Mechanical testing of CFRP materials for application as skins of sandwich composites

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Abstract: *Sandwich structures are ultralight materials that are part of a special class and consist of two face skins, that are thin, light and stiff. These materials are of great interest for aeronautical and aerospace applications and they represent one of the important research directions in this field. As skins, a large variety of materials can be used, i.e. aluminium, titanium or polymeric laminates. For the evaluation of sandwich composites based on metallic foam core, a larger study is being currently conducted, one of the objectives within this study being the evaluation of the sandwich system components (CFRP skins developed by two different methods: manual lay-up/room temperature curing and prepreg processing; as well as evaluation of core materials). This paper contains technical work that presents the preliminary results regarding the evaluation of CFRP skins based on CARP/T193 carbon fiber fabric and low viscosity L20 epoxy resin (Diglycidyl Ether of Bisphenol A) developed by manual lay-up/room temperature curing. The obtained materials were tested at different mechanical loads and the failure mode was analyzed with the aim to evaluate their performances as possible skins of the sandwich structure with metallic foam core.*

Key Words: *CFRP skins, manual lay-up, mechanical strength, elasticity modulus*

1. INTRODUCTION

Sandwich composites represent a special class of materials that offer unique properties that cannot be provided by the component materials individually used. Due to their specific nature, these materials show increased flexural rigidity and low structural weight. Composite sandwich structures are widely used in marine, ground transportation, aircraft, space and other high-tech industries; as sandwich constructions used in these applications, they typically consist of a lightweight foam core bonded to thin face sheets to achieve excellent weight to strength and weight to stiffness ratios [1, 2].

Sandwich structures consisting of composite skins and core material (foams, honeycomb structures etc.) are believed to have an added value for primary aircraft structures by fulfilling mechanical and non-mechanical functions (such as thermal and acoustic insulation). Moreover, using the sandwich concept can result in part integration and weight reduction actions, which consequently lead to structure manufacturing and the operating costs diminishing [2].

A wide variety of materials can be used as rigid skins in sandwich composites systems. Choosing between the suitable classes of materials is decided mainly by the application domain of the sandwich structure, as the operating conditions determine the technical requirements of the materials to be used. The main advantages of sandwich composite systems are the properties adjustment according to the technical and environmental demands, the large variety in choosing the component materials, high rigidity, low density, high resistance to vibrations and high damage tolerance [3].

The faces are commonly made of steel, Aluminium and lately composite materials (such as FRP- fiber reinforced polymers) and the core material may be foam (organic or inorganic), honeycomb (polymeric or metallic) and balsa wood. The faces and the core material are generally bonded together with an adhesive to facilitate the load transfer mechanisms between the components [4]. In case of carbon fiber reinforced polymeric skins, the materials properties can be controlled directionally with the aim of controlling the sandwich composite properties [1]. Most used core materials are Aluminium honeycomb or NOMEX honeycomb. The latest trend in metallic core materials is represented by the metallic foams. However, the disadvantages of carbon fiber/ aluminium foam sandwiches are, for instance, poor interfacial toughness and poor residual properties after impact or crack initiation. Interfacial failures frequently occur due to the poor interfacial toughness and stress concentration at the interface zone.

The interfacial failures lead to reduced structural properties such as flexural stiffness, compressive strength and impact resistance. Therefore, toughening the interfacial fracture toughness of the carbon fiber/aluminium foam sandwich structures is necessary and crucial. Two common methods to toughen the interface are producing advanced interface through inserting interleaf reinforcement and improving substrate features by physical and chemical treatments [2].

The work presented in this paper is part of a larger study focused on developing metallic foam core-CFRP sandwiches. The extended study concerns the evaluation of two types of CFRP skins (epoxy resin carbon fiber composites impregnated by manual lay-up and epoxy resin carbon fiber composites based on prepregs), in terms of the properties, adhesion to the metallic foam core and obtained sandwich properties evaluation.

