Analytical And Numerical Analysis of Sandwich Composite Materials With Different Core Structures

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Abstract- *Sandwich panels consists of thin, stiff face plates which are separated by thick core material. The face plates carry the bending loads and the core is carries longitudinal loads. The face plates and core are choosen from metals such as stainless steel or aluminium alloy or copper but the core can also possess various sandwich structures such as O-core, I-core, Web Core, I-Core, etc. This construction has often used in lightweight applications such as aircrafts, marine applications and wind turbine blades. Sandwiched panels have advanced high stiffness and strength to weight ratio.*

In this current project, comparison is drawn among different sandwich structures by numerical analysis in ANSYS software and analytical method. Based on the results obtained from both analytical and numerical analysis best suited structure is suggested for replacement of honeycomb structure.

Keywords- Sandwich Panels, ANSYS, weight optimization, honeycomb, core

I. INTRODUCTION

Composite sandwich structures have been widely used in aerospace structures, ship building, infrastructure, etc. due to their light weight and high strength to weight ratio. Traditionally, light-weight core materials such as foam core, truss core, honeycomb core have been used in fabricating sandwich structures with limited success. In the case of modern engineering materials included in aeronautical materials, apart from strength properties, low weight of the final element is a crucial aspect. Such properties are directly connected with increasing operational properties of a given structure. The most common purpose of manufacturing sandwich structures is to obtain the greatest stiffness at minimum total density. All the mentioned parameters can have satisfactory values provided that the following conditions are met: produced structures will be distinguished by low quantity (density) of faults and lower amount of resin in the material. Improving these conditions of production is the scientific objective of developing more effective and advanced manufacturing methods. The continuity of the sandwich structure is especially significant in aeronautics, where a structural fault may lead to the failure of a flying object in consequence of subsequently happening events.

Sandwich composite materials belong to the group of anisotropic materials. It means that their strength properties change depending on the applied load. Using the knowledge concerning this anisotropy makes it possible to produce composite materials, which display specific properties in desired directions, depending on needs. They are developed depending on requirements posed in relation to a given composite. Moreover, these requirements are directly connected with the application of a given structure. The most significant requirements are as follows: stiffness, strength, specific volume, thermo-insulating power, acoustic resistance, ability to absorb energy, and hydrostatic weighing.

Sandwich structured composites are a special class of composite materials which have become very popular due to high specific strength and bending stiffness. Low density of these materials makes them especially suitable for use in aeronautical, space and marine applications. Sandwich panels are composite structural elements, consisting of two thin, stiff, strong faces separated by a relatively thick layer of low-density and stiff material. The faces are commonly made of steel, aluminium, composite and the core material may be foam, honeycomb and balsa wood. The faces and the core material are bonded together with an adhesive to facilitate the load transfer mechanisms between the components. This particular layered composition creates a structural element with both high bending stiffness - weight and bending strength – weight ratios.

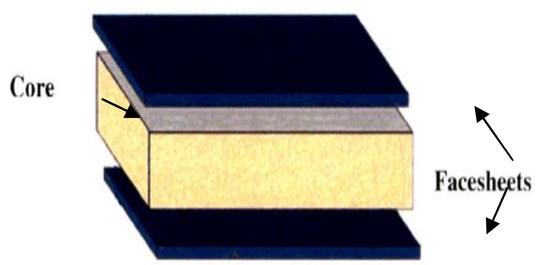

Fig: Sandwich composite material

Sandwich Composite Structures With Cores Honeycomb Core Structure:

Honeycomb is a well known core used to build sandwich structure. The name originates from the structure of honeycombs built by bees to store honey. The usage of honeycomb sandwich structures is advantageous. First and foremost the material itself is very light and a wide variety of materials can be used, for instance carbon, paper, aluminum, etc. Additionally, the core has a high strength to weight ratio and a very good compressive strength. The sheets of honeycomb can be available in different thicknesses and densities and can be deformed to follow the shape of the tool where the component will be laminated.

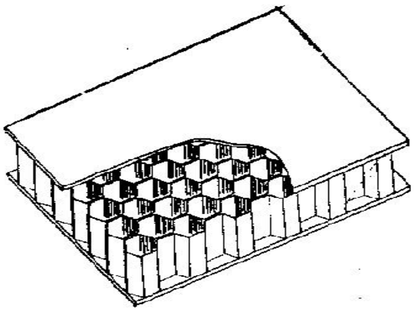

Figure: Honeycomb core structure

Foam Core Structure:

Foam cores are used in various markets to enhance the overall composite product. Cores are mainly used in sandwich structure and are rigid and closed cells. This means the gas is surrounded by resin and each cell is isolated from other cells, making the foam cores usable for the marine industry (preventing water immigration). Depending on usage temperature, resin compatibility, costs and manufacturing aspects, each one is more suitable for a specific application.

