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NUMERICAL INVESTIGATION ON FLEXURAL STRENGTH OF LATTICE SANDWICH STRUCTURES

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***Abstract** - Sandwich structures have huge applications attributable to their improved properties when compared with that of conventional structures. Sandwich structures give high solidarity to weight proportion and offer improved quality properties. Sandwich structures became an area of great interest for researchers throughout world because of its wide range of applications in the field of Medicine, Aerospace, Marine, Automobiles etc., By the introduction of 3d printing Lattice sandwich structures manufacturing became easy and problems faced by core failure have been reduced. By varying unit cell in Lattice Sandwich structure lot of contribution is done in the properties of sandwich structure. Even unit cell in Lattice Sandwich structure became an Area of interest for Researchers.*

The present work was completed by examining the Flexural conduct of sandwich structures for various areas of applications. The principle objective is to supplant the regular structures with sandwich structures. Simple Cubic Lattice Sandwich structures and unit cell dimensions are considered as per ASTM standards. Lattice Sandwich Structure is 3d printed and three point bending test is performed to evaluate Flexural Strength. Solidworks software is used to create a 3D model as per dimensions calculated. Created 3d model is imported in ANSYS workbench. After assigning Material properties, Mesh size, boundary conditions Model is utilized to analyze the three point bending conduct of the sandwich structure and approving the outcome with scientific outcomes. Analytical value is also calculated by using formulae. Analytical value and simulated value are compared and are found to be with minimum error.

1. INTRODUCTION

A sandwich structure is a manufactured composite made out of two little, unbending confronting sheets associated with each side of a substrate or framework with a low density. Isolating the facings by a lightweight center significantly improves the second moment of region (and in this manner the bending stiffness) of the cross-segment of the composite for only a slight weight gain. For lightweight structures, for example, ships, maritime vehicles, wind turbine sharp edges, producing offices, and dividers, this plan is likewise utilized. Sandwich board face sheets guarantee auxiliary unbending nature and ensure the core against physical damage and disintegrating. The face sheets get compressive and tensile loads during testing, and the center is exposed to shear loads between the faces, subsequently offering solid rigidity to bending. Sandwich structures are utilized in frameworks including huge weight proportions rather than strong or I-bar structures, as the sandwich structures have an essentially higher moment of inertia for a given weight.

The rigidity of material and design of sandwich panels is improving because of the growing interest for development of basic, streamlined and warm protection/heat exchanging execution of sandwich structures for a wide scope of building applications. It is demonstrated that the multifunctional use of sandwich structures can be improved by the designing of microarchitecture of the core in manufacturing the sandwich structures. The ongoing advancement in cutting edge fabricating innovations, for example added substance producing (3D printing) and laser cutting, has permitted assembling of architected cellular cores which were difficult to be created by ordinary assembling forms, for example extrusion, milling and corrugation. Utilizing additive manufacturing for fabrication of sandwich structures with architected cores has many advantages over the regular sandwich structures with a hexagonal honeycomb or foam core. Among the advantages are references to the programmability of multifunctional properties over a multiple length scale by adjusting the architecture, and geometrical features of the cellular core.

1.1 Classification of Sandwich Structures

Basic facing materials generally used are metals (for example steel or aluminum) and composite materials (for example reinforced polymers with fiber). Metallic stiffeners, foams (polymer or metallic), honeycombs, and balsa wood are regular core materials or structures. Typically, the center to-face connection is achieved through bonding by an adhesive or a weld. Figure 1.1 gives a few configurations for the sandwich structures.

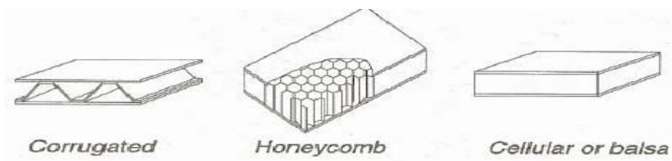


Fig 1.1. Typical sandwich configurations.

Almost any substance or configuration might be the strong foundation of a framework, in general fall into four categories.

a) *Honeycomb core*

b) *Corrugated core*

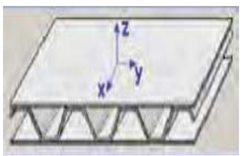
c) *Web core*

d) *Truss core*

e) *Foam or solid core*

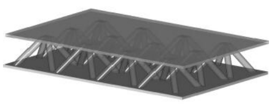
The two most widely used popular types of honeycombs are the square cell and the hexagonally molded cell form. The center structure is like an assortment of I-beams, welded with their flanges. The U.S. Naval force calls the design of this site center as a double hull. Truss or triangular structure configuration is utilized generally corrugated lattice truss framework has a small contribution to the axial compression stiffness and strength. Its strength comes mainly from the skin. The mono-cell buckling load of this new cylinder may be smaller compared to the foam-core and honeycomb-core sandwich cylinders, reducing the minimum thickness of the face layer.

