COMPARISON BETWEEN COMPOSITES AND STEEL IN IMPACT ENERGY ABSORPTION

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***Abstract**. The car weight is considered an extremely important point of a project due to its influence on the performance, drivability, fuel consumption, environmental impact, endurance of components, et al. New requirements and goals for reducing fuel consumption and greenhouse gas emissions have increased the necessity to manufacture lighter vehicles, ensuring compliance of international laws. Besides legal requirements, the low weight certainly is fundamental to guaranty competitiveness for new generation vehicles. The work goals at the equivalence between steel 1010 SAE and hybrid composite manufactured with epoxy resin and carbon/glass/aramid fiber, the latter has the role of impact energy absorption, as an alternative to substitute a steel strap used to manufacture the CVT (continuously variable transmission) box protector. Both materials were tested in impact tower and shown to be equivalent regarding the amount of absorbed energy.*

***Keywords**: energy absorption, hybrid composite, automobilist application.*

1. INTRODUCTION

The automotive industry has sought alternatives to replace metal components for lighter materials, durable and economically viable. In this context, composite materials have been introduced in this industry segment.

This class of materials combines mechanical characteristics of metals, ceramics and polymers to achieve higher levels of stiffness, toughness and strength, in both environmental conditions and high temperatures (Callister, 2002).

Most of the composite material consists in two phases: matrix and reinforcement. The matrix has the function of distribute the loads through the interface, protect and provide structural stability to the composite. The reinforcement bears the applied loads and increases the strength of the composite (Callister, 2002).

The advantage of composites consists in the possibility of joining interesting properties for the mentioned purpose, forming a system of unique characteristics of low specific weight comparing to metal (Wang *et al*, 1997). Car interior parts have already been produced in polymer composites with synthetic and natural fibers, always aiming to reduce weight and costs and increase sustainability, keeping the quality and safety in projects.

Polymer matrix composite materials also have the advantage of complying the needs of vehicle design and durability, resistance to the vehicle operating temperature ranging from -40 to 120 ° C and chemical resistance to automotive fluids (Corum *et al*., 2001). Another advantage is the reduced process cost, due to the tooling used to process the composite has lower cost than used in metal, which demands higher pressure to obtain the final product (Sapuan *et al*., 2004).

Studies and technological advances became possible the application of composites in structural components and safety items. Cheon *et al.* (1999) showed in his work that hybrid composite glass/aramid absorbs 80% more impact energy than the composite made only with glass fibers. However, the carbon fibers are those with the noblest applications because they are seen as ideal for aircraft and aerospace industry as regards the manufacture of structural components (Rezende, *et al.*, 2000).

Considering this, the present study purposes to evaluate the impact absorption of a hybrid carbon/glass/aramid composite and compares it with SAE 1010 steel. Actually SAE steel 1010 is used to manufacture the protective box of the CVT (continuously variable transmission*)* of Prototype BAJA SAE off-road, which is designed and built by (under)graduate students at this university. The objective is replacing the component material, i.e., steel for composite.

2. EXPERIMENTAL METHODS AND MATERIALS

A total of 8 composites sample were prepared for each material tested, hybrid composite and steel 1010. The characteristics of each one is described as followed:

The composite was prepared using 3 plies of plain wave textile for each kind of material (carbon/glass/aramid, in this sequence) totalizing 9 plies. The epoxy system used as matrix was ARALDITE 5052, used for aeronautic application. The laminate was prepared using vacuum bag to guaranty uniform distribution through 3.0 mm thickness.