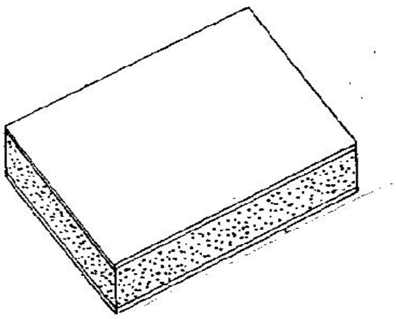

Fig: Foam core structure

Corrugated-Core Structure:

A corrugated-core sandwich structure is embraced of a corrugation sheet between two thin surface sheets. The important feature of this structure is its high strength-to-weight ratio. The corrugated-core keeps the face sheets apart and stabilizes them by resisting vertical deformations, and also enables the whole structure to act as a single thick plate as an asset of its shearing strength. This second feature gives better strength to the sandwich structures.

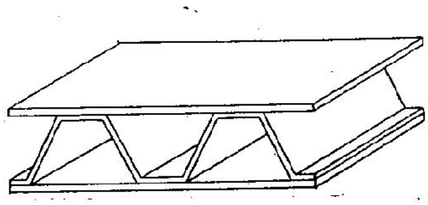

Fig: Corrugated core structure

Advantages

Typical advantages compared to traditional structural materials:

- High stiffness to weight ratio, making them suitable for lightweight design.
- Good buckling resistance compared to thin orthotropic plate structures.
- Good crashworthiness properties.
- Reduced constructional heights.
- Large unsupported spans, thereby reducing the requirement for supporting elements and increasing architectural freedom.
- Reduced part counts through integrated design.
- Good dimensional accuracy and flatness.

Applications

The use of sandwich structures continues to increase rapidly for applications ranging from satellites, aircraft, ships, automobiles, rail cars, wind energy systems, and bridge etc.

II. LITERATURE REVIEW

Fan et al. [9] designed and fabricated integrated woven corrugated sandwich composite panels, which enhanced the skincore debonding resistance. The predictions for mechanical behaviour of integrated woven corrugated sandwich composite panels were close to tested data.

Xiong et al. [12] researched the out-of-plane compression properties and energy absorption capacity of all composite sandwich panels made of the new three-dimensional (3D) grid cores that were interlocked. This new pattern cores have higher energy absorbing ability than traditional cores.

Xiong et al. [15] investigated the shear and bending properties of composite sandwich panels with pyramidal truss core using theoretical models and experimental observation. The measured failure load matched well with the analytical results.

Isaksson et al. [23] fabricated composite sandwich panels with arc-tangent, wavy trapezoidal and hemispherical shaped cores. It was found that the arctangent and trapezoidal cores were prone to buckle, whereas the hemispherical core was more stable under out-of-plane compression. The research about all-composite sandwich structure with Y-shaped cores is limited at present.

Tilbrook et al. [24] studied the dynamic out-of-plane compressive response of stainless steel Y-shaped sandwich cores by finite element predictions and experiments. The results showed that the front and rear face peak stresses remained approximately equal for impact velocities less than 30 m/s and 60 m/s.

Rubino et al. [25] fabricated sandwich beam comprising a Y-shaped core by assembling and brazing. Experiments and finite element calculation indicated that the out-of-plane compressive response of the Y-frame was dominated by bending of its constituent members. Additionally, simulations demonstrated that energy absorption capacity of Y-frame beam exceeded that of the metal foam core sandwich beam.

Rejab et al. [14] showed that corrugated cores when tested in the longitudinal direction offer shear strengths that are comparable with square honeycombs and significantly greater than those exhibited by diamond cores and more traditional foam cores. The second different feature of a corrugated-core is its ability to gives outstanding ventilation characteristics, avoiding problems related with humidity retention that is common in cellular core materials (e.g. polymeric foams and honeycombs). Humidity-retention can be a problem in many aerospace structures, e.g. aluminium honeycombs, but the adoption of corrugated, origami-type and truss core structures can minimize this problem.

Corrugated-cores with metal sandwich panels are an interesting industrial solution as structural components this is because their high stiffness-to-mass ratio. However, using detailed finite element models for numerical computation of their properties leads to large models and long solution time, specifically for acoustic simulations. Then, decrease of the complex shaped core to an equivalent homogenous material is usually used [25].

Amongst all sandwich panels, corrugated-core structures are an interesting alternative that is being progressively used in the transportation industry. For these panels there are dissimilar core shapes, such as truss-type corrugations (i.e. triangular), circular shape or trapezoidal cores [25].