The main objective of this paper is the study of CFRP skins obtained through manual lay-up processing followed by room temperature curing under pressure. The obtained composites are mechanically tested in tensile, compression and 3-point bending and the tested specimens fracture mode is evaluated by optical microscopy. This data is very important in order to use the materials as skins in sandwich composite systems.

2. EXPERIMENTS

2.1 Materials

The epoxy system used in this study was purchased from Faserverbundwerkstoffe Composite Technology (Germany) and it is an Aero-approved product (approved by the federal aviation authority LBA). The epoxy resin was L20 and the hardener was EPH161 (based on 3-aminomethyl-3,5,5-trimethylcyclohexylamine). The system specifications are presented below [5].

Table 1 – General specifications of using EPH161 hardener for epoxy resin L 20 [5]

EPH161/L20 System processing parameters	**Value**	**Unit**
Processing time for 100 g mixture (at 20°C)	90	min
Mixing ratio for 100 mass units of L20	25	g
Density (at 20°C)	1,0	g/cm^3
Storage (sealed at15°C)	12	months

Carbon fiber fabric was CARP/T193 purchased from Polydis Romania (twill weave, 3K, 0.25 mm thickness, with 193 g/m^2 areal weight and sizing agent compatible with epoxy resins) with.

The resin/hardener mixture forms a laminating matrix with low viscosity that shows superior impregnating and wetting properties towards carbon fiber.

Table 2 – Specifications of unreinforced, cured L20/EPH161 system [5]

Specifications of unreinforced, cured L20/EPH161 system	**Value**	**Unit**
Density	1,158	g/m^3
Tensile strength	70,2	MPa
Flexural strength	130	MPa
Compression strength	125	MPa
Impact strength	40	kJ/m^2
Tensile modulus of elasticity	3400	MPa
Flexural modulus of elasticity	3600	MPa
Elongation at break	9,5	%
Shear modulus of elasticity at 54°C	1019	MPa
Bend fatigue strength	1 500 000	Load cycles

2.2 Methods and Instrumentation

The CFRP skin plates were manufactured by manual lay-up/ mould pressing, using hydraulic CARVER press.

The resin/hardener was cured according to the epoxy system technical specifications. EPH161 hardener was added at 25 % by weight function of the L20 resin, the carbon fabric was manually impregnated with the obtained mixture and the curing was performed under pressure, at room temperature (for 24 h), afterwards, the materials can be subjected to a post-cure stage at 60°C, for 15 h.

The obtaining process of the CFRP skins was composed of several stages:

- Cutting of the carbon fiber fabric plies at the dimensions required by the mould;
- Preparing the resin/hardener mixture for impregnating the fabric;
- Impregnating manually the carbon fiber fabric layers (by brushing);
- Cleaning and degreasing the Aluminium foil (with 0.3 mm thickness) used as matrix, using acetone and ethanol;
- Placing the composite into the mold between the hydraulic press platens;
- Pressing of the composite for 24 h at room temperature, with 3 kg/cm^2;
- After 7 days, cutting of the specimens for mechanical tests, using 3D sample cutter device.

