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New Advanced Sandwich Composite with twill weave carbon and EPS

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The paper presents the most important mechanical properties determined in a simple tensile test on a 0.4 mm thickness 2/2 carbon twill weave fabric impregnated with epoxy resin, used as skins for an advanced ultralight sandwich composite structure with expanded polystyrene as core. The sandwich panel is subjected to flexural load-unload tests. This kind of fabric presents very good drapeability and is suitable to reinforce a quite large range of epoxy resins. The aim of using this fabric is to obtain thin structures with complex shapes and high stiffness for the automotive industry. A comparison with a sandwich structure with EWR-300 glass fabric/epoxy resin skins has been accomplished. Due to its high stiffness, the twill weave carbon fabric is used as skins in large sandwich structures even with low stiffness cores. The flexural load-unload tests show an outstanding stiffness of the whole sandwich panel. Various specimens' thickness have been used.

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1. Introduction

Carbon fibre-reinforced epoxy resins are used extensively to build composite structures with an outstanding specific weight/strength ratio. Such structures, usually called laminates, present a relative poor tensile stiffness and the flexural stiffness remains at a low level due to low sensitivity at flexural loads of the carbon fibres, especially of the unidirectional reinforced ones [1] - [3].

A method to increase a little bit this flexural stiffness is the use of a large variety of fabrics as reinforcing material. A common fabric is a so called twill weave. The main feature of this weave is that the warp and the weft threads are crossed in a programmed order and frequency, to obtain a flat appearance with a distinct diagonal line. A twill weave fabric needs at least three threads. More threads can be used for fabrics with high specific weight depending on their complexity [4]-[6]. After the plain weave, the twill is the second most common weave. It is often denoted as a fraction, for instance three twill weaves can be designated, in the following way:

- 2/1 in which two threads are raised and one is lowered when a weft thread is inserted;
- 2/2 in which two threads are raised and two are lowered when a weft thread is inserted;
- 3/1 in which three threads are raised and one is lowered when a weft thread is inserted.

The characteristic structure of the twill weave fabric makes it to present a very good dreapability. In general, composite laminates are manufactured from thin layers called laminae. These laminates present a quite low stiffness and flexural rigidity. A solution to increase their stiffness could be the use of stiffening ribs [7], [8]. Not all constructive situations require built-in ribs. A solution could be the increase of the layers but this leads to the disadvantage of increasing the overall weight as well as the resin and reinforcement consumption. For pre-impregnated composites, to predict their elastic properties, homogenizations and averaging methods can be used [9]. A better solution to increase the overall stiffness of a composite laminate is to use a thin non-woven polyester mat as core material embedded in the structure [11, 12]. This core of non-continuous and non-woven mat presents the advantage to absorb the excessive resin [10].

A composite laminate with this kind of embedded core material presents following main advantages: weight saving, stiffness increase, quick build of the structure's thickness, saving of resin and reinforcement as well as an increased possibility to obtain a better surface finish when it is applied against the "gelcoat". This mat when is impregnated with resin presents high drapeability being suitable for complex shapes and for hand lay-up and spray-up processes [13].

2. Material and method – The sandwich structure

The sandwich presents two carbon/epoxy skins reinforced with 300 g/mm^2 twill weave carbon fabric and an expanded polystyrene (EPS) 9 mm thick core with a density of 30 kg/m^3. The final thickness of the structure is 10 mm. Other input data are [11]: structure's thickness: 10 mm; skins plies number: two; thickness of each ply: 0.175

mm; skins thickness: 0.35 mm; core thickness: 9 mm; fibres' disposal angle of each ply: 90° and 0°; fibres' volume fraction of each ply: 56%. The data regarding the structure features are: skins reinforcement: HM carbon fibres; fabric type: twill weave; fibres' specific weight: 0.3 kg/m^2; matrix type: epoxy resin; core type: expanded polystyrene.

Other useful data are: core density: 30 kg/m^3; core Young's modulus: 30 MPa; core Poisson's ratio: 0.35; core shear modulus: 11 MPa; fibre Young's modulus in longitudinal direction: 540 GPa; fibre Young's modulus in transverse direction: 27 GPa; fibre Poisson's ratio: 0.3; fibres' shear modulus: 10.38 GPa; matrix Young's modulus: 3.5 GPa; matrix Poisson's ratio: 0.34; matrix shear modulus: 1.42 GPa.

