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Enhanced mechanical performance of foam core sandwich composites with through the thickness reinforced core

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ABSTRACT

The purpose of this study is to improve the mechanical performance of the foam core sandwich composites with a rather simpler method of core reinforcement. With this aim; sandwich composite panels are manufactured using only-perforated foam and perforated-stitched foam as the core with multi-axial glass fabrics as the facesheet materials by vacuum infusion method using epoxy resin. Sandwich composites with perforated core, stitched core and plain core have been compared in terms of compressive, bending, shear and impact performances. It was seen that newly proposed perforated core specimens and stitched core specimens with relatively insignificant weight increase have superior mechanical performances than plain core specimens. Thus reinforcing foam core with perforation and stitching is proposed as simpler but very effective method in performance improvement for the sandwich composites.

1. Introduction

Sandwich composites, which have been preferred to be popularly used in marine applications, wind turbines, space and aircraft vehicles due to their high bending rigidities in addition to their lighter weights, are composed of the core, which is lighter but thicker and has lower strength, and the facesheet, which is rigid and stronger. The properties of the facesheet, stiffness and strength properties of the core and the strength of core-to-facesheet bonding determine the characteristics of the sandwich composites.

Closed cell foams, as core materials, are reported to have higher modules and strength than open cell equivalents and therefore preferred for impact loadings [1], however foam core sandwich structures are indicated to be inferior to honeycomb and some other core concepts [2]. Thus studies, in order to increase the foam core strength and improve core-to-facesheet bonding characteristics, have been carried by stitching and z-pinning.

Stitching has been adapted and used in the manufacture of foam core sandwich composites [3–13]. Despite majority of these studies have indicated improvement in the mechanical properties of stitched sandwich composites stitching is either possible by hand stitching, which is time consuming and labor intensive, or has to be done by accustomed stitching machinery, which is not always available. As an alternative; z-pinning has been under investigation and improvements on the mechanical properties including compression, impact damage resistance, in-plane shear properties, and delamination fracture toughness have been achieved with z-pinning [14–17]. For z-pinning, it is necessary to prepare the pins and there is the need of additional processing to place the pins into the cores. In addition when stitching and z-pinning are performed through one or more layers of facesheet, the fiber orientation of the facesheets is disordered and damage is given to the facesheets. Thus studies have still been carried out on the reinforcement of foam cores.

Vaidya et al. [18] compared z-pin reinforced foam core and foam filled honeycomb core with the aim to improve strength and stiffness of closed cell cores and performed high strain impact loading. Birman et al. [19] included aluminum nanoparticles in the core by impregnation and analyzed the effect on the performance of sandwich panels. While the impregnation was found beneficial for local failure its effects on overall bending and stiffness were indicated to be very small. George et al. [20] manufactured CFRP pyramidal lattice structures using braided Kevlar to reinforce closed cell polymer foams in a hybrid CFRP truss/foam core sandwich panel. The manufactured hybrid CFRP lattices are found to have

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compressive and shear modules and strength between those of the foams and CFRP lattices/honeycombs. Nilanjan [21] proposed a method to improve shear properties of sandwich composites by opening grooves on the core and inserting shear key elements of any material into these grooves. Resultant sandwich composites are reported to have improved in-plane shear strength and stiffness. Wang et al. [22] punched holes through the core after placing nonwoven facesheets on the core; in this way fibers from the nonwoven reinforcement were inclined towards the core through the holes and bending, out of plane compression and shear properties of the resultant sandwich composites are reported to be improved with the increase in the hole density. However a comparison with non-punched core sandwich composites was not performed and still damage has been given to the facesheet. Zhou et al. [23] placed composite rods of glass and carbon fiber into the pre-drilled holes in the foam core prior to sandwich composite manufacture. The compression and impact performances are reported to improve significantly with the inclusion of such composite rods in the foam core of the sandwich composite. Belingardi [24] analyzed glass fiber foam core sandwich composite to be used in the construction of the front shield of a high speed train. In order to improve the foam core compression stiffness they have inserted resin walls into the foam core perpendicular to the facesheets with 30 mm intervals and the resin walls were observed to increase the compressive strength and stiffness of the sandwich composite.