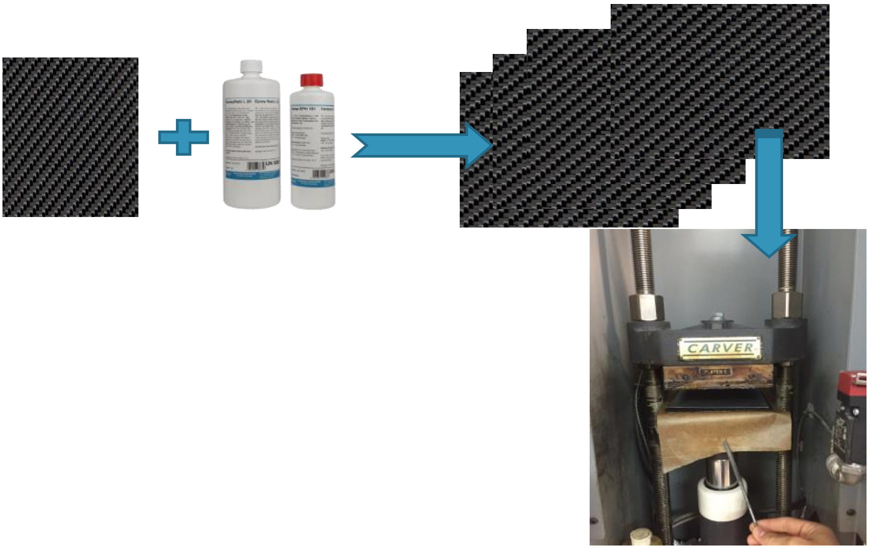


Fig. 1 – Schematic representation of the obtaining process for CFRP skins

Fig. 2 presents two samples from CFRP skins before cropping them into specimens with specific geometry for mechanical tests.

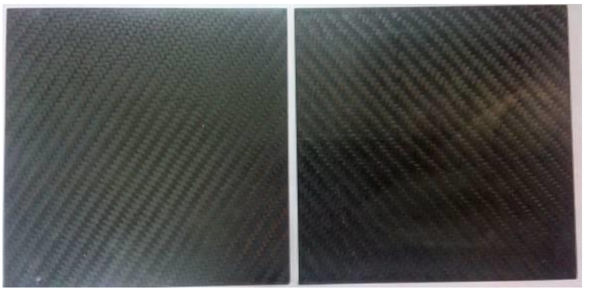


Fig. 2 − CFRP skins

The CFRP skins were tested in tensile, compression and 3-point bending using INSTRON 5982 testing machine, equipped with video extensometer. Each mechanical test was performed on minimum 5 specimens per sample. Tensile testing was performed according to SR EN ISO 527 standard [6], using 5 mm/min tensile rate, using dumbbell shape specimens. Compression testing was performed according to ASTM D6641 [7] standard, at 1.3 mm/min testing speed, while 3-point bending was performed according to SR EN ISO 178/14125 [8, 9] standard specification, using 2 mm/min speed; both tests used rectangular shape specimens.

The failure modes were analyzed using Meiji 8520 optical microscope, equipped with video camera.

3. RESULTS AND DISCUSSIONS

In order to achieve a clear image of the main behavior of the developed CFRP skins under different mechanical loads, three mechanical tests were performed: tensile, compression and 3-point flexural. The tested specimens were afterwards, analyzed with the aid of optical microscopy.

The average test results are presented in the table below:

Table 3 – Average values of strength and rigidity of the CFRP skin samples

CFRP skin sample	Load (N)	Strength (MPa)	Elasticity modulus (GPa)
Tensile	3522	491.12	31.5
Compression	14280	457.42	91.8
3-point bending	1000.39	757.8	51.45

The preliminary results are comparable to the ones presented in literature [10] in the case of the materials from this class. Therefore, the preliminary results suggest that there is a good response at the mechanical tension. The high strength and elasticity modulus obtained in all three testing conditions (tensile, compression and 3-point bending) show that the material has the proper mechanical properties suitable for use in applications where mechanical performance is mandatory.

