BENDING AND COMPRESSION PERFORMANCE OF COMPOSITE TUBE REINFORCED FOAM CORE SANDWICH STRUCTURES

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Abstract
In some applications such as walls and roofs, it is important to supply low thermal conductivity and high bending stiffness to structures. Generally, foam materials are preferred, which have low thermal conductivity. However, bending stiffness and compression properties of foam materials are low. In this study, composite tubes were inserted to the foam core material to improve the compression and bending properties of the structure. Vacuum infusion method was used to manufacture the sandwich structures. To measure the bending stiffness, shear properties, and compression properties of the structure, three-point bending and compression tests were conducted according to ASTM standards, respectively. The manufacture procedure is very easy and can be applied large panels. The bending performance of the structure was compared to the foam core structure which does not include composite tubes. A parametric analysis was done to investigate the effect of the tube spacing and the diameter of the tubes on bending stiffness of the structure. According to the test results, the samples including tubes gave higher bending stiffness as compared to the samples without tubes.

1. Introduction

Composite sandwich structures are ideal for a wide range of products in home and building construction, boat building, aerospace craft, and automobiles due to their superior properties of high stiffness to weight ratio. The separation of face sheets by a core material have an increase in the moment of inertia of the structure, resulting in higher bending stiffness, which is the main characteristic of the sandwich structures. In some applications, this characteristic does not meet all the requirements that expected from the structure.

Various core materials and core designs have been considered under compression, flexural, indentation and dynamic loadings. Core structures can be categorized according to materials used and their geometries. Honeycomb, foam, corrugated, truss, grid/web, and contoured cores are mainly studied core structures. Some of the core structures such as foams and honeycombs are modified by inserting structural elements in order to improve mechanical properties such as in-plane shear, core compression strength and buckling instability of sandwich structures. Stitching [1, 2, 3] and z-pinning [4, 5, 6] has been developed to increase the foam core strength and improve the core-facesheet debonding. Kim et al. [1] investigated the effect of stitching on the static and fatigue characteristics of polyurethane foam- cored sandwich structures. The bending strength of the stitched specimen was improved by 50% compared with the non-stitched one, on the other hand, the stitched specimen cannot improve the bending fatigue strength due to brittle resin rich regions built-up around the stitching thread, which are easily broken under fatigue loading condition. Potluri et al. [2] compared the performance of the stitched and non-stitched specimens under indentation load. It was observed that core-face debonding area decreased when stitch spacing decreased. Although there is improvement in the mechanical properties, stitching is labor intensive method and it is difficult to be applied to the circular shape structures. As compared to the stitching method, z-pinning method is more convenient to the complex geometry of cores. Cartie and Fleck [4] inserted Titanium and carbon fiber pins into the polymer foam core sandwich structure and quasi-static and dynamic compressive loading were applied to the specimen. The stiffness, strength and energy absorption were increased by introducing the metal and the carbon pins. Also, it was shown that the compressive strength was governed by elastic buckling of the pins. Abdi et al. [7] and Yalkin et al. [8, 9] modified the foam core of the sandwich structure by inserting polymer pins into the core and stitching the core by glass roving of different counts, respectively. Increasing the diameter of polymer pins improved the flexural and flatwise compression properties of the panel [7]. Glass fiber stitched foam core structure had improved mechanical performance in comparison to the perforated one [9]. Zhou et al. [10] reinforced the PVC core by carbon and glass fiber rods to increase the compression strength and energy absorbing capacity. Carbon fiber rod reinforced foam panels offered higher compression strength and energy absorbing capacity to their glass fiber counterparts.

In the light of above discussion, a more convenient method is need to improve the shear and compressive properties of the core material, which should not be time consuming, labor intensive and it should be applied large and complex geometries. In the current study, it was proposed that glass composite tubes were introduced to the foam material. Vacuum infusion method was considered to manufacture the sandwich structure at a time. 3-point bending and compression tests were done to determine the performance of the sandwich structure. Composite tube diameter and tube spacing were considered to be design parameter and the effect these parameters on the shear and compressive properties were investigated.

