia results from the fact that they have four important raw materials available which provide resources for both income and foreign exchange. These are petroleum, rubber, tin and lumber. Additionally, agriculture is strong and Malaysia reportedly produces most of the food required to feed its entire population.

At Kuala Lumpur there is experimental production of several chipboard products from various waste lumber materials, some of which could be used in low-cost roofing.

At the Rubber Research Institute, it was found that the recent price of rubber had advanced rapidly, concurrently with the petroleum shortage, so that the price of rubber crumb in Malaysia is now $0.54/lb. Importantly, the Malaysians have fixed the price of crude rubber latex at only $0.05/lb lower than that of finished crumb. The latex price is deliberately set at this level to discourage the export of crude rubber latex from the country, and to shelter the development of finished raw rubber

An important consequence of this policy, from the standpoint of our roofing program, is that crude rubber latex is not likely to be available at a sufficiently low cost to make it attractive as a binder material. Since Malaysia sets the price for rubber products throughout Southeast Asia, this price level is expected to prevail elsewhere as well.

1.4 Thailand

Thailand was visited to discuss the project with the Asian Institute of Technology (AIT) where some interesting concepts on low-cost housing are being developed under the direction of Dr. Seng-Lip Lee, and to visit the U.N. Economic Commission on Asia in the Far East (ECAFE), with headquarters in Bangkok, to observe the role of this regional organization in housing and building activities.

Although Thailand is not recommended as a country for the location of the roofing project, the regional institutions (AIT and ECAFE), located in Bangkok, will undoubtedly prove useful in the upcoming phases of the program, which include dissemination of research results. Direct collaboration with Dr. Seng-Lip-Lee at AIT is planned, wherein some roofing concepts might be tested and installed on experimental houses at AIT. This would be particularly valuable in considering possible transfer of the developed technology to other nations, since students come to AIT from throughout Southeast Asia.

1.4.1 Geographic Location, Climate and Language

Thailand is located just north of the equator and the climate is benign compared to either the Philippines or Bangladesh. It is bounded by Burma, Laos, Cambodia and Malaysia.

There are several Thai dialects spoken in various part of the country. However, as in other Southeast Asian countries English is a second language of the intellectual and technical technical personnel throughout the country. Because the average Thai does not speak English, communication with unskilled and semi-skilled workers might be difficult.

1.4.2 Interest and Attitudes

In Thailand, the principal housing problem as perceived by the government involves low-cost housing for the greater Bangkok area and, to a lesser extent, a few of the provincial urban centers where squatting has begun to be a problem. In Thai terms, urban housing needs are great, but compared to other candidate countries visited in the region, needs are less severe. Bangkok and other Thai population centers have not yet experienced the tremendous pressures of rural-to-urban migration that have been seen in the other developing countries. The Thai government apparently does not consider rural housing problems severe enough to warrant programs in those areas. The highest priority is given to alternative methods of increasing farm employment and income.

1.4.3 Need for Low-Cost Housing and Roofing

On a per capita basis, Thailand is relatively rich in resources and her foreign exchange position is generally good, in food and in manufactured building materials.

On balance, the housing situation in Bangkok is substantially better than in other developing world capitals, and the resources to deal with such problems as do exist seem to be at hand. For these reasons, the need for roofing research, and the potential for impacting the shelter problem are considerably less than in other countries visited.

At the Applied Scientific Research Corporation of Thailand (ASRCT), the director, Dr. Kasem Balajiva reported, "We have not solved the low-cost housing problem yet. We have succeeded in making low-cost walls of rammed earth and soil cement, but were stopped by the cost of roofing material and supports."

Much of the low-cost housing in the Bangkok area is of the multi-story apartment type. In these buildings, the roofs are made of reinforced concrete and there are reportedly no problems with this type of construction.

In the individual houses, roofs are often made of asbestos-cement. The asbestos is imported from South Africa and thus requires foreign currency exchange.

CGI sheeting is used on the lowest cost housing because (as in the Philippines) asbestos-cement requires more support. The galvanized iron sheet used most commonly is 35 gauge with inadequate galvanizing and, in many areas, this thin sheet lasts no longer than 3 years.

A Thai company produces "Stramit" board of compressed rice straw with a very small quantity of urea/formaldehyde surface binder. However, unless extensively protected from the weather, this Stramit board is not suitable for roofing and can only be used in interior walls, partitions, etc.

There is also "Mon," made by packing rice paddy husk with clay, which is then air-dried then stacked in a lattice and fired. These, and other fired clay tiles, make good roofs but require heavy (expensive) supporting substructures.

1.4.4 Housing Trends, The Economy and Urbanization Degree

Thailand is still predominantly a rural country, with no city other than the capital, Bangkok, having a population greater than 100,000. Neither has Thailand experienced the pronounced urban-to-rural migration seen in many of the other developing countries in Southeast Asia.

A primary "solution" to the housing problem in Bangkok areas has been to turn to high rise steel and reinforced concrete buildings having roofs of the same material. This approach is emphasized by the government in order to maximize utilization of land in the already crowded metropolitan area of Bangkok.

The general economy in Thailand is good. Foreign exchange reserves, equal to one billion dollars, or about six months of imports, were on hand in 1974. The country is not yet over-populated. A combination of rich, fertile soil and highly developed cultivation of rice, fruits and vegetables makes it possible for the Thai to be self-sufficient in food.

1.4.5 Resources

Indigenous raw materials appear to be quite similar to those reported for the Philippines. Cement is produced in Thailand in sufficient quantity for almost all of their needs. Asbestos, for asbestos-cement tiles and sheeting, is imported from South Africa and Canada and thus requires foreign exchange.

Rice hulls, bamboo, grasses and a leaf similar to nipa palm (atlop) are all found in Thailand. Good wood for lumber is also available, and some quantities of hardboard and chipboard, using urea/formaldehyde binder, are produced. Kenaf is also grown in Thailand, but current plans are to use this fiber for making paper, and a mill is already going up.

Potential resin binders for roofing composites are also very similar to those in the Philippines. Some urea/formaldehyde resin is made in Thailand. Polyvinyl chloride is made from monomer, imported from Japan. Polyesters are imported from Germany. Rubber is produced in Thailand in some quantity, but the majority of the rubber trees are old, and rotation with new replantings has started late. However, the old rubber trees constitute a possible source of carbon for steel making or other use.

1.4.6 Existing Institutional and Technology Base

The Applied Scientific Research Corporation of Thailand (ASRCT) has the major government program in industrial and technical research, including building materials. The director of ASRCT, Dr. Kasem, offered the opinion that in Thailand, cost reductions will come primarily through new housing design, and to a lesser extent with innovative materials. As at FORPRIDECOM in the Philippines, ASRCT is actively engaged in developing various types of cement and clay composite building materials. No low-cost shelter research is underway at ASRCT, although their work with clay products and textiles may eventually lead to applications in low-cost housing.

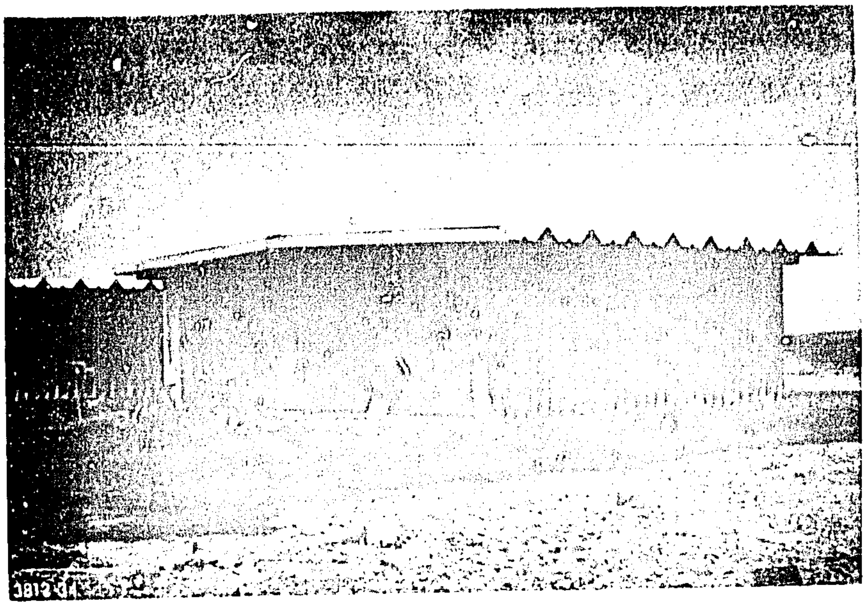
The Asian Institute of Technology (AIT) is involved to a minor extent in research into materials specifically directed at low income housing. Dr. Seng-Lip Lee at AIT has designed and built some low-cost housing units on campus for occupancy by engineering and maintenance staffs. These consist of corrugated cement-asbestos walls (cantilevered out of the foundations) and the same material for roofs. These houses were contractor-built at AIT at a cost of about $2.00/sq ft, and the prices included contractors' overhead and profit. These low-cost houses are pictured in Figure 8. In retrospect, Dr. Lee stated that one change he would make would be to design more overhang in future houses so as to provide a larger active area for the customary "outside" cooking.

The headquarters for the UN Economic Commission for Asia and the Far East (ECAFE) is also located in Bangkok. Mr. S. F. Garcia, a Filipino, is Chief of Housing. The role of ECAFE is to disseminate information, and coordinate selected activities of its member countries. ECAFE has no funds for actual research and development, except through UNDP funds which may be assigned to it.

1.5 Bangladesh

1.5.1 Geographic Location, Climate and Language

Bangladesh is located in the tropic zone north of the equator. The country occupies the alluvial plains of the Ganges, Brahmaputra, and the Meghna Rivers, which drain vast land areas, and whose tributaries carry off some of the highest recorded rainfall in the world. These rivers flood in June and July during the monsoon rains, which amount to 70 inches, creating a massive flow of water over the land.



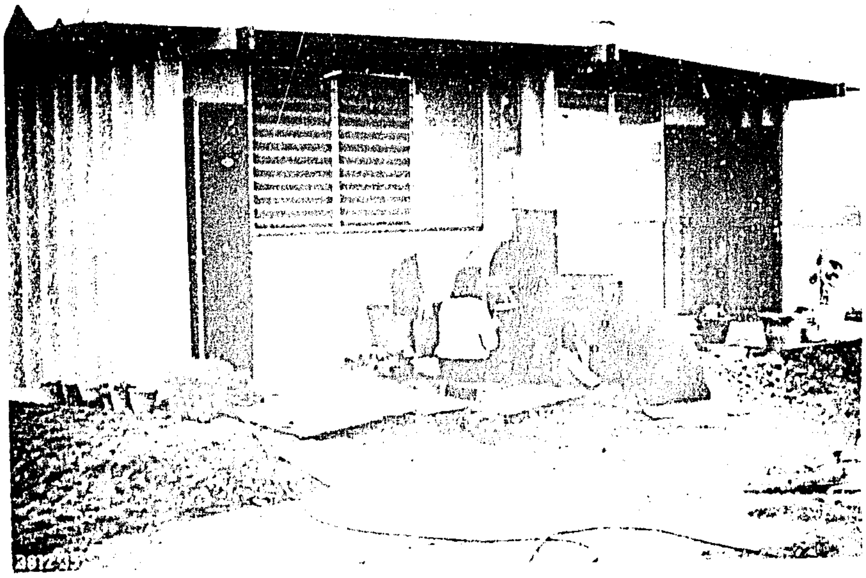


Figure 8. House Developed and Constructed by the Asian Institute of Technology (AIT). The construction is of corrugated cement-asbestos walls (cantilevered out of the foundation) and the same corrugated cement-asbestos for roofing. They were built at a total contractor cost of $2.00/sq ft. Note the overhang at the rear of the house which accommodates an area for cooking.

Except for the Chittagong hills and the low hills of the northeast, Bangladesh lies at a maximum elevation of 300 ft above sea level. Many places 100 miles from the sea have an elevation of only 30 ft and the gradients are about 5 inches per mile from north to south. In this topography, rivers and streams are constantly changing their courses, and assailing tides (aggravated by storms in the Bay of Bengal) frequently encroach on the land in the Delta area.

Following the monsoon season, drainage and absorption leave the land dry, the streams and the smaller rivers disappear or become unnavigable, and water for farming is available mainly from the river channels. The cycle of flood and drought, compounded by cyclones and assailing tides, is the main impediment to adequate cultivation of the land. Although the land is fertile and replenished by the annual deposits of silt from the floods, the varying water depth and the rate of drainage make crop yields unstable and unpredictable.

The official language of Bangladesh is Bengali. However, in common with many other former British Commonwealth countries, English is spoken by the majority of technical and educated people. Communication with a Bengali taxi driver, or day laborer, could be difficult or nearly impossible without an interpreter.

1.5.2 Interest and Attitudes

There is indeed interest on the part of the Bangladesh Government in improving the housing of the people, and especially that of the lower income groups. However, Bangladesh has many problems and housing is secondary to population control, adequate food, schools, medical aid, roads, etc. In the last two decades, population pressure has created a food deficit, and food production and distribution has been severely disrupted by the effects of the 1970 cyclone and the "liberation war" of 1971. Bangladesh is one of the poorest countries in the world, with an average annual per capita income of $60.00.

Although there is significant and real interest in housing (primarily shelters) on the part of the government, priority for scarce funds must be given to food and other more basic needs.

Almost certainly, the need for housing and everything else is greater in Bangladesh than in any of the other countries in Southeast Asia surveyed by the project team. However, the need for food, educational facilities, medical help and hospitalization is greater.

Bangladesh is an agrarian country with a population of about 80 million and a growth rate of over 3% per year. The Harvard Center for Population Studies has estimated that, at the present growth rate, population will reach about 240 million by the year 2002, and even with the most stringent population control measures there is no way to prevent a doubling of the present population in the next 20 years.

Bangladesh has about 35 million acres of habitable land, 25 million of which are cultivatable. The population is 90.4% rural. The World Bank has estimated that in 1970 the overall population density was about 2000 persons per square mile of cultivatable land and predicted that it would reach 3200 by 1985. During the flood season, when perhaps only about 10 to 20% of the country is above water, densities of population in the higher area are estimated to range from 20,000-40,000/sq mile of dry land.

1.5.3 Need for Low Cost-Housing and Roofing

The need for more and better low-cost housing and roofing in Bangladesh is thus very apparent. The need for pukka (permanent) or semi-pukka houses is widespread. However, for many years to come, cost constraints will dictate that shelter in Bangladesh continue to be built primarily of natural or modified natural materials, rather than of predominantly manufactured materials. This is the traditional method of building houses in Bangladesh, but there is sufficient evidence of shortages of indigenous materials to suggest that the day may already have arrived when there simply is not enough land to provide space for settlements, to grow food crops, and to grow the supply of building materials needed to shelter the natural population increase.

Bamboo and grasses for roofing make a good case in point. In the rural areas of most of the tropical countries, these materials are usually free for the taking, for building of local houses. In Bangladesh, they are marketed commodities, fetching prices that have doubled in the last two years. The government has been forced to establish plantation reserves of bamboo to insure a supply of this building material for emergency housing repairs, and for sale at controlled prices.

1.5.4 Housing Trends, The Economy and Urbanization Degree

Only a very small percentage of rural houses can be classed as truly pukka--permanently resistant to floods and storms. Probably 95% of rural housing is kutcha (temporary) construction, utilizing bamboo, reeds and grasses for walls and roofs. Most are built on earthen plinths, built up of compacted earth to heights which vary according to local flood levels--ranging from a few inches in the north to as much as four feet in coastal areas. Such houses are mostly of skeleton frame construction, bamboo rounds for posts, beams, rafters and purlins. Split bamboo woven into mats is the most common wall infilling; small canes are also used for walls and interior partitions.

In some areas, mud daubing on split bamboo wattle is used for walling, but the most common solution is bamboo matting woven into various patterns, most commonly square or diamond-shaped designs. Most rural roofs are double-pitched, thatched with local grasses, reeds or palm leaves; CGI roofing is preferred by the more affluent, while clay tiles can be found on some of the older, more substantial housing. Rural houses are generally small, rectangular, 16 ft to 24 ft long by 10 ft to 15 ft wide--160 to 260 sq ft--divided into 2 or 3 rooms with woven bamboo or reed partitions.

Figure 9 shows typical temporary (kutcha) housing based on various plant materials in a peri-urban situation. Figure 10 shows houses in a rural location.

The shortage of basic raw materials has led the Bengalis to consider unconventional approaches to building. For example, William Woudenberg (CARE-Bangladesh) is investigating the fabrication of several designs of cylindrical shell houses based on a composite of jute cloth and polyester resin. This type of shell house construction combines the roof and supporting

Figure 9. Typical Peri-Urban Housing in Bangladesh Showing Use of "Found" Materials and CGI Sheet

Figure 10. Typical Rural Housing in Bangladesh Showing Extensive Use of CGI Sheeting for Roofing and Walls. Note land eroded away due to flooding.

substructure into a single unit and eliminates the need for heavy, costly beams, rafters, etc. Shell houses of concrete on woven bamboo mats are being investigated by others. Dr. Jamilur R. Choudhury at Dacca University of Engineering and Technology is evaluating the production of corrugated roofing sheets from rigid polyvinyl chloride.

1.5.5 Resources

Bangladesh has few natural resources of any type.

There is no indigenous cement industry in Bangladesh. This results from the fact that there is no limestone rock readily available from which to make cement.

Limestone is reported to be available 1500 ft underground in the north hills. One cement plant is in operation with limestone imported from India, producing 120,000 tons per year. There is also one plant producing cement from imported clinker (Taiwan). The building of additional plants for producing cement from both limestone and clinker is planned, to bring the capacity up to the desired level.

The use of CINVARAM soil cement blocks for making the walls of houses has been promoted by CARE and USAID. These houses are usually roofed with CGI sheets.

Aggregate for use in making concrete and for road building is often produced by first making bricks from clay, firing them, then crushing them to produce aggregate of appropriate size, as shown in Figure 11.

Small brickyards are found throughout the delta region of Bangladesh. However, several of the Bengalis told us that stripping of the top soil for making bricks left exposed subsoil which was then unsuitable for farming. This would set up a vicious cycle wherein each brick produced for housing (or roads) is at the expense of good land for production of food. An example of a rural brickyard is also shown in Figure 11.

There are no iron ores, or other materials of importance, in Bangladesh, and consequently no indigenous metal industry.

There is some timber produced in the Chittagong hill tracts to the south, and in the Sylhet district in the northeast. In these regions of the country timber houses and half timber construction is fairly common.

Jute production in Bangladesh is large, and jute is extensively used in making cloth for packaging materials. Unfortunately, jute is having difficulty competing with high performance synthetics on world markets. In the process of producing jute, a much larger quantity of "jute sticks" is also produced. Some of these jute sticks are used in making particle board at a plant located just outside Dacca.

As the Bengalis pointed out to us, jute is produced on many small isolated farms. The jute bark, representing less than 10% of the weight of the complete plant, is removed on the farm where it is produced. The jute sticks remaining are thus scattered in many individual locations, and collecting and transporting them to some site for manufacturing particle board could be expensive. More importantly, the jute sticks are also used by the farmers as fuel for cooking. If these sticks were diverted to use as a roofing component some other fuel (e.g. petroleum, coke, etc.) would have to be made available to the farmer.

Although petroleum is not available in Bangladesh, some petrochemicals are available from natural gas production. These include urea, polyvinyl chloride and acrylic (polyacrylonitrile).

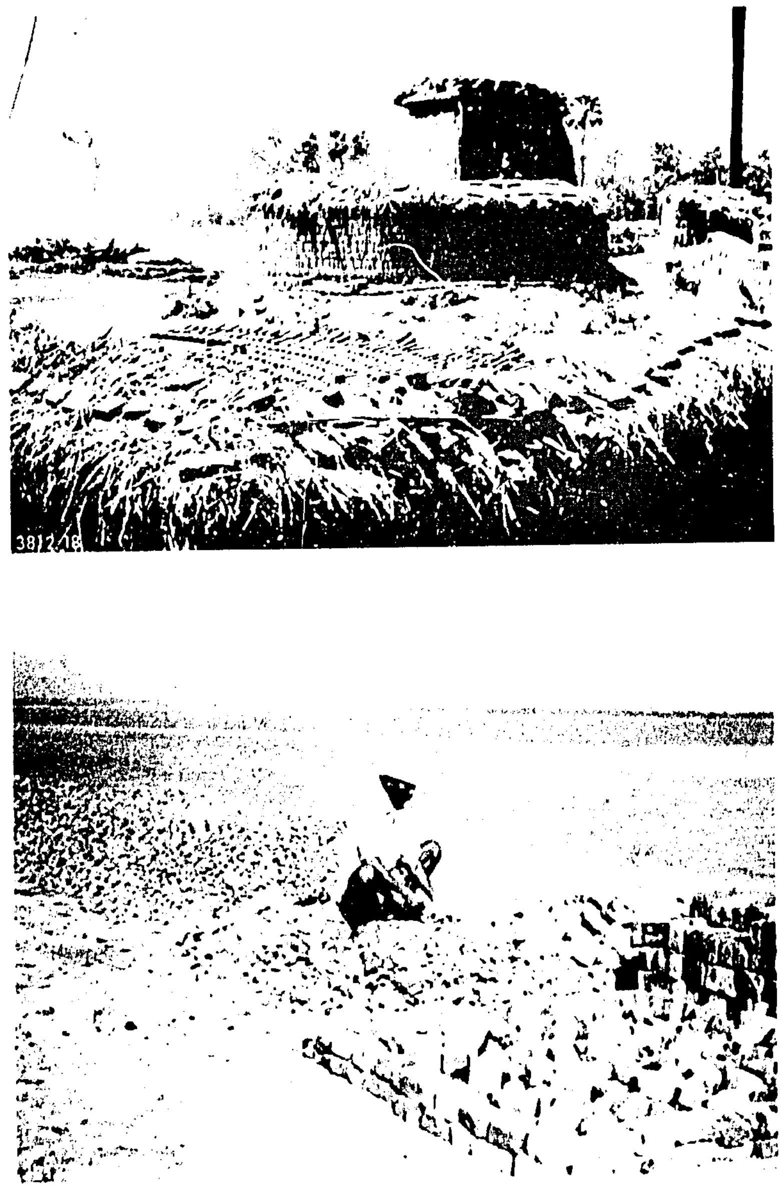


Figure 11. Illustration of Typical Rural Brickyard in Bangladesh Using Indigenous Clay from Under Valuable Agricultural Land. Bricks are broken up into aggregate for use in road beds.

1.5.6 Existing Institutional and Technology Base

There is a reasonably well developed institutional and technology base in Bangladesh. In the present capital Dacca, and Chittagong, and in some other principal cities, institutions and universities for higher learning do exist. However, during the recent "war of liberation" in 1971, many intellectural leaders and university students were reportedly killed by the Pakistani army. This loss of intellectural leadership has had a disruptive effect on the operation of the universities, research institutions, etc. Additionally, the new government of Bangladesh has many other urgent problems to deal with, such as population control, adequate food, medical care, etc. As a result, the direction and support of the universities has until now (of necessity), been neglected. Thus, the existing institutional and technology base in Bangladesh is understandably lower than would otherwise have been anticipated in a country of its population and stage of development.

1.6 India

India was visited primarily to observe recent research at the Central Building Research Institute (CBRI) in Roorkee on the use of coconut husk fibers for building boards Since the process does not require binders other than those which are inherent in the husk itself, it was thought to be of particular interest to the roofing project. However, the end result as viewed at Roorkee was less promising than expected. The board product is moisture sensitive and appeared to be useful primarily for interior walls and ceiling. Water-proofing is required for exterior wall or roofing use, and this will add costs beyond those of more conventional solutions.

A second interest in the visit to Roorkee lay in observing the several other approaches taken by CBRI in their building materials research. Brick and clay products are considered by CBRI to be India's main building resource. This is reflected in their roofing research, which is directed at the use of bricks, flat arches, and roof beams reinforced with steel rods.

In general, the CBRI gives the impression of commitment to cement brick and other clay products, to the extent of ignoring other material research possibilities. Their attitude toward polymeric binders was distinctly negative; they cited bad experience with costs and fear of fire hazard. However, the regional source approach they have taken is noteworthy, and doubtless will make an important contribution to Indian building solutions. A view of two of the flat arch roof systems using brick and gypsum is shown in Figure 12. This approach may also be useful in Bangladesh.

Figure 12. Illustration of Flat-Arch Roof System of the Central Building and Research Institute, Roorkee, India. Materials are brick and gypsum.

2. AFRICA

The African countries surveyed were Zambia, Ghana, Ethiopia, Malawi, the Sudan and Kenya. The first three are primary countries and the second three are secondary countries. The survey of Ghana was limited to part of one week by a member of our team. Consideration of Ghana was then cut short and Ghana was eliminated for the time being, at the request of the USAID Mission there. This action was taken because it was felt that the objectives of the AID-sponsored A. D. Little program on "Achievement of Reductions in Costs of Public Construction" paralleled our proposed effort, and would perhaps overload the capacity of the Building and Road Research Institute at Kumasi.

Again, the surveys were made primarily in and around the capital cities, since the greatest amount of information existed there (in Government agencies and individuals). However, some brief visits were made outside of the cities to observe the rural and peri-urban situation. Cities visited included Accra and Kumasi (Ghana), Lusaka (Zambia), Addis Ababa (Ethiopia), Zomba and Blantyre (Malawi), Khartoum (Sudan) and Nairobi (Kenya).

2.1 Zambia

With the initial exclusion of Ghana, Zambia was considered a primary candidate because of an expressed official interest from the Zambian Government. Therefore, Zambia was surveyed more extensively than the other African countries.

2.1.1 Geographic Location, Climate and Language

Zambia, formerly Northern Rhodesia, is in south-central Africa. It has no coastal region and is bounded by Zaire, Tanzania, Malawi, Mozambique, Southern Rhodesia, Botswana, and Angola.

Zambia has an area of about 290,000 square miles (size of Texas) and a population of 4.4 million (1971). The capital city Lusaka (population 381,000) is centrally located

Zambia is typical of a tropical plateau region, tempered by altitude. There are three definable seasons:

Cool and dry - May to August
Hot and dry - September to November
Warm and wet - December to April

Rainfall varies from over 50 inches annually to the north, to something less than 25 inches in the south. For fully half the year, there is apt to be no rain at all in the country. The highest plateau occurs in the north and much of it is above 4000 ft, whereas the northern part is generally below 3000 ft in elevation. Because of the high average altitude, Zambia's year-round climate is mild for a tropical country.

The official language of Zambia is English, but about 70 local languages and dialects are also spoken. As a result of the many dialects, oral communication with the uneducated is often difficult. British expatriates are excellent interpreters when available.

2.1.2 Interest and Attitudes

Among the African countries surveyed, Zambia indicated, by far, the strongest interest and most positive attitude toward acceptance of our roofing development program. There was also a strong indication that housing is a problem, much of it attributable to roofing, which is deemed to be inadequate

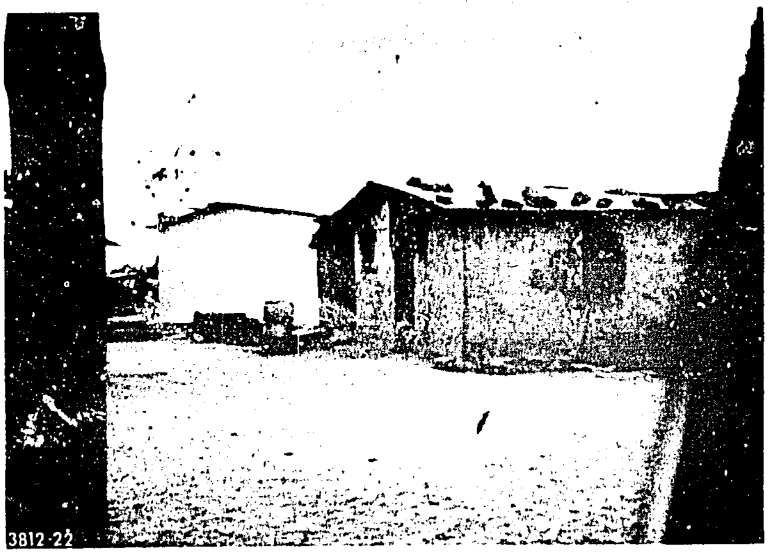
The desire for the roofing program to be brought to Zambia was intense. Unsolicited invitations from the Zambian Government (Ministry of Local Government and Housing) strongly urged our selecting Zambia as a test site, as did the U.S. Embassy in Lusaka.

2.1.3 Need for Low-Cost Housing and Roofing

Extensive use of corrugated galvanized iron roofing was evident in all parts of Zambia surveyed. Corrugated galvanized iron roofing is formed and galvanized in Zambia, but importation of the steel bears heavily on Zambia's balance of payments.

Cement-asbestos is also used extensively along the main transportation corridors, or "line of rail," where shipping is less of a problem.

The very significant migration of Zambians to the urban areas has introduced an uncontrolled growth of squatter settlements around the cities and towns. By 1971 the total squatter population had reached 260,000, with 100,000 of these people living in 30 shanty towns around Lusaka alone. This migration swelled the capital's population by half. This urban influx of people generated an intense need for improved housing and roofing, especially in these squatter settlements, where housing is chiefly single story, single family units. (See Figure 13).



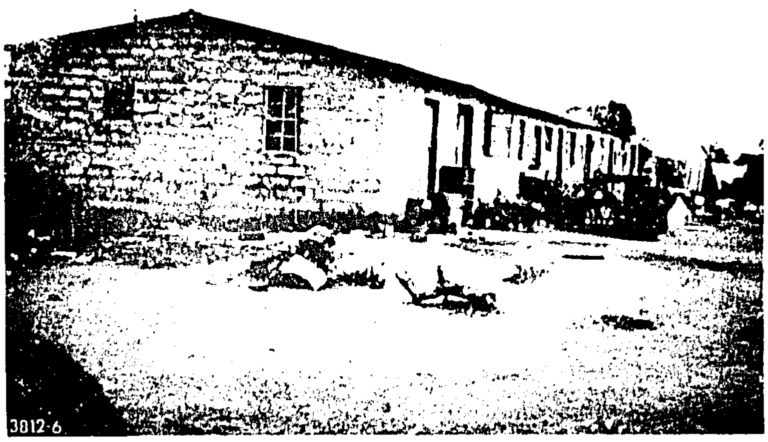


Figure 13. Typical Squatter Housing in the Lusaka, Zambia Area. Extensive use of CGI sheet held down in a number of crude ways is illustrated.

2.1.4 Housing Trends, The Economy and Urbanization Degree

Significant housing plans have been in effect since 1965. These included the Transitional Development Plan (1965-1966), the First National Development Plan (1966-1970), and the Second National Development Plan (1972-1976).

In the Second National Development Plan a strong policy statement is made in regard to housing, reaffirming a 1968 commitment to self-reliance through self-help and home ownership at all economic levels. A directive from the Permanent Secretary of the Ministry of Local Government and Housing was issued in July 1972 interpreting the housing policy. The main points of this directive are summarized:

> Home ownership is to be encouraged, with all housing constructed to be for sale. Rental of housing is to be used only where jobs require individuals to move frequently. The problem of land tenure is to be addressed and local authorities are requested to submit suggested plans for acquisition (and presumably redistribution) of land in their areas. This is one of the largest obstacles to home ownership and the solution to the problem does not seem to be near at hand.
>
> Henceforth, all income levels will be expected to house themselves, and plots will be made available for this. Thus, sites and services programs will be promoted and not restricted to low-cost housing. Self-help building is to be the chief feature of the housing policy to be encouraged by the Government in every possible way. Loan terms for self-help are to be liberalized.

Squatter settlements are recognized as social and economic problems. However, it is desirable to contain existing squatter settlements to their present sites. Wholesale demolition is not practical. Upgrading the existing squatter settlement by providing the necessary infrastructure is suggested, and is being pursued via a loan from the World Bank. A loan in the amount of $40 million has recently been negotiated.

In terms of housing goals, proposed new units in urban districts well exceed those in the rural areas (67,000 to 3,000). The main thrust in rural housing is toward the improvement of housing standards through research and a better use of local materials. Technical assistance is given to rural cooperatives manufacturing building materials.

Zambia's economy is in much better condition than that of many developing countries, primarily because of the exploitation of their substantial copper resources. However, Zambians have not benefited from their mineral resources to the degree possible. The building of a new railroad through Zambia and Tanzania is presently a very significant drain on the balance of payments. Though Zambia has significant assets, the current load of liabilities make improvement in their balance of payments worthwhile.

A trend in Zambia seems to be toward cement-asbestos roofing. This roofing survives well and is being actively marketed by the Turner Asbestos Products (TAP) Company (see Figure 14). The asbestos has been imported from Uganda, Rhodesia and South Africa but now comes mainly from Swaziland. Despite its weight and tendency to become black from mold, the cement-asbestos roof has gained wide acceptability. National Housing Authority

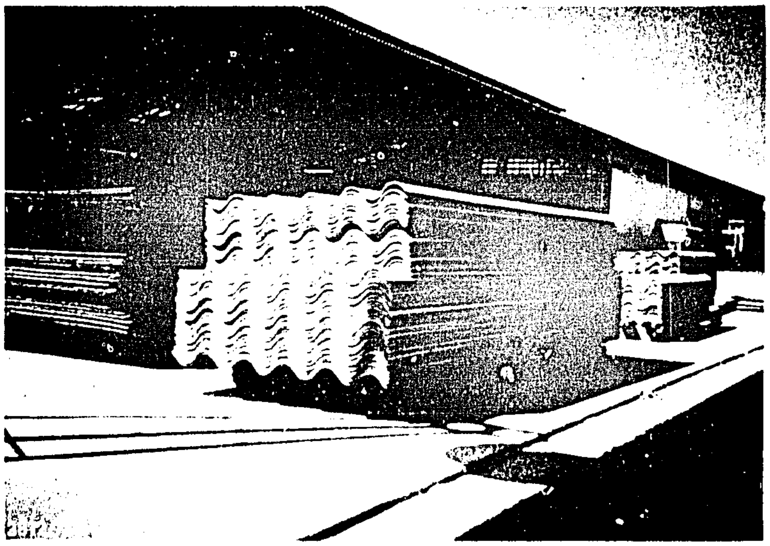


Figure 14. Cement-Asbestos Roofing Manufactured by the TAP Company On the Outskirts of Lusaka, Zambia. Shown on the Loading Dock at the Factory and Installed on a Low-Cost House.

encouragement to use indigenous material (cement) tends to promote the use of the cement-asbestos roofing, and also reduce the use of corrugated galvanized iron. However, the asbestos component in this roofing still requires significant foreign exchange.