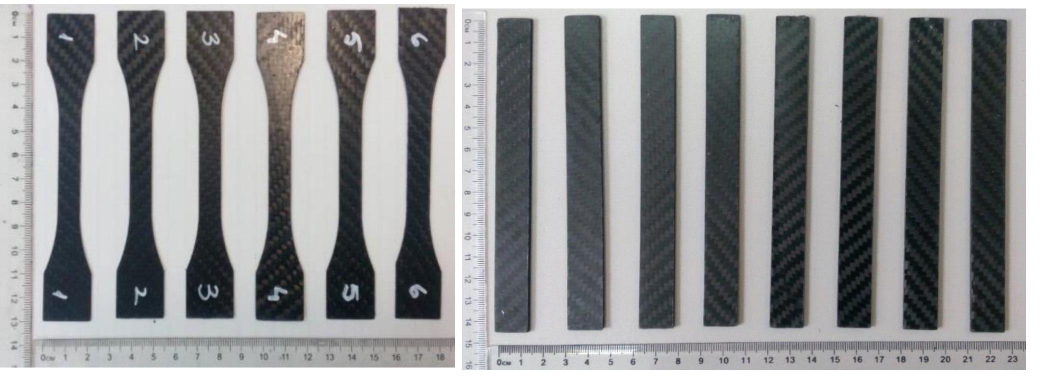


Fig. 3 − Tensile, compressive and 3-point bending testing specimens before testing

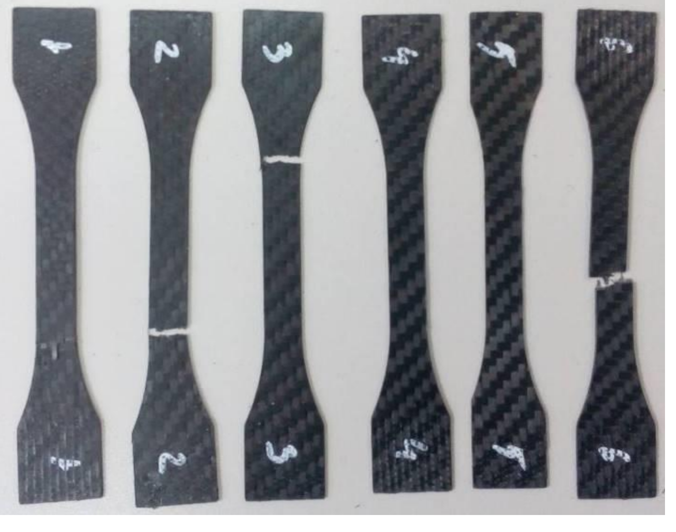


Fig. 4 − Tensile testing specimens after testing

In the case of tensile testing, as it can be observed from Fig. 4, some of the testing specimens fractured in the narrow area of the geometry, which is considered to be a valid fracture mode, according to the testing standard. However, there were some samples that fractured near the wide area, close to the grips, a fracture mode that is not considered to be valid by the testing standard; therefore, these specimens were not taken into consideration when calculating the average mechanical results. Also, some of the samples did not present complete fracture of the fabric layers, but only a supposed failure of the middle layers (that will further be evaluated with the aid of optical microscopy images).

The brittle nature of these materials was confirmed by the fracture mode, as well as by the stress-strain curves allure shown in Fig. 5.

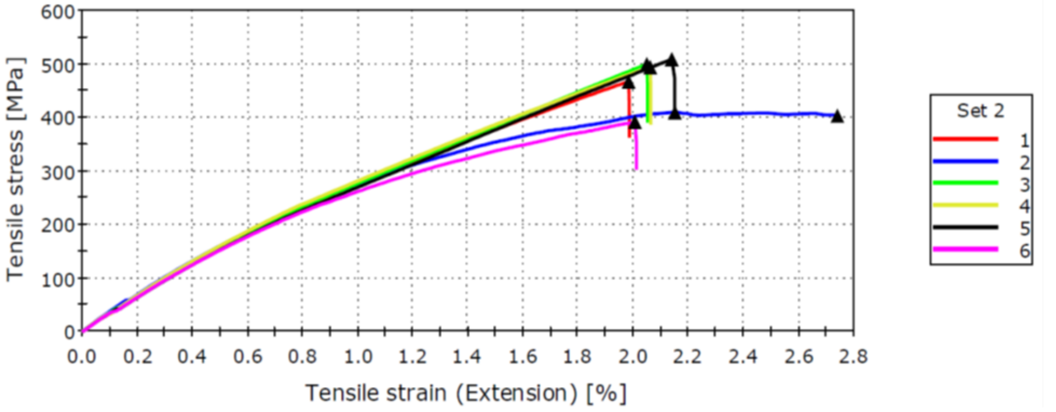


Fig. 5 – Stress-strain curves obtained in tensile testing of the materials

The mechanical test results (regarding properties values, as well as fracture mode) were complemented by optical microscopy analysis, used to identify the main fracture mechanisms and explain the manner in which the materials suffered mechanical failure.

