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Comparison of Compressive Properties Between Vacuum Infusion and Hand Lay-Up Method Toward Balsa Core Sandwich Composites

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Abstract: The aim of this work is to evaluate the influence of fabrication methods on the compressive properties of sandwich composites using both experimental work and numerical simulations. Two types of sandwich composites with E-glass/Kevlar/polyester resin facings and End-grain balsa wood as core have been produced by vacuum infusion processing (VIP) and hand-lay up (HL) method. Compression tests on sandwich composites showed that the mean values of compressive strength of HL and VIP composites are 15.02 MPa and 28.27 MPa, respectively. The performance of sandwich composites manufactured by VIP are presented and compared to the sandwich composites manufactured by HL method. Based on the experimental tests, VIP appears to produce higher results of sandwich composite compressive properties compared to the HL method. Consequently, in this work, the compressive properties of sandwich composites were characterized by finite element analysis (FEA) and a comparison of the compressive properties in various fabrication methods was then presented. The correspondence between the predicted numerical results and the experiments proves the accuracy of this model.

Keywords: Strain Rate Sandwich Composites, Compressive Properties, Vacuum Infusion Processing, Hand Lay-Up Method

1. Introduction

The concept of a thick and light core sandwiched between two strong thin facings has been used to produce stiff and lightweight panels since the 19th century [1- 4]. Sandwich structures are widely being used in the marine, aerospace and automotive industry due to their unique advantage of very high stiffness-to-weight ratio and high bending strength-to-weight ratio [5]. The sandwich composite is the composition of a weak core material with strong and stiff faces bonded on the upper and lower sides. Facings are stiff and strong because they carry most of the loads, while core enhances the energy absorption capability during an impact.

There are many wide varieties of process for the manufacture of sandwich structures currently in use. Among them, vacuum infusion processing (VIP) and hand lay-up (HL) are the most widely used. VIP is a widely used moulding process for the manufacture of large sandwich structures with high mechanical properties. It is a closed mould technique in which fibrous or porous material is impregnated by a resin flow. The resin flow is created by applying vacuum on the bagged material. Its popularity is partly due to the low cost of the tooling and the environmental safety (the process eliminates more than 90 % of the volatile organic compound emitted by unsaturated polyester resins [6]). In addition, low operator involvement increases the repeatability of the process compared to open mould techniques such as HL and the

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components are of relatively high fiber content, up to 60 % by volume.

The mechanical properties of the laminate will change when a HL product is switched to VIP. A reduction of overall part thickness, up to 30% in some cases, will occur due to the pressure on the laminate from the vacuum bag. In fact, the laminate stiffness (EI) is reduced with the loss of thickness, causing increased deflections under design loads. However, for structures with primarily in-plane loads, or in sandwich structures, the reduction in laminate thickness is not normally a concern [7].

The research work will focus on the compressive behavior of two types of sandwich composites with E-glass/Kevlar/polyester facings and end-grain balsa wood as core. As for the processing technique, it will involve several processing stage in fabricate the sample by using VIP and HL methods. Following this, the testing stage and numerical simulations will be conducted in order to investigate compressive properties between these two types of process.

2. Materials and fabrication of specimens

2.1. Materials

The materials used in the manufacturing of the sandwich composites are E-glass mats (CG) and bi-axial E-glass fabric (WG) by Camelyaf®, bi-axial Kevlar fabric (WK) by COLAN®, Synolite 8488-G-2 isophetalic polyester resin (VIP resin) and Synolite 0288 isophetalic polyester resin (HL resin) by DSM composite resins and SB.100 end-grain balsa wood by BALTEK Co. The mechanical properties of the fibers, resins and the core material are listed in Table 1.

2.2. Sandwich composite fabrication methods

The sandwich composites structure consists of 12 E-glass mats (150 g/m^2), 2 bi-axial E-glass fabrics (600 g/m^2) and 3 bi-axial Kevlar fabrics (480 g/m^2) in a (CG / CG / WG / CG / CG / WG / CG / CG / WK / CG / CG / WK / CG / CG /Balsa / CG/ WK / (CG) configuration. The resulting sandwich composite thickness is approximately 20 mm. The thickness of balsa wood as core material is 12 mm. The skins were laminated by HL and VIP methods, which ensure uniform thickness of the adhesive layer. The fabricated sandwich composites were cured for 72 h before trimming and cutting.