2.1.5 Resources

The Zambian construction industry is chronically hampered by shortages and erratic supplies of building materials. It is heavily dependent on import. The First National Development Plan emphasized import substitution, but little was achieved during this period. At the beginning of the plan the foreign exchange component of construction (including materials) was about 30% and apparently has not changed much since then.

The building materials industry has been centralized in the government-controlled Industrial Development Company (INDECO), rather than in private industry. INDECO owns and operates cement and clay-tile pipe factories. Steelbuild Holdings Limited controls about a dozen operating companies in INDECO and has the main responsibility for providing the country's construction materials. However, this is still accomplished largely by importation.

A select list of these building materials and their foreign exchange component include: Portland cement (10%), steel-reinforcing bars (100%), galvanized wire (100%), bituminous felt (100%), pre-cast concrete blocks (15%), asbestos-cement roofing sheets (12-1/2%), roofing nails (100%), hollow core flush doors (80%), building hardware (100%), metal windows (60%), window glass (100%), and paints (70%). This information was gained from the National Housing Authority and did not include corrugated galvanized iron roofing. This is formed and galvanized (from Zambian zinc) in Zambia, and the foreign exchange component was estimated by the project team to be 60%.

The following materials were found to be indigenous and available in varying degrees: Portland cement, lime, clay, coal, wood waste, eucalyptus and pine trees, maize stover, grass, papyrus, reeds, cotton waste and copper sulphate (from copper refining). Zambia is in a good fuel position, having available coal and hydroelectric power.

The availability of wood wastes is increasing, especially due to the forestation of parts of the country (copperbelt) with eucalyptus and pine trees. Interestingly, however, no particle board, hardboard or fiber softboard is now produced in Zambia.

Other tree associated materials include pine needles, which may be used as fillers, pine rosins, which may be extracted for binders, and eucalyptus oil, which is extracted from foliage. Growing of sunflowers is also being examined.

The raising and exporting of cotton has shown a tremendous increase in recent years. Even though specific data were not on hand, a very significant amount of waste should be available from the cotton crops.

This very briefly summarizes the material resources available in Zambia, but is based on a very subjective overview. It is anticipated that in the second phase of the program more specific information will be obtained involving the exact nature of the materials, their actual availability, their location and costs.

In terms of manpower resources, Zambia suffers from a shortage of artisans and supervisors, even though the construction labor force is increasing. Worker productivity is also increasing at an estimated 6% per year, but wages in construction are only one fifth those paid in the mining industry, which obviously detracts from the availability of more skilled manpower.

2.1.6 Existing Institutional and Technology Base

The National Housing Authority (NHA) was established in 1971 by an act of Parliament. This authority was given much broader responsibility than the Zambia Housing Board which preceded it. Members of the National Housing Authority are appointed by the Minister of Housing and Local Government, and include representatives of the Ministry, the Commissioner for Town and Country Planning, the University of Zambia, the Zambia National Building Society, District Governors and others.

The broad responsibilities of the NHA include implementation of the National Housing Policy, which encompasses improvement of squatter areas, recommendations on housing law, recommendations for housing research, and even the development, building, and managing of housing estates. They have the power to require local authorities to provide housing in their communities. Thus, a very strong institutional base exists for development of housing.

Three organizations were visited which indicated the existence of a firm technology base in Zambia. These were the National Council for Scientific Research (NCSR), the National Housing Authority (NHA), and a division of Forest Products Research of the Ministry of Lands and Natural Resources (FPR).

The National Council for Scientific Research is a fairly young organization (1967), but in 1971 had a total staff of 233, including about 30 senior professional and technical personnel and 30 technical assistants. This organization was chartered to coordinate and promote scientific, technological and architectural research, and to provide advice for the government on national scientific research policy and activities. Research projects sponsored in the building area included: soil-cement blocks, properties of rural and urban bricks, properties of Zambian soils, and the effect of solar heat load on various building forms and orientations. NCSR is committed to the establishment of a Building Research Institute, probably through a cooperative effort with the National Housing Authority, and expressed the hope that the institute would be operational late in 1974.

The National Housing Authority maintains a materials testing laboratory, reported to be a good one, equipped with basic test facilities and adequately staffed. It performs quality control testing of concrete and concrete products, foundation soils, etc., at the request of government and industry.

The Forest Products Research is centered in Kitwe, an area which has been selected as a center for forestation in pine and eucalyptus. The forestation is intended to upgrade the quality and quantity of the indigenous Zambian trees, which for the most part are poor. FPR is committed to two major R&D projects in wood utilization and building. One is in low-cost housing. The second involves veneers, plywood, laminates, other composites, residue utilization, and utilization of little-used Zambian tree species. Because of the concentration of mining activity in Zambia, the technological level could be relatively high; however, getting skilled people to carry out R&D work remains a problem.

2.2. Ghana

Our initial proposal toward implementing the roofing development program included Ghana as a primary demonstration site. It had been selected because of our subcontractor's experience in Ghana (J.P.R. Falconer worked there for three years and G. N. Coleman is a citizen of Ghana), and our knowledge that appropriate collaborating institutions (such as the Building and Road Research Institute) with a strong technology existed in Ghana. Further, G. N. Coleman, on a personal trip to Ghana, made contact with a number of appropriate agencies and individuals to determine their interest in our program. Thus, a wealth of information was already available on the country, its climate and material resources, the housing situation, etc.

2.2.1 Geographical Location, Climate and Language

Ghana is situated on the Gulf of Guinea on the west coast of Africa.

It is bounded on the north by Upper Volta, on the west by the Ivory Coast and on the east by Togo. It has an area of 92,100 square miles and a population of 9.5 million.

Ghana is an attractive location for the roofing project because of its varied topography and climate confined in a small area. The coastline is mostly a low sandy shore, backed by plains and scrub and intersected by several unnavigable rivers and streams.

Two good ports (Tema and Takoradi) provide access. A belt of tropical rain forests extends along the western edge of Ghana and is broken by heavily forested hills and many streams and rivers. North of this belt the country varies from 300 to 1300 ft elevation and is covered by low bush and grassland plains.

The climate is that of an equatorial country. The eastern coastal belt is warm, and comparatively dry; the southeast corner is hot and humid; the forest belt is warm and humid; and the north is hot and dry. Except in the north, there are two rainy seasons, separated by a short and fairly dry period in July and August, and a long dry season from December to February. A dry northeasterly wind (harmattan) blows in January and February. The average annual rainfall in the coastal zone is 33 inches.

English is the official and commercial language and is taught in all schools. About 25% of the general population is literate in English, although there are more than 50 languages or dialects spoken within the country. Oral communication in English, however, is not without its difficulties.

2.2.2 Interest and Attitudes

A very high degree of interest in both the roofing concept and program was found in our brief survey of Ghana. Those indicating a positive interest and desire to cooperate were: The Building and Roads Research Institute, Forest Products Research Institute, and Crops Research Institute of the Council for Scientific and Industrial Research; Department of Housing and Planning Research, University of Science and Technology; Ministry of Works and Housing; Ministry of Lands and Mineral Resources; Ministry of Agriculture; Ghana Housing Corporation; TEMA Development Corporation; Ghana Industrial Holding Corporation; and the Ghana Geological Survey.

In spite of this expressed interest on the part of a number of organizations and individuals, the AID Mission felt that the program may parallel or duplicate an existing program involving utilization of indigenous materials being conducted by A. D. Little, Inc., under AID sponsorship. Accordingly, Ghana was eliminated from consideration as a roofing demonstration country. However, this decision is now being reviewed and it is possible that Ghana could be added to the program later.

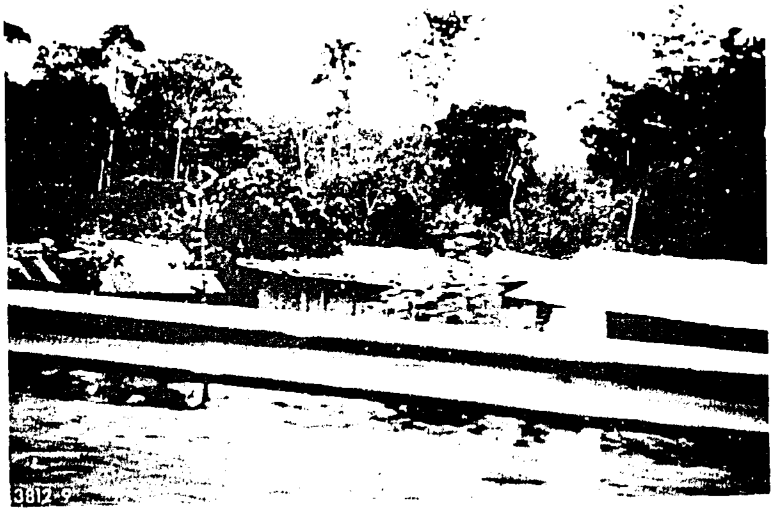
2.2.3 Need for Low-Cost Housing and Roofing

Corrugated galvanized iron is used extensively in both urban and rural Ghana, and has a high foreign exchange component. The need therefore exists for a roofing system made from indigenous materials to accommodate the extensive housing needs of the country. (see Figure 15).

2.2.4 Housing Trends, The Economy and Urbanization Degree

Ghana's per capita income is one of the highest in Africa. The economy is based on the production of a limited number of agricultural and mineral commodities. The basic crop is cocoa (1/3 to 1/2 of the world supply). Also included are peanuts, coconuts, palm kernels, palm oil, and coffee. Significant quantities of precious wood such as mahagony are produced for export, and rubber production exists and is increasing.

Mineral production (concentrated largely in aluminum, gold, manganese, and industrial diamonds) ranks second to agriculture as a source of foreign currency earnings. Marketing of diamonds has been promoted but has progressed slowly.



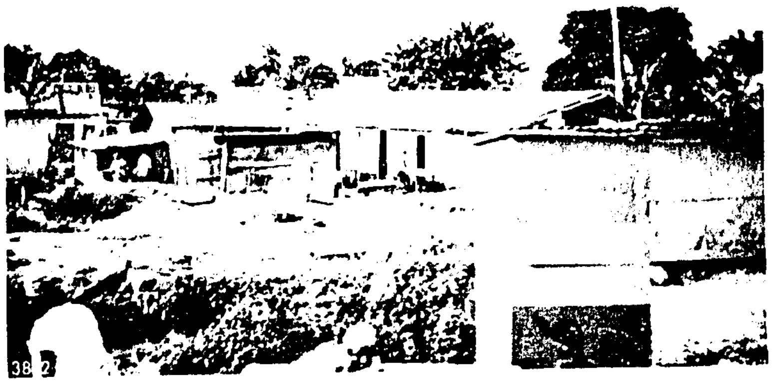


Figure 15. The Extensive Use of CGI Sheet in Both Urban and Rural Situations is Illustrated in the Accra-Kumasi, Ghana area.

A very significant factor in Ghana's economic picture is the Volta River project, which consists of a hydroelectric plant and aluminum smelter. A consortium of private American companies built and operate the aluminum smelter using power generated by the dam. The U.S. aluminum companies purchase aluminum produced by the smelter at a price which will cover debt and operating costs.

As in most developing countries, urbanization in Ghana is increasing. However, the Government continues to emphasize rural development, and more resources are being devoted to agricultural and agricultural-related industries.

2.2.5 Resources

As explained above, only a brief, informal survey has been made of Ghana. However, there are several agricultural residues which should be readily available wherever they are not used as fuel or for animal forage. These include cocoa pods (Figure 16), nut shells, palm leaves, coir and wood waste. Rubber may also be important. Aluminum is produced in ingot form for export, and processed into finished shapes outside the country. By-product waste from the aluminum processing may supply a valuable raw material for making pozzolana cements.

Unemployment remains relatively high in Ghana, especially in the urban centers. Accordingly, manpower resources (unskilled) are readily available.

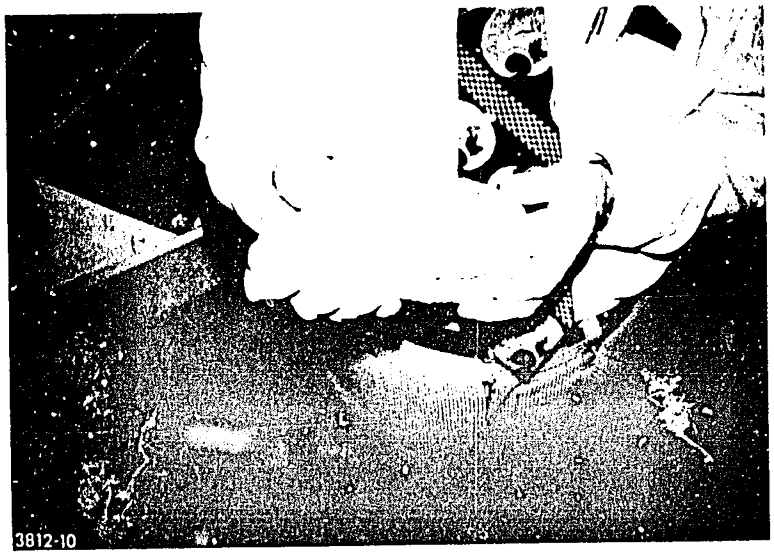


Figure 16. Cocoa Pods, Unripe at Top and Ripe at the Bottom Grown in Ghana. Ghana produces nearly one-half of the world supply of cocoa and this pod, therefore, represents a high volume residue. It may be necessary, however, that it be returned to the soil to feed back its high potassium content.

2.2.6 Existing Institutional and Technology Base

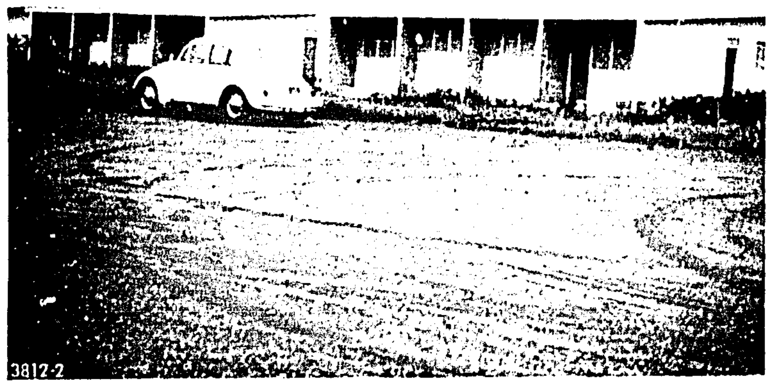
Based on our experience in the African countries, the existing institutional and technology base is outstanding in Ghana. This base is represented somewhat by the organizations briefly mentioned above (Section 2.2.2) who have indicated their interest in this project.

The reason for originally proposing Ghana as a primary site involved, to a great extent, our knowledge of the strong technological base provided by the Building and Road Research Institute and our acquaintance with its personnel (in particular J.W.S. DeGraft-Johnson, the Director). The institutional base is also well structured through the various ministries, including Works and Housing, Lands and Mineral Resources, and Agriculture. We have been very impressed with the efforts and results of the Ghana Housing Corporation and the TEMA Development Corporation in making available some very necessary low-cost housing. (see Figure 17).

2.3 Ethiopia

Ethiopia is located in northeast Africa. It has a land area of approximately 409,000 square miles and is bounded by Sudan, Egypt, and the Somali Republic. The population is estimated to be 25,000,000. The capital is Addis Ababa.

Ethiopia is relatively convenient to get to by air. It also has a serviceable seaport, which makes outside materials available by low-cost sea shipping.



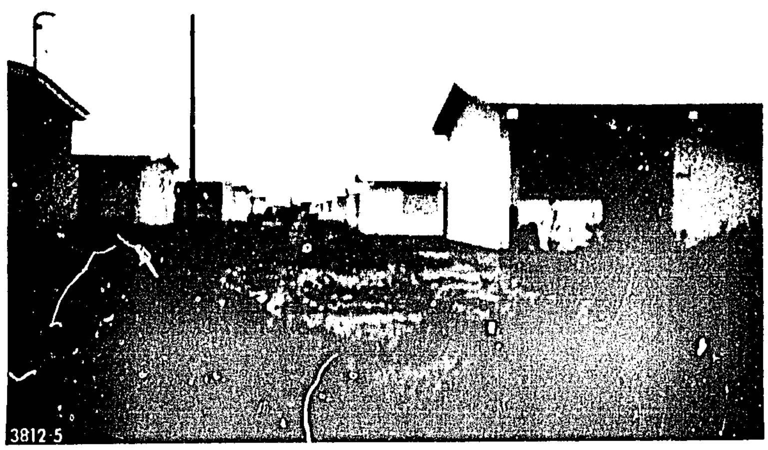


Figure 17. Typical Low and Moderate Income Housing Constructed by the TEMA Development Corporation in Tema, Ghana. This was not representative of housing throughout Ghana.

The climate in Ethiopia varies from very hot and dry to hot and humid, typical of a tropical African country.

The official language of Ethiopia is Amharic. Few of the lesser skilled people understand English. This would result in a communication problem for our research and development team.

2.3.2 Interest and Attitudes

No strong positive indication of official government interest in the roofing project could be established for Ethiopia.

2.3.3 Need for Low-Cost Housing and Roofing

Among the African countries visited, Ethiopia has the greatest need by far for housing and the associated roofing. This is reflected in inadequate housing for millions of people. However, the need for other basics such as food are also very great and tend to reduce the relative priority for shelter and housing in the Government's view.

2.3.4 Housing Tends, the Economy and Urbanization Degree

Very few housing programs have been carried out in Ethiopia. It seems safe to presume that roughly the same housing situation prevails today as in 1965 when the country was surveyed by a team of AID-sponsored advisors to the Imperial Government. One member of the National Planning Commission interviewed was quite frank about the situation, stating that there simply is no housing policy in Ethiopia, and that although development planning goals are being set, as yet there is no strategy to meet these goals.

Housing is the responsiblity of the Department of Public Housing in the Ministry of Works. Most of the administrative problems seem to lie in the authority of municipal government to override national policy, and their failure or lack of lack of willingness to come to grips with the problems of land tenure in the cities.

Ethiopia is one of the most populous of the tropical African countries (second to Nigeria) and one of the least urbanized. There are just six cities of 30,000 population or more, and only 5% of the population is estimated to live in urban areas. To a large extent the rural population is not in the cash economy of the country, the major exception to this being those who work on the cotton plantations. One Ethiopian official stated that archaic institutional and family traditions, rather than rural density or lack of resources, perpetuate poverty in the rural areas.

2.3.5 Resources

Portland cement, lime, clay, wood fiber, wood pulp, sisal, asbestos, grass and bagasse are indigenous to Ethiopia. Fuel, however, must be imported for the conversion of some of these materials.

Wood fibers are available as waste from a small lumber industry. Eucalyptus trees are grown for poles, but this agriculture could be expanded. Sisal was formerly grown in the southern provinces, but with the growth of synthetic fibers, the plantations became near idle (a situation which may readily change because of the increased costs of the petrochemicals).

Short-fiber asbestos is indigenous but has not been developed to a very large extent. It needs to be determined whether or not this type of asbestos has utility as a roof reinforcing material. Grasses are readily available and are presently being used for thatching, fences, and breaks. Bagasse is present but is used to a great extent as fuel for the one sugar mill.

Some 90% of the houses in Addis Ababa are built of wattle and daub wall construction ("chica"). Over 80% of the urban houses are roofed with corrugated galvanized iron.

2.3.6 Existing Institutional and Technology Base

Research on building materials and methods is carried out by the Materials Research and Testing Department, College of Technology, Haile Selassie University. The departmental staff engage in both teaching and research activities. The research activities are in two principal areas, soil mechanics and building materials. The department performs quality control tests for government industries, and the construction industry, on concrete and concrete products, aggregates, bricks and clay products and foundation soils. Expansive clay soils are a problem in Ethiopia and thus receive considerable attention.

The Materials Research and Testing Department also operates an Information Center (for the building industry) which has an impressive collection of literature and maintains contact with international organizations in the building field, including ASTM and CIB. Files on Ethiopian building construction and materials industries have been established but appeared not to have been kept up to date. There was no evidence of research effort directed to improvement of low-cost housing construction or at lowering housing costs.

2.4 Kenya

Kenya, Malawi and Sudan were surveyed primarily to get a broader background in the nature of housing and housing problems in Africa. Accordingly, analysis were conducted only in a very subjective manner. However, interviews were held to discuss the subject of indigenous materials for roofing and to learn about any past or current research in the area of interest.

The most promising country surveyed in Africa, other than Zambia, was Kenya. Accordingly, only the roofing situation there is discussed. Notes on Malawi and Sudan are contained in the detailed trip reports issued separately.

Discussions were held at the Crop Section, Ministry of Agriculture in Kenya, centering on possible underutilized agricultural products or wastes which may be made a part of the roofing material. Bagasse may be surplus in some areas but it is generally used to fire plant boilers, although increased efficiency may release about 20%. In Kenya (and Tanzania), the vast plantings of sisal are sold well in advance of harvesting. Not all the sisal is first class, and there may be a surplus of the lower qualities. Coconut shells and husks (coir) are both being exported. Expansion in production is planned and an excess may eventually exist. Papyrus is plentiful around lakes and rivers. It is very durable but must be collected.

In Kenya, bamboo, residues from groundnuts (peanuts) and kenaf were dismissed as not being plentiful enough to warrant collection. While collection techniques and costs would probably be a problem, other possibilities included sugar cane tops, banana stalks, coffee bean hulls (upon which some studies have been made) and maize husks. It was pointed out that there is a great need to clear land of weeds, trees and brush for agriculture. Chipping and splitting of this waste wood may provide a useful filler.

The Kenya Building Center, under the Ministry of Works, publishes quarterly reports on research and standardization in the areas of building, civil engineering, housing and physical planning. A brief review of these reports indicates some very sophisticated subject areas. There appears to be good monitoring of building and material costs in the housing area. Several reports are directed at testing and evaluation of roofing materials, including CGI, clay tiles, fiber glass sheets and a patented material "Stramit," which is a building material from compressed straw. No evidence was found, however, of R&D on innovative roofing based on the use of indigenous materials at the Kenya Building Center.

On the other hand, discussions with some of the staff at the Housing Research and Development Unit at the University of Nairobi indicated that low-cost innovative roofing solutions had a high priority for them, but to date they have met with little design success. One individual approach was described - sisal-jute-reinforced Portland cement panels - that was apparently unsuccessful due to serious problems of quality control. The University had also produced sisal-reinforced polyester panels, apparently adequate technically but economically no solution, since the finished product was 80% or more imported material. They felt that it was very difficult to be cost competitive with standard roofing materials such as CGI and cement-asbestos.

Some additional comments made by individuals at the Housing Research and Development Unit of the University of Nairobi concerned some specific alternative materials. The cost of asphalt shingles alone is not bad, but the cost of the supporting structure and deck makes this approach impractical for low-cost housing. A local venture, however, has started up. The "Stramit" (compressed straw) boards make a good insulating roof deck but must be water-proofed, and the total cost is thus more than that of CGI or CA (cement-asbestos). The available papyrus is termite proof and mats are a rural tradition. Bamboo has suffered from a severe termite infestation.

Gypsum is available, but costs from 25-40% more than cement. Lime is also available, but costs 40% more than cement. Good particle board is available from Tanzania, although supplies are erratic. No softboards are made in Kenya, but there is a lot of timber waste.

The fibrous leaf waste products from the enlarging pineapple industry might be investigated. Good clay tiles are produced but their heavy weight and need for extra substructure makes them impractical in Kenya for low-cost housing. Concrete tiles are heavier and more costly than the clay tiles.

Mr. Peter Campbell of the Department of Civil Engineering, University of Nairobi, passed on the fact that the CGI now costs $0.20/sq ft for the material alone (26, 28 gage), and about $0.30/sq ft in place (not including roof supporting structure). The Portland cement industry is sophisticated, and good quality is produced in Kenya. There is little asbestos in Kenya. A short-fiber type is imported from Uganda, but the product made from it is brittle. Cashew nuts represent a very large crop in Kenya and the hulls could be available for use as a filler.

2.5 Malawi

Malawi is an inland country located in southeastern Africa. It has an area of 45,000 square miles and a population of 4.4 million.

Malawi is bounded on the west by Zambia, on the north by Tanzania, and on the south by Mozambique. The climate is very similar to that in Zambia, with the exception that the annual rainfall is significantly higher.

After the surveys of the principal African countries of Zambia and Ethiopia had been completed, a brief visit was made to Blantyre, the capital city of Malawi, in order to make comparisons of the need for housing, available resources, etc., of this country with the others being surveyed.

The government of Malawi has a strong interest in providing low-cost housing for its people. This has mostly taken the form of sites and services type of development. The most common material used for the walls of low-cost housing was mud brick or blocks--often taken from the exact site where the buildings were being constructed. To an even greater extent than in Zambia, the roofs of these low-cost houses are predominantly corrugated galvanized iron.

Sometime ago, the government of Malawi, by decree, made the wages of rural-agricultural workers equal to those of their urban counterparts. They thereby discouraged the mass migration of rural people into the capital city area, and other principal cities of Malawi. As a result, large squatter settlements of the type found in Lusaka (Zambia), and Accra (Ghana) were not observed in Blantyre.

Malawi is primarily an agricultural country. The principal exports are agricultural products such as corn (maize unmilled), vegetables, tea, tobacco and ground nuts (peanuts). They have little in the way of mineral resources, coal, or petroleum.

In the short visit made, it was not possible to make any judgements regarding the existing institutional and technology base in Malawi. From the visits which were made to institutions in and around the capital city of Blantyre, it appears to be less well developed than in larger countries such as Zambia and Ghana.

2.6 Sudan

The Sudan is an inland country in Northeastern Africa. It is located in the tropic zone, about 15° north latitude, and is bounded on the north, east, south and west principally by Egypt, Ethiopia, Zaire, and Chad, respectively. It has an area of 967,000 square miles and a population of about 15,000,000. The capital is Khartoum.

One member of the country survey team, Mr. William Littlewood, AID Program Manager, made a brief visit to the Sudan in order to compare the situation in this country with the others already surveyed. A questionnaire regarding government policies on housing, the housing need, resources etc., was also left with the Government Office of Housing in Khartoum. Partial replies to some of these questions were later received in the form of copies of some pertinent memos relating to housing.

In common with the other African countries surveyed, there is a pronounced need for low-cost housing (and roofing). However, the Sudan, along with other countries located in this part of Africa, has been suffering from the effects of an intense, prolonged drought. As a result, it is likely that at the present time, insufficient food constitutes a much greater problem than housing. The economy of the country is largely agricultural and there is a dearth of other natural resources. Additionally, it is not believed that the existing institutional and technology base approaches that of Ethiopia or Zambia.

3. LATIN AMERICAN COUNTRIES

Bolivia, Honduras, Jamaica, and Peru were surveyed by a two-member team.

3.1 Jamaica

3.1.1 Geographic Location, Climate and Language

Jamaica is a tropical island located in the Caribbean Sea 90 miles south of Cuba and 100 miles west of Haiti, and 700 miles south of Miami, Florida. It has a land area of 4,411 square miles and a population of 1.95 million (1973). Mountains cover 80% of Jamaica's surface. The capital, Kingston, has a population of 510,000.

The rainfall is about 40 inches in some areas, such as Kingston. At other locations it can be 200 inches or more.

Languages are English and Jamaican creole.

3.1.2 Interest and Attitudes

An enthusiastic and encouraging attitude was expressed by both the public and private sectors in Jamaica. These included the Ministry of Housing, the Scientific Research Council, the Knox Foundation, and a few architectural firms. Collaboration with all of these is possible.

3.1.3 Need for Low-Cost Housing and Roofing

Jamaica has a shortage of low-cost houses. Extensive use is made of CGI in those that do exist. Development of a roof, based on indigenous raw materials and resins, can reduce costs and help alleviate this problem.

3.1.4 Housing Trends, The Economy and Urbanization Degree

The Jamaican Ministry of Housing is involved in construction and marketing of low-cost houses in the $5000-10,000 range by providing assistance to private developers. Houses costing above $10,000 are entirely handled by independent developers. The Ministry is presently involved through a World Bank loan, in the implementation of "site and service" self-help projects for low income housing, which will eventually provide 6000 serviced lots in the four largest Jamaican cities.

Jamaicans have a dynamic approach towards acceptance. Concepts such as the duplex, townhouse, and condominium have recently become popular.

The Urban Development Corporation (UDC) is a Jamaican Government enterprise, engaged in efficient coordination of efforts and resources between the public and the private housing sectors. The corporation engages in design of housing and planning of communities.

The impact of UDC is visible in this country; it is a growing and constructive force and appears to maintain a good working relationship with the Town Planning Department.

In rural areas, generally, people help each other in building a house. Wood construction is most frequently used. In some cases, the wood raw materials may be available at very low cost from nearby forests. Low-income bracket Jamaicans will probably accept and welcome innovative low-cost housing solutions but not unconventional structural forms or materials.

3.1.5 Resources

Agriculture is the basic industry of Jamaica. Sugar cane and bananas are the major agricultural products of Jamaica. By-product bagasse is therefore available in quantity, but is now largely used for fuel. Bagasse is an inefficient fuel since one ton of this material will only produce heat equivalent to 32 gallons of petroleum. Sugar factories are presently powered mostly by diesel oil. A switch from oil to bagasse is not expected because of plant design constraints. Some of the bagasse is already being used to make resin-bonded bagasse board for use in interior walls, ceilings, and partitions.

Jamaica is one of the leading banana-exporting countries of the world. Conceivably, the stalks from old plants would also be a useful low-cost fibrous material for roofing. However, the availability of and methods for processing the stalks have not been defined.

Jamaican forests are mainly evergreen and broad-leaved plants, with limited occurrence of valuable timber species. Timber is expensive and in short supply, and some is imported from Honduras. Bauxite and alumina are the major foreign exchange earners. After the bauxite is mined, it is chemically cleaned to remove silicate, etc.; the waste is called "red mud," due to the coloration from iron compounds. This inorganic waste, if utilized in roofing, would also solve a waste disposal problem.

Portland cement is made by one plant in Kingston which produced 421,000 tons in 1972. This production is in excess of current needs; however, the local consumption is growing. Gypsum is mined and used primarily in cement to retard too-rapid setting. Calcining gypsum produces plaster of paris which is useful for making ceiling tiles. Limestone is the most abundant mineral in Jamaica and is used in sugar refining, glass manufacture, and in building construction.

3.1.6 Existing Institutional and Technology Base

Jamaica has the capability of implementing and furthering the building research and development work. This is mainly due to the existence of adequate institutional bases on the island.

The role of the Ministry of Housing has been partially described. The Jamaican Bureau of Standards and Scientific Research Council (SRC) have material characterization and testing capabilities. Moreover, the SRC is involved in some phases of clay tile research.

3.2 Peru

3.2.1 Geographic Location, Climate and Language

Peru is the third largest country in South America with a land area of 496,000 square miles. It has a population of 13.6 million (1972). It is bordered on the north by Ecuador and Columbia, on the south by Chile, on the east by Brazil and Bolivia, and on the west by a 1,400-mile Pacific Ocean coastline.

Peru has several distinct climatic regions. The western coastal plain is dry with moderate temperature, a condition which poses problems for the building industry. Forty percent of Peruvians live in this area. About 50% of the population live in the Andean ranges. Building conditions are difficult in the high slopes of the Andes owing to low temperatures and earthquake problems.

The Selva, east of the Andes, contains 61% of the land area of Peru but only about 10% of the population. This area has tropical forests due to humidity, rainfall, and high temperatures.

Spanish is the official language of Peru, although many Indians speak only their native Quechua and Aymara.

3.2.2 Interest and Attitudes

At the present time there are two large USAID programs operating in Peru. One is directed towards the low income housing problem. The other is aimed at middle income housing. The middle income project is scheduled to be completed by 1976, and the lower income program will be finished by 1977. The roof project, therefore, generated some interest at the Engineering University of Lima, which is involved in these projects.

3.2.3 Need for Low-Cost Housing and Roofing

Peru is advanced in terms of the institutional basis for housing. Furthermore, this country has developed the important links between housing and urban structuring. This has happened owing to an earlier history of population pressure on Peruvian urban centers.

The Peruvian urban planning and structuring, the design of housing, and the building methods are rather impressive. Building research is well directed. Based on these observations, the need is less pronounced when compared with the other Latin American countries.

3.2.4 Housing Trends, The Economy and Urbanization Degree

Peru has a number of well organized housing programs covering a wide spectrum. In the last ten years, this country has codified national housing policies. The 1970 National Plan deals with improving housing conditions via construction and through creation of community services in urban centers. Priority has been also given to developing existing population centers and creating new urban settlements. Since Peru is prone to earthquakes, the trend is toward reinforced masonry. Bamboo-reinforced stabilized adobe is popular, however, in rural areas and villages for individual houses.

3.2.5 Resources

The research on stabilized adobe was done at the Engineering University in Lima. Stabilized adobe may be one solution for low-cost housing. It is made from inexpensive raw materials, namely, pulverized dirt and asphalt. Demonstration units have been built on the campus. Full scale demonstration is under consideration. Cement, limestone, clay, bagasse, and bamboo are important indigenous materials.

3.2.6 Existing Institutional and Technology Base

Junta National Vivienda (National Housing Board) and Banco de la Vivienda del Peru (Peruvian Housing Bank) were created during the 1960's and promote planning, financing, and execution of housing problems. Now the National Office for Urban and Regional Planning under the Ministry of Housing is responsible for the housing aspects.

The contributions of the Engineering University have already been discussed in relation to adobe.

