Effect of Saline Degradation on the Mechanical Properties of Vinyl Ester Matrix Composites Reinforced with Glass and Natural Fibers

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ABSTRACT: One important application of polymeric composites reinforced with natural fibers is in the area of naval engineering design. The objective of this work was to study the influence of saline degradation on the mechanical properties of vinyl ester matrix composites reinforced with glass, sisal, and coconut fibers and natural fibers modified with bitumen. All samples presented mass loss after exposure in a salt spray chamber. All materials, except the composite reinforced with coconut–bitumen, showed a decrease in toughness after a salt spray test. The fracture of the vinyl ester resin with sisal and sisal–bitumen fibers showed a fiber bridging mechanism. These materials showed the highest value of toughness among the materials studied. The presence of fiber pullout was observed in the samples of vinyl ester resin reinforced with glass, coconut, and coconut fibers covered with bitumen. In these samples, poor adhesion between the fiber and matrix was observed. The treatment of fibers with bitumen increased the mass loss and decreased the stability of samples in a saline atmosphere. © 2008 Wiley Periodicals, Inc. J Appl Polym Sci 108: 2494–2502, 2008

Key words: adhesion; fracture; reinforcement; resins; toughness

INTRODUCTION

Natural fibers are a potential substitute for nonrenewable synthetic fibers such as glass and carbon fibers.[1]

The application of composites reinforced with natural fibers in naval engineering design reduces costs, fuel consumption, pollution, and density and increases the possibility of reaching a higher limit of velocity and power.[2,3] Natural fibers are also biodegradable and environmentally friendly.[4] Another reason for using natural fibers is the possibility of obtaining environmentally correct parts that can be designed by molding. The security and stability of these composite pieces are related to the life cycle analysis from the conception of the material up to the disposal.[5]

Polymeric materials reinforced with glass fiber are generally used in the naval industry and have high dimensional stability because of their hydrophobic nature.[4,6] The hydrophilic nature of natural fibers is a major drawback for their application in the reinforcement of composites. The poor moisture resistance of natural fibers leads to incompatibility with hydrophobic polymers, and this promotes poor interaction bonding at the fiber/matrix interface.[7] Chemical or physical modifications of natural fibers are usually applied to impart bonding and adhesion affinity to polymeric matrices.[8–12] In this work, the natural fibers, which were hydrophilic, were covered with bitumen (hydrophobic) to improve their compatibility with the usually hydrophobic resin.

The sisal plant, *Agave sisalana*, is native to Mexico; however, sisal fiber is mainly produced in Brazil and Tanzania.[13] The sisal leaves contain three types of fibers: mechanical, ribbon, and xylem.[14] The mechanical fibers are rough and are extracted from the periphery of the leaf, and they are mostly used commercially. The conductor tissue is the structure of the ribbon fiber, and it is responsible for tensile and flexure properties. Properties of the sisal fiber such as the hardness, toughness, and resistance depend on the cellulose content, the age of the plant, and the conditions in which they were planted.[14] The natural fibers are generally hydrophilic because of the lignocellulose, which contains hydroxyl groups.[15]

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Multicellular fibers extracted from the fibrous husk (mesocarp) of *Cocos nucifera L.* make up the structure of coconut fibers.[16] Coconut fiber has a high lignin content and thus a low cellulose content, as a result of which it is resilient, strong, and highly durable. The remarkable lightness of the fibers is due to the dried out sieve cells, which form cavities.

Coconut and sisal fibers were selected as raw materials in this work, as these fibers are important components of organic waste in Brazil. In 2006, coconut fibers reached 20% of this type of waste in some Brazilian states. This year, Brazil has produced 7000 tons of coconut fibers and is also a great world manufacturer of sisal fiber.

Vinyl esters are chemically similar to both unsaturated polyesters and epoxy resins. They were developed as a compromise between the two materials, providing the simplicity and low cost of polyesters and the thermal and mechanical properties of epoxies. Vinyl ester resins are employed when high corrosion resistance is necessary.[6]

The objective of this work was to produce vinyl ester matrix composites reinforced with glass, sisal, and coconut fibers and natural fibers modified with bitumen and to study the influence of saline degradation on the mechanical properties of these green composites for their application in the naval industry.

EXPERIMENTAL

Materials

All the materials employed in this work were obtained from commercial sources. The mixture of 40 mL of vinyl ester resin Dion VER 9100 (Reichhold Chemicals, Research Triangle Park, NC) was obtained by the addition of 4 drops of dimethyl aniline, 8 drops of an accelerator of cobalt, 20 g of Hydrogard GP, and 12 drops of Centerox (methil, ethil ketone peroxide).