2. Materials and manufacturing procedures

A conventional epoxy resin MGS R285 (Hexion) and its hardener MGS H285 were used as a matrix material and non- crimp [-0/45/90/45] Quadriaxial E-glass fabric (Metyx-Q625 E10C) was chosen as the reinforcement material. Extruded polystyrene (XPS) DT was the foam core material. The material properties of the resin, E-glass fabric, and foam are given in Table1.

Table 1. The material properties of cured epoxy and E-glass fabric.

Cured resin [11]	
Tensile strength, S_{yt} (MPa)	70–80
Compressive strength, S_{yc} (MPa)	120–140
Elastic modulus, E_m (GPa)	3.2
Poisson's ratio, ν_m	0.36
Shear modulus, G_m (GPa)	1.18
E-glass fabric [12]	
Elastic modulus, E_{f1} (GPa)	72.4
Poisson's ratio, ν_f	0.22
Shear modulus, G_f (GPa)	26.2
Foam [13]	

Density kg/m^3	24
Compression strength (kPa)	100

Sandwich panels were manufactured using vacuum assisted resin transfer molding (VARTM) method. Firstly, the foam core was drilled using a special cutting tool that creates smooth holes without any ruptures from the foam. Then, the composite tubes cut using a diamond saw were inserted into the holes and the cylindrical foams got from the previous step were inserted into the composite tubes. These steps were represented in Figure 1. The thickness of foam and composite tubes was 20 mm.

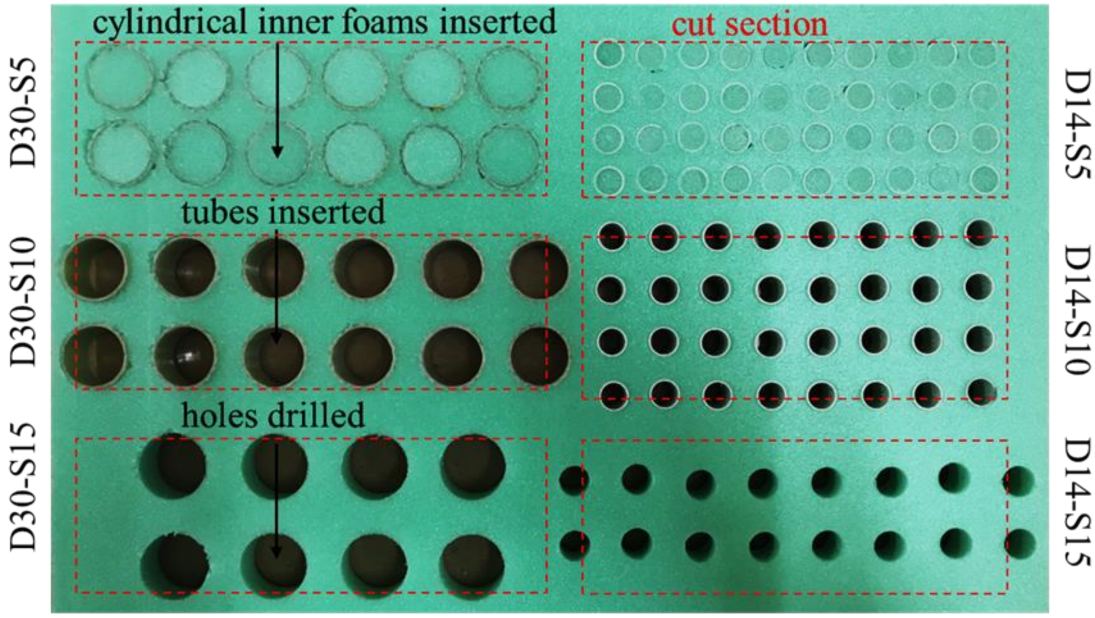


Figure 1. The composite tubes reinforced foam core configuration.

E- glass fabrics were then laid on the upper and lower surface of the reinforced foam with desired stacking sequence of [0/-45/45/90]s. The schematic representation of the lay-up is shown in Figure 2. Six different configurations were considered to investigate the effect tube diameter and tube spacing on shear behavior of the sandwich structure. The outer diameter of the tubes was chosen as 14 mm and 30 mm. Three tube spaces of 5 mm, 10 mm, and 15 mm were selected. Thus, 21 samples were manufactured by the replication of three for 3-point bending test. The sample designation code is given as D_- S_. Here, D and S represent the diameter, and tube spacing, respectively. All configurations can be seen in Figure 1 with their designation codes. The width, length, and thickness of the samples were 75 mm, 200 mm, and 22.4 mm, respectively.