Cote et al. [26] explain that prismatic, such as the Y-core and NavTruss, are chosen in naval sandwich structure for two reasons (i) they are direct to construction on large length scales by a welding route and (ii) the high longitudinal elongating and shear strength of the cores makes them ideal for application in sandwich beams.

Hou et al. [27] aims to investigate the effects of the key shape and dimensional parameters on the crashing behaviors of corrugated sandwich structures and improve the sandwich cores with the trapezoidal and truss-type corrugation configurations for crashworthiness standards. It will also compare the improved crashworthiness of these two different corrugated sandwich structures, thus given some guides to design of sandwich structures. [26].

Modelling

Creo Parametric 2.0 is a computer aided design (CAD) program that is used to create models on a computer in three-dimensions. The Creo Parametric interface consists of a navigation window, an embedded Web browser, toolbars, information areas, and the graphics window. Each Creo Parametric object opens in its own window. We can perform many operations from the ribbon in multiple windows without cancelling pending operations. Only one window is active at a time, but you can still perform some functions in the inactive windows. Creo Parametric 2.0 consists of sketcher, part modelling and assembly modules.

Models created in Creo Parametric 2.0

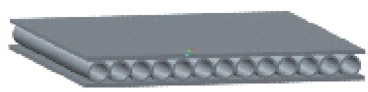

Fig: Horizontal cylindrical Core Structure

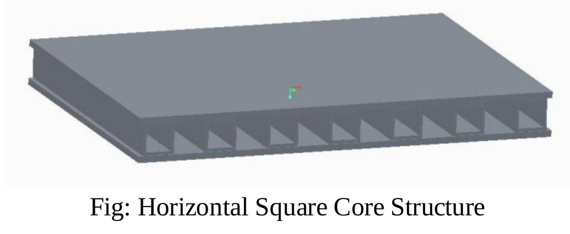

Fig: Horizontal Square Core Structure

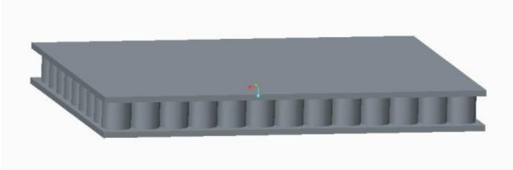

Fig: Vertical Cylindrical Core Structure

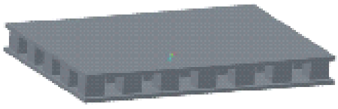

Fig: Vertical Square Core Structure

Numerical Analysis

As numerical computation techniques have advanced and computing power has increased, analysis tools have also advanced to solve more complex problems. A real-life engineering problem may involve different physics such as fluid flow, heat transfer, electromagnetism and other factors. The ANSYS philosophy can be summarized as one that aims to simulate the complete real-life engineering problem. The simulation usually begins by using a three dimensional CAD model to construct a finite element mesh followed by imposing loads and boundary conditions and then computing the solution to the finite element problem.

Static analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time. The types of loading that can be applied in a static analysis include:

- Externally applied forces and pressures.
- Steady-state inertial forces (such as gravity or rotational velocity).

Materials used

In this project materials used are:

1. Stainless Steel for face sheets
2. Copper and Aluminium Alloy for core

Properties of stainless steel

Density = 7750 kg/m3
Tensile Yield Strength = 2.07*10^8 Pa
Compressive Yield Strength = 2.07*10^8 Pa
Tensile Ultimate Strength = 5.86*10^8 Pa

Properties of copper

Density = 8970 kg/m3
Tensile Yield Strength = 7*10^7 Pa
Compressive Yield Strength = 7*10^7 Pa
Tensile Ultimate Strength = 2.2*10^8 Pa

Properties of aluminium alloy

Density = 2770 kg/m3
Tensile Yield Strength = 2.8*10^8 Pa
Compressive Yield Strength = 2.8*10^8 Pa
Tensile Ultimate Strength = 3.1*10^8 Pa

Boundary conditions

By considering sandwich panel as a simply supported beam:
Supports – simly supports at both ends
Force –2 kN applied at mid-span of the geometry

Analysis Of Sandwich Composite With Horizontal Cylindrical Core Structure At a load of 2kN

