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DEVELOPMENT OF REINFORCED COMPOSITE SANDWICH PANELS BASED ON 3D FABRICS

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Abstract

A relative new type of sandwich material was investigated, based on 3D knitted sandwich fabric preforms. Due to the integrally interlacement of both sandwich-fabric the skins by the connection yarns – core debonding resistance of panels and structures based on the perform is very high. [1].

In this work the mechanical performance of sandwich composite panels based on sandwich knitted fabrics is presented and discussed. Different 3D sandwich knitted fabric performs have been produced varying the thickness and the interlacement pattern. Composite panels using these performs have been produced using vacuum infusion technique. Panel thicknesses of 8, 15 and 25 mm, using two resin types – polyester and epoxy – have been produced. Materials thus obtained have been tested in tensile, bending and impact. The results obtained are presented, discussed and compared to models. Various samples of 3D sandwich spacer fabrics using vacuum infusion process have been produced in order to study the impregnation process. The dimensional properties investigated for non-impregnated core structures include cross-threads density, areal mass, yarns linear density, etc. Results obtained show that the mechanical performances vary according to the type of 3D knitted sandwich perform and the type of resin used.

Keywords: *sandwich panels, textile composites, mechanical properties, processing.*

1 Introduction

Sandwich structures are used increasingly in applications where light weight structures are desired, due to the excellent structural capabilities of the sandwich structure. A sandwich element consists of three main parts: two faces separated by a core. The faces are usually made from metal or fibrous composites, while the core is often made from cellular polymers, balsa wood, or honeycomb materials. The general properties of sandwich structures have been described by several authors in textbooks, such as Allen [2] and Zenkert [3].

Sandwich composites are commonly used for marine, aerospace, and other structural applications due to their exceptional properties, such as low weight, high specific strength and bending stiffness [4].

Textiles are commonly used as reinforcement for composite materials. Because of increasing high-tech applications, the development of complex shaped textile structures meet the demands required by such domains. A near net shape preform produced by new textile technologies offers the advantages of waste elimination, high quality standards, reduction of processing time and cost, over the conventional production systems. Composites made from spacer fabrics offer the great ability to be used in lightweight applications due to their high tensile, flexural, impact and crash properties replacing the conventional panel structures [5].

Conventionally, spacer fabrics connected with pile yarns, produced by weaving and knitting technologies, are elastic in nature and they allow only a limited distance between the surface layers. However, these spacer fabrics do not meet 3D structural requirements for high performance composites applications. Knitted fabric composites, for instance, have the highest deformability and impact resistance compared to other textile based composites. In addition, mechanical properties could be increased by integrating reinforcement inlay yarns in knitted structures.

Vacuum-Assisted Resin Transfer Molding (VARTM) has grown significantly in popularity over the past decades in part due to advantages of a significantly reduced environmental footprint, lower weight per unit area, and debatably lower manufactured part cost. Suppliers of reinforcements and resins have undertaken considerable research on the physical properties of "single-skin" composites produced by vacuum-infusion. However, few has been presented on similar comparisons for structural sandwich composites [6].

In this work, the properties of composite materials reinforced by sandwich fibrous structures are presented and discussed, and the influence of parameters like resin type and sandwich fibrous structure thickness analyzed.

2. Raw materials

The reinforced composite sandwich studied in this work were produced using three 3D sandwich fibrous structures, with thicknesses of 8, 15, 22 mm, as reinforcement and epoxy resin EPIKOTE RESIN 04908 and unsaturated polyester resin POLIPLAS R96.02D as matrices. Table 1 summarises the most relevant properties of the resins used.

Property	Unit	Epoxy Resin	Polyester resin
Density	g/cm3	1,15	1,21
Tensile strength	MPa	74	45
Tensile strain	%	9,4	3,80
Modulus in tensile	MPa	2900	3800
Flexural strength	MPa	112	84
Modulus in flexure	MPa	3100	2900
Water absorption after 24h, 23°C	pbw	0,18	0,29

Table 1 – Proprieties of epoxy and polyester resins

Tables 2 shows the main dimensional properties of the 3D fibrous structures used in this research work. The values presented are based on experimental work carried on the samples and on the manufacturer data sheets.