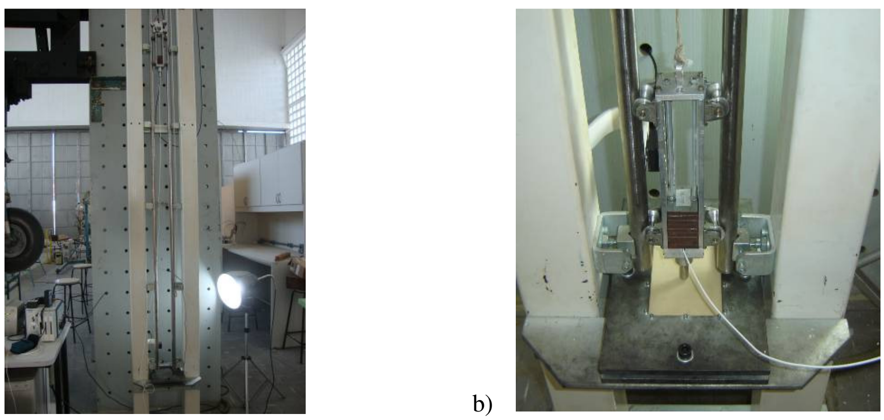
The metallic material used for sample preparation was SAE 1010 steel, with 1.5 mm thickness, removed from a steel plate which is in compliance with the industry supplier.

The thickness of composite tested was defined according to SAE Standard for BAJA World Competition, which defines that any material used to substitute same metal must to be manufacture with twice the thickness at least and warranty results similarity.

The samples were prepared according to ASTM D 7136, with 100X150 mm, Fig. 1. The same standard leads the tests.

Figure 1 - Composite sample prepared (carbon face).

The tests were performed at CTA (Aerospace Technical Center - Brasil). The instrumented drop-weight equipment was used for the impact tests is showed in Fig 2.



a) b)

Figure 2 - a) Test Machine; b) Impact test dispositive.

It consists in realeasing a sphere of a determinate height. The height can be varied, and therefore different impact energy can be obtained. For this work the sphere used was 1.5 Kg weight, it was adjusted to impact the samples with 25 J of energy.

The C-Scan analysis was performed using 5 MHz transducer in a Matec Ultrassonic Inspection System equipament in order to verify the fiber and resin uniform distribution and the damage caused by the impact.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Table 1 shows the properties and specifications of fibers and resin used to manufacture the hybrid composite and the SAE 1010 steel. One can see the advantages of replacing the metal material, since the mechanical properties of fibers are excellent and their density are lower than the cited metal.

Table 1 - Mechanical Properties of fibers, resin and metal (Callister, 2006).

Material	E (GPa)	Tensile Strength (MPa)	Density (g/cm³)
Glass Fiber	72.5	3450	2.58
Carbon Fiber	285	4650 – 6350	1.78
Aramid Fiber	131	3600 – 4100	1.44
Epoxy Resin	2.4	27.6 – 90.0	1.40
Steel 1010	207	420	7.85

The macroscopic damage aspects of composites are showed in Fig. 3. It can be observed a uniform damage pattern, where the matrix is crushed in front face (and fiber is sheared on rear face. According to Morais *et al.* (2005a), the rear surface suffers more damage and the pattern of cracks reproduces the direction of the fibers. This effect can be seen in Fig. 3b that shows the hexagonal pattern, typical of plain wave textile.

The Figure 3.b shows the translaminar failure of carbon plie. The dominant aspect is the presence of fractured fibers. This kind of failure has transverse orientation relative to the laminate plane and irregular topography when caused for tensile force, according to Marinucci (2001).

a) b)

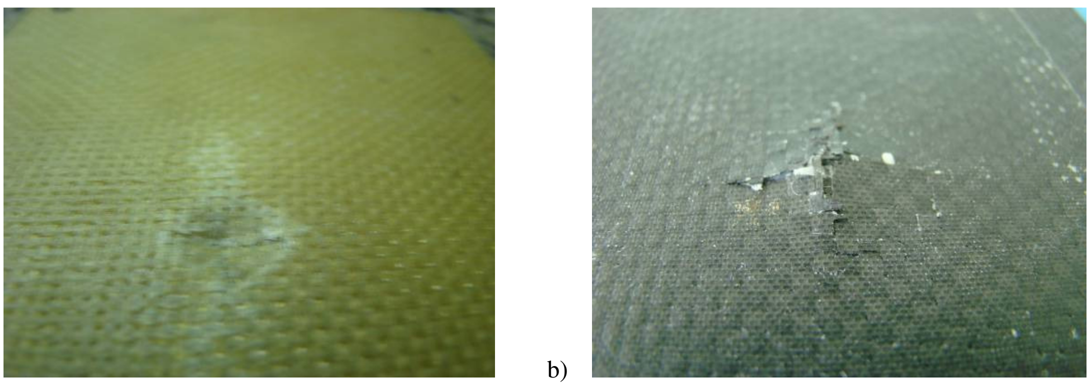


Figure 3 - Macroscopic damage aspects of impacted composite: a) front face; b) rear face.

