PREDICTING MECHANICAL BEHAVIOR OF NOVEL SANDWICH COMPOSITE PANELS BASED ON 3D WARP-KNITTED SPACER FABRICS USING FINITE ELEMENT METHOD (FEM)

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Abstract

In the present work, mechanical behavior of novel sandwich composite panels based on 3D knitted spacer fabrics has been predicted using Finite Element Method (FEM). Composite panels were produced using three different types of spacer fabrics having different structural parameters. The sandwich panels were fabricated based on an unsaturated polyester resin using a modified vacuum assisted resin transfer molding (VARTM) process which allowed the formation of low density core structures. The produced sandwich composite panels were simulated for flexural, compressive and flatwise tensile strength using Abaqus 6.9.3 FEM package.

1 Introduction

Sandwich structures are being used increasingly in applications where lightweight, durable, and cost effective structures are desired. A sandwich structure 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 [1, 2]. Sandwich composites are commonly used for marine, aerospace, another structural applications due to their low weight, high specific strength, and bending stiffness [3].

Textile structures are commonly used for the reinforcement of composite materials. The growing high-tech applications are demanding complex-shaped textile structures to meet the requirements of such domains. Spacer fabrics are one of the complex shaped 3D constructions composed of two separate fabric layers connected vertically using piles yarns, cross-threads, or fabric layers. Composites made from spacer fabrics offer the great potential to be used in lightweight applications replacing conventional structures due to their high tensile, flexural, impact, and crash-resistance properties [4-8]. However, conventional 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. These spacer fabrics do not meet the 3D structural requirements for high-performance applications. These problems can be overcome in spacer fabrics with cross-threads or fabric layers produced by modern flat knitting technology, which also leads to waste reduction and faster production rate. Moreover, knitted fabric composites exhibit greater drapability and impact resistance as compared to other textile-based composites. Another advantage of 3D knitted spacer fabric is that the mechanical performance can be significantly improved using multilayer reinforcement inlays in to the fabric structure [9-12].

Recently, a few researchers have investigated the mechanical performance of sandwich composites based on 3D weft-knitted textile structures. In some of these studies, mechanical behavior (under compressive and impact loading) of 3D biaxial weft-knitted spacer fabric composites has been investigated [13-17]. The researchers have developed a unit-cell model and performed Finite Element Method (FEM) calculations of the impact responses of these novel composites.

Thermoplastic composites based on flat-knitted 3D multilayer spacer fabrics have been investigated recently by Md. Abounaim et al [9-12]. These 3D-knitted preforms were developed using glass/polypropylene hybrid yarns performance of these composites was greatly influenced by the different arrangement of reinforcement yarns and the integration of reinforcement yarns as biaxial inlays was found to be the most cost-effective method.

The present work reports the prediction of mechanical behavior of a new type of sandwich composite panel manufactured based on 3D warp-knitted spacer fabrics. Abaqus 6.9.3 FEM package was used to predict the flat-wise tensile, flexural and compressive properties.

2 Materials and testing methods

2.1 Raw materials

Three types of 3D-knitted spacer fabrics used in this work were purchased from E. Cima (Spain). These fabrics have different thickness (8, 15, 22) and construction parameters as listed in Table 1.

Table 1. Structural parameters of 3D knitted spacer fabric.

Fabric type	**Fabric thickness (mm)**	**Type of fibre**		**Linear density of yarn (tex)**	**Diameter of yarn (mm)**	**Cross-threads density (threads/cm^2)**	**Fabric areal density (g/m^2)**
1	8	Face	Polyester multi-filament	15	*	107	621
		Cross threads	Polyester mono-filament	22	0.13		
2	15	Face	Polyester multi-filament	35	*	96	1551
		Cross threads	Polyester mono-filament	40	0.18		
3	22	Face	Polyester multi-filament	77	*	73	1509
		Cross threads	Polyester mono-filament	50	0.48		

* diameter could not be measured due to non-circular cross-sections.

The basic structure of these spacer fabrics is, however, similar and has been illustrated in Figure 1.

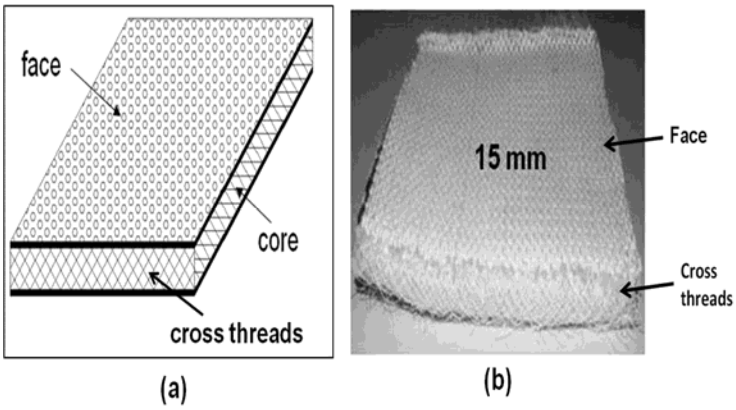

Figure 1. Schematic diagram (a) and original picture (b) of 3D-knitted spacer fabric (15mm thickness) showing different parts

The spacer fabric consists of three main parts: two faces separated by a core. The core is made of cross-threads that connect the two faces together. The properties of polyester yarns are provided in Table 2. Sandwich composite panels were produced by impregnating these spacer fabrics with an unsaturated polyester resin (Poliplast R96.02 D). The important properties of this resin are listed in Table 3.