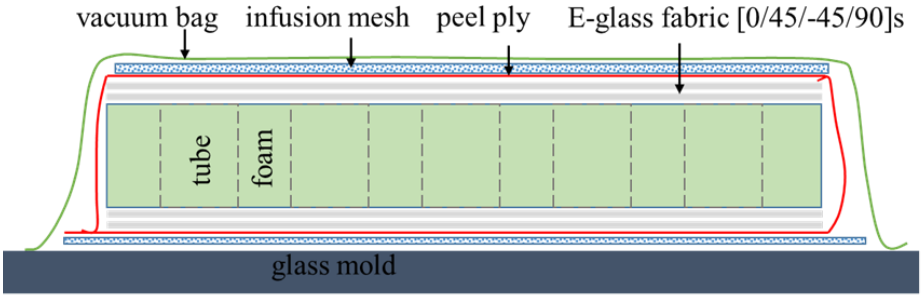
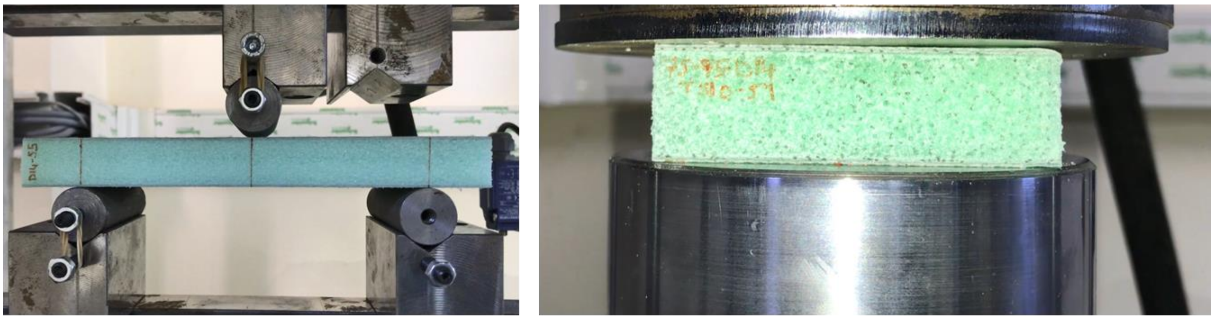


Figure 2. The schematic representation of the lay-up.

3. Bending and compression tests

Three sandwich plates were tested for each configuration using the 3-point bending test setup according to ASTM 393, shown in Figure 3(a). The width, length, and thickness of the 3-point bending test samples were 75 mm, 200 mm, and 22.4 mm, respectively. The diameter of the bars was 25 mm. The test is displacement controlled with the rate of 2 mm/min. Compression tests were done according to ASTM 365 test standard and test set-up is shown in Figure 3(b). The in-plane dimension of the samples was 50x50 mm and 75x75 mm. A 100 kN ALSA tensile testing machine was used for the tests.



(a) (b)

Figure 3. (a) three-point bending test set-up, and (b) compression test set-up.

4. Results and discussion

This study examined the effect of tube diameter and tube spacing on the bending stiffness and the compression strength of the sandwich structure. For this purpose, bending and compression tests were conducted and discussed.

4.1. Bending test results

Load versus mid-span deflection curves are shown in Figure 4 for all configurations considered. The samples including tubes gave higher bending stiffness and core ultimate shear load as compared to the specimen without tubes. The behavior of three replicates for all configurations are shown in the figure and successful replications were had except for D14-TS10.