Analysis Of Sandwich Composite With Copper As A Core Material

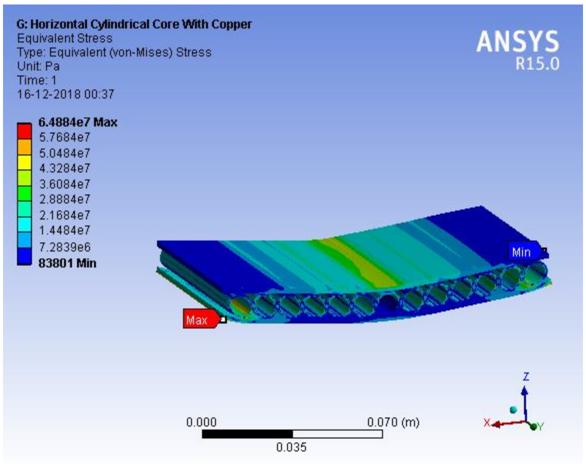

Fig: Equivalent (Von-Mises) stress of horizontal cylindrical core

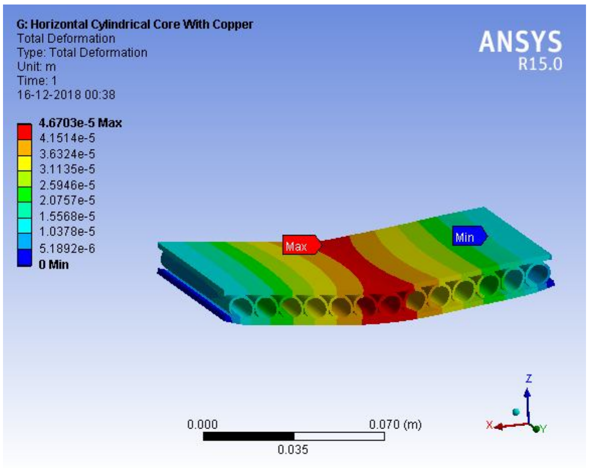

Fig: Total deformation of horizontal cylindrical core

Analysis Of Sandwich Composite With Aluminium Alloy As A Core Material

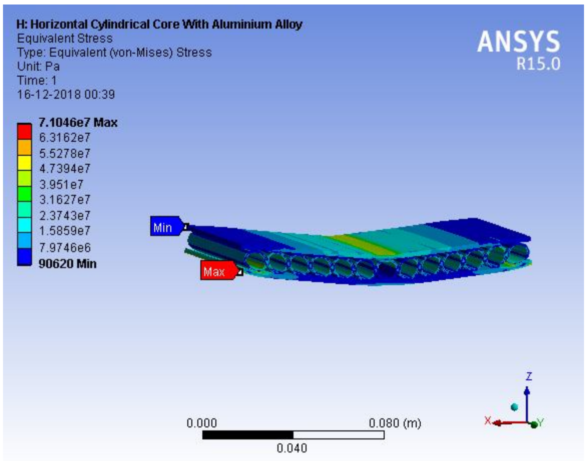

Fig 4.5 Equivalent (Von-Mises) stress of horizontal cylindrical core

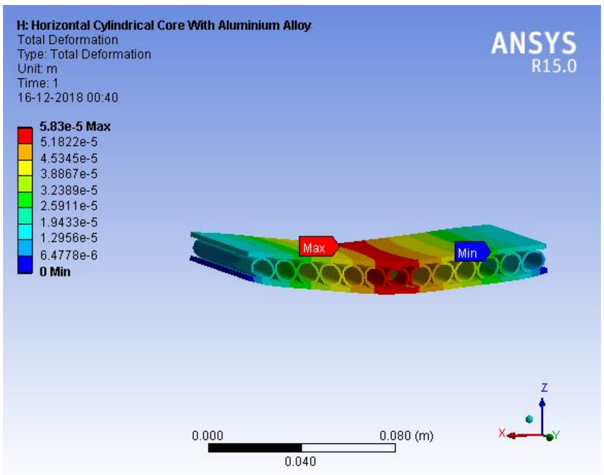

Fig: Total deformation of horizontal cylindrical core

Analysis Of Sandwich Composite With Horizontal Square Core Structure At a load of 2kN