The *Agave sisalana* fibers were produced in Mariana, Brazil. The plantation system consisted of simple rows, with the space between them measuring 2.80×0.70 m^2 and with a plant density of 0.5/m^2. The plantation rows were directed in a north–south direction. At harvest, the age of the plant was 6 years old. The sisal fiber was 0.14 ± 0.02 mm in diameter. The *Cocos nucifera L.* fibers were commercial fibers 0.24 ± 0.04 mm in diameter. The age of the plant was 6 years old. Owens Corning Co. produced the inorganic fiber glass. Betunel Kock Co. supplied the bitumen. The characterization of bitumen is shown in Table I.

The coconut and sisal fibers were weighed on an analytical scale and dried in an oven at 105°C until the mass was constant. The fibers were submitted to extraction with 350 mL of ethanol and cyclohexane (1 : 1 v/v) to determine the concentration of the compounds soluble in organic solvents. The humid mass of the coconut and sisal fibers was weighed. The fibers were then dried in an oven for 3 h at 105°C and weighed on an analytical scale. The fibers were washed by means of agitation in distilled water at 60°C for 1 h. The fibers were dried in an oven for 12 h at 60°C and for 2 h at 105°C and then weighed. The ash content was evaluated. Six platinum crucibles were weighed, heated in an oven at 600°C for 1 h, cooled in a dryer, and weighed again. Fibers (1 g) were deposited in each crucible, heated over a Bunsen burner, and weighed. The crucibles were heated in an oven for 4 h at 600°C and then weighed. A Mitutoyo micrometer was employed to measure the diameter of the fibers studied.

TABLE I
Characterization of Bitumen

	ASTM method	Result	Unit
Penetration	D 5	50	0.1 mm
Softening point	D 36	49.5	°C
Brookfield viscosity (135°C)	D 4402	356	mPa s
Brookfield viscosity (150°C)	D 4402	179	mPa s
Brookfield viscosity (177°C)	D 4402	66	mPa s
Ductility (25°C)	D 113	>150	cm
Solubility in trichloroethylene	D 2042	99.8	% w/w
Flash point	D 92	274	°C
Thermal susceptibility (PVD index)		−1.3	
Relative density (20/4°C)	D 70	1.011	

PVD, physical vapor deposition.

Treatment of the fibers with bitumen

A humid mass of coconut and sisal fibers (1 g) was weighed. The fibers were washed in 1 L of distilled water for 30 min, dried in an oven for 3 h at 60°C, and weighed. The bitumen was heated at 150°C and became liquid. Coconut and sisal fibers were agitated in 10 g of bitumen, which was dissolved in 100 mL of perchloroethylene. Fibers were filtered and dried in a vacuum oven at 30°C for 3 h. Natural fibers were mixed with bitumen, filtered, and dried in a vacuum oven at 30°C for 6 h. The diameter of the sisal–bitumen fiber was 0.20 ± 0.07 mm, and the diameter of the coconut–bitumen fiber was 0.33 ± 0.02 mm.

Composite production

The vinyl ester resin mixture was composed of 40 mL of vinyl ester resin, 4 drops of dimethyl aniline, 8 drops of 6% cobalt accelerator, 12 drops of Centerox ADM 90, and 20 g of Hydrogard GP in that order. A laboratory stirrer was used to homogenize the mixture at a constant rate of 1 rpm to prevent bubble formation. Preliminary tests were performed