3. Experimental results

During the flexural tests of the sandwich panel, following experimental determinations have been accomplished:

- Two flexural load-unload tests of the sandwich panel clamped on contour (Fig. 1);
- One simple three-point bend test (load-unload) of the sandwich panel supported linearly on two opposite edges (Fig. 2).

The loads are applied in the middle of the panel and a displacements' measuring device has been placed under panel at its center. The tensile test on one layer 2/2 twill weave carbon fabric impregnated with epoxy resin has been accomplished on a LR-5KPlus materials testing machine produced by Lloyd Instruments (Fig. 3). The testing machine presents the following characteristics:

- Force range: 5 kN;
- Speed accuracy: <0.2%;
- Load resolution: <0.01% from the load cell used;
- Analysis software: NEXYGEN Plus.


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Fig. 1. Flexural load-unload test detail. Sandwich panel clamped on contour.

Fig. 2. Three-point bend load-unload test detail. Sandwich panel supported linearly on two opposite edges.


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Fig. 3. Tensile test detail on an epoxy impregnated 2/2 twill weave carbon fabric.

The features of the 2/2 twill weave carbon fabric is presented below:

- Fabric type: twill weave;
- Fibres type: HM carbon;
- Fabric specific weight: 300 g/m^2;
- Type of resin impregnation: epoxy resin;
- Impregnation process: vacuum bag moulding;
- Impregnation resin: epoxy;
- Fabric thickness: 0.4 mm.

The specimen has been subjected to a test speed of 1 mm/min and the length between extensometer's lamellae is 50 mm. The tensile test results on an epoxy impregnated 2/2 twill weave carbon fabric are presented in Table I. Following main features have been determined: Stiffness; Young's modulus;Load at Maximum Load; Stress at Maximum Load; Extension from preload at Maximum Load; Strain at Maximum Load; Load at Maximum Extension; Stress at Maximum Extension; Extension from preload at Maximum Extension; Strain at Maximum Extension; Load at Minimum Load; Stress at Minimum Load; Extension from preload at Minimum Load; Strain at

Minimum Load; Load at Minimum Extension; Stress at Minimum Extension; Extension from preload at Minimum Extension; Strain at Minimum Extension; Tensile Strength; Extension at Maximum Load; Extension at Maximum Extension; Extension at Minimum Load; Extension at Minimum Extension; Load at Break; Stress at Break.

Due to the non-linear behaviour of the carbon fibre subjected to tensile loads, the stress-strain as well as the load-extension distributions of an epoxy impregnated 2/2 twill weave carbon fabric subjected to tensile loads follows the same non-linear behaviour. The results of the flexural load-unload tests applied to the sandwich panel are presented in Figs. 4-6.

Table 1.Tensile test results on an epoxy impregnated 2/2 twill weave carbon fabric

Characteristics	Value
Length between extensometer’s lamellae (mm)	50
Preload stress (kN)	0.0056
Preload speed (mm/min)	21
Test speed (mm/min)	1
Fabric width (mm)	18.5
Fabric thickness (mm)	0.4
Stiffness determined as ratio between load and extension (N/m)	5785656.99
Young’s modulus (MPa)	31273.82
Load at maximum load (kN)	1.92
Stress at maximum load (MPa)	207.61
Strain at maximum load (-)	0.009
Strain at maximum extension (-)	0.344
Strain at minimum load (-)	0.087
Load at minimum extension (kN)	0.005
Stress at minimum extension (MPa)	0.582
Load at break (kN)	1.919
Stress at break (MPa)	207.55
Strain at break (-)	0.009
Tensile strength (MPa)	207.61

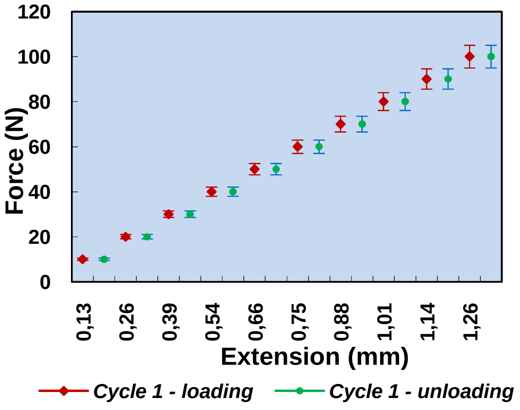

Fig. 4. Flexural test of the sandwich panel clamped on contour. Cycle 1 loading-unloading.

