Influence of core and matrix modifications on the mechanical characteristics of sandwich composites

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Abstract. Sandwich composites are increasingly being used for a variety of applications owing to excellent properties like high bending strength and stiffness, low strength-to-weight ratio and excellent damping and acoustic properties. However, there are certain issues faced while using sandwich structures for structural applications which includes debonding of face sheets from core, matrix cracking and core shear failure. In the current work, an effort is made to enhance the mechanical characteristics of sandwich composites by altering poly vinyl chloride (PVC) foam core and adding multi-walled carbon nanotubes (MWCNT) to epoxy resin used as the matrix. Four different configurations of sandwich laminates were fabricated using vacuum bagging process: (1) plain core and neat epoxy resin (2) core with blind holes and neat epoxy resin (3) core with blind holes and epoxy resin with MWCNT (4) core with through holes and epoxy resin with MWCNT. Flexural and compression tests were carried out on these sandwich specimens according to American Society for Testing Materials (ASTM) standards. Sandwich specimens with through holes in the core and resin mixed with MWCNT exhibited better mechanical characteristics compared to the other sandwich laminates. Type 4 sandwich specimens were able to withstand 12% and 16% more flexural and compressive loads respectively compared to conventional sandwich specimens.

1. Introduction

Sandwich composites consist of two thin composite face sheets separated by lightweight core and are widely used as structural materials for various applications in the fields like aerospace, marine, wind energy and automotive. Face sheet or skin is generally made up of E-glass fiber reinforced thermosetting polymer as it provides cost-performance advantage and also offers superior resistance to environmental attack [1]. In a sandwich structure, face sheets carry bending loads while core carries shear loads. Sandwich panels in modern aircrafts use glass or carbon fiber skins separated by aluminium or paper-resin honeycombs or by rigid polymeric foams giving a panel with enormous specific bending stiffness and strength [2]. The major advantages of sandwich composites include high specific bending stiffness, high strength-to-weight ratio, good energy absorption and acoustic characteristics. However, there are certain drawbacks like skin-core debonding, crack formation on the sub-surface of core during shear loads which lead to failure of sandwich structures.

The interfacial bond between face sheet and core is highly crucial to maintain the structural integrity of sandwich composites [3]. Separation of skin and core may result in performance degradation leading to collapse of structure [4]. Therefore, it is very much essential to improve debonding resistance and shear strength of the core for better performance of the sandwich structure [5]. Various methodologies like z-pinning, stitching, peel stopper, shear key etc., have been adopted to improve the mechanical characteristics of sandwich composites [6-8]. Mouritz reviewed z-pinning
process and its effect on mechanical properties [9]. Z-pins are thin metal rods made up of high strength materials such as titanium alloy, steels etc. inserted in the through-thickness direction of the composite laminates. Z-pinned composites resulted in improved mechanical performance like delamination resistance, impact damage tolerance and bearing strength. However, a reduction in the in-plane elastic properties of z-pinned composites is reported owing to fiber waviness, crimp and damage caused by z-pinning process. A micro-mechanical approach was developed to analyze the bridging action exerted by the introduction of z-pins for preventing delamination in laminated composites [10]. The effect of carbon rods, pin orientation, light weighted bolts and stitching on the performance of sandwich composites were investigated [11-15]. The concept of peel stopper was used to improve delamination resistance [16]. Sandwich laminates with peel stopper were subjected to three-point bending test and it was observed that peel stoppers were able to prevent delamination of skins from core. A methodology of inserting shear keys into the grooves of poly vinyl chloride (PVC) foam core was proposed to improve the delamination resistance of sandwich composite with face sheets of glass fiber/epoxy [17]. The addition of nano-materials like multi-walled carbon nanotubes and nano clay showed improved mechanical characteristics of sandwich composites [18-19].