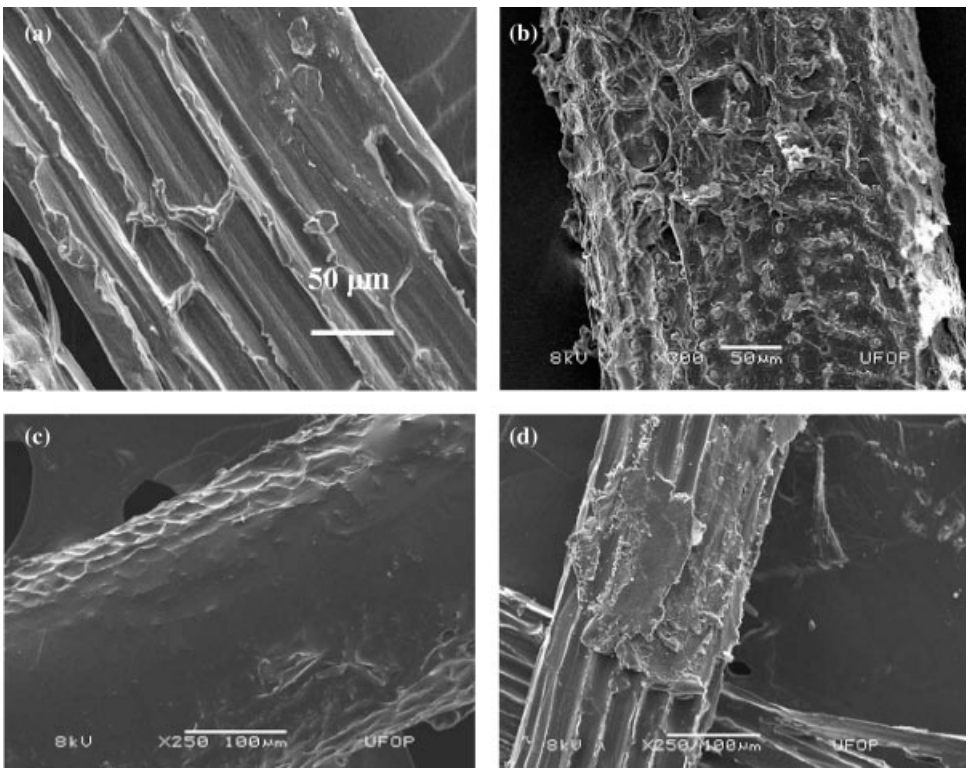

Figure 1 (a) Sisal and (b) coconut fiber surfaces and (c) sisal and (d) coconut fiber surfaces after the treatment with bitumen.

with different agitation rates: agitation of the resin at 1 rpm, dimethyl aniline and cobalt addition at 3 rpm for 2 min, Hydrogard GP addition at 5 rpm for 10 min, and final agitation at decreasing rates for 10 min to eliminate the trapped air as well as the final addition of Centerox ADM 90.

The resin mixture was placed in iron molds, whose shapes and dimensions were in accordance with the ASTM D 256-93 standard. A rubber film was placed between the molds. The molds contained 5% of one of the following randomly placed fibers: fiberglass, sisal, and coconut fibers. The resin cure was initially done at room temperature (35°C) for 30 min. Internal bubbles were produced during the resin cure because of the relative humidity, temperature, and molding process. The resin cure was tested at a temperature of 263.8 K for 30 min and then at room temperature for 4 h, with a long period of time required for total cure. The condition chosen for the resin cure was room temperature. The bubble formation was prevented by the use of a brush to mix the resin and fibers before the resin cure. External bubbles appeared as a result of the mold-filling process.

The sisal and coconut fibers were cut in lengths of 3.0 ± 0.1 cm and weighed in a 5% (w/v) proportion with respect to the resin. The fibers were distributed in a discontinuous and unoriented way in molds before the resin addition. The samples produced were vinyl ester resin, vinyl ester resin reinforced with glass fiber, vinyl ester resin reinforced with sisal fiber, vinyl ester resin reinforced with coconut fiber, vinyl ester resin reinforced with sisal–bitumen fiber, and vinyl ester resin reinforced with coconut–bitumen fiber.

Saline degradation

The composite samples were produced according to the ASTM D 256 standard for the impact test. They were exposed in a salt spray chamber (model CA 680, Corrotest Druckman, Druckman, São Paolo, Brazil). The test was performed according to the ASTM B-117 standard, for 304 h, with 38 cycles of 8 h of exposure in the chamber and 16 h of exposure in the laboratory atmosphere. The temperature was 35 ± 2°C, the pH was 6.5–7.5, and the relative humidity was 97%.

Mechanical characterization

Impact tests were carried out according to the ASTM D 256-93a standard with a mechanical impact testing machine (Microtest Charpy). For each test, five samples were tested before and after exposure in the salt spray chamber. The test temperature was 23°C, and the relative humidity was 57%.

Scanning electron microscopy was used to analyze the morphology of the natural fibers, the effect of saline degradation on the composite surfaces, and the fracture surface of the samples.

RESULTS AND DISCUSSION

Characterization of the fibers

The morphology of natural sisal and coconut fibers is shown in Figure 1(a,b). Coconut fibers have a structure of connected microfibers, cellulose chains, and cavities. Figure 1(c,d) shows the morphology of sisal and coconut fibers covered with bitumen. The surface of sisal–bitumen fibers is different from the surface of coconut–bitumen fibers. Sisal fibers appear almost uncovered with bitumen. Large heterogeneities in the coating appear on the surface for sisal–bitumen. Coconut fibers covered with bitumen show a smoother and more homogeneous surface than the natural coconut fiber because bitumen fills the cavities of the coconut fibers. Bitumen can be considered a colloidal dispersion of asphaltenes in an oily medium of maltene.[17,18] Asphaltenes contain large fused aromatic rings and saturated paraffin as straight-chain and branched compounds along with metal and heteroatoms (nitrogen, sulfur, oxygen, and vanadium) as part of a ring system.[19,20] Maltenes are hydrocarbons of smaller molecular weights and can be separated into resins, saturated oil, and aromatic oils.[21]

Plantation and harvest conditions and the age of the plant determine the properties and composition of natural fibers.[14] The plantation system of sisal consisted of simple rows with a plant density of 0.5/m^2. The plantation rows were directed in a north–south direction. At harvest, the age of the sisal plant was 6 years old. The age of the coconut trees was 6 years at harvest time, and the coconuts were picked 6 months after the blossoms appeared.

