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Mechanical behavior of carbon fibre-reinforced epoxy/ plain200 prepregs subjected to three-point bend tests

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Within this paper, extended experimental researches regarding the behavior of plain weave carbon fabric-reinforced epoxy composite laminates subjected to three-point bend tests have been carried out. As reinforcement material, 200 g/m^2 specific weight plain weave carbon fabric has been used. Various specimens have been cut from plates of five, six and seven layers of epoxy resin impregnated fabric according to ISO 14125:1998: “Fibre-reinforced plastic composites – Determination of flexural properties”. These plates have been cured in an autoclave with controlled temperature and pressure. Following mechanical properties have been determined during three-point bend tests: Young’s modulus of bending, stiffness, flexural rigidity, maximum bend stress/strain at maximum and minimum load/extension, load/stress/strain at maximum and minimum load/extension and so on.

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Keywords: Plain weave, Carbon fabric, Three-point bend test, Prepreg, Young’s modulus of bending

1. Introduction

Plain weave carbon fabrics are extensively used both for medium size composite structures and large size ones due to their high ratio between tensile strength and specific weight. These fabrics present good drape ability, a feature that allows them to be placed on complex shapes. Other carbon fabrics widely used as skins, especially in sandwich structures applications, are so-called twill weave fabrics. The main feature of this kind of weave is that the warp and weft threads are crossed in a programmed order and frequency, to obtain a flat appearance with a specific diagonal line [1]. A twill weave fabric needs at least three threads and presents excellent drape ability. More threads can be used for fabrics with high specific weight depending on their complexity. After plain weave, the twill is the second most common weave [2]. It is often denoted as a fraction, in which two or three threads are raised and one or two is lowered when a weft thread is inserted. For instance, plain weave presents the fraction 1/1. For composite materials that include resin, reinforcement materials and fillers, to compute their elastic properties it is suitable to use homogenization methods and/or averaging procedures. For a three-phase polymer matrix composite it is usual to compute upper and lower limits of these elastic properties [3]. A better understanding of a composite structure behavior is obtained by subjected it to dynamic or even static cyclic loads. Some experimental results have been determined on three-phase polymer matrix composites, that means unsaturated polyester resin, glass fibers chopped strand mat as reinforcement and ceramic particles as filler [4], [5]. An interesting approach regarding the determination of elastic properties of various glass, carbon and Kevlar49 composite laminates with different plies sequences subjected to off-axis loading system is presented in reference [6]. Theoretical approaches regarding the simulation of elastic properties of various types of polymer matrix laminates are presented in references [7].

2. Material and method

Plates of five layers (1.0 mm thickness), six layers (1.2 mm thickness) and seven layers (1.4 mm thickness) prepregs of plain weave carbon fabric with 200 g/m^2 specific weight impregnated with epoxy resin have been placed in an autoclave and cured at a certain temperature and pressure. From each type of plate, eight specimens have been cut using a diamond powder drill and subjected to three-point bend tests. The tests have been carried out on a “Texture Analyzer TA Plus” universal materials testing machine produced by Lloyd Instruments (Fig. 1).

Fig. 1. Texture analyser type TA plus.

The machine presents following features:

- Force range: up to 1 kN;
- Test speed accuracy: < 0.2%;
- Load resolution: < 0.01% from the load cell used;
- Displacement resolution: < 0.1 μm;
- Type of load cell: XLC-1K-A1;
- Software: NEXYGEN Plus.

Some three-point bend test features and specimens dimensions are presented in Table 1.

Table 1. Three-point bend test and specimens features.

Feature	Value
Span (mm)	80
Specimens width (mm)	10.8
Test speed (mm/min)	15
Five layers thickness (mm)	1
Six layers thickness (mm)	1.2
Seven layers thickness (mm)	1.4
Cross-section area (mm$^{2)}$	10.8/12.9/15.1

3. Results

Young’s modulus of bending, maximum load, maximum extension, maximum strain, stiffness and other important features are presented in Figs. 2-9.

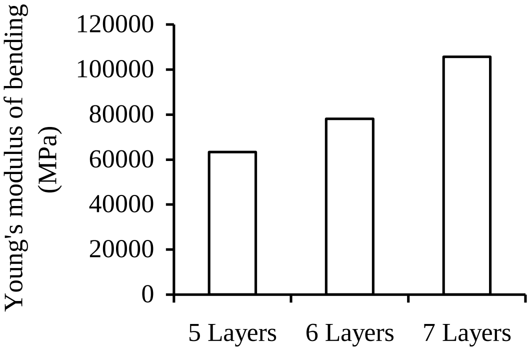

Fig. 2. Young’s modulus of bending distributions of five, six and seven layers epoxy based plain weave carbon fabric cured prepregs.