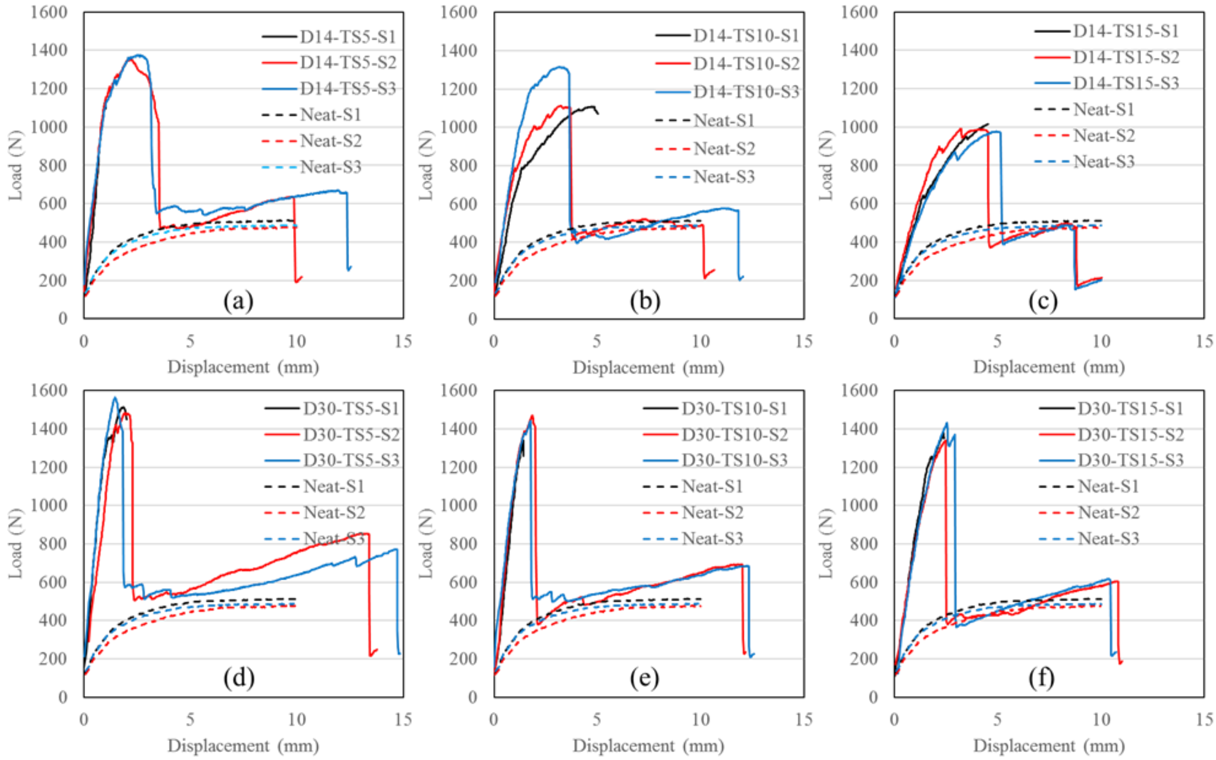


Figure 4. Three-point bending test: load versus mid-span deflection. (a) D14-TS5 (tube diameter of 14 mm and tube spacing of 5 mm), (b) D14-TS10, (c) D14-TS15, (d) D30-TS5, (e) D30-TS10, and (f) D30-TS15.

The effect of the tube spacing on the bending stiffness, and core ultimate shear strength was more effective for the samples including smaller tubes, shown in Figure 5. As the tube spacing decreased the bending stiffness and ultimate core shear strength increased. In addition, as the diameter of tubes increased the bending stiffness and ultimate core shear strength increased. Thus, D30-TS5 configuration had the highest bending stiffness and core ultimate shear strength. Through changing these parameters the bending stiffness of a sandwich structure can be adjusted for specific applications. The weight of the sandwich structure should also be considered because as the tube spacing decreased the weight of the structure increased. Also, it should be noted that after sudden failure the sandwich structure continued to bear load which is nearly the same load as neat foam sandwich structure bears, nearly 450 N.

