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FIBRE REINFORCED CONCRETE ROOFING SHEETS
Technology Appraisal Report

May 1985

AT INTERNATIONAL

Save the Children

[redacted]

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By

Carlos R. Lola

A.T. International

Save the Children Federation

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A.T. International is a private, non-profit corporation, created in 1977 in response to a mandate from the U.S. Congress to "promote the development and dissemination of technologies appropriate for developing countries."

Save the Children Federation, founded in 1932, is a private, voluntary, nonsectarian, non-profit agency devoted to community development and is largely dependent on direct contributions.

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A B S T R A C T

Fibre reinforced concrete (FRC) roofing sheets have been in use in several developing countries since the late 1970's. Appropriate Technology International (ATI) and Save the Children Federation (SCF) have actively promoted the use of FRC roofing sheets as a low cost roofing alternative based on a product design and community-based production techniques developed and tested by Intermediate Technology Building Materials Workshop (ITBMW), United Kingdom.

This paper presents the findings, conclusions and recommendations from a recently completed appraisal of FRC roofing sheet technology as applied in production/dissemination and adaptive research projects separately financed by ATI and SCF. The appraisal was informed by three related activities: performance data collected in independent technical reviews of SCF Alliance field projects in Guatemala, the Dominican Republic and Sri Lanka; findings of ATI supported adaptive research projects carried out by Servivienda (Colombia) and CII-Viviendas, Dominican Republic; and a jointly sponsored ATI/SCF technical meeting on FRC roofing sheets held in the Dominican Republic in November 1984.

The principal finding of the appraisal is that FRC roofing sheets manufactured in community-based production units using the ITBMW process demonstrated a limited service life of two to four years. In 25,000 FRC sheets produced and installed in different construction sites, a high incidence of visible cracking occurred ranging from a minimum of 19 percent to a maximum of 50 percent of the total sheets produced. In Bogota at Servivienda, experimental roofs in controlled outdoor conditions showed 50 to 80% cracking within one year. Although our study was unable to draw a direct correlation between the problem of cracking and its cause(s), we did examine in depth a range of possible factors including product design, production process and control, producer skill and technical support services.

Based on these findings, ATI and SCF have concluded that FRC roofing sheets, while a possible product option, are not suitable as currently applied for rural housing and facility construction. It is recommended that research work be undertaken to determine the durability of FRC roofing sheets, appropriate production methods and product quality standards before further dissemination of this product in tropical settings. Other organizations engaged in FRC roofing sheet projects should be encouraged to appraise their performance.

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1. EXECUTIVE SUMMARY:

The development of durable, low-cost roofing materials is a major technological challenge in developing countries. The vast majority of the rural poor use traditional, locally available roofing materials, such as straw, palm leaves, and grasses. The life span of "vegetable roofs" is short and roofs made of these materials have to be replaced every few years. These roofs are also subject to fire and infestation. Clay tiles, although a lower cost material, requires more expensive roofing structures and are energy intensive in their production. The available alternatives, galvanized iron and asbestos cement sheets, though more durable, are simply too costly for the poor rural consumer. For example, the cost of a galvanized iron roof for a Nepali house of 40 sq. meters is approximately 80% of annual per capita income. There is an import component with both products requiring the use of foreign exchange. Because of the problems of both properties and price associated with traditional and modern roofing materials, it is clear that there is a need for durable, low cost roofing materials that can be economically produced locally in developing countries.

In recognition of this need ATI and SCF have financed adaptive research and field application projects in which fibre reinforced concrete (FRC) roofing material was used as an alternative. Over the past five years both organizations have supported projects in the Dominican Republic, Colombia, Guatemala, Sri Lanka and Kenya. ATI has financed two adaptive research projects in Latin America: one in Colombia from 1982 - 84 with Servivienda, a non-profit organization engaged in the design and construction of low cost housing units, and in the Dominican Republic from 1983-84 with CII-Viviendas-Cetavip, a non-profit institution coordinating low-cost housing programs and community development. ATI has also financed seminars to disseminate the FRC roofing sheet technology in Kenya and the Dominican Republic.

Since 1979, Save the Children Federation through their Sri Lanka country program, has installed almost 15,000 sheets (3). In the Dominican Republic, the Foundation for Community Development (FUDECO) has installed approximately 6000 sheets since 1979. In Guatemala the Alliance for Community Youth Development (Alianza para Desarrollo Juvenil Comunitario) has installed approximately 1500 sheets since 1980 (5).

A preliminary appraisal of several existing FRC roofing sheets projects was undertaken in the rural areas of the Dominican Republic in late November 1983. A high incidence of cracking and considerable performance deficiences were observed and reported by the occupants of houses with FRC roofs (6). Almost simultaneously, Servivienda in Colombia documented a high incidence of cracking in experimental FRC roofs built outdoors in Bogota.

Because FRC technology demonstrated alarming levels of cracking both in the field (Dominican Republic) and the laboratory (Colombia), ATI and SCF decided in early 1984 jointly to undertake a comprehensive technical appraisal of FRC roofing sheets.