3.3 Bolivia

3.3.1 Geographic Location, Climate and Language

Bolivia is an inland country located 15° south of the equator in the northwestern part of South America. It has a land area of 404,000 square miles and a population of about 4 million. Bolivia is bounded by Brazil and Paraguay on the east, Argentina and Chile on the south, and Peru on the west. The capital city of La Paz is located at an altitude of 12,000 feet above sea level.

The country has three different topographic and climatic regions. The Altiplano, which houses the capital city of La Paz, has an average altitude of 12,000 feet. The "Yungus" is south-southeast and is the agricultural region. The hot, wet, lowland plains in the east are least developed and are full of tropical jungles.

As in Peru, Spanish is the official language for communication but several Indian dialects are also spoken.

3.3.2 Interest and Attitudes

Some interest was found here at the Urban Housing Ministry. However, due to insufficient commitment and less organization capability for low-cost housing, the above mentioned interest did not translate into concerted action.

3.3.3 Need for Low-Cost Housing and Roofing

The housing programs of the public sector are administered by an agency called Viviendo Urbanismo (Urban Housing). Consejo National de Viviendo (National Housing Council) is a department of this ministry responsible for housing of government employes. The Council is functional in construction of dwelling units. The Bolivian government also achieves housing construction via other ministerial channels.

All the above housing activities in Bolivia produce units for the middle income group. Effective programs, within the government, to construct shelters for the low income bracket were not found at the time of field study, December 1973. On the other hand, the Central Office of Savings and Loans (Caja Central), a private enterprise, is involved financially in low-cost houses. There were no other avenues for housing at the low-income level.

3.3.4 Housing Trends, The Economy and Urbanization Degree

In recent years, Bolivia has seen rural population moving into urban centers. The movement in this direction is slower than in other South American countries, partly because the economy of Bolivia is not vigorous toward producing a fast industrialization of its current urban centers.

At the present time, a formal and planned urbanization and housing policy is not visible in Bolivia. It also appears that such approaches will not emerge soon. A comprehensive housing study entitle "Estudio Integral de Los Materiales de Construction en Bolivia" ("An Integral Study of the Materials of Construction in Bolivia") has been recently completed. The investigation includes history and statistics of housing, mathematical models and recommendations for future trends. This study has been conducted by the National Council for Housing.

Bolivia has no national building code to set construction standards. The quality of construction is controlled, to some extent, by the building permit and a possible inspection while the structuring is in progress.

3.3.5 Resources

The commonly used materials for walls and auxiliary components are adobe brick for very low-cost houses, and fired clay brick and tile or concrete for middle and higher cost units. Corrugated galvanized iron, asbestos-cement tiles and clay tiles are used for roof coverings (see Figure 18). No foreign exchange is involved in these materials, except for CGI which Bolivia must import.

There are a number of different materials for building purposes, and the lack of good highway and railroads forces otherwise unnecessary increases in materials strength and weight. Clay tiles, cement tiles, and asbestos-cement tiles are bulky and hence their distribution into the rural areas is not practical. Another factor is the high cost of freight. CGI on the other hand is more mobile due to its light weight. Iron sheets imported from Japan are corrugated and galvanized in Bolivia.

According to Caja Central, the cost of a $5,000 house can be broken down as follows:

	%
Labor	21.2
Local Materials	32.1
Imported Materials	19.7
Design	0.8
Supervision	1.0
Overhead	14.6
Profit	10.6
	100.0

No exact figures are available on the production of bricks and tiles in Bolivia. There are large and small factories, distributed over the country, manufacturing bricks and tiles.

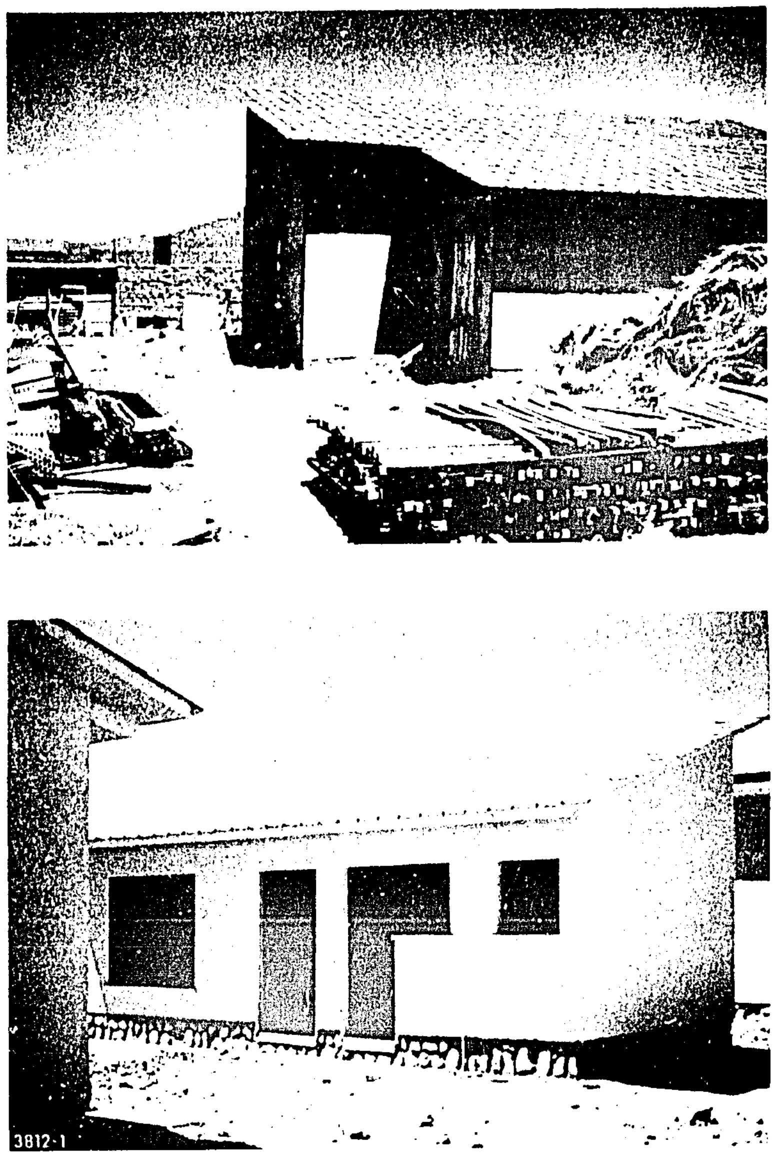


Figure 18. New Housing in the Alto Plano Area Near La Paz, Bolivia Which is Representative of the Widespread Use of Cement-Asbestos and Tile Roofing. This heavy roofing is advantageous due to the climatic conditions controlled by a high degree of radiation.

Currently, 265,000 tons/year of cement is produced and the consumption is about 150,000 tons. The excess is exported to Brazil. Production expansion to 380,000 tons is planned by 1975.

Aggregates, limestone, and gypsum are available in natural deposits throughout Bolivia. Timber is abundant and is exported to Argentina. Imported materials useful in construction, are reinforcing steel, aluminum frames, galvanized metal, electrical wiring, plumbing supplies, and other hardware.

In Bolivia there is a strong preference for clay roofing tiles. These are initially more expensive, and difficult to transport, but are favored due to longevity and social considerations.

3.3.6 Existing Institutional and Technology Base

It must be said that institutional bases are less adequate in Bolivia. The role of Caja Central in housing has been described earlier.

3.4 Honduras

3.4.1 Geographic Location, Climate and Language

Honduras is located in Central America, bounded by the Caribbean Sea on the north, Nicaragua on the south, El Salvador and the Pacific Ocean on the southwest, and Guatemala on the west. Honduras has a land area of 42,300 square miles (about the size of Ohio) and a population of 2.6 million. The capital is Tegucigalpa (pop. 250,000).

The clim̃ate ranges from temperate in the mountainous interior to tropical in the lowlands. The dry season lasts from November to May.

Spanish is the predominant language, although some English is spoken on the Bay Islands (in the Caribbean Sea) and along the northern coast.

3.4.2 Interest and Attitudes

The fast growth and rapid urbanization of Honduras has resulted in the government's high priority in the area of health and education and low activity in the housing field. Housing and physical planning agencies are organized under an economic commission and this presents considerable inertia to the housing activities. Because of less organizational capacity, the commitment of the public sector is nearly absent in Honduras.

3.4.3 Need for Low-Cost Housing and Roofing

There is a serious shortage of houses here and the need is therefore high. The total deficit of dwelling units will increase due to low housing production and, thus, overcrowding will increase.

3.4.4 Housing Trends, The Economy and Roofing

Honduras is a country with about 75% of the people living in rural areas. Rural housing is handled by the Institute Nacional Agracio (National Institute of Agriculture). The National housing policy is administered by the Instituto de la Vivienda (Institute of Housing). The Consejo Superior de Planification

Economia (National Planning Council) has a close working relationship with the Instituto de la Vivienda, and the former sets housing priorities and determines the housing trend of the country. Under this Council, an agency known as the Department of Physical Planning is involved in urban-oriented housing problems. Cement block walls are popular and cement-asbestos is gaining importance.

3.4.5 Resources

Clay, limestone, cement and wood are the principal materials used for house building in Honduras. Adobe block is made from clay and used as a rural wall material. Clay tiles and fired bricks are produced and preferred in Honduras.

CGI is imported from Japan and the USA and is less expensive than tile, but its performance is unsatisfactory to the people. Timber is plentiful and inexpensive; however, it is not extensively used in Honduran housing.

3.4.6 Existing Institutional and Technology Base

Some of the government agencies described above have not developed strength and, thus, the base must be termed weak. It appears that the participation of the public sector in the housing activity is increasing in Honduras, yet the private sector is still the principal source for production.

APPENDIX C

ESTABLISH CONTACTS WITH KNOWLEDGEABLE INDIVIDUALS, ETC.

APPENDIX C

ESTABLISH CONTACTS WITH KNOWLEDGEABLE INDIVIDUALS, ETC.

Contact Index

SOUTHEAST ASIA

ASIA

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APPENDIX D

SELECTION OF ONE COUNTRY EACH IN SOUTHEAST ASIA, AFRICA AND LATIN AMERICA

APPENDIX D

SELECTION OF ONE COUNTRY EACH IN SOUTHEAST ASIA, AFRICA AND LATIN AMERICA

A major portion of the first phase effort was to establish the basis for selecting three countries as demonstration sites for the roofing development program, one each in Africa, Latin America and Asia. A leading criterion was that the countries considered have existing collaborative programs with AID. At the start of the program, 12 prime candidate countries were selected for survey by MRC and Washington University investigators in conjunction with the AID Project Manager and other AID personnel. The countries surveyed are shown on the map in Figure 19.

The final selection of three countries was made by MRC personnel (assisted by our Washington University subcontractor) using the criteria and analysis described below.

1. CRITERIA AND RATIONALE

The criteria used in providing the basis for selection of the countries for demonstration included 13 categories. These were: (1) interest, (2) need, (3) resources, (4) existing technology base, (5) existing institutional base, (6) language, (7) economy, (8) attitudes, (9) housing trends, (10) climate, (11) geographic location, (12) urban-rural mix, and (13) probability for program success.

The "interest" criterion included (1) the desire of individuals and organizations (public and private) within a country to have the program and participate in it; (2) concurrent and interest of the USAID Mission (or representative) to that country, and (3) interest of the Office of Science and Technology of USAID, and the various country or region desks in Washington.

Figure 19. Countries Surveyed in Asia, Africa and Latin America as Potential Roof Development Sites

The criterion of "need" included the requirements for housing in the particular country and the degree to which roofing contributed to the housing problem. The lack of both a sufficient quantity and quality of housing was a factor. The extensive use of CGI and its required foreign exchange also constituted a need in terms of the program objectives.

Resources included availability of indigenous materials, labor, and skills required to translate a development into a useful roofing system.

The existing technology and institutional bases included the structured formal institutions and already developed technology which may provide a base for expanding the development and making it work. This included such things as existing universities, research organizations, public housing programs, etc., which are already trying to solve housing problems.

Communications were most important for determining the existence of the various criteria in a country, obtaining detailed information, passing on the essence of the development work, and providing an interchange, finally resulting in some technology transfer. While some foreign language capability does exist in the MRC team, the primary and common language of the team members is English. Accordingly, maximum communication would be available with an English speaking country. Having to work in other languages would result in additional problems in the transfer of information in sometimes unknown degrees.

The criterion of economy was very important, even though it was assumed that a lower level of economy already existed since USAID countries are developing nations. A higher rating would be placed on a country with a poorer foreign exchange position, i.e., where exports do not balance the present imports. This was a very significant factor since one of the primary objectives of this development work is to reduce the foreign exchange component in roofing. On a relative basis, this would be of greater value for a country with a poorer foreign exchange position.

The criterion of attitudes included a variety of social, cultural, psychological and economic considerations that would allow the use of a new development. For instance, if the attitudes were such that making a change, whether for better or worse, would be difficult, then making the program work would be difficult. For instance, corrugated galvanized iron represents "status" in many of the countries and, therefore, something even better, but lacking this associated status symbol, would present additional difficulties.

Housing trends were most important as a criterion, and could be coupled somewhat with need. First of all, housing had to have some priority in both government and private sectors. These sectors needed to believe that something could be done about housing and an effort and institutional structure had to be in existence for promoting this priority. For instance, where food and population represent very severe problems, then housing may be secondary until something is done about these basic needs.

Climate and geographical location were criteria, since it is desirable to make roofing available for a combination of climatic conditions, including both hot and humid and hot and dry. The geographic location is important in terms of the practicality of working in a particular country, and in reducing the time and expense associated with getting a job done in a particular country with respect to our development team located in the United States.

The criteria of urban-rural mix involved the nature of both the urban and rural problems, with respect to the corrugated galvanized iron roofing and the degree of problem which exists in each of these areas. Recently, more emphasis has been placed on the rural situation by USAID and the United Nations. It is therefore being emphasized in this program, although the periurban situation must also be considered.

The final and dominating criterion involved the probability for success in a particular country. This was a somewhat subjective criterion, but involved an overall estimation of the above twelve criteria which, when combined, would indicate whether or not the objectives of the roofing development program could be met. The reason for the selection process was to find countries where the development program will be worthwhile and can solve a problem.

2. TECHNIQUE

The surveyed countries differ widely in scope and nature. The amount of information gathered was extensive, but very qualitative in some categories. The degree of confidence that could be placed on the data varied considerably. For instance, some relatively unqualified statements such as "roofing is needed," "housing is needed, "a lot of this product is available", etc., while probably valid within reason, are not related to some absolute quantitative base. Accordingly, some sort of decision analysis was required to select the three candidate countries.

A modified Kepner-Tregoe method of analysis was used. This method of decision analysis is based on action questions and a resultant numerical rating involving action sequences. The operational questions produce a set of objectives via program analysis. A weighting factor is assigned to each objective to normalize the factors in their proper perspective in arriving at the decision.

Some weighting must also be done of the operators (personnel) who provide the ratings. This is done by providing a profile of these operators related to the disciplines anticipated as being valuable to analyzing the problem. The more operators that can be involved, the better the situation. In our particular analysis, three operators were utilized; however, they incorporated the data accumulated by at least six investigators. This provided the weighting.

The analytical technique involves scoring by operators (S^1, S^2, S^3) of thirteen criteria ($P_1 \longrightarrow P_{13}$) on a rating scale from 1 to 10, with 10 being the highest positive rating. The ratings of the three operators (S^1, S^2, S^3) are then averaged and multiplied by the appropriate weighting factor (W), to give the point score (P_{ave}). The summation of all the point scores then leads to the cumulative point total (P_{cum}).

The final rating (R) is then defined as the cumulative point total divided by the maximum possible cumulative points times 100. The higher the final numerical rating, the more appropriate is the country as a site for the roofing development program.

This method is further illustrated in detail as follows:

Legend:

S = Score on scale of 1 to 10 for each criterion

S^1, S^2, S^3 = Scores by operators 1, 2, 3

S_{ave} = Average score of all operators

W = Weighting Factor

P_{ave} = Average score of all operators multiplied by weighting factor W

P_{cum} = Sum P_{ave} for all thirteen criteria

Thus:

(1) Point Score P_{ave} for any criteria (1-13) =

$$\left(\frac{S^{operator^1} + S^{operator^2} + S^{operator^3} \quad x \text{ Weighting Factor (W)}}{3}\right)$$

$$P_{ave} = \frac{S^1 + S^2 + S^3 \ x \ W}{4}$$

(2) Cumulative Points (P_{cum}) = Sum of P_{ave} for all thirteen criteria

$$P_{cum} = P_{ave}{}^1 \text{ to } P_{ave}{}^{13}$$

(3) Final Rating (R) = $\frac{P_{cum} \ x \ 100}{\text{max. possible score (850)}}$

$$R = \frac{P_{cum} \ x \ 100}{850}$$

3. ANALYSIS AND SELECTION

The profiles of the rating operators participating in the country selection are given in Figure 20. Of particular interest are the disciplines represented: architecture, product design, information science, marketing insight, structural engineering, materials engineering, materials chemistry, systems analysis, management, and general knowledge of developing countries.

The specific analytical data for the modified Kepner-Tregoe treatment of the Asian, African and Latin American countries is shown in Tables 2, 3 and 4. These data are based on the total analysis of the field surveys discussed in Appendix B. The cumulative points for the various countries are given in the three tables.

A summary of the modified Kepner-Tregoe treatment of the Asian, African and Latin American countries is given in Table 5. Here the rating (R) is also given, which is based on the cumlative point total divided by 850.

In Asia, the countries of Bangladesh, the Philippines and Thailand were surveyed, studied and analyzed. The rating for the Philippines was 81.9, the highest in the Asian series. The Philippines present the most favorable overall situation, and this country is judged to be the place where the project is most likely to be successful. Bangladesh, where the need is admittedly greater, just did not have enough significant pro-factors to make it even a second candidate.

Discipline	Rating Operator 1	2	3
Architecture	◓	◓	◓
Product Designing	●	●	●
Urban Planning	◓	◓	◓
Sociology	◐	◐	◐
Psychology	◓	◓	◓
Information Science	●	●	●
Futurology	◐	◐	◐
Marketing Insight	◐	◓	◐
Acoustics	○	●	○
Optical Physics	○	◐	◓
Color Chemistry and Physics	◐	◐	●
Metallurgy	○	○	◐
Educationist	○	◓	◐
Philosopher	◐	○	○
Structural Engineer	○	○	◓
Material Engineer	●	●	●
Material Chemist	●	◐	●
Environmental Chemist	◓	○	○
Systems Analyst	◓	◓	◓
Laboratory Management	●	◐	◐
Product Management	◓	◓	◐
Agriculture Chemist	◓	○	○
Statistician	◓	◓	◓
World Traveler	●	◐	●
Biomedical Research and Application	●	●	○

● Expert
◐ Familiarity
◓ Has interacted previously
○ No experience

Figure 20. Profiles of Rating Operators Participating in Country Selection by a Modified Kepner-Tregoe Analysis

Table 2

KEPNER-TREGOE TREATMENT OF ASIAN COUNTRIES IN CONTEXT TO ROOF PROGRAM PLANNED AND CONDUCTED BY FIELD TEAMS

Set No.	Analysis Program Objective	Classi-fication	Weight Factor (W)	Country Analyzed BANGLADESH S_{10}^1	S_{10}^2	S_{10}^3	S_{10}^{ave}	P= WXS_{10}^{ave}	PHILIPPINES S_{10}^1	S_{10}^2	S_{10}^3	S_{10}^{ave}	P= WXS_{10}^{ave}	THAILAND S_{10}^1	S_{10}^2	S_{10}^3	S_{10}^{ave}	P= WXS_{10}^{ave}	S_{10}^1	S_{10}^2	S_{10}^3	S_{10}^{ave}	P= WXS_{10}^{ave}
1	Interest (at location, in USA, of AID mission)	must	10	10	9	10	9.7	97	10	8	10	9.3	93	6	7	6	6.3	63					
2	Need (roofing problems, housing problems, unemployment)	must	10	10	10	10	10	100	8	6	8	8	80	6	5	6	6	60					
3	Resources (labor, filler, reinforcement, matrix, raw materials market, housing subcontractors, materials manufacturing)	must	9	4	5	4	4.3	39	8	7	8	7.7	69	10	7	7	8	72					
4	Existing technology base	want	8	6	6	6	6	48	10	8	10	9.3	74	8	7	7	7.3	58					
5	Existing institutional base (research, material testing, housing authorities)	want	7	4	5	4	4.3	30	8	8	8	8	56	8	8	8	8	56					
6	Language	want	6	4	4	4	4	24	8	8	8	8	48	4	6	5	5	30					
7	Economy (foreign exchange position, ability to purchase)	want	4	2	9	2	4.3	17	8	6	8	7.3	29	10	6	6	7.3	29					
8	Attitudes (social, cultural, economic)	must	6	8	5	5	6	36	10	6	8	8	48	8	6	7	7	42					
9	Housing trends (local, Government)	want	5	4	6	6	5.3	27	10	7	10	9	45	8	6	6	6.7	34					
10	Climate (absolute and relative)	want	5	8	6	6	6.7	34	8	7	8	7.7	39	8	7	8	7.7	39					
11	Geographic location (absolute, relative)	want	3	6	5	5	5.3	16	10	5	5	6.7	20	8	5	5	6	18					
12	Urban-rural mix	want	2	6	8	6	6.7	13	10	6	6	7.3	15	8	7	6	7	14					
13	Probability for program's success	want	10	4	4	4	4	40	8	8	8	8	80	6	6	6	6	60					
				CUMULATIVE POINTS				521					596					575					

LEGEND: S_{10}^1 — 1 = number operator; S = score from 10 to zero in whole numbers; 10 = score 10 maximum possible

S_{10}^{ave} average of S_{10}^1, S_{10}^2 and S_{10}^3

Maximum cumulative points possible = 850

Table 3

KEPNER-TREGOE TREATMENT OF AFRICAN COUNTRIES IN CONTEX TO ROOF PROGRAM

PLANNED AND CONDUCTED BY FIELD TEAMS

Country Analyzed

Set No.	Analysis Program Objective	Classification	Weight Factor (W)	ETHIOPIA S^1_{10}	S^2_{10}	S^3_{10}	S^{ave}_{10}	$P = WXS^{ave}_{10}$	KENYA S^1_{10}	S^2_{10}	S^3_{10}	S^{ave}_{10}	$P = WXS^{ave}_{10}$
1	Interest (at location, in USA, of AID mission)	must	10	8	7	7	7.3	73	4		4	4	40
2	Need (roofing problems, housing problems, unemployment)	must	10	8	9	8	8.3	83	6		5	5.5	55
3	Resources (labor, filler, reinforcement, matrix, raw materials market, housing subcontractors, materials manufacturing)	must	9	6	7	6	6.3	57	10		8	9	81
4	Existing technology base	want	8	8	8	8	8	64	8		8	8	64
5	Existing institutional base (research, material testing, housing authorities)	want	7	8	5	5	6	42	8		8	8	56
6	Language	want	6	6	5	6	5.7	34	8		8	8	48
7	Economy (foreign exchange position, ability to purchase)	want	4	6	7	7	6.7	27	8		8	8	32
8	Attitudes (social, cultural, economic)	must	6	6	5	5	5.3	32	8		6	7	42
9	Housing trends (local, Government)	want	5	6	7	6	6.3	32	8		6	7	35
10	Climate (absolute and relative)	want	5	8	6	6	6.7	34	8		7	7.5	38
11	Geographic location (absolute, relative)	want	3	6	5	5	5.3	16	8		5	6.5	20
12	Urban-rural mix	want	2	6	5	5	5.3	11	8		8	8	16
13	Probability for program's success	want	10	6	4	5	5	50	4		4	4	40
	CUMULATIVE POINTS							555					568

Set No.	MALAWI S^1_{10}	S^2_{10}	S^3_{10}	S^{ave}_{10}	$P = WXS^{ave}_{10}$	SUDAN S^1_{10}	S^2_{10}	S^3_{10}	S^{ave}_{10}	$P = WXS^{ave}_{10}$
1	4	5	4	5.3	53	8	6	6	6.7	67
2	6	6	6	6	60	8	8	8	8	80
3	10	6	8	8	72	4	5	4	4.3	39
4	8	5	5	6	48	4	4	4	4	32
5	8	6	6	6.7	47	4	4	4	4	28
6	8	8	8	8	48	6	7	6	6.3	38
7	8	4	4	5.3	21	4	5	4	4.3	17
8	8	6	6	6.7	40	4	5	4	4.3	26
9	8	7	8	7.7	39	4	6	4	4.7	24
10	8	7	8	7.7	39	8	6	8	7.3	37
11	8	4	5	5.7	17	6	5	5	5.3	16
12	8	5	5	6	12	8	4	5	5.7	11
13	4	7	4	5	50	4	5	4	4.3	43
CUMULATIVE POINTS					546					458

Set No.	ZAMBIA S^1_{10}	S^2_{10}	S^3_{10}	S^{ave}_{10}	$P = WXS^{ave}_{10}$	S^1_{10}	S^2_{10}	S^3_{10}	S^{ave}_{10}	$P = WXS^{ave}_{10}$
1	10	10	10	10	100					
2	8	7	8	7.7	77					
3	8	7	8	7.7	69					
4	6	5	6	5.7	46					
5	6	7	7	6.7	47					
6	8	9	9	8.7	52					
7	8	3	8	6.3	25					
8	8	6	8	7.7	46					
9	8	8	8	8	40					
10	8	7	8	7.7	39					
11	8	4	6	6	18					
12	8	6	8	7.7	15					
13	10	9	10	9.7	97					
CUMULATIVE POINTS					671					

LEGEND: S^1_{10} — 1 = number operator; S = score from 10 to zero in whole numbers; 10 = score 10 maximum possible

S^{ave}_{10} = average of S^1_{10}, S^2_{10} and S^3_{10}

Maximum cumulative points possible = 850

Table 4

KEPNER-TREGOE TREATMENT OF LATIN AMERICAN COUNTRIES IN CONTEXT TO ROOF PROGRAM
PLANNED AND CONDUCTED IN FIELD TEAMS

Country Analyzed

Set No.	Analysis Program Objective	Classi-fication	Weight Factor (W)	BOLIVIA S^1_{10}	S^2_{10}	S^3_{10}	S^{ave}_{10}	P= WXS^{ave}_{10}	HONDURAS S^1_{10}	S^2_{10}	S^3_{10}	S^{ave}_{10}	P= WXS^{ave}_{10}	JAMAICA S^1_{10}	S^2_{10}	S^3_{10}	S^{ave}_{10}	P= WXS^{ave}_{10}	PERU S^1_{10}	S^2_{10}	S^3_{10}	S^{ave}_{10}	P= WXS^{ave}_{10}	S^1_{10}	S^2_{10}	S^3_{10}	S^{ave}_{10}	P= WXS^{ave}_{10}
1	Interest (at location, in USA, of AID mission)	must	10	6	7	7	6.7	67	8	6	6	6.7	67	10	10	10	10	100	6	7	6	6.3	63					
2	Need (roofing problems, housing problems, unemployment)	must	10	6	6	6	6	60	10	7	10	9	90	10	7	10	9	90	6	6	6	6	60					
3	Resources (labor, filler, reinforcement, matrix, raw materials market, housing subcontractors, materials manufacturing)	must	9	8	6	7	7	63	6	5	5	5.3	48	6	7	6	6.3	57	8	5	8	6.7	60					
4	Existing technology base	want	8	8	6	6	6.7	54	6	6	6	6	48	6	7	6	6.3	50	8	8	8	8	64					
5	Existing institutional base (research, material testing, housing authorities)	want	7	6	7	6	6.3	44	6	6	6	6	42	6	8	7	7	49	8	8	8	8	56					
6	Language	want	6	6	5	5	5.3	32	6	5	6	5.7	34	10	9	10	9.7	58	6	5	5	5.3	32					
7	Economy (foreign exchange position, ability to purchase)	want	4	10	5	7	7.3	29	6	5	6	5.7	23	8	5	7	6.7	27	10	4	6	6.7	27					
8	Attitudes (social, cultural, economic)	must	6	8	7	7	7.3	44	8	7	7	7.3	44	10	8	10	9.3	56	8	7	7	7.3	44					
9	Housing trends (local, government)	want	5	6	8	7	7	35	8	7	7	7.3	37	10	8	8	8.7	44	6	9	9	8	40					
10	Climate (absolute and relative)	want	5	6	6	6	6	30	8	6	6	6.7	34	10	7	7	8	40	6	7	6	6.3	32					
11	Geographic location (absolute, relative)	want	3	4	5	4	4.3	13	8	8	8	8	24	10	9	10	9.7	29	6	6	6	6	18					
12	Urban-rural mix	want	2	8	6	6	6.7	13	8	7	7	7.3	15	10	7	10	9	18	8	5	5	6	12					
13	Probability for program's success	want	10	4	5	4	4.3	43	6	5	5	5.3	53	10	8	10	9.3	93	4	4	4	4	40					
			CUMULATIVE POINTS					527					559					711					548					

LEGEND: S^1_{10} — number operator; score from 10 to zero in whole numbers; score 10 maximum possible

S^{ave}_{10} = average of S^1_{10}, S^2_{10} and S^3_{10}

Maximum cumulative points possible = 850

Table 5

SUMMARIZED RESULTS OF THE KEPNER-TREGOE TREATMENT TOWARDS COUNTRY SELECTION IN AFRICA, ASIA AND LATIN AMERICA

Number	Continent	Country	Cumulative Point, P	Rating $R_{country}$	Rank in the Continent
1	AFRICA	Ethiopia	555	65.3	third
2		Kenya	568	66.8	second
3		Malawi	546	64.2	fourth
4		Sudan	458	53.9	fifth
5		Zambia	671	78.9	first
6	ASIA	Bangladesh	521	61.3	third
7		Philippines	696	81.9	first
8		Thailand	575	67.6	second
9	SOUTH AMERICA	Bolivia	527	62.0	fourth
10		Honduras	559	65.8	second
11		Jamaica	711	83.6	first
12		Peru	548	64.5	third

Important Note: The ranking of countries are expressed for the purpose of "Monsanto Roof Program". It is not to be construed or conjectured for any other purpose whatsoever.

In Africa, the rating for Zambia was 78.9, which is the highest among Ethiopia, Kenya, Malawi, the Sudan, and Zambia. The primary factor in Zambia's achieving the highest rating was the intensely strong interest in the program on the part of its Ministry of Local Government and Housing. It was believed that this interest would help to insure cooperation of the government in setting up and following up with the demonstration project in Zambia. Ethiopia suffered from other more pressing needs (food) and considerable political problems.

In Latin America, Jamaica received a signficantly higher rating (83.6) than the other countries. This was based, to a great extent, on expressed government interest, a pronounced need, a balanced urban and rural situation, a convenient geographical location, and the absence of a language barrier. The warm-moist climate of the island also presents a much greater challenge to materials than the cooler, dryer climate prevalent in Bolivia and Peru.

APPENDIX E

MATERIALS DEFINITION AND DEVELOPMENT

APPENDIX E

MATERIALS DEFINITION AND DEVELOPMENT

During the first contract year (Phase I) Materials Definition and Development included three separate tasks. First, a preliminary analysis of the availability of indigenous filler and binder materials was made in each country surveyed (see Appendix B). Second, several indigenous fiber and/or filler materials were obtained during the field survey and shipped back to the United States. These samples have been catalogued and some have received preliminary characterization. (See Section 1 below). Third, a minor roofing materials development study was initiated during the last quarter of the year in our Dayton Laboratory (Section 2 below).

1. MATERIALS ACCUMULATED ON SURVEY VISITS TO AFRICA, ASIA AND LATIN AMERICA

A number of indigenous samples were collected in Asia, Africa and Latin America by the survey teams. These were obtained from the countries visited, whether primary or secondary. The These materials are listed below by country and are also illustrated in Figures 21 through 37.