The deformation mechanism of struts switches from stretching dominated to bending dominated by weak limits. Strong limits hold the process of deformation unchanged. Still dominated by stretching, in finite-size composite lattice systems, the deformation and loading capability of struts is similar to struts in infinite intact lattices. The reduction process of the basic stiffness and specific strength depends on the improvement of the mass resulting from the added or thickened struts at the boundaries, not the local deformation and stress concentration for weak boundary lattice structures.



(a)Corrugated core

(b) Foam core



(c) Truss core

(d)Honeycomb core

The most significant contribution of the strong edges to the structure in practise is that they bind all boundary nodes together. Under uniform stresses, the rigid boundaries deform uniformly and local stress concentration at the contact surface is greatly weakened. Loads are distributed evenly to each strut and distributed to the entire structure efficiently. The composite lattice structure can then be constructed with the best weight efficiency, but the nodes are independent of each other at weak boundaries. Because of output tolerance, it is difficult for poor boundaries to maintain uniform contact. Local stress concentrations on the boundaries can occur and loads cannot be effectively spread to the entire system.

Locally, the framework falls well below the normal loading capacity. By numerical simulations, the localizations of deformations and strut forces under concentrated loads can be further clarified. The scale of deformation of the five deformed isogrids is similar. The grid of weak edges has observed greater local deformations and strut forces. The overall local deformation and strut forces transform to smaller when the edges are reinforced by growing t1 / t. As base beams, the edges work.

In astronautical structures, composite lattice structures with high specific stiffness and strength have been used extensively. Work has concentrated on the identical mechanical characteristics of infinite periodic structures. In reality, finite layers of cells are often made up of composite lattice structures. The structure's overall stiffness and strength would be disrupted by the edges. With a local buckling on the edge, the missing horizontal struts or flanges on the borders of the lattice stiffened cylinder failed.

Via periodic extensions from finite-size lattices to infinite periodic structures, the analogous continuum approach is efficient in predicting the analogous stiffness and strength of the finite-size composite lattice structures with strong limits. FE models have testified to these experimental predictions. The proposed laws are useful in designing optimal composite lattice structures with improved weight efficiency. It is concluded that the reinforced edges significantly affect the equivalent real stiffness.

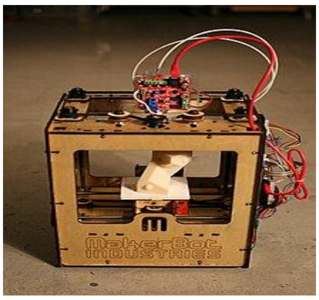
When the lattices only have few layers of unit cells, the corresponding real stiffness is typically much smaller than that of the infinite lattices. The equivalent basic stiffness gets much smaller as the thickness of the reinforced edges increases. Although the cell layers reach more than 10-20, to be overlooked, the edge effect decreases rapidly. These rules are often obeyed by the edge effects of the equivalent particular power. In practice, edges are often reinforced by thickening edge struts or adding additional thicker struts (or flanges) in order to decrease local stress concentration and effectively pass loads to the entire lattice structure. Stiffer edges make the borders deform uniformly and reduce the concentration of local tension. There was no longer a grid failure near the limits of the stiffened cylinder with solid edges.

Strengthened edges hold the deformation mechanism of the stretching dominated strut of lattices unchanged, according to the analysis. The reduction of the basic stiffness and strength equivalent is primarily derived from the increase of struts in mass. The most significant gain of the strong boundary relative to the weak boundary is a significant reduction in local concentrations of pressure and stress. Solid edges serve as elastic base beams, according to the *report. Stronger edges reflect elastic base beams with greater bending stiffness, which can more extensively spread the loads to the structure and help minimize local strain and stress concentrations.*

Overall performance of sandwich structures is improved by the introduction of Lattice Cores. Each core is repetition of unit cell. Change in parameters of unit cell like no. of sides, angles etc., result in different lattice structure core. Lattice Cores are also used for multifunctional purpose. Evolution of 3D Printing made the manufacturing of lattice cores easier. Lattice Cores with Honeycomb Structure as unit cell are stiff, have high energy absorption capacity and are light in weight. In Closed Cell Lattice structures gases are trapped which causes decrease in thermal conductivity and also decrease in life of core. It is overcomed by the use of open cell cores like truss core structures. Auxetic core is the only core which is observed with negative poison ratio. Auxetic cores are found with increase indentation resistance, fracture toughness, shear resistance and energy absorption capacity. Auxetic Cores are best for places with applications of sensors ad actuators. Auxetic Cores are also very much capable of resisting impact loads. Octet Cubic cells are cores with maximum stiffness in all directions and also are of very low density with maximum toughness and crush resistance. Core cell topology is one of the major parameter which decides energy absorption capability of a sandwich structure.

