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POLYMERIC COMPOSITES REINFORCED WITH FIBERS OBTAINED FROM AGAVE *ANGUSTIFOLIA* HAW BAGASSE AS MATERIALS FOR BIPOLAR PLATES

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Abstract - Bipolar Plates (BPs) are one of the most important components in Polymer Electrolyte Membrane Fuel Cells (PEMFCs), as they play a fundamental role in water and gas management, electrical performance and mechanical stability in PEMFCs. Currently, graphite is the most widely used material in BPs due to its satisfactory corrosion resistance, high thermal and electrical conductivities and stable chemical properties. However, this material has several drawbacks such as limited mechanical properties, high weight and volume, as well as high manufacturing cost.

Therefore, to address these drawbacks, fiber-reinforced polymer composites have been extensively studied, as they offer several advantages, such as light weight, easy machinability and corrosion resistance. Therefore, this study proposes the design and production of polymeric composites reinforced with fibers obtained from Agave *angustifolia* Haw bagasse. Different fiber concentrations (0.0, 1.0, 1.5, 2.0, 2.5, 3.0, 3.0, 3.5, and 4.0, in wt %) were explored in the polymeric composites.

Regarding the distribution of fibers in the composites, a good distribution of fibers was observed in the polymeric composites. Regarding the mechanical properties, the elastic modulus tends to increase with the increase in the percentage of fibers, which suggests that the polymeric composites reinforced with bagasse fibers can be good candidates to be used in the bipolar plates of fuel cells.

Keywords: Fuel cells, Agro-industrial wastes, Energy conversion, Hydrogen.

Abstract -- Bipolar plates (BPs) are one of the most relevant components in the Polymer electrolyte membrane fuel cells (PEMFCs), as they play a fundamental role in water and gas management, mechanical stability, and electrical performance in this technology. Currently, graphite is widely used in BPs due to its high thermal and electrical conductivities satisfactory corrosion resistance, and good chemical properties. However, this material suffers several drawbacks such as high manufacturing cost, high weight and volume, limited mechanical properties.

Consequently, to address these drawbacks, fiber-reinforced polymer composites have been widely investigated, as these offer several advantages such as easy machinability, corrosion resistance, and light weight. Therefore, in this investigation, the design and production of fiber-reinforced polymer composites obtained from the bagasse of Agave angustifolia Haw is proposed. Different fiber concentrations (0.0, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, and 4.0, in % wt.) in the polymer composites were explored.

On the distribution of the fibers in the polymer composites, a good distribution of the fibers in the composites was observed. Regarding the mechanical properties, it can be observed that when the fibers are

added, the elastic modulus tends to increase considerably, which suggests that the polymer composites reinforced with bagasse fibers may be better candidates to be employed in the BPs plates for PEMFCs.

Key words: Fuel cells, Agro-industrial waste, Energy conversion, Hydrogen

INTRODUCTION

Currently, our society relies mainly on fossil fuels; however, this energy source is finite and combustion by-products can produce various environmental problems, such as climate change [1, 2]. Therefore, it is necessary to move towards the use of less polluting and environmentally friendly energies to reduce the impact of anthropogenic activities associated with conventional energy conversion and production. In this sense, hydrogen can play a very important role in achieving the energy transition, since it has a higher calorific value compared to conventional fuels [3,4]. Due to this interest, different technologies have been proposed to obtain electrical energy from hydrogen, highlighting the Polymer Electrolyte Membrane Fuel Cells (PEMFCs), since they allow converting the chemical energy contained in hydrogen into electrical energy [5-7]. However, it is necessary to improve the performance and reduce the manufacturing cost of several of their components to achieve their mass use [5-7]. In particular, the Bipolar Plates (BPs) are one of the components that have gained the most importance due to their role in gas and water management, electrical performance and mechanical stability of PEMFCs [8-10]. Therefore, the most promising materials for use as BPs must meet several technical objectives set by the U.S. Department of Energy (DOE) [11].

To date, various materials have been proposed for use in BPs. Currently, graphite is the most widely used material for BPs due to its corrosion resistance, high thermal and electrical conductivities, as well as its stable chemical properties [9,10]. However, graphite has several drawbacks such as limited mechanical properties and high fabrication costs [12,13]. Therefore, to address these drawbacks, fiber-reinforced polymer composites have been studied recently, as they offer several advantages, such as light weight, easy manufacturability, and high corrosion resistance [14-17].