A. BANGLADESH

1. Clay
2. Clay with red tint (Figure 21)
3. Concrete block
4. Gypsum
5. Jute bast fiber
6. Jute branch (Figure 22)
7. Jute fabric: coarse, extra coarse, medium and fine
8. Jute fiber, fine quality
9. Jute rope (Figure 23)
10. Jute steam

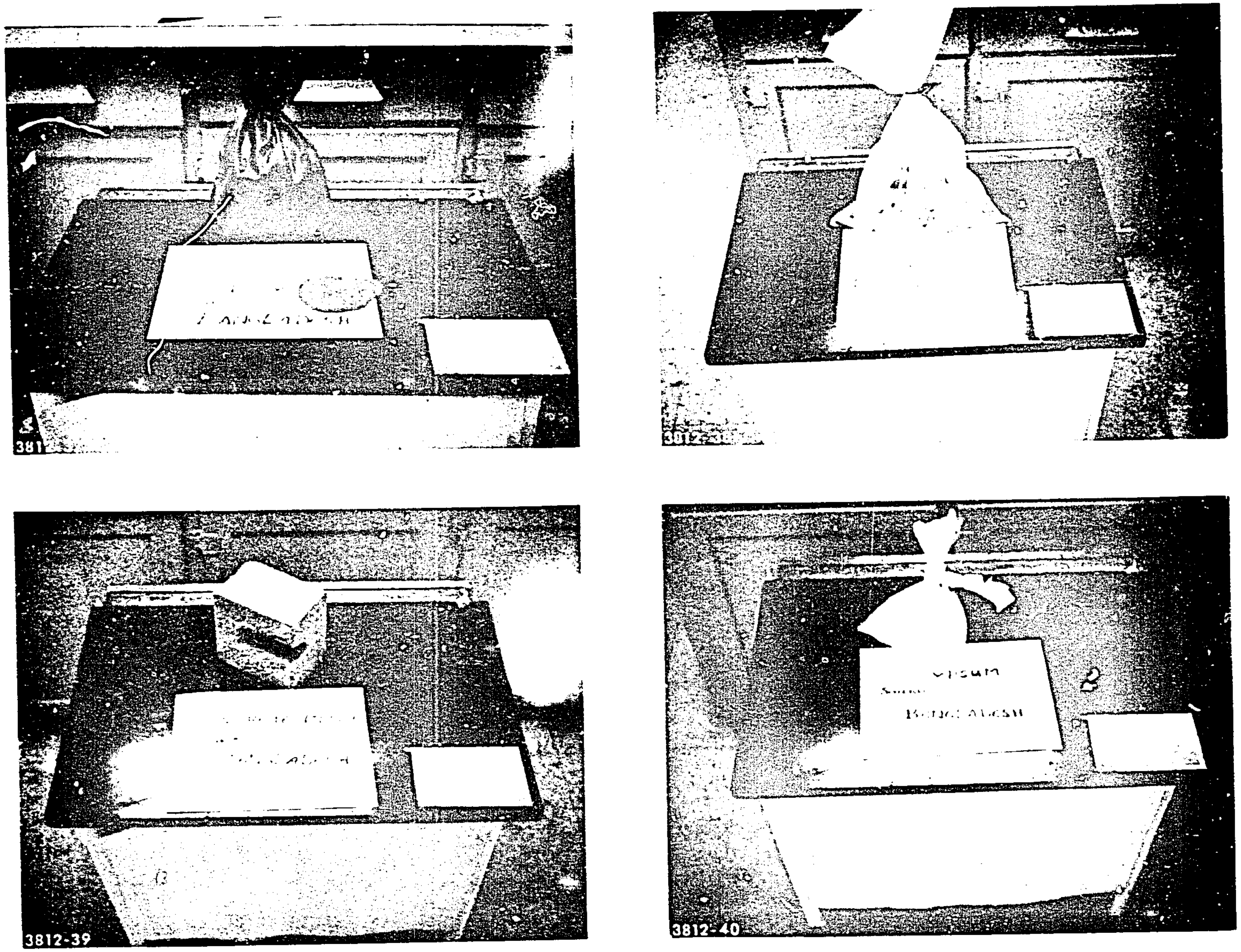


Figure 21. Clays, Concrete Block and Gypsum Obtained as Indigenous Materials from Bangladesh

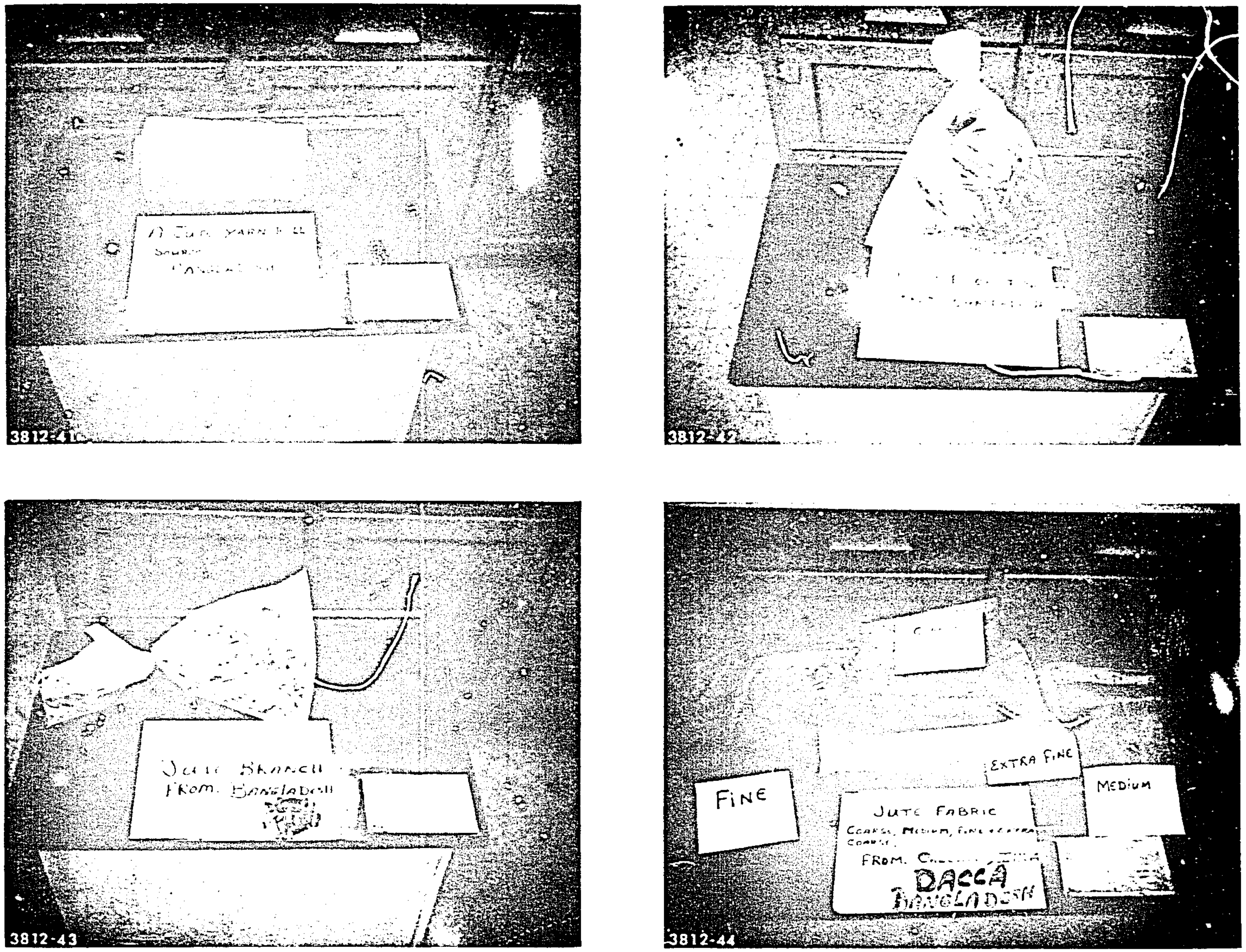


Figure 22. Jute Yarn, Bast Fiber, Jute Branch and Fabric Collected as Indigenous Material from Bangladesh

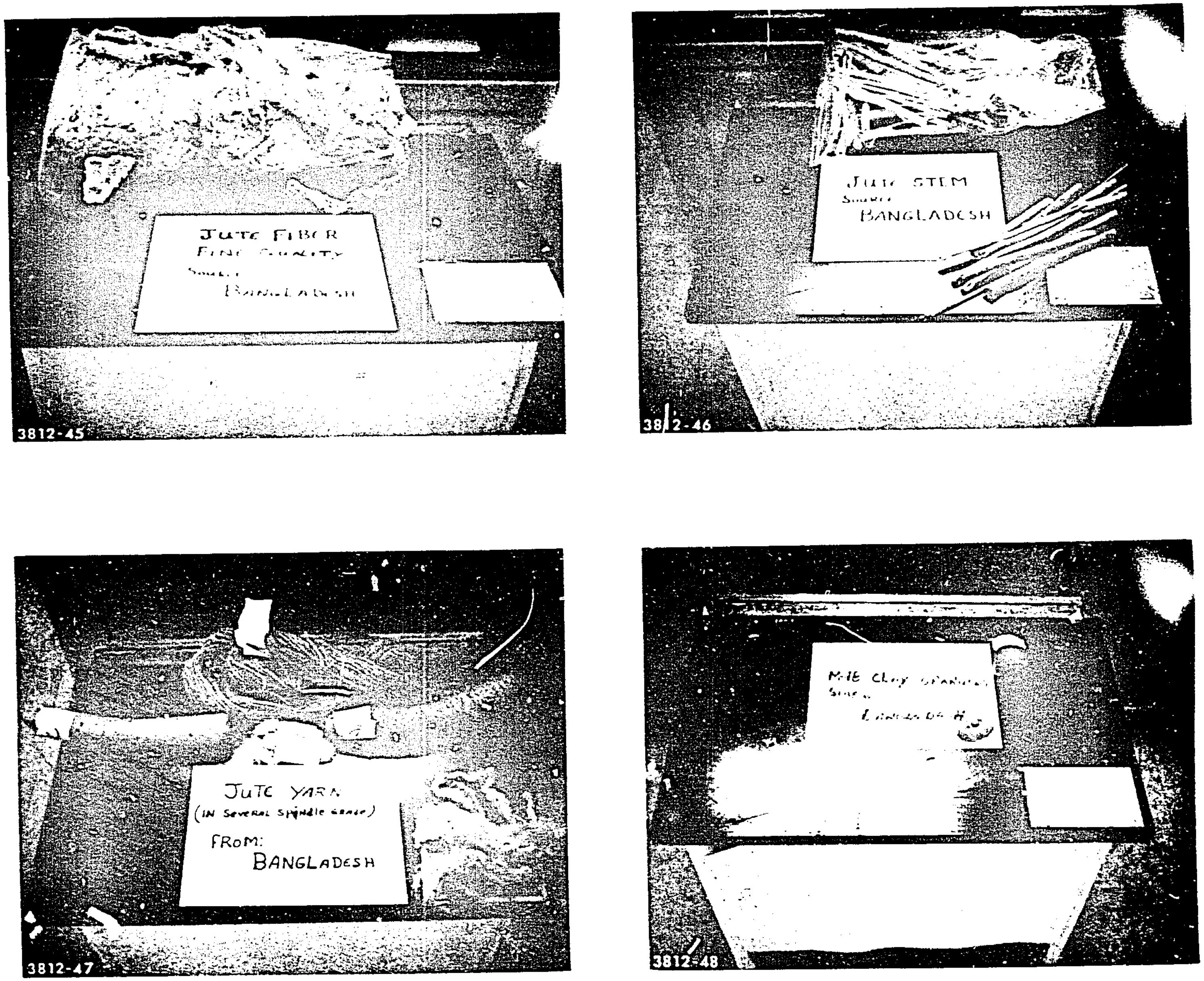


Figure 23. Clay Granules, Jute Fiber Stem and Yarn Collected as Indigenous Materials from Bangladesh

11. Jute yarn
12. Jute yarn in several grades (Figure 24)
13. M-18 clay granules
14. Red brick
15. Takiron rigid PVC
16. Typical rice hull
17. Urethane panel interfaced with jute/polyester and glass fiber (Figure 25)
18. Water hyacinth, ash
19. Water hyacinth, dry

B. ETHIOPIA

1. Asbestos fiber in three grades (Figure 26)
2. Bagasse

C. INDIA

1. Pressed coconut husks (Figure 27)

D. JAMAICA

1. Bagasse board (Figure 28)

E. MALAYSIA

1. MG-49 crumb rubber
2. MG-49 gum rubber
3. MG-49 latex
4. Tropical board

(Figure 29)

F. PHILIPPINES

1. Abaca hemp, bast fiber
2. Cement block
3. Lightweight cement (Figure 30)
4. Native straw
5. Particle board
6. Typical rice hull
7. Wood shaving with cement binder (Figure 31)

G. THAILAND

1. Cement-asbestos roof tile
2. Cement roof tile (Figure 32)
3. Corrugated galvanized iron

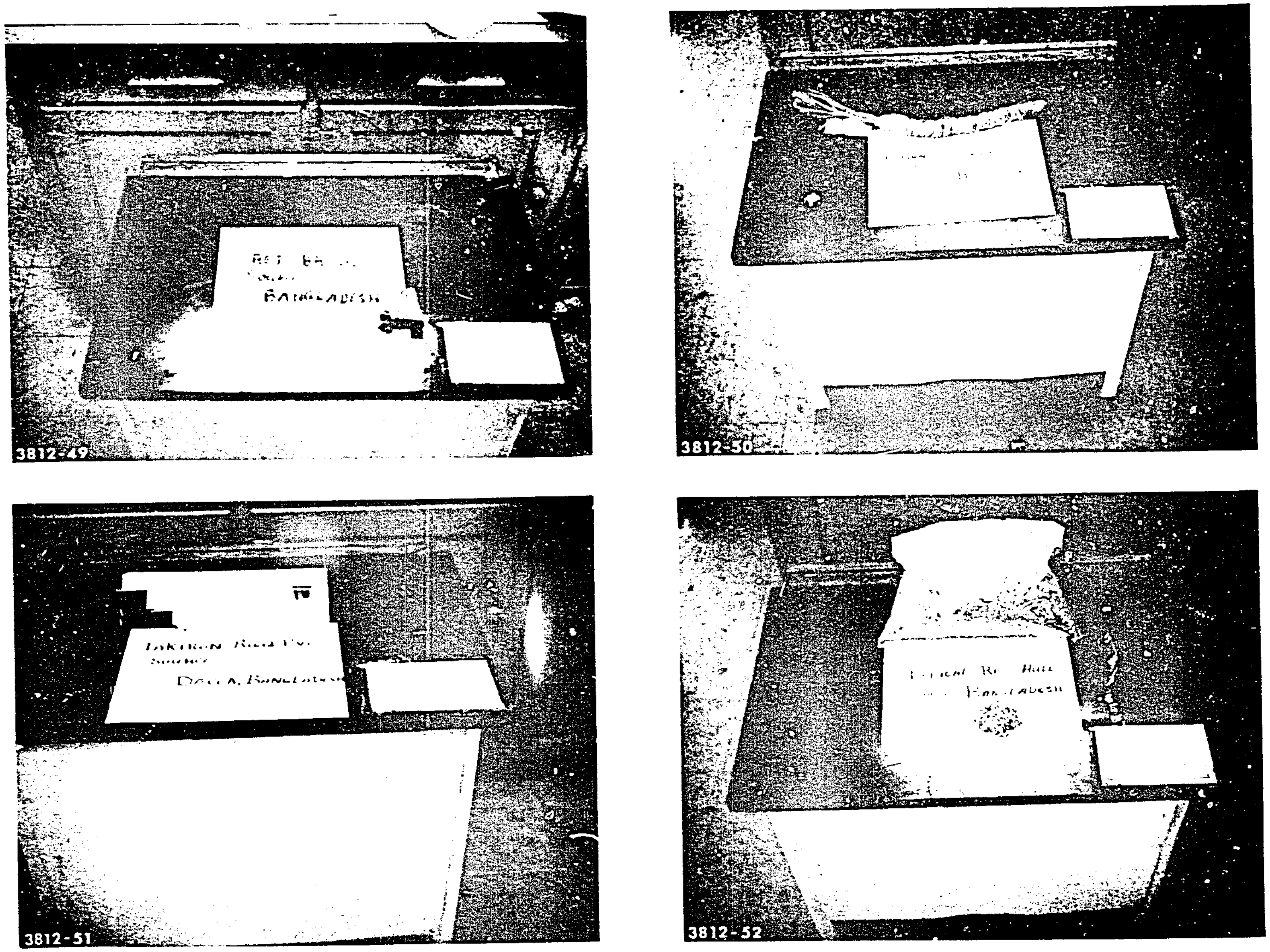


Figure 24. Brick, Hand-Woven Jute Rope and Rice Hulls Collected as Indigenous Materials from Bangladesh. Rigid PVC Corrugated Panel Also Obtained in Bangladesh, but as an Import from Japan.

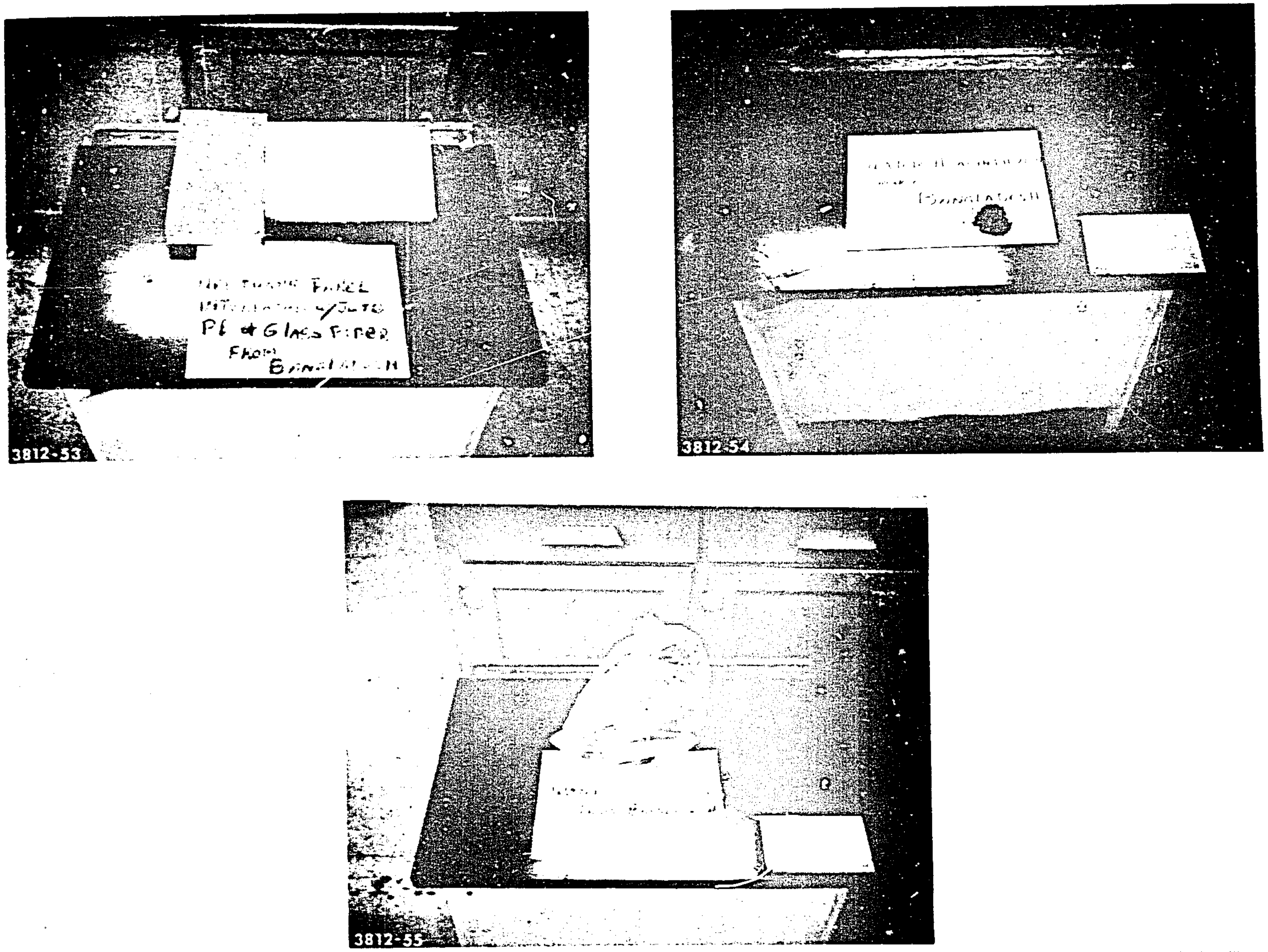


Figure 25. Urethane Foam Core Jute Polyester **Panel and** Water Hyacinth Materials Obtained **from** Bangladesh

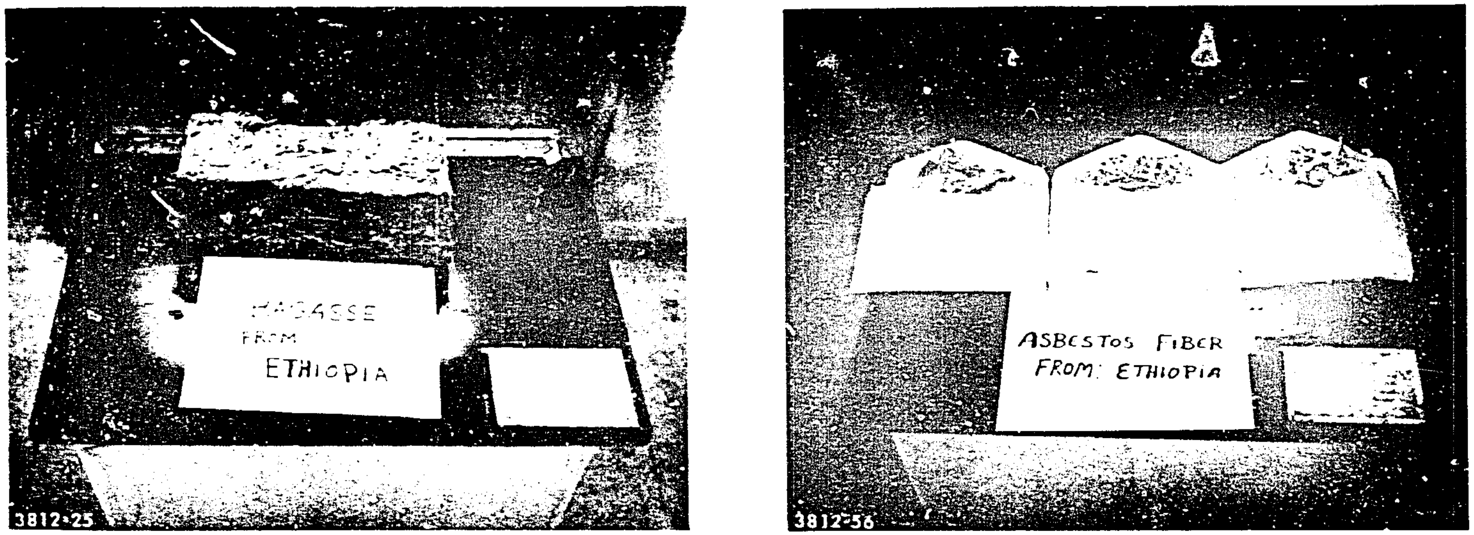


Figure 26. Bagasse and Asbestos Fiber Collected as Indigenous Materials from Ethiopia

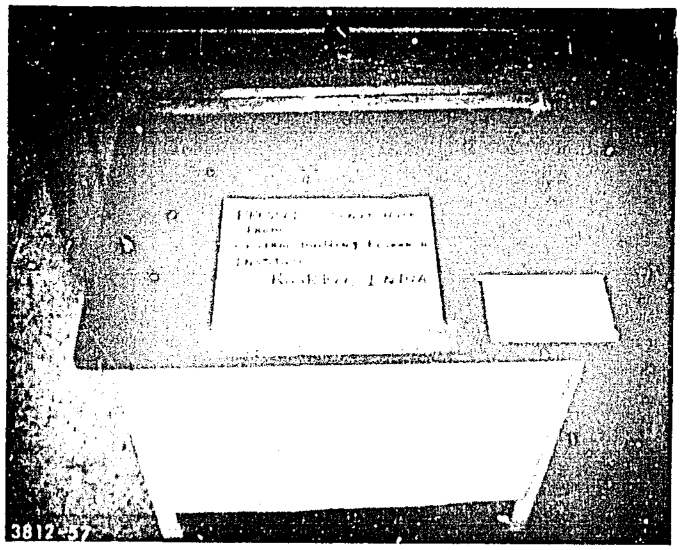


Figure 27. Pressed Coconut Husks Collected as Indigenous Materials from India

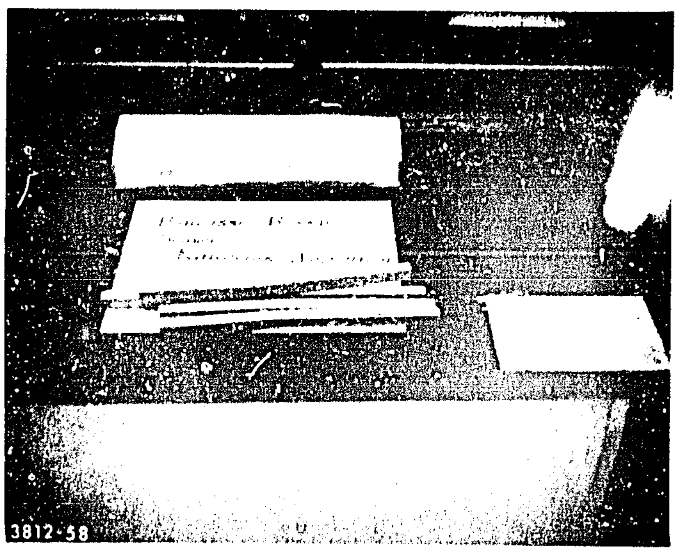


Figure 28. Bagasse Board Used in Construction Collected From Jamaica. The bagasse is bonded with a urea/formaldehyde or phenol/formaldehyde resin.

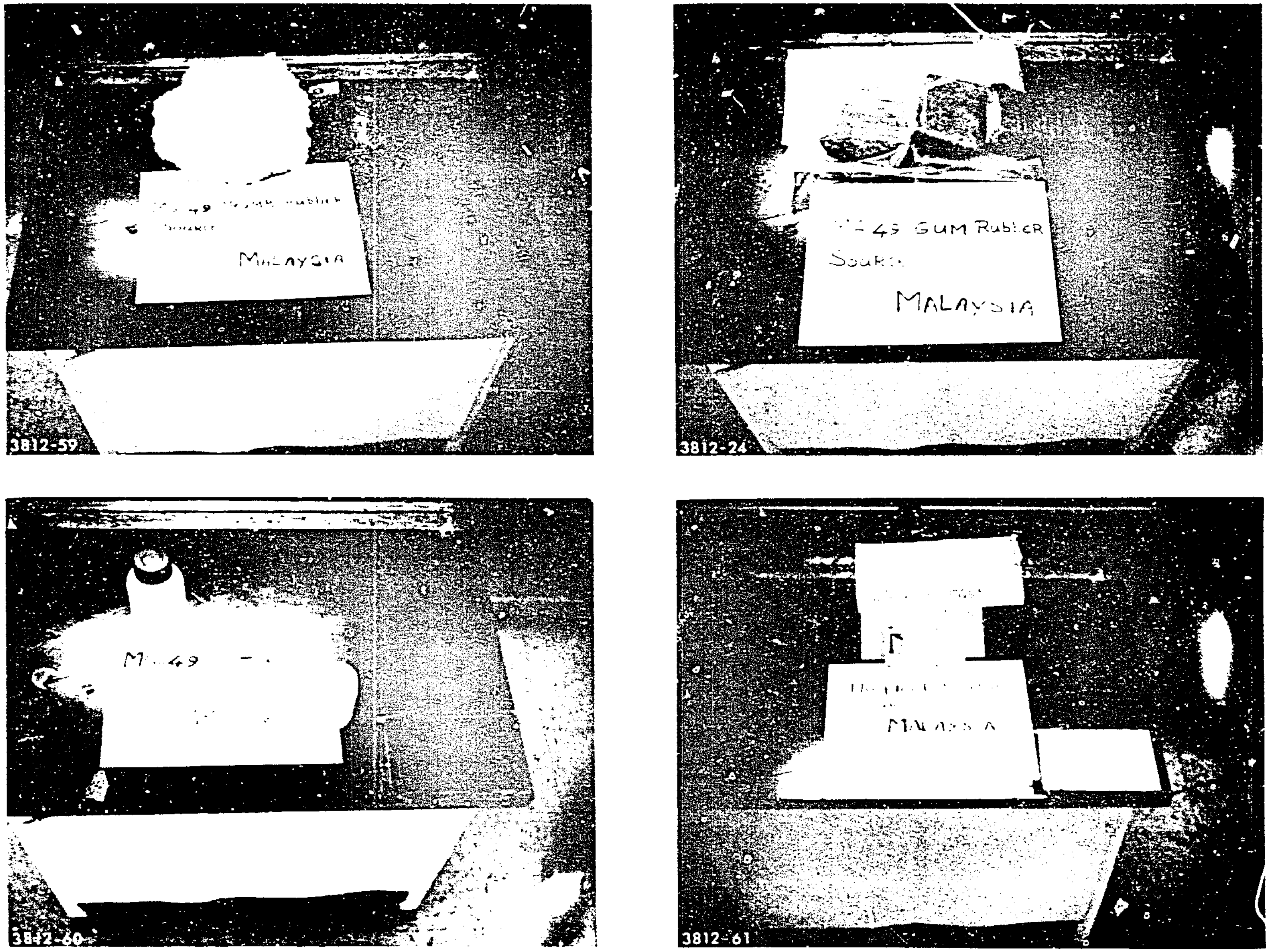


Figure 29. Crumb Rubber, Gum Rubber, Latex and Tropical Board Samples Obtained in Malaysia

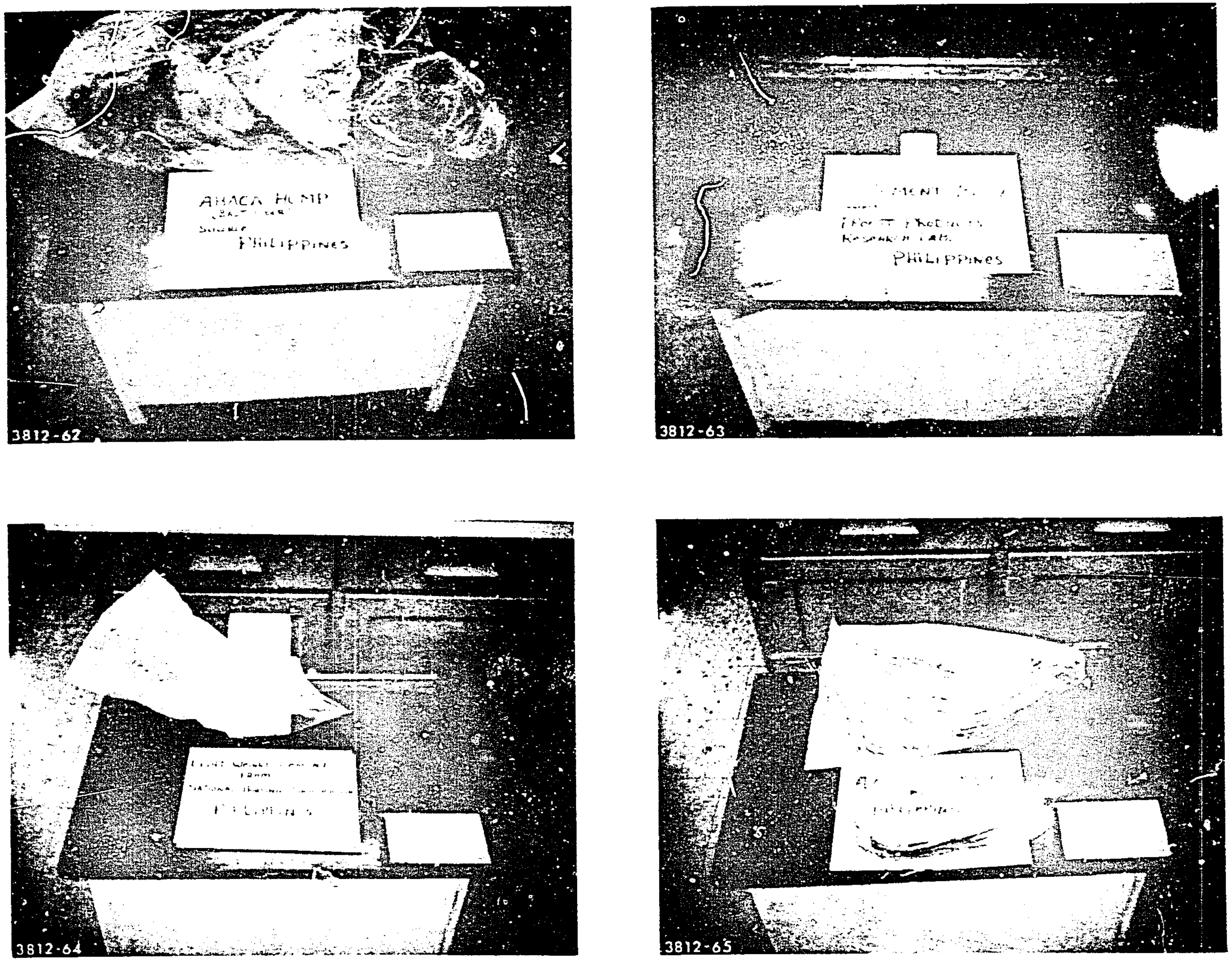


Figure 30. A Hank of Hemp, Bloated Cement Block, Lightweight Cement and Rice Straw Samples Collected from the Philippines

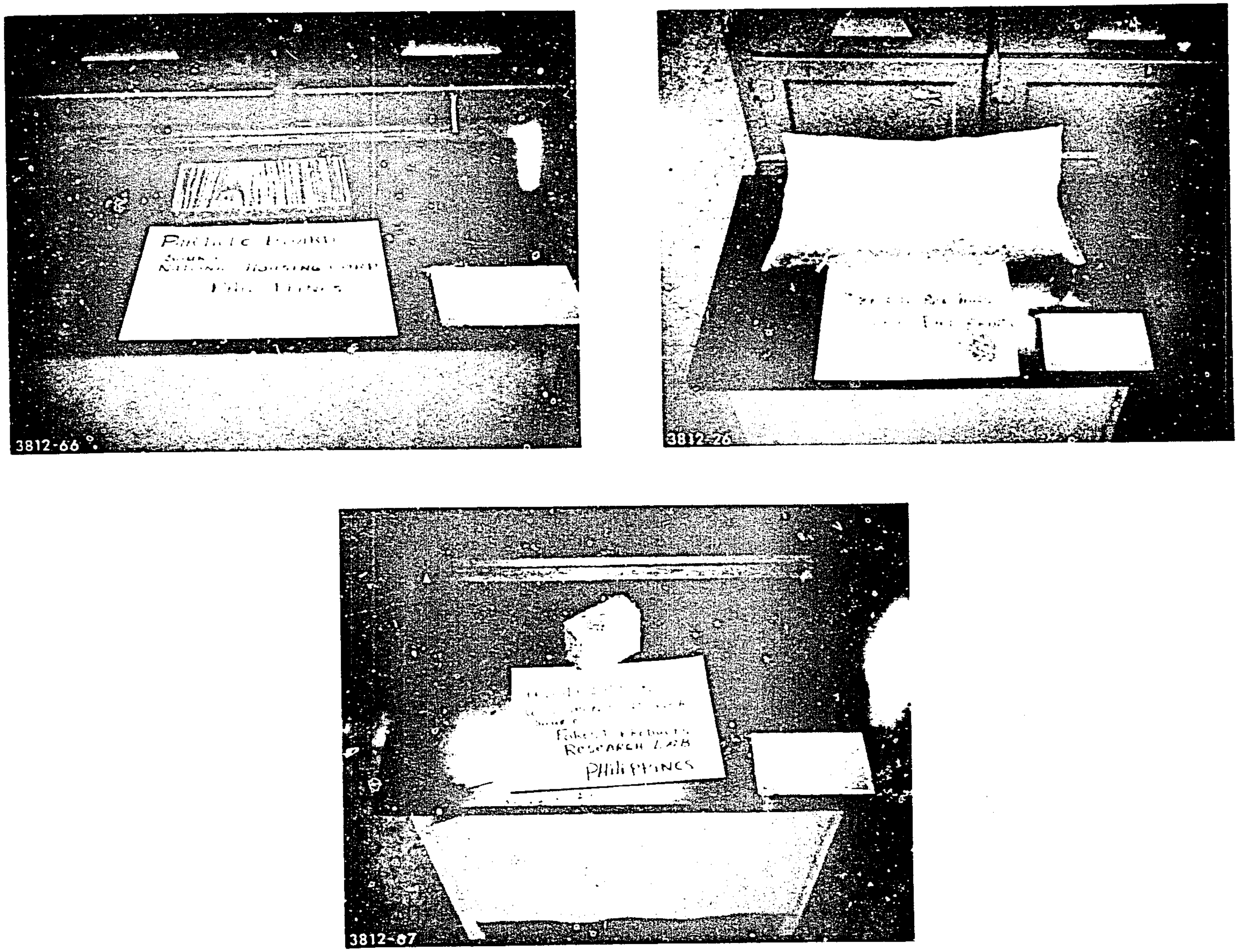


Figure 31. Particle Board, Rice Hulls and Wood Shavings (bonded with cement) Collected in the Philippines