In the current work, a novel approach is proposed to enhance the mechanical characteristics of sandwich composites by making perforations in the PVC foam core and adding multi-walled carbon nanotubes (MWCNT) to epoxy resin. Four different configurations of sandwich laminates were fabricated using vacuum bagging process: (1) plain core and epoxy resin (2) core with blind holes and neat epoxy resin (3) core with blind holes and epoxy resin with MWCNT (4) core with through holes and epoxy resin with MWCNT. Mechanical characteristics like flexural and compressive properties of these sandwich specimens have been evaluated according to American Society for Testing Materials (ASTM) standards. The influence of core and matrix modifications on the mechanical performance of sandwich composites has been discussed.

2. Experimental Procedure

2.1. Materials
PVC foam H80 of thickness of 40 mm and density 80 kg/m³ from DIAB was used as core for manufacturing sandwich composites. The face sheets/skins of the sandwich composites comprised of two alternate layers of chopped strand mat (CSM) and woven rowing mat (WRM) on either side of the foam material. CSM of surface area 450 g/m² and WRM of surface area 610 g/m² were used. MWCNTs were obtained from United Nanotech, Bangalore India. MWCNTs had an external diameter of 20–30 nm and length of 20µm. The nanotubes purity is greater than 98%. The specific surface area is 330 m²/g and the bulk density is 0.20 – 0.35 g/cm³. Epoxy Araldite LY556 resin mixed with HY951 hardener was used as matrix.

2.2. Modification of core and matrix
PVC foam cores are modified in two ways: (1) blind holes of 3mm diameter and 10 mm depth were made on the top and bottom surfaces of PVC foam core (2) through holes of 3 mm diameter were drilled in PVC foam core. Each hole was made at the junction of a 3 * 3 cm grid. These holes were made using a portable drilling machine. Epoxy matrix was modified by mixing 1.5 wt.% of MWCNTs using mechanical stirrer.

2.3. Fabrication of sandwich composites
Four types of sandwich composites of dimensions 500 mm * 500 mm were manufactured using vacuum bagging process. A flat glass plate was used as mould. For the vacuum bagging process, suitable resin feed and vacuum lines were selected. Four layers comprising alternate layers of CSM and WRM were placed on either side of PVC foam. Peel ply and distribution medium were arranged above the fiber layers and the entire setup was completely sealed with a vacuum bag using sealant tape.
as shown in figure 1. The bag was then checked for any leakages. Once no leakage was ensured, resin feed hose connected to the bucket containing epoxy resin was unclamped. The resin started impregnating the layers of fibers and core. After the resin completely impregnated the fibers, resin flow was cut off. The pressure attained during the process was 740mm of Hg. The sandwich laminate was cured for 20-22 hours before it was released from the mould.

**Table 1.** Codes and descriptions of sandwich composites.

| Code | Description |
|------|-------------|
| PC   | Conventional - sandwich with plain PVC foam core |
| BH   | Sandwich composites with PVC foam core having blind holes |
| BHCNT | Sandwich composites with PVC foam core having blind holes and MWCNT modified epoxy |
| THCNT | Sandwich composites with PVC foam core having through holes and MWCNT modified epoxy |

![Figure 1. Vacuum bagging process.](image)

![Figure 2. Sectional view of (a) PC (b) BH (c) BHCNT (d) THCNT.](image)
The same process was followed for manufacturing four types of sandwich composites: (i) plain PVC foam core (ii) PVC foam core having blind holes (iii) PVC foam core having blind holes and epoxy resin mixed with 1.5 wt.% of MWCNTs (iv) PVC foam core having through holes and epoxy resin mixed with 1.5 wt.% of MWCNTs. The codes used to represent these types of composites are listed in Table 1 and their sectional views are shown in figure 2.

3. Mechanical Characterization

3.1. Flexural Strength
Flexural stiffness of the fabricated sandwich composite specimens was determined by three-point bending test conducted according to ASTM standard C393. The span length was kept as 150 mm and the test was carried out in a universal testing machine at a constant crosshead speed of 2.5 mm/min. Flexural strength was calculated using equation (1).

\[ \sigma = \frac{3FL}{bd^2} \]  

where F is the ultimate load, L is the span length, b, d – width and thickness of sandwich composites respectively. The flexural test conducted on the four types of sandwich specimens are shown in figure 3.