Due to the importance of fiber-reinforced polymeric composites as materials to be used as BPs for PEMFCs, this study proposes the design and production of fiber-reinforced polymeric composites obtained from Agave *angustifolia* Haw bagasse. The present research proposes the use of bagasse as raw material for obtaining microfibers, since the state of Oaxaca is one of the main producers of mezcal and from its production process a significant amount of bagasse is discarded and dumped as waste [18]. Therefore, research on the reuse of bagasse in the production of cleaner energy is of great importance.

DEVELOPMENT

Materials

The polymer used was Acrylonitrile Butadiene Styrene (ABS), which was purchased from 3D Anycubic. The raw material used to obtain the microfibers was bagasse from Agave *angustifolia* Haw, which was collected from the residues of the mezcal production process in the Central Valleys of Oaxaca, Mexico.

Obtaining microfibers

The agave bagasse fibers were cleaned and processed to separate the non-fibrous components based on the methodology proposed by reference [19]. For this, they were washed in a 2% HCl solution at 60 °C for 2 h, in a 1:100 (w/v) ratio of fiber and solution, respectively. Subsequently, the mixture was neutralized to a pH of 7.0 with an alkaline solution (20% NaOH) and then the fibers obtained were washed with boiling distilled water. Once the process was finished, 200 ml of 95% ethyl alcohol were added and left to stand at 5 °C for 12 h for drying. To reduce the size of the fibers, they were ground in a high speed multifunction comminutor 800A (Figure 1).

Figure 1. Bagasse fiber size reduction mill.

Specimen design

The specimens were designed in SolidWorks software, considering the dimensions, tolerances and characteristics necessary for mechanical testing according to ASTM D638 [20] for tensile determination. The dimensions of the specimens are shown in Figure 2.

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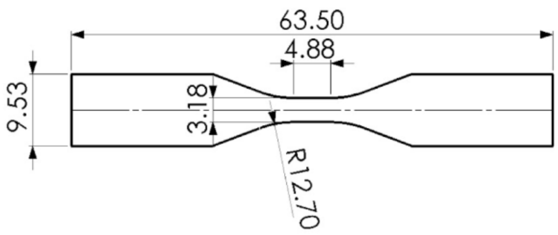


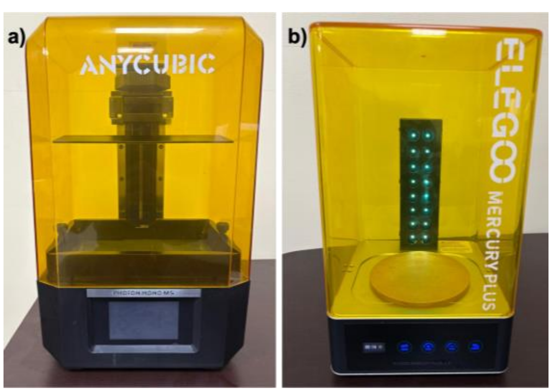
Figure 2. Specimen dimensions. The dimensions are reported in mm.

Specimen production

The specimens were obtained by mixing different concentrations of the ABS polymeric matrix and bagasse fibers, as indicated in Table 1. The specimens were obtained using a 3D printer model ANYCUBIC PHOTON MONO M5 (Figure 3a). After the specimens were produced, they were subjected under UV light for 15 min to fully cure the resin and obtain the final mechanical properties (Figure 3b).

Table 1. Composition of bagasse fiber-reinforced ABS polymeric specimens. Compositions are indicated in % by weight.

Test tube	ABS	Bagasse fiber
1	100	0
2	99	1
3	98.5	1.5
4	98	2
5	97.5	2.5
6	97	3
7	96.5	3.5
8	96	4



Equipment for specimen production. a) 3D printer and b) specimen dryer.

Mechanical tests

Tensile tests were performed based on ASTM D638 [20] using a 500 N capacity universal machine, which was adapted for dumbbell specimens. An extensometer was attached to the specimen surface to measure the elongation and calculate the modulus of elasticity and tensile stress. The mechanical tests were carried out at room temperature. Ten specimens for each composite composition were used in the mechanical tests to ensure reproducibility.

RESULTS

Structural analysis of the composites

Figure 4 shows the specimens obtained by varying the concentration of bagasse fibers in the composites. It is observed that when the concentration of the fibers increases, the specimens change from a light color to a yellow color, indicating the presence of bagasse fibers in the specimens. When the fiber concentration is higher than 2%, there is no longer a substantial change in the color of the fibers, indicating that the specimens are saturated with fibers. To observe in detail the distribution of fibers in the composites, Figure 5 illustrates the distribution of fibers in the composite formed from 2.5% bagasse fibers. According to this figure, an adequate distribution of bagasse fibers is observed, which can favor the mechanical properties of the specimens produced. These properties are presented and discussed below.