2.3. Specimen preparation

To avoid uncertainties related to size effects, the specimens in all the tests have the same geometry. Specimens were cut from the plates in the specified dimensions 400 mm × 400 mm × 20 mm according to standard ASTM C 365/C 365M, using a water jet cutting machine. After cutting to predetermined dimensions, the specimens were coded and their dimensions were measured. Specimens were divided into two groups: (1) HL group, (2) VIP group. All the specimens in each group were stored at room temperature until testing. Three replicates of each specimen type were prepared and tested.

The details of the specimens are listed in Table 2. Specimens HL-1, HL-2 and HL-3 represent sandwich composites fabricated by HL method while specimens VIP-1, VIP-2 and VIP-3 represent sandwich composites fabricated by VIP method.

Table 1. Mechanical properties of the fibers, resins and the core material.

Material	Modulus of elasticity (GPa)	Compressive strength (MPa)	Volume density (g.cm^{-3})
E-glass mat	70	1750	2.57
E-glass bi-axial	76	3000	2.60
Kevlar bi-axial	131	3800	1.44
Synolite 0288 resin	4.1	60	1.20
Synolite 8488-G-2 resin	3.5	66	1.05
End-grain balsa	3.92	12.67	0.15

Table 2. Details of composite sandwich specimens for compressive test.

Specimen Code	Dimensions (mm)	Cross section (mm^2)	Depth (mm)
HL-1	23.93×23.01	550.63	19.38
HL-2	23.95×24.33	582.70	20.4
HL-3	24.09×23.91	575.99	20.34
VIP-1	23.44×23.14	542.40	19.87
VIP-2	24.28×23.40	568.15	19.87
VIP-3	24.28×24.30	590.00	20.10

2.4. Compressive testing

Compressive tests were performed on a universal testing machine (Gotech Co., Taiwan) according to ASTM C365/C365M, at 0.5 mm/min crosshead speeds. After installing the specimens into the testing machine, the compressive loading is applied to the specimen until the failure of core occurs. Three specimens of each category were tested using this procedure. The compressive strength was computed by dividing the failure load by the area of the specimen. The experiments were conducted at ambient temperature (+23 ºC) and relative humidity (50%) conditions.

3. Finite element modelling

Finite element calculations of the compressive response of the sandwich composites with a square balsa core were performed using the finite element package ANSYS. The specimen geometries were simulated numerically using finite element modelling. The mechanical properties of the skins and the core listed in Table 1 are used directly in the model. The skins are modelled as laminate material consisting of plies consisted of different fibers and the core as solid elements with homogenous and isotropic properties. Typically, the model comprised 3 layered solid elements through the thickness of composite upper face sheet, 1 layered solid element through the thickness of composite lower face sheet and 5 solid elements through the depth of the balsa core. Boundary conditions similar to those used in compressive testing were utilized and all nodes on the bottom of the model were fully clamped. The skin is assumed to be perfectly bonded to the core, eliminating the delamination failure mode.

4. Results and discussion

The compressive force-deflection curves of the two types of sandwich composites are shown in Figs. 1 and 2. From results, it can be seen that mean values of compressive strength was of 15.02 MPa and 28.27 MPa for the HL and VIP composites, respectively.

Fig. 3 shows the FEA models and compressive failure in core for the HL and VIP composites. The ultimate compressive stress corresponded with applied load was determined and compared with the experimental results.

The compressive strength calculated from the tests and numerical simulation is shown in Table 3 for the composites with different manufacturing methods.

It was clearly observed that the samples fabricated by VIP have higher compressive strength than hand HL method. The reason contributed to this phenomenon is the processing route.