Sample		*Fiber*	*Linear density (tex)*	*Diameter (mm)*	*Cross-threads density (threads/cm^2)*	*Aerial mass (g/m^2)*
8	Layer Cross threads	100% polyester	36 36	N. A. 0.13	107	621
15	Layer Cross threads	100% polyester	40 40	N. A. 0.18	96	1551
22	Layer Cross threads	100% polyester	68 58	N. A. 0.48	73	1509

Table 2 – 3D fibrous structures dimensional properties

The notation 8, 15 and 22 represents the thickness of the 3D fibrous structures used.

2.1 Air Permeability

The air permeability of a fabric is closely related to the construction characteristics of the yarns it is made of, in which large volumes are occupied by air. There are several factors affecting the air permeability of the fabric, such as fabric's structure, thickness, surface characteristics, etc [7]. All samples were kept under a standard atmosphere (22±2 ºC, HR 70±2%) for 24 hours before testing, which was done according to standard ISO 9237:1995, using the TEXTEST FX 3300 Air Permeability Tester III. The results are shown in Figure 1.

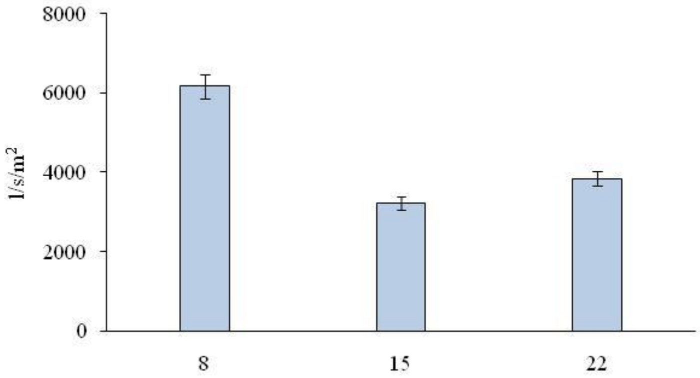

Figure 1 – Air permeability for the 3D fibrous structures used

As can be seen, sample 8 presents much higher air permeability than that of samples 22 and 15. This means that the air permeability mainly depends on the opening of the fabric structure. The difference in air permeability between structure 8 and structures 15 and 22 is large which shows that structure 8 has a lower areal mass and diameter of beams than structures 15 and 22

2.2 Compression characteristics

Fabric compression behaviour is generally described by the relationship between the applied force per unit area and the resulting fabric thickness. The compressive testing was performed on the HOUSFIELD H10KS universal testing machine. Test specimens are cylindrical shaped. Sample dimensions are 25.4 mm diameter. The rate of loading is 5 mm/min. The compression curves obtained are shown in Figure 2.

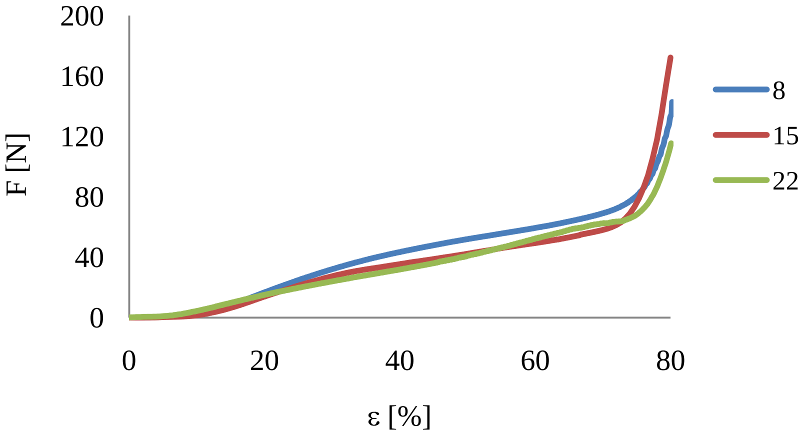

Figure 2 – Compression curves of 3D fibrous structures

Table 3 shows the compression stress [σ], strain energy [U], compressive modulus [E]. As can be observed, the different properties in compression greatly depend on the 3D fabric yarn type. The energy from deformation is calculated through the area of the graph, stress – deformation.