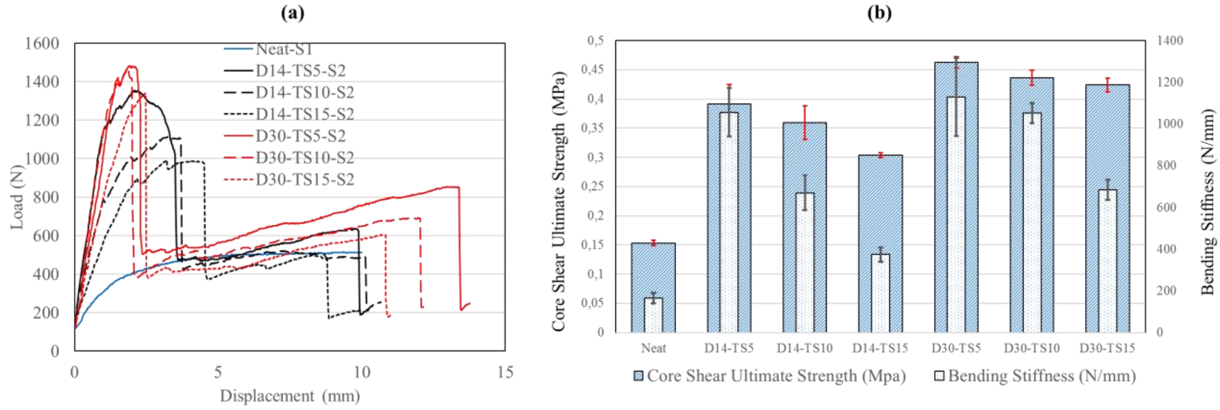
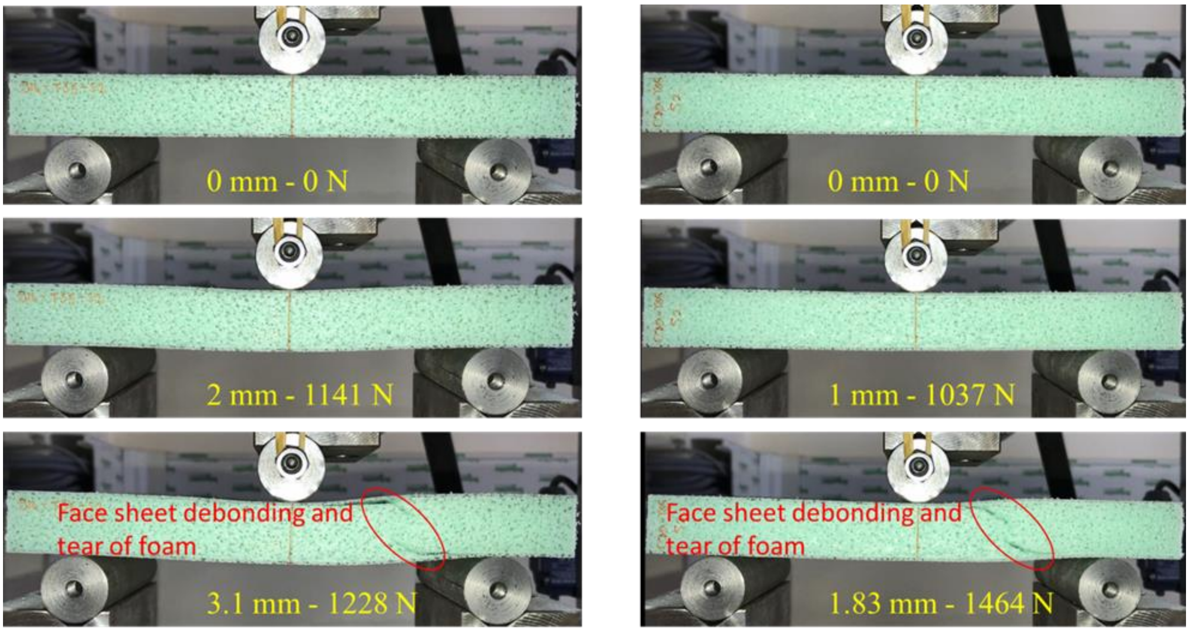


Figure 5. (a) three-point bending test: typical load versus mid-span deflection for all configurations, and (b) calculated core shear ultimate strength and bending stiffness from the curves.

Images were captured during the bending test and some of them are shown in Figure 7(a) and 7(b) for D14-TS5 and D30-TS5, respectively. Tube-facesheet deponding initiated the failure and the tear of the foam occurred due to movement of tubes. Same failure modes occurred for all configurations. The abrupt tear of foam occurred at the load of 1228 N and 1464 N for D14-TS5 and D30-TS5, respectively.