In composite materials, flaws at microscopic level appear in the form of voids in the matrix, at the fiber-matrix interface and in particular at fiber crossovers and at macroscopic level in the form of possible non-uniform ply spacing [8]. Therefore, the differences in the measured values for both HL and VIP specimens is a reflection of micro-structural heterogeneity, which is often described by the volumetric distribution of inherent flaws introduced during fabrication.

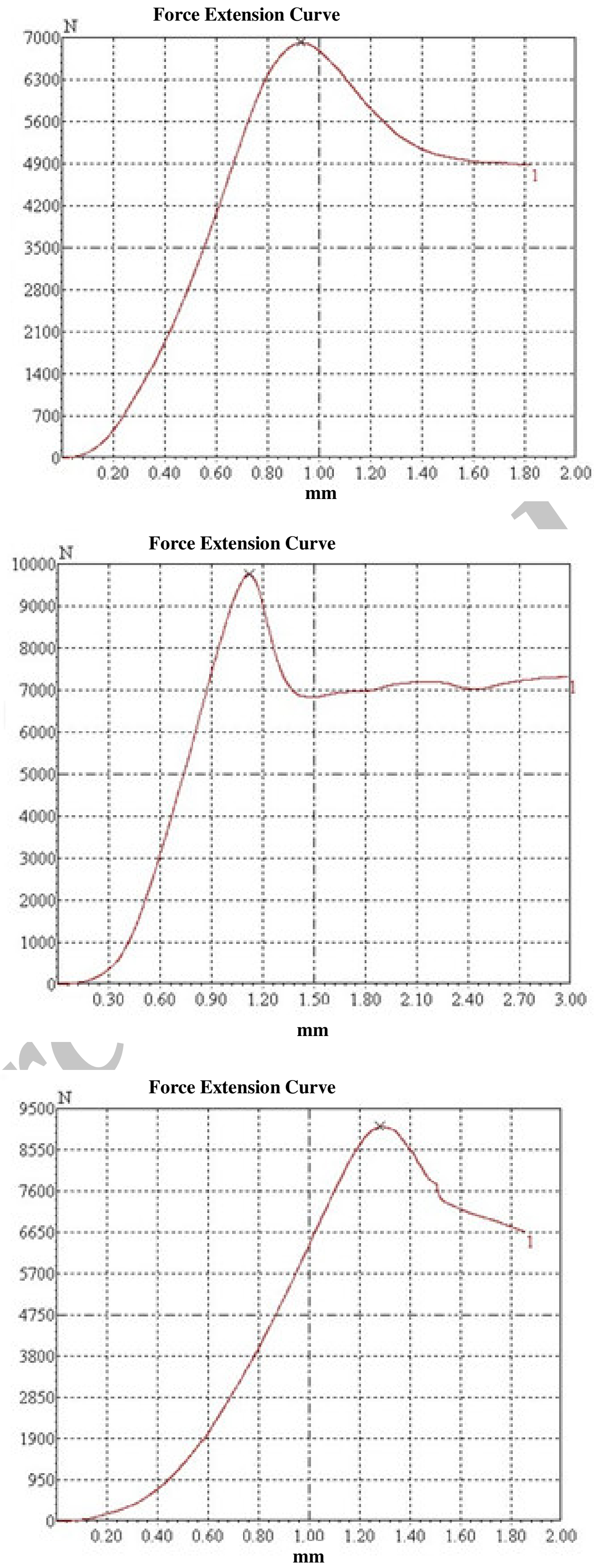

Fig. 1. Force versus deflection curves for the sandwich composites fabricated by HL.