Property	Unit	Value
Tensile modulus	MPa	2700
Yield stress	MPa	90
Yield strain	%	6.7
Density	g/cm3	1.37

Table 2. Proprieties of polyester resin**.**

Property	Unit	Values*
Density	g/cm^3	1.21
Tensile modulus	GPa	3.8
Tensile strength	MPa	45
Flexural modulus	GPa	2.9
Flexural strength	MPa	84

*Source: Carlo Riccò & Fratelli SpA – Laboratorio RS & CQ – Correggio RE

Table 3- Properties of polyester yarns

Table 4 summarizes the mechanical properties of sandwich composite with 8 mm thickness. They have been calculated using rule of mixtures.

Property	Unit	Calculated Values
Longitudinal Strength	GPa	0.101
Longitudinal Modulus	GPa	3.03
Transversal Strength	MPa	3.06
Transversal Modulus	GPa	3.07
Shear Strength	MPa	
Shear Modulus	GPa	1.084
Poisson's Ratio		0.379
Density	g/cm^3	1.322
Fiber content	%	70

Table 4 - Properties of sandwich composites

2.2 FEA analysis

The Abaqus 6.9.3 FEM package was used to predict the mechanical behavior using finite element analysis. Linear analyses were used in the mechanical behaviour simulations of composites. The properties presented in Tables 3, were used in the simulations. The Von-Mises criteria was used to predict the failure in the composites. Figure 2 shows the model of composites used in the FEM simulations. The finite element analysis was used to predict the tensile, compressive and flexural behavior according to the requirements of the ASTM C 297, ASTM C 365, and ASTM C 393, respectively.

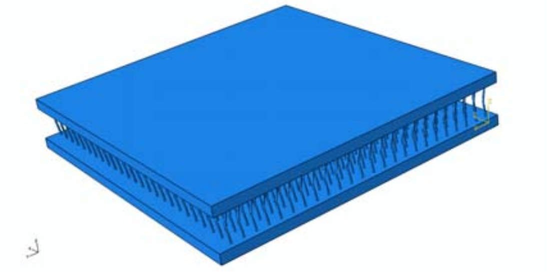

Figure 2. Model for sandwiched composites used in FEM

3 Results and discussion

3.1 Flat-wise Tensile Properties

To predict the flatwise tensile strength, it was submitted to a constant force increase in the FEA model. The Von Mises stress fields obtained from the simulations are shown in Figure 3, for structure having 8 mm thickness.

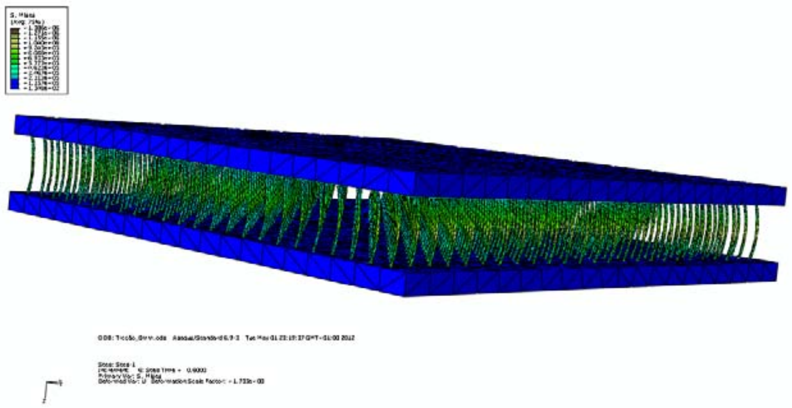

Figure. 3 - Von Mises stress field in flatwise tensile loading

Figure 4 shows the stress-displacement curves obtained from the simulation. According to the simulation, it can be predicted that the sandwich composite will fail under tensile loading at a stress of 231062 Pa.

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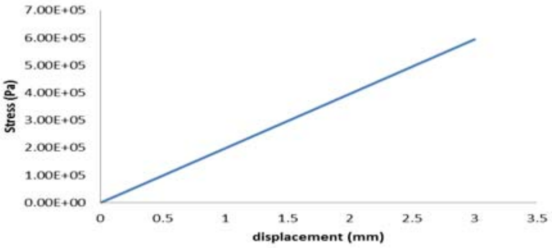

Figure. 4 – Plot of stress vs displacement in tensile loading.