Sample	***σ (MPa)***	***U (mJ.mm^{-3})***	***E (MPa)***
8	72,73 ± 3,44	1,40 ± 0,22	3,80 ± 0,50
15	87,44 ± 3,64	1,46 ± 0,15	2,80 ± 0,19
22	58,56 ± 2,89	1,40 ± 0,13	6,31 ± 0,93

Table 3 – Compression proprieties of 3D fibrous

In this experiment, through the compression test, the pressure needed to compress the 3D fibrous structures during impregnation process was determined. The structure was compressed 80% of the thickness, determining the value of compression stress. This value will be used to perform the infusion of the 3D fibrous structures. During the molding process the 3D fibrous structures is being compressed necessary to maintain a given pressure.

3 Reinforced composite materials

The reinforced composite sandwich panels were prepared by vacuum assisted resin transfer molding (VARTM). Both resins used in the current study, were curable at room temperature. Hence, the impregnated performs were cured for 24 h at room temperature The resin fraction obtained in the final composite is 67.27% ± 0.06, as measured by the mass fraction (weight fraction) of the 3D fibrous (W_f) and the resin ($W_{m)}$. It are defined as:

$$W_f = \frac{w_f}{w_c} \tag{1}$$

and

$$W_m = \frac{w_m}{w_c} \tag{2}$$

w_f, w_m, w_c is mass of 3D fibrous, resin and composite respectively. Note that the sum of mass fractions is

$$W_f + W_m = 1 \tag{3}$$

The resin fraction was measured in several samples of panels produced.
The compressive and flexural testing was performed on a HOUNSFIELD H10KS universal testing machined. The compressive and flexural testing was conducted at a cross-head speed of 5 mm/min. In the compression test, the specimens are cylindrical shaped, and samples dimensions are 25.4 mm diameter. The sample dimensions for flexural test were according to ASTM C 393 - 00.

3.1 Mechanical proprieties

3.1.1 Charpy impact strength

The determination of Charpy Impact Strength, according to ISO 179:1993 serves to investigate the behavior of materials used in industrial practice, impact loading often occurs in addition to static loading. Examples of this include: demoulding, traffic accidents, hail impact on plastics roves and window profiles. Impact testing defines the ability of a material to absorb energy. Table 4 shows the energy required by the pendulum to break the sample. Different specimens were used in this test, one lot impregnated with polyester resin (PR) and another with epoxy resin (EP). The reinforced composites were tested in two directions: length direction of infusion (LD) and width direction of infusion (WD).

Sample	**Sandwich with polyester resin**			**Sandwich with epoxy resin**		
	8	**15**	**22**	**8**	**15**	**22**
E [KJ.m^{-2}] width direction	13,79 ± 0,47	64,82 ± 2,47	125,55 ± 0,76	13,77 ± 0,22	57,52 ± 0,72	139,29 ± 2,01
E [KJ.m^{-2}] length direction	13,83 ± 0,26	64,82 ± 2,82	133,29 ± 0,14	13,79 ± 0,47	66,54 ± 0,09	125,55 ± 0,76

Table 4 – Energy consumed by pendulum to beak different sample.

The results of the energy consumed by the pendulum to cause breakage of the sample are similar for samples infused with polyester resin and epoxy resin. The same analysis can be performed for the length direction of infusion and width direction of the infusion. The larger the thickness of the structure the greater the energy consumed by the pendulum to break the sample.

3.1.2 Flexural proprieties

The flexural test according to ASTM C 393 - 00 covers the determination of the properties of flat sandwich structures subjected to flat wise flexural loads, in such a manner that the applied moments produces curvature of sandwich plates. Figure 3 shows the F - ε curves obtained in flexural tests on flat sandwiches. Different samples were tested: one lot impregnated with polyester resin (PR) and another with epoxy resin (EP). The reinforced composites were tested in two directions: length direction of infusion (LD) and width direction of the infusion (WD).

