

Investigation on Flexural Properties of Cotton Fiber/Polyurethane Laminate Composite with Alumina Thi-Hydrate

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Abstract: The present work aims to evaluate the mechanical behavior of the composite of polyurethane derived from a vegetal oils blend (PU) reinforced with cotton fiber fabric (CF) and with addition of Alumina Trihydrate (ATH). The manufacturing process that was used to produce the laminate in a study with different orientations of the fibers (from 0°, ± 45°, 90°) was the vacuum bag. For comparison and study purposes, were tested the neat PU, PU with addition of ATH (PU + ATH) and the laminate of PU reinforced with cotton fiber fabric and ATH. The mechanical behavior under flexural tests were evaluated. For the composite of PU+ATH+ 7CF-0° (64.45 MPa and 3.473 GPa), the flexural strength was increased compared to a non-reinforced polymer matrix, PU+ATH (48.73 MPa and 2.259 GPa). With the variation of fiber orientation there was variation of the maximum flexural stress and flexural modulus, as expected.

Keywords: composite, polyurethane, cotton fiber fabric, laminate, flexural properties.

INTRODUCTION

Awareness of reduced environmental impacts and the durability of non-renewable petroleum based materials in the environment have resulted in a range of applications of composites reinforced with natural fibers within industries (QUIRINO *et al.*, 2015; MILANESE *et al.*, 2012). Restrict the emission of gases such as CO₂, in the atmosphere and a growing awareness of the finiteness of fossil energy resources, leads to the development of new materials based entirely on renewable resources (RAMESH; PALANIKUMAR; REDDY, 2017). The composites with natural fibers are an alternative to replace synthetic materials that are harmful to the environment and help control pollution problems (SANJAY *et al.*, 2017; GOMES *et al.*, 2007). For these reasons, research on renewable or green materials is being carried out with the aim of reducing the disruption of products made from fossil-source materials (MACHADO *et al.*, 2010; SANJAY, ARPITHA, YOGESHA, 2015; ALOMAYRI, SHAIKH, LOW, 2014).

Composite materials are designed to combine desirable characteristics of two or more distinct materials (ALMEIDA *et al.*, 2012). The reinforcement can be synthetic (E-glass, carbon and aramid) or from natural sources (curauá, sisal, jute, hemp, cotton, flax, banana, etc). Natural fibers have advantages such as: abundance, low cost, non-abrasiveness, easy processing, non-toxicity, high flexibility, sound insulation and low density (CARVALHO; CAVALCANTI, 2006).

Once density and cost that some natural fibers have been relatively small, natural fibers have been widely used as reinforcement in composites of interior parts of commercial vehicles (KORONIS, FONTUL, 2013; HOLBERY, HOSTON, 2006). Because of the low costs of natural fibers compared to synthetic fibers, there is a gradual substitution of synthetic fibers, *e. g.* such as glass fiber, which brings many social advantages (ZAH *et al.*, 2007). In their application, synthetic resins, such as polypropylene and polyethylene, are commonly used as a matrix for natural fiber composites (GOMES *et al.*, 2007). In the present work, polyurethane derived from vegetable oils will be used as matrix for the laminate composite, which is a material from renewable and biodegradable sources, similar to the natural cotton fiber that will be applied as reinforcement.

Aiming at the application of polymeric composites reinforced with natural fibers in interiors of transport vehicles, they must present a certain safety when placed in fire situations, allowing the necessary time for the rescue of the victims in accidents. Many products have been developed in order to reduce the combustion probability or the burning propagation rate in polymeric products (TONET, 2009). In Brazil, the CONTRAN (the Nacional Transit Council) n° 675 Resolution required that the internal coatings used in vehicles by the automotive industry have a flame propagation speed of 250 mm/min. Already in countries with advanced research in this subject, this value is 80 mm/min.