3.2. Edgewise Compression Test
Compressive properties and failure behaviour such as development of crack and de-bonding of face sheets were determined in this test. The test was carried out in accordance with ASTM C364 standard on a universal testing machine. Compressive force was applied at a crosshead speed of 2.5 mm/min. figure 4 shows the compression testing of sandwich specimens. Compressive strength was calculated using the equation (2).

\[ S = \frac{F}{A} \]

Figure 3. Flexural testing of the four types of sandwich specimen.
4. Results and Discussion

4.1. Flexural Strength
The type four sandwich specimens (THCNT) with through holes in the core and infused with MWCNT modified epoxy resin exhibited maximum flexural strength of 5.2 MPa while the conventional sandwich specimens have an average flexural strength of 4 MPa and the comparison is shown in figure 5. Through holes in the core infused with epoxy resin act as column support between top and bottom face sheets resulting in effective load transfer between face sheets while the load transfer is not so effective in the specimens with core having blind holes owing to the discontinuous column supports. In addition to the support provided by the resin filled columns, the greater surface area provided by MWCNTs help in distributing the load. MWCNTs provide additional reinforcement to glass fibers enhancing the stiffness of face sheets leading to enhanced flexural strength of the type four specimens. The scanning electron microscope images of fracture surface of face sheets from

![Figure 4. Compression testing of the four types of sandwich specimen.](image)

![Figure 5. Comparison of flexural strength of sandwich composites.](image)
conventional and THCNT sandwich specimen are shown in figure 6. From the images it could be observed that conventional specimen has more brittle fracture of fibres compared to THCNT specimen which shows less fracture of fibres resulting in better flexural strength.

![Figure 6](image_url)

**Figure 6.** SEM image of (a) PC and (b) THCNT specimen.

### 4.2. Compressive Strength

The comparison of compressive strength of the four types of sandwich specimens is shown in figure 7. It can be observed that the compressive strength of THCNT type specimen is 48.7% higher than conventional sandwich composites. In the type four specimen, MWCNTs infused with epoxy resin provide through thickness reinforcement between layers of glass fibres and also along the foam core-face sheet interface thus enhancing the compressive load bearing capacity of THCNT specimens. Also, the resin filled through holes in the foam core act as reinforcing cross beams which resists compression loading thereby enhancing the compressive strength of type four sandwich specimens. Though BH and BHCNT specimens have higher compressive strength than conventional sandwich specimens, they are not as effective as THCNT specimens due to the presence of discontinuous resin filled columns. There is no complete load transfer between top and bottom face sheets because of the discontinuity in the resin filled columns owing to the presence of blind holes. The improvement in mechanical properties is also attributed to the additional reinforcement provided to the composites by the resin-filled holes acting as columns and the presence of MWCNTs in the interface of fibres and core providing through-thickness reinforcement.

![Figure 7](image_url)

**Figure 7.** Comparison of compressive strength of sandwich composites.
5. Conclusions

- In this work, an effort was made to enhance the mechanical characteristics such as bending strength and compressive strength of sandwich specimens by incorporating structural modifications in core and matrix modification.
- Sandwich composites with different core modifications like core with blind holes, through holes and neat and MWCNT modified epoxy resin were successfully fabricated by vacuum bagging process.
- Sandwich specimens fabricated with core having through holes and MWCNT modified epoxy resin showed higher resistance to de-bonding and better flexural strength compared to conventional sandwich composites fabricated with plain core and neat epoxy resin.
- Further research work can be carried out by varying the weight percentage of MWCNTs and analyzing their effect on the mechanical properties. Also, various core modifications can be made and their effect can be studied.

6. References

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