IMPACT RESISTANCE EVALUATION OF METALLIC AND COMPOSITE MATERIALS USED IN MINI-BAJA OFF-ROAD PROTOTIPE

Fabrício Álvares Machado, fabricioalvares@gmail.com
Túlio Hallak Panzera, tuliopanzera@hotmail.com
André Luiz Christofóro, alchristoforo@ufsj.edu.br
Emerson de Souza Cruz, emersonscmec@gmail.com
José Antônio da Silva, jant@ufsj.edu.br
Marcos Sávio de Souza, msavio.ufla@yahoo.com.br
Pedro Bachir Asmar Filho, pedrobachir@gmail.com
Pedro Henrique de Andrade da Costa, pedrohandradec@hotmail.com
Universidade Federal de São João Del Rei – Departamento de Engenharia Mecânica
Praça Frei Orlando, 170, Centro, São João Del Rei – MG, Brasil

Abstract. *One of the mechanical components used in a off-road prototype, namely as Baja, is the continuous-variable transmission (CVT). For this type of transmission it is required the use of a cover protection in order to avoid that any unscrewed parts can injury the driver and hinder the operation of the CVT. The steel 1010 is commonly used to manufacture this device which is recommended by the competition´s regulation. A hybrid polymeric composite material reinforced with carbon and aramid fibres was investigated in this work in order to replace the metallic cover, achieving a lower specific weight, besides the enhancement of mechanical and impact absorption properties. The results demonstrated that the hybrid composites exhibit satisfactory properties becoming an alternative material for this proposal.*

Keywords*: Baja, Impact test, Carbon fibre, Aramid, CVT's Protection*

1. INTRODUCTION

Since 1995 the Society of Automotive Engineers Brazil (Brazil SAE) has organized a competition among universities of engineering around the country. This competition encourages undergraduate students to design and build an off-road prototype, namely as Baja, with tubular structure. The off-road prototype design is evaluated by a committee of professionals prescribed by SAE Brazil (2011). In this way, this is an opportunity for the engineering students to practice their knowledge, gained in classroom, in a real situation. This event has grown gradually in the country, becoming one of the most important extracurricular activities for engineering courses.

One of the mechanical components of an off-road prototype is the continuous-variable transmission (CVT). For this type of transmission it is necessary to use a cover protection preventing accidents possibly caused by unscrewed moving parts of the system.

For this reason, the organization of the event requires that such protection being manufactured of a conventional material, the steel 1010 with 1.524 mm in thickness, or using an alternative material with twice in thickness, which means 3.048 mm. This alternative material must absorb energy similarly or superior to 1010 steel.

In order to evaluate the hybrid composite material as a possible alternative for this proposal, the impact testing, ASTM D6110-10 (2010), was conducted to compare the energy absorption between the metallic and composite materials.

The commonly material used to cover the CVT is steel 1010. The laminated composites reinforced with carbon and aramid fibres bring advantages over the metallic material class, such as high specific strength and modulus as mentioned by Askeland (2006). The competition rules require that all participating teams use a standard engine, model Briggs & Stratton^{TM} 10 HP, consequently the prototype's performance can be enhanced reducing the weight factor.

For this reason, the Baja team from Federal University of São João Del Rei, namely as Komiketo Baja SAE, investigated a hybrid polymeric composite material reinforced with carbon and aramid fibres in order to replace the traditional material, 1010 steel previously used, improving the performance during the Baja competition.

The laminated composites have been used in the automotive industry due to its high mechanical strength and low density. Several world renowned automotive manufacturers such as Audi^{TM}, Mercedes-Benz^{TM}, and Porsche^{TM} have been using such composite materials in their products.

This work focus on the investigation of hybrid composite as a potential replacement of metallic cover, achieving a lower specific weight, besides the enhancement of mechanical and impact absorption properties. A full factorial design was conducted in order to identify the effect of fibres on impact resistance and energy absorption based on Charpy testing.

2. MATERIALS AND METHODS

According to Askeland (2006), the Charpy impact testing is a device widely used to determine the amount of energy that a material absorbs during fracture, which is equivalent to material toughness. This absorbed energy is the physical measure that characterizes the behaviour of the material as ductile or brittle. The test was carried out based on the recommendations of American Standard ASTM D6110-10 (2010).

The Charpy impact device consists basically of three main parts: base to support the specimen, a pendulum with a defined mass attached to a rotating arm attached to the machine body and a display which exhibits the reading of the absorbed energy measured in Joules. The machine used for the impact testing is showed in fig. 1.