Flame Retardants are products which serve to avoid or suppress the combustion of flammable material exposed to high temperatures or fire. Alumina Trihydrate (ATH) is the most used flame retardant in the world and its usage correspond to 45% of the total flame retardant volume. It is largely used in materials processed in temperatures below 250°C (CANAUD; VISCONTE; NUNES, 2001).

Therefore, the main objective of this work is the mechanical characterization of a green composite of polyurethane derived from a blend of vegetable oils (PU) reinforced with cotton fiber fabric (FA) and with addition of Alumina Trihydrate (ATH), using the flexural test, according to ASTM D790-03.

MATERIALS AND METHODS

Polyurethane (PU)

The polyurethane used is obtained by mixing two components, polyol (component B – AG201) and prepolymer or isocyanate (component A – AG201), supplied by the company KEHL. The proportion used of the components (polyol and prepolymer) is 1:1, indicated by the manufacturer.

Cotton Fiber (CF)

The cotton fiber unidirectional fabric (Figure 1), 100% cotton, used as reinforcement of the composite under study was kindly provided by the company Toalhas São Carlos.



Figure 1 – Cotton fiber unidirectional fabric.

Alumina Trihydrate (ATH)

Aluminum hydroxide is one of the most widely used flame retardant additives (JEON *et al.*, 2017), this consumption is due to the low cost, besides the fact of being easily handled and have low risks to human health or the environment (FELIX, 2010). Alumina Trihydrate (ATH) or aluminum hydroxide ($\text{Al}(\text{OH})_3$) decomposes into alumina form (Al_2O_3) with the release of water at a temperature of around of 200°C. It decomposes endothermically forming water vapor, diluting the radicals in the flame, while the alumina residues build a form of protective layer (HULL; WITKOWSKI; HOLLINGBERY, 2011). The Alcoa Corporation generously was donated the ATH, which was used as flame retardant.

Manufacturing Process

The composite of PU reinforced with 7 (seven) layers of CF unidirectional fabric (7CF) and with addition of ATH is manufacture by the vacuum bag process.

For the manufacture of the PU+ATH+7CF composite, the first procedure was the definition of the amount of flame retardant that would be used. Tests were performed with the PU with addition of 10%, 20%, 30% and 50% of ATH of the total mass. It was defined that the largest amount of flame retardant would be applied, respecting the limitations of the vacuum manufacturing process. The PU with 50% of ATH was very dense, not allowing the resin to be spread over the entire length of the fibers. The amount of ATH most suitable for application in PU+7CF composite was 30% of ATH, being termed as PU+30%ATH+7CF.

The process of obtaining PU additivated with ATH based on two simple stages, ATH, standardized and controlled granulometry is previously mixed with polyol derived from vegetable oils (AG201 - Component B) is added after homogenization the prepolymer (AG201 - Component A), and the final homogenization was done. The used ratio of polyol and prepolymer is 1: 1, according to the manufacturer's information.

Previously, the area of the vacuum bag is delimited by a tacky tape responsible for fixing and sealing the bag. Thereafter, a thin layer of carnauba-based wax is applied in this area to facilitate demolding at the end of the process. In the sequence a T-connection and the spiroduit are attached, which allows the vacuum to be applied throughout the lateral extent of the bag not only at one point.

After doing this process is respected the stacking sequence for manufacturing vacuum bag, as shown in Figure 1a. Starting with the first layer of Peel Ply, following the PU+30%ATH is applied and above is positioned 4 layers of CF fabric. Again is applied the PU+30%ATH, always being spread with movements in the direction of the fibers to prevent misalignment. The remainder of the CF fabric layers is positioned (3 layers), and the last impregnation of the fibers with PU+30% ATH is done.

The second layer of Peel Ply and the distribution media are placed and, finally, with the vacuum bag plastic made a seal with the aid of tacky tape, and then a vacuum pump is turn on (Figure 2b). The vacuum pump is operated for 24 hours and, after that, the resulting plate stays for 72 hours finishing the curing process.