Analysis Of Sandwich Composite With Copper As A Core Material

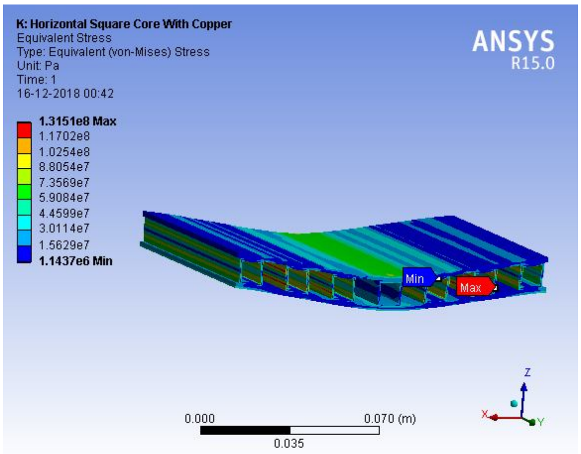

Fig: Equivalent (Von-Mises) stress of horizontal square core

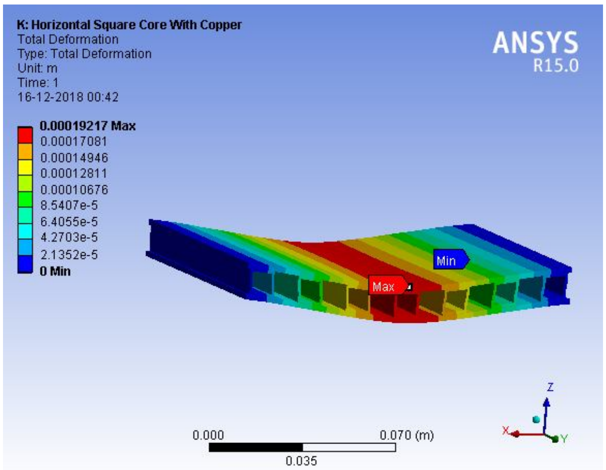

Fig: Total deformation of horizontal square core

Analysis Of Sandwich Composite With Aluminium Alloy As A Core Material

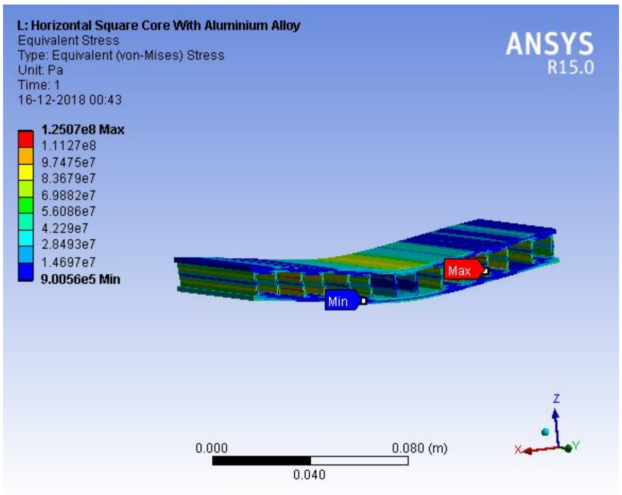

Fig: Equivalent (Von-Mises) stress of horizontal square core

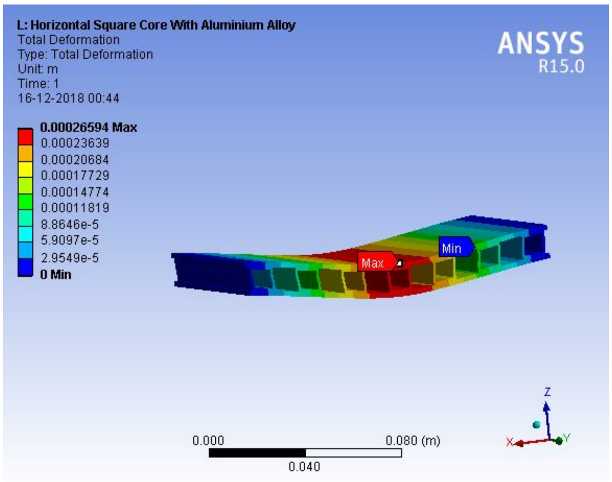

Fig: Total deformation of horizontal square core

Analysis Of Sandwich Composite With Vertical Cylindrical Core Structure At a load of 2kN