The impact event produces delamination on composite and this becomes the useless part. The C-Scan analysis (Fig.4) shows that did not have delamination besides around the impacted region, allowing later substitution with safety. This affirmation is based on small black region detected through C-Scan. Is important to say that delaminated regions are not able to return any signal previously emitted for C-Scan transducer, since this regions are several discontinuous.

Also it is possible to observe the uniform distribution of resin and fibers, besides low presence of defects, sustained for low and uniform attenuation signal.

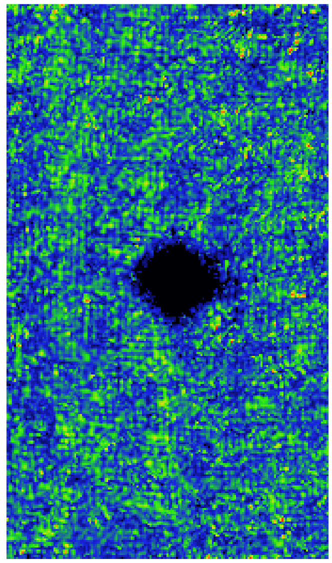


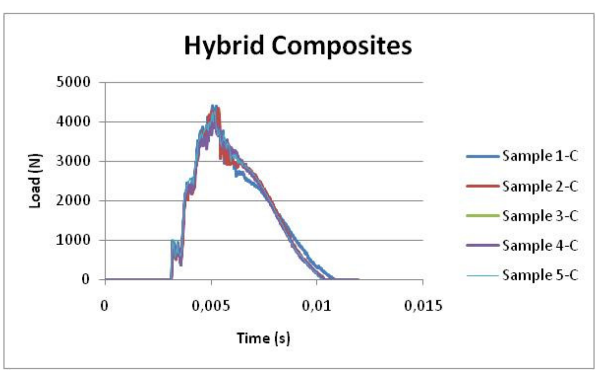
Figure 4 - C-Scan map analysis of composite plate.

The data of energy absorption are described on Tab. 2. The values show the similarity between the amount of energy absorption for each material, function of the difference between kinetic energy values before and immediately after the impact.

Table 2 - Energy absorption for each material

Composites		**SAE Steel 1010**	
Composite Sample	Energy Absorption (J)	Steel 1010 Sample	Energy Absorption (J)
1	22.29	1	21.00
2	21.52	2	22.65
3	20.67	3	21.82
4	21.65	4	22.63
5	20.42	5	22.40

Figure 5 shows the typical Load (N) *versus* Time of impact curve for all composites (Fig. 5a) and metals (Fig. 5b) samples. We can note the similar profile and results that did not have much scattering. The maximum load is defined by the position (height) of the impactor, because this, we can see a little difference between maximum loads applied to composite and metallic materials.



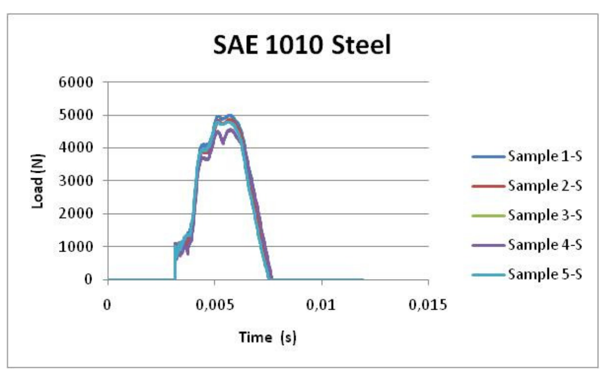


Figure 5- Load (N) *versus* Time of impact curve for: a) Composites; b) SAE Steel 1010.