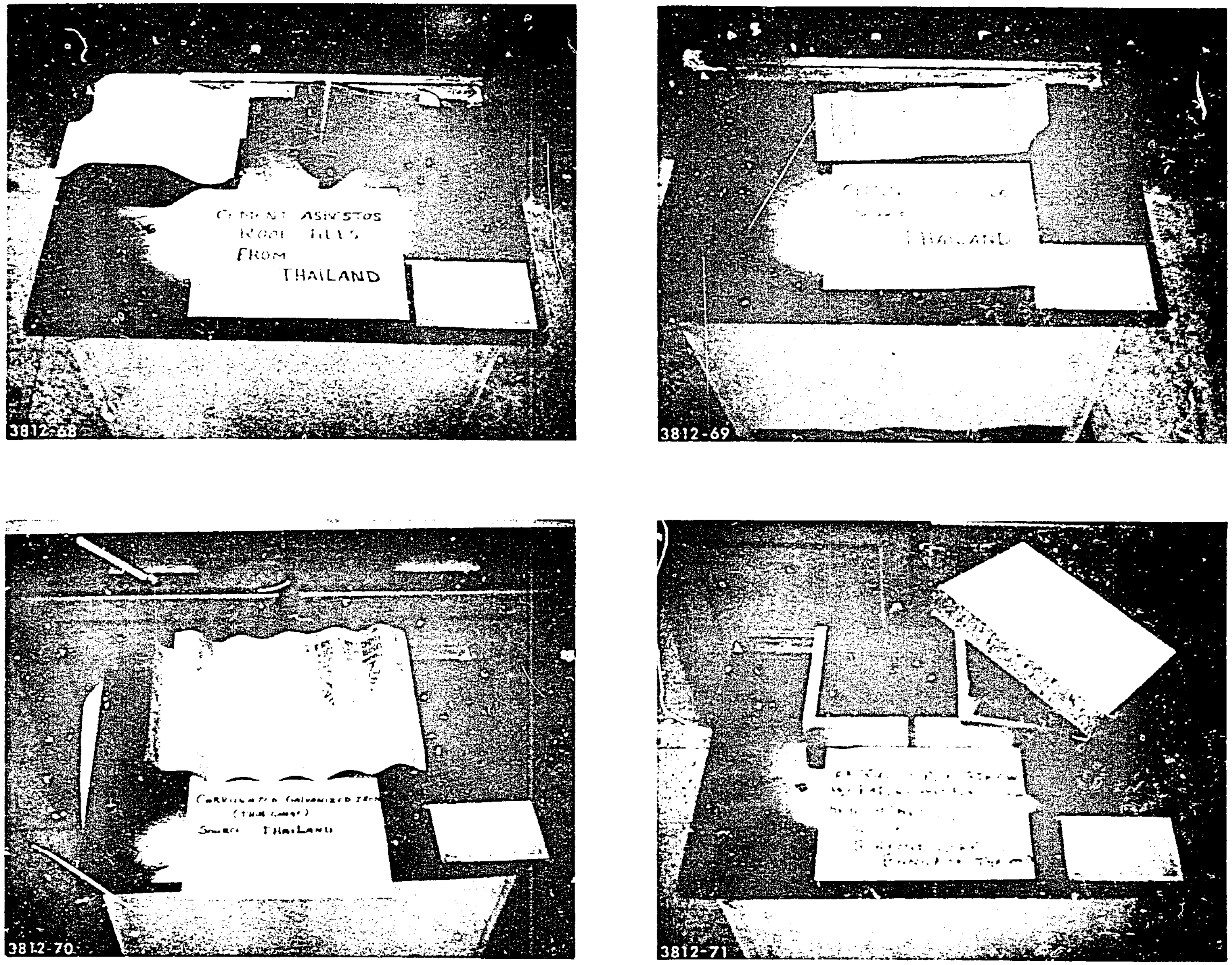


Figure 32. Portions of Cement-Asbestos Roof Tile, Cement Roof Tile, Corrugated Galvanized Iron and Extruded Rice Straw with Paper and Urea/ Formaldehyde Adhesive Collected in Thailand

4. Extruded rice straw with paper/ urea/formaldehyde adhesive
5. Gum damar (Figure 33)

H. USA

1. Aggregate, number 5 (Figure 34)
2. Bagasse (courtesy of Louisiana State U.)
3. Cement, Type I
4. Corrugated polystyrene bead foam tile (Figure 35)
5. Clay, Miami Valley
6. Metal interfaced with concrete
7. Plaster of paris
8. Plastic packing material covered with aluminum
9. Potting clay
10. Sand, fine (Figure 36)

I. ZAMBIA

1. Smelter slag
2. Stalk of wild bamboo (Figure 37)
3. Stalk of wild bamboo (small circumference)

1.1 Indigenous Materials

Some well known and available materials were not collected during the survey visits. These are nonetheless included in this discussion. The materials are classified in the following categories:

(1) Agriculture based

(2) Mineral based

(3) Synthetic

1.1.1 Agriculture Based Materials

Abaca Hemp

Abaca is the by-product fiber from the production of Manila hemp. It is obtained from the outer portion of the leafstalks

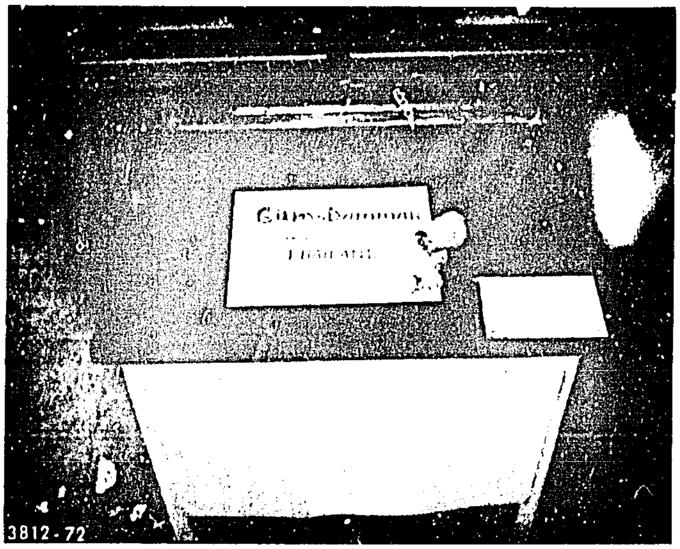


Figure 33. Gum Damar Collected from Thailand

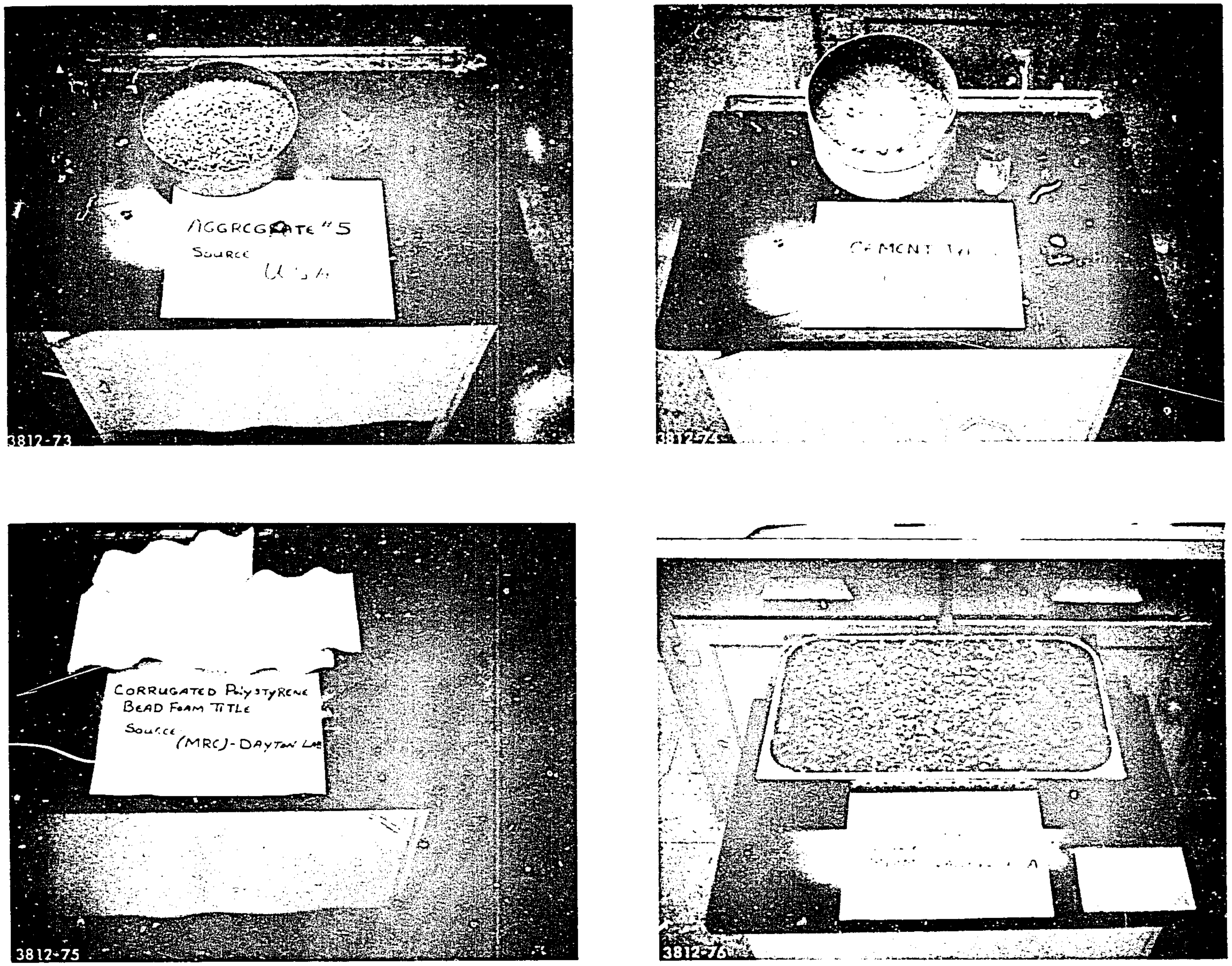


Figure 34. Aggregate, Cement, Corrugated Polystyrene Bead Foam Tile and Clay Samples Collected in the United States

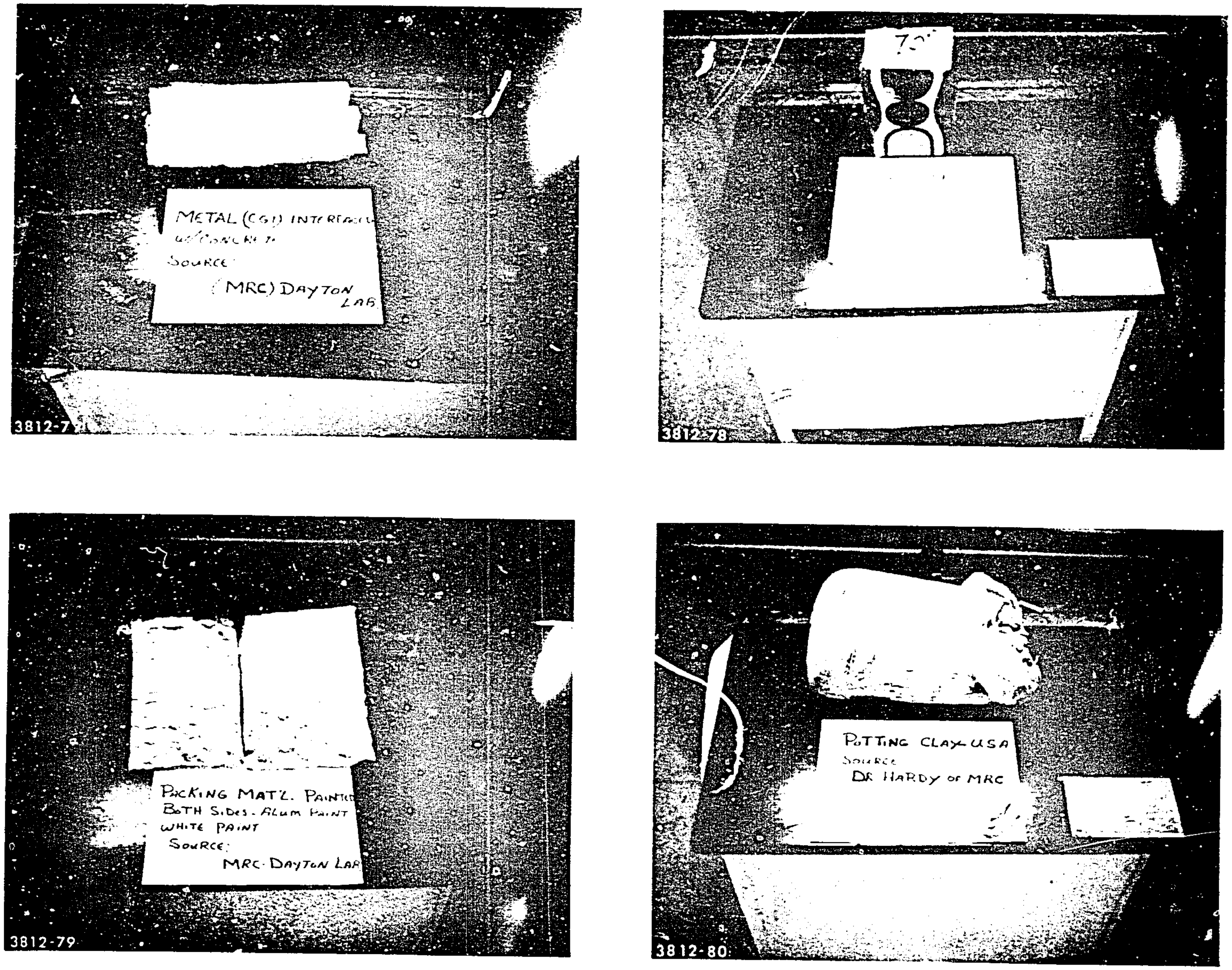


Figure 35. Metal Interfaced with Concrete, Plaster of Paris, Plastic Packaging Material and Potting Clay Samples Obtained in the United States

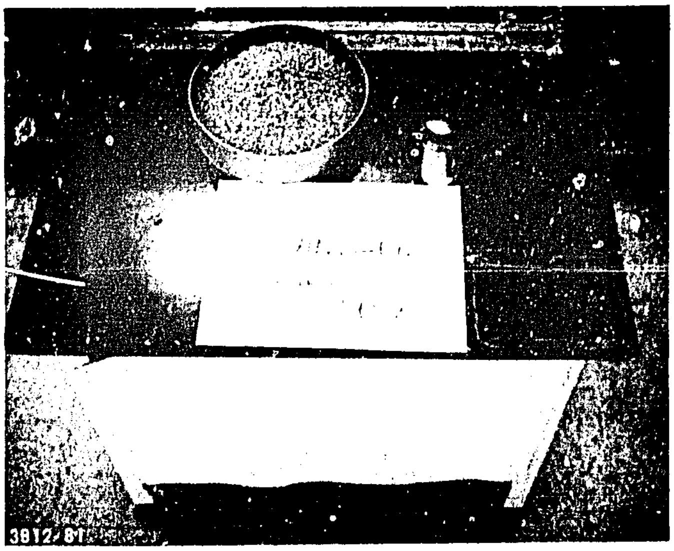


Figure 36. Fine Sand Sample Collected in the United States

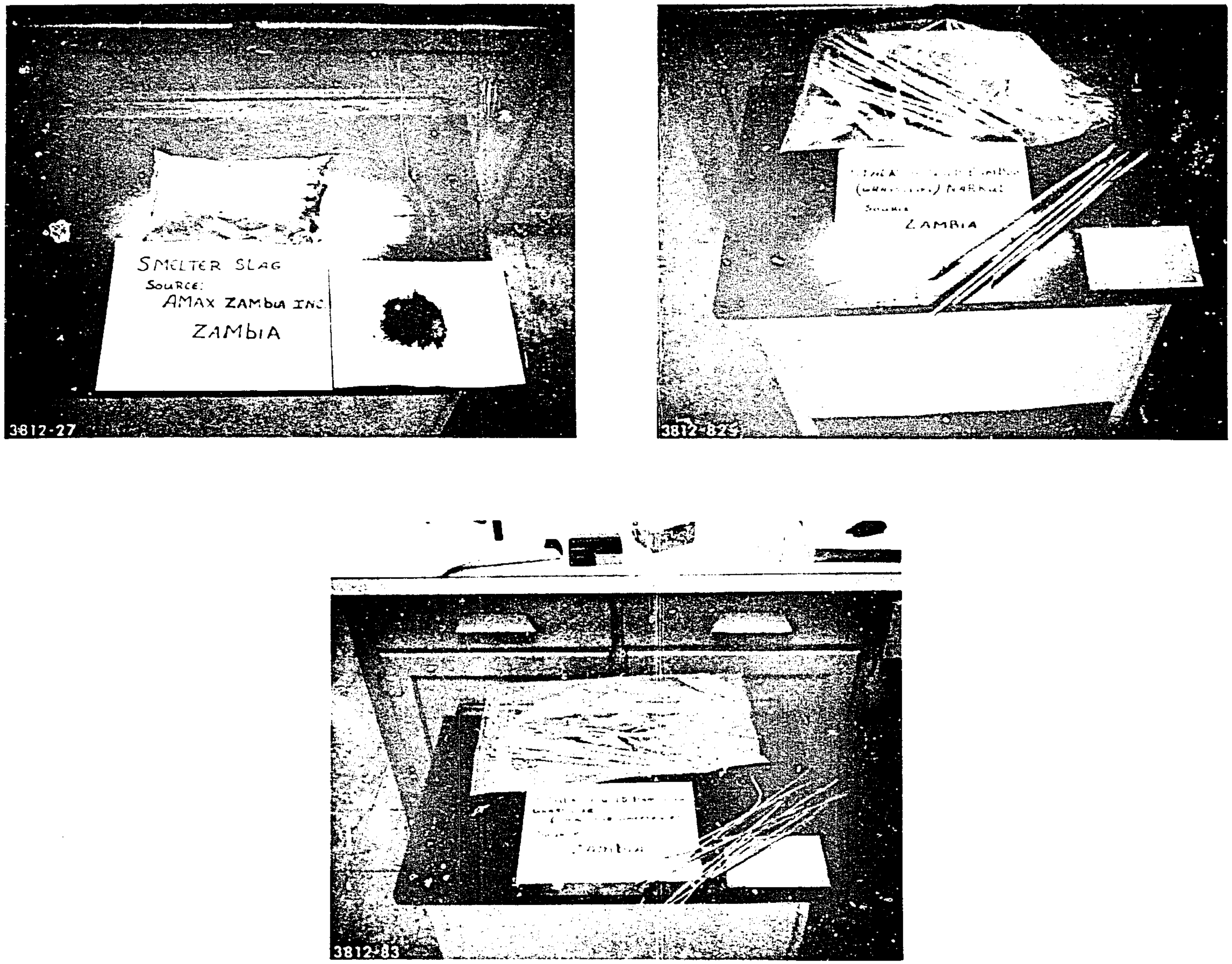


Figure 37. Copper Smelter Slag and Stocks of Large and Small Circumference Bamboo Collected from Zambia

of several species of wild bananas. The principal source, *Musa Textiles*, resembles true banana but produces inedible fruit. The fiber is 6-12 ft long, white to light brown in color, and lustrous. Abaca is strong, durable, and resistant to water.

Banana

Banana belongs to the *Musaceae* family. It is important to point out that the plant portion above the ground is a false stem. It can be called a pseudostem and consists of several concentric leaves, from the center of which the stalk develops. The fibers from the banana stalk are not as strong or durable as those from abaca.

Coconut

Coconut is a palm, *Cocos nucifera*, and its fruit is common throughout the tropical world. (See Coir.) The hull of the nut is used to make a high quality charcoal.

Coir

Coir is a natural coarse brown fiber obtained from the husk of the coconut. It is stiff but elastic, and can be molded.

Jute

Jute is a fiber obtained from two species - *Corchorus capsularis* and *Capsularis obitorius*. These are 8-12 ft tall, slender and half shrubby annuals. After harvesting, the stems are soaked in pools to ret out the softer tissues. The strands of the jute fiber are then loosened by heating the stems in water. Jute fibers are not strong (cf abaca) and degrade in the presence of water. Despite these weaknesses, jute is extensively used to make woven cloth for packaging.

Palm

There are about 1500 species, mostly tropical, belonging to the *Palmae* family in the form of shrubs, trees or vines. The most common is the coconut palm described earlier. The common date palm (*Phoenix dactylifera*) supplies materials used in construction, textiles, and thatch for roofing.

Rice and Rice Hull

Rice is obtained from the plant *Oryza sativa*. The Philippines, Bangladesh, and other Southeast Asian countries are major producers and consumers of rice. The rice hulls are produced in a quantity equal to that of the rice, and may be a useful low-cost filler or raw material for pozzolana cements.

Sisal

This plant, *Agave sisalana*, is a native of Central America. The leaf contains coarse, stiff, yellow fiber. The fiber can be removed by hand and then dried.

Sugar Cane/Bagasse

Saccarum officinarum is a grass. The cane stalk is cylinderical, is divided into nodes and internodes, and have lateral buds. Bagasse is a fibrous residue of crushed cane, and is available in quantity in all three of the selected countries.

1.1.2 Mineral Based Materials

Asbestos

Asbestos is a general name for the useful fibrous varieties of a number of rock-forming minerals. Asbestos fiber is valued because it is incombustible and has high strength. In the mining process, the asbestos fiber is removed from the host rocks and milled. Fibers are graded by their length.

Clay

Clay is widely found in both large aggregate and small particulate forms. Chemically, clays are composed of silica, alumina and water. Iron, sodium, potassium and alkaline earth salts are often present in appreciable amounts. Clays are used to make fired bricks, tiles, etc.

Gypsum and Plaster of Paris

Gypsum is $CaSO_4 \cdot 2H_2O$. Gypsum can be calcined, in kilns at 190-200°C, to remove water of crystallization to produce plaster of paris which can set in 6-8 minutes with water. Gypsum is used as a retarder in Portland cement.

1.1.3 Synthetic

Cement

Hydraulic cement is produced by combusting well mixed and finely divided *Calcareous* and *Argiu aceous* (limestone) materials. The resultant mass, ground into a fine powder, is cement. The above calcining process produces a host of calcium silicates and calcium aluminates. These compounds react chemically with water to form a hard stone-like structure. Cement, in conjunction with sand, coarse aggregate and water, produces mortar and concrete.

The most important cement is the commonly known Portland cement and is used extensively in construction.

Cement-Asbestos

These are compositions of asbestos fiber and cement. Low pressure is used to compact them into dense and monolithic sheets. Corrugation is normally provided for structural functionality.

1.2 Physical Testing and Analysis of a Few of the Composite Materials Obtained in the Field Surveys

A bagasse board is used in Arnett Gardens, a low-cost housing project in Kingston, Jamaica. Similarly, resin-bonded wood particle board is utilized in the Philippines. The CARE panel, which is under field test in Bangladesh, consists of a jute and glass reinforced polyester with urethane foam insulation. In order to obtain information about these panels, some analyses were run. The purpose was twofold, namely:

(1) to gain an understanding of the materials which may help in the composite research

(2) to correlate the performance of the various roofing materials via structural parameters

1.2.1 Bagasse Board

Our team had been told in Jamaica that the binder in the bagasse board was phenol/formaldehyde. However, analysis showed it was a urea/formaldehyde polymer. This was determined by subjecting the sample to pyrolsis and running a transmission infrared spectrum on the resultant pyrolyzate.

Water was a main product and the hydroxyl adsorptions masked other peaks. However, a weak absorption band at 2210 cm^{-1} was observed. This is characteristic of nitrile, C=N, and pyrolysis of urea/formaldehyde resins are known to produce this pyrolytic pattern. No other evidence of a phenolic resin in the binder, even in a small amount, was observed, The presence of formaldehyde was established by colorimetric test.

The bagasse board has a rough surface; sufficient contact with KRS-5 or germanium optics was not possible and hence reflectance spectra could not be recorded.

A thermogram of the bagasse board, run in air, is shown in Figure 38. Thermogravimetric analysis with adiabatic and isothermal modes gave the following board composition:

water	4%
resin	43%
bagasse	47%
residue such as silica from bagasse and/or inorganic fillers	6%

The results of the flexural testing for the board are described in Table 6 and compression results are given in Table 7.

1.2.2 Particle Board (from the Philippines)

Particle board in the Philippines is a relatively new product and uses for it are still developing. In the Philippines, consumption of hard board in housing is low. However, the soft board industry seems to be well developed.

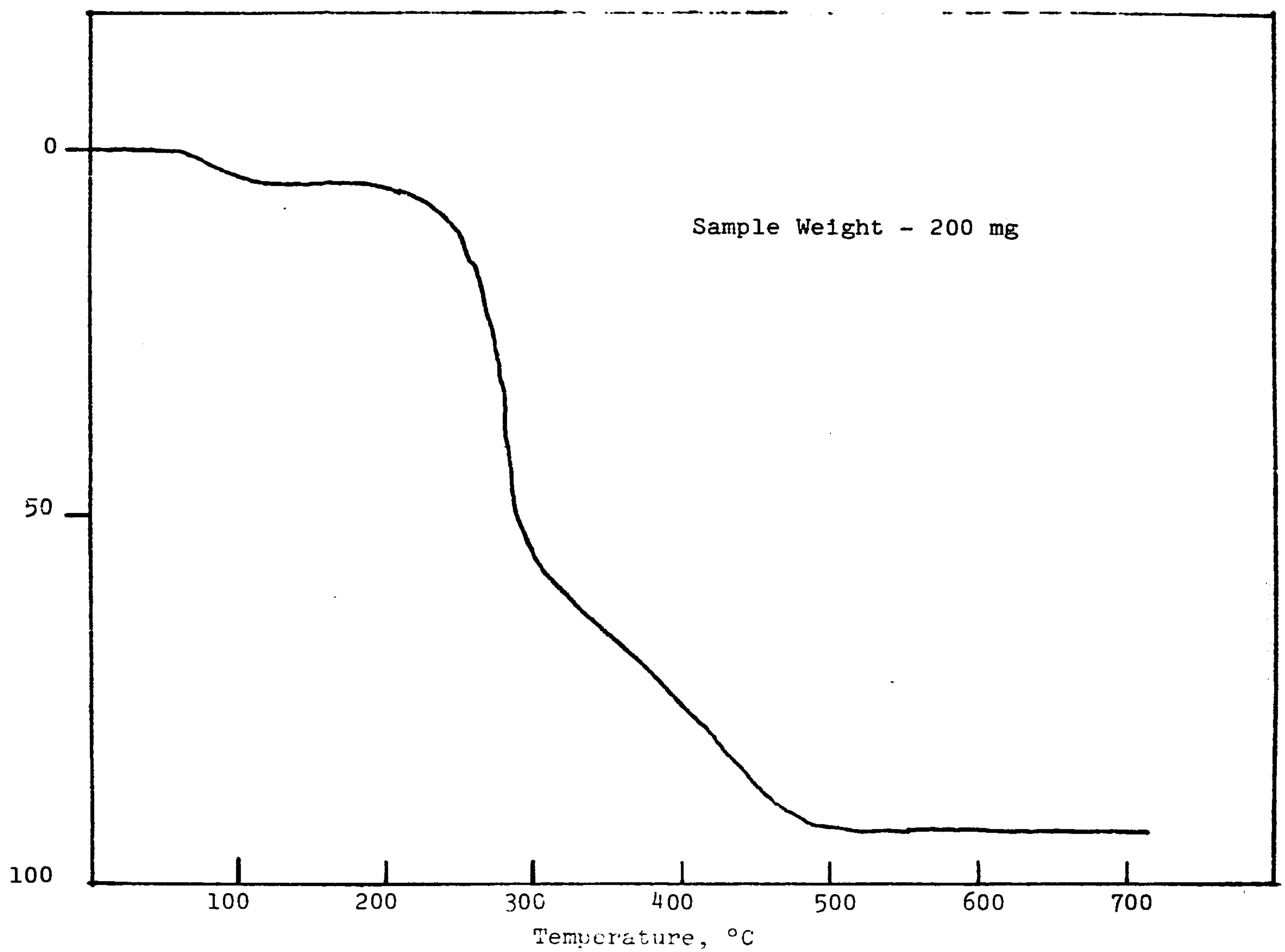


Figure 38. Thermogravimetric Analysis Characteristics Determined in Air of the Bagasse Board Collected in Jamaica. This analysis was determined to assist in defining the composition of the bagasse board.

Table 6

FLEXURAL CHARACTERISTICS OF THE JAMAICAN BAGASSE BOARD AS A FUNCTION OF IMMERSION TIME IN WATER. FLEXURAL STRENGTH DETERMINED ON DRY SPECIMEN

Bagasse Board Immersed in 74°F Water (hours)	Apparent Dry Density* (g/cc)	Water Absorbed By Weight (percent)	Flexural Strength (psi)	Maximum Strain in Outer Fiber (in./in.x10^{-3}	Elastic Modulus
0 i.e. dry	0.571	-	1362	9.73	183,000
24	0.548	92	596	17.00	72,000
48	0.587	87	726	20.15	85,200
72	0.589	94	764	18.25	82,500

*Immersed samples were dried before density determinations

Note: In all cases, yield is not observed until the specimen fails.

Table 7

COMPRESSIVE DATA ON BAGASSE BOARD OBTAINED IN JAMAICA AS A FUNCTION OF FIBER-ORIENTATION

Sample	Compressive Strength (psi)	Compressive Modulus of Elasticity (psi)
Per ASTM D-695, Dry Board	11,000	14,000
Dry/compression in direction of the bagasse fiber and mold	16,000	12,500
Dry/compression perpendicular to the fiber and mold	1,880	33,300
Per ASTM D-695, Board immersed in water for 72 hours	10,600	2,960

Note: No yield observed; cf. flexural test results

The thermogram of the particle board determined in air is shown in Figure 39. An approximate composition is estimated to be:

water	6%
cellulosic material namely, wood particles	53%
synthetic resin	37%
inorganic filler	4%

The results of flexural testing of the particle board are given in Table 8 and compression data in Table 9. The effect of water is demonstrated.

1.2.3 Jute and Glass Reinforced Polyester Panels Insulated With Urethane Foam (Bangladesh)

The panel size was insufficient to complete flexural tests in accordance with ASTM Test Method D-790. A 1.230 inch x 1.255 inch x 9.53 inch specimen failed initially at 297 psi. Major structural damage occurred at 458 psi.

A 1.2 inch x 3.06 inch x 5.6 inch sample was tested for compressive strength by ASTM D-695. Failure occurred at 43 psi and major structural damage at 106 psi. The composite was also tested for compressive strength by ASTM D-1621 which is the test for a rigid cellular plastic. A specimen 1.25 inch x 1.88 inch x 3.06 inch failed at 83 psi. Major damage occurred at 103 psi.

Table 8

FLEXURAL CHARACTERISTICS OF THE PARTICLE BOARD OBTAINED IN THE PHILIPPINES AS A FUNCTION OF IMMERSION TIME IN WATER. FLEXURAL STRENGTH DETERMINED ON DRY SPECIMEN

Bagasse Board Immersed in 74°F Water (hours)	Apparent Dry Density* (g/cc)	Water Absorbed By Weight (percent)	Flexural Strength (psi)	Maximum Strain in Outer Fiber (in./in./10^{-3})	Elastic Modulus (psi)
0 i.e. dry	0.661	-	760	4.46	212,000
24	0.659	87	315	7.92	79,000
48	0.655	90	203	10.60	41,000

*Immersed samples were dired before density determinations.

Note: In all cases, yield is not observed until the specimen fails.