Analysis Of Sandwich Composite With Copper As A Core Material

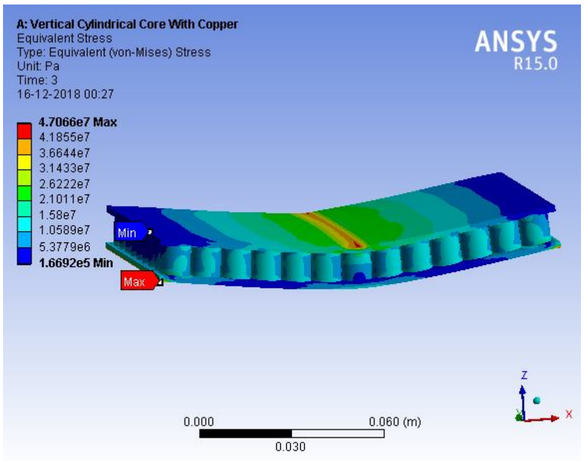

Fig: Equivalent (Von-Mises) stress of vertical cylindrical core

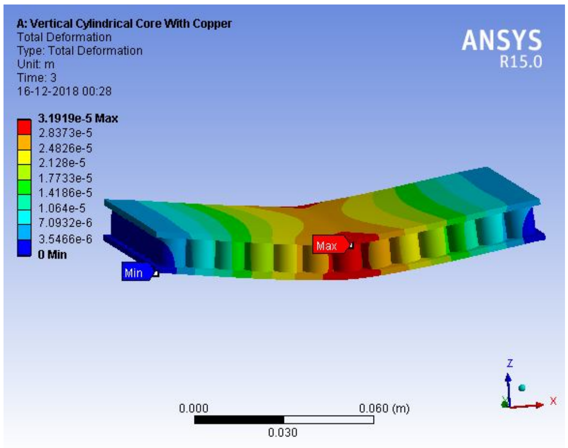

Fig: Total deformation of vertical cylindrical core

Analysis Of Sandwich Composite With Aluminium Alloy As A Core Material

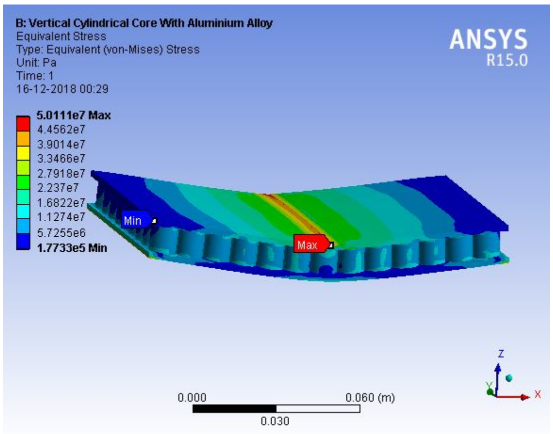

Fig: Equivalent (Von-Mises) stress of vertical cylindrical core

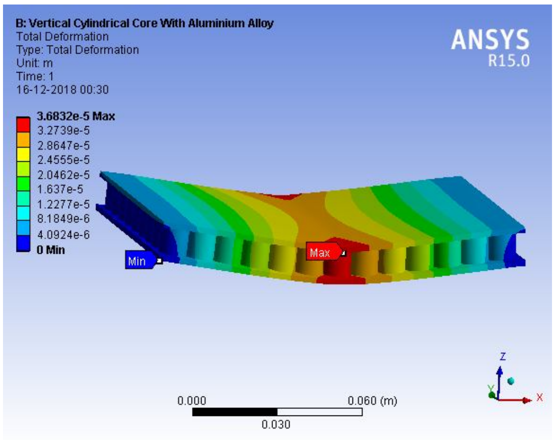

Fig: Total deformation of vertical cylindrical core

Analysis Of Sandwich Composite With Vertical Square Core Structure At a load of 2kN