According to Morais *et al*. (2005b), the magnitude of the peak indicates the elastic wave propagation and the quantity of defects inside of material. The higher the peak, greater the elastic wave propagation and lower the intensity of defects on material, indicating more capability to absorb energy.

Analyzing the graphics on Figure 5, there is a greater contact time of the indenter with the composite material. This fact can be attributed to the greater stiffness of the composite, which works in the elastic region. Thus, deformation of the composite was located and promoved deeper damage in the sample (Fig. 6a), justifying the higher contact time.

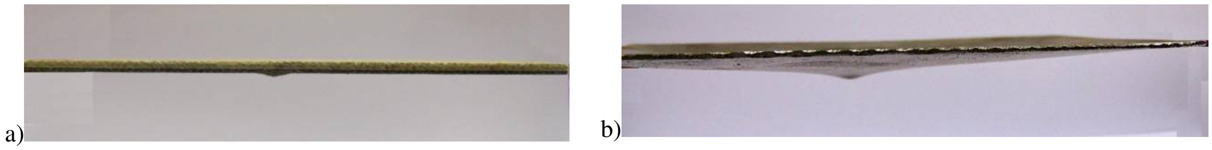


Figure 6 - Deformation caused from impact: a) composite sample; b) metal sample.

The metallic material was less time in contact with the indenter due to the plastic deformation of the plate, forming a deflection. The distortion occurs because of the ductility of the metal, favored by low content of carbon in this alloy. This fact justifies the slight advantage of the metal to absorb energy and less penetration of the indenter, helping to reduce the contact time indenter-sample.

The average energy absorption for hybrid composite was 21.31 J while SAE steel 1010 was 22.1 J, a difference less than 1 J. However, the difference between values is low enough to allow the substitution of the material used on CVT Box protection of BAJA SAE, considering the advantageous weigh reduction.

Figure 7 shows the CVT box protection made of composite after this study, reducing 52% on weight.

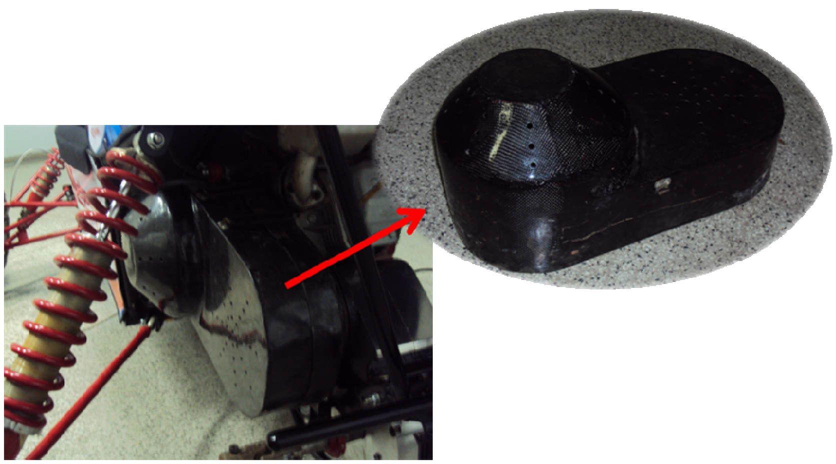


Figure 7 - CVT made of hybrid composite.

4. CONCLUSIONS

From the experimental results obtained in this study it can be concluded that hybrid composites aramid/glass/carbon with 3.0mm thickness is able to absorb similar quantity of impact energy than SAE Steel 1010 with 1.5 mm thickness.

The impact causes more damage on composite material that follow the fiber orientation. However, the ultrasonic analysis showed that did not have delamination around the damage, allowing subsequent replacement with safety.

Therefore, composite material can be used to replace parts made of SAE Steel 1010 since thickness is maintained.

5. ACKNOWLEDGEMENTS

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