(a) D14-TS5 (b) D30-TS5

Figure 6. Failure load and deflection values for (a) D14-TS5 and (b) D30-TS5

4.2. Compression test results

The compression load versus displacement for a neat foam sample, samples including smaller tubes, and samples including larger tubes for tube spacing of 10 mm are shown in Figure 7. The maximum compression load value for the larger tube configuration was higher than the smaller tube configuration. There was an abrubt failure occurred in the samples including larger tubes which is not preferable in the applications on the other hand samples including smaller tubes continued their deformations with the failure load. The specific absorbed energy (SAE) levels were calculated as 3.4 kJ/kg, 70.0 kJ/kg, and 112.6 kJ/kg for neat foam sandwich structure, D30-TS10 configuration, and D14-TS10 configuration, respectively. The structures including smaller tubes had higher SAE values.

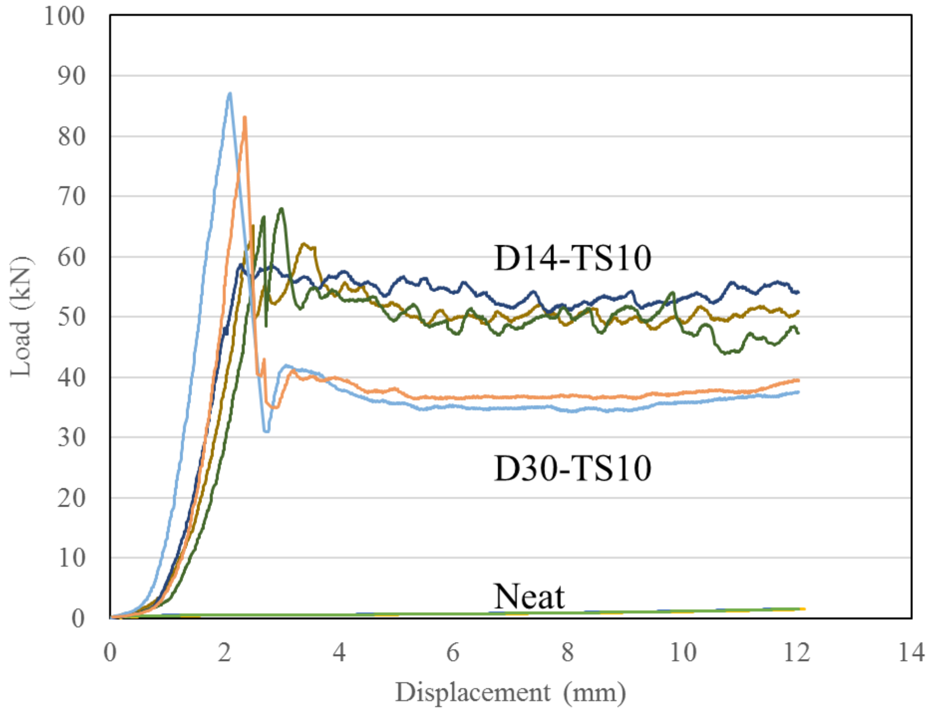


Figure 7. Compression load versus displacement for a neat sample, samples including smaller tubes, and samples including larger tubes for tube spacing of 10 mm.

4. Conclusions

In this study, a more convenient method was proposed to improve the shear and compressive properties of the core material, which was not time consuming, labor intensive and it can applied large and complex geometries. Thus, glass composite tubes were introduced to the foam material. Vacuum infusion method was considered to manufacture the sandwich structures. The effect of the tube spacing and the diameter of tubes on the bending stiffness, and core ultimate shear strength was investigated and it was found that tube spacing was more effective for the samples including smaller tubes. As the tube spacing decreased the bending stiffness and ultimate core shear strength increased. In addition, as the diameter of tubes increased the bending stiffness and ultimate core shear strength increased. Thus, D30-TS5 configuration had the highest bending stiffness and core ultimate shear strength. The maximum compression load value for the larger tube configuration was higher than the smaller tube configuration. There was an abrubt failure occurred in the samples including larger tubes which is not preferable in the applications on the other hand samples including smaller tubes continued their deformations with the failure load. Also, the structures including smaller tubes had higher SAE values.

Acknowledgments

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