Analysis Of Sandwich Composite With Copper As A Core Material

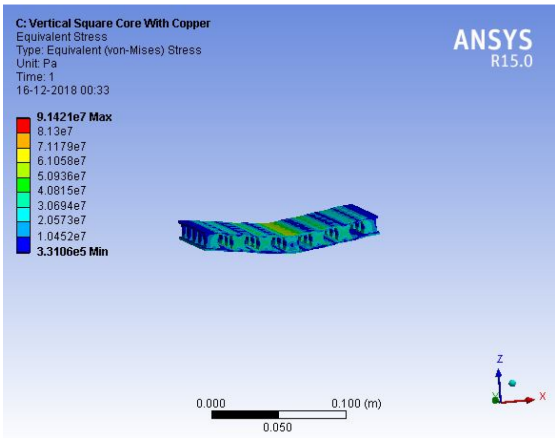

Fig: Equivalent (Von-Mises) stress of vertical square core

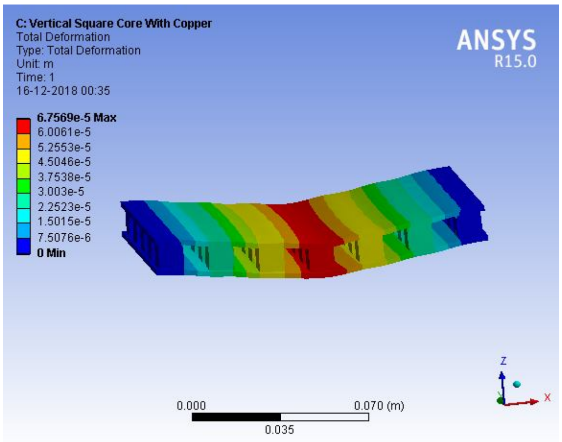

Fig: Total deformation of vertical square core

Analysis Of Sandwich Composite With Aluminium Alloy As A Core Material

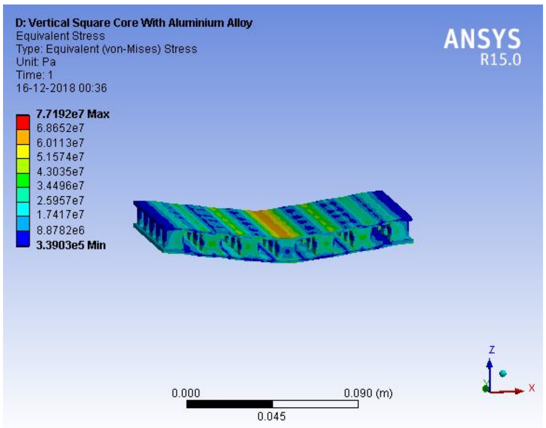

Fig: Equivalent (Von-Mises) stress of vertical square core

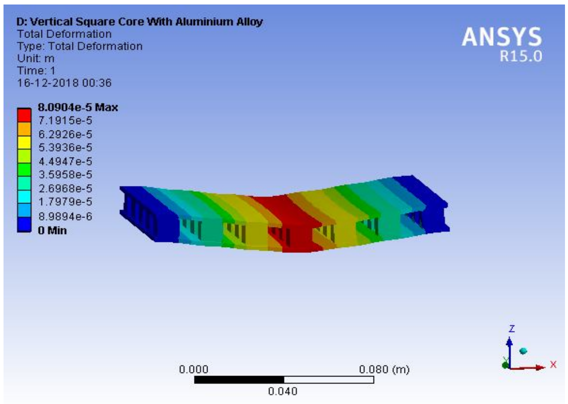

Fig: Total deformation of vertical square core

Analytical Analysis

The three point bend test is a traditional experiment in mechanics, used to quantify the Young's modulus of a material in the state of a beam. The beam, of length L, lays on two fixed support and is liable to a gathered load P at its center.

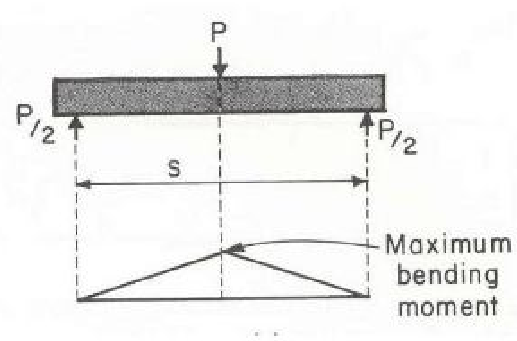

Fig: B.M diagrams of three point bending test

Figure 5.1 Schematic view of the three point bend test (top), with diagrams of bending moment M, shear Q and deflection w.

It can be shown (see, for example, the Cambridge University Engineering Department Structures Data Book) that the deflection w_0 at the centre of the beam is

w $=PL^3/48EI$ ------------------------ **(1)**

Where
E = Young's modulus.
I = second moment of area defined by

I $=ba^3/12$ ------------------------------- **(2)**

Where 'a' is the beam's depth and 'b' is the beam's width. By measuring the central deflection w0 and the applied force P, and knowing the geometry of the beam and the exploratory mechanical assembly, it is conceivable to compute the Young's modulus of the material.

$\delta = \delta_b + \delta_s$ { Bending deflection + Shear deflection }

(arises from core sheared & $E_c^* <<<< E_f$)

$$\boxed{\delta_b = \frac{Pl^3}{B_1 (EI)eq}}$$

B_1 = constant depending on loading configuration (3-Point bend, $B_1 = 48$)

$$(EI)_{eq} = \left\{\frac{E_c^*\, bc^3}{12}\right\} + 2\left\{\frac{E_f bt^3}{12}\right\} + 2\left\{E_f\, b\, t\, \left(\frac{c+t}{2}\right)^2\right\} \text{ (Parallel axis theorem)}$$

$$(EI)_{eq} = \left\{\frac{E_c^*\, bc^3}{12}\right\} + \left\{\frac{E_f bt^3}{6}\right\} + \left\{\frac{E_f\, b\, t\, \{c+t\}^2}{2}\right\} \text{ typically } E_c^* <<< E_{f,}\ t <<< c$$

Approximate, $(EI)_{eq} = \left\{\frac{E_f btc^2}{2}\right\}$

$$\delta_b = \frac{2Pl^3}{B_1 E_f btc^2}$$

$$\delta_s = ?$$

$$\tau_c = G_c^*\, \gamma$$

$$\frac{P}{A_c} \propto G_c^* \frac{\delta s}{l}$$

$$\delta_s = \frac{Pl}{B_2 G_c^* A_c}$$

(B2 another constant depend on loading configuration, B2 = 4)

$$\delta_s = \frac{Pl}{B_2 G_c^* bc}$$

$$\boxed{\delta = \left\{\frac{2Pl^3}{B_1 E_f btc^2}\right\} + \left\{\frac{Pl}{B_2 G_c^* bc}\right\}}$$