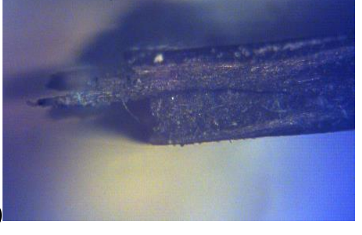
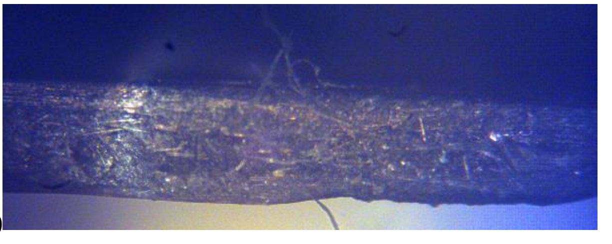
(a)  (b) 

Fig. 6 – Optical microscopy images of tensile tested samples: (a) specimen that fractured completely (b) specimen that did not fracture

Optical microscopy images of tensile tested specimens (Fig. 6) show that for the samples fractured mainly by fiber failure, the delamination phenomenon was not observed, neither debonding of layers or cracks. In the case of the samples that did not break structurally, optical microscopy images confirm the fact that failure occurred within the layered structure. This failure mode is very dangerous as it is difficult to be detected and repaired; besides this fact, this type of behavior is unpredictable and difficult to evaluate.

In case of flexural testing, all tested specimens fractured in the middle area (Fig. 7-b).

