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# Improvement of Poisson's Ratio using Carbon Nanotubes Reinforcement for Laminated Sandwich Plate

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**ABSTRACT:**

*The focus of this study is to improve the material properties like Poisson's ratio and flexural strength of a sandwich plate by adding carbon nanotubes. A comparative analysis is carried out between sandwich plate with and without addition of carbon nanotubes. Nastran / Patron are the main tools used for this analysis. The experimental work focuses on the behaviour of the sandwich plate while applying tensile and compressive loads. The reduction of displacement in orthogonal sides under compressive stress and tensile stress are observed for carbon nanotubes enriched sandwich plate. This is due to increased face sheet relative difference of lateral strain with longitudinal strain. It is also observed that the mechanical properties of carbon nanotubes enriched sandwich plate are improved in comparison to sandwich plate without carbon nanotubes. It is concluded that the Poisson's ratio for the sandwich panel enriched with carbon nanotubes is advantageous than sandwich panel without carbon nanotubes.*

**KEYWORDS:**

*Carbon nanotubes; Sandwich plate; Poisson's ratio; Mechanical properties*

**CITATION:**

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## 1. Introduction

Structural members, who have the ability to bear the fatigue loads, are also capable of resisting undesirable effects of the surrounding environment to them. Oskooei and Hansen [1] mentioned that undesirable effects may lead them to lose their property value. Jae Hoon Kim et al [2] pointed out that structural members were predominantly used for flying objects in space and within the earth atmosphere. The recent advancements in science and technology required the structures to be with lesser weight and high in strength to meet the soaring demand of the aerospace industry requirements [2]. The sandwich form of arrangement makes a material to withstand high temperature, and its ability to store more resonance of acoustics. Also, it is least acceptance to fire, easier to cut and can be formed into other shapes, and has good ability to resist the deflection corresponding to the applied load. Godoutos and Daniel [3] mentioned about the framework of sandwich involved in placing the face sheets on the top and bottom, and keeping the core material in between them. The outer layer materials were made from reinforced silicon carbide fiber. The core was made from PVC foam and the nanotubes were walled along its prominent direction. Also, it was laid perpendicular to the orientation of the fibre.

The recent advancements in elemental analysis of materials includes discretization it into finite structure and analysing them individually. This type of analysis was carried out by Gautam and Pathak [4]. This approach can also be used for the sandwich sheets. The outer layer of the sandwich sheet was made of multiple materials combination. The material resistance to force along the orthogonal directions was observed by the theory of analysis by plates which itself is very classical and old form of approach, but still it is prominent. It was observed that sandwich sheets, which had foam as the core material in its arrangement, especially polyurethane material, experienced a reduction in deflection resisting property with respect to the applied load due to the continuous exposure to gradual loading [5].

Albernaz [6] recommended a particular type of arrangement where reinforced sandwich panels had good load withstanding properties compared to unwoven sandwich panels. Sandwich panel was made of multiple materials and it was bound together by its significant physical nature of the individual components. An analysis was also made regarding their binding properties with other dissimilar materials. The load resisting properties of the material at particular location was also considered. The stress along the orthogonal directions in two and three dimensions was also accounted by the expressing appropriate failure criteria. Rudolf and Andrei [7] focussed on analytical evaluation of a fibre reinforced plastic (FRP) corrugated sheet. ANSYS software was used to perform theoretical analysis on fibre reinforced corrugated sheet employing four point bend loading. A comparative analysis between theoretical and experimental investigations was carried out by Thybo [8] and the results indicated that the values of both were nearly the same.

The sandwich panels reinforced with multi-walled carbon nanotubes (MWCNT) material possessed higher Poisson's ratio due to its reduced displacement in all directions under the applied load. Later, it was also compared to a sandwich panel without adding MWCNT. The significance of face sheet was investigated by Mercado et al [9]. The authors also stated the relative difference of lateral strain and longitudinal strain together. The elongation and load resisting ability was also verified. The results indicated a minor deflection when it was subjected to different loading conditions. Further, the materials were tested under normal stress and shear stress conditions [9, 10]. Sandwich plates were fabricated using face sheets of a silicon carbide microfiber composite, reinforced with carbon nanotubes.

Carbon nanotubes were predominantly used in aircraft industry because of its several advantages as listed by Etemadi et al [11]. The authors also recommended an additive, epoxy matrix, to enhance the elastic modulus of composites as suggested by earlier researchers [5, 6]. Rudolf and Andrei [7] stated that the elastic properties of the latter would not reach the full potential in case the arrangement was not in according to the order in multi combined materials. They also suggested that the stiffness of the composite would not reach the full potential until the nanotubes had variations in dispersion of composites. The multi combined materials enforced with a mono layer of carbon tubes of minimum size undergone both theoretical calculation and discretization. The conclusion was made that old method of plate theory was useful and ideal for this analysis as suggested by Mercudo et al [9].