Figure 1. Charpy testing machine

Seven experimental conditions were set for this experiment (see Tab. 2). Not only the composite materials but also the steel were tested. The composite materials were manufactured according to ASTM D3171-99 (2002) standard, with the sample sizes of 80 x 15 x 1.5 mm. The laminated composites were manufactured using cross-ply carbon and aramid fibres. The thermoset polymer phase used was a high performance epoxy resin supplied by Resiqualy Company (São Paulo). The epoxy resin consists of two parts, one called araldite, and the other hardener. The mix ratio by weight used was 68.97% of araldite and 31.03% of hardener. The viscosity, density and curing time were provided by the manufacturer, which are presented in Tab. 1.

Table 1. Properties of epoxy resin and hardener

	Epoxy resin	Hardener
Viscosity at 25 ° C (mPas)	1200 – 1400	70 – 120
Specific mass (g/cm^3)	1,10 – 1,20	0,94 – 0,95
Mass ratio (%)	68,97	31,03
Curing time	7 days	7 days

Five specimens for each experimental condition were manufactured. The composites were laminated varying the type of fibre (carbon or aramid) and the volume fraction of matrix phase as 30% or 50% (see Tab. 2). Two replicates were adopted, thus the experimental conditions were made on different days in order to avoid uncontrollable variables such as room temperature, relative humidity which could affect the analysis.

Table 2. Experimental conditions

Condition	Carbon (%)	Aramid (%)	Carbon steel (%)	Polymeric Matrix (%)
C1	50	-	-	50
C2	70	-	-	30
C3	-	50	-	50
C4	-	70	-	30
C5	30	20	-	50
C6	42	28	-	30
C7	-	-	100	-
C7*	-	-	100	-

The composite materials were laminated upon a glass plate in order to achieve a better surface finishing. Each composite was laminated using six layers of fibre. Fig. 2, 3 and 4 exhibit the composite impact samples made of carbon fibre, aramid fibre and carbon/aramid fibre, respectively.

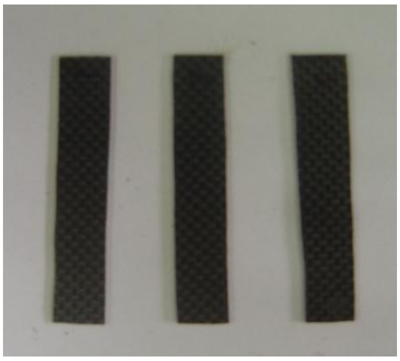

Figure 2. Specimen of carbon fibre

Figure 3. Specimen of aramid fibre

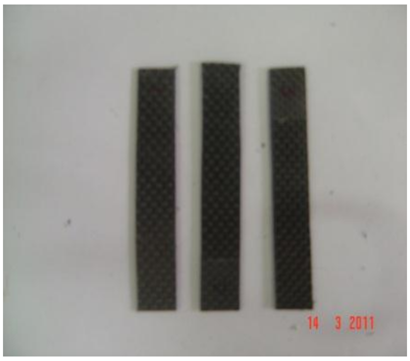

Figure 4. Specimen of carbon/aramid fibre

The 1010 steel samples were tested according to ASTM D6110-10 (2010) standard, with the following dimensions: 10 x 10 x 125 mm. There was no need to perform replicates considering that this material was not prepared in the laboratory. In order to compare the results of the composites, the steel was cut in the same dimension of the composites namely as C7* (see Tab. 2). Fig. 5 shows the 1010 steel impact samples C7 and Fig. 6 the 1010 steel C7*.

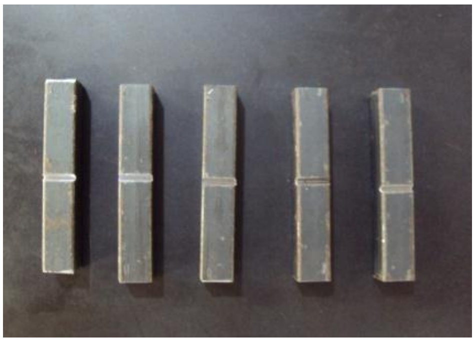

Figure 5. Specimen of 1010 steel

Figure 6. Samples of 1010 steel (C7*) before the impact test

The impact resistance was calculated using the followed Eq. (1), according to the manual of Charpy machine, brand Chengde Jinjian, model XJJ-50 for unnotched specimens.

$$Ri = \frac{E_c\ x\ 10^3}{h\ x\ b} \tag{1}$$

where Ri is the impact resistance in kJ/mm^2, Ec is the absorbed energy in Joules (J), h is the width in mm and b is the thickness in mm.