Fig. 7 – Specimens after testing in (a) compression, (b) flexural

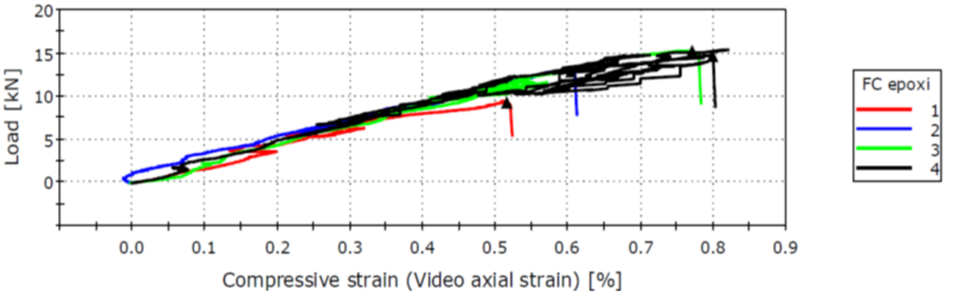


Fig. 8 – Load-strain curves during compression testing

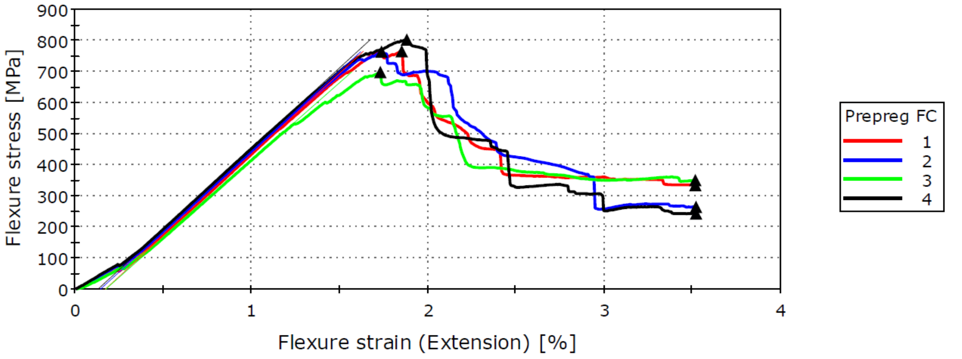
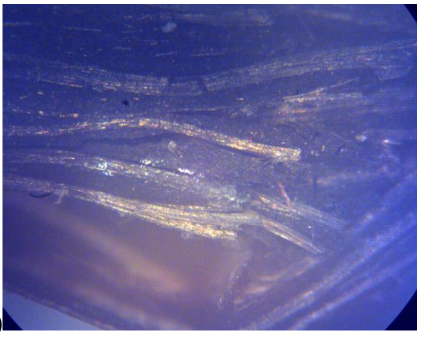


Fig. 9 – Stress-strain curves during 3-point flexural testing

Optical microscopy images of the samples tested in compression illustrate that the crack propagates towards the middle area of the fracture zone, without moving towards adjacent areas.

(a) 

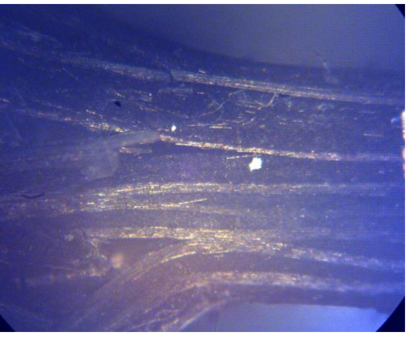
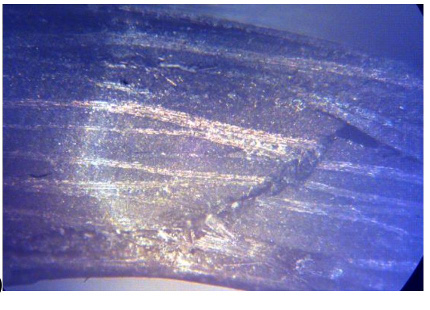
(b) 

Fig. 10 – Optical microscopy images of one of the samples tested in compression
(a) fracture area, (b) adjacent area

(a) 

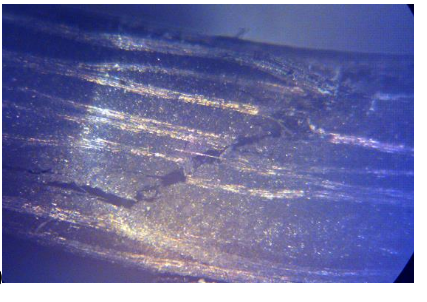
(b) 

Fig. 11 – Optical microscopy images of samples tested in flexure (3-point bending)

In the case of the specimens tested in 3-point bending, the crack propagates in transverse direction, resulting in the fracture of the carbon fibers. There is no delamination or fiber/matrix interface detachment phenomenon observed.

4. CONCLUSIONS

The paper presents preliminary results of testing of one type of CFRP to be used as skins of a sandwich structure. The studied CFRP is based on epoxy resin and carbon fiber fabric, processed by manual lay-up and room temperature mould pressing.

The CFRP skins were subjected to three basic mechanical tests namely tensile, compression and flexural (3-point bending), to evaluate the mechanical strength and elasticity modulus. The obtained results indicate the high performance of the CFRP composites, while corroborating them with the fracture mode analysis (by optical microscopy means) suggests that their failure occurred mainly by fiber breakage, without the occurrence of any dangerous phenomenon such as delamination or fiber/matrix detachment at the interface. These results indicate that the obtained CFRP composites present suitable mechanical performance for application as skins of sandwich type composites.

The results presented in this study represent an important starting point in the larger study regarding developing and testing of CFRP skins sandwich composites based on different core materials (such as different metallic or nonmetallic foams).

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