Table 9

COMPRESSIVE DATA DETERMINED ON PARTICLE BOARD FROM THE PHILIPPINES AS A FUNCTION OF IMMERSION TIME IN WATER. TEST RUN ON DRY SPECIMEN

Sample	Compressive Modulus of Elasticity, psi
Per ASTM D-695, dry particle	11,900
Board immersed for 24 hours	2,900
Board immersed for 48 hours	2,440

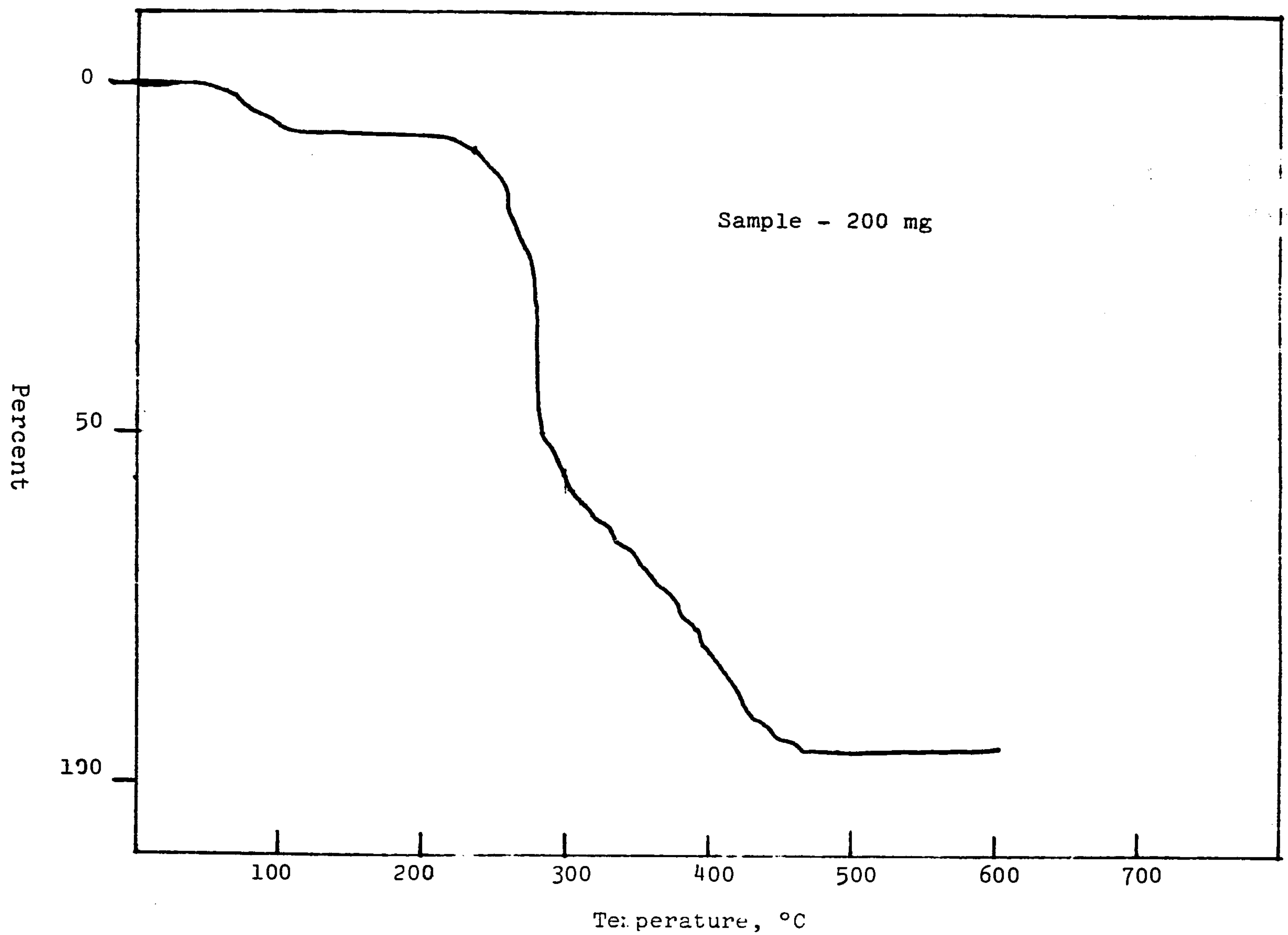


Figure 39. Thermogravimetric Analysis Characteristics in Air of the Particle Board Collected in the Philippines. This analysis was conducted to assist in determining the composition of the particle board.

2. LABORATORY DEVELOPMENT

The laboratory development involved only a minor effort, since the major emphasis of the first year was on definition of the problem and selection of countries as potential test sites.

However, it became somewhat obvious, early in the field surveys, that indigenous binders would not be available. Thus, an effort to select the best binders must be pursued in our laboratory, regardless of other information found. Accordingly, some model systems were examined to demonstrate concepts, evaluate designs and suggest processibility (including self-help). Additionally, efforts were initiated toward selecting the cheaper binders and taking a look at how they may best be utilized in a very low-cost roofing situation.

Some relatively high cost binders (such as epoxies) were used in the experimental work. However, it should be emphasized that this was strictly for the purpose of modeling and the convenience of using a well worked out system, and not in anticipation of their ultimate use.

2.1 Binders

Both thermosetting and thermoplastic binders were examined. A thermosetting material becomes useful by a chemical reaction, which transforms it from a liquid (usually) to a rigid material. The reacted material cannot be converted back to its original form without causing some irreversible damage. In contrast, thermoplastic materials are used by softening them with heat (no chemical reaction) then forming them to the desired shape, and setting them by cooling. This physical heating, changing of shape, cooling, and setting can be done repeatedly on a given material. Thermoplastics also may be dissolved in a solvent, cast into place, and the solvent evaporated to form a particular item.

Low-cost thermosetting binders being considered are the styrenated polyesters, urea/formaldehyde, and phenolics. The low-cost thermoplastics are polystyrene, polyethylene, polyvinyl chloride, and polypropylene. Each of these materials has its own distinct advantages and disadvantages, which will be pointed out as they are examined.

Generalizing, it may be said that the thermosetting resins, such as the polyesters, are more expensive materials than the high volume thermoplastics. However, they require only simple processing equipment (such as a mixing vessel) to blend a number of components together, and a mold for casting. Some of the thermosetting resins are quite cheap, however, the more inexpensive ones normally suffer from poor strength and poor water resistance.

Generalizing again, the thermoplastics are less expensive but require more sophisticated processing equipment and energy for heating than the thermosetting materials.

In addition to selection of materials, it is desirable to (1) develop an inexpensive method of processing a thermoplastic, or (2) make significant improvements in low-cost thermosetting resin properties, or (3) greatly extend the thermosetting or thermoplastic resin with a low-cost material.

Our efforts so far have included work only on thermosetting polymers such as polyesters and urea/formaldehyde. Epoxies have been used for modeling purposes.

Binders for clays are discussed in Section 2.4.

2.2 Fillers, Reinforcements, Etc.

Fillers, reinforcements, etc., can be used for a number of purposes in composites. These include reduction in their weight or cost, addition of texture or color, increase in rigidity, etc.

In our present effort, the utility of the filler is primarily that of reducing cost, especially foreign exchange cost, by using fillers available indigenously. It is anticipated that these fillers could make up from 70 to 90% of the volume of a roofing panel. Strength, rigidity, and durability of the panel may in fact be enhanced by optimum fillers.

Since the resource surveys had not been completed when this work was started, full information on the indigenous fillers in the candidate countries was not available. However, it was obvious that air and water would be available at all sites. Additionally, both particulate and fibrous fillers of some type would be available.

Accordingly, our initial composite development efforts started with the use of the indigenous fillers such as air, water and typical particulate and fibrous materials. Representative potentially available fibrous fillers tested included jute and rice straw.

2.3 Composite Materials and Structures

The composite materials and structures examined included: straw-filled epoxy panels, air-filled urea/formaldehyde, jute-reinforced polyester, air-filled polyester, foam core jute-polyester panels, and water-filled polyesters. While the economics are known to be attractive for these systems, evaluation of physical properties has not yet been completed.

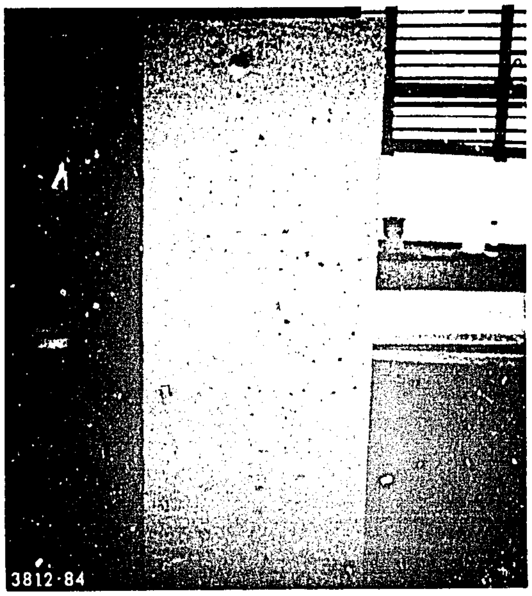
2.3.1 Flat and Corrugated Air-Filled Epoxy Panels (Model Structures)

The first panels produced were of an air-filled epoxy having a density of 4 lb/cu ft. Air-filled epoxies are relatively expensive and require a fair amount of sophisticated equipment for processing. However, they are valuable for making model structures.

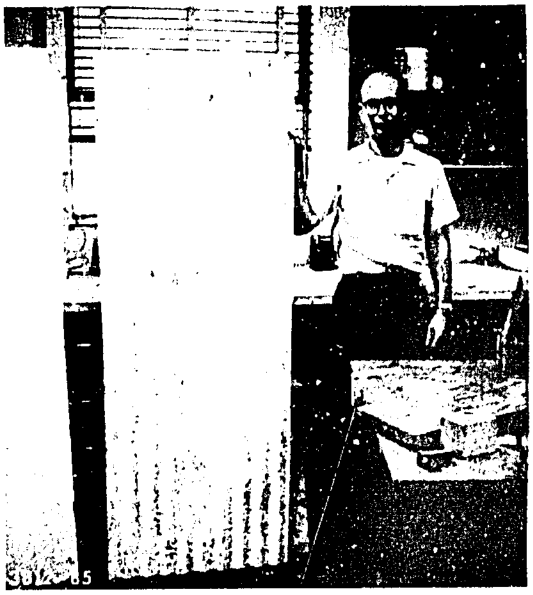
This air-filled epoxy was produced on a continuous basis in the form of a froth which resembles "shaving cream" before it is cured. The cure is at room temperature and takes approximately 4 hours. Simple plywood molds were constructed and filled. The flat panels produced measured 2 ft x 6 ft x 1 inch. One, illustrated in Figure 40a weighted 0.33 lb/sq ft.

In order to increase the rigidity of the larger panels, a corrugating mold was fabricated. The mold was fabricated by making a 1 inch spacer for two sheets of CGI. Polyethylene film was used for release. The air-filled epoxy was poured in, and the mold held together with C-clamps. Panels of densities from 4 to 8 lb/cu ft were made, some of which also used straw as an additional filler, as illustrated in Figures 40b and 40c The weights of these panels were 0.3 to 0.7 lb/sq ft.

Small panels 10 in. x 18 in. x 1 in. were also made, some of which contained an aluminum foil skin. This skin was easily applied by lining the mold with aluminum foil prior to pouring the froth, which then adhered to the foil. It was also shown that straw could be placed in the mold and the froth poured over it. During the curing process, the epoxy froth undergoes a slight expansion which causes it to fill in around the straw quite well. Figure 40d shows a sectioned panel of air-filled epoxy with aluminum skins and straw filler.

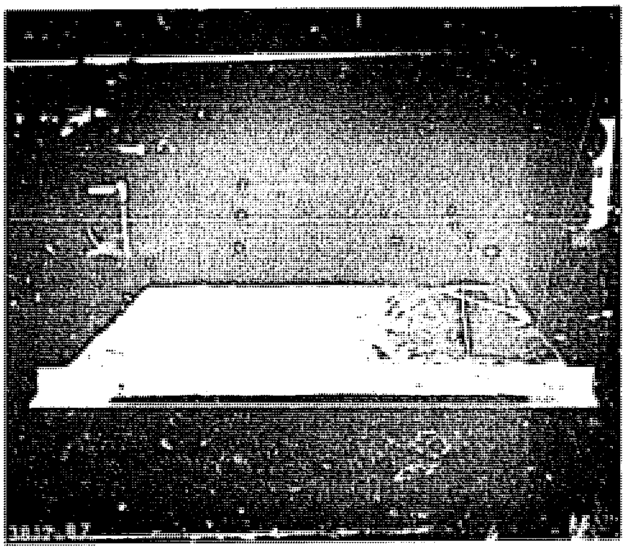


(a) 1 inch thick flat air-filled epoxy panel having a weight of 0.3 lb/ft^2



(b) 1 inch thick corrugated air and rice straw-filled epoxy panel having a weight of 0.66 lb/ft^2

(c) close-up of air and straw-filled corrugated epoxy panel



(d) air and straw-filled flat epoxy panel with thin aluminum skins to provide additional environmental protection

Figure 40. Flat and Corrugated Air Filled Epoxy Panels Fabricated as Model Roofing Panels. Rice Straw also used as filler/reinforcement.

2.3.2 Air-Filled Urea/Formaldehyde Panels

The very low-cost material urea/formaldehyde (U/F) was used to prepare some 1 inch thick foam with densities as high as 7 lb/cu ft (0.6 lb/sq ft). Such densities are not readily available in U/F foams and modification of the system was required. Low density U/F foams are normally poor in terms of friability and water sensitivity. Overcoming some of these limitations was attempted by the addition of modifiers to achieve densities higher than the normal 1 to 2 lb/cu ft. The modifiers included vinyl chloride latices, which improved toughness and reduced water sensitivity.

Panels of the higher 7 lb/cu ft U/F foam are shown in Figure 41. The strength of the material was insufficient, and improvements would need to be made to provide strengths needed for a roofing panel application.

2.3.3 Low Cost Styrenated Polyester

The most widely used laminating resins are the styrenated polyesters. This is because of their low cost, ease of processing, and excellent physical performance. Polyesters were considered from two standpoints: (1) as a laminating or binder resin, and (2) as an air-filled core material. The second application requires development of a new system just for this program.

The general purpose styrenated polyester resin can be used to prepare good laminates with fibrous materials such as jute cloth, glass, or woven mats of many different materials, as has been done by Winfield and Woudenberg in Bangladesh, CARE.

To illustrate the utility of laminates of this type a panel was prepared by cutting 2 in. x 10 in. x 1/2 in. thick strips of low density foam, such as urea/formaldehyde, and adhering a layer of woven jute around the strips in a rectangular pattern. This gave the effect of thin polyester-impregnated jute struts running from top to bottom. Then, layers of jute saturated with polyester

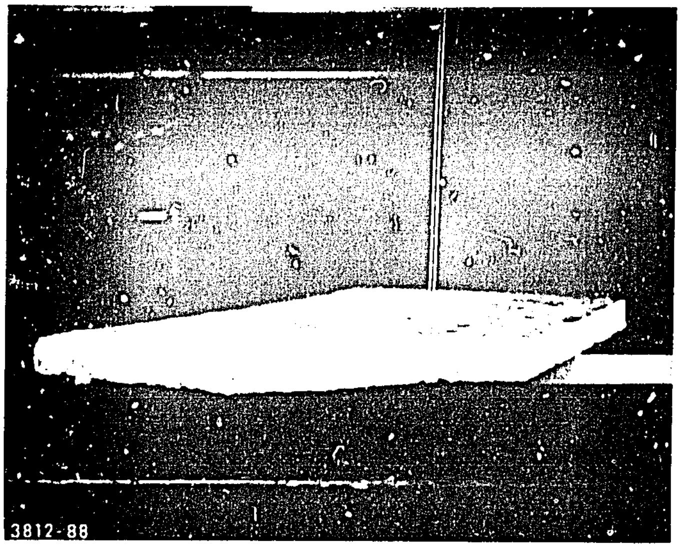


Figure 41. Air-Filled Urea/Formaldehyde Panel Toughened with Modifiers and Increased Density. Weight in 1 inch thickness is 0.6 lb/ft^2

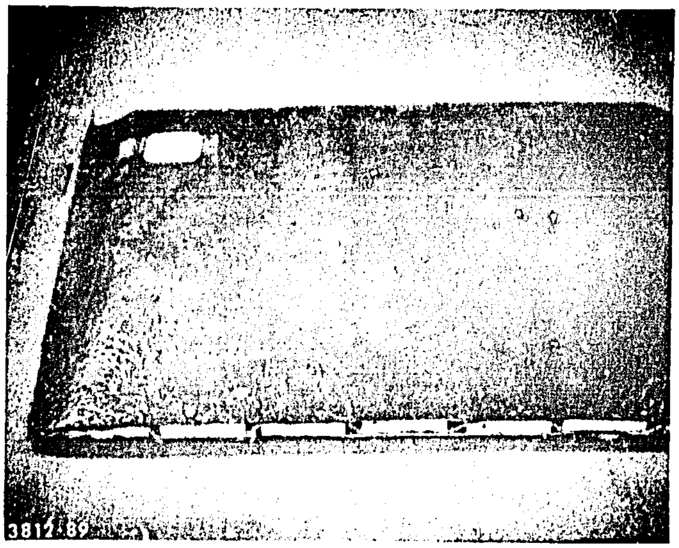


Figure 42. Jute-Reinforced Polyester Panel with Integral Structural Webbing and Urea/Formaldehyde Low Density Foam Insulation

were placed on the top and bottom, cured, and a gel-coat finish applied. Figure 42 shows this completed panel, which has a weight of 1.2 lb/sq ft.

Expanded (Gas-Filled Polyester)

In addition to using the polyester as a laminating resin, an air (gas) filled system was developed from general purpose polyester. The incorporation of air into polyester resins is not easily accomplished because the resin tends to gel from crosslinking before it reacts exothermically. The trick is to slow down the rate of crosslinking so that the resin is still a liquid while it is heating. Thus, as the gas is generated internally, the resin can expand.

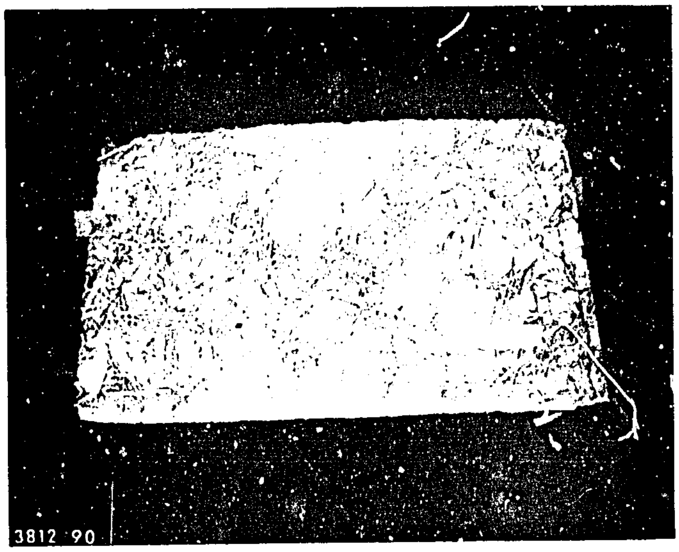
To accomplish this, additional maleic anhydride is incorporated into the polyester resin. The maleic anhydride reacts rapidly with the styrene monomer present and generates heat which causes the gas to be evolved and expand the resin. At the same time the polyester resin is curing and sets up into a rigid gas-filled structure with a density around 8 lb/cu ft.

Fillers such as rice straw may also be included as shown in Figure 43.

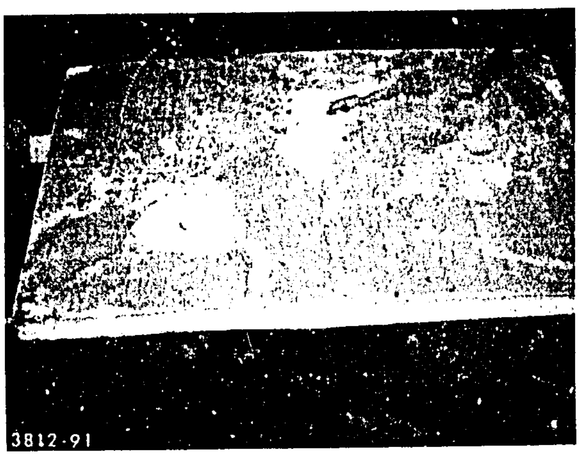
Expanded (Foam) Polyester Core-Reinforced Polyester Skin Panels

Several panels were prepared by pouring the expandable polyester liquid into a closed mold and allowing it to cure for 25 minutes. Figure 43b.shows panels made of the expanded polyester.

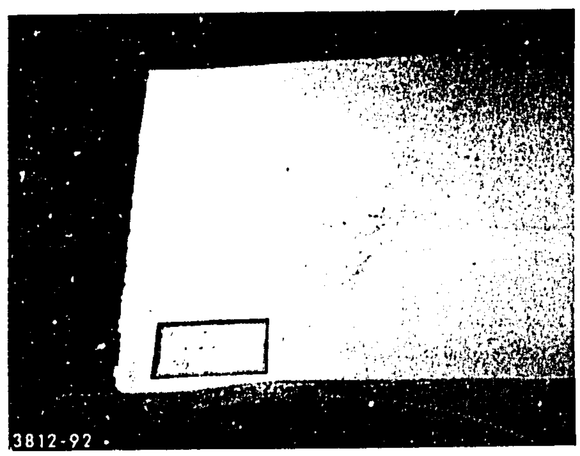
The panels have a jute-reinforced polyester skin on both sides. The jute was incorporated during the expanding process. The bottom of the mold was first lined with a piece of jute cloth. Then, the polyester formulation was poured in and a second



(a) air-filled polyester used as a binder for rice straw



(b) air-filled polyester bonded directly to jute fabric skins



(c) air-filled polyester containing jute cloth skins with a polyester gel coat. Weight is approximately 1 lb/ft^2

Figure 43. Potential Roof System Panels Fabricated from a Newly Developed Air-Filled Polyester Containing Rice Straw and Jute Fabric

piece of jute cloth was placed in the mold on top of the solution. When the polyester expanded it pushed the second layer of jute to the top of the mold, and bonded to and through it.

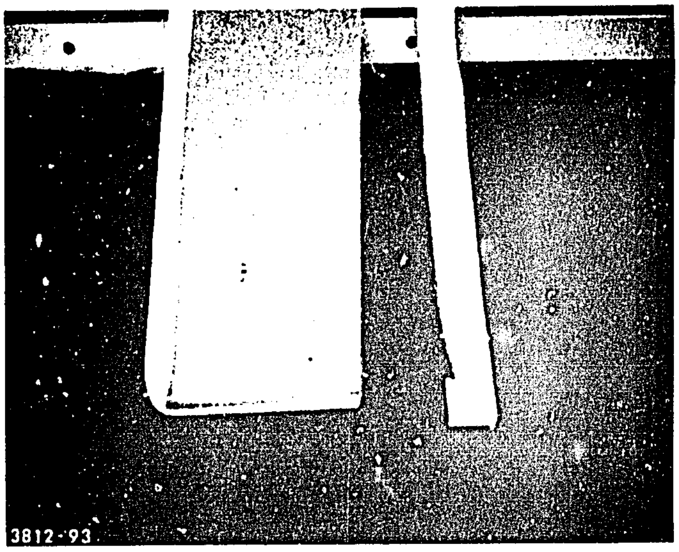
In some cases (see Figure 43c), a gel coat of polyester resin was applied to the surface of the panel in order to give a more weatherable finish. A typical panel weighed 1.0 lb/sq ft.

A highly attractive second type of polyester that is quite different is under consideration. In this case, the polyester is extended with a liquid, namely, water.

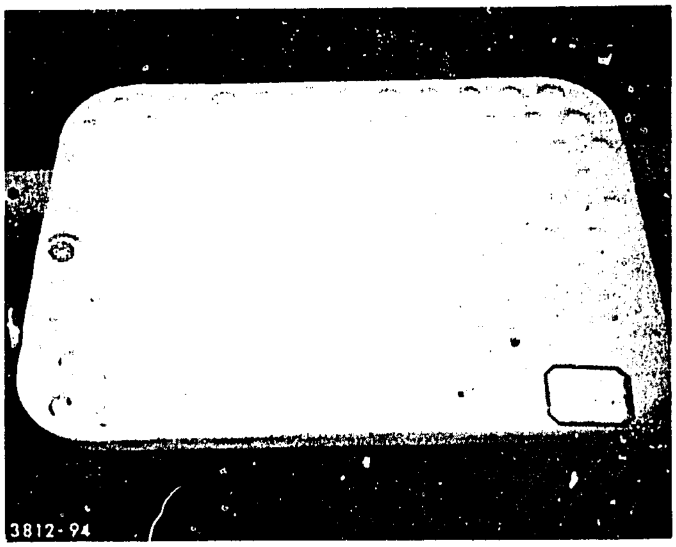
Polyester resin is blended with water to form an emulsion containing 50-60% by weight water (up to 75% is possible). The water is in the form of small droplets 2-3 microns in size. The emulsion is catalyzed and sets up to a rigid material with the water permanently sealed in. This system is not new, and is used for fabricating furniture due to its low cost and excellent casting characteristics.

Several types of panels were made using water-extended polyester. First, panels were made by simply casting the emulsion into trays, as shown in Figure 44. This resulted in a density of 60 lb/cu ft. In order to decrease the density, hollow polyethylene balls were incorporated into the panels. Figure 44a shows a panel of water-filled polyester resin cast over 3/4 in. hollow balls. It has a density of ~29 lb/cu ft, or 2.3 lb/sq ft weight.

It was also shown that the water-extended polyester (WEP) could be used in a manner fairly similar to general purpose polyester resin for laminating. Figure 45 shows laminates (flat and corrugated) consisting of three layers of jute with water-extended polyester in and between the layers. These had weights of 0.95 lb/sq ft.

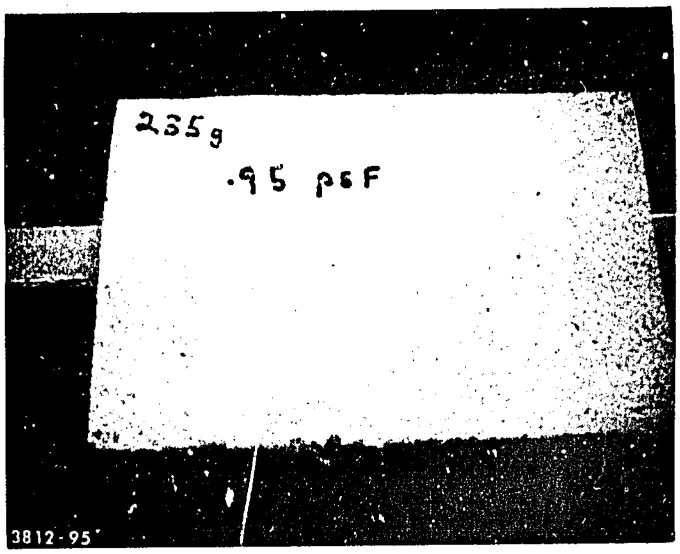


(a) 50% water-filled rigid polyester casting with [illegible] cloth surfaces

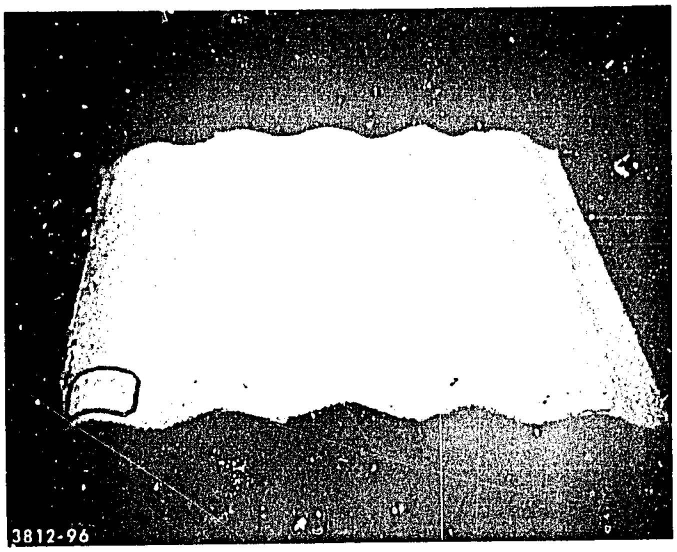


(b) 50% water-filled polyester panel extended with air-filled polyethylene spheres. Weight [illegible] 2.4 lb/ft^2 for a 3/4 inch thick panel

Figure 44. Panels Prepared from Water and Air-Filled Polyesters, Thus Incorporating the Two Primary Indigenous Materials in the World



(a) 3 ply jute cloth lay-up having a weight of about 0.95 lb/ft²



(b) 4 ply jute cloth corrugated panel

Figure 45. Thin Laminated Panels Prepared from a 50% Water Extended Polyester Resin and Jute Fabric Reinforcement

One advantage of the WEP system is that its natural color is a creamy white, so it is opaque. The emulsion can also be tinted with water soluble dyes, which stay in the water phase, or with organic and inorganic pigments.

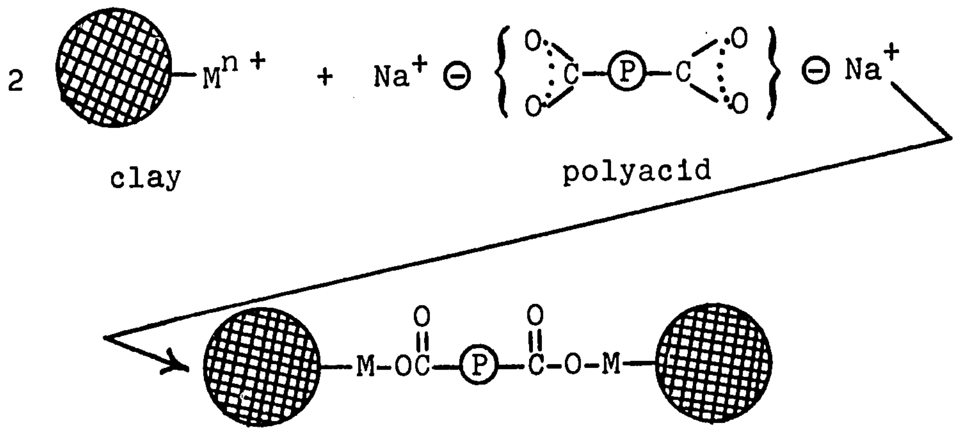
Using a combination of WEP and the polyester laminating resin, some interesting panels were made. First, structural elements were prepared. Jute was layed in a mold and then about 1/4 in. of the WEP was poured over it. Another layer of jute was placed on the gelled resin and the process repeated. The end product was a slab 1/2 in. thick with three plies of jute (top, bottom and center) each separated by 1/4 in. of WEP resin. This panel was cut up into strips 1/2 in. wide for tests.

The reinforced WEP strips were then layed down in a pattern to give 4 in. square boxes. These boxes were covered with a top and bottom layer of polyester-impregnated jute cloth which was bonded with the same polyester. Figure 46 shows a panel of this type of construction. The weight of the panel is 2.2 lb/sq ft.

2.4 Polymer (Polyelectrolyte)-Clay Interaction Studies

Some work was conducted to examine the feasibility of using a polyelectrolyte binder with clays to provide tiles without the need for firing.

A clay containing multivalent metal ion(s), M^n, will react with a polyacid as follows:



Reaction of Clay with a Polyelectrolyte to Form a Polymer-Clay Ineracted Product

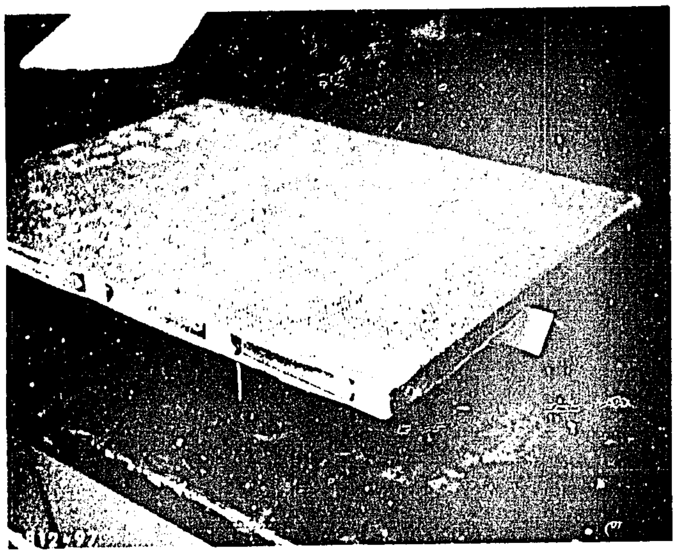


Figure 46. Panel Fabricated from 50% Water Extended Polyester Ribbing and Jute/Polyester Skins. The water and jute make up over 50% of the weight of the panel. The panel also contains air between the ribs and thus the volume of the panel is made up of over 75% potentially indigenous materials.

2.4.1 Polyelectrolytes to be Considered as Clay Binders

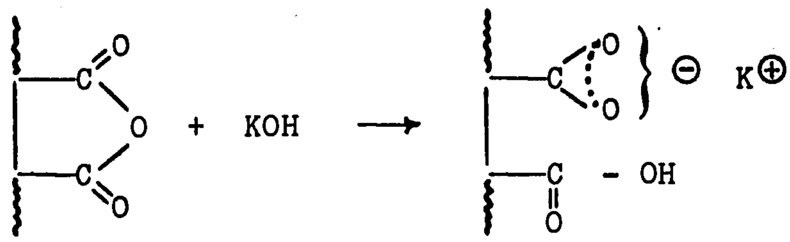
Vinyl Acetate/Maleic Anhydride Copolymers and Modifications

A family of water-soluble vinyl acetate/maleic anhydride copolymers is made by Monsanto Company. These are designated VAMA Resins - Lytron 897, 898 and 899. The resins are characterized by high carboxylic acidity, with solubility in water.