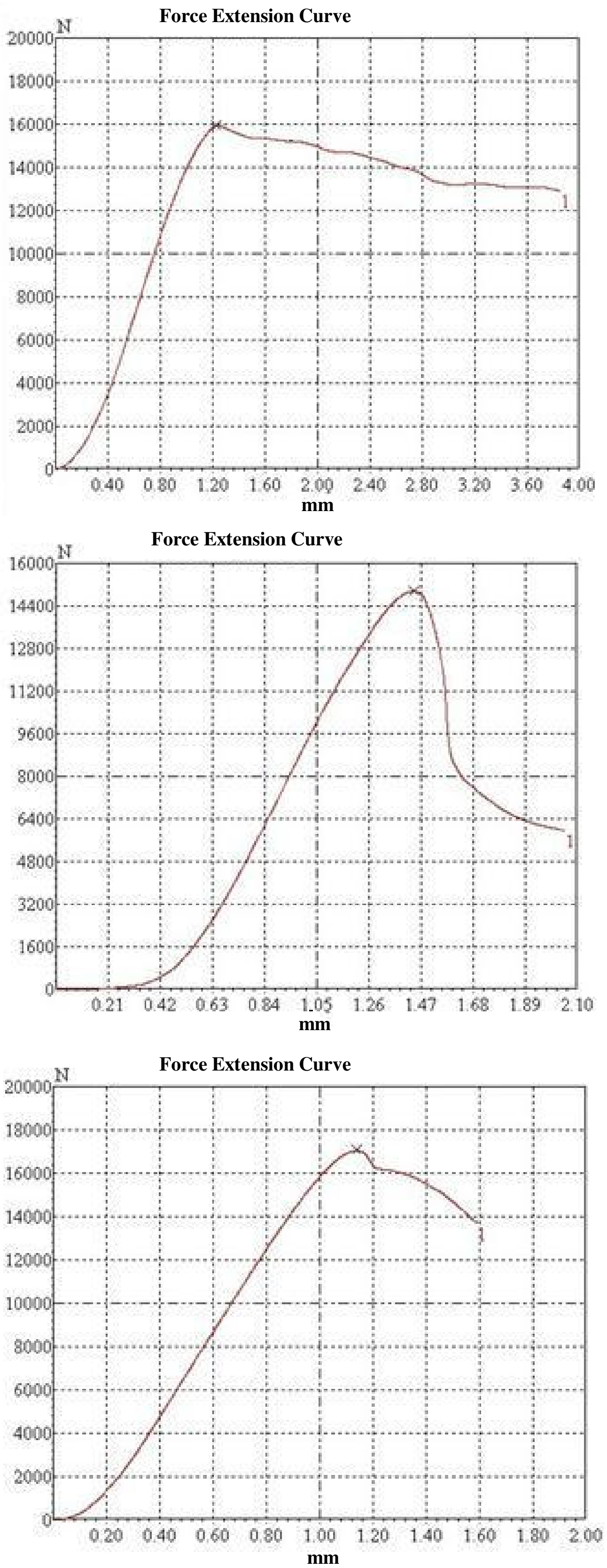

Fig. 2. Force versus deflection curves for the sandwich composites fabricated by VIP.