Sisal fibers contain more compounds (9.54 ± 3.08%) that are soluble in water than coconut fibers (2.41 ± 0.29%). Coconut fibers contain more inorganic products (1.95 ± 0.49%) than sisal fibers (1.48 ± 0.26%).

The diameter of sisal fibers is 0.14 ± 0.02 mm, and that of coconut fibers is 0.24 ± 0.04 mm. The diameter of natural fibers covered with bitumen is 40% higher than the diameter of natural fibers. Mukherjee et al.[22] reported that the fiber diameter did not affect the tensile resistance and rupture strain of sisal fibers.

The densities of the composites are shown in Table II. The volumetric fraction of natural fibers used in the composites was higher than the fraction of glass fibers used because of the comparative mechanical properties. The high concentration of natural fibers decreased the density of the composite material with respect to the composite reinforced with glass fibers.[4] A bitumen layer deposited on the surface of the coconut fibers increased the density of the composite because bitumen filled the cavities of the coconut fibers and was incorporated by fibers. However, the density of the composite reinforced with sisal–bitumen was lower than the density of the resin reinforced with sisal fiber. The surface of sisal–bitumen fibers is different from the surface of coconut–bitumen fibers. As shown in Figure 1(c), sisal fibers appeared almost uncovered with bitumen. In general, the addition of natural fibers covered or not covered with bitumen did not significantly modify the density of the resin.

TABLE II
Density, Mass Loss, and Toughness of the Samples

Sample	Density (g/cm^3)	Mass loss (%)	Toughness (J/cm^2)	Toughness after the salt spray test (J/cm^2)
VE	1.237	0.36 ± 0.04	230.1	199.3
VEGF	1.422	0.22 ± 0.01	1162.8	966.5
VESF	1.299	0.20 ± 0.13	1637.3	1561.5
VECF	1.232	0.45 ± 0.11	729.7	414.9
VESB	1.209	0.40 ± 0.05	1429.0	1178.4
VECB	1.322	0.70 ± 0.09	345.6	364.1

VE = vinyl ester resin; VECB = vinyl ester resin reinforced with coconut–bitumen fiber; VECF = vinyl ester resin reinforced with coconut fiber; VEGF = vinyl ester resin reinforced with glass fiber; VESB = vinyl ester resin reinforced with sisal–bitumen fiber; VESF = vinyl ester resin reinforced with sisal fiber.

Salt spray test

All samples presented a mass loss after exposure in the salt spray chamber, as shown in Table II. The mass change of the composites could have occurred because of processes such as water absorption, the solubility of the resin and fiber compounds, the hydroxylation of vinyl groups (—CH=CH_2), and the hydrolysis of ester groups.

Water absorption and the hydroxylation of the vinyl groups can produce a mass gain for all samples because hydroxylation introduces hydroxyl groups into the polymer chain. Hydroxylation of poly(ethylene terephthalate) has been reported in the literature.[23]

Mass loss of the resin occurred because of the predominance of the solubility of the resin in the salt spray chamber with respect to the other phenomena previously described in this work and because of the hydrolysis of ester groups of the resin. Vinyl ester resins are similar in their molecular structure to polyesters but differ primarily in the location of their reactive sites (C=C), these being positioned only at

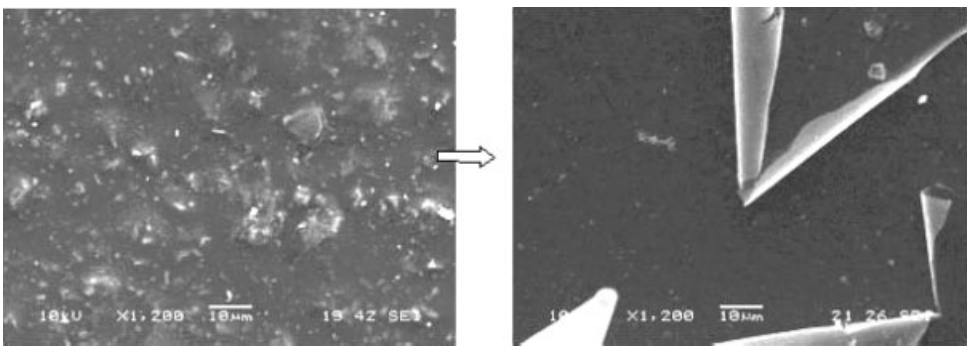

Figure 2 Vinyl ester resin surface before (left) and after (right) exposure in the salt spray chamber.

the ends of the molecular chains. The vinyl ester resins also feature fewer ester groups than polyesters. These ester groups are susceptible to water degradation by hydrolysis, and this means that vinyl esters exhibit better resistance to water and many other chemicals than their polyester counterparts and are frequently found in applications such as pipelines and chemical storage tanks.