Veedu et al [10] carried out an approach that ensured various combinations by combining graphene with carbon, in tubular form which were very small in size. They were arranged in linear as well as in lateral patterns. The carbon was also reinforced in between stritched glass. In this work, glass material and epoxy material were manually laid one over the other in order to form a framework. This arrangement was given time to bind with each other. Later, it was pressed on both sides and exposed to tests like hitting the material with force and speed [12-16]. Iwasa [17] used scaling law to model wrinkle dissipation. In this work, the effect of Poisson's ratio on wrinkling was found. Later, it was concluded that when the Poisson's ratio was 0.3, the wrinkling was found to be reduced by 64%. The mathematical formulation to determine the shear was done by Kardomateaset al [18]. Also, this theory was associated with incorporating the correction factor for shear. A comparative study was also carried out with the already existing and established theory of sheer determination. The proposed model was found to be advantageous than the already existing model.

The response of the sandwich panel when subjected to low speed was explained in detail. The type of sandwich panel used for this analysis contained a core made of gel. This also had the advantages of thickening the core. A comparative analysis was performed with sandwich panels made of chloroprene. A numerical analysis was performed and the results were compared with the experimental values. It was found that the proposed model of sandwich panel was much stronger in terms of shear resistance [19]. A better replacement for the artificial fibres was suggested by Khan et al [20]. The advantage in the use of natural fibres was well recommended in this work. Some natural fibres suggested were kenaf and flax. It was concluded that natural fibres were also good decomposers. The objective of this present study is to analyse the multi-layered material with different compositions. The composite material is analysed for mechanical properties like Poisson's ratio with carbon nanotubes and without carbon nanotubes. The comparative study is carried out by subjecting both the forms of composites to same load conditions. The stress distribution on the sandwich panel is also analysed.

## 2. Methodology

Modified sandwich panels modelled using Nastran software is used for the analysis. It involves computing the deflections and stresses in sandwich panel under uniform or concentrated loads. This mode of analysis is chosen because of the tendency to analyse the load withstanding capabilities in all possible positions of multi-layered plates. Some of the factors justifying the selection of foam cores are that, these foams are significantly lighter, and more easily mouldable when compared to metal honeycomb. Bending analysis by Jessica [6] highlighted the importance to analyse the displacements and stress in sandwich panel. Two sandwich panels are analysed for comparison. In the first one, face sheets are made of the woven composite enhanced with carbon nanotubes. The second is a sandwich panel containing the same composites without carbon nanotubes.As shown in Fig. 1, the analysis is performed in the simply supported beam conditions using three points bending of sandwich plate. Each sandwich panel is exposed to four different uniformly distributed loads: 500 N, 1000 N, 1500 N, and 2000 N on the upper layer of various arrangements. The dimensional details of the multi-layered arrangement analysed is this study is 40mm ×40mm. The thickness of the face sheet is kept same for both sandwich panels as mentioned by Jessica [6].

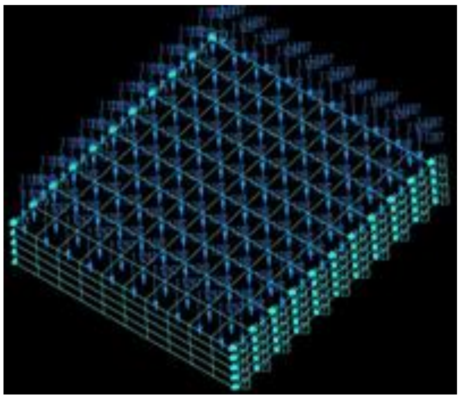

**Fig. 1: Loads and boundary conditions of sandwich panel**

### *2.1. Modelling*

The sandwich panel consists of two face sheets, one on the top and another at the bottom made of fibre and a core at the center which is made of PVC foam. The fibre is made of silicon carbide. This fibre is added with multi-walled carbon nanotubes at the top face sheet of the sandwich panel. The resin, Biphenyl A, is used to bind the silicon carbide fibre with the multi-walled carbon nano tubes. The two face sheets and the core forms a stack of the sandwich panel which is of 1.80mm thick. The sandwich is modelled using Nastran / Patron. The layup stacking sequence of sandwich panel is followed while modelling. The material is modelled with specification as given in Table 1.

