NOVEL AUXETIC THERMOSET AND THERMOPLASTIC COMPOSITES FOR ENERGY ABSORPTION

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1 Introduction

Auxetic materials are characterized as materials with negative Poisson’s ratio (NPR), i.e. stretching of these materials in longitudinal direction results in widening in the transverse direction. This counterintuitive behaviour provides higher energy absorption capacity and damage resistance. Auxetic composites can be made from conventional materials, using the laminated angle-ply method, in which the layers are stacked in a special sequence resulting in NPR. Accordingly, the use of carbon fibers as reinforcement is more appropriate than kevlar or glass fibers as they combine exceptional mechanical properties and low weight. Indeed, there are several carbon fibers and matrices that make them suitable for a range of end-uses [1, 2].

This research work focuses on investigating the mechanical properties of composites reinforced with unidirectional carbon fibers. For this purpose, the effects of fiber orientations and the influence of resin type on the mechanical properties and Poisson’s ratio have been investigated as regards to the tensile and impact behaviours. Carbon fiber stacked at different angles reinforcing thermoset and thermoplastic polymers were studied.

2 Experimental details

2.1 Materials

Carbon fiber reinforced composites used in this investigation were fabricated from eight plies of carbon fiber-based PAN, Grafil 34-700. An epoxy resin Biresin CR83 combined (100:30 ratio) with hardener Biresin CH83-2, both from Sika Deutschland, was used as matrix for the composites produced within this work. In order to produce thermoplastic composites, low density Polyethylene (PE) Lupolen 2426 H, was also used as matrix for carbon fiber reinforced composites. Carbon/PE (C/P) composites were produced using compression moulding, while carbon/epoxy (C/E) composites were fabricated by vacuum bag moulding. The process and cure were done according to the manufacturer's specifications.

2.2 Mechanical tests

In this work, laminate composites with modified matrices were evaluated by tensile and impact tests. Tensile tests were performed based on ASTM D3039 using an Instron universal testing machine at room temperature and the crosshead speed was 2 mm/min with 50kN load cell. Tensile strength and the tensile modulus was estimated within the range of tensile strain: 0.15% to 0.25%, using a strain gauge device. The impact test was used to measure the energy required for breaking the materials. Specimens were low velocity impacted with energy of 49 J by a 20 mm diameter hemispheric format that weighed 10.044 kg and using a Fractovis Plus drop weight impact testing. At least three tests were performed at each drop height for every specimen type.

3 Experimental results and discussion

3.1 Thickness, areal density and fiber volume fraction

The thickness and areal density of the produced thermoset and thermoplastic composites are listed in Table 1. There are no significative differences among the composites in terms of their composition (matrix and fiber orientation).

Table 1. Thickness and areal density of carbon/epoxy and carbon/PE composites produced.

Composite lay-up	Thickness (mm)	Areal density (kg/m^2)
C/E-$[0]_{8s}$	1.19 (3)*	1.46 (2)
C/E-$[0/15/75/15]_s$	1.15 (3)	1.57 (4)
C/P-$[0]_{8S}$	1.12 (3)	1.27 (1)
C/P-$[0/15/75/15]_s$	1.22 (5)	1.42 (2)

*The values of coefficient of variation are given between parentheses.

The fiber volume fractions of composite laminates obtained from the burn test were identical, 58±4% and 54±1% for C/E and C/P, respectively. The ASTM "Standard Test Method for ignition loss of cured reinforced resins - D2584-68" was used.

3.2 Tensile properties and Poisson's ratio

The average mechanical properties determined for the carbon/epoxy composites are shown in Table 2. The tensile strength of the composites varies significantly with the layer orientations. The fibers stacked at 0º showed highest tensile strength and modulus in the direction of the applied load which led to stiffer composites.

Table 2. Properties of carbon fiber stacked at different angles in an epoxy matrix (C/E).

Composite lay-up	Tensile strength (MPa)	Tensile Modulus (GPa)	Elongation at break (%)
$[0]_{8s}$	1171.8 (3)	104.26 (4)	1.16 (11)
$[0/15/75/15]_s$	467.7 (5)	53.43 (3)	1.08 (4)

Regarding to the Poisson's ratio measurement, the C/E-$[0/15/75/15]_s$ had NPR of -0.12, while the $[0]_{8s}$ exhibited values of about 0.33.

3.3 Impact properties

The impact energy of C/E and C/P composites obtained are shown in Fig. 1.

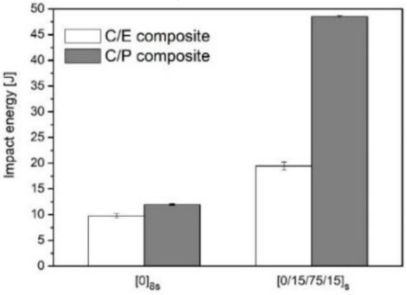

Fig. 1. Impact energy of C/E and C/P composites extracted from the low-velocity impact tests.

The graphic clearly represents the influence of the fiber orientation as well as the type of polymeric matrix on the impact behaviour of the laminated composites. Indeed, the $[0/15/75/15]_s$ presents better capacity to absorb energy when compared to the fibers stacked at 0º. Besides, the increased plastic deformation in carbon/PE contributes to higher values of energy absorption. Hence, more energy is required for damage C/P when compared to C/E laminate composites, for the same fiber orientation.

4 Conclusions

The importance of the current study lies in characterize and compare the mechanical performance of carbon fiber composites with different matrices, in order to evaluate their potential application in personnel protection products, where energy absorption is a key factor to be considered. The results show that the performance of the composite samples was influenced by the fiber orientation and polymer matrix. The C/P-$[0/15/75/15]_s$, showing auxetic behavior, presents the greatest effect on the impact properties. Further testing and discussions are being performed on carbon/PE composites.

5 References

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