The presence of water and oxygen in the environment of the chamber and the presence of chain unsaturations in the resin are favorable for the occurrence of hydroxylation and hydrolysis. In this work, a vinyl ester resin was submitted to 38 cycles (304 h) of 8 h of exposure in the salt spray chamber at 35°C and 16 h of exposure in the laboratory atmosphere.

The reinforcement with sisal fibers and glass fibers reduced the mass loss of the vinyl ester resin. The addition of sisal fibers with hydrophilic characteristics could have contributed to increasing the mass gain due to the water absorption of the material and to decreasing the mass loss. In this case, water absorption is the predominant parameter of mass change and compensates for the leaching out of the fiber materials. In the sisal fiber, the fraction of compounds soluble in water is 9.54%.

Glass fibers have high dimensional stability because of their hydrophobic nature and did not solubilize in a saline solution.[4,6] The addition of a fraction of glass fibers stabilized the resin and decreased the extension of the solubility of the resin and the mass loss. Despite the lower mass loss of composites reinforced with sisal fibers, the degradation of these samples was higher than the degradation of composites reinforced with glass fiber because of the higher levels of water absorption.

The composites reinforced with coconut fiber showed a higher value of mass loss among the samples studied. The coconut fibers were not as stable in a saline solution as the glass fibers, but they did not absorb the same volume of water as the sisal fibers because of their low cellulose content. Therefore, the composites reinforced with coconut fibers showed a mass loss due to the low water absorption, the solubility of the resin and some compounds in the coconut fibers, and the hydrolysis of ester groups to a minor degree.

Both the surface of the vinyl ester resin and the surface of the composite reinforced with glass fiber appeared to be smooth after the salt spray test (Figs. 2 and 3). This result was due to the leaching out of the resin material in a saline solution, which contributed to making the surface smoother.

Figure 4 shows that the surface of the composite with sisal fibers became smoother with a less irregular topography and with holes on its surface after the salt spray test. The holes could have originated from

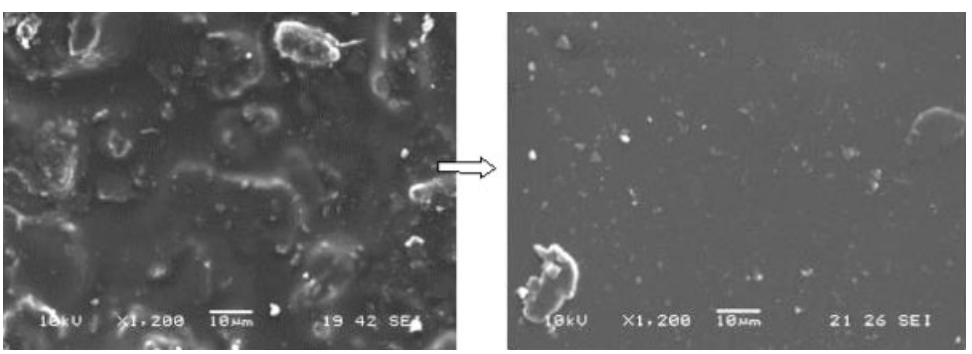

Figure 3 Vinyl ester resin reinforced with the glass fiber surface before (left) and after (right) exposure in the salt spray chamber.

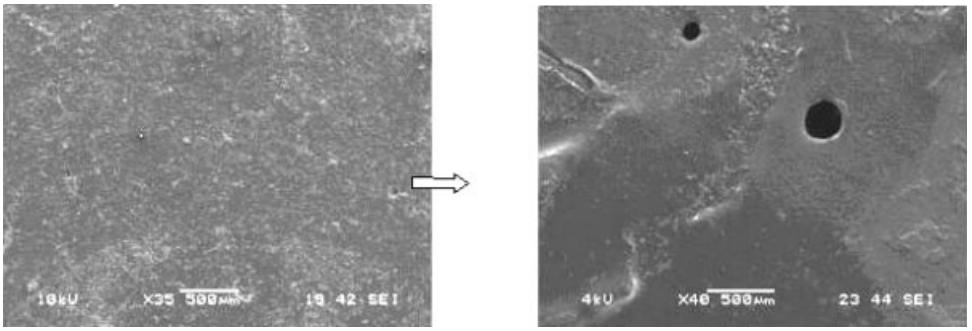

Figure 4 Vinyl ester resin reinforced with the sisal fiber surface before (left) and after (right) exposure in the salt spray chamber.

the high level of water absorption. After a prolonged period of moisture exposure, excess swelling with extraction of the water-soluble substances from the sisal fibers caused damage to the fiber structure. The extraction degree of the water-soluble compounds could be higher in a saline solution than in water. The damage in the fiber structure provided additional channels for water to diffuse into the composite and further weaken the fiber/matrix interface.