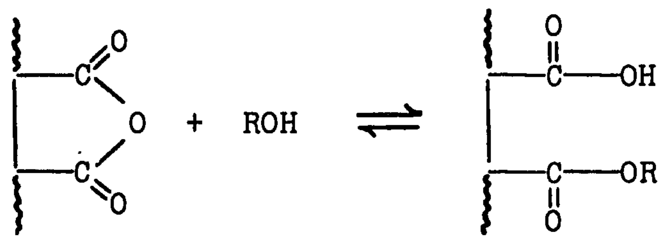
PROPERTIES OF LYTRON RESINS

	Lytron		
Property	897	898	899
Form	fine, off-white powder	coarse, crushed product	fine, off-white powder
Bulk density	46 lb/cu ft	55 lb/cu ft	45 lb/cu ft
Acid value, mg , KOH	440	580	320
Solubility	water, alcohol	water, alcohol	water above pH,4
pH of 1% solution	2.0	2.0	

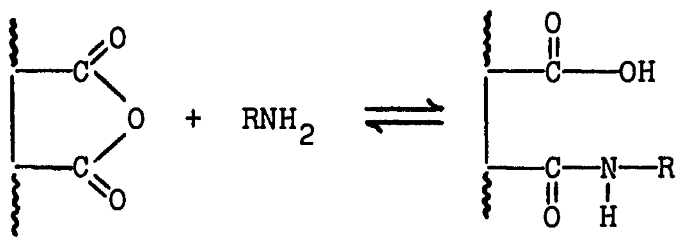
The solution of Lytron in water behaves as a weak polyacid. Through concerted reactions of functional anhydride groups, it is possible to produce strong polyacids and other useful products. Examples are illustrated below:



(HPS) half potassium salt



(HME) half maleic ester



(HMA) half maleic amide

In a similar vein, alternating copolymers of styrene/maleic anhydride can offer a set of polyacids.

2.4.2 Preparation of Clay

Miami Valley (Ohio) clay was used for the experiments because of its availability. It was rendered free of weeds, roots and other organic matter. It was then dried and pulverized to pass through a number 8 sieve.

2.4.3 Laboratory Processed Polyelectrolyte-Binder Clay-Filled Compositions

A clay filler bonded with a small amount of polyelectrolyte can produce compositions of apparently good physical and chemical characteristics. The degree of physical enhancement, however, is yet to be determined quantitatively.

2.4.3.1 Mold and Press

The aluminum mold shown in Figure 47 was used to densify the clay. The clay composition is introduced into the female part. The male part is then inserted. The metal bar rests on top of the mold and the whole unit is then placed in a hydraulic press. See Figure 48.

The Carver laboratory press shown can supply a maximum pressure of 24,000 pounds.

2.4.3.2 Typical Composition

Numerous samples were prepared. However, only a typical preparation will be discussed. The formula is as follows:

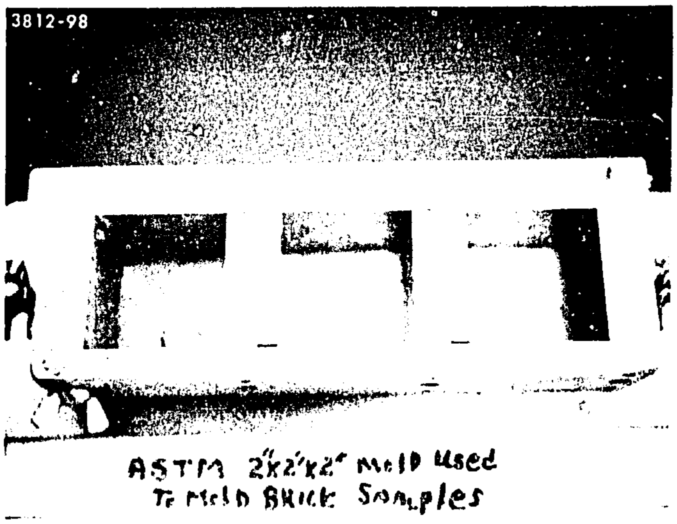


Figure 47. Simple Compression Molds for the Preparation of Composites Consisting of Polyelectrolyte Binders and Clay Fillers. The blended materials are dumped into the female portion of the mold (a) and the block inserts (b) are used to provide the compression. Two samples can be made in one molding by placing the large pressure foot over the three cavities.

FORMULA

	Grams
Miami Valley Clay	98.5
Calcium oxide	0.5
Lytron 897	1.0
Tap water	40.0
	140.0

The clay was mixed with calcium oxide. The polyelectrolyte solution, (Lytron 897) was prepared in water and added to the clay. After mixing, the composition was placed in the mold and pressed at an operating pressure of 650 pounds for 30-60 minutes. After removal from the mold, the product was dried in the sun for about 8 hours. The photograph of this composition is shown in Figure 49.

2.4.4 Further Work in Polyelectrolyte Binders for Clay

The work on the polyelectrolytes will be extended, in terms of the clay analysis and the statistical design of the compositions. Clay stabilization by polybases will also be investigated. Soil solidification by sodium silicate and calcium chloride will be investigated in terms of the product and process.

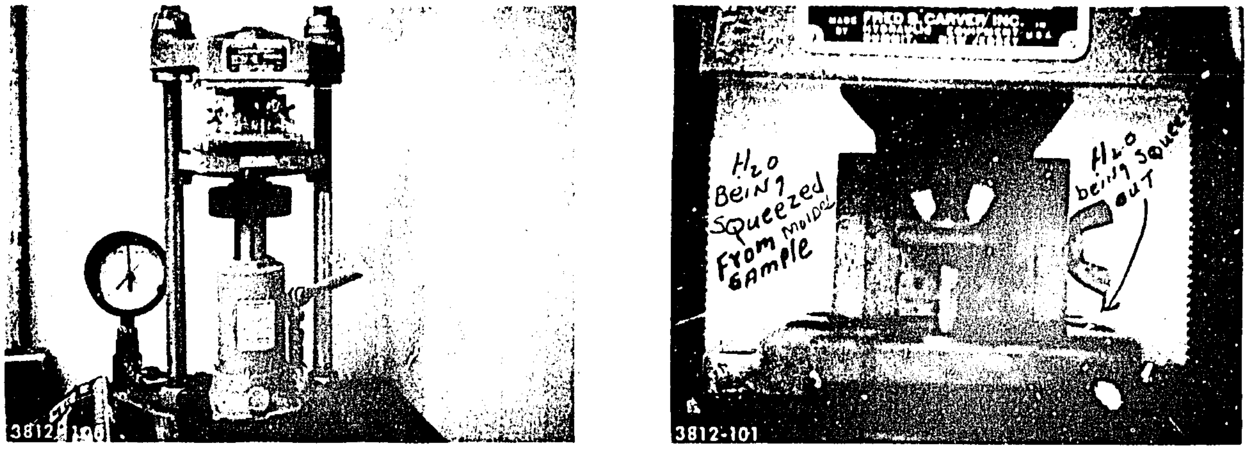


Figure 48. Demonstration of Technique of Densifying Clay Containing the Polyelectrolyte Binder. Shown (a) is a compression mold in a hand-operated hydraulic press. In the operation (b) water is squeezed from the sample as shown.

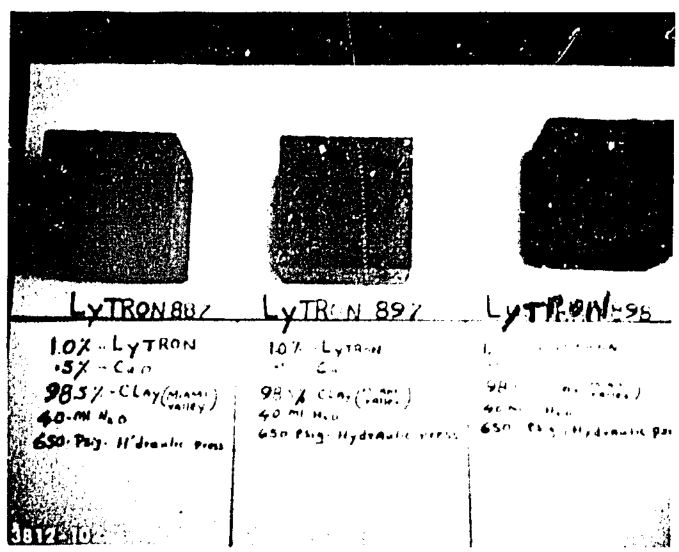


Figure 49. Unfired Fused Clay Tiles Bonded with Polyelectrolytes. The monolithic product produced results from a chemical bonding of the polyelectrolyte with the clay and the removal of water. Relatively low forming pressures are required.

APPENDIX F

<u>COLLECTION, REVIEW AND INDEXING OF CURRENT RELEVANT LITERATURE</u>

APPENDIX F

COLLECTION, REVIEW AND INDEXING OF CURRENT RELEVANT LITERATURE

As pointed out in Section 2.7 of the Summary of this report, the collection, review, and indexing of the current literature was started in Phase I and will continue throughout the program. This is not an attempt to review the voluminous past literature on low-cost housing and roofing, nor is it planned to make a separate report on this collected literature. Rather, the objective is to review the current literature, use it where applicable, and file it systematically by a method which will permit ready retrieval by the project team at any time desired during the program.

The problem of housing in developing nations is chronic and urgent, and second only to the problems of population and food. Extensive research on low-cost housing is going on in both the developed and developing nations around the world. Several recognized centers for research and development in this area have also emerged. In Southeast Asia, this includes work being done at such places as Mindanao State University in the Philippines, the Building Research Institute at Bandung, Indonesia and the Asian Institute of Technology at Bangkok, Thailand, and the Building Products Research Institute at Roorkee, India. Similar centers of research and development on low-cost housing have also grown up in other parts of the world. Several international organizations individually and collectively support the continuing research and development in low-cost housing and report and disseminate the results through periodic regional or worldwide symposia.

It is the literature concerning these current developments that MRC is attempting to follow, collect, review, and index for our own use as well as that of others who may be working in this area.

The cataloging and indexing is being accomplished by the use of a "Keyword in Context" index (KWIC), which is being done by listing the subject, authors, titles, and sources on computer cards. Every significant word in the title is indexed. Thus, for example, all of the literature articles which contain "housing" as a significant word in the title would be found by looking in the index under "housing". If the article concerned "housing in Ghana" it would also be indexed under the word Ghana. The KWIC index can be easily kept up to data as information is added. Included is the subject index, an author listing, and a basic bibliography listing. The index is used by first selecting the desired subject area (for instance bamboo). The subject listing under bamboo shows that there is now one article on that subject. It is identified by the code number at the right of the page (MCCLAFA53BBM). The source of this information is obtained by going to the bibliography listing and finding that code number from the alphabetized list on the left (bottom of page 7 of the bibliography listing).

Thus, there are three main subsections of this appendix under which all the information is indexed: Keyword Listing (1.1), Author Listing (1.2), and Bibliography Listing (1.3)

An additional Unindexed Listing (1.4) is given for more recently obtained literature, and pertinent unofficial documents. This listing will be added to the KWIC index along with other new material obtained in the interim.

This computer indexing of the accumulated information was readily performed using the software and program for this purpose already available in our laboratory.

It is expected that the KWIC index will be useful to the project team members throughout the program and in the preparation of the final report after completion. It is also expected that the KWIC index will be an additional source of information to readers of this report in developing nations who can thereby readily determine where some significant article of interest to them can be found. Conversely, if readers of this report are aware of other current articles which should be added to this literature index, it would be greatly appreciated if they would send a copy of the article to the attention of I. O. Salyer at Monsanto Research Corporation, Dayton Laboratory, P.O. Box 8, Station B, Dayton, Ohio 45407, USA.

1.1 KEYWORD LISTING

ADOBE
MORTAR FOR ADOBE BRICK .= AUTHUN00MAB

ADOBE-BLOCKS
CENTO-SYMPOSIUM ON RURAL HOUSING IMPROVING THE MECHANICAL-
PROPERTIES OF ADOBE-BLOCKS USED IN RURAL-BUILDINGS .= AUTHUN75CSR

AFRICA
AIDED SELF-HELP HOUSING IN AFRICA .= DIVIIN69ASH

AFRICAN-DEVELOPMENT
AFRICAN-DEVELOPMENT ZAMBIA-SURVEY .= AUTHUN72ADZ

AFRICAN-STATES
AFRICAN-STATES MUST FORM UNITED-FRONT IN SOLVING
ECONOMIC PROBLEMS .= ACHEIK73ASM

AGADIR-AND-THE-SOUS
MOROCCO AGADIR-AND-THE-SOUS .= AUTHUN00MAS

AGENCY-FOR-INTERNATIONAL-DEVELOPMENT
AGENCY-FOR-INTERNATIONAL-DEVELOPMENT CONTRACT-PROGRAM IN
CENTRALLY-FUNDED-RESEARCH .= AUTHUN72AID

AGRICULTURAL-RESIDUES
PRODUCTION OF PANELS FROM AGRICULTURAL-RESIDUES .= AUTHUN70PPA

AIDED
AIDED SELF-HELP HOUSING .= AUTHUN63ASH
,,COLONIA MANAGUA,, AN AIDED SELF-HELP HOUSING PROJECT IN
NICARAGUA .= DEPARU62CMA
AIDED SELF-HELP HOUSING IN AFRICA .= DIVIIN69ASH

AIDED
AIDED SELF-HELP IN HOUSING IMPROVEMENT .= WEAVRC67ASH

APPLICATIONS
FERROCEMENT. APPLICATIONS IN DEVELOPING-COUNTRIES .= REPOAD73FAD

APPLYING
APPLYING TECHNOLOGY TO A SOCIAL CONTEXT. EDUCATION HOUSING .= MORGRP72ATS

APPROACH
EPOXY WALL MATRIX. A NEW APPROACH TO SIDING .= REILWS72EWM

ASPHALT-EMULSION-STABILIZED
THE MANUFACTURE OF ASPHALT-EMULSION-STABILIZED SOIL BRICKS AND BRICK-MAKER-S-MANUAL .= INTEIN72MAS

ASSEMBLY
ASSEMBLY INDUSTRIES IN THE CARIBBEAN .= AUTHUN73AIC

ASSESSED
WORLD POPULATION PROSPECTS AS ASSESSED IN 1963 .= DEPAEC66WPP

ASSOCIATION-ONR/ARPA-PROJECT
,,COUPLING,, IN THE MONSANTO/WASHINGTON-UNIVERSITY-ASSOCIATION-ONR/ARPA-PROJECT ON HIGH-PERFORMANCE-COMPOSITES .= AUTHUNOGCMU

BAMBOO
BAMBOO AS A BUILDING MATERIAL .= MCCLFA53BBM

BAMBOO-REINFORCED
HOW TO BUILD A BAMBOO-REINFORCED POLYURETHANE-FOAM ROOF .= CENTDE73HBB

BANGLA-DESH
EXAMPLES OF SYSTEMS BUILDINGS LOW-COST HOUSING AND SCHOOLS BANGLA-DESH HOUSING IN HONDURAS HOUSING IN THE U-S-A .= ARCHENOOESB

BARK
UTILIZING BARK RESIDUE .= ALLIRC71UBR

BASICS
BASICS OF CONCRETE .= DEPAHO60BOC

BEARING
STRUCTURAL FOAM BEARING WALLS CAN SHORE UP BUILDING-INDUSTRY .= JONERM72SFB

BRICK
MORTAR FOR ADOBE BRICK .= AUTHUNOGMAL
CORROSION OF REINFORCEMENT IN REINFORCED BRICK AND REINFORCED CEMENT CONCRETE .= GOVEIN69CFF
MUD BRICK ROOFS .= OFFIIN57MBR

BRICK-MAKER-S-MANUAL
THE MANUFACTURE OF ASPHALT-EMULSION-STABILIZED SOIL BRICKS AND BRICK-MAKER-S-MANUAL .= INTEIN72MAS

BRICKS
THE MANUFACTURE OF ASPHALT-EMULSION-STABILIZED SOIL BRICKS AND BRICK-MAKER-S-MANUAL .= INTEIN72MAS

BUILD
HOW TO BUILD A BAMBOO-REINFORCED POLYURETHANE-FOAM ROOF .= CENTDE73HBB

BUILDING
BUILDING MATERIALS FROM COCONUT-HUSK AND ITS BYPRODUCTS .= BUILMAOOBMC

CLAY
THE DEVELOPMENT OF CLAY BUILDING MATERIALS INDUSTRIES IN DEVELOPING-COUNTRIES .= INTESE66DCB

COCONUT-HUSK
BUILDING MATERIALS FROM COCONUT-HUSK AND ITS BYPRODUCTS .= BUILMA00BMC

COME-AND-TALK
COME-AND-TALK BUSINESS WITH GHANA .= AUTHUN00CTB

COMPONENTS
PREFABRICATED CONCRETE COMPONENTS FOR LOW-COST HOUSING CONSTRUCTION .= DEPAHO63PCC

COMPOSITES
,,COUPLING,, IN THE MONSANTO/WASHINGTON-UNIVERSITY-ASSOCIATION-ONR/ARPA-PROJECT ON HIGH-PERFORMANCE-COMPOSITES .= AUTHUN00CMU

CONCRETE
BASICS OF CONCRETE .= DEPAHO60BOC
PREFABRICATED CONCRETE COMPONENTS FOR LOW-COST HOUSING CONSTRUCTION .= DEPAHO63PCC
CORROSION OF REINFORCEMENT IN REINFORCED BRICK AND REINFORCED CEMENT CONCRETE .= GOVLIN69CRB

CONDOMINIUMS
CONDOMINIUMS THEIR DEVELOPMENT AND MANAGEMENT .= GREZAC72COM

CONSTRUCTION
DESIGN CRITERIA AND METHODOLOGY FOR CONSTRUCTION OF LOW-COST HOUSING TO RESIST TYPHOONS AND HURRICANES .= CENTBU73DCM
PREFABRICATED CONCRETE COMPONENTS FOR LOW-COST HOUSING CONSTRUCTION .= DEPAHO63PCC
TRADE-ASSOCIATIONS AND PROFESSIONAL-SOCIETIES OF THE CONSTRUCTION AND BUILDING-MATERIALS-INDUSTRIES .= PITCCB72TAP
DESIGN SITING AND CONSTRUCTION OF LOCALLY PLANNED STRUCTURES BETTER RESISTANT TO EARTHQUAKES AND WIND STORMS .= REPSWF72DSC

CONTEXT
APPLYING TECHNOLOGY TO A SOCIAL CONTEXT. EDUCATION HOUSING .= MORGRP72ATS

CONTRACT-PROGRAM
AGENCY-FOR-INTERNATIONAL-DEVELOPMENT CONTRACT-PROGRAM IN CENTRALLY-FUNDED-RESEARCH .= AUTHUN72AID

CORROSION
CORROSION OF REINFORCEMENT IN REINFORCED BRICK AND REINFORCED CEMENT CONCRETE .= GOVLIN69CRB

COUNTRY-REPORT
HUD-INTERNATIONAL COUNTRY-REPORT PERU .= AUTHUN00HIC
HUD-INTERNATIONAL COUNTRY-REPORT ISRAEL .= AUTHUN00HID
HUD-INTERNATIONAL COUNTRY-REPORT UNITED-KINGDOM .= AUTHUN00HIE

CREDIT-RISK-ANALYSIS
MORTGAGE CREDIT-RISK-ANALYSIS AND SERVICING OF DELINQUENT-MORTGAGES .= GREZAD72MCR

CRITERIA
DESIGN CRITERIA AND METHODOLOGY FOR CONSTRUCTION OF LOW-COST HOUSING TO RESIST TYPHOONS AND HURRICANES .= CENTBU73DCM

CUMULATIVE-LIST
  CUMULATIVE-LIST OF UNITED-NATIONS DOCUMENTS-AND-PUBLICATIONS IN THE FIELD OF HOUSING-BUILDING-AND-PLANNING .= REPODO70CLU

DELINQUENT-
  MORTGAGE CREDIT-RISK-ANALYSIS AND SERVICING OF DELINQUENT-MORTGAGES .= GREZAL72MCR

DESIGN
  DESIGN CRITERIA AND METHODOLOGY FOR CONSTRUCTION OF LOW-COST HOUSING TO RESIST TYPHOONS AND HURRICANES .= CENTBU73DCM
  DESIGN SITING AND CONSTRUCTION OF LOCALLY PLANNED STRUCTURES BETTER RESISTANT TO EARTHQUAKES AND WIND STORMS .= REPSWF72DSC

DEVELOPING-AREAS
  INDUSTRIALIZED HOUSING THE OPPORTUNITY AND THE PROBLEM IN DEVELOPING-AREAS .= AUTHUN72IHD

DEVELOPING-COUNTRIES
  URBAN PLANNING IN DEVELOPING-COUNTRIES .= AUTHUN69UPI
  A PROGRAM FOR DEVELOPMENT OF NEW SOLUTIONS TO ROOFING PROBLEMS IN DEVELOPING-COUNTRIES .= BRABBF72PDS
  STRENGTHENING URBAN-ADMINISTRATION IN DEVELOPING-COUNTRIES WITH EMPHASIS ON LATIN-AMERICA .= DEPAIR71SUA
  THE DEVELOPMENT OF CLAY BUILDING MATERIALS INDUSTRIES IN DEVELOPING-COUNTRIES .= INTESE68DCB
  FERROCEMENT. APPLICATIONS IN DEVELOPING-COUNTRIES .= REPOAD73FAD

DEVELOPMENT
  A PROGRAM FOR DEVELOPMENT OF NEW SOLUTIONS TO ROOFING PROBLEMS IN DEVELOPING-COUNTRIES .= BRABBF72PDS
  DEVELOPMENT OF A TROPICAL ROOFING MATERIAL .= CENTBL71DTR
  CONDOMINIUMS THEIR DEVELOPMENT AND MANAGEMENT .= GREZAP72CTM
  THE DEVELOPMENT OF CLAY BUILDING MATERIALS INDUSTRIES IN DEVELOPING-COUNTRIES .= INTESE68DCB
  MINISTRY-OF-WATER-AND-POWER IRAN JIROFT-DEVELOPMENT-PROJECT VOLUME-VIII - STAGE-I DEVELOPMENT A. BUILDING PLANS AND SPECIAL SPECIFICATIONS .= IRALEN72MWP

DISCOVERY
  HIS DISCOVERY OF A REVOLUTIONARY NEW-BUILDING-MATERIAL CAPABLE OF WITHSTANDING TREMENDOUS STRESS .= COX G 00DRB

DOCUMENTS-AND-
  CUMULATIVE-LIST OF UNITED-NATIONS DOCUMENTS-AND-PUBLICATIONS IN THE FIELD OF HOUSING-BUILDING-AND-PLANNING .= REPODO70CLU

DWELLING
  PLASTICS RESCUE VANDALIZED DWELLING .= WILLJG72PRV

EARTH
  HANDBOOK FOR BUILDING HOMES OF EARTH .= DEPTHO00HBH

EARTHQUAKES
  DESIGN SITING AND CONSTRUCTION OF LOCALLY PLANNED STRUCTURES BETTER RESISTANT TO EARTHQUAKES AND WIND STORMS .= REPSWF72DSC

ECONOMIC
AFRICAN-STATES MUST FORM UNITED-FRONT IN SOLVING ECONOMIC PROBLEMS .= ACHEIK73ASM

ECONOMIC-SCENT
ECONOMIC-SCENT GHANA-S INVESTMENT-POLICY .= AUTHUN73ESG

EDUCATION
APPLYING TECHNOLOGY TO A SOCIAL CONTEXT. EDUCATION HOUSING .= MORGRP72ATS

ELECTRIC-HEATING
HOW TO INSULATE HOMES FOR ELECTRIC-HEATING .= AUTHUN00HIH

EMERGENCY
EMERGENCY STRUCTURE .= PLASCO71EST

EMPHASIS
STRENGTHENING URBAN-ADMINISTRATION IN DEVELOPING-COUNTRIES WITH EMPHASIS ON LATIN-AMERICA .= DEPAHO71SUA

EMPLOYMENT
EMPLOYMENT GENERATION THROUGH STIMULATION OF SMALL-SCALE INDUSTRY .= HAMMRW00EGT

EPOXY
EPOXY WALL MATRIX. A NEW APPROACH TO SIDING .= REILWS72EWM

ESTIMATED
WORLD HOUSING-CONDITIONS AND ESTIMATED HOUSING-REQUIREMENTS .= DEPAEC65WHC

EUROPEAN
EUROPEAN HOUSING SUBSIDY SYSTEMS .= WELFIH72EHS

EVALUATING
EVALUATING PLASTICS AS A BUILDING-MATERIAL .= MACDWD72EPB

EXAMPLES
EXAMPLES OF SYSTEMS BUILDINGS LOW-COST HOUSING AND SCHOOLS BANGLA-DESH HOUSING IN HONDURAS HOUSING IN THE U-S-A .= ARCHENOOESB

EXISTING
PROPOSED MINIMUM STANDARDS FOR PERMANENT LOW-COST HOUSING AND FOR THE IMPROVEMENT OF EXISTING SUBSTANDARD-AREAS .= OFFIIN66PMS

FACTOR-PROPORTIONS
THE TRANSFER OF TECHNOLOGY AND THE FACTOR-PROPORTIONS PROBLEM. THE PHILIPPINES AND MEXICO .= MASORH00TTF

FACTS
FACTS ABOUT GHANA THE LAND .= AUTHUN00FGL
FACTS ABOUT GHANA .= INFOSF72FG

FERROCEMENT
FERROCEMENT. APPLICATIONS IN DEVELOPING-COUNTRIES .= REPOAD73FAD

FESTIVALS
GHANA TRADITIONAL FESTIVALS .= INFOSE73GTF

FIBRE
HARD FIBRE RESEARCH .= AUTHUN72HFR

FIELD
CUMULATIVE-LIST OF UNITED-NATIONS DOCUMENTS-AND-PUBLICATIONS IN THE FIELD OF HOUSING-BUILDING-AND-PLANNING .= REPODO70CLU

FOAM	STRUCTURAL FOAM BEARING WALLS CAN SHORE UP BUILDING-INDUSTRY .=	JONEHM72SFI
FUND-FOR-POPULATION-	WPY-BULLETIN OF THE UNITED-NATIONS FUND-FOR-POPULATION-ACTIVITIES .=	AUTHUN73WFU
GENERATION	EMPLOYMENT GENERATION THROUGH STIMULATION OF SMALL-SCALE INDUSTRY .=	HAMM[illegible]
GHANA	COME-AND-TALK BUSINESS WITH GHANA .=	AUTHUN00CTB
	FACTS ABOUT GHANA THE LAND .=	AUTHUN00FCL
	GHANA HARDWOODS .=	AUTHUN00GH
	HOUSING IN GHANA .=	AUTHUN00HG
	GHANA AND GHANA INTERNATIONAL-TRADE-FAIR .=	AUTHUN710GI
	2ND GHANA INTERNATIONAL-TRADE-FAIR .=	AUTHUN710IT
	THE NEW GHANA .=	
	THE NEW GHANA .=	AUTHUN73NGT
	VILLAGE MARKETS IN GHANA .=	HOUSPC63VMG
	ONE-COUNTRY-ONE-PEOPLE - GHANA .=	INFOSE00CCL
	HISTORY OF GHANA .=	INFOSE71HG
	FACTS ABOUT GHANA .=	INFOSE72FG
	GHANA TRADITIONAL FESTIVALS .=	INFOSE73GTF
GHANA-S	OUTLINE OF GHANA-S INVESTMENT-POLICY .=	AUTHUN00GIP
	ECONOMIC-SCENT GHANA-S INVESTMENT-POLICY .=	AUTHUN73ESG
GRASSES	GRASSES - THEIR USE IN BUILDING .=	DEPARO72GUB
HANDBOOK	HANDBOOK FOR BUILDING HOMES OF EARTH .=	DEPTHO00HBH
HARD	HARD FIBRE RESEARCH .=	AUTHUN72HFR
HARDWOODS	GHANA HARDWOODS .=	AUTHUN00GH
HIGH-PERFORMANCE-	,,COUPLING,, IN THE MONSANTO/WASHINGTON-UNIVERSITY-ASSOCIATION-ONR/ARPA-PROJECT ON HIGH-PERFORMANCE-COMPOSITES .=	AUTHUN00CMU
HISTORY	HISTORY OF GHANA .=	INFOSE71HG
HOMES	HOW TO INSULATE HOMES FOR ELECTRIC-HEATING .=	AUTHUN00HIH
	HANDBOOK FOR BUILDING HOMES OF EARTH .=	DEPTHO00HBH
HONDURAS	EXAMPLES OF SYSTEMS BUILDINGS LOW-COST HOUSING AND SCHOOLS BANGLA-DESH HOUSING IN HONDURAS HOUSING IN THE U-S-A .=	ARCHENOOESB
HOT-WEATHER	PHYSIOLOGICAL OBJECTIVES IN HOT-WEATHER HOUSING .=	HOUSHO63POW
HOUSING	EXAMPLES OF SYSTEMS BUILDINGS LOW-COST HOUSING AND SCHOOLS BANGLA-DESH HOUSING IN HONDURAS HOUSING IN THE U-S-A .=	ARCHENOOESI

HUD-S

PUBLICLY-PROVIDED-AND-ASSISTED HOUSING IN THE U-S-A REPORT ON HUD-S HOUSING MANAGEMENT POLICIES-AND-PROGRAMS .= MACEJ 72PPA

HUMAN-SETTLEMENTS

HUMAN-SETTLEMENTS .= CENTH072HS
HUMAN-SETTLEMENTS .= CENTH073HS

HURRICANES

DESIGN CRITERIA AND METHODOLOGY FOR CONSTRUCTION OF LOW-COST HOUSING TO RESIST TYPHOONS AND HURRICANES .= CENTBU73DCM

IGLOOS

IGLOOS IN MANAGUA .= REESKM73IM

IMPERIAL-CITIES

MOROCCO THE IMPERIAL-CITIES .= AUTHUN00MIC

IMPROVEMENT

PROPOSED MINIMUM STANDARDS FOR PERMANENT LOW-COST HOUSING AND FOR THE IMPROVEMENT OF EXISTING SUBSTANDARD-AREAS .= OFFIIN66PMS
AIDED SELF-HELP IN HOUSING IMPROVEMENT .= WEAVRC67ASH

IMPROVING

CENTO-SYMPOSIUM ON RURAL HOUSING IMPROVING THE MECHANICAL-PROPERTIES OF ADOBE-BLOCKS USED IN RURAL-BUILDINGS .= AUTHUN73CSR

INDIA

RURAL HOUSING AND VILLAGE PLANNING INDIA .= AUTHUN00RHV
CATALOGUE OF BUILDING RESEARCH IN INDIA VOL-IV .= GOVEIN00CBR
NBO-ABSTRACTS INDIA .= GOVEIN72NAI
RURAL HOUSING MANUAL INDIA .= MINIWU62RHM
REPORT ON STUDY OF METHODS USED FOR WATER-PROOFING OF ROOFS IN INDIA .= NATIBU62RSM

INDUSTRIALIZED

INDUSTRIALIZED HOUSING THE OPPORTUNITY AND THE PROBLEM IN DEVELOPING-AREAS .= AUTHUN72IHO

INDUSTRIES

ASSEMBLY INDUSTRIES IN THE CARIBBEAN .= AUTHUN73AIC
THE DEVELOPMENT OF CLAY BUILDING MATERIALS INDUSTRIES IN DEVELOPING-COUNTRIES .= INTESE66DCB

INDUSTRY

EMPLOYMENT GENERATION THROUGH STIMULATION OF SMALL-SCALE INDUSTRY .= HAMMRW00EGT
STRUCTURAL FOAM BEARING WALLS CAN SHORE UP BUILDING-INDUSTRY .= JONERM72SFB

INNOVATIVE

VICMAN-S INNOVATIVE ROOFING-SYSTEM .= AUTHUN00VIR

INSULATE

HOW TO INSULATE HOMES FOR ELECTRIC-HEATING .= AUTHUN00HIH

INTERAMERICAN-CONFERENCE

III INTERAMERICAN-CONFERENCE ON MATERIALS TECHNOLOGY .= AUTHUN72ICM

INTERIM-REPORT

INTERIM-REPORT ON TWO-COMPONENT JOINT-SEALERS .= HUTCCB72IRT

INTERNATIONAL-TRADE-FAIR
GHANA AND GHANA INTERNATIONAL-TRADE-FAIR .= AUTHUN71GGI
2ND GHANA INTERNATIONAL-TRADE-FAIR .= AUTHUN71GIT

INVESTMENT-POLICY
OUTLINE OF GHANA-S INVESTMENT-POLICY .= AUTHUN00GIP
ECONOMIC-SCENT GHANA-S INVESTMENT-POLICY .= AUTHUN73ESC

INVESTORS-MANUAL
CIB INVESTORS-MANUAL .= AUTHUN00CIM

IRAN
MINISTRY-OF-WATER-AND-POWER IRAN JIROFT-DEVELOPMENT-PROJECT VOLUME-VIII - STAGE-I DEVELOPMENT A. BUILDING PLANS AND SPECIAL SPECIFICATIONS .= IRABEN70MWP

ISRAEL
HUD-INTERNATIONAL COUNTRY-REPORT ISRAEL .= AUTHUN00HID

ITS
BUILDING MATERIALS FROM COCONUT-HUSK AND ITS BYPRODUCTS .= BUILMA00BMC

JIROFT-DEVELOPMENT-
MINISTRY-OF-WATER-AND-POWER IRAN JIROFT-DEVELOPMENT-PROJECT VOLUME-VIII - STAGE-I DEVELOPMENT A. BUILDING PLANS AND SPECIAL SPECIFICATIONS .= IRABEN70MWP

JOINT-SEALERS
INTERIM-REPORT ON TWO-COMPONENT JOINT-SEALERS .= HUTCCB72IRT

JUTE-CLOTH
PLASTICS REINFORCEMENT WITH JUTE-CLOTH .= PHILAR65PRJ

LAND
FACTS ABOUT GHANA THE LAND .= AUTHUN00FGL

LATIN-AMERICA
STRENGTHENING URBAN-ADMINISTRATION IN DEVELOPING-COUNTRIES WITH EMPHASIS ON LATIN-AMERICA .= DEPAHU71SUA
TECHNOLOGY-TRANSFER AND LATIN-AMERICA .= MORGRP00TTL

LOCALLY
DESIGN SITING AND CONSTRUCTION OF LOCALLY PLANNED STRUCTURES BETTER RESISTANT TO EARTHQUAKES AND WIND STORMS .= REPSWF72DSC

LOW-COST
EXAMPLES OF SYSTEMS BUILDINGS LOW-COST HOUSING AND SCHOOLS BANGLA-DESH HOUSING IN HONDURAS HOUSING IN THE U-S-A .= ARCHEN00ESB

DESIGN CRITERIA AND METHODOLOGY FOR CONSTRUCTION OF LOW-COST HOUSING TO RESIST TYPHOONS AND HURRICANES .= CENTEU73DCM

PREFABRICATED CONCRETE COMPONENTS FOR LOW-COST HOUSING CONSTRUCTION .= DEPAHO63PCC
PROPOSED MINIMUM STANDARDS FOR PERMANENT LOW-COST HOUSING AND FOR THE IMPROVEMENT OF EXISTING SUBSTANDARD-AREAS .= OFFIIN66PMS

MANAGEMENT
CONDOMINIUMS THEIR DEVELOPMENT AND MANAGEMENT .= GREZAD72CDM

PUBLICLY-PROVIDED-AND-ASSISTED HOUSING IN THE U-S-A REPORT ON HUD-S HOUSING MANAGEMENT POLICIES-AND-PROGRAMS .= MACEJ 72PPA

MANAGUA

IGLOOS IN MANAGUA .= REESKM73IM

MANAGUA,

,,COLONIA MANAGUA,, AN AIDED SELF-HELP HOUSING PROJECT IN NICARAGUA .= DEPAHO62CMA

MANUAL

RURAL HOUSING MANUAL INDIA .= MINIHO62RHM

MANUFACTURE

PLANT REQUIREMENTS FOR MANUFACTURE OF WALLBOARD .= DEPAHO67PRM

THE MANUFACTURE OF ASPHALT-EMULSION-STABILIZED SOIL BRICKS AND BRICK-MAKER-S-MANUAL .= INTLIN72MAS

MARKETS

VILLAGE MARKETS IN GHANA .= HOUSHO63VMG

MARVELOUS

THE MARVELOUS REED .= MONSMA73MRT

MATERIAL

DEVELOPMENT OF A TROPICAL ROOFING MATERIAL .= CENTDE71DTR

MATERIAL ON HOUSING PUT OUT BY THE NATIONAL-BUILDINGS-ORGANISATION NEW-DELHI GUHAS 73MHP

BAMBOO AS A BUILDING MATERIAL .= MCCLFA53BBM

MATERIALS

III INTERAMERICAN-CONFERENCE ON MATERIALS TECHNOLOGY .= AUTHUN72ICM

BUILDING MATERIALS FROM COCONUT-HUSK AND ITS BYPRODUCTS .= BUILMA00BMC

THE DEVELOPMENT OF CLAY BUILDING MATERIALS INDUSTRIES IN DEVELOPING-COUNTRIES .= INTESE66DCB

MATRIX

EPOXY WALL MATRIX. A NEW APPROACH TO SIDING .= REILWS72EWM

MECHANICAL-

CENTO-SYMPOSIUM ON RURAL HOUSING IMPROVING THE MECHANICAL-PROPERTIES OF ADOBE-BLOCKS USED IN RURAL-BUILDINGS .= AUTHUN73CSR

METHODOLOGY

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MACEJ 72PPA MACEY JOHN HOUSING CONSULTANT
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ARMAND G WINFIELD INC.