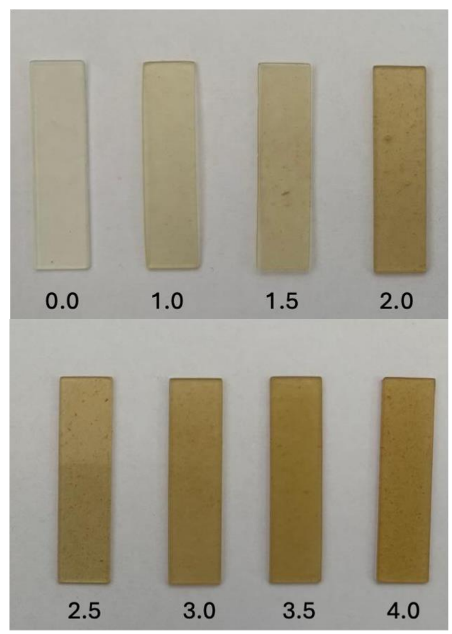
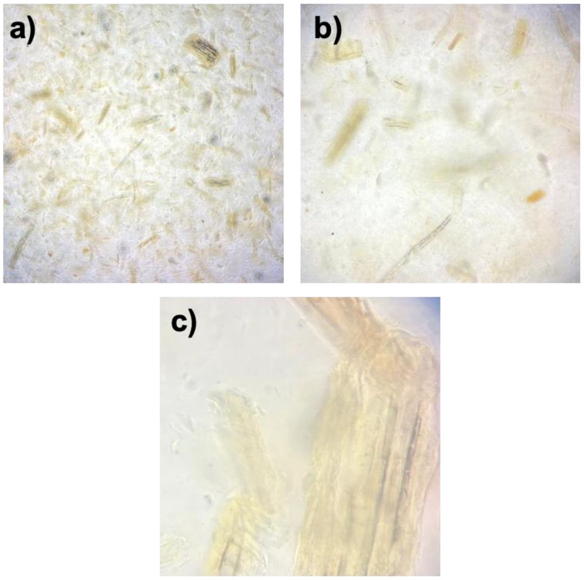


Figure 4. Specimens varying the concentration of bagasse fibers in the composites. The values reported in the figure are the percentages of fiber in the specimen, which are reported in % by weight.



Distribution of bagasse fibers in the specimens with 2.5% fiber in the composite at different magnifications. a) 40x, b) 100x, c) 400x.

Mechanical properties of the composites

In the first instance, the effect of the composition of the composites on the elastic modulus was analyzed. According to Figure 6, it can be observed that the addition of 1% fiber decreases the elastic modulus of the polymer composite; however, the percentages of 1.5% and 2% do not have a negative effect on this mechanical property with respect to the control. At 2.5%, 3.0%, 3.5% and 4.0% fiber percentages, the elastic modulus of the polymer composite increases significantly. This beneficial effect can be attributed to the fact that a higher concentration of fibers allows a better distribution of these fibers throughout the composite. This suggests that an addition of more than 2.5% of fibers in polymer composites can produce materials with better mechanical properties to be used in the bipolar plates of PEMFCs.

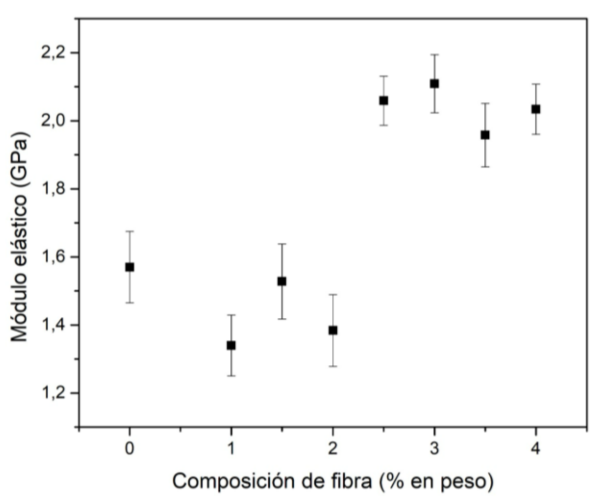
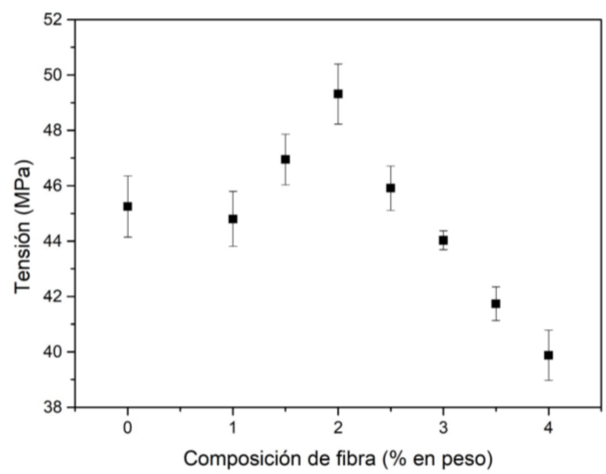