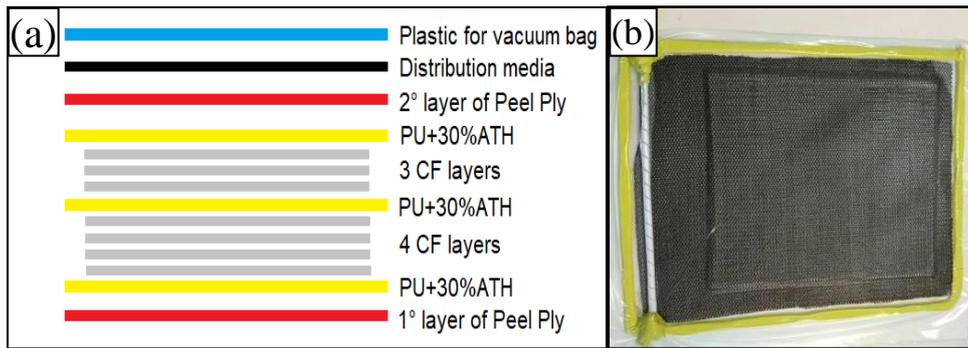


Figure 2 – (a) Stacking sequence of the manufacturing process by vacuum bag. (b) Vacuum bag finished with the vacuum pump already activated.

Samples of the laminated composite were produced with different fiber orientations, with 0° , $\pm 45^\circ$ and 90° . For the fabrication of samples with oriented fibers at 0° and 90° , seven CF plies are stacked with the fibers aligned in the same direction ($[0_7]_T$). Thereafter, the plates are cut in the longitudinally direction of the fibers to obtain the samples oriented at 0° , as well as these plates are cut crosswise in the direction of the length of the fibers to obtain the samples with fibers oriented at 90° . In the manufacture of specimens with orientation at $\pm 45^\circ$, seven CF plies are used alternating the direction of the fibers between 0° and 90° ($[0/90/0/90/0/90/0]_T$) as shown in Figure 2, and the samples were cut in a 45° direction with respect to the fibers.

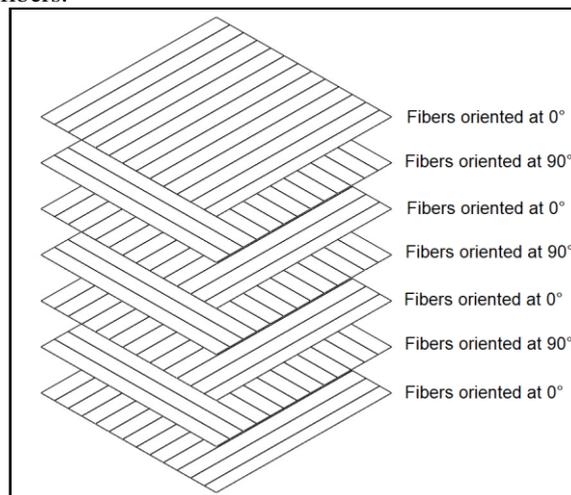


Figure 3 – Laminated composite $[0/90/0/90/0/90/0]_T$ (SILVA *et al.*, 2017).

RESULTS AND DISCUSSIONS

All bending tests were performed according to ASTM D790-03, with a span of 49 mm. The results obtained for each material tested, in this case, pure PU, PU+30%ATH and the composite of PU+30%ATH+7CF will be presented and discussed.

Polyurethane (pure PU) and Polyurethane with 30% of ATH

Three pure PU specimens (S1, S2 and S3) were tested, according to ASTM D790-03, using the machine data (crosshead) and the DIC process, for greater accuracy of the results, at a speed of 1 mm/min.

In Figure 4a, the flexural stress-strain curves of the pure PU specimens can be seen. The mean maximum flexural stress obtained was 57.90 ± 3.29 MPa and the flexural modulus was 1.530 ± 0.107 GPa. None of the specimens ruptured during the tests, demonstrating a great tenacity capacity of the polymer in bending.