**Table 1: Sandwich arrangement properties [6]**

| Physical significance | Nanotube enriched panel | Nanotube non-enriched panel |
|---|---|---|
| | **Face sheet** | |
| $E_{11}$ & $E_{22}$ | 24.30 GPa | 23.10 GPa |
| $G_{12}$ | 2.05 GPa | 2 GPa |
| $G_{23}$ & $G_{31}$ | 1.13 GPa | 1.13 GPa |
| $\gamma_{12}$ | 0.31 | 0.31 |
| Thickness | 0.53 mm | 0.53 mm |
| Density | 1800 kg/m$^3$ | 1800 kg/m$^3$ |
| | **Core** | |
| $E_{11}$,$E_{22}$ & $E_{33}$ | 0.1 GPa | 0.1 GPa |
| $G_{12}$,$G_{23}$ & $G_{31}$ | 0.037 GPa | 0.037 GPa |
| $\gamma_{12}$,$\gamma_{13}$&$\gamma_{21}$ | 0.35 | 0.35 |
| $\gamma_{23}$,,$\gamma_{31}$&$\gamma_{32}$ | 0.35 | 0.35 |
| Thickness | 1.8 mm | 1.8 mm |
| Density | 100 kg/m$^3$ | 100 kg/m$^3$ |

The size of the nanotube embedded is also given as input. The same model is meshed using Nastran / Patran. The type of elements used is solid elements which can also be called as brick elements. This solid element was also used by other researcher [3]. For meshing this arrangement, the sandwich panel is meshed with eight node solid elements. The same approach is followed throughout the panel domain. First, the face sheet is meshed at the top and bottom and later, the core is meshed. Face sheet contains 200 solid elements on the top and bottom. The core has another 200 solid elements. The number of nodes in the face sheet is 1600 and in the core, is 1600. The contact between the core and face sheet is given as surface contact.

### *2.2. Boundary conditions*

The two edges of the sandwich panel are fixed so that a fixed-fixed type of boundary condition is applied. Then, the uniformly distributed load (UDL) is applied at all nodes. The nodes in the face sheet are assigned as node set. Then, the load is applied in the node set. This procedure is repeated for different loads. The values are obtained from load displacement history available in the software. The results are obtained in the form of stress and strain. The sandwich panel enriched with multi-walled carbon nanotubes is subjected to tensile loading. The multi-walled carbon nanotubes in the face sheet experiences the lateral strain under tensile loading conditions. Under this loading conditions, the sandwich panel experiences stress along both longitudinal and lateral direction. The ratio of respective strain gives the Poisson's ratio. The same method is applicable to sandwich panel without multi-walled carbon nanotubes. Poisson's ratio, a mechanical property, is enforced to be 0.31 and it is kept as a standardized value in this present work. Similar assumption is also made by Jessica [6].

## 3. Results and discussions

The analysis is performed on sandwich panel with carbon nanotubes and other without the carbon nanotubes. As can be seen Fig. 2, it is understood that Poisson's ratio variation is linear for both sandwich panel, with and without carbon nanotubes. It is understood that the multilayer arrangement without carbon nanotubes, the deflection is more. The same observation is also observed in Fig. 3 but, the difference is that the former displacement is along the longitudinal directions and in the latter, the deformation is along the lateral directions. Fig. 4 gives the ability of the above mentioned materials during ultimate tensile load conditions. It is observed that the material without nanotubes is subjected to more deformation in the form of stress than the material with carbon nanotubes.