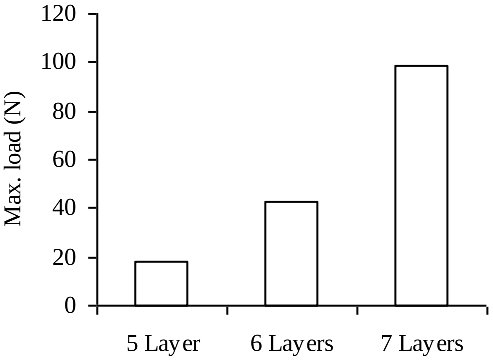

Fig. 3. Maximum load distribution of five, six and seven layers epoxy based plain weave carbon fabric cured prepregs.

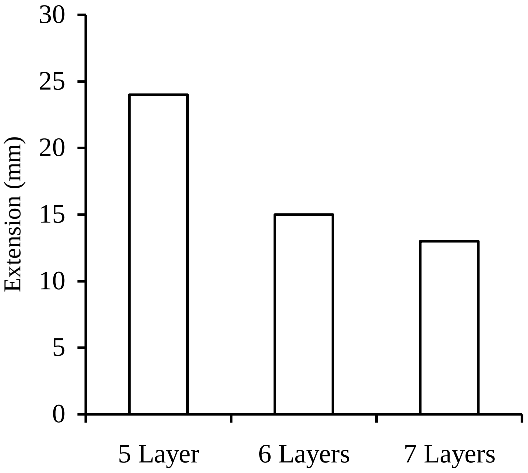

Fig. 4. Maximum extension distribution of five, six and seven layers epoxy based plain weave carbon fabric cured prepregs.

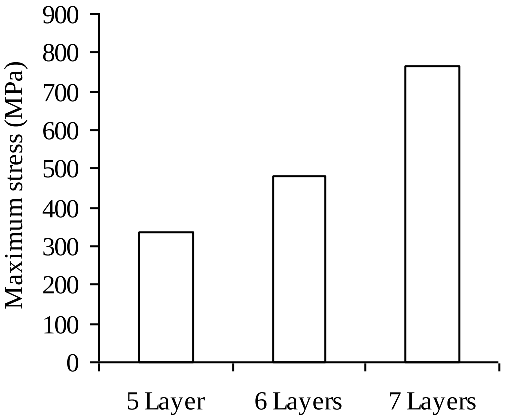

Fig. 5. Maximum stress distribution of five, six and seven layers epoxy based plain weave carbon fabric cured prepregs.

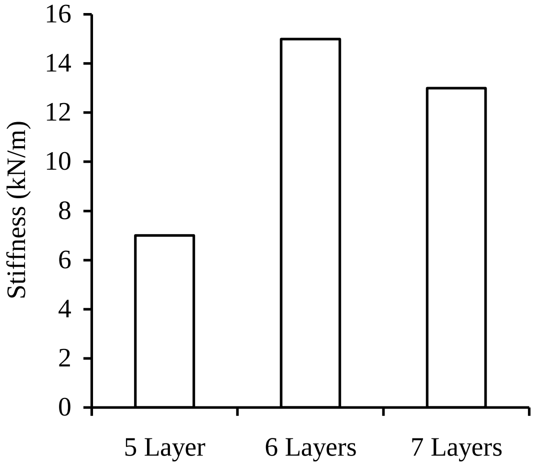

Fig. 6. Stiffness distribution of five, six and seven layers epoxy based plain weave carbon fabric cured prepregs.

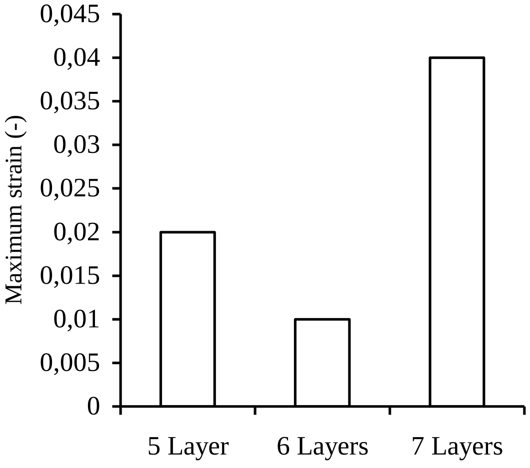

Fig. 7. Maximum strain distribution of five, six and seven layers epoxy based plain weave carbon fabric cured prepregs.