For PU with 30% of ATH the average maximum flexural stress obtained was 48.73 ± 0.94 MPa and the flexural modulus was 2.259 ± 0.18 GPa (Figure 4b). Featuring a reduction in stress compared to pure PU. All the samples tested showed the same behavior, indicating a repeatability in the results.

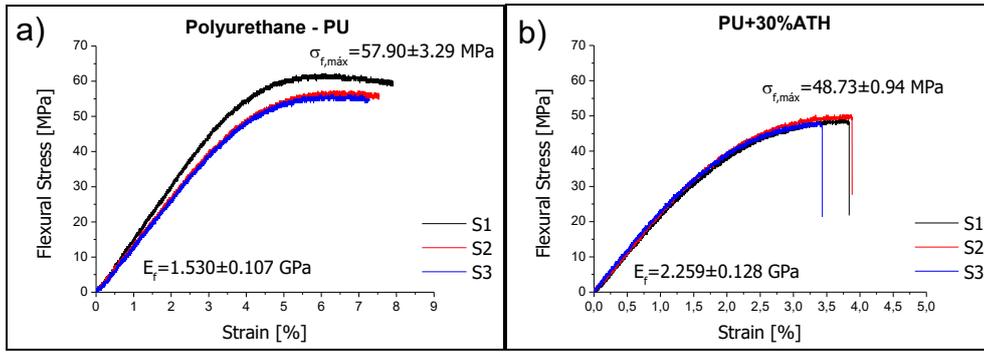


Figure 4 – (a) Flexural stress-strain curves of the pure PU. (b) Flexural stress-strain curves of PU+30%ATH.

Composite of Polyurethane with ATH and reinforced with Cotton Fiber (PU+30%ATH+7CF)

Mechanical flexural tests were performed on 3 specimens of PU+30%ATH with 7 layers of CF fabric orientated at 0° (S1, S2 and S3), the flexural stress-strain curves of the composite are shown in Figure 5. The mean maximum flexural stress was 64.45±3.85 MPa and the flexural modulus 3.473±0.232 GPa.

Comparing the results of the PU+30%ATH+7CF composite with your PU+30%ATH matrix (48.73±0.94 MPa and 2.259±0.128 GPa), there was an increase of approximately 30% in the maximum flexural stress and 54% in the flexural modulus.

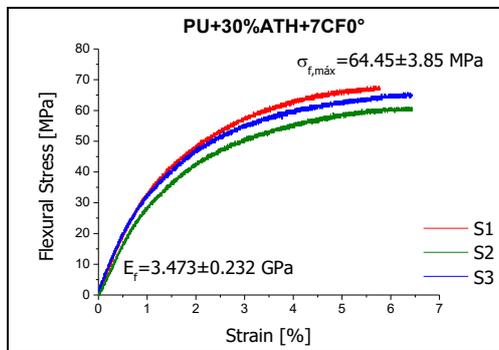


Figure 5 – Flexural stress-strain curves of the PU+30%ATH+7CF-0° composite.

Flexural tests were performed on 3 specimens of PU+30%ATH+7CF orientated at ±45°, as can be seen in Figure 6 (a), the mean maximum flexural stress reached was 44.72±6.71 MPa and the flexural modulus of elasticity of 2.538±0.366 GPa. For the composites of PU+30%ATH+7CF with fibers orientated at 90°, as can be seen in Figure 6 (b), the average maximum flexural stress is 20.93±1.14 MPa, considerably lower than that presented by the composite with fibers orientated at 0° and by the matrix with 30% of ATH. The modulus of elasticity also reduced considerably (1.349±0.267 GPa), exhibiting the value close to that of pure PU (1,530±0.107 GPa). Therefore, the higher the fiber angle, in the range of 0° to 90°, the lower the stiffness and the strength were exhibited by the composite.