1.3 3D PRINTING

3D Printing is a production technique which is used to produce 3 Dimensional object from a CAD model. It involves many processes like material deposition, material solidification which are performed under computer control. In former days 3D Printing is used only for production of functional prototypes and is also known as Rapid prototyping. At present because of the improvement in precision, repeatability and material range it is used as Industrial Production Technology. One of the major benefit of 3D printing is its ability to produce complex shapes, hollow parts etc., which are difficult to produce by hand.

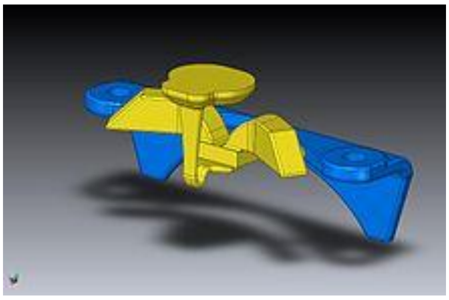


3DPRINTER

3D printing is also called as Additive manufacturing technique because it is the only manufacturing technique in which 3D object is manufactured by adding material layer by layer. Even at present 3D printing is referred as polymer technology and Additive Manufacturing is referred as Metal Working and end use part Production Technology. Even though both 3D printing and Additive Manufacturing techniques are similar. 3D printing is used by consumer maker communities and media and Additive Manufacturing is used more by industrial end use Part Producers, Machine Manufacturers etc., 3D Printing Machines are of low cost when compared to Additive Manufacturing Machines.

1.3.1 3D MODELLING:

3D printable models are modelled by a computer-aided design(CAD) package via a 3D Scanner or by a plain digital camera and photogrammetry software. Errors in 3D Printed Models created by CAD are less. Before printing errors in 3D printable models are identified and are corrected. Process of collecting digital data on shape and appearance of a real object to create a digital model is called 3D Scanning. Stereolithography File format (STL) is a defacto CAD file format used to save CAD Models and stores data in triangulations of the surface of CAD Models. STL format generates large sized files for topology optimized parts and lattice structures because of which it does not fit for Additive Manufacturing. To overcome this problem a new CAD file format called as Additive Manufacturing File Format (AMF) was introduced. Curved triangulations are used to store information in AMF

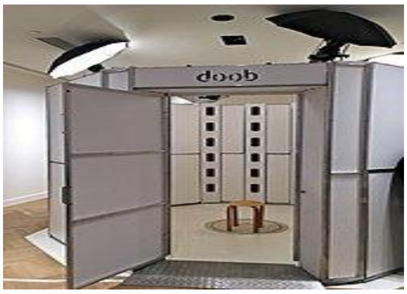


CAD ***MODEL USED FOR 3D PRINTING***

1.3.2 PRINTING:

After examination of errors only 3D Model must be printed from an STL File. In output STL files errors that are seen generally are Holes, Self Intersection, Faces Normals, Manifold Errors, Noise Shells. Repair Fixes in STL generation is used to fix all the above errors in the Original Model. STL's produced by scanning will have more errors when compared to STL's produced from 3D reconstruction. After completion of STL file a software named 'Slicer' is used to process the file. Purpose of slicer is to convert the model into thin layers and also a G-Code File is produced containing instructions. After G-Code File is generated then it is again 3D- printed by using a 3D printing client software. Layer thickness is defined by

Printer Resolution. Time taken for the production of 3D – Model is dependent upon the method and size and complexity of the Model.



3D PHOTO BOOTH

1.3.3 FINISHING:

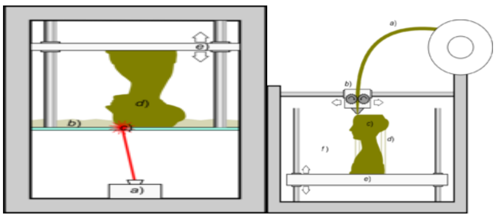
For most of the 3D printed products printer resolution is enough to achieve accurate size but sometimes they are printed slightly oversized and machined with high resolution to achieve more accuracy. Stair – Stepping effect is an inevitable effect on part surfaces curved or tilted that are produced due to layered structure of Additive Manufacturing process.

1.4 DIFFERENT TYPES OF 3D PRINTING PROCESSES:

Though there are many number of Additive Manufacturing Processes only some few are mentioned and they are:

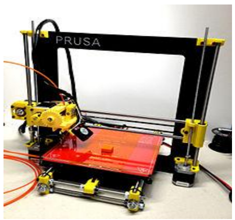
- *Material Jetting*
- *Powdered Fusion*
- *Direct Energy Deposition*
- *Vat Photopolymerization*
- *Binder Jetting*
- *Material Extrusion*
- *Sheet Lamination*

Depending upon the way the layers are deposited to create parts and materials used above classification is done. Cost of 3D Printer, Speed, Printed Prototype, Choice and Cost of the materials and Color Capabilities are considerations seen while selecting. 3D Printing Machine Printers that use metals are costly. In order to reduce cost of printer they prepare moulds and make Metal Parts.