For notch samples the manual suggests Eq. (2), which was used for C7 condition.

$$Ri' = \frac{E_c \, x \, 10^3}{h \, x \, bn} \tag{2}$$

where *Ri* is the impact resistance for notched specimens, in kJ/mm^2, *Ec* is the absorbed energy, in Joules (J), *h* is the width, in mm and *bn* is the remaining thickness, in mm.

3. RESULTS

Tab. 3 shows the absorbed energy and impact resistance average results for replicate 1 and 2.

Table 3. Experimental results

SETUP	Replicate	Absorbed Energy (J)	Impact resistance (KJ/mm^2)	Standard deviation
C1	1	3.8	137.2	25.2
C1	2	4.8	164.5	32
C2	1	5.2	193.5	25
C2	2	5	171.5	6.3
C3	1	8	254.2	22.7
C3	2	6.1	223.5	16.3
C4	1	4	145.3	22.7
C4	2	6	194.3	2.15
C5	1	6.9	235.5	27.2
C5	2	6.4	220.9	7.2
C6	1	5.5	183.9	29.5
C6	2	6.1	217	30
C7	-	182.5	1825	81.7
C7*	-	11.7	474.4	29.9

An α-level of 0.05 is the level of significance which implies that there is 95% of probability of the effect being significant. The results will be presented via “main effect” and “interaction” plots. These graphic plots cannot be considered typical ‘scatter’ plots, but serve to illustrate the statistical analysis and provide the variation on the significant effects. The main effect of a factor might be interpreted individually only if there is no evidence that one factor does not interact with other factors. When one or more interaction effects of superior order are significant, the factors that interact must be considered jointly. A second order interaction between the “type of fibre and fraction of fibre” exhibited a significant effect on impact resistance. The interaction effect plot for the Impact resistance can be seen in fig. 7.

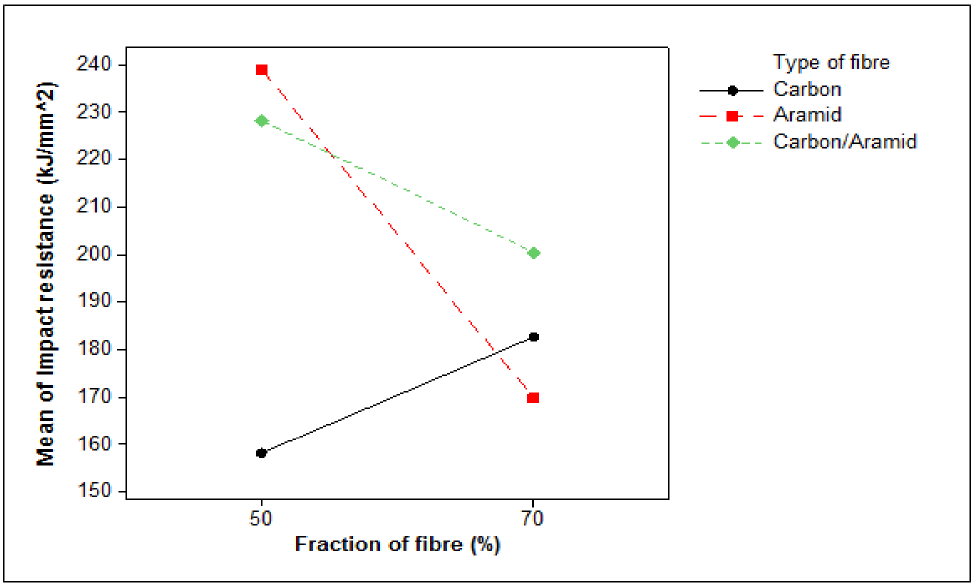

Figure 7. Interaction effect plot for the impact resistance.

It is observed that the amount of fibre affects the impact resistance. The specimens made of carbon fibre (C1 and C2) were laminated with a large amount of resin, contributing to reduce the absorption of energy; with 50% fibre volume the specimen absorbs 15% less energy. For the aramid fibre composites (C3 and C4) the behaviour is the opposite. The increase of polymer matrix phase implies on the percentage increase of 41% of energy absorption. This behaviour is also observed for the hybrid composites with carbon/aramid fibre made of 50% of matrix phase; in this case the material achieved an impact resistance of up to 14% higher.