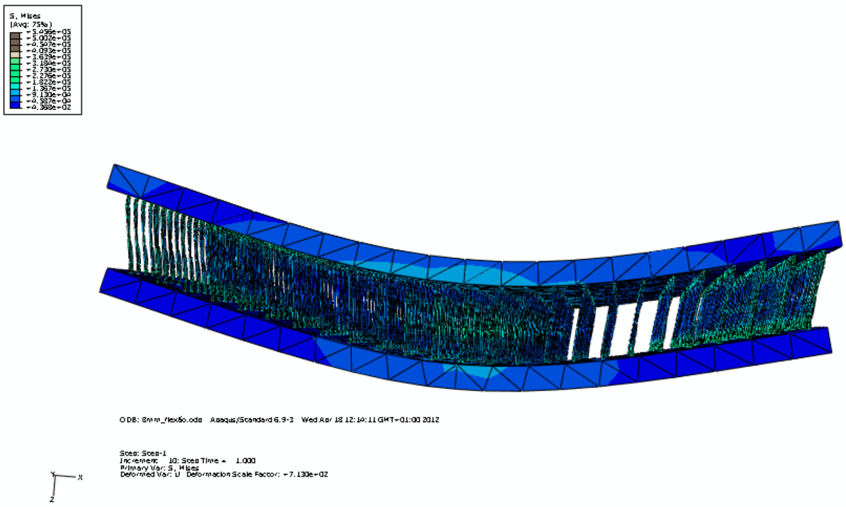

Figure. 5 - Von Mises field stresses determined in the flexural test

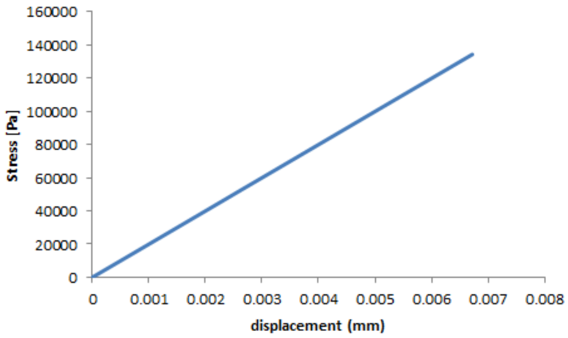

Figure. 6 – Plot of stress vs displacement in flexural loading

3.2 Flexural Properties

The Von Mises stresse fields and stress-displacement behavior obtained from the simulations under flexural loading are presented in Figure 5 and 6 respectively. According to the simulation, it can be predicted that the sandwich composite will fail under flexural loading at a stress of 545597 Pa.

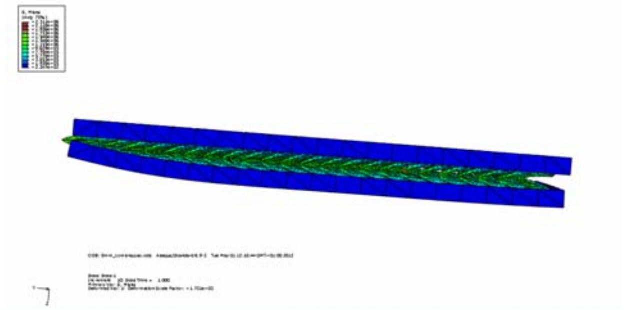

Figure. 7 - Von Mises field stresses determined in the compression test

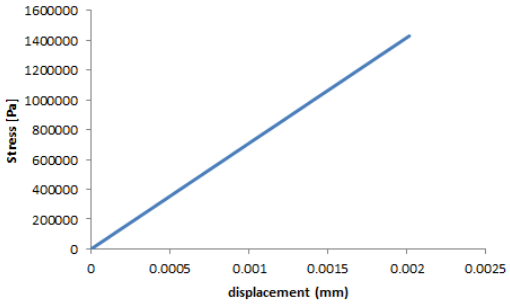

Figure. 8– Plot of stress vs displacement in compression test

3.3 Compressive Properties

The Von Mises stresse fields and stress-displacement behavior obtained from the simulations under compressive loading are presented in Figure 7 and 8 respectively. According to the simulation, it can be predicted that the sandwich composite will fail under compressive loading at a stress of 462124 Pa.

4 Conclusions

This work shows that Finite element analysis could be a powerful tool to. predict mechanical behavior of sandwich composite panels based on 3D knitted spacer fabrics. According to this simulation, these sandwich composites will fail at a stress of 1.38 MPa in flat-wise tensile test, 0.55 MPa in flexural test and 0.47 MPa at compression test.

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