In this study it is aimed to enhance the mechanical performance of the foam core sandwich composites by drilling holes in the foam core prior to composite manufacturing and to analyze systematically the effect of these holes on the bending, shear, impact and out-of plane compression performances of the resultant composites. Even though foam cores have been reinforced by drilling holes in the previous studies, either it was a groove not a hole or the holes were filled with composite or metal/alloys rods, which meant additional processing and preparation. However the foam cores can be supplied as drilled and then used in composite manufacturing without the need of additional processes or preparation. Thus, with this study mechanical performances of sandwich composites with perforated foam cores and stitched foam cores are analyzed and compared with sandwich composites of non-perforated foam cores. So a new method is proposed and is also analyzed comparatively so that this method can be considered as a simpler method to improve the performance of sandwich composites. In this way the difference between these core reinforcements will be outlined and the results can be used in choosing the appropriate core reinforcement according to the intended end use.

2. Material and methods

In this study, Airex C71.55 PVC foam with 0.06 g/cm^3 density and 15 mm thickness was used as the core material. Six different kinds of core were prepared and are listed in Table 1. Non-perforated (plain) core was used in the manufacture of reference composite. Perforated core panels were drilled having 3.5 mm diameter holes with hole density as 0.5 hole/cm^2 by CNC milling machine. In order to prepare stitched cores, the core was again drilled as explained and then hand-stitched with glass rovings of different counts; 600 Tex, 1200 Tex, 1800 Tex and 2400 Tex. The core perforated and stitched can be seen in Fig. 1a.

As the reinforcing material in the facesheets; unidirectional E-glass fabrics with an areal density of 300 g/m^2 were used. The stacking sequence of the sandwich composite was [+45/−45/(0/90)$_2$/CORE/(90/0)$_2$/−45/+45]. Momentive L160 epoxy and its hardener H160 were used as resin. Sandwich composites were manufactured by vacuum-assisted resin infusion process [25]. During composite manufacturing, the resin infuses into the glass fabrics and the holes. All of the composite specimen were cured initially at room temperature for 24 h, and then were post-cured at 80 °C for 15 h. The nominal thickness of all of sandwich composite samples was 18 mm. The sandwich composite structure can be seen in Fig. 1b: here for perforated core specimens the columns are composed of the resin and for stitched core specimens the columns are composed of the glass rovings with the resin.

To assess the mechanical performance of the sandwich composites with different core specifications, out of plane compression, bending, shear and low velocity impact tests were performed according to related ASTM standards. For each type of specimens five tests were performed, mean values and standard deviations were calculated. The sandwich composite specimen with non-perforated core (R) was referred as the reference specimen.

3. Compression test

Out-of-plane compression tests were performed according to ASTM C365/365M [26]. Specimens were in the form of tetragonal prism with square base having dimensions of 50 mm × 50 mm while the thickness was 18 mm. The tests were done on Shimazdu AG-X 100 kN universal equipment and the test set up can be seen in Fig. 2a. During the trials realized prior to the testing, it was seen that there was not any significant difference between the movement amount of the crosshead and the deflection amount measured on the specimen by displacement transducer. In fact this is an expected result for such types of sandwich composites having cores with low compression strength. Thus the tests were evaluated considering the movement amount of the crosshead during the test. All of the tests were performed at constant crosshead displacement of 0.5 mm/min. The stress and strain values of the specimen are calculated from the Equation (1).

$$\sigma_z = \frac{P}{a \cdot b}, \quad \varepsilon_z = \frac{\Delta t}{t_c} \qquad (1)$$

where σ_z and ε_z are the out-of-plane stress and strain respectively, a and b are the base dimensions of the specimen, Δt is the deflection amount through the thickness and t_c is the initial thickness of the core, P is the measured compression force value.

Flat-wise modulus of elasticity and compression strength of the specimen can be obtained from the stress-strain curves. From such a stress-strain curve, the slope of the linear portion gives modulus

Table 1
Specifications of the sandwich composite specimens used in the study.

Composite code	Core type	Facesheet	Column material
R	Non perforated (reference material)	Glass-epoxy	None
P	Perforated	Glass-epoxy	Epoxy
S1	Perforated-600 tex stitched	Glass-epoxy	Glass-epoxy
S2	Perforated-1200 tex stitched	Glass-epoxy	Glass-epoxy
S3	Perforated-1800 tex stitched	Glass-epoxy	Glass-epoxy
S4	Perforated-2400 tex stitched	Glass-epoxy	Glass-epoxy