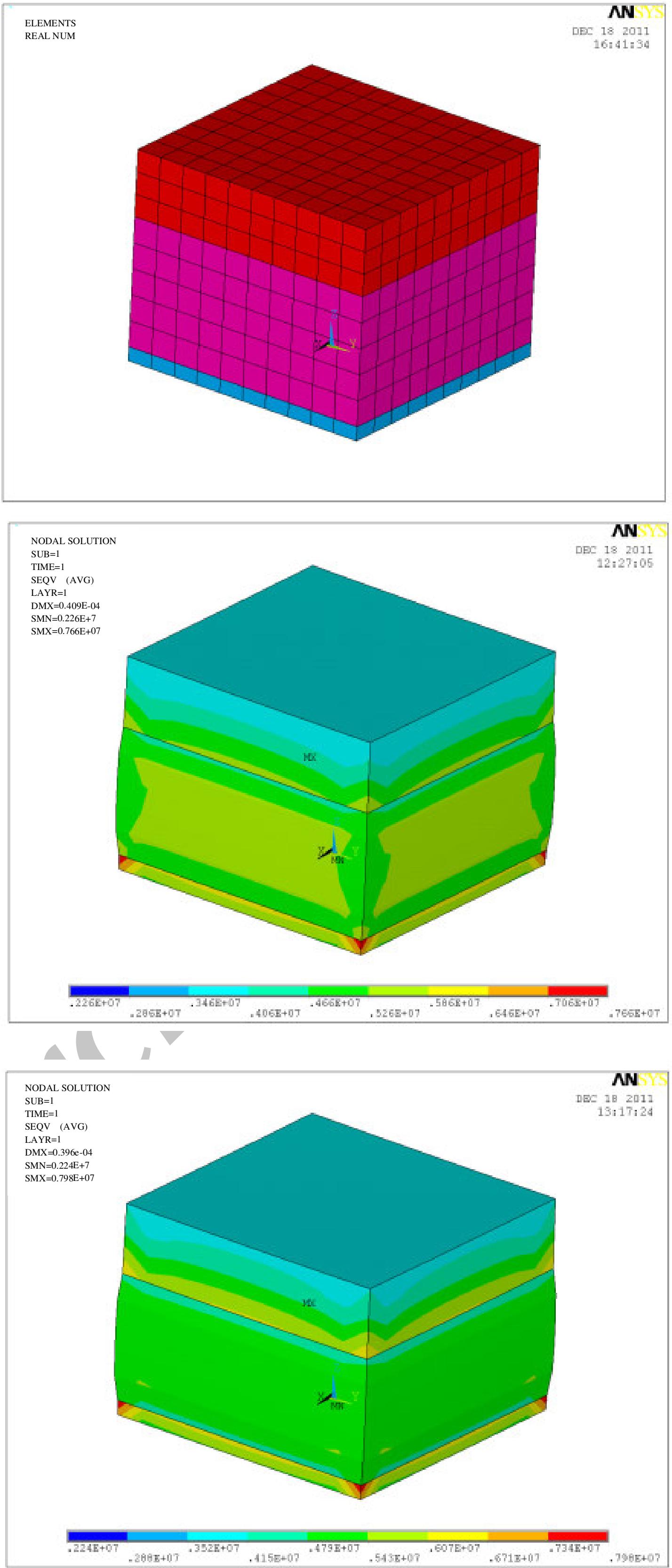

Fig. 3. (a) FEA model of a sandwich specimen, (b) Compressive failure in core for the HL composites, (c) Compressive failure in core for the VIP composites.

The resin infusion process in vacuum condition will pressurize the samples automatically when the gases inside the mold have been removed. Indirectly, the atmospheric pressure will reduce the voids or space inside the samples. Therefore, minimizing the voids can greatly improve the mechanical properties of samples [9].

Furthermore, as the process involves creating a vacuum, there is a little or no moisture content when the resin sucked into the mold. Reducing the moisture content of the sample during the curing phase will contributed to better mechanical properties of composites as well. For HL method, the process was carried out in environment that exposed to the moistures and gaseous so it will be react or affect the composites during the curing process [9].

Finally, results showed a good agreement in the compressive behavior of sandwich composites between the numerical simulation and the experimental values.

The predicted failure strength was of 17.24 MPa and 31.41 MPa for the HL and VIP composites, respectively. It was resulted that FEM simulation gave the relative errors 14% and 11% for the HL and VIP composites, compared to the test results.

The failure strength of sandwich composites determined by FEM simulation was higher than the test results. As the cause explains the bonding between facings and core is considered perfect bonding when modeling in ANSYS.

The correspondence between the predicted numerical results and the experiments proves the accuracy of this model, which has also been applied to a real application.

Table 3. Mean compressive strength derived from the force-deflection data and predicted failure strength.

Properties	Composite type	
	HL	VIP
	6.9	15.9
Breaking load (kN)	9.8	17.07
	9.08	14.96
	12.57	27
Failure strength (MPa)	16.75	31.47
	15.77	26.33
Mean (MPa)	15.02	28.27
Standard deviation	2.18	2.79
Predicted failure strength (MPa)	17.24	31.41

5. Conclusions

Effect of compressive loading on sandwich composites fabricated by VIP and HL methods was investigated experimentally and numerically. The main outcomes of the conducted activities are as follows:

1. The sandwich composites fabricated by VIP has the superior compressive strength compared to HL method. The mean value of compressive strength was of 15.02 MPa and 28.27 MPa for the HL and VIP composites, respectively.
2. The predicted failure strength of the sandwich composites in the elastic range is in good agreement with the experimental results.

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