The amount of resin directly affects the density of the composites, besides there is an optimal fraction of fibre/polymer for each situation. As observed in Tab. 4, the composites C1 and C2 exhibited a percentage increase of 13% on specific mass. For composites C3 and C4, the difference reached up to 34%. For composites C5 and C6, the increase of specific mass was 8.3%.

Table 4. Specific mass of the composites

Material	Specific mass (g/mm^3)
Carbon 50%	6.65 x 10^{-4}
Carbon 70%	6.52 x 10^{-4}
Aramid 50%	6.41 x 10^{-4}
Aramid 70%	5.47 X 10^{-4}
Carbon/Aramid 50%	6.00 X 10^{-4}
Carbon/Aramid 70%	5.63 x 10^{-4}
Steel 1010	7.78 x 10^{-3}

Table 5 exhibits the minimum thickness required for a composite material behaves as the steel 1010 (C7), considering the impact absorption characteristics. It was expected the steel 1010 would absorb much more energy than the composite material. However it is important to clarify that the energy absorption is proportional to the thickness and width of the structure. If the results are compared based on the different thicknesses, the composite materials would present higher toughness with a lower density, which make this result of major interest.

Table 5. Minimum thickness compared with the 1010 steel

Material	Minimum thickness (mm)
Carbon 50%	17.6
Carbon 70%	15.2
Aramid 50%	11.6
Aramid 70%	16.4
Carbon/aramid 50%	12.2
Carbon/aramid 70%	13.9

It is verified in Tab. 5 that there is a significant difference in thickness between the composite and steel 1010. Among them the hybrid composite of carbon/aramid fibre made of 50% of volume fraction (C5) requires a 20% increasing in thickness and the aramid fibre made of 50% of volume fraction (C3), requires a 15% increasing in thickness to achieve the same impact resistance of the metallic material.

Figures 8, 9 and 10 show the composite specimens samples after impact testing. It should be noted that some specimens do not fracture as to break off into two parts. This characteristic can be attributed to the aramid fibre addition. For this reason, the Baja/UFSJ team concluded that this composite is the most suitable material to manufacture the protection for the off-road prototype CVT.

Figure 8. Specimen of carbon/aramid fibre

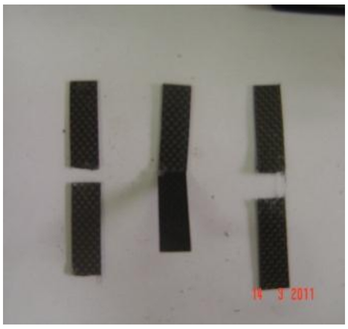

Figure 9. Specimen of carbon fibre

Figure 10. Specimen of aramid fibre

4. CONCLUSION

This work revealed the mechanical behaviour of laminated composites made of carbon fibre, aramid fibre and hybrid-type carbon/aramid fibre based on a Charpy testing. The composites made of carbon fibre showed lower values of impact resistance, particularly when impregnated with a higher amount of resin. Otherwise, the composites made of aramid fibre and carbon/aramid fibre with 50% fibre volume, achieved higher impact resistances, making them more appropriate for the desired application. The polymeric matrix phase increases the energy absorption of the carbon fiber composites. The equivalent thicknesses of the composites in which is possible to obtain the same impact resistance of steel 1010 (1825 KJ/mm^2) are: 660% more in thickness for aramid fibre (50% fibre volume fraction), 1050% more in thickness for carbon fibre (70% fibre volume fraction) and 700% more in thickness for carbon/aramid fibre (50% fibre volume fraction).

However, based on the results of C7* (474,4 KJ/mm^2) the equivalent thicknesses of the composites are: 97% more in thickness for aramid fibre (50% fibre volume fraction), 163% more in thickness for carbon fibre (70% fibre volume fraction) and 110% more in thickness for carbon/aramid fibre (50% fibre volume fraction). It is noteworthy that this conclusion is not scientifically valid, due to the C7* does not follow any standard testing.

Finally, the laminated composites made of aramid fibres presented not only suitable impact characteristics, but also lower density for the proposal application, which it is expected a significant performance improvement of the prototype off-road Baja during the competition.

5. ACKNOWLEGMENT

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