The appraisal methodology was divided into three related but distinct activities; first, the Servivienda adaptive research program was redefined to concentrate on product design and improved production techniques. The use of corrugated cross sections was discontinued and flat sheets with border re-inforcement in two different sizes were introduced. A modified production procedure using metal molds and a vibrating table was tried. Second, three independent technical reviews were commissioned to appraise the field application projects in Guatemala, the Dominican Republic, and Sri Lanka using terms of reference developed by ATI and SCF (see Appendix 1). Third, a technical discussion panel comprised of project engineers and managers from the ATI/SCF projects met in the Dominican Republic in November 1984 to review the findings of the independent technical appraisals and the adaptive research work.

The technology appraisal undertaken by ATI and SCF was based on the assumption that the high incidence of cracking was a function of product design and community level production techniques. Therefore, the purpose of the appraisal was to analyze and isolate those product design and production factors that correlate with cracking and to identify corrective measures to improve FRC roofing sheets design, production, and management. Finally, the cost of the technology would be assessed to determine if it remained a low cost, reliable roofing alternative.

The principal finding of the technology appraisal is that in the projects surveyed, the FRC roofing technology has demonstrated a limited useful life between two and four years under actual weather conditions. This finding is based on the evidence of the high percentage of visible cracks through the sheets observed in the technical reviews and reported in the research findings. Table 1 shows the level of cracking in different construction sites. It was found that the level of cracking ranged from a minimum of 19% of the sample in some construction sites up to 50% in other construction sites.

TABLE 1.
Incidence of Cracking in Field Projects

Country	Total Sheets Manufactured	Sample Size Observed	Sample as % Total	Percent of Sample Cracked
Guatemala	1472	589	40	20
Sri Lanka	17850	14000	78	20-50%
Dominican Rep.	5995	3403	57	19-47%

In experimental roofs under controlled outdoor conditions at Servivienda in Bogota, the level of cracking is 50-80% within one year (see Table 13 on page 19.) All efforts in trying to seal the cracks with different materials (eg, cement, animal fat), proved unsuccessful.

The appraisal identified and analyzed a number of factors that caused cracking. While it was not possible to rank the relative importance of each factor, most of these factors relate to the variability observed in product quality and production controls:

1. Difficulties were observed in achieving the recommended ITBMW water/cement mixture using manual mixing techniques. The finding is supported by the variability in mix proportioning reported in all three reviews.

2. Difficulties were observed in following the recommended use of curing facilities, procedure and times. Field data indicated that many of the producers used inadequate procedures due to lack of water and funds to build curing pools. Lack of adequate supervision was identified as the main factor responsible for the high degree of variability in curing practices.

3. It was found that the wooden table recommended for use in casting loses its rigidity as a result of continuous use. Unless reinforced, proper casting does not occur and sheet quality is negatively affected.

4. While variability in product quality and production controls can be expected to occur from project to project, it was found in the three technical reviews that increased levels of training and technical assistance in production did not correlate with significant decreases in the occurrence of cracking. A comparison of both field and research data showed that regardless of the levels of training and technical assistance the minimum level of cracking was 20 - 25% within four years.

5. While secondary to the findings mentioned above, it was found that poorly designed roof structures, the use of unseasoned timber elements and the use of rigid roof bolt fixings contribute to the problem of cracking.

6. In the adaptive research work completed by Servivienda (described in detail later in this report), it was found that the combination of improved production techniques (ie. steel molds and a vibrating table) and product shape did not significantly reduce cracking. The incidence of cracking in the experimental roofs after employing improved production techniques, was reported to be between 45-50%.

The findings from the independent technical reviews and the adaptive research were presented and discussed at the ATI/SCF-sponsored technical meeting held in the Dominican Republic in

November 1984. A list of the individuals attending the conference is found in Appendix 2. The most important conclusions and recommendations formulated at the meeting follow:

1. To date, FRC sheets produced at the community level in several countries have demonstrated a limited useful life of two to four years.

2. The technology package used for the manufacture of FRC sheets demands a greater level of producer skill, production management and quality control than can be reasonably expected at the community/village level.

3. The limited service life of the sheets produced at community level entails a replacement cost sometime within four years. Although the initial investment required to produce FRC sheets is significantly smaller than other options (ie., clay, galvanized iron and asbestos cement), the added costs to replace a roof within a short period of time make FRC sheets more expensive than alternatives. (See Table 12 on comparative cost).

Based on these conclusions it was recommended at the meeting that:

1. The production of FRC sheets at the community level be discontinued until the production process has been standardized and can be judged suitable given the constraints that generally face village level productive enterprises.

2. Further research should be conducted: (1) to study the effect of alkalinity of cement in tropical environments, (2) to develop geometrical shapes for sheets that minimize the risk of damage during production and installation, and (3) to develop standards for roof construction and installation.

Coincidentally to and independently of the ATI and SCF technology appraisal, the Swedish Agency for Research Cooperation with Developing Countries (SAREC) published in 1984 the findings of a three year study (1979-82) directed by Dr. Hans-Erik Gram, a scientist at the Swedish Cement and Concrete Research Institute (CBI) on the durability of natural fibre concrete.

The study was conducted in cooperation with the following bodies: Engineering Department of the University of Dar es Salaam, Tanzania; Departments of Construction Engineering, Polymer Technology and Cellulose Technology of the Royal Institute in Stockholm; the Swedish Laboratory for Research on Forest Products; Oy Partek AB in Pargas, Finland; and AKE Skarendahl Konsultbyra AB, Stockholm.

The study concluded that thin roofing sheets of sisal fibre concrete stored outdoors in a tropical climate become markedly embrittled within a period of six months. The reason for this is that the alkaline pore water in the concrete dissolved components in the fibres so that they became decomposed and lost their reinforcing capacity. While Dr. Gram's study draws a correlation between the durability of sisal fibre concrete and the decaying of the fibres it has also been asserted that the principal role of the fibre is not its reinforcing capacity but rather to mitigate the formation of miscroscopic cracks in the concrete when it sets.

ATI and SCF do not intend with this paper to postulate a scientifically based theory on the role and effects of natural fibres in a concrete matrix. However, the extensive cracking documented over a significant sample size by the ATI/SCF technology appraisal provides sufficient practical evidence that there are flaws in this product. Thus, ATI/SCF conclude that we should discontinue financing or other promotion of fibre reinforced roofing sheets in community-based production units until product defects can be eliminated.

The identification of reliable, low cost roofing materials that can be economically produced locally in developing countries remains a priority of ATI and SCF. The technology of fibre reinforced concrete roofing sheets should be considered a possible option but in our view the emphasis now should back away from dissemination and return to research, product development and further testing in tropical settings. The various possible causes of cracking -- the properties of the materials, product design, production process and control, skills of producers and environmental factors -- need to be carefully studied. Testing standards and programs should be established for FRC technology that combine accelerated testing techniques in the laboratory and field testing. Organizations engaged in FRC roofing sheet projects should be encouraged to appraise the performance of the roofing sheets. We have learned that the Swiss Center for Appropriate Technology (SKAT) will carry out an independent technical review of FRC projects it has supported.

2. DESCRIPTION OF NATURAL fibre CONCRETE TECHNOLOGY

2.1 Materials:

The matrix generally consists of ordinary portland cement, water and a suitable grading sand. This matrix generally called 'mortar' is here referred to as 'concrete'. The combination of a low water/cement ratio and a clean and fine-graded sand produces a high quality matrix. Sisal and other natural fibres are used to enhance the characteristics of concrete products. Sisal was used in the projects which were reviewed, except for those in Sri Lanka where coconut fibre was used. The fibres could be used in short lengths (1-3 cms) or in continuous lengths.

2.2 Production Techniques

The production of sisal fibre concrete roofing sheets involves the following steps:

- preparation of materials
- proportioning and mixing
- casting
- curing

In the late 1970s J.P.M. Parry and Associates from the Intermediate Technology Building Materials Workshop (ITBMW), U.K., developed a production scheme for roofing sheets at the village level (9). The production procedure published by the ITBM Workshop in its brochure is as follows.

"1. Prior to beginning the sheetmaking process, preparatory work may be needed on the fibres, trimming them to appropriate lengths (1/2 in or 12mm) and removing any knots.

2. Sheetmaking begins, the fibres are mixed into a wet mortar of sand and cement and the material then spread into a simple frame on a smooth plastic sheet.

3. The panel of wet mortar is trowelled flat, tamped and the surrounding frame removed. After this the table is fitted and the flat bed slowly drawn out, allowing the mortar to take the shape of the corrugated former underneath.

4. The wet sheet on its former is then set aside to cure. The sheets stay in the primary curing stack for 24 hours. Secondary curing is two to four weeks."

The ITBM Workshop procedure involves limited capital investment and uses very simple tools such as shovels, buckets, trowels, machete, polyethylene sheets, mold, forming table, etc. The procedure is labor intensive and training is considered essential to securing good quality products. This production procedure has been disseminated to various countries by different modes.

3. TECHNOLOGY APPRAISAL

This part of the report is a synthesis of the three technical reviews and research reports submitted to ATI by Servivienda and Cetavip.

3.1 Type, Source, Quality of Data:

A common format was used to gather basic project data in the three technical reviews (See Appendix 1). Flexion and impact tests were carried out on roofing sheets sampled from existing projects. Since different testing procedures were used from country to country no comparative assessment is feasible on these tests. The complete data are, however, presented. Data on roofing sheets' permeability were gathered. The extent of cracking is measured by counting individual open cracks. The minimum sample size is 40% of the total number of sheets at each project. Cost data was gathered from project records and surveys. Data collected on the production of sheets were derived from the review of existing project information, personal interviews with project engineers, masons, foremen and site visits to production facilities.

Another set of data was obtained from research activities carried out by Servivienda in Colombia. A number of sisal concrete roofing sheets were manufactured in laboratory conditions. Some of the sheets were used to build experimental roofs in outdoor conditions and others were used in flexion and permeability tests. The extent of cracking is also reported as a result of counting individual open cracks.

3.2. Appraisal Criteria:

Since the primary function of roofing sheets is to protect from the elements, the most important indicator measured during appraisal was permeability of the sheets. Although data was collected on flexural strength and impact, these indicators were considered as secondary in the appraisal of product quality.

The production criteria used to appraise product quality were producers' skills and production controls applied at the community level. In addition to these criteria, each technical review assessed the input of technical assistance and training on product quality.

Since FRC sheets have been considered an alternative low cost roofing material, product cost was also included as an appraisal criteria.

3.3. Field/Research Findings:

From the technical reviews the following findings can be summarized.

3.3.1 Product Quality

Table 2 describes dimensions of the product manufactured in the three project sites. The smallest width of FRC roofing sheets is observed in the Kirillapone project. This was done in an attempt to diminish the level of cracking.

TABLE 2.
Roofing Sheets Description by Country

Country	Project	Width (cms)	Length (cms)	Thickness (mm)
Dominican Rep. (sisal fibre)				
	CAOTACO de Partido	75-87	115	5.5-16
	Caotaco	73-83	115	6-12
	Las Cienagas	92	112	6-12
	Los Bancos	109	120	8-12
	Villa Mella	9	161	9-11
	Fondo Negro	75	146	8-10
Sri Lanka (coir fibre)				
	Kirillapone	39	100	10-15
	Maggona	90	105	6
	Palletalavinna	100	90	9-10
	Batticoloa	91	101	10
Guatemala (sisal fibre)				
	San Jacinto	73	98	6-9
	San Miguel	77	99	6-8.6

Impermeability

These tables illustrate the level of cracking calculated by counting individual open cracks. It is noted that cracking ranges from 19 percent to 50 percent. The cracking observed can cause the roof to leak.

TABLE 3.
Cracking Occurrence in Guatemala

Project	No. Sheets	Sample Observed	Age	Remarks
San Miguel	872	300	4 yrs	About 20% of the sample observed was cracked
San Jacinto	600	289	4 yrs	About 20% of the sample observed was cracked
Total	1472	589		

TABLE 4.
Cracking Occurrence in Sri Lanka
(Reinforced with coir fibre)

Projects	No. of Sheets	Sample Observed	Age	Remarks
*Kirillapone (SCF)	15000	14000	6 mo- 1 1/2 yr	cracking in less than 25%
Maggona (I.D.B)	1350	1000	2 yrs	cracking in less than 25%
Palletalavinna	800	500	2 yrs	cracking in less than 25%
Batticoloa (Sarvodaya)	700	500	4 yrs	cracking from 25% to 50%
Total	17850	16000		

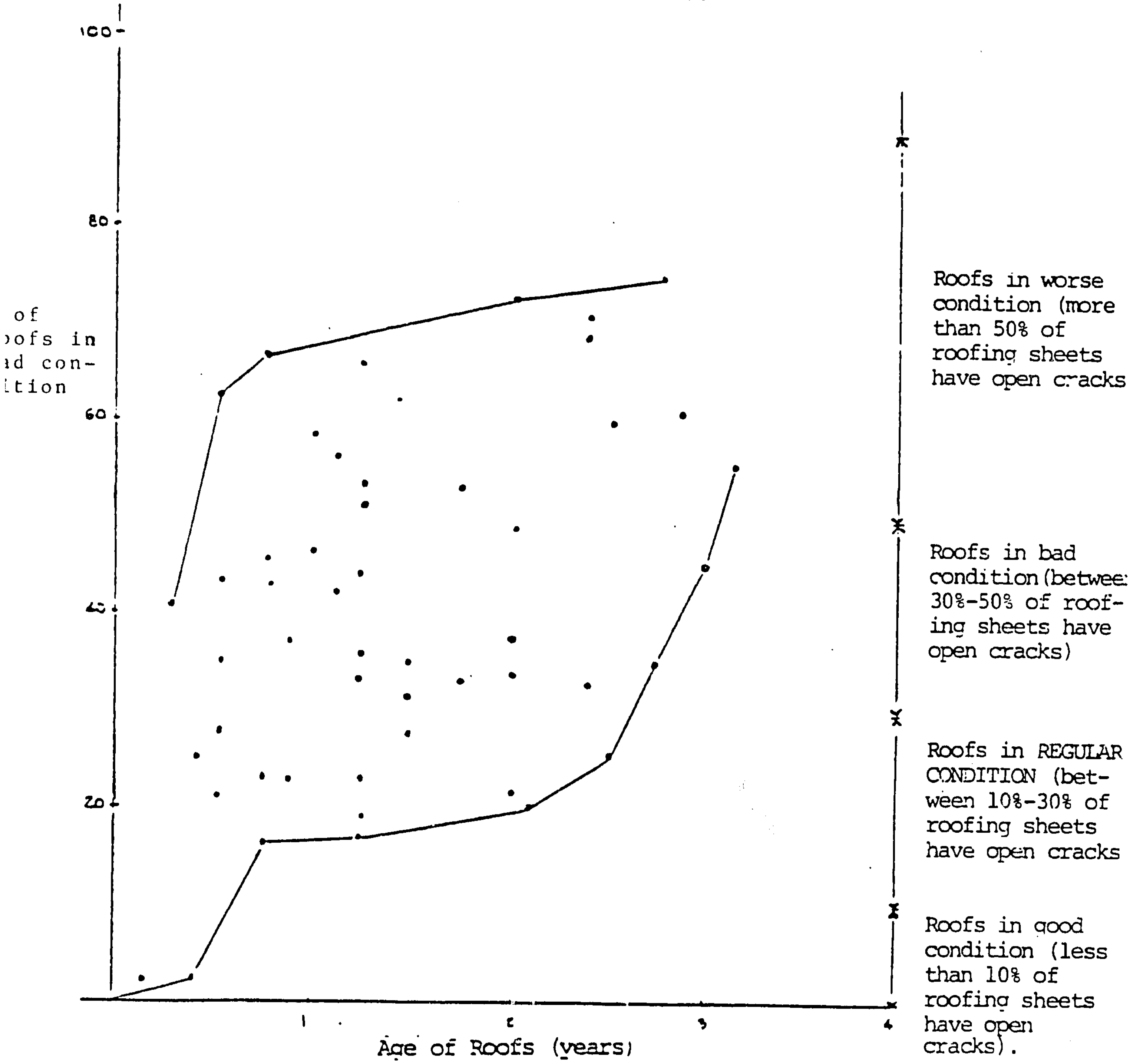
*Only project that received ITBMW assistance.

TABLE 5.
Cracking Occurrence in the Dominican Republic

Projects	No. of Sheets	Sample Observed	Age	Remarks
CAOTACO de Partido	1166	302	2 yrs	39% cracking in the sample observed
Bldg. around CAOTACO de Partido	1267	504	1-2 yrs	47% cracking in the sample observed
CAOTACO de Matayaya	1034	293	1-2 yrs	19% cracking in the sample
Bldgs around CAOTACO de Matayaya	448	224	1-2 yrs	36% cracking in the sample
Las Cienagas	1684	1684	1-2 yrs	40% cracking in the sample
Los Bancos	172	172	6mo-lyr	26% cracking in the sample
Villamella	224	224	6mo-lyr	42% cracking in the sample
Total	5995	3403		

The above data make reference to cracking as a function of time. A graphic illustration is shown in Figure 1:

Fig. 1 **Percentage of sheets in bad condition vs. Age of roofs in the Dominican Republic.** After Jimenez (4). The figure shows that there is a relationship between the conditions of the sheets and time.



Footnote: Each dot represents the condition of FRC roofing sheets manufactured on an specific date in the Dominican Republic projects.

Table 6, 6A, 7 present the results of flexion and impact tests undertaken in the independent technical reviews. Since no common testing procedure was followed in each country, no comparative statement is feasible. It is also noted that at this time there is no available standard to measure flexural strength and impact for sisal concrete roofing sheets.

TABLE 6.
Flexion Tests Results (Field Projects)*

Country	Width (cms)	Span (cms)	Maximum Load (kgs)	Unit Load kg/cm	Remarks
Guatemala					
	73	90	195	2.65	Tests were conducted at the engineering lab at San Carlos University. UNE 88-101 Spanish Standards procedures were followed.
	73	90	210	2.84	
	73	90	135	1.84	
	77	90	235	3.02	
	77	90	200	2.5	
Sri Lanka					
	39	70	97	1.65	Tests were conducted at the engineering lab of the Bureau of Ceylon Standards following. C.S.9 Ceylon Standards
	90	70	162.5	1.19	
	101	76	92.81	1.01	
Dominican Rep.					
	50	100	50-70	1-1.4	
	85	100	115-160	1.3-1.88	Test were conducted in the field.
	75	100	128-147	1.7-1.66	
	82	100	55-75	0.67-0.92	

*These were roofing sheets sampled at different projects during the technical reviews.

TABLE 6A.
Flexion Test Results (Servivienda)

The following table presents the results of flexion tests conducted at Servivienda (1)

Width (cms)	Span (cms)	Maximum load (kgs)	Remarks
84	110	207.4	Test were conducted using INCONTEC 160 Colombian Standards
84	110	193.5	
95	110	191.5	
75	110	235.7	
60	110	138.8	
60	110	99	

TABLE 7.
Impact Test Results

The results of the impact tests were as follows:

Country	Falling Weight (kgs)	Falling Height (cms)	Impact Strength (kgm)	Remarks
Guatemala				
	0.395	1.00	0.395 (cracked)	Tests were conducted using DIN 53453 Standards.
	0.395	1.00	0.395 (cracked)	Testing conducted at the Univ. of San Carlos
	0.395	1.00	0.395 (cracked)	
	0.395	0.80	0.395 (cracked)	
Sri Lanka				
	1.0	1.00	0.98 (cracked)	Test were conducted at Sri Lanka Standards Institute using Ceylon Standards
	0.75	1.00	0.74	
	0.80	1.00	1.18 (cracked)	
	0.80	1.00	1.18 (cracked)	
	0.80	1.00	0.78	
Dominican Rep.				
	1.00	1.2	1.17 (cracked)	
	1.00	1.2	1.17 (cracked)	Field tests.
	1.00	1.2	1.17 (cracked)	
	1.00	1.2	1.17 (cracked)	

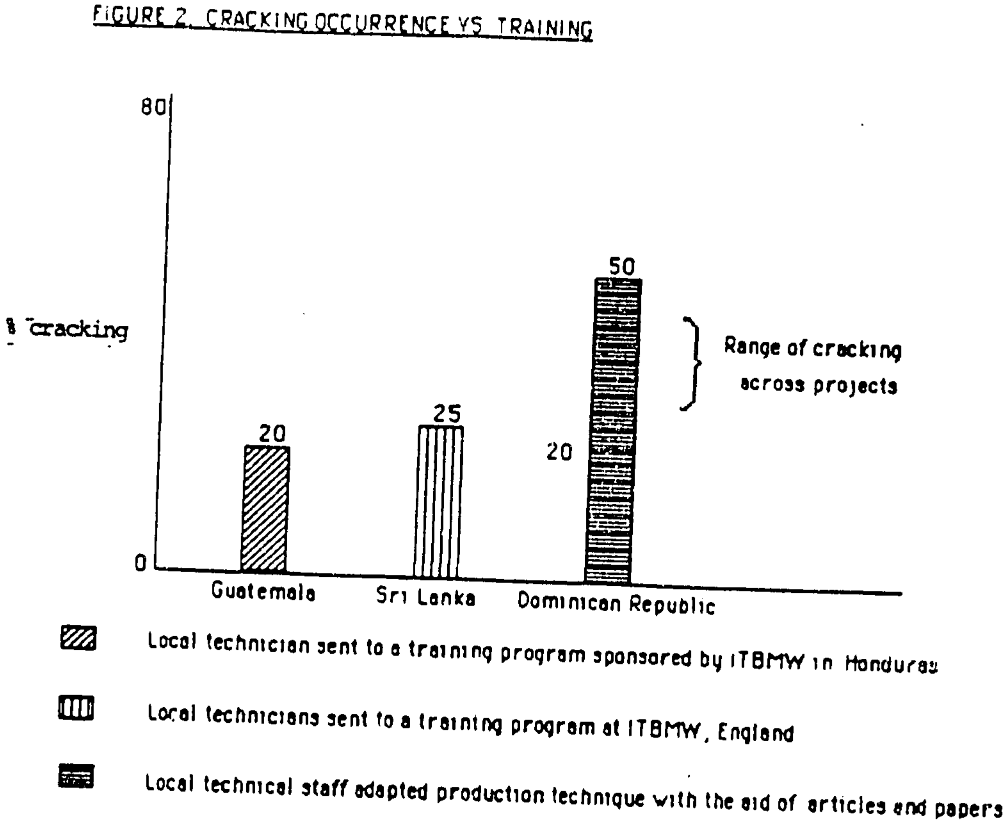
3.3.2 Production Performance

Variability in producer skills: In every one of the technical reviews (3), (4), (5), it is reported that variability in producer skills is a factor that contributes to the quality of the roofing sheets. The producers were generally unskilled persons who received training and supervision by skilled persons such as masons and foremen. The principal finding was that regardless of the level of training and technical assistance received the minimum level of cracking was 20 to 25 percent.

TABLE 8.
Level of Technical Training and Supervision

Sri Lanka (3)	Guatemala (5)	Dom. Repub. (4)
Local technicians received roofing sheets production training from IT Building Mat Workshop (ITBMW) in England (1979)	Local technician sent to Honduras for training program sponsored by ITBMW (1981)	Local technicians adapted the production technology with the aid of technical articles and papers (1979)
Technical assistance provided by ITBMW staff (1979) at Kirillapone.	Trainee from ITBMW course in Honduras organized training programs for local participants	Technicians trained community members and masons
Trainers from ITBMW course set up training program for local participants	Production of FRC roofing sheets is carried out by local participants as supervised by the trainer	Production of FRC roofing sheets is carried out by community members (Las Cienagas) as supervised by masons and technicians
Production of FRC roofing sheets is carried out by local participants as supervised by the trainer (masons)		

Fig 2. **Level of cracking from technical reviews.** The minimum level of cracking is 20% to 25% regardless of the level of training at the three technical reviews.



Variability in production control: When the production process is carried out in rural areas with a low level of technical assistance the production control is deficient. The principal difficulties arising in the field are as follows:

- proportioning the mixture; Jimenez (4) and Mendis (3) report that the most critical factor in the production of sheets is measurement of the water. In the Dominican Republic Jimenez (4) reports that the mix ingredients are generally measured by volume in different types of containers. However, Mendis (3) reports that in Sri Lanka the mix proportions are measured by weight but very little control is exerted on the water measurement. The general tendency is to add water until the mortar mix becomes easy to handle.

- casting; Gandara (5) reports that the wooden casting table loses its rigidity as a result of continuous use. Unless reinforced, proper casting does not occur and sheet quality is negatively affected. He also indicates that transferring the wet mix slab to the mold produces deformations in the sheets. Jimenez (4) reports that three different versions of the ITBMW table have been used in the Dominican Republic.

- curing: Table 9 illustrates the high degree of variability in curing times practiced and conditions used in projects reviewed.