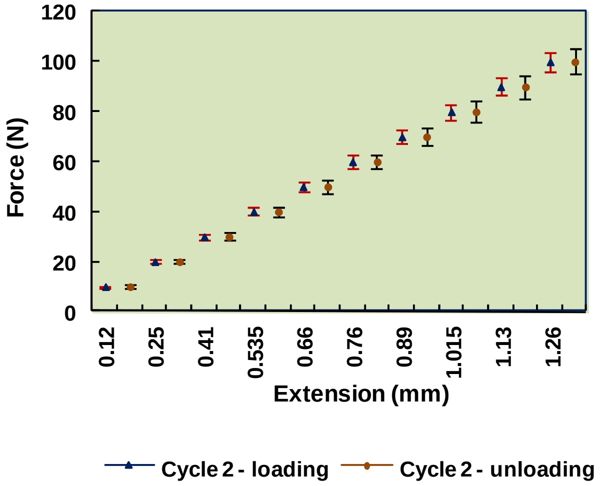

Fig. 5. Flexural test of the sandwich panel clamped on contour. Cycle 2 loading-unloading.

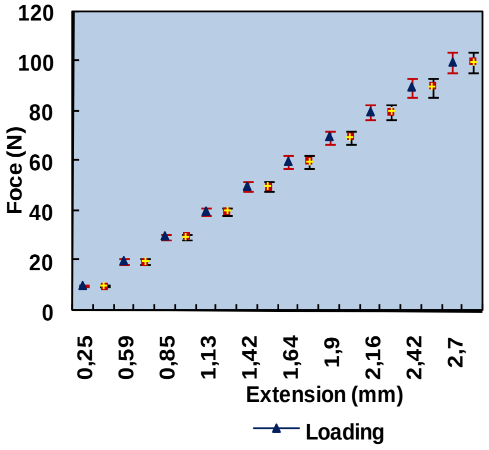

Fig. 6. Three-point bend test of the sandwich panel supported linearly on two opposite edges.

Various specimens with different thickness (10, 20, 30 and 40 mm) have been manufactured and subjected to three-point bend tests until break occurs. Force-extension distributions of these specimens are presented in Figs. 7-10.

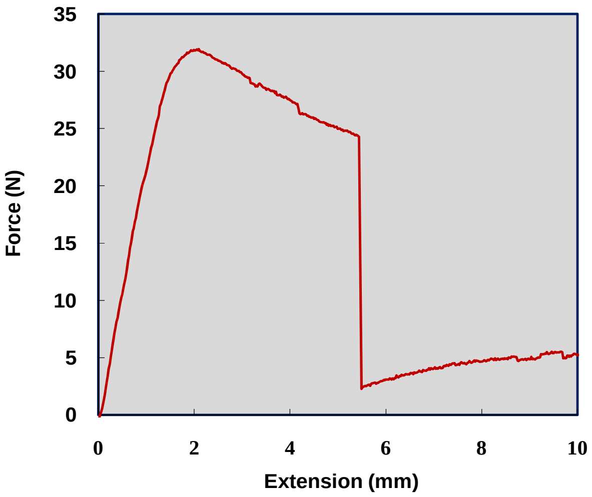

Fig. 7. Force-extension distribution on 10 mm thickness specimen subjected to three-point bend test.

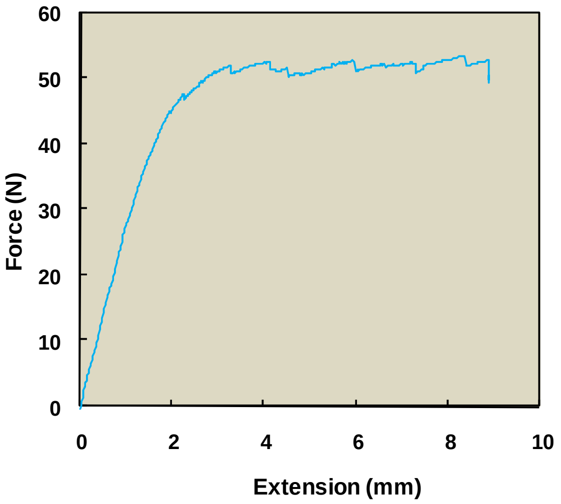

Fig. 9. Force-extension distribution on 30 mm thickness specimen subjected to three-point bend test.