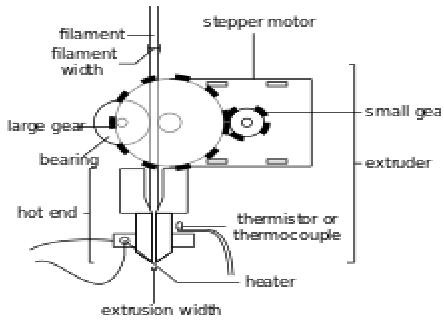
SCHEMATIC REPRESETATION OF FUSED DEPOSITION MODELLING

Among all the processes Fused Deposition Modelling is very widely used because of its less cost and versatility. Fused Deposition Modelling uses a continuous filament of a thermoplastic material. Filament is fed from a large spool, through a moving, heated printer extruder head and is deposited on the rising work. Computer Control is used to define printed shape by moving computer control. Print Head is restricted to move in horizontal and vertical directions only. Extruder head speed is used to control deposition in start and end and forms an interrupted plane without string.



A SIMPLE FUSED FILAMENT PRINTER

For Hobbyist grade 3D printing Fused Filament printing is the most popular one. Even though photo polymerisation and powder sintering offer better results they are not preferred because they are expensive. 3D printer head is used to melt the raw material and form a continuous profile. For Extrusion a wide variety of Filament materials including thermoplastics such as Polyactic Acid(PLA), Acrylonitrile Butadiene Styrene(ABS), High-Impact Polystyrene (HIPS), Aliphatic Polyamides(nylon) and Thermoplastic Polyurethane(TPU).



EXTRUDER WITH LABELLED PARTS

1.5 COMPOSITE MATERIALS

Composite materials are built materials made by the mix of at least two constituents, which brings about preferable properties over those of the individual constituents utilized alone. The two constituents are reinforcement and a matrix. The reinforcing stage gives strength and stiffness. By and large, the reinforcement is harder with more strength, and stiffer than matrix. Normally a fibre or particle is the reinforcement. Particulate composites have measurements that are around equivalent in all directions. They might be circular, platelets, or some other customary or irregular geometry. Particulate composites will in general be a lot more vulnerable and less hardened than continuous fiber composites. However, they are typically considerably less *costly. Particulate reinforced composites ordinarily contain less reinforcement (up to 40 to 50 volume percent) because of processing difficulties and fragility. The ceaseless stage is the matrix, which is a polymer, metal, or ceramic. Polymers have low strength and stiffness while metals have intermediate strength and stiffness yet high ductility, and ceramics have high strength and firmness, but are fragile or brittle. The matrix (continuous phase) plays out a few basic critical functions, such as fibre maintenance in the right orientation and abrasion protection from the outside environment. In polymer matrix composites, a solid bond between the fiber and the matrix is shaped and the framework sends loads from the matrix to the fibers through shear loading at the interface. The primary advantages of composite materials are their high strength and stifness, along with low density, in comparison with bulk materials, considering a weight decrease in the finished specimen.*

1.6 BIOCOMPOSITES

Bio composites are also known as Green Composites. Green composites are quite popular among researchers because of their advancement in the improvement of materials like biodegradability, fossil fuels preservation, and reduction of carbon dioxide gas into the air. Bio composite properties are custom-made dependent on composition of design and the later processing. It comprises of at least two phases of natural or biological origin.

The bio plastic is preferred as a polymer matrix and the natural fiber or filler as support or reinforcement. This sort of composite is completely biodegradable and shields the environment from greenhouse gases, eventually preventing white pollution. The bio composite products have changed our lives by the proper and safe recycling. It is utilized in different fields like aviation, car, building, construction, marine, everyday consumer products, electrical and electronic components. Figure shows the various techniques or methods to prepare bio composites.

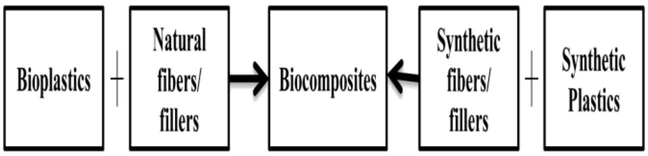


Fig 1.5. Different routes to manufacture bio composites

1.7 BIOPLASTICS

Bioplastic materials are generally called as green plastics. They are biodegradable thermoplastic reinforced compounds. They are now being chