Development of a New Composite Material from Waste Polymers, Natural Fiber, and Mineral Fillers

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Synopsis

This work describes a panel made from waste polyethylene, henequen fibers, and mineral fillers. The physical and mechanical properties of the product were determined and compared with the properties of commercial panels. The new material has good mechanical properties and high environmental resistance. Its thermal insulating capacity is about 10 times better than that of asbestos-cement panels. The adhesion grade between fibers and polymer was investigated.

INTRODUCTION

The construction industry needs materials with high environmental resistance, low thermal conductivity, and good mechanical properties for different uses such as roofs, soffits, divisionary panels, etc. Besides it is desirable that the materials should have a low cost.

For this reason, in this investigation, we tried to develop a composite panel using henequen fibers as the reinforcement element and waste polyethylene (PE) as the matrix element. Such a composite panel may be usable in the construction industry. However, one of the most serious deficiencies of PE and other vinyl polymers is its low environmental resistance, especially to ultraviolet light (UV).[1] This, therefore, made necessary the addition of a third component to the composite.

The third component was river sand, which was found to improve the environmental resistance and in particular reduce the degradation by UV light.

EXPERIMENTAL

Materials. The PE used in this work came from waste films employed for packing. The films were first cut in an industrial shredding machine, and then were washed with a commercial detergent. Finally the recovered PE was pulverized in an industrial crushing machine.

The PE obtained in this way was a powder with a mean diameter of 200 E-5 m. The density of the powder PE was 0.92 $\pm$ 0.01 g/cm^3. This was determined according to ASTM D 1505, using benzene as immersion liquid at 20°C.

The henequen fiber came from the *Agave fourcroydes*. The fibers used had a length from 15 to 40 cm. A thin matt was formed with the

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fibers present in a randonm arrangement. The matt had a weight of about 0.9000 kg/m^2.

The river sand had a composition fundamentaly formed by feldspar and quartz. In Figure 1 is shown the X-ray spectrum of the sand. Its mean density was 2.6 g/cm^3, and it was determined by pycnometry using water as immersion liquid at 20°C. The sand particles had a mean diameter of 420 μm.

ELABORATION METHOD

The composite panel was made by first mixing the PE powder and sand using a laboratory mixer. Due to the difference in the specific weight of the components, it was necessary to employ a paraffinc liquid of low mo-

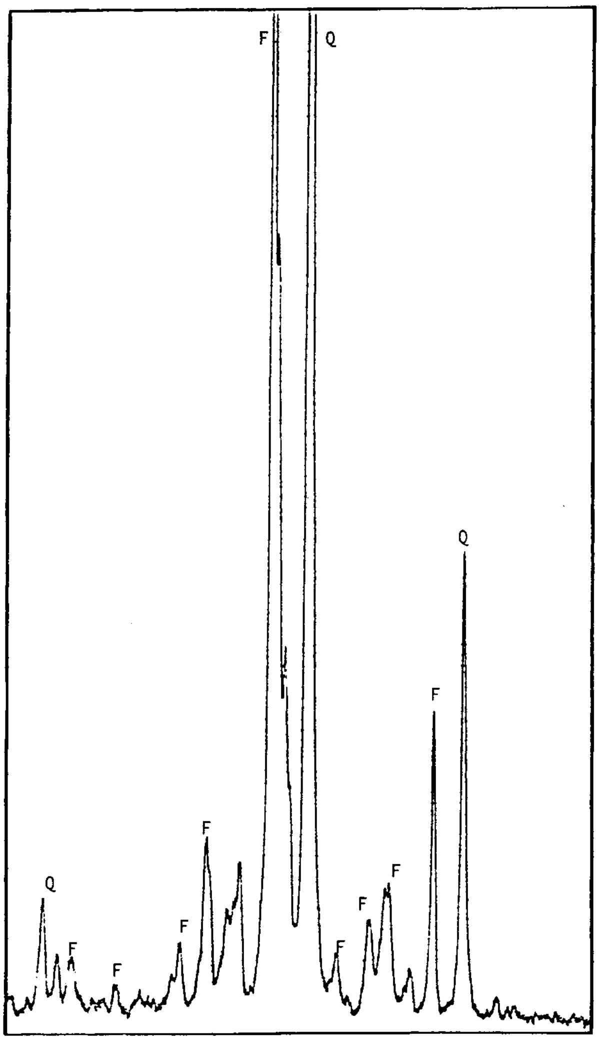

Fig. 1. The specific X-ray spectrum of river sand: (Q) quartz; (F) feldspar.

lecular weight in order to avoid the sedimentation of the sand. About 2 w% of paraffinc was used.

The PE sand blend was deposited over the fiber matt and the subjected to a molding process. The molding conditions were: temperature 150°C, pressure 30 kg/cm^2, and molding time 10 min. The fabrication process was either a discontinuous hot plate system or a continuous one using infrared radiation of high frequency for the fusion of the PE–fillers mixture (see Fig. 2).

TEST PROCEDURES

The adhesion grade between PE and henequen fibers was determined at the beginning of the investigation. This was compared with the adhesion grade obtained between nylon fiber and PE and between glass fiber and PE. All of the fiber/PE systems were evaluated through measurement of the ultimate strength of the pullout test.[2-4]

The flexural strengths of the polyethylene henequen panel and other commercial panels were determined according to ASTM-D-790-66 using an Instron machine, Model 1125. The cross speed was 2 mm/min.

The mechanical properties of the corrugated panels were determined with a load rate of 35 kg/s and 1200 mm of span according to national test C-27-1982 of the Secretaria de Patrimonio y Fomento Industrial.

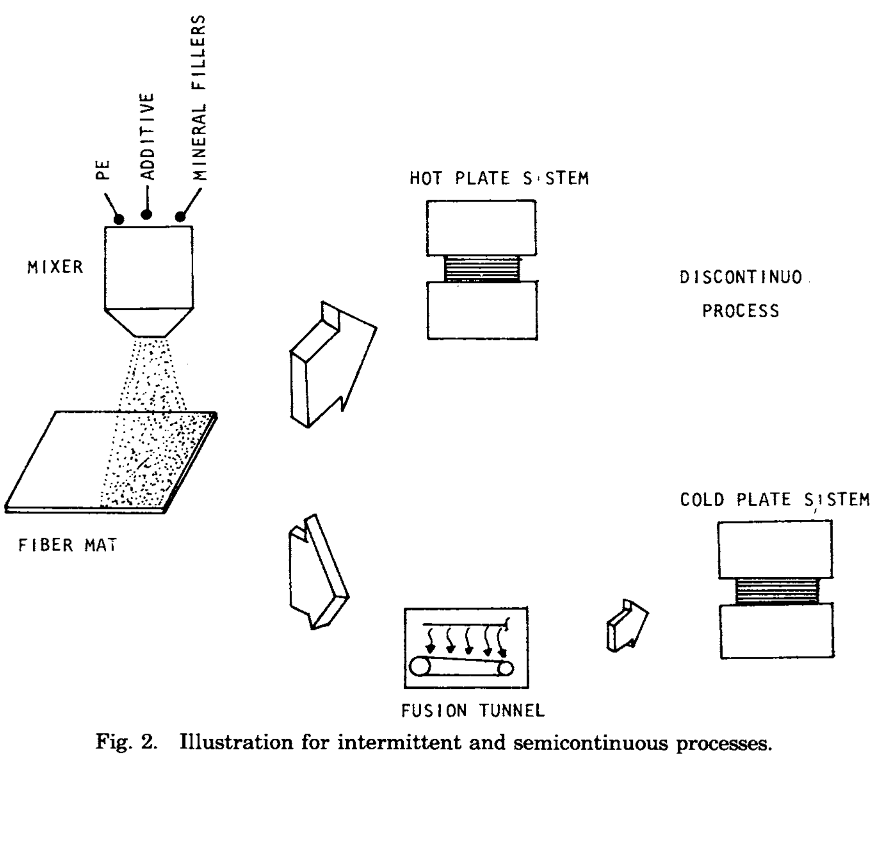

Fig. 2. Illustration for intermittent and semicontinuous processes.

The water absorption test of the PE–H panel and the other commercial panels were carried out according to ASTM-D-570. The water absorption was calculated from the weight difference before and after the immersion of the sample in water.

The thermal conductivity of the different panels was determined using a rapid K thermal conductivity instrument according to ASTM-C-518.

Finally the environmental resistance of the panels was studied in an accelerated weathering tester. The conditions of the cycle test were 18 h of UV radiation at 348°K and 2 h of fog, 2 h of UV radiation at 348°K and 2 h of cold at 253°K. The total time of exposure of the samples was 720 h.

RESULTS AND DISCUSSIONS

Adhesion Grade. The results in Table I show that the bigger ultimate strength pull of the joint is obtained between henequen fiber and PE. This is due to the fact that the failure in this system is in the fiber phase. On the other hand, the failure in the PE–nylon fiber system and PE–glass fiber system is in the interphase between PE and fiber. This is showed clearly in Figure 3. The zigzag portion of the curve, especially in the PE–glass fiber curve, shows the slipping of the fiber relative to the matrix.

The high adhesion grade between PE and henequen fibers is partially due to the topography of the fiber, which allows it to have a good mechanical mooring (see Fig. 4). For this it is not necessary to employ coupling agents.

Environmental Resistance. Addition of the sand to the PE increases the environmental resistance by about 1000%. These results are reported in Table II. In Table III are reported the results of the accelerated weathering test on the PE–henequen panel and other commercial panels. In addition the incorporation of mineral fillers such as sand improves other properties of PE such as flexural strength and abrasion resistance. The first increased by about 300% and the second by about 37%. These results are reported in Table IV.

Flexural Strength. The flexural mechanical properties of the composite panel and other commercial panels are reported in Table V. The high flexural strength of the PE–henequen panel is due to its high tenacity. The panel is not completely cracked at the end of the test. This is due to the presence of the fiber matt. Similar results are obtained with a PE–henequen corrugated panel. In Table VI are showed the mechanical properties of the PE–henequen corrugated panel and other commercial corrugated panels.

TABLE I
Ultimate Strength of Pullout Test[a]

Joint	Ultimate strength of joint (N/m^2) $E + 05$
PE–henequen	3.19 ± 0.16
PE–nylon	2.45 ± 0.14
PE–glass fiber	1.43 ± 0.14

[a] According to ASTM-638.

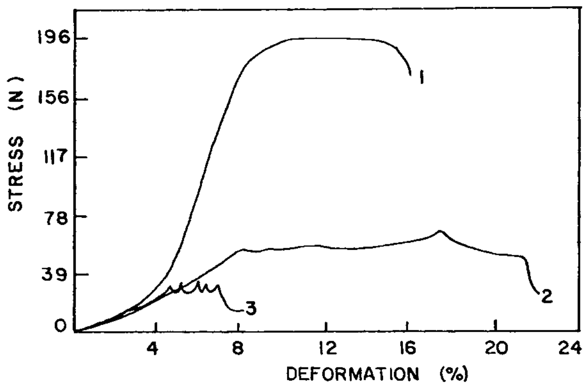

Fig. 3. Typical curves stress–deformation of the pullout test: (1) PE–henequen fiber; (2) PE–nylon fiber; (3) PE–glass fiber.

Fig. 4. Image of henequen fiber by scanning electron microscope.

TABLE II
Ultraviolet Radiation Resistance of PE-Henequen Panel

Material	Ultraviolet radiation resistance	Flexural strength
PE without mineral fillers	$\simeq$ 1 year	Decrease about 50%
PE reinforced with mineral fillers	> 10 years	Decrease about 5%

TABLE III
Environmental Resistance of Panels

Material	Environmental resistance	Damage
PE–henequen	720 h (10 years)	Light hardening and yellowish
Asbestos–cement	720 h	Light cracking by the water evaporation contained inside of the panel
Asphalt pasteboard[a]	180–200 h	Hardening and cracking
Plywood[a]	55–72 h	Ungluing of wood capes
Coconut laminated[a]	44–72 h	Swelling and cracking

[a] Variable with the material quality.

TABLE IV
Flexural Strength and Abrasion Resistance of PE Reinforced with Mineral Fillers

Material	Flexural strength (Pa) $E + 05$	Abrasion resistance[a] (volume loss · cm^3)
PE without mineral fillers	68–82	0.625
PE with mineral fillers	202–247	0.454

[a] According to ASTM D 635.

TABLE V
Flexural Mechanical Properties of Panels

Material	Thickness (m) $E - 03$	Elastic modulus (Pa) $E + 05$	Flexural strength (Pa) $E + 05$
PE–henequen	5.6	16180	343
Coconut laminated	4.6	15493	297
Plywood	6.6	31183	597
Asphalt pasteboard	2.5	8727	84
Asbestos–cement	5.5	97079	319

TABLE VI
Mechanical Properties of Corrugated Panels[a]

Material	Thickness (m) $E - 03$	Maximum load transversal (N · m)	Moment flexion (N · m/m)	Observations
PE–henequen	50	4952	519	Did not fracture and recover its original shape
Asphalt pasteboard	25	1519	153	Did not fracture but did not recover its shape
Asbestos–cement	55	31418	1826	Shows fragile fracture

[a] According to c-27- 1982 National test.

TABLE VII
Thermal Conductivity of Different Materials

Material	Density (kg/m^3) $E + 03$	Thermal conductivity (W/m · K)
PE–H laminated	0.60	22.59
Asbestos–cement	1.92	241.0
Asphalt pasteboard	0.43	20.71
Wood (pine)	0.55	48.58
Cork	0.16	13.93

Thermal Conductivity. The PE henequen panel has a low thermal conductivity due to the presence of the fiber. This is ten times smaller than that of the asbestos–cement panel. The thermal conductivity measurements are reported in Table VII.

Water Absorption. The PE–henequen panel has a low water absorption due to the PE matrix impermeability. The water absorption is not greater than 2% in weight. The absorption occurs through the sides of the panel. When these sides are sealed, the material is completely impermeable. In Table VIII are shown the results of the water absorption test.

CONCLUSIONS

The composite material presented here has good physical and mechanical properties and a high environmental resistance, which permits manufacturing roofs, divisionary panels, and other constructive elements. In Figure 5 are shown some constructive elements made by this composite material.

With respect to the addition of mineral fillers, these increase the environmental resistance of the PE and lead to a composite material with high mechanical properties and a low cost. This composite material can also be made from other thermoplastics such as poly(vinyl chloride), polystyrene and polypropylene. Also it is possible to employ other fibers such as ixtle fiber (from *Agave lechuguilla*), mezcal fiber (from *Agave tequilana*), coconut fiber, etc.

The advantage of using these thermoplastics and fibers for manufacturing composite materials is that the fibers are not degradated in the molding process. This allows them to keep their mechanical properties.

TABLE VIII
Water Absorption of PE–Henequen Panel and Similar Materials

Material	Water absorption (wt %) 24 h	Water absorption (wt %) 48 h
PE–H laminated	2.0	2.1
Coconut laminated	38–183	43–188
Plywood[b]	61–64	62–66
Asphalt pasteboard	20–25	24–30
Asbestos–cement	14–20	20–25

[a] According to ASTM D-570.
[b] Variable with the material quality.

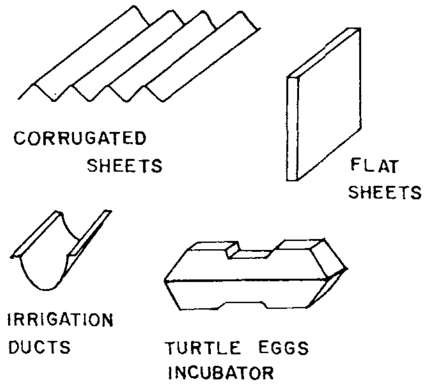

Fig. 5. Some uses of PE–henequen panel.

One possible benefit must be the use of recycled polymers in materials that have a long useful time life. This also must contribute to decreasing the environmental contamination associated with waste polymers.

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