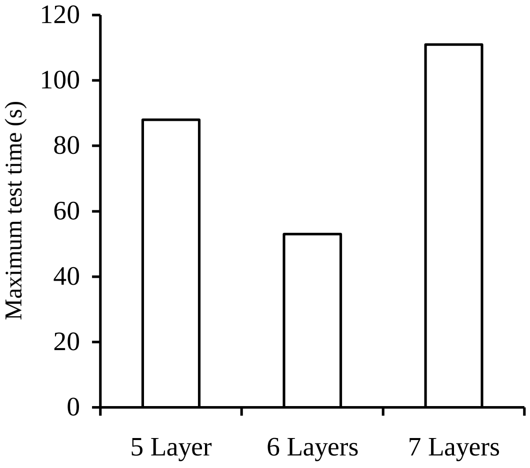

Fig. 8. Maximum test time distribution of five, six and seven layers epoxy based plain weave carbon fabric cured prepregs.

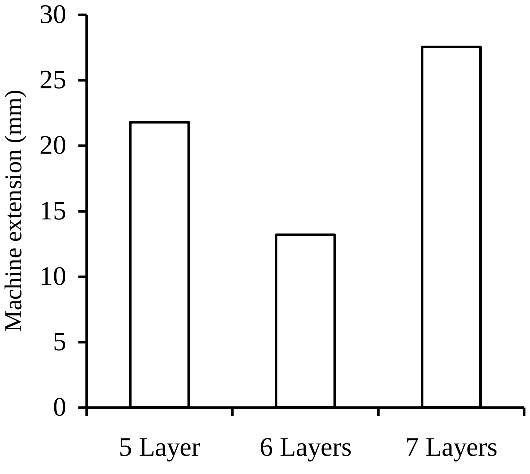

Fig. 9. Machine extension distribution of five, six and seven layers epoxy based plain weave carbon fabric cured prepregs.

4. Discussion

The stress-strain distributions in all types of epoxy based plain 200 g/m^2 weave carbon fabric cured prepregs present a non-linear tendency. Two of these prepregs subjected to three-point bend tests have presented a fall of their stiffness at certain strain values. For instance, in case of the five layers epoxy based plain 200 g/m^2 weave carbon fabric cured prepreg, this fall begun at 0.006 strain value. In case of the six layers epoxy based plain 200 g/m^2 weave carbon fabric cured prepreg, this fall took place at 0.004 strain value. It seems that with the increase of layers number, this fall is not so significant. The Figs. 10-12 present this phenomenon and a comparison between the stress-strain distributions of all epoxy based plain 200 g/m^2 weave carbon fabric cured prepregs is shown in Fig. 13.

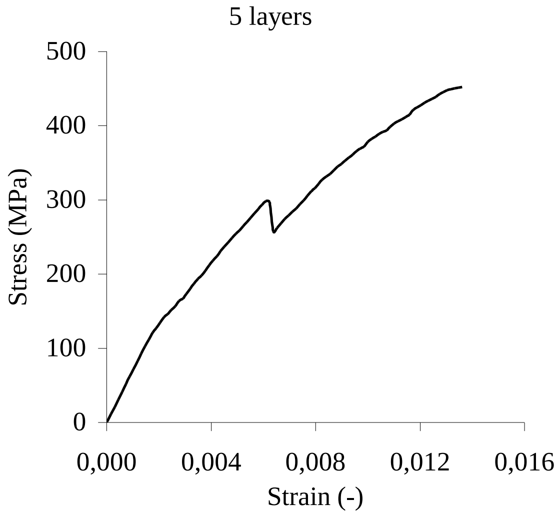

Fig. 10. Stress-strain distribution of five layers epoxy based plain weave carbon fabric cured prepregs.