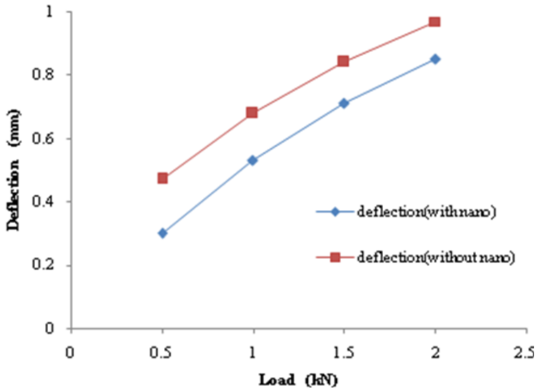


**Fig. 2: Maximum X-displacement vs. Load**

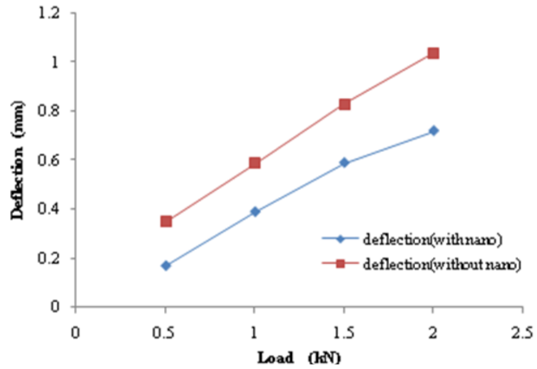


**Fig. 3: Maximum Y-displacement vs. Load**

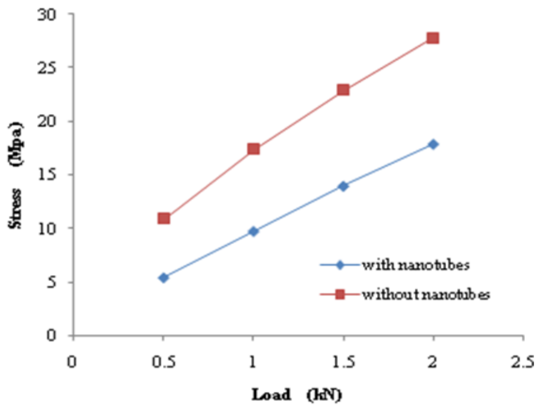


**Fig. 4: Maximum tensile stress vs. Load**

Further analysis is also carried out for ultimate compressive form of loads. The only difference observed is that the negative form of stress, as can be seen in Fig. 5. This reveals that the material arrangement with carbon nanotubes performs better under adverse loading conditions. When the beam is subjected to uniformly distributed load, it bends in the form of curvature in which on the, compressive stress occurs at the top side of the beam. The Poisson's ratio for the material is estimated to be 0.31 based on the plot between the tensile stress and load. This value enhanced to 0.35 by using Biphenol-A resin at the top of the face sheet imprinted with carbon nanotubes. Further, the movement of material arrangement in the form of deformation along its thickness (i.e., z direction) is evaluated in terms of ratio of lateral to linear strain. The same is found out at different loading conditions as depicted in Fig. 6. The same is applied to analyse the ultimate tensile load resisting capability under similar loading conditions and the details are plotted in Fig. 7.

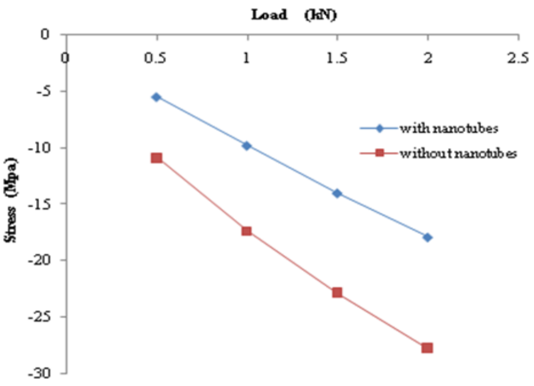


**Fig. 5: Maximum compressive stress vs. Load**

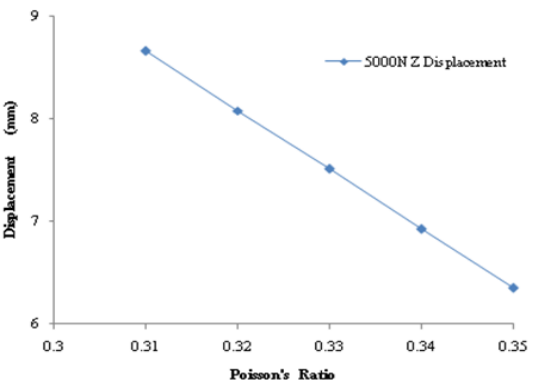


**Fig. 6: Maximum Z-displacement vs. Poisson's ratio**

The outputs are tensile stresses, compressive stresses and deflections in x, y, and z direction in the sandwich panel under uniform applied load as shown in Table 2. Using this obtained result, the face sheet ratio of lateral to longitudinal strain on multilayer arrangement is determined. The results are compared with the tensile stress and the third orthogonal direction elongation in non-enhanced multi-layered arrangement. The ultimate deflection of both the sandwich plates in x and y directions are shown in Fig. 3 and 4 are linear. It is to be noted that the nanotube enriched panel has less elongation along geometric sides in relative to non-enriched arrangement. This shows the advantage of including carbon nanotubes in its tubular form of smallest sizes to the sandwich panel. The deflection of sandwich panel to maximum possible geometric sides is related to the application of load in z direction.