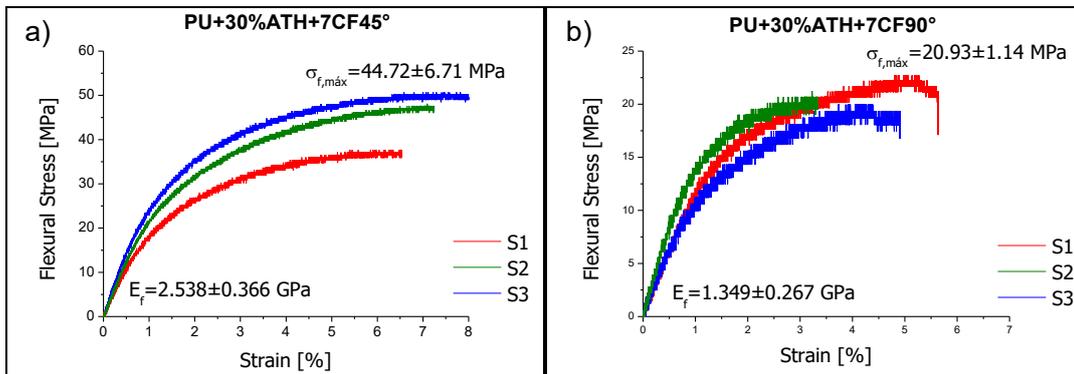


Figure 6 – Flexural stress-strain curves of the composites a) PU+30%ATH+7FA-45° e b) PU+30%ATH+7FA-90°.

In the work of Vera (2012) the mechanical and flammability behavior of interior aeronautical structures made from composites reinforced by natural fibers, specifically phenolic resin composites with cotton and sisal fibers, and also the same ones with 30% of ATH. The manufacturing process used for the natural composites was compression molding in closed metal mold under controlled temperature and pressure, short fibers, sisal and cotton fibers with lengths of 30 and 50 mm, respectively. With respect to the determination of the mechanical properties of the natural composites with addition of ATH, an increase in the modulus of elasticity and a reduction in the bending rupture stress were observed. In the case of the phenolic resin and cotton fiber composite, a maximum flexural stress of 69.10±11.25 MPa and a flexural

modulus of 2.52 ± 0.44 GPa is obtained. For the composite under study, of PU+30%ATH+7CF, there was an increase in the maximum flexural stress (64.45 ± 3.85 MPa) and in the flexural modulus (3.473 ± 0.232 GPa).

For each type of composite material, laminate, composites reinforced with chopped fibers, there is a type of mechanical behavior, so the importance of the characterization when a new type of material is developed.

CONCLUSIONS

Based on the results, the flexural mechanical behavior of materials, it is concluded:

- With addition of ATH in the Polyurethane, as flame retardant, there was an increase of the modulus of elasticity (E_f) and a reduction of the flexural resistance limit (σ_{fmax}) and the deformation. Specimens of pure PU and PU+30%ATH presented repeatability in the results indicating a good process of manufacturing and homogenization of ATH.
- For the composite of PU+30% ATH+7CF-0 ° (64.45 ± 3.85 MPa and 3.473 ± 0.232 GPa), the flexural strength and stiffness was increased compared to the matrix applied therein, PU+30% ATH (48.73 ± 0.94 MPa and 2.259 ± 0.128 GPa). The flexural properties for the PU+30% ATH+7FA laminate exhibited a reduction of the flexural modulus and the maximum flexural stress when the fiber angulation was increased, in the range of 0 to 90 degrees analyzed.
- For future works, it is necessary to perform flammability tests to verify the effectiveness of Alumina trihydrate in the reduction of the flame extinction time and the velocity of flame propagation, verifying the possibility of applying the composite of PU+30%ATH+7CF in interiors of transport vehicles.

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