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Wear resistance and friction behavior of thermoset matrix reinforced with *Musaceae* fiber bundles

Carlos Eduardo Correa [a,*], Santiago Betancourt [b], Analía Vázquez [c], Piedad Gañan [d]

[a] Grupo de Nuevos Materiales, Circular 1 73–76 bloque 22B 1r piso, Escuela de Ingeniería, Universidad Pontificia Bolivariana, Medellín, Colombia
[b] Facultad de Ingeniería Mecánica, Circular 1 No. 70-01, Bloque 11, Universidad Pontificia Bolivariana, Medellín, Colombia
[c] Instituto de Tecnología en Polímeros y Nanotecnología (ITPN), UBA-CONICET, Avda General Las Heras, 2214 Capital Federal, Buenos Aires, Argentina
[d] Facultad de Ingeniería Química, Circular 1 No. 70-01, Bloque 11. Segundo piso, Universidad Pontificia Bolivariana, Medellín, Colombia

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Fiber bundles from agricultural residues are promising sources of reinforcement for composite materials due to their technical and economic advantages. This work aims to compare the effect of variation of the fiber size, resin type and curing agent on friction and wear behavior of polymer matrix composites reinforced with fiber bundles obtained from *Musaceae* rachis. A pin on disc test equipment was used to study sliding of composites and steel as counter body with fixed test parameters. SEM images were used to identify the wear mechanisms. Results show that the wear resistance of composites is better than neat resin and increases when fiber size is reduced. The main wear mechanisms evidenced in all samples were adhesion, surface fatigue and crazing.

1. Introduction

Composite materials have been used to replace components traditionally fabricated with common materials with higher weight. The main reinforcements for polymeric composites are synthetic fibers like glass or carbon. Some researchers have shown [1,2] that an advantage of these composites is the improvement of the wear resistance behavior of the neat resin. It has also been shown that the fiber orientation is an important feature in the wear resistance [2–6]. These composites have the main wear mechanisms such as fracture, fibers debonding, as well as micro and macro cracking [1–6].

A strong trend in the world for environmental sustainability and the material availability issues is leading researchers all over the world to look for more environmentally friendly composites, using natural fibers in traditional synthetic resins or using biopolymers [7]. The use of these reinforcements may reduce the environmental influence of the polymers used [7]. These composites have low cost due to many of the fibers are obtained from crops residues. Their low density, flexibility during the processing, high specific strength and stiffness which is comparable with those of the composites reinforced with glass fibers [8].

The use of natural fibers has been studied in order to assess the suitability of these materials to replace the synthetic fibers in tribological applications. Early works with polyester resin and unidirectional cotton fibers were performed by Eleiche and Amin [9] who demonstrated that the use of the fibers decreased the wear rate as the fraction of reinforcement increased and depending on the orientation of the fiber respect to the sliding direction. In this case the fiber tips increased the diameter and spread out covering part of the resin preventing the composite from severe wear as is shown by the neat resin.

El-Tayeb has worked extensively with sugarcane fibers to reinforce polyester resin, studying dry sliding and abrasive wear [10–12]. Abrasive wear [10,11] shows that wear resistance of the composites is highly dependent on fiber size in the case of randomly distributed chopped fiber, and on the orientation of the fiber related to the sliding direction. However, in this abrasion case the best behaved composite was the glass fiber composite [11]. The sugarcane fiber reinforced composites have potential for tribological applications [10]. The wear mechanisms that El Tayeb found in these works include severe plastic deformation, microploughing, fibrillation, microcutting, and deterioration of the matrix among others. [10–12]

Similar dependence on the fiber orientation or size was observed in dry sliding of the sugarcane fiber reinforced composite. In this process, the polymer formed a layer that protected it from more damage giving it more wear resistance than the glass fibers reinforced composites. This lead El-Tayeb to conclude that the composites of polyester reinforced with sugarcane fibers can be competitive with those reinforced with glass fibers. [12].

These same results of wear resistance and wear mechanisms of natural fiber composites compared with the glass fiber reinforced ones

* Corresponding author. Tel.: +57 4 3544532.
E-mail addresses: carlos.correahe@upb.edu.co (C.E. Correa), santiago.betancourt@upb.edu.co (S. Betancourt), avazquez@fi.uba.ar (A. Vázquez), piedad.ganan@upb.edu.co (P. Gañan).

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have been found by other researchers such as Nirmal et al. [13–15]. He used chemically treated betelnut fibers as reinforcement, also appreciating the back transfer layer that reduced the wear previously mentioned by El-Tayeb [12].

Yousif using coir fibers [16] also found that this composite enhances the sliding wear performance of the neat resin. These results were also achieved by Yousif and El-Tayeb using treated and untreated oil palm fibers [17]. In this study they concluded that the treated fiber behaved better than the untreated one; both of them had better wear resistance than the neat resin.

All these successful studies with natural fiber for reinforcing polyester lead the authors to explore the *Musaceae* fiber bundles to reinforce polyester and vinyl ester resins for sliding wear applications such as gears or electrical isolation material, among others. *Musaceae* are a very important crop in the Uraba region in the Northern part of Antioquia Department – Colombia. The rachis of these plants are agroindustrial residues that have non-commercial use, but have a considerable amount of fibers in them that may be used as reinforcement for composite materials [18,19] such as those used in the present work. To the best of the authors' knowledge, no work has been found with the *Musaceae* fiber bundles to reinforce these resins for tribological purposes.