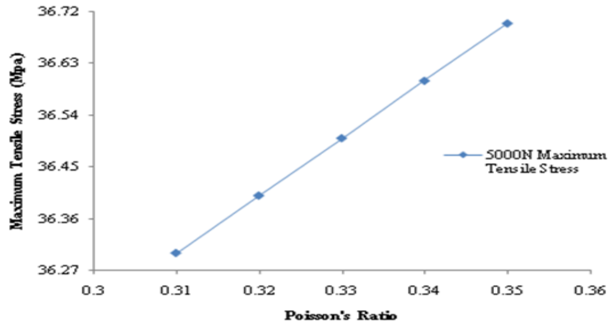


**Fig. 7: Ultimate tensile load resisting capability vs. Poisson's ratio**

**Table 2: Sandwich plate with uniformly distributed load**

| Load (N) | Deflection (mm) (nanotube-enhanced panel) | | Deflection (mm) (nanotube-non enhanced panel) | |
|---|---|---|---|---|
| | X dir.(mm) | Y dir.(mm) | X dir.(mm) | Y dir.(mm) |
| 500 | 0.30 | 0.17 | 0.47 | 0.35 |
| 1000 | 0.53 | 0.39 | 0.68 | 0.59 |
| 1500 | 0.71 | 0.59 | 0.84 | 0.83 |
| 2000 | 0.85 | 0.72 | 0.97 | 1.04 |

The deformations of panels increase with increment in applied load. The result shows that nanotube enhanced sandwich panel reduced the deflections in all directions under different loading conditions. The results are also computationally verified using ANSYS as shown in Fig.8.This indicates that the load in the sandwich panel is uniformly distributed. Similarly, tensile stresses of the nano enhanced sandwich panel are observed to be lesser than those without them. The comparison of compressive stress between nano enhanced sandwich panel and without nano enriched panel under different loading conditions is shown Fig. 5. Fig. 6 depicts that the deformation under various loading conditions for carbon enriched sandwich panel. Fig. 8 shows the distribution of load over the entire nano enhanced sandwich panel. It is evident from the contour that the carbon nanotubes enriched sandwich panel can withstand additional tensile stress at the centre of the top face sheet due to higher Poisson ratio recorded at the upper face sheet which in turn enhances the elongation load resisting capabilities and reduces the deformation.

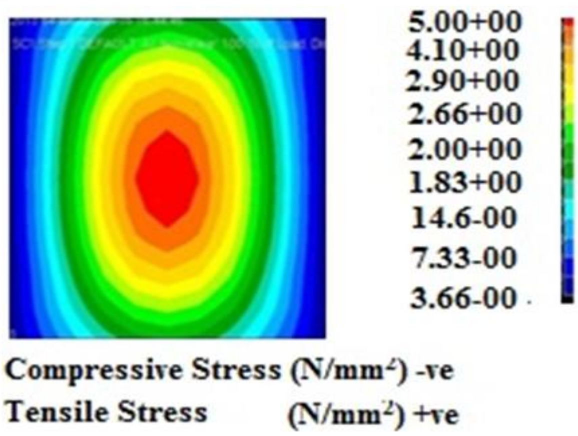


**Fig. 8: Sandwich panel with uniformly distributed load**

The Poisson's ratios obtained from this study are compared in with the earlier work done by Jessica [6] and it is shown Table 3. The values are observed to be closer to the earlier reported value [6].

**Table 3: Comparison of Poisson's ratio with earlier work**

| Physical significance | Carbon nano tube embedded sandwich panel | Carbon nano tube non-embedded sandwich panel |
|---|---|---|
| $\gamma_{12}$ [6] | 0.31 – 0.35 | 0.31 – 0.351 |
| Present investigation | 0.31 – 0.36 | 0.31 – 0.35 |

## 4. Conclusion

The multi-layered sandwich arrangement with enriched carbon nanotubes clearly demonstrates the advantages over sandwich panel without carbon nanotubes. The tensile and compressive stresses are reduced in x, y and z directions within the sandwich panel with carbon nanotubes. With the addition of carbon nanotubes, at the maximum load condition, the displacement in x and y directions are reduced by 1.14 times in comparison to sandwich panel without carbon nanotubes. The tensile and compressive stresses also increase in the carbon nanotube enhanced panel under the applied loads. The face sheet Poisson's ratio of the nanotubes enhanced panel is higher. Apart from degradation in elongation and load resisting capability, the sandwich panel with carbon nanotubes does not fail at the ultimate force applied of 2000 N. In all the cases, displacement analysis demonstrates that the nanotubes enriched panels under loads are stiffer and less stressed.

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