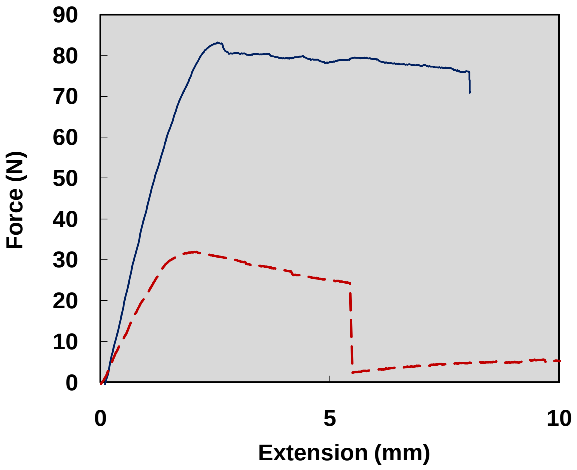

Fig. 8. Force-extension distribution on 20 mm thickness specimen subjected to three-point bend test.

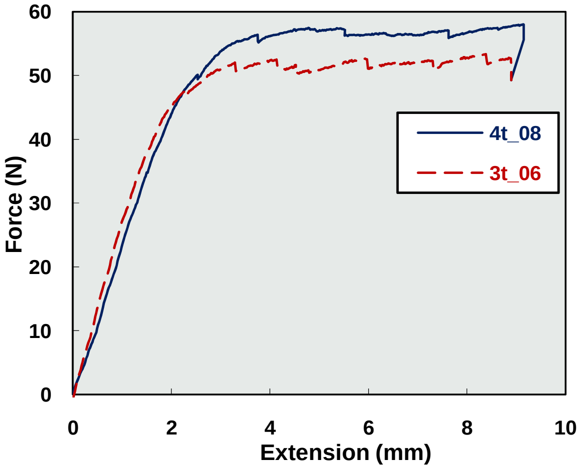

Fig. 10. Comparison betwwen force-extension distributions on 30 mm and 40 mm thickness specimens subjected to three-point bend tests.

4. Conclusion

Due to its high stiffness and good dreapeability the epoxy impregnated 2/2 twill weave carbon fabric can be used as skins in large sandwich panels even with low stiffness cores, with applications in the automotive industry. Carbon fibres are suitable to fit special structures and devices for the future car due to their excellent thermal and electric conductivity. The comparison between the flexural rigidity of the structure obtained experimentally and that obtained through the theoretical approach shows a good agreement between the experimental data and the theoretical approach. The following conclusions can be drawn:

- The sandwich structure with two carbon/epoxy skins reinforced with a 300 g/m^2 twill weave fabric and an expanded polystyrene (EPS) 9 mm thick core with a density of 30 kg/m^3, fulfils following special requirements:
    - Panel dimensions: 10 × 2350 × 4070 mm;
    - Overall weight: maximum 10 kg.
- The sandwich structure’s strains with skins based on twill weave carbon fabric reinforced epoxy resin are comparable with those of the structure with skins based on EWR-300 glass fabric/epoxy resin;
- Stresses in fibres direction in case of the sandwich structure with carbon fabric/epoxy resin reinforced skins, are up to six times higher than those existent in EWR-300 glass fabric/epoxy resin skins;
- Stresses transverse to the fibres direction in case of the sandwich structure with carbon fabric/epoxy resin reinforced skins are 20% lower than those existent in EWR-300 glass fabric/epoxy resin skins;
- The shear stresses in carbon fabric/epoxy resin reinforced skins’ plies are almost identical with those existent in EWR-300 glass fabric/epoxy resin skins’ plies;
- The core stresses are almost zero, so the loading is taken over exclusively by skins;
- Using a 9 mm thick expanded polystyrene core (EPS) the stiffness of the sandwich structure with carbon fibres reinforced epoxy resin skins is more than ten times higher than the skins’ plies stiffness.

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