This work assesses the effect of the variation of the composite raw materials (resin type, hardener and fiber size) in the coefficient of friction and the wear behavior of these materials in sliding contact with carbon steel as counter-body. The behavior of the composites was compared with the one of the neat resin. The authors did not find any other work that has evaluated the effect of using different peroxides as hardeners in the wear behavior of the composites. This work is the first to do such comparison.

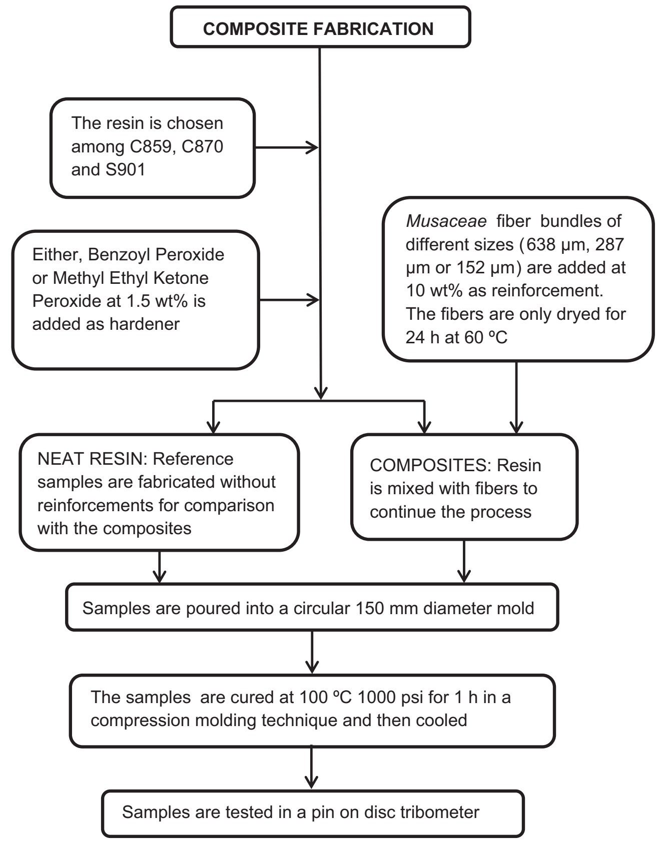

Fig. 1. Scheme of the composites fabrication process.

2. Experimental

2.1. Materials

Matrices: Resins correspond to: an orthophtalic polyester resin, reference Cristalan 859, denoted in this work as C859; one isophtalic polyester resin, reference Cristalan 870, denoted in this work as C870; and one vinyl ester resin, reference Swancor 901-3, denoted in this work as S901. These resins did not contain cobalt or any other promoter. Hardeners used in this work were methyl-ethyl-ketone peroxide (MEK) and benzoyl peroxide (BPO). Resins and hardeners used in this work were kindly supplied by ANDERCOL S.A.

Fiber bundles: The fiber bundless used in this work were extracted from the rachis of Colombian *Musaceae* plants. The plants are *Cavendish Valery* variety, and were this fiber bundles kindly supplied by BANACOL S.A.

The fiber bundles were delivered milled and a process of sieving was used to separate the fibers. Only those with an average fiber length of 638 μm, 287 μm and 152 μm were taken. These sizes were chosen because there were the 3 sizes of higher percentage on the sieving process in ANSI mesh size corresponding to those retaining in mesh 30, 50 and passing mesh 100. The fibers were not submitted to any chemical or physical treatment before being used in the composites. They were, however, dried for 24 h at 60 °C in order to eliminate any residual humidity that the fiber bundle may have held. The fiber bundles were then stored in sealed containers until their use in the composites.

2.2. Composites fabrication

The composites fabrication process is schematized in the Fig. 1 and is as follows.

Eighty grams of resin was poured into a pot with 1.5 wt% of hardener, and mechanically stirred with a NIPPO 5 speed handheld electric mixer in the second speed. Then, 10 wt% of fibers were added and the stirred for about 5 min. The mixture was then poured into a circular steel mold of 150 mm in diameter and 3.5 mm of thickness obtaining a uniform distribution of the blend. By using the BMC fabrication technique the mold was closed and compressed to 1000 psi with a hydraulic jack and the plates compressing the mold were heated to 100 °C. 1 h, then the heat was turned off and the mixture allowed to slowly cool for another hour. The pressure was then released and the plate unmolded.

Plates made of neat resin of each reference and each hardener, were also fabricated in order to have comparisons with the composites in the tribological behavior.

The Table 1 presents a summary of the Rockwell R hardness of all the composites and the neat resin plates fabricated in this work.

2.3. Tribological testing:

Sample preparation: Five (5) samples, 9 mm each, were cut and affixed to a 10 mm long metallic pin with cyanoacrylate contact adhesive. Samples were machined to match the pin diameter of 6.3 mm (1/4 in.) and the front of the pin was face turned in order to have a parallel face with the counterbody. A pin scheme is shown in the Fig. 2.

Tribological test: The tribological test was performed using a pin on disc machine as schematized in Fig. 2. Parameters of the experiment were fixed with speed: 200 m min^{-1}, distance: 3 km, normal load: 4.9 N.

A 1040 steel disc was used as a counter-body. In Table 2 is presented the chemical composition of the counter-body. The disc was machined after each run of the test with exactly the same turning parameters to assure the same surface finish with a roughness of $Ra = 5.997 \pm 0.32$ μm and $Rq = 7.494 \pm 0.41$ μm. These roughness parameters were measured with a Mitutoyo Surt test SV 3000 roughness