TABLE 9.
Variability in Curing Time and Conditions

Country	Project	Curing in mold (hours)	Curing in moist* conditions (days)
Dominican Rep.(4)			
	Caotaco de Matayaya	72	7-10
	Las Cienagas	72	8
	Los Bancos	72	N/A**
	Villa Mella	144	15
	Fondo Negro	72	N/A**
Sri Lanka(3)			
	Kirillapone	15-24	7(submerged in water)
	Maggona	24	14 "
	Palletalavinna	24	7 "
	Batticoloa	24	21 "
Guatemala(5)			
	San Jacinto	24	7
	San Miguel	24	7

* Sprinkling with water 2 or 3 times/day

** Not available

3.3.3 Production Cost

Table 10 illustrates unit cost at each of the sites of the technical reviews. Sri Lanka reports the lowest unit cost of the three.

TABLE 10.
Unit Costs/Sheet in Dollars

	Sri Lanka		Guatemala	Dominican Rep. (Community)*	Dominican Rep. (Continuous)*
	min	max	min max		
Labor	.15	.27	0.8	0.36	0.60
Cement	.46	.77	1.0-1.2	0.55	0.55
Sand	.01	.02	0.1	0.09	0.09
Fibre	.00	.00	0.15-0.25	0.15	0.15
Contingencies (10%)	.11	.11	0.05 (brick dust)	0.04	0.49
(plastic)			0.25-0.3	0.14	0.16
	0.65	1.17	2.45-2.6	1.42	2.04
Dimensions:	1.05mx.90m	1.00mx.039	.97mx0.75m	1.35mx0.74m	

***Footnote**

Continuous: It is assumed that an organization installs a small production unit that works permanently and sells its product.

Community: A community organizes a production unit to supply its own roofing, and labor is provided by the community.

From the technical reviews the following data presents a comparison amc various roofing materials:

TABLE 11.
Cost Per Square Meter in Dollars
(Not Including Roof Structure)

Roofing Materials	Guatemala(5)	Sri Lanka(3)	Dominican Republic(4)
fibre cement roofing	3.25	1.65	1.47-2.04
clay tiles	2.25	1.5	N.A
asbestos	3.75	4.25	3.25-4.09
galvanized iron	3.35	4.25 (guage 26) 3.75 (guage 24)	2.85

Based on the useful life (up to four years) of the sisal-roofing sheets in the Dominican Republic, Jimenez (4) provides the data presented in Table 11. Jimenez (4) concludes that although the initial cost required for sisal roofing may be significantly lower than that of the other options, the low quality of the sheets currently produced entails a replacement cost every four years. Within a short period of time, the sisal cement roof coverings therefore become more expensive than the alternatives.

TABLE 12.
Investment Comparison of Different Roofing Materials in Colombia

	SISAL Average	ASBESTOS Average	GALVANIZED IRON Average
Total Cost/M2	3.66	6.14	5.02
Comparison of initial cost	1.00	1.68	1.37
Percentage increase in cost due to replacement of sheets after:			
4 years	0.41	0	0
8 years	0.41	0	0
12 years	0.41	0	0
Total Percentage increase	1.23	0	0
Total cost at 12 years	8.16	6.14	5.02

4. LABORATORY RESEARCH FINDINGS

4.1 Servivienda Research Project

This research program (1) was financed by A.T. International from February 1982 to October 1984 at the Servivienda plant in Bogota, Colombia. The results of flexion tests on plaques of 25 cm x 25 cm were used to define the optimal mortar mix, as follows:

sand/cement: 0.85
sisal fibre/cement and sand: .005
water flow 85-100%

In the first phase of the research, more than 300 roofing sheets were produced using the ITBMW procedure under controlled conditions at the plant. The sheets were used for flexion tests and to build experimental roofs under actual weather conditions. Table 13 shows the results from the experimental roofs:

TABLE 13.
Characteristics of Sheets Exposed to Actual Bogota Weather Conditions

Section	Length (cms)	Width (cms)	Thickness (cms)	Sample size	Exposure time/days	Remarks
(c)	120	84	1.2	41	120	cracking observed in 82% of sheets
(c)	120	75	1.2	56	120	
(c)	120	60	1.2	9	120	
(f)	114	61-48	1.0	154	120	some degree of cracking in 50% of sheets. Impermeability was doubtful
(f)	114	61	1.0	53	365	45% cracking

(c) corrugated cross section; these sheets were produced following ITBMW.

(f) flat sections, these sheets were produced using steel molds and a shaking table.

The research program focused attention on different production procedures and designs of sheets to reduce the occurrence of cracking. Jimenez (1) concluded that casting has a negligible impact and suggested that smaller sized sheets (tiles) were less susceptible to cracking. He noted that the need for using fibres in small roofing elements is doubtful. It was also observed that cracking was a function of time.

The research findings indicate that flexural strength diminishes significantly as sheets age. The following Table (14) shows some of the results from specimens of 25 cms x 25 cms.

Out of 40 sheets two and half years old, 33 showed a reduction in flexural strength. In some cases the reduction reached 33% and only a few showed an increase in strength (1).

TABLE 14.
Flexural Strength at Different Ages in Specimens of 25 cm x 25 cms

Sand/ Cement	Sisal Cement & Sand	Sand Type	Fibre Description	Flexural Strength kg/cm2 28 days	Flexural Strength kg/cm2 months
1.00	-	# 8	-	41.77	47.71 (32)
1.00	.011	# 8	Sisal (2cms)	39.89	35.75 (32)
0.5	.011	# 8	Sisal (2cms)	38.44	30.69 (32)
0.75	.011	# 8	Sisal (2cms)	42.16	36.68 (32)
1.25	.011	# 8	Sisal (2cms)	40.29	37.52 (32)
1.5	.011	# 8	Sisal (2cms)	40.95	34.38 (32)
1.0	.011	#16	Sisal (2cms)	44.89	39.81 (32)
1.0	.011	# 4	Sisal (2cms)	42.00	41.24 (31)
1.0	.005	# 8	Sisal (2cms)	49.88	34.5 (31)
1.0	.015	# 8	Sisal (2cms)	41.07	40.15 (31)
1.0	.02	# 8	Sisal (2cms)	40.61	41.47 (31)
1.0	.011	# 8	Sisal (1.5cms)	40.91	31.74 (31)
1.0	.011	# 8	Sisal (2.5cms)	43.44	39.57 (31)

4.2 C11-Viviendas Cetavip Research Program

This research program was financed by A.T. International and conducted from January 1983 to November 1984 (Center for Appropriate Technology for Popular Housing) in Santo Domingo, the Dominican Republic. The study (2) considered different natural fibres but finally selected sisal as the most suitable. After flow tests on mortars and flexural tests on plaques (25 cmsx25 cms) the optimal mortar mix was defined as:

cement/sand =	1.0 by weight
fibre/cement and sand	0.01
fibre length =	2-3 cms

The main objective of the project was to advance research work on sisal roofing sheets and to establish guidelines for the production of sheets in the Dominican Republic.

The project studied different production processes including that of ITBMW. A remodeled table was proposed and a "Production Manual" outlining the procedures for production of roofing sheets was developed. A major effort was undertaken to apply a quality control program during the production.

The study proposes a new method for fastening the sheets to the roofs to prevent cracking.

4.3 Other Research Efforts

Two aging methods have been developed by the U.K. Building Research Establishment (BRE) and the Swedish Cement and Concrete Research Institute (CBI), to study the durability of sisal fibres in concrete. The first, the BRE method, includes storage of sisal concrete specimens in hot water for different periods and temperatures. The second, the CBI method, includes storage of the sisal concrete specimens under alternatively wet and dry conditions.

These two methods have been subjected to careful review. Gram (8) in his paper, "Durability of Alkali-Sensitive Fibres in Concrete", published in May 84 concludes "that the method for accelerated aging developed at BRE is not applicable for sisal fibre concrete".

Efforts have been made at CBI by Gram (7) to search for counter-measures against embrittlement. Studies were conducted on impregnating the fibre with water repellent agents, on effects of reduced alkalinity of the matrix, and on the effects of sealing the matrix.

Further research on FRC technology is encouraged to examine the properties of the materials, product design, and production processes and control. Testing standards and programs are also suggested for the FRC technology that combine accelerated testing techniques in the laboratory and field testing in tropical settings.

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A P P E N D I X 1

TERMS OF REFERENCE FOR TECHNICAL REVIEWS
OF FIBRE-REINFORCED CONCRETE
IN THE DOMINICAN REPUBLIC, GUATEMALA AND SRI LANKA

Objective

The mission's objective is to identify and analyze the factors that indicate the effectiveness of fibre-reinforced cement sheet production technology at the community level as an appropriate alternative in technical and economic terms.

Methodology

The following research methods will be used to achieve the objectives of this evaluation: observation, document analysis, study of records, interviews with producers and users, physical examinations and measurements, and tests.

Indicators

The following preliminary selection of verifiable indicators will be used:

Technical

- flexural strength
- impermeability
- resistance to impact
- weight of the tiles

Production

- number of persons participating in the production process
- records of production, sales and costs
- division of labor
- procedure and equipment

Local production economies

- manufacturing costs: raw material, capital for labor, administration costs, etc.
- prices and availability of materials most commonly used as alternatives to FRC.

Additional elements of research

- geographical conditions at the project site: minimum and maximum temperatures, altitude, etc.
- types of production processes and measures to ensure quality control of the sheets

- problems encountered and margin of error during:

- -- selection of raw materials
- -- production, curing and storage
- -- transportation
- -- roof construction

provision of training and mastery of production process

- o development of new techniques and products at the local level
- o behavior of the sheets after installation, in terms of permeability, wind resistance and durability

<u>Technical reports</u>

The results of the technical reviews shall be presented according to the following tentative outline:

- o Introduction
- o Methodology
- o Description of the projects; number of sheets produced or area of roofed construction; production system and costs, production dates
- o Training programs (if any)
- o Tests: flexural strength, porosity, resistance to impact, etc.
- o Technical discussion:
  - -- production
  - -- construction
  - -- sheet repair options
- o Economic factors
  - -- production
  - -- comparison with alternatives
- o Conclusions and recommendations
  - -- technical
  - -- economic

A P P E N D I X 2

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