Equivalent (Von-Mises) Stress for Sandwich Panel:

$$\sigma = \frac{pl}{B3*b*t*c}$$

Where B_3 is the constant depending on the loading condition ($B_3 = 4$)

Deflection for for Sandwich Panel with Copper as Core Material:

For Vertical Cylindrical Core:
$\delta = 0.016$ mm
For Vertical Square Core:
$\delta = 0.056$ mm

Equivalent (Von-Mises) Stress

For Vertical Cylindrical Core:
$\sigma = 39.87$ MPa
For Vertical Square Core:
$\sigma = 84.86$ MPa

Deflection for for Sandwich Panel with Aluminium Alloy as Core Material:

For Vertical Cylidrical Core:
$\delta = 0.054$ mm
For Vertical Square Core:
$\delta = 0.096$ mm

Equivalent (Von-Mises) Stress

For Vertical Cylindrical Core:
$\sigma = 42.\ 32$ MPa
For Vertical Square Core:
$\sigma = 76.5$ MPa

IV. RESULTS AND DISCUSSION

Table: Total deformations of different core structures in mm

S.No	Core Structure	Copper	Aluminium Alloy
1	Horizontal Cylindrical Core	0.046703	0.0583
3	Horizontal Square Core	0.19217	0.26594
5	Vertical Cylindrical Core	0.031919	0.03682
6	Vertical Square Core	0.067569	0.080904

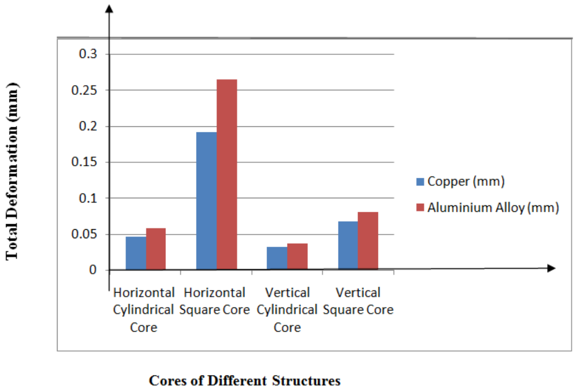

Fig: Comparison of total deformation of different core structures

Table: equivalent (von-mises) stresses of different core structures in mpa

S.No	Core Structure	Copper	Aluminium Alloy
1	Horizontal Cylindrical Core	64.884	71.046
3	Horizontal Square Core	131.51	125.07
5	Vertical Cylindrical Core	47.065	50.111
6	Vertical Square Core	91.421	77.192

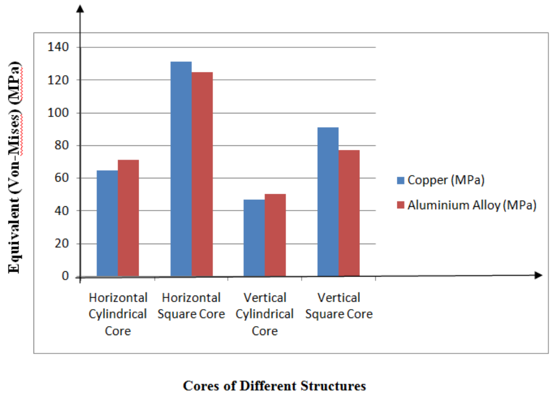

Fig: Comparison of equivalent (Von-Mises) stress of different core structures

Table: Comparison of analytical and numerical analysis of different core structures

Core Structure	Core Material	Total Deformation (mm)		Equivalent (Von-Mises) Stress (MPa)	
		Analytical Analysis	Numerical Analysis	Analytical Analysis	Numerical Analysis
Vertical Cylindrical Core	Copper	0.016	0.0319	39.87	47.06
	Aluminium Alloy	0.054	0.0368	42.32	50.1
Vertical Square Core	Copper	0.056	0.0675	84.86	91.42
	Aluminium Alloy	0.096	0.0809	76.5	77.19

V. CONCLUSIONS

In this project cylindrical and square core structures of sandwich materials are analysed numerically and analytically. The total deformation and equivalent (Von-Mises) stress of both structures are calculated at a load of 2 kN. The results obtained from both analytical and numerical are compared for different structures. After comparing the results, the following observations are made:

- Vertical Cylindrical Core is the best core structure in replacement of honeycomb structure and
- The core material copper is less deformed when compared to aluminium Alloy at same load.

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