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APPENDIX G

WORK PLAN PHASE II

APPENDIX G

WORK PLAN FOR PHASE II

Phase II is the second year of the roofing development program (May 1974-May 1975). The following ten taks will be performed:

(1) Socio-Economic Survey of Roofs

(2) Manpower Resource Survey

(3) Roof Design and Construction Definition

(4) Material Resource Definition

(5) Site Selection

(6) Selection of Collaborators

(7) Material and Process Development

(8) Literature Survey and Analysis

(9) Prototype Roof Section Fabrication, and

(10) Environmental Exposure Testing

The schedule for completing these tanks during Phase II, and Phase III is shown graphically in Figure 50. As shown in this figure, several of the tasks (e.g. socio-economic survey) will be performed sequentially in the three selected countries (Jamaica, Zambia, Philippines). Two tasks (Material and Process Development and Exposure Tests and Analysis of Composites) will be performed continuously at the Dayton Laboratory throughout Phases II and III. The roofing literature survey will also continue throughout the program. Methodology for the in-depth socio-economic studies of Jamaica, Zambia, and the Philippines is discussed in Section 2 below. The methodology for the composite materials and process development, prototype roof section fabrication, environmental exposure, and literature survey and analysis is discussed below in Section 1.

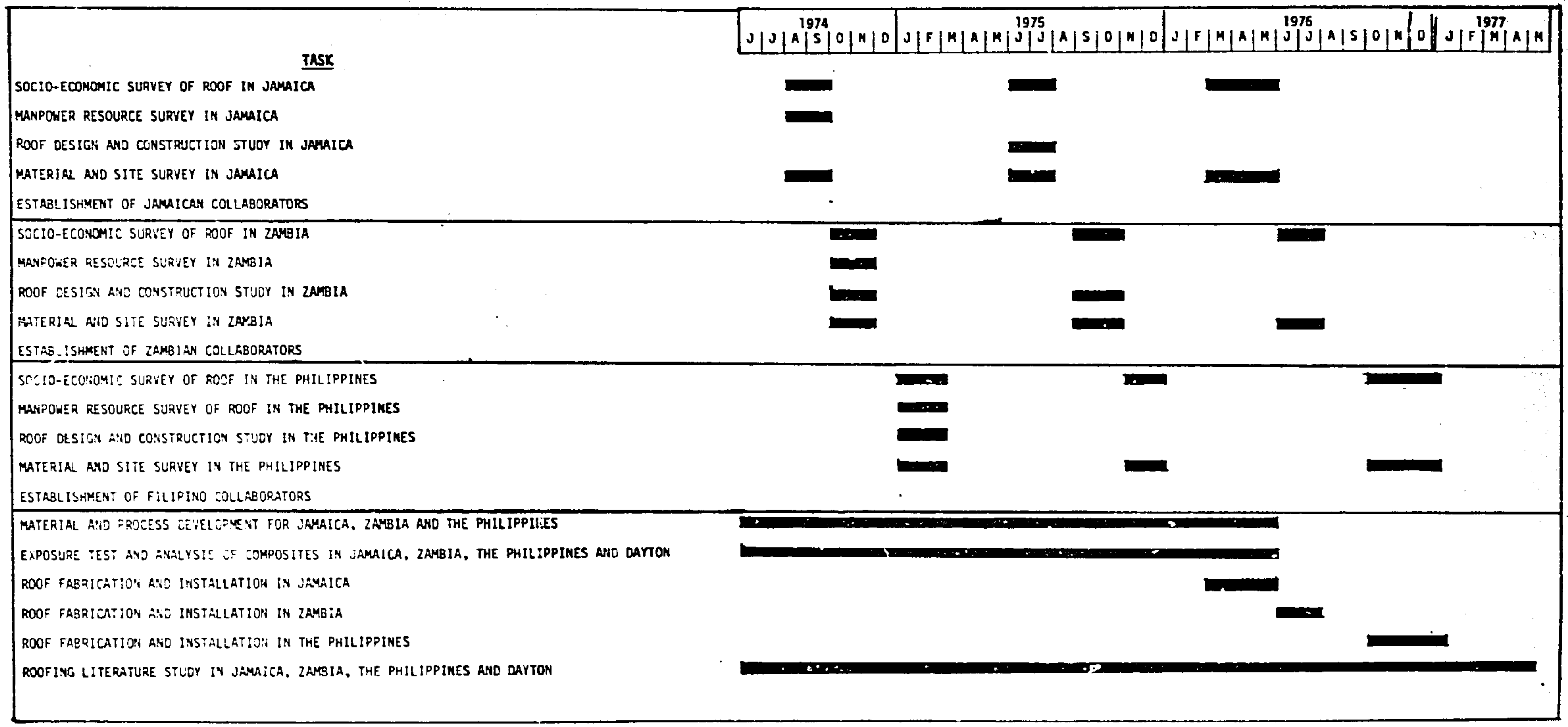

Figure 50. Program Schedule for Additional Three Phases Indicating Tasks, Their Timing and the Scheduling for the Efforts in the Three Selected Countries

1. TECHNICAL APPROACH AND RATIONALE IN ROOFING DEVELOPMENT

The research is to be directed toward use in low-cost housing, and is aimed primarily at village-level industry and self-help projects, but does not exclude surburban and urban applications.

As stated earlier in this report (summary), the objective in the roofing research is to match indigenous fibers and fillers with low-cost binders to produce roofing with a wide range of applicability in developing countries. However, as predicted, in the original study conducted by the National Academy of Sciences and Engineering, low-cost indigenous binder resins are not readily available in the developing countries and may have to be imported.

The basic considerations in the development of a roofing systems are outlined in Figure 51,which shows that materials, architectural design, construction and detailing, sociological factors and economics must all be considered. Insofar as the roofing material itself is concerned, we believe that the optimum cost/performance, strength/weight, etc. will be achieved in a composite material consisting of a minor amount of binder resin, combined with a major quantity of reinforcing fibers or fillers as illustrated graphically in Figure 52. Other additives such as thermal stabilizers, anti-oxidants, UV screeners vulcanizing or crosslinking compounds, and waterproofers may be added in order to obtain better thermal resistance, outdoor durability, etc.

Composite technology has been highly developed in the United States, especially in the aerospace industry, as a means of obtaining the highest level of performance at the lowest weight and cost. The general principles of this space age technology can also be applied to the development of strong,

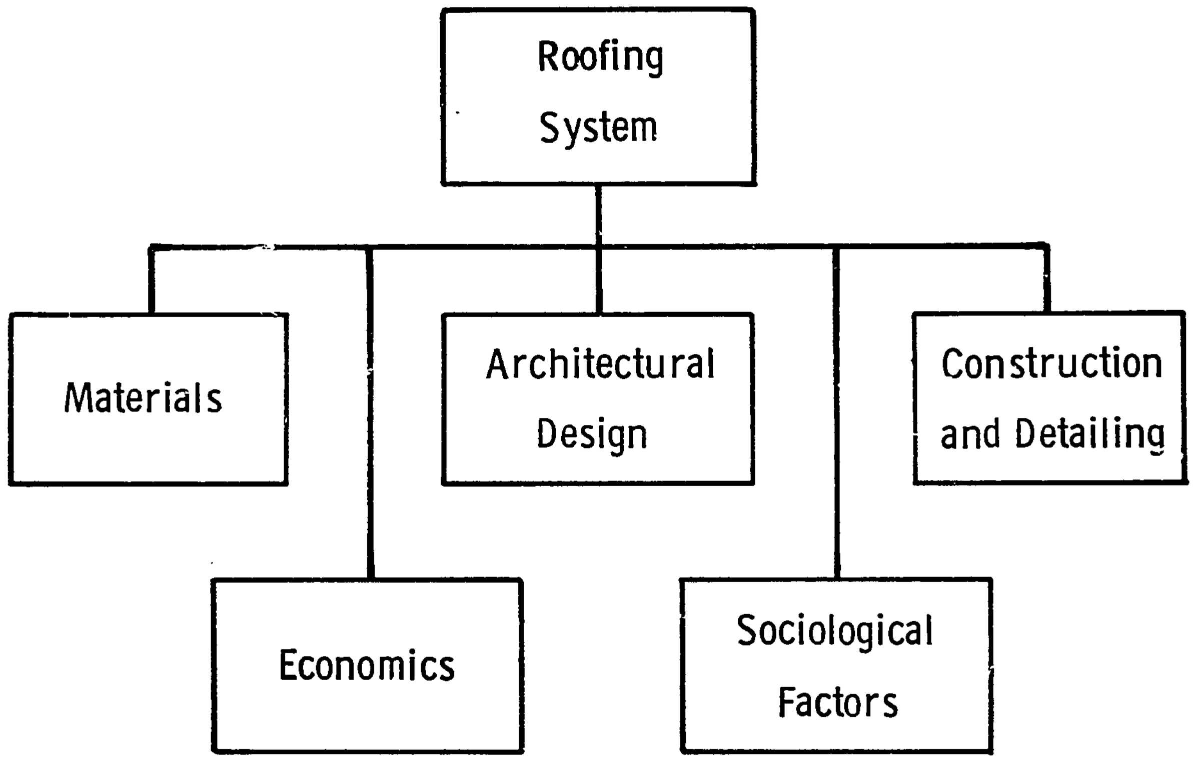

Figure 51. Factors Involved in the Development of a Viable Roofing System

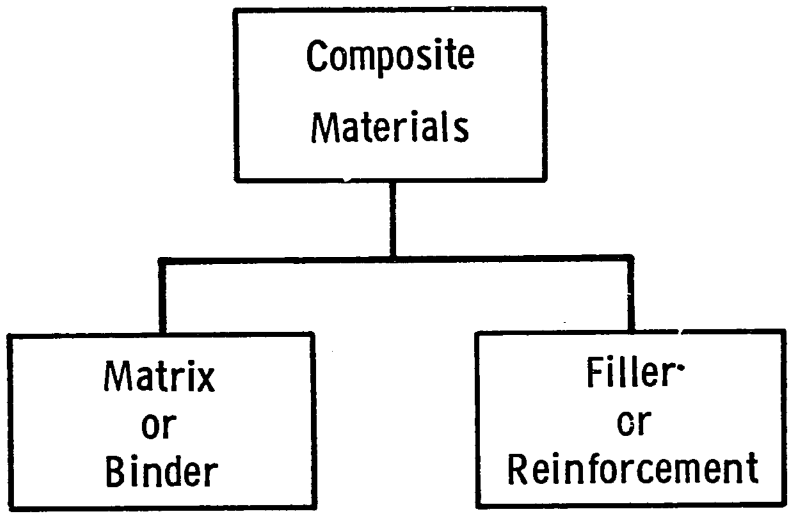

Figure 52. The Makeup of a Composite Material Which is the Basis for A Roofing System Material

light weight, low-cost composites for roofing in developing countries. Low-cost available indigenous fiber materials wuch as those obtainable from bagasse, hemp, jute, and wood are especially desirable fillers since they are substantially lower in cost than the resin binders, and additionally contribute high strength tc he composite. However, other types of indigenous fillers including sand, water and air (foams) may also be used advantageously. Composites of foam cores, combined with a high strength weather-resistant skin (e.g. jute cloth) are strong and light weight, and have excellent sound and thermal insulation characteristics.

A list of low-cost fillers, potentially indigenous to the countries of interest, is shown in Figure 53.

The proposed composite roofing material requires a low-cost binder resin (or matrix). As shown in Figure 54, binder resins may be chosen from any one of five thermosetting plastics. Low-cost polyesters, phenol/formaldehyde resin and urea/formaldehyde resins are the prime thermosetting candidate binders. Synthetic thermoplastic reins for consideration include polystyrene, polyethylene and polyvinyl chloride. Indigenous resins such as natural rubber, asphalt, rosins and gilsonite soft coal also need to be considered. Finally, inorganic binders such as Portland cement, polymer cements, water glass, sulfur, and clays bonded in various ways will be tested in the program.

Emphasis will naturally be on combinations of both indigenous resin binders and indigenous fillers. For example, in the Philippines, natural rubber is available, as are some asphalts and tars from petroleum refining. Polystyrene (for bead foam) and polyvinyl chloride are both manufactured on some scale.

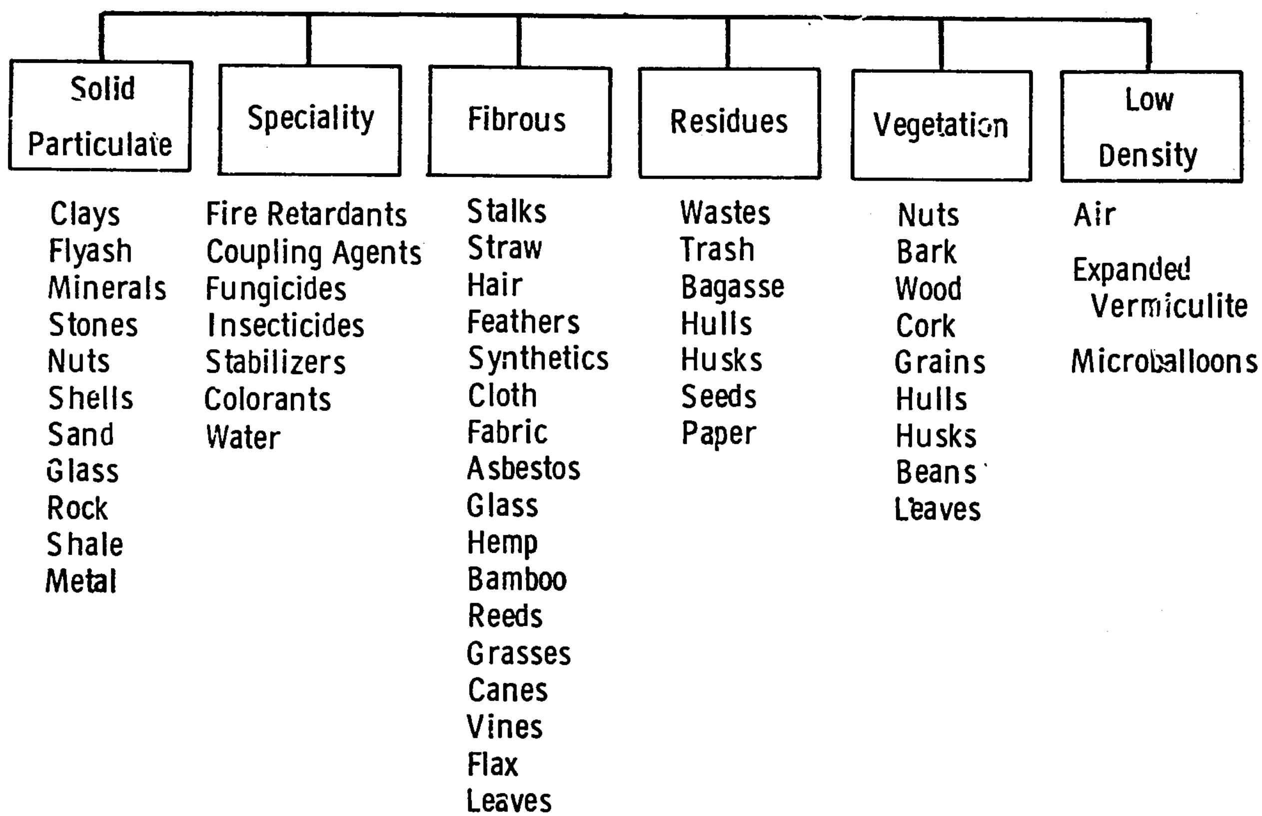

Figure 53. Types and Identification of Fillers and Reinforcements Having Potential Value in Composite Roofing

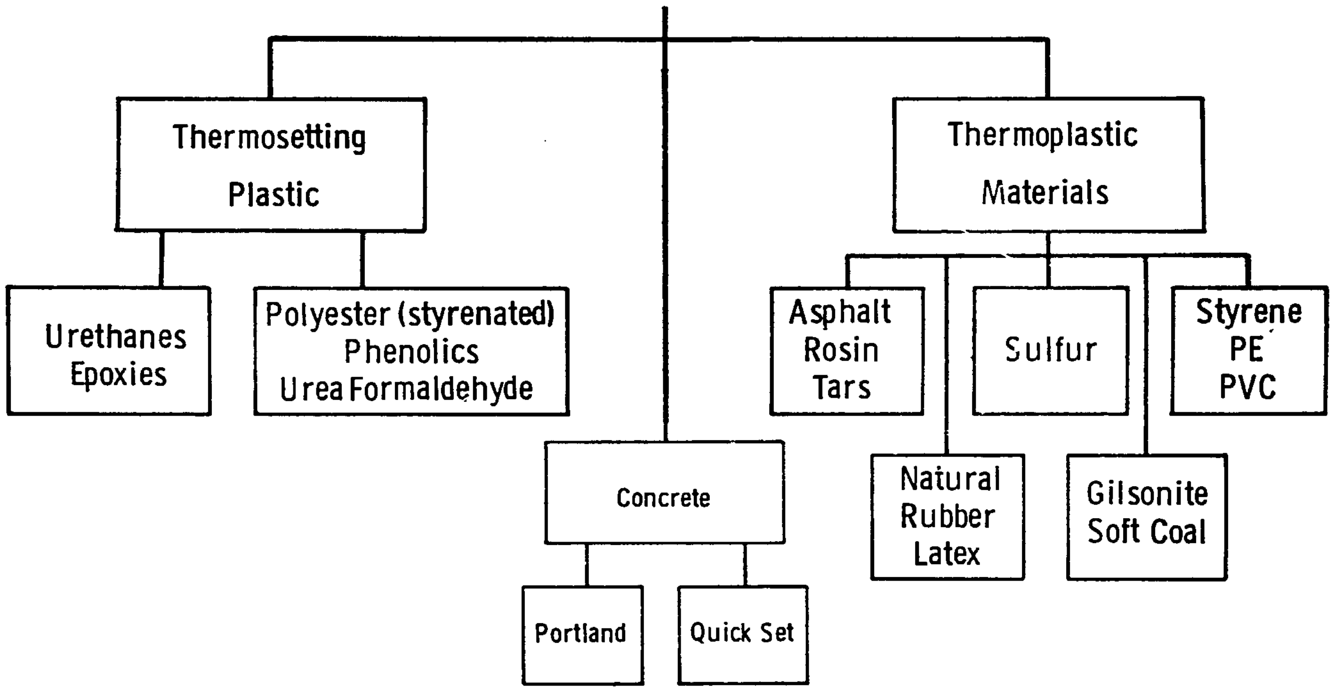

Figure 54. Types and Identification of Matrix or Binder Materials to be Examined in Composite Roofing Research

Polyesters and urea/formaldehyde resins are also produced in experimental quantities. Likewise in Zambia and Jamaica, some indigenous or locally produced resin binders may be available.

However, if imported resin binder has to be used this will not be an insurmountable handicap. The indigenous fillers are expected to compose upwards of 85% of the volume of the roofing system and the resin binder required to be 15% or less. Thus, both total and foreign exchange costs of the new roofing should compare favorably with CGI, aluminum and cement/asbestos roofing.

Combinations of indigenous fillers with suitable resin binders will be prepared as described in Appendix E and tested to determine strength, durability, water-resistance, etc. The trade-offs in cost versus performance for the several systems will be determined. The candidate roofing materials will be compared in both properties and cost (including foreign exchange costs) with the competitive roofing systems such as corrugated galvanized iron, aluminum and cement-asbestos.

A graphical representation of the schedule of events for low-cost binder evaluation and composites for roofing is contained in Figure 55. As is indicated here, we plan to complete the testing of the candidate binder systems (plus any others that may materialize in the interim) during the second phase of the contract which ends in May 1975. By that time, we expect to have one preferred roofing composition, plus at least one alternate for each of the three countries in Jamaica, Zambia, and the Philippines. Some of the roofing composite systems (e.g. bagasse) may be evaluated in more than one of the three countries. Owing to the large difference in available raw materials it is not likely that all the candidates tested in the three countries will be identical.

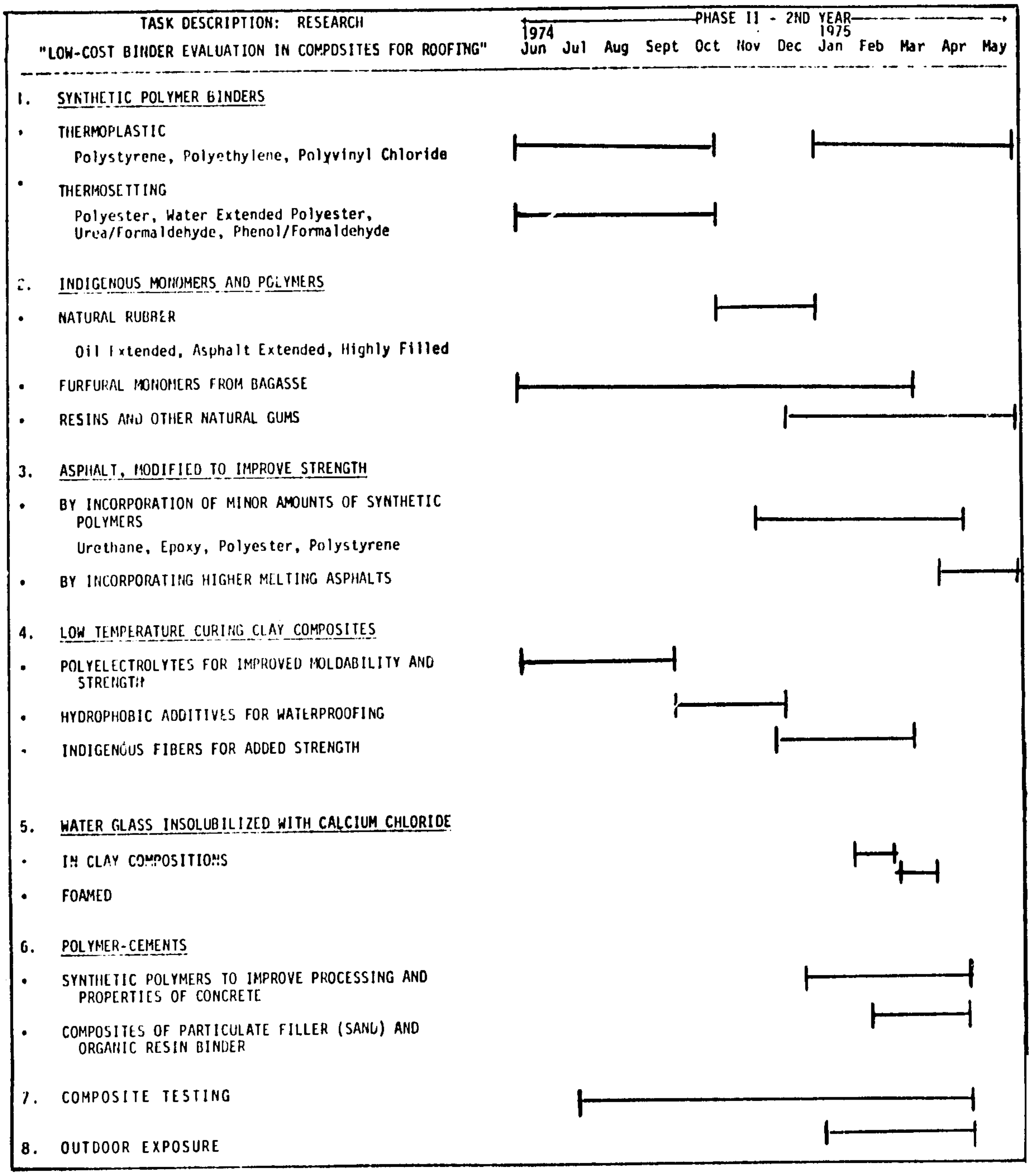

Figure 55. Composite Materials Development Anticipated Schedule of Events

The tests performed on samples of roofing materials obtained in the country survey and the data obtained are contained in Appendix E, Section 3. The preparation of new composite materials from combinations of indigenous fillers and fibers with binder resins; and the strength and other properties measured on these composites is also contained in Appendix E, Section 4.

2. OBJECTIVES AND METHODS FOR PHASE II ARCHITECTURAL, BUILDING AND SOCIO-ECONOMIC STUDIES

2.1 BACKGROUND

Available statistics and information will be reviewed and reported to provide the project with a broad frame of reference for technical development, with specific attention given to the listed areas below. Data collected to date will be reviewed, and additional necessary information will be identified by means of further literature searches and interviews with government and industrial sources within eacn country.

- Housing

a) Housing conditions and needs: urban and rural areas.

b) Government housing policy, present and planned.

c) Institutional framework for the implementation of housing policy.

d) Institutional framework for the financing of housing.

e) Employment and income distribution.

f) The housing industry: public and private construction

- Architectural and Building

a) Geo-climatic conditions and influence on design.

b) Cultural influences on design

c) Traditional and contemporary materials use and building methods.

d) Roofing costs as a factor of housing costs.

e) Building codes, standards and regulations.

2.2 CRITERIA FOR AND SELECTION OF SITES FOR DEMONSTRATION

Criteria will be established for the selection of sites for the demonstration of the roofing materials and methods developed. Factors to be considered in establishing criteria are listed below. Actual criterial will be developed following review of these factors with those responsible for housing policy and its implementation in each of the countries.

- The rural/urban housing need; government policy related to meeting these needs, including rural development policy; redundant labor in rural and urban areas; the potential impact of local industrial development at rural and urban scales.

- The socio-economic characteristics of low-income housing user groups, including income ranges, housing expenditures, employment and skills available for the production and construction of roofing.

- The physical character of alternative available sites, i.e. density, heterogeneity vs. uniformity, as these formal characteristics place demands on the usage and adaptability of new materials.

- The viability of alternative sites in terms of the liklihood of their retention for housing use.

- The availability of socio-economic and other data such as housing usage and preferences, and the likelihood of future monitoring of such data on the residents.

- The particular geo-climatic characteristics of alternative sites, such as rainfall, wind, industrial pollution and other factors which might afford opportunities for observation, testing, and evaluation of developed materials.

- The relative visibility of alternative sites (physical location, sponsorship, political representation of residents) related to potential project value for demonstration and evaluation of the response of local and external observers.

Visits to countries during Phase II will be utilized to identify alternative demonstration site possibilities. Consultation and advice on the establishment of site selection criteria will be sought from local housing authorities and from those local institutions and individuals familiar with social and economic characteristics of potential users. The availability of data bearing on criterial will be determined by reviewing existing housing survey material. Consideration will be given to progress in the technical development of alternative material systems for roofing, as this affects the relationship of raw materials need and manufacturing process to site location. Specific sites will be selected based on the refined list of criteria.

Following selection, the social and economic characteristics of potential occupants of housing to be erected and roofed with the developed material will be determined by use of available survey data, augmented as necessary by sample surveys and interviews. Particular attention will be given to housing expenditure related to income, employment, building skills, and individual or culturally determined preferences for or prejudices against specific uses, forms and materials of roofing. These data will be reported, with recommendations on the requirements for roofing materials.

2.3 DESIGN AND CONSTRUCTIONAL DETAILING

Preliminary roofing designs will follow the development of alternative materials, based on physical and mechanical characteristics of the materials. Roofing systems will be developed based on optimization of materials use, and taking into account the needs of users in the selected sites, with final designs established for housing appropriate to these needs and site conditions.

3. INFORMATION GATHERING MODES

The collection of valid information is most critical for meeting the goals of the overall program, and for the continued success of the roofing system once the program is over in the three developing countries. Invalid information, in terms of availability of particular resources or consumer desires, could be disastrous to an otherwide quite successful development. Accordingly, a significant portion of Phase II will involve obtaining data, then checking it and double-checking it with as authoritative a source as possible.

The information will be gathered through a number of forms which include:

- Structured meetings,
- Non-structured meetings,
- Literature,
- Tours of low-cost housing areas,
- Meeting Professionals in the private sector at the site of their work
- Conducting conferences and seminars

Structured Meetings

Structured meetings include seminars, talks, work sessions, public business meetings, etc. An effort will be made to determine the existence of such meetings and to provide for attendance by at least one member of the project team. Such meetings would be those like the conference on low-cost housing held in Montreal in May 1974, talks by public officials at luncheon or dinner meetings, and seminars sponsored by the construction industry.

Non-Structured Meetings

These include private discussions with individuals set up by appointment or on the spur of the moment. This will include known experts in the field or individuals who will be able to designate the source of the best information. Where appointments can be made they will be obtained by letter or telephone, through some local government official or USAID representative. The unreliable nature of the telephone system in Zambia makes arranging appointments by telephone rather difficult and, therefore, a request by letter may be much more appropriate. This will also be true, to a limited extent, in Jamaica and the Philippines.

Literature

This source provides the most reliable and accurate information, since printed material tends to be more factual. Obtaining the most reliable literature is not always easy, however. This will be done mainly through search of libraries, and also through recommendations of individuals and surveys of some personal files. While factual, the information in the literature tends to be less timely, especially in some of the faster moving developing countries. Accordingly, the information obtained will be correlated with oral information, and attempts will be made to upgrade it through personal contacts.

Tours and Personal Visits

Actual visits and tours of low-cost housing areas, sources of resource information, institutions, etc., will be made by the survey team to provide an overall perspective on the information from these sources and some qualification of comments such as, "We have an excellent test facility" and "There is ten times more material here than some place else" etc. It will also be most important to determine various individuals' ideas of just what a "low-cost" house means. The figures quoted have varied from $300 to $10,000 per house. We have found a more generally acceptable definition to be $1.50 per sq ft, at June 1974 prices.

Meetings with Professionals

Meetings with professionals have been listed separately to indicate meetings with people at the working level, who finally have to put the roofing system into application. These include qualified individuals at the demonstration sites, experts in construction materials, experienced materials handling personnel, etc. The input from these individuals will assist greatly in guiding the research and development work, and in greasing the path for acceptance of the system, once it is available.

4. LIAISON AND TECHNICAL INTERFACING

Establishing liaison and technical interfacing will be a natural broadening of the selection of collaborating institutions and individuals. The techniques of interfacing and specific individuals to be involved, must be detailed. We feel that it is extremely important that our team interface with people, not titles, institutions or government agencies on an official basis. This may be difficult to achieve at times, and will require some unofficial contacts, but it will be the best way to provide the desired communications.

Typically, in Jamaica, the interaction of the Monsanto Research Corporation (MRC) team with the anticipated collaborators will include the Scientific Research Council (SRC), the Jamaican Bureau of Standards (JBS), Urban Development Corporation (UDC), Ministry of Housing (MH), Douet, Brown, Adams and Associates (DBA), and the Knox Development Foundation (KDF). The MRC team also consists of individuals from Washington University who will interact directly with the individuals and institutions, but as part of the MRC team.

We will attempt to designate one individual at each of the institutions as the primary contact for the development team, at least initially. As the program requirements become more detailed, more appropriate individuals may be specified and contacts changed or broadened.

Initial contact with the Permanent Secretary of the Ministry of Local Government and Housing in Zambia has resulted in the designation of the Secretary-General, National Council for Scientific Research, as the primary contact in Zambia. The actual working group under the National Council for Scientific Research (NCSR) will involve the Engineering and Construction Committee and its Chairman, Mr. Simon Zukas. The committee will include members from the National Housing Authority, The Ministry of Local Government and Housing, University of Zambia, and other highly appropriate individuals.