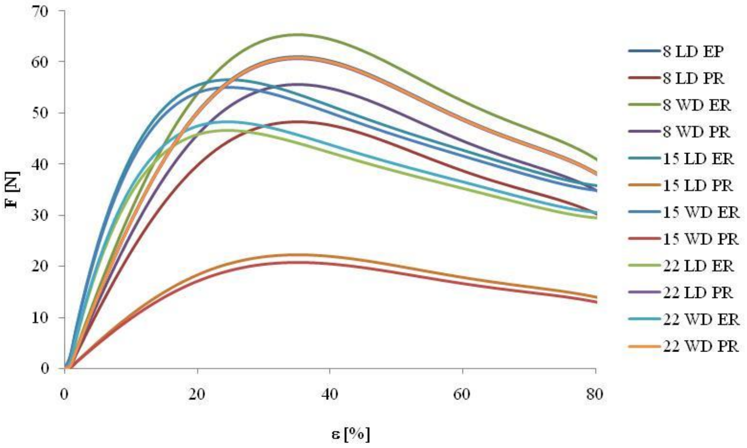

Figure 3 – Curves F- □ obtained in flexural test on flat sandwich

In the three point bending test, facing bending stress is calculated the facing bending stress (σ) as follows

$$\sigma = \frac{PL}{2t(d+c)b} \tag{4}$$

σ is the facing bending stress, t is the facing thickness, d sandwich thickness, c core thickness, b sandwich width P load, and L is the span length. Figure 4 shows the facing bending stress [σ] for each sample tested.

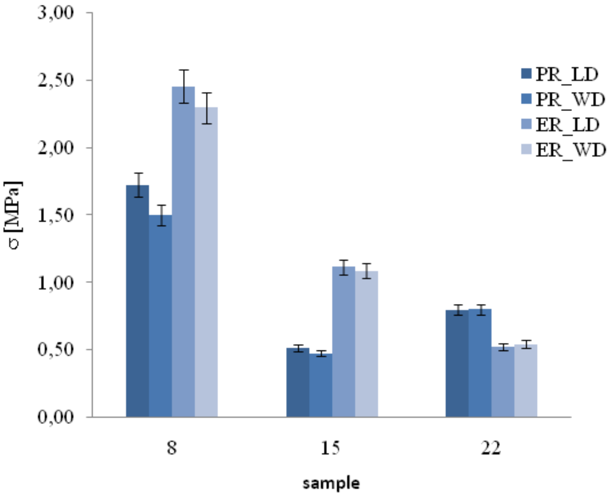

Figure 4 – Facing bending stress of reinforced composite

Samples 8 present the higher facing bending stress values than those shown by Samples 15 and 22. In general the use of epoxy resin leads to lower performance. The same trend is shown for the specimens in the width direction of the infusion (WD).

The core shear stress is calculated as follows:

$$\tau = \frac{P}{(d+c)b} \tag{5}$$

where τ is the core shear stress, d sandwich thickness, c core thickness, b sandwich width and

P the applied load. Figure 5 shows the results obtained for facing bending stress [τ].

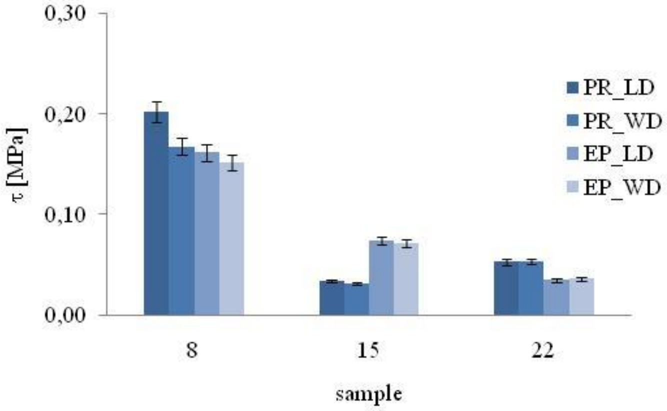

Figure 5 – Core shear stress of reinforced composite

The same can be concluded about the facing bending stress, ie, best results are obtained for samples with polyester resin and similar results are obtained for both directions. Sample 8 showed better results than the other samples. This sample has a smaller thickness compared with the other samples. The volume fraction of resin is higher than in other samples.

3.1.3 Flat wise compression properties

The flat wise compression test was conducted according to ASTM C 365 - 03. This test method covers the determination of the flat wise compressive strength and flat wise compressive modulus of sandwich cores. Figure 6 shows the curves F- ε obtained in flat wise compressive properties of sandwich cores.