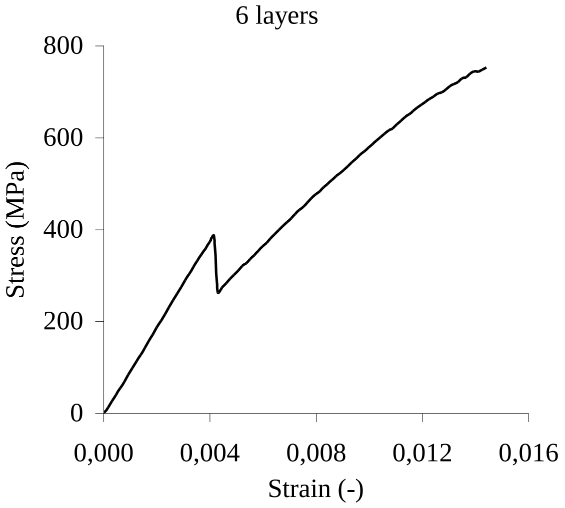

Fig. 11. Stress-strain distribution of six layers epoxy based plain weave carbon fabric cured prepregs.

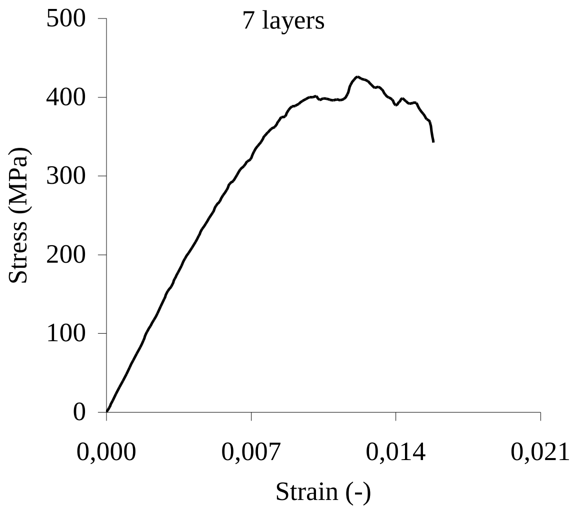

Fig. 12. Stress-strain distribution of seven layers epoxy based plain weave carbon fabric cured prepregs.

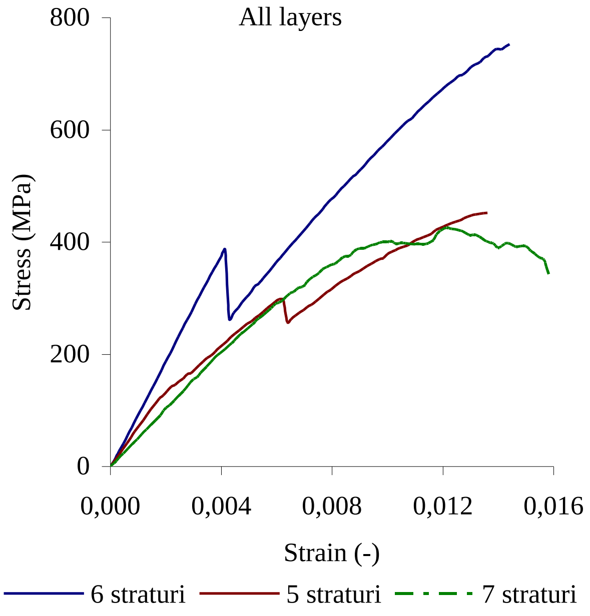

Fig. 13. Comparison between stress-strain distributions of all layers epoxy based plain weave carbon fabric cured prepregs.

The distributions of Young's modulus of bending, maximum load and maximum stress present an increased tendency with the increase of layers (Figs. 2, 3 and 5) while the distribution of maximum extension presents a decreased tendency with the increase of layers (Fig. 4). The stiffness distribution presents a maximum at the prepreg with six layers (Fig. 6) while the distributions of maximum strain, maximum test time and machine extension present minimum values in case of six layers epoxy based plain weave carbon fabric cured prepreg (Figs. 7-9). Due to the minimum value of the maximum strain of six layers prepreg, the fall of stiffness took place at 0.004 strain (Fig. 13).

5. Conclusions

Due to its high stiffness and good drape ability the epoxy pre-impregnated plain 200 g/m^2 weave carbon fabric can be used in various composite laminates as well as skins in large sandwich panels even with low stiffness cores. This type of carbon fabric can be used for instance in the manufacture of adaptive wings in the aerospace industry. Carbon fibers are suitable to fit special structures and devices for future airplanes due to their excellent thermal and electric conductivity as well for their good force at break distribution as a function of Young's modulus.

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