Figure 6. Elastic modulus of bagasse fiber reinforced polymer composites with varying fiber composition.

Figure 7 presents the relationship between tensile stress and fiber composition of the polymeric composites under study. As the percentage of agave fiber increases, a general increase in the tensile stress that the composite material can withstand is observed up to 2% fiber percentage. At higher percentages, the composite stress decreases as the fiber percentage increases. This suggests that the addition of agave fiber improves the tensile strength when fiber is added up to 2%.

Based on the results presented in the present research, it can be stated that the addition of bagasse fibers up to 2% improves the mechanical properties of modulus of elasticity and tensile strength of polymeric composites. This suggests that these compounds can be used in the manufacture of BPs and with them the possibility of obtaining energy sources with less environmental impact. In addition, the improvement of the mechanical properties studied by adding bagasse fibers allows the possibility of reusing this agro-industrial waste, which by itself no longer has commercial value in the mezcal industry.

However, it is important to mention that in order to use these compounds in BPs, it is necessary to investigate other properties established by the DOE, such as thermal and electrical conductivity as well as corrosion resistance).



Tensile strength of bagasse fiber-reinforced polymer composites with varying fiber composition.

DISCUSSION AND ANALYSIS OF RESULTS

The results obtained in this study demonstrate that the addition of Agave *angustifolia* Haw bagasse fibers significantly improves the mechanical properties of ABS composites, especially the elastic modulus and tensile strength at fiber concentration of 2% by weight. These findings are in agreement with previous research highlighting the potential of natural fibers as reinforcement in polymeric matrices. For example, Annandarajah et al [21] reported that materials with agave fibers in concentrations of 10-20% increase the mechanical properties in thermoplastic and polypropylene resins. Likewise, they reported the incorporation of fibers in polymeric composites of polylactic acid increasing some mechanical properties [22-24].

On the other hand, Antunes et al [9] highlighted that polymer-based composites can overcome the mechanical limitations of graphite, but emphasized the need to adjust the reinforcement ratio to avoid decreasing other properties. However, unlike those works, here an agro-industrial waste was used, which not only improves the mechanical properties, but also provides a sustainable approach by revaluing waste.

Finally, the decrease in tensile strength with fiber concentrations higher than 2% could be related to the formation of agglomerates, a phenomenon reported [25] in composites with high percentages of reinforcement. This underlines the importance of optimizing the fiber-matrix interface, an aspect that future studies could explore by chemical or physical treatments of the fibers to improve their adhesion.

CONCLUSIONS

The present study reported the production of polymer composites reinforced with bagasse fibers, varying the fiber composition in the composites. The composites produced present a good distribution of bagasse fibers in the polymeric matrix. The mechanical properties of the polymeric composites improve significantly with the incorporation of the fibers, which makes them possible candidates for BPs. However, in order to use these composites in BPs, it is necessary to measure other properties established by DOE such as thermal conductivity, electrical conductivity and corrosion resistance.

Additionally, it is proposed to explore the effect of surface treatments on bagasse fibers, such as chemical couplings, to optimize fiber-matrix interaction and mitigate the reduction in tensile strength observed at high concentrations. Studies along these lines could increase the efficiency of the composites and extend their applicability to other components of clean energy systems, thus consolidating their role in the transition to sustainable technologies.

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Project Management project	Alejandro Gomez-Sanchez Heriberto Cruz-Martinez
Data Curation	Alejandro Gomez-Sanchez Luis H. Robledo Taboada
Validation	Victor A. Franco-Luján Luis H. Robledo Taboada
Writing - Preparation of the original draft	Alejandro Gomez-Sanchez Rita T. Martinez-Salgado Heriberto Cruz-Martinez
Resources	Heriberto Cruz-Martinez