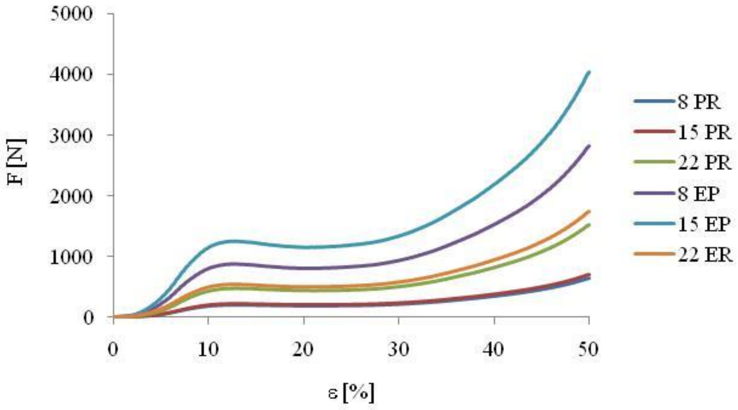

Figure 6– Compressive F- □ behavior of 3D sandwich with polyester and epoxy resin.

The calculated flat wise compressive strength is performed as follows;

$$\sigma = \frac{P}{A} \tag{6}$$

where σ is the core compressive strength, P ultimate load, A cross sectional area.

To calculate the flat wise compressive modulus the following equation is used:

$$E = \frac{St}{A} \tag{7}$$

E - Core compressive modulus slop of initial linear portion of load deflection curve, S slope of initial linear portion of load-deflection curve.

Table 5 shows the results for compressive strength [σ], strain energy [U], modulus in compression [E]. The results obtained show the great influence of the 3D fibrous structure type and the resin type.

Sample	***Type Resin***	*σ_{max} (MPa)*	*U (mJ.mm^{-3})*	*E (MPa)*
8	Epoxy	1,64 ± 0,65	29,94 ± 10,65	74.11 ± 25,81
	Polyester	0,33 ± 0,16	7,21 ± 3,14	447,69 ± 167,71
15	Epoxy	2,33 ± 0,45	20,21 ± 2,79	91.68 ± 9,53
	Polyester	0,41 ± 0,11	8,82 ± 1,96	121,05 ± 70,72
22	Epoxy	1,01 ± 0,22	12,40 ± 1,71	100,51 ± 19,79
	Polyester	0,87 ± 0,05	14,94 ± 2,50	252,85 ± 55,72

Table 5 – Compression proprieties of the reinforced composites

Samples infused with epoxy resin appear to present the higher values for core compressive strength and for strain energy. The compression modulus is higher for samples infused with polyester resin. The core compressive strength has a tendency to decrease with increasing thickness of the samples. The opposite situation is verified for compression modulus and strain energy.

4 Conclusions

Reinforced composite sandwich panels based on 3D fibrous structures were successfully manufactured based on epoxy and polyester resins using a vacuum infusion process. The work conducted under this study has shown the potential of 3D spacer fabrics as reinforcement of composite materials using vacuum assisted resin transfer molding (VARTM). The following conclusions were established through this work:

- The 3D fibrous structures used present different compression properties than those of planar fabrics due to the presence of cross-threads presented. The compression curves on the tested samples show similar behaviors to each other. However, the force and the deformation shown by each sample are different, varying according to the density of the cross-threads.
- Sample 8 presents much higher air permeability than Samples 15 and 22, due to the lower cover factor.
- Increasing the core thickness of the sandwich composites leads to greater impact load, higher impact energy absorption, lower impact damage and better impact performance for the same impact energy levels. There have been large differences in impact energy absorption in structures infused with polyester resin and epoxy resin, as for width direction and length direction of infusion.
- The thickness affects the facing bending stress and the core shear stress. Its increasing reduces the facing bending stress and the core shearing stress, considerably.

- The flat wise compressive strength and the flat wise compressive modulus increase with the increase in thickness of the core. Composites produced with epoxy resin present higher values of compressive strength.
- The epoxy resin influences the results of compression and bending, as compared with the polyester resin, for structures with the same thickness.

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