The surfaces of the composites reinforced with sisal–bitumen and coconut–bitumen showed a higher level of degradation among the samples studied after exposure in the salt spray chamber (Figs. 5 and 6, respectively). The bitumen coating increased the mass loss and decreased the stability of samples in the saline spray medium. The composite reinforced with coconut fiber covered with bitumen also showed the highest mass loss among the samples. Cracks were observed on the surface of the composites reinforced with coconut–bitumen fibers (Fig. 6). The moderate swelling of the coconut fibers did not cause damage to the fiber structure; however, the water absorption of fibers could have produced stress concentration and nucleated cracks at the fiber/matrix interface.

The surface of composites reinforced with sisal–bitumen fibers showed several holes with variable diameters, which could have been produced because of the water absorption at the sisal–bitumen interface and the solubility of the resin and fiber compounds (Fig. 5). As already reported, the surface of sisal–bitumen fibers is different from the surface of coconut–bitumen fibers. Sisal fibers appeared almost uncovered with bitumen. Excess swelling with extraction of the water-soluble substances from the sisal fibers caused damage to the fiber structure and the observed holes.

The bitumen coating treatment of sisal and coconut fibers did not reach the objective and decreased the stability of composites reinforced with fibers in the salt spray chamber.

Charpy test

The results of toughness obtained after the Charpy test are shown in Table II. The toughness of the composites reinforced with fibers was higher than the toughness of the vinyl ester resin. This result was expected and was in accordance with literature data.[24] The vinyl ester resin samples showed total rupture after the Charpy test and the lowest toughness value.

All materials, except the composites reinforced with coconut–bitumen, showed a decrease in toughness after the salt spray test. It is widely recognized that water has a pronounced effect on the mechani-

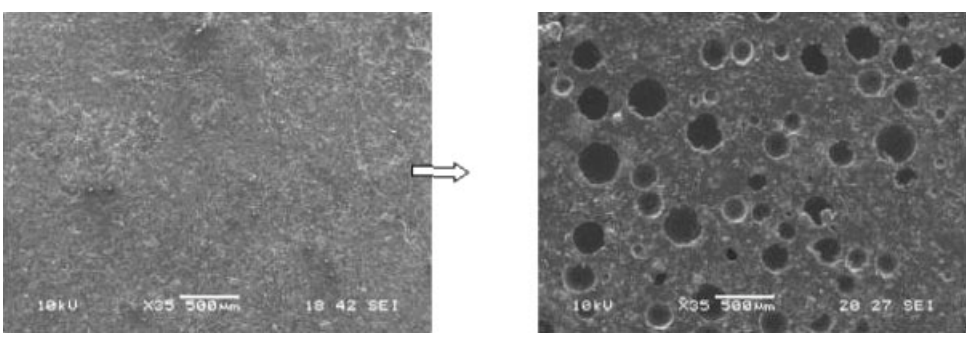

Figure 5 Vinyl ester resin reinforced with the sisal–bitumen fiber surface before (left) and after (right) exposure in the salt spray chamber.

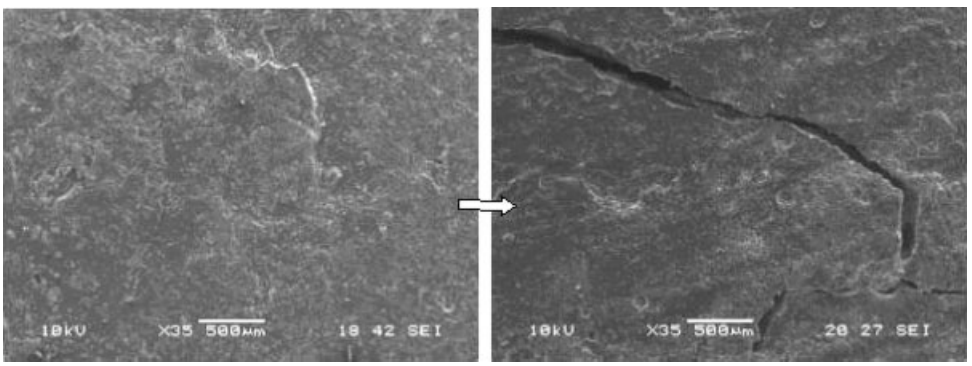

Figure 6 Vinyl ester resin reinforced with the coconut–bitumen fiber surface before (left) and after (right) exposure in the salt spray chamber.

cal properties of fiber-reinforced polymer materials.[25,26] Chow et al.[27] reported that the Izod impact strength was improved by a water immersion treatment until reaching a maximum value and then decreased. Water penetrates the resin and attacks the matrix, the reinforcement, and the fiber–matrix interface of several composite materials.

Coconut fibers are more hydrophobic than sisal fibers, and the water absorption of coconut fibers is lower than that of sisal fibers. The moderate swelling of the coconut fibers did not cause damage to the fiber structure; however, the water absorption of fibers could have produced stress concentration and nucleated cracks at the fiber/matrix interface. Bitumen is hydrophobic, and the adhesion at the coconut–bitumen interface could be higher than the adhesion at the sisal–bitumen interface. The degradation of these composites occurred from cracks (Fig. 6), which nucleated at the fiber–matrix interface. There are anchorage forces restricting the sliding of fibers and the presence of pullout,[28] and fiber/matrix debonding was observed in the samples of vinyl ester resin reinforced with coconut and coconut fibers covered with bitumen (Fig. 7). It is known that when plant fibers begin to swell in composites exposed to humidity, interfacial shear stress develop because of the increased osmotic pressure, leading to adhesive debonding (Fig. 7).[29]

Coconut fibers covered with bitumen showed a smoother surface than the natural coconut fiber (Fig. 1), and the adhesion at the coated fiber–matrix interface displayed signs of weakness producing total rupture. The composites with coconut–bitumen fibers showed a total rupture and presented the lowest level of toughness among the reinforced composites. This fracture behavior of samples was the same after the salt spray test. Roe and Ansell[30] observed the pullout mechanism in the fracture behavior of the vinyl ester resin reinforced with jute fiber and a weak adhesion fiber–matrix.

Because of the hydrophilic characteristic of the sisal fibers, the wetting of the sisal fibers by bitumen was poor [Fig. 1(c)], and bitumen did not protect the sisal fiber from the effects of the saline atmosphere. The toughness of sisal–bitumen composites decreased by 250 J/cm^2 after the salt spray test. After exposure in the salt spray chamber, the surface of composites of sisal–bitumen fibers presented several holes (Fig. 5). In this case, water penetrated the sisal–bitumen interface, causing sliding of the sisal fibers and the presence of holes on the surface (Fig. 5). The fracture of the vinyl ester resin with sisal

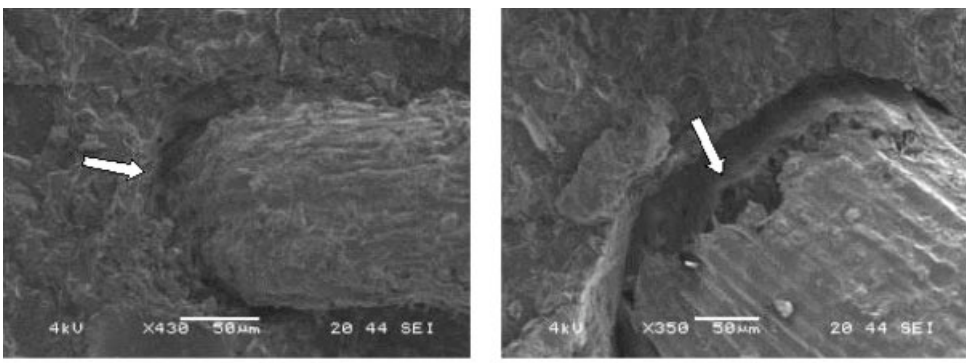

Figure 7 Vinyl ester resin reinforced with the coconut–bitumen fracture surface after the Charpy test: (a) 430 and (b) 350 × magnifications.

and sisal–bitumen fibers showed a fiber bridging mechanism,[31] with the sliding of fibers (Fig. 8). These materials showed the highest value of toughness among the materials studied. The swelling of the sisal fibers enhanced the frictional work from fiber sliding from the resin matrix and increased the energy absorption. Interfacial degradation contributed to the enhancement of toughening by fiber bridging.

The toughness of the sisal and coconut fiber composites decreased after the salt spray test. After a prolonged period of exposure in the salt spray chamber, excess swelling with extraction of the water-soluble compounds from the sisal fibers caused damage to the fiber structure, weakening the fiber/matrix interface, and decreased the energy absorption. Coconut fiber composites presented a higher mass loss and a higher decrease (of 314.8 J/cm^2) in toughness after the salt spray test (Table II). The swelling of the coconut fibers could have produced stress concentration and nucleated cracks at the fiber/matrix interface. The cracks were additional channels for water penetration and increased the mass loss of the composites reinforced with coconut fibers. Coconut fibers generated a brittle fracture of the composites with a lower value of toughness in comparison with composites reinforced with glass fibers.

The composites reinforced with sisal fibers showed partial surface rupture after the Charpy test. The sisal fibers furnished the characteristic of ductile fracture behavior to the composite.

The fracture of the vinyl ester composites reinforced with glass fibers showed a fiber pullout mechanism and total rupture of the fiber and matrix after the Charpy test (Fig. 9). This behavior was observed before and after the salt spray test and occurred because of the brittle fracture of the glass fibers and poor adhesion at the fiber–matrix interface.

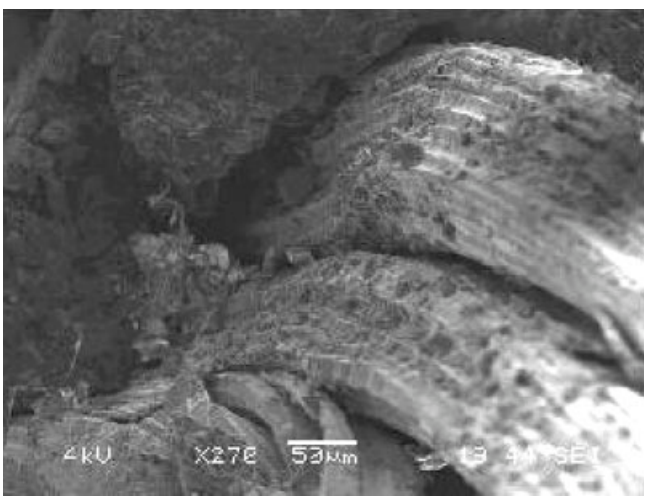

Figure 8 Vinyl ester resin reinforced with the sisal–bitumen fracture surface after exposure in the salt spray chamber and the Charpy test: 270 × magnification.

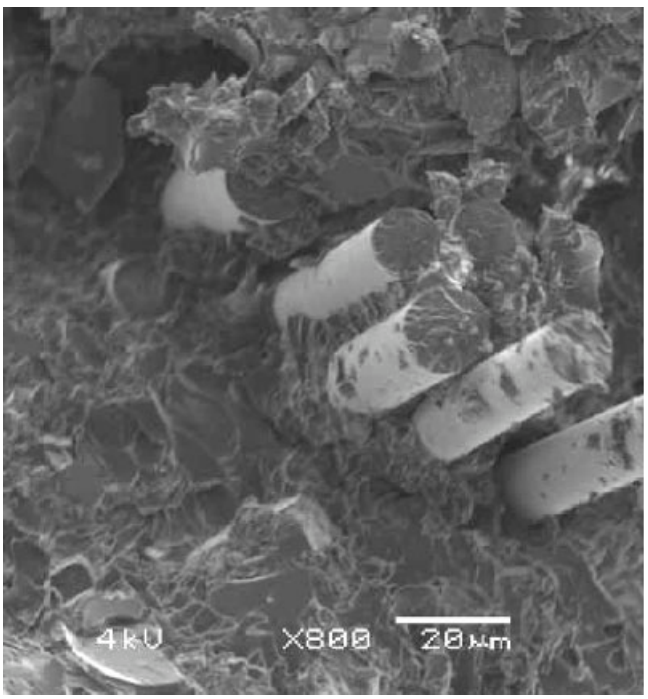

Figure 9 Vinyl ester resin reinforced with the glass fiber fracture surface after the Charpy test: 800 × magnification.

The application of composites reinforced with natural fibers in naval engineering design reduces costs, and natural fibers can be recycled from organic waste, contributing to reducing an environmental problem. The low density of the natural-fiber-reinforced composites, as shown in Table II, decreases fuel consumption and increases the possibility of reaching a higher limit of velocity and power. One disadvantage of composites reinforced with sisal and coconut fibers is degradation in a marine atmosphere. All materials, except the composites reinforced with coconut–bitumen, showed a decrease in toughness after the salt spray test. However, the reinforcement with sisal fibers and glass fibers reduced the mass loss of the vinyl ester resin after exposure in the salt spray chamber. Despite the lower mass loss of composites reinforced with sisal fibers, the degradation of these samples was higher than the degradation of the composites reinforced with glass fiber because of the higher levels of water absorption and because of the solubility in water of the resin and fiber compounds.

One reason for using natural fibers is the possibility of obtaining environmentally correct parts that can be designed by molding. Low-density materials such as composites reinforced with natural fibers have priority in the application of designs for panel boards, cabins, and furniture in the naval and automobile industries because of the increase in motor power. This

Figure 10 Piece of a car door molded with resin reinforced with sisal fibers.

resin reinforced with sisal fiber was molded as a piece of a car door, as shown in Figure 10.

CONCLUSIONS

The polymeric composites reinforced with glass and natural fibers presented mass loss after exposure in the salt spray chamber. The vinyl ester resin reinforced with sisal fibers showed the lowest mass loss of all. The composite with coconut fiber and coconut fiber covered with bitumen showed a higher mass loss among the samples.

The surfaces of the composites reinforced with sisal–bitumen and coconut–bitumen showed a higher level of degradation among the samples studied after exposure in the salt spray chamber.

The bitumen coating treatment of sisal and coconut fibers did not reach the objective and decreased the stability of composites reinforced with fibers in the salt spray chamber.

All materials, except the composite reinforced with coconut–bitumen, showed a decrease in toughness after the salt spray test.

The fracture of the vinyl ester resin with sisal and sisal–bitumen fibers showed a fiber bridging mechanism. These materials showed the highest value of toughness among the materials studied.

The presence of a pullout mechanism was observed in the samples of vinyl ester resin reinforced with glass fibers, coconut fibers, and coconut fibers covered with bitumen after the Charpy test. In these samples, poor adhesion at the fiber–matrix interface was observed.

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