EVALUATION OF PERFORMANCE PROPERTIES OF ASPHALT-IMPREGNATED CORRUGATED SHEETS

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Asphalt-impregnated corrugated sheets (ACS) of organic fiber felts were studied for their performance requirements. Six sample materials from different countries—two from North America, and one each from Europe, Central America, South America and Asia—were procured for this purpose. The manufacturing of this type of roofing material in many countries, each one using somewhat different technology, indicates that the asphaltic sheets are adaptable to a wide range of climatic conditions—from northern cold climates to tropical heat. Accordingly, a number of performance characteristics were considered that would satisfy the requirements for a variety of weathering conditions. They include asphalt saturation, tensile strength, bending strength, impact resistance, nail pull-out resistance, water absorption, weatherability or protective coating, effect of heat on bending strength, and cold temperature.

Samples from each of the materials were tested for these properties. It is seen from the test results that a significant variation exists between properties. This suggests that an international standard for asphalt corrugated sheets could be developed to help improve the quality. Presently, the test results are presented without attempting to correlate the properties with the types of sheets, and some tests are recommended for the evaluation of performance properties.

KEYWORDS

Asphalt sheets, bituminous sheets, corrugated sheets, fiber mat, natural fibers, organic felt, roofing sheet.

INTRODUCTION

Most of the world population lives in the underdeveloped areas where one of the basic needs is appropriate housing.[1] The roof is the most significant part of the house, both technically and functionally. It is commonly used as a symbol for shelter and conveys a sense of security and comfort.

Construction materials in various countries are of different origins. Roofing materials range from the traditional palms, grasses and fibrous plants, to metal sheets and cement products. The former is of comparatively poor durability, high flammability and susceptible to insect infestation. Of the conventional materials, asbestos-cement sheets are no longer used in most countries due to the potential health problems, while galvanized iron (GI) sheets transmit heat radiation from the sun, and noise from rain and hail causing an uncomfortable indoor environment. They are expensive, and not generally affordable by low income families. In coastal regions, they show poor behavior due to their corrosion susceptibility.

The energy cost of firing clay tiles is high, although the raw material is inexpensive. In addition, the product is heavy requiring a stronger structure to support the tiles. This adds to the cost of the roof.

The difficult economic conditions of these countries makes it hard to provide adequate solutions to the roofing problem. Imported goods are high priced and they do not represent the most appropriate material in every case.

The most suitable solution to the roofing problem is the fabrication of other types of materials that will reduce the high cost of importing and make use of locally or nationally available raw materials. Experience generated worldwide in the making of fiber-reinforced cement tiles,[2,3,4,5] sulphur impregnated sheets,[2,3,6] and asphalt-impregnated corrugated sheets (ACS)[7] is potentially beneficial. There is considerable experience generated with ACS in a number of developing countries in medium scale production of roofing sheets.

Asphalt corrugated sheets are made of organic fibers, consisting of paper and cardboard wastes, to which cloth or other natural fibers may be added. The material is processed by mechanical means to form fiber sheets, like thick cardboard, which is corrugated and saturated with hot asphalt. The corrugated sheets are then painted for UV protection. Their future use in the developing countries as alternatives to the traditional roofing materials, depends largely on improvement of their properties to make them economical and durable.[8]

In order to evaluate properties of ACS, samples from six different manufacturers were obtained—two from North America, one each from Europe, Central America, South America and Asia—and were tested. Some plants were visited to study the production techniques. This investigation shows that ACS are appropriate for underdeveloped regions, although of less interest to developed countries. Standardization is needed for uniformity and to ensure that they are durable as well as attractive.[9] In this paper preliminary studies concerning the properties and performance of the

ACS are reported. No attempt has been made to correlate the properties based on the types of materials manufactured. Some tests and their requirements are recommended for the evaluation of performance properties.

PRODUCTION OF ACS

Different manufacturers use different technologies in the production of asphalt corrugated sheets. In the intermittent system, each sheet is made individually starting with the forming of fiber mat with layers of felt, to the finishing of exposed surface with protective coating. In the continuous production process, the fiber mat is formed as a continuous ribbon that is corrugated, dried and then cut into sheets for impregnation and finishing. This process uses expensive automated equipment with a low labor content, while the intermittent system uses a low capital cost and is highly labor intensive which makes it well suited for the underdeveloped countries.

Different types of organic fibers obtained from paper, cardboard waste, cloth and other natural fibers are added to water and mechanically reduced to a pulp. In the intermittent system, the pulp stock is pumped to a sheet forming machine which consists of a rotating drum covered with a fabric felt to collect the fibers and to deposit it onto a receiving drum. The thickness of the material is controlled by the number of turns. Each turn deposits a layer of fiber mat. Once the desired thickness is reached, the drum stops and the mat is removed to a flat bed.

The individual mats are partially dried in the open or in a kiln. They are trimmed to size and corrugated to the desired size of corrugations by rolling them through a pair of geared rods. The sheets are then loaded into baskets and each basket in turn is placed in the open tank containing heated asphalt for impregnation by gravity and capillarity. An alternative method uses a vacuum tank.

After impregnation, the basket is removed from the tank and the sheets are left for conditioning at normal temperature. The exposed surface is spray painted with an acrylic latex or other paint to provide protection from solar radiation. The paint is formulated to penetrate the surface cracks and adapt to the surface expansion and contraction.

It was observed during visits to some of the plants that a number of variations exist in the manufacturing process. These are listed as follows:

- Quality of fibers obtained from locally available cardboard waste, rags, etc.
- Type of asphalt used for impregnation of fiber mat.
- Manufacturing of mat using the two methods—thin felt layers combined, or a single uniform layer of fibers from pulp stock spread on a moving belt—to give required thickness.
- Drying of mats either in open air or in an oven.
- Corrugation of sheets using either of these three arrangements:
- Steel rods move with and press on the mat ribbon.
- Individual mats pass through a pair of geared corrugation cylinders.
- A battery of rods pressed on the individual mats. (These methods cause different stresses in the mats.)
- Asphalt impregnation, done either by gravity or by vacuum in the heated asphalt tank.
- Different types of protective coatings which may or may not be applied.

In addition to the above differences, quality control varies from minimal to adequate at different plants. At one plant, there was practically no quality control, except for checking weight or thickness.

In the developing countries, a significant number of processes in a manufacturing plant are carried out by manual labor which adds to the variation in quality control.

INVESTIGATING PERFORMANCE PROPERTIES

Samples from different manufacturers were obtained for investigating the roof sheet properties. Most manufacturers have established manufacturing limits that they feel are adequate for ensuring production of a suitable product. Some aspects of sheets related to their performance were also considered. These were grouped in broad areas for discussion.

Asphalt Content

Asphalt provides the corrugated sheets with waterproofing property as well as durability and dimensional stability when exposed to weather. Different types of asphalts are processed to impart the properties suitable for roofing, pavements and other uses. The roofing asphalts are further divided into various types with different properties for use in coating, saturating, or modifying.

Two aspects of saturation must be considered; the amount of asphalt absorbed by the sheet, and the uniformity of impregnation. They are affected by the variation of temperature at different areas in the asphalt tank and the depths of immersion of the sheet.

The quantity of asphalt should be optimum for durability.[10] It must be sufficient to render the sheet waterproof. Insufficient asphalt allows the fiber to gradually absorb water in regions where the relative humidity is always high. The resulting swelling of the fiber breaks the bond with the protective coating and leads to ingress of additional water. Excessive asphalt not only adds to the cost but also may cause flowing and dripping of asphalt in hot weather.

Both the quantity of asphalt and uniformity of impregnation can be improved by maintaining uniformity of temperature in the tank by a stirring mechanism and using a vacuum system for impregnation.

Moisture Effects

Water affects the durability of the ACS. The base material is cellulose, which is prone to fungus attack and is subjected to the degradation of fibrous matrix. The degradation of the matrix reduces the strength of the element, and the excessive water also increases the weight of the sheet. The factors which are affected by moisture are:

- Water absorption
- Water permeability
- Waterproofness
- Dimensional Change
- Strength

The absorption of water affects the strength of the sheet and was therefore included in the study for tensile strength before and after the absorption. Out of other factors the water tightness test answers questions to the permeability and waterproofness.

A sample with a higher void content absorbs more water and tends to lose strength. As such, these two tests were considered adequate for assessing the effect of moisture content.

Fire

Fire is an important factor since it concerns the safety of people and is an economic factor for property owners. Different regulatory authorities ask for different fire tests depending on the type of construction and size and occupancy of the building. For example, in Canada roofing materials for small buildings, for residential or commercial use, which meet the specified limits of building height and roof area, do not require any fire rating according to the National Building Code (NBC). Regional governments may have their own requirements in addition to the NBC.

The issue of fire testing has been included in the present study for the purpose of discussion only; ACS has not been tested for fire resistance. Because this is a specialized test, and its requirements vary from one area to the other, the manufacturers normally get their materials assessed for fire resistance where it is required. A roof designer should ask for such testing while specifying the product if so desired or wherever required by law.

Strength

Strength is needed at different stages of the product life, starting from the manufacturing, transportation, storage, installation and maintenance. There are various situations where sheets are subjected to stresses (e.g., tensile, bending, shear impact, etc.). Most roofing materials are tested for one or more stresses depending on the product and its usage. For example, tensile or bending stresses are involved in most situations; such tests are therefore relevant. Shear loads commonly lead to interply slippage or tearing during application or service. These properties are tested for in most roofing materials. Impact loads are more common on roofs compared with other sections of a building envelope, such as falling objects during storms or tools by workers during installation or maintenance. Sheets must have adequate resistance to tensile, flexural and impact loads.[11]

Weather Factors

Testing for the effect of weathering is essential as the roof sheets are exposed to inclement weather. Although natural weathering tests help in studying behavior during service, it is quite cumbersome to maintain long-term records of field performance. Consequently, various methods of accelerated artificial weathering are used in the lab. They include cyclic exposure to water spray/radiation, condensation/radiation, heating/cooling, freezing/thawing, wetting/drying, etc. In this study, it was considered adequate to use the fluorescent UV/condensation apparatus for exposing roof sheets and visually examining and comparing them with control specimens. The common defects visible after exposure include loss of protective paint, discoloration, deformation (form change), delaminations, etc. In the case of non-availability of accelerated test equipment, as is common in underdeveloped countries, with tropical climates natural exposure for six months to a year can show defects in many cases. Also, mechanical tests after weathering may give useful information as to the degradation of these materials. Hence, testing for strength before and after accelerated exposure should be considered.

Chemical and Biological Attack

Resistance to fungus, termites and rodents is important to both siding and roofing applications. The ACS should have resistance to attack by chemicals (salts, acids, alkalies) as chemical environments are commonly found in industrial and coastal areas. However, special treatments to provide the resistance and specialized tests to evaluate the results are required. As a result such products may be an expensive solution for those areas. For such products the manufacturer should be consulted.

Dimensional Change During Fabrication and After Exposure

Dimensional change affects appearance and serviceability, and causes the development of stresses that could cause further degradation. This aspect requires strict control of the design dimensions of the sheets by the manufacturer. In tropical climates, the material should be tested after six months to a year of exposure to natural conditions. In general, tropical areas provide an excellent environment for weathering. Monitoring of the materials performance could provide useful information about durability.

Thermal and Acoustical Properties

Thermal and acoustical properties are of concern in buildings where environmental conditions such as thermal gain and noise pollution are important factors. Testing for the measurement of thermal coefficient of expansion, sound transmission rate and other acoustical properties should be called for when the building design includes these factors. These are specialized tests and should be considered. In the case of low cost housing however, these aspects are of little concern particularly when the testing and treatment are economically not feasible.

TESTING

The following tests were selected for use in evaluating ACS. As most test specimens were required to be flat for testing, they were obtained from the somewhat flat portion between adjacent corrugation (i.e., in the contraflexural region). Each one of the six samples was tested to determine the listed properties, and the results are given in Tables 1-3.

Dimensional

Sheets were received from the manufacturer cut in quarter pieces for convenience of shipping. The dimensions of length and width were obtained from literature supplied by the manufacturers. Other dimensions were determined by measurement and testing in the laboratory using standard procedures. Thickness was measured using a dial gauge and the other measurements, using a pair of calipers, steel ruler, a steel tape and a travelling microscope. At least five readings were taken at different spots for each quantity and averaged. These are shown in Figure 1 and included in Table 1.

Asphalt and Cellulose Content

The cellulose and asphalt contents were determined using two methods in different laboratories.

Lab 1—First, surface paint was removed from each sample by lightly scraping and then rubbing with sand paper. Samples were then extracted with dichloromethane under reflux. The extracts were filtered and the asphalt recovered by the Abson Method (ASTM D 1856). The weight of asphalt was subtracted from the total weight to obtain the quantity of cellulose. A negligible amount of contaminants was detected but ignored in the computation.

Lab 2—In the second method, some 10-50 g of sample was cut into small pieces and placed in a Whatman Cellulose Extraction thimble. The sample was soxhlet extracted with toluene. The cellulose component of the sample was dried in an air-circulating, and vented oven at 70°C for 4 hours. Discernable flakes of paint were removed and weighed. The remainder of cellulosic mixture was also weighed. Their weights were subtracted from the original sample and taken as the weight of asphalt.

Since the individual results of the two laboratories were within 5 percent of their mean values, they were adopted and recorded in Table 2. The difference in the total of asphalt and cellulose varies between 0.5 percent and 8.5 percent. It is attributed to dust and impurities.

Water Absorption, Length Change

Specimens, 127mm X 12.7mm, were cut from the flat portions and, without sealing the edges, were immersed in a water bath maintained at 20 ± 3°C for 24 hours. After that period, samples were mopped with a paper towel and dried with a light air jet. The weights were taken and water absorption computed. Their average was recorded.

For length change measurements, the specimens were conditioned at normal temperature and humidity (22/65) for 24 hours. Before immersion their lengths were measured using a travelling microscope. Measurements were taken again after removal from the water bath. Percentage length change values are recorded in Table 2.

Tensile Strength

Specimens approximately 127mm X 12.7mm were taken out of the contraflexural part of the sample and the cross-sectional dimensions were carefully measured and recorded. The specimens were conditioned at room temperature and humidity (22/65) for at least 24 hours before testing in the universally tensile testing apparatus (Instron model 1122).

Each specimen was mounted in the hydraulic grips space at 50mm. The test was carried out with a crosshead speed of 5mm/min. The test results were stored in the computer as well as recorded on the machine chart. At least five specimens of each material were tested and their mean value recorded.

Each set of specimens was also conditioned simultaneously at three temperatures (normal 22°C, hot 70°C and cold −40°C) for 12 hours, as both of the extreme temperatures occur on the roof surfaces in Canada. The specimens were tensile tested at those temperatures using an environmental cabinet mounted on the tester. The mean values of the results for each product are given in Table 3.

Flexural Strength

Samples of 110mm X 12.7mm were cut out from the asphalt impregnated mat or sheet and conditioned at normal temperature and humidity (22/65) before testing in flexure. Cross-sectional dimensions of each specimen were recorded and the specimen was placed on two supports set at 80mm apart. A loading tip or nose was lowered on the middle of the span at the rate of 5mm/min. The load gradually increased until the material was locally squashed, and the load started dropping. The peak load was adopted for computing the flexural stress.[10] The mean values of five tests for each product are recorded in Table 3.

Bending of Sheet (Foot Load)

This test simulated the situation where a person on the roof steps on the middle of roofing panel between two battens 610mm apart. Each sheet sample was approximately 680mm long and 400mm or more wide. The width contains full four corrugations. The sheet was placed on two supports 610mm apart. A wooden plate 100m X 100m was placed at the center of the middle two corrugations. A loading tip on the universal tester was gradually lowered on the plate at a crosshead speed of 50mm/min. After coming to a peak, the load started dropping. The peak load was considered the end point of the load at yield. The test was repeated three times and the mean value is recorded in Table 3 for each product.

Nail Pull-Out Test

This failure of roof in the wind uplift situation is caused by either the nails being pulled out of the wood battens, or the sheets lifted with the nail heads tearing through the holes. The latter situation of each nail is simulated by the pulling of one nail through a sample corrugation sheet.

A simple apparatus was designed to conduct a pull-out test using a nail having a 10mm diameter head or a nail with a washer of 10mm diameter (Figure 2). The assembly is mounted on the Instron tensile tester and the nail is pulled at a speed of 5mm/min. until it ruptures through the hole. The pull force (in Newtons) for one nail multiplied by the number of nails in a sheet provides the value of theoretical wind uplift resistance of the roof sheet assembly, assuming the structure is adequate. The single nail values are given in Table 3.

Dynamic Impact (Puncturing) Test

ACS samples were tested for impact resistance at 22°C in an apparatus shown in Figure 3. It consists of a long tube acting as a guide for a mass (steel rod) that falls on an indentor fitted with a hemispherical tip of 10mm diameter that hits the corrugated sample. The total mass of the falling rod is 1 kg and it can be dropped from different heights. Specimens from the six materials were tested with the impactor falling from four different heights of 75, 150, 250 and 500mm to establish the performance requirement. These generated impact energy values of 0.74, 1.47, 2.45 and 4.95J, respectively.

The rating was based on the visual examination of indentation as follows: (1) for visible puncture through the sheet thickness; (2) for possible puncture but not discernible; (3) for slight indentation but no puncture, and (4) for no puncture and no indentation.

Four replicates were tested for each of the four drops. Their averages are shown in Table 3.

Accelerated and Natural Weathering

Four samples from each material were placed in a UV/condensation accelerated weathering apparatus described in

ASTM G53. The samples were partly flattened in a press in order to fit them in the panels. The samples were exposed to cycles of 4 hour radiation and 8 hour condensation for a total of 1000 hours.

After exposure, samples were visually examined for any surface degradation. Also, specimens of 12.5mm X 125mm were cut out of them and tested for tensile and flexural strengths using the sample parameters as for the control samples. Their results are recorded in Table 3.

One sample (approximately 450mm X 450mm) from each of the six products was exposed to natural weathering in Costa Rica on a roof sloping at about 30°. A similar specimen of each was kept in the laboratory as control. Both sets of samples were examined on a regular basis for any visible deterioration. Photographic records and notes on their condition were maintained.

RESULTS AND DISCUSSION

The six samples procured from different countries exhibit significant variation in their properties. These differences can be attributed to various factors such as the quality of fibers, type of asphalt, fiber felt making process, drying in air or oven, corrugating technique, asphalt impregnation method, type of protective coating and, lastly, the variation in quality control.

Many results are inconsistent. It was found in repeating the tests on some products, that the test results differ from one batch of sheets to the other.

- The data given in Table 1 shows that the dimensions vary partly due to differences in the basic technologies and the local construction practices. Redesigning of corrugation sizes could help in making the sheets, uniform in size and economical without adding weight to the sheet.
- Variation in asphalt content appears to be significant, 33-55 percent, (Table 2). This important factor in the performance of ACS should be addressed when developing the standard. The amount of volume change due to water absorption ranging between 6.7 and 15.6 percent appears to be excessive and not consistent with the amount of water absorption. This aspect should be studied further particularly from the point of view of volumetric change and change in strength with water absorption.
- Mechanical properties (Table 3) show large variation among different products. For example, tensile strengths (line 1) range from 8.9 to 26.3 MPa. The effect of accelerated weathering (line 2) shows a general trend in the reduction of strength values which range between 5.7 and 25.0 MPa. These variations will, of course, be reflected in their durabilities. The differences in the values of two sets of tests at 22°C (lines 1 and 3) are due to the latter being from a different batch of productions.

Examination of the results of testing at extreme temperatures +70°C or −40°C (lines 4 and 5), indicates a significant difference. The hot and cold averages are 12.9 and 33.7 MPa, respectively, compared to the normal temperature average of 15.7 MPa (line 3). This would accordingly affect the flexural strength of the sheet. It is evident that the softening of the sheet when hot is critical if someone walks on the roof. This aspect should be taken into consideration when designing for very hot climates. In very cold temperatures, the material will be comparatively much less flexible.

The test results for "flexure of materials" before and after accelerated weathering (lines 6-8) reveal variation similar to those in the tensile results. It was anticipated that this test, in addition to giving bending strength, would show a shearing effect in the mat which has layered fiber felts. The shear effect was not visible indicating the layers are well bonded.

Bending of sheets is an important performance criterion. The variation in test results (line 9) is significant. This test should be extended to use a bigger specimen so as to include the effect of continuity of a sheet in either direction. Also, a deflection limit should be established in addition to the load limit.

Nail pull force or wind uplift resistance (line 10) varies between 132 and 284 units. These figures will change if the nail head size is changed. In order to establish the performance requirement for a region, the wind velocity data of that region and sheet installation details, as well as the nail dimensions and wood type, should be taken into consideration.

Dynamic impact behavior was studied using different drop distances (lines 11-14). Adoption of the test method, based on the indent rating average, can be settled for a drop distance between 150mm and 250mm. Beyond these limits the test may be very harsh or very lenient. This range can be narrowed down by repeating the tests with different size indentors which could give optimum size of indentor and drop distance.

The samples from the accelerated weathering tester after 1000 hours of UV/condensation exposure exhibited varying degrees of color fading of protective paint. In one sample, some flaking and loss of paint was evident. There was an average reduction in the strength of about 12 percent (lines 1 and 2) in the specimens tested.

It was observed during inspection of the samples after six months of exposure to natural weathering in Costa Rica that almost all had shown significant fading of colors. One sample, which was unrestrained, had suffered deformation. This is evident in Figure 3 where flattening of the corrugations have occurred when compared to the control sample placed on top of the deformed one.

In the inspection after one year of natural weathering, one sample with brick red color paint was seen with significant loss of paint due to flaking (Figure 4), which was much more severe than a similar sample after artificial weathering of 1000 hours. Another sample which was unpainted showed extensive fading and surface cracking (Figure 5).

Visual comparison of weathering effect indicates that one year of natural weathering in Costa Rica was more severe than 1000 hours of accelerated weathering in the laboratory.

- The dimensional data and the test results of physical and mechanical properties are given in Tables 1-3, including the ranges and means of their values. Specific tests and their minimum requirements given in Table 4 are considered important for the performance of ACS. The dimensional aspects, except thickness, have not been included in the assessment, as they depend on a regional tradition in the construction practice.

CONCLUSION

The study shows that there is need for improvement of the corrugated sheets through standardization and quality control. This will help developing countries improve the durability and the life cycle cost of roofs.

A number of performance-oriented tests have been recommended. Others should be developed, particularly for cold climates, coastal regions and toxic environments.

Specific areas concerning the raw materials such as fibers and asphalts, and the consistency in impregnation need further research for improving the durability and economics of the product.

Natural weathering in a tropical climate like Costa Rica is quite severe, and this instead of accelerated weathering in the laboratory should be used for the study of durability of materials.

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REFERENCES

[1] Population Reference Bureau, World Population Data Sheet, 25th Edition, Washington, D.C., 1987.

[2] Hick, Charles G., "Appropriate Technology for Building Materials from Argo Wastes and Natural Fibres," Report Number THA/CDT 80/2, Washington University, St. Louis, Mo., p. 201, 1980.

[3] Gram, H.E., Parry, J.P.M., et al., Fibre Concrete Roofing, A Comprehensive Report on the Potential of Fibre Concrete Roofing, The Limits of Applications, The State-of-the-Art, Swiss Center for Appropriate Technology, University of Saint-Gall, Switzerland, 1987.

[4] Ramirez, Aldo, Utilizacion de Residuos Fibrosos de la agricultura para la fabricacion de elementos de Vivienda Economica. Instituto Tecnologico de Costa Rica, Cartago, p. 318, 1986.

[5] Hannant, D.J., "Cement Based Roof Sheeting Containing Continuous Networks of Polypropylene Film," International Symposium on Roofs and Roofing: New Materials, Industrial Applications, Uses and Performance, J.O. May, Editor, Ellis Horwood Limited Publishers, Chichester, 1988.

[6] Bryant, Ben. S. and Byung, G. Lee, "Structural Fibre Reinforced, Sulphur Based Composites," Sulfur 81 Conference, Calary, Alberta, p. 14, May 22, 1981.

[7] Lola, C.R., Asphalt Roofing, Appropriate Technology International, USA, June 1985.

[8] Mukerji, K., et al., "Roof Construction for Housing in Developing Countries," Report on a Research Study in Central America, Published by German Agency for Technical Cooperation, Eschborn/Ts. Federal Repubic of Germany, p. 165, 1982.

[9] Booth, Robert J., "Evaluation, Testing and Standard for Modified Bitumen," 8th Conference on Roofing Technology, National Institute for Standards and Technology, Gaithersburg, Md., p. 91- 98, April 1987.

[10] Aslam, M. and Jain, Sp.P., "Studies on the Surface Temperature Variations of Bituminous Roofing Sheets in Tropics," Proceedings of the Second International Symposium, RILEM, Budapest, pp. 315-323, September 1975.

[11] Singer, Ferdinand L. and Pytel, Andrew, Strength of Materials, Harper and Row Publishers, New York, N.Y., pp. 153-166.

Properties	Products						Values	
	A	B	C	D	E	F	Average	Range
Length, mm	2000	2000	1830	2000	1830	2550	2035	1830-2035
Width, mm	1200	1090	700	1200	685	700	930	695-1200
Thickness, mm	2.5	2.5	2.7	2.8	2.7	2.3	2.6	2.3-2.8
Corrugation Pitch, mm	90	77	92	92	77	65	82.2	65-92
Corrugation Depth, mm	36	27	35	35	23	21	30	21-36
Weight of Material, kg/m^2	2.6	3	3	2.6	2.6	2.1	2.6	2.1-3.0

Table 1 Dimensional data.

Properties	Products						Values	
	A	B	C	D	E	F	Average	Range
Asphalt Content, %	33.4	48.7	50.7	49.0	40.0	55.3	46.2	33.4-55.3
Cellulose, %	58.1	48.9	48.8	49.6	56.0	43.4	50.8	43.4-58.1
Water Absorption, % (after 24h)	16.1	16.3	7.2	7.9	15.1	12.6	12.4	7.2-16.1
Length Change, %* (24 h absorption)	0.49	0.40	0.35	0.19	0.99	0.33	0.46	0.19-0.99
Volume Change, %* (24 h absorption)	12.3	6.7	7.2	6.4	15.6	10.0	9.7	6.7-15.6

*Positive change means increase in property value.

Table 2 Physical properties.

Properties/ Tested at	Products						Values	
	A	B	C	D	E	F	Average	Range
Tensile Strength, MPa:								
1. 22°C	26.3	15.7	8.9	9.2	22.8	17.7	16.8	8.9-26.3
2. a/w*, 22°C	25.0	14.3	10.7	5.7	17.5	14.9	14.7	5.7-25.0
3. 22°C (second batch)	26.0	18.7	6.6	6.6	23.5	12.5	15.7	6.6-26.0
4. 70°C	25.8	12.7	7.5	4.5	18.6	8.5	12.9	4.5-25.8
5. −40°C	51.6	34.4	24.1	14.8	50.1	27.4	33.7	14.8-51.6
Flexural Strength of Material, MPa:								
6. 22°C (Lab 1)	15.7	12.2	8.0	7.5	16.0	12.3	12.0	7.5-16.0
7. 22°C (Lab 2)	19.7	16.5	11.3	8.4	14.1		14.0	8.4-19.7
8. a/w, 22°C (Lab 2)	17.3	15.2	12.1	8.0	13.2	11.8	12.9	8.0-17.3
Bending of Corrugated Sheets, Foot load N								
9. 22°C	-	331	321	439	253	132	295	132-439
Nail Pull Force (or Wind Uplift Resistance)/nail, N								
10. 22°C	270	284	161	270	259	132	229	132-284
Dynamic Impact, Rating Drop (mm): 22°C								
11. 75	4	4	4	4	4	3.0	3.9	3-4
12. 150	3.0	3.0	2.3	3.0	3.0	2.0	2.7	2-3
13. 250	3.0	2.8	1.7	3.0	2.3	2.5	2.6	1.7-3.0
14. 500	3.0	1.2	1.0	2.0	1.0	1.8	1.7	1.0-3.0

a/w* = After accelerated weathering in QUV for 1000 hours.
Note: All samples except in lines 2 and 8 are unweathered or unaged.

Table 3 Mechanical properties.

	Properties	Requirements
1.	Thickness, min, %	2.2
2.	Asphalt content, min, %	45
3.	Water absorption (in 24 h), max, %	12
4.	Linear dimensional change, max, %	0.5
5.	Tensile strength, min, MPa	10
6.	Flexural strength of material, min, MPa	8
7.	Bending of corrugated sheets (foot load), min, N	300
8.	Nail pull force per nail, min, N	200
9.	Dynamic impact, min rating	2.5
10.	Fire rating	As per territory's code requirement

Note: Additional tests for cold climate and toxic environment conditions can be included for performance evaluation.

Table 4 *Performance properties of asphalt corrugated sheets and their requirements.*

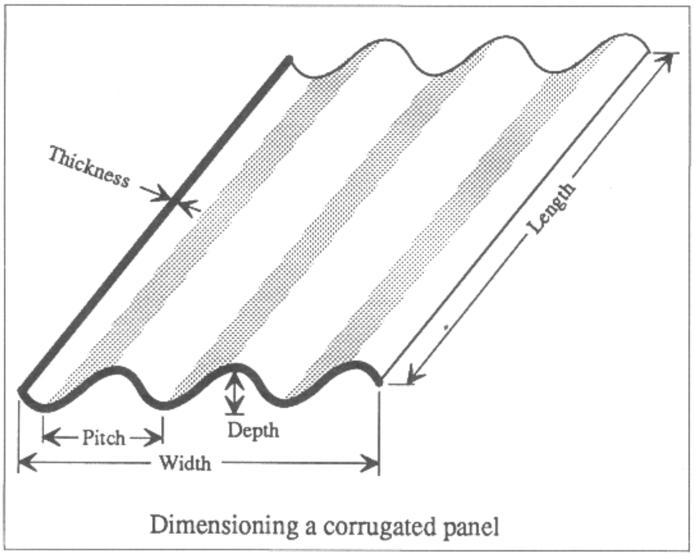

Figure 1 *A typical corrugated sheet.*

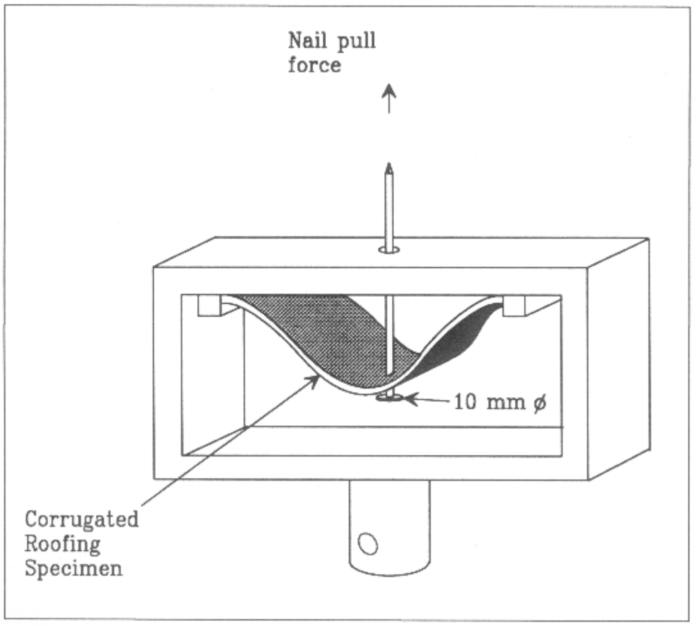

Figure 2 *Apparatus for nail pull (wind uplift) test using a tensile tester.*

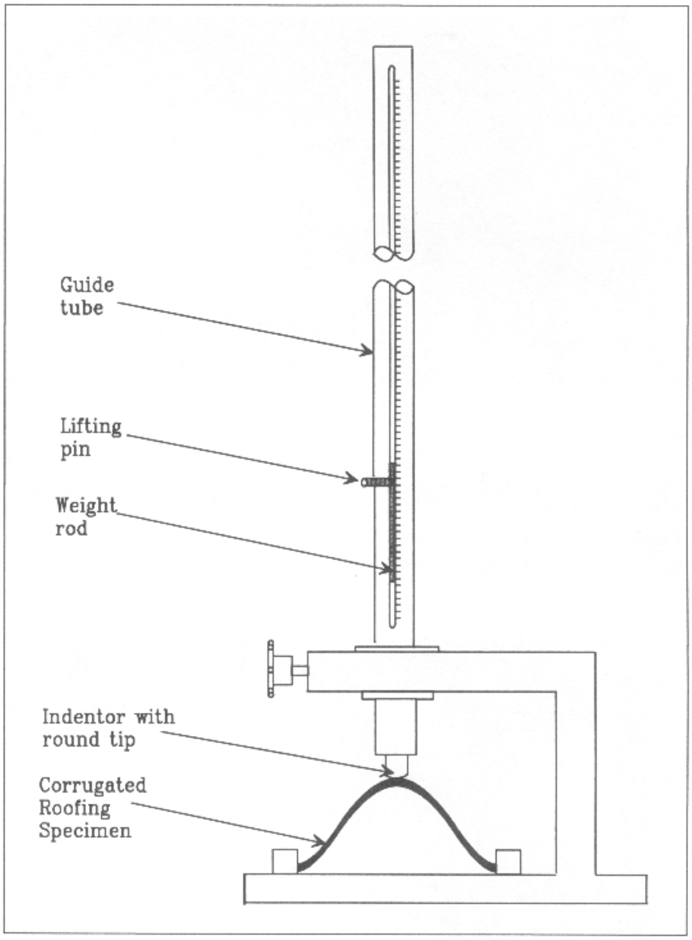

Figure 3 *Impact load test apparatus.*

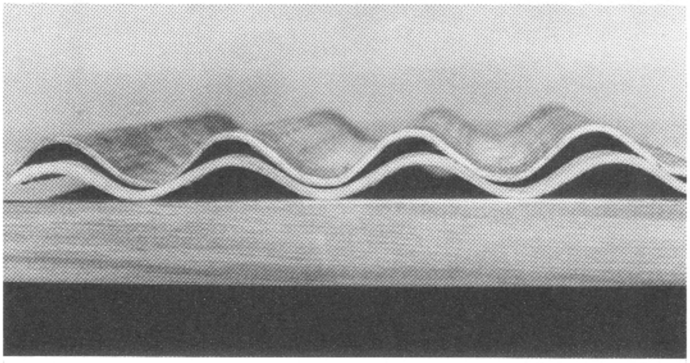

Figure 4 *Deformation (flattening) of corrugated sheet after six months of natural weathering (in Costa Rica) in an unrestrained condition. The control sample placed on top is for comparison.*

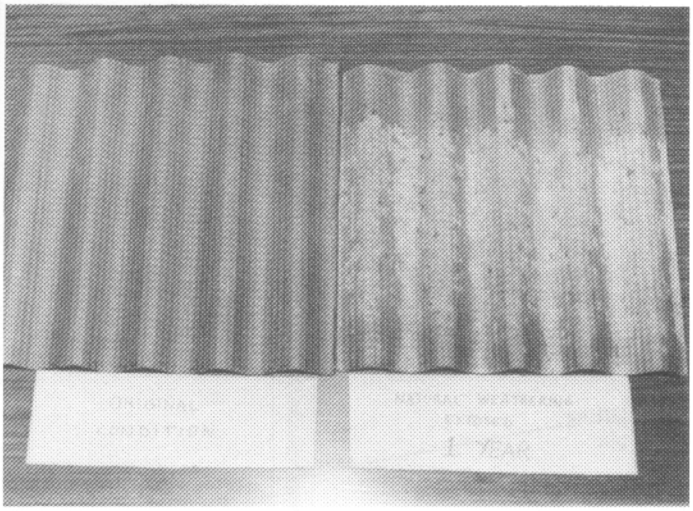

Figure 5 *Protective paint (brick red color) partially flaked after one year of natural weathering in Costa Rica.*

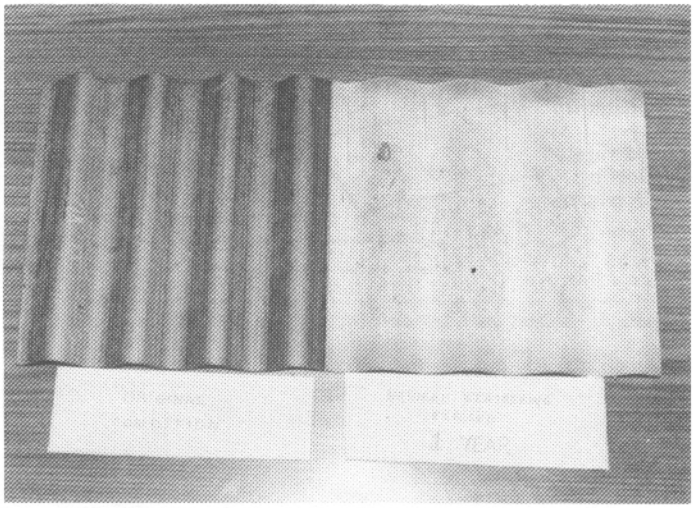

Figure 6 *Unpainted asphalt surface showing fading and cracking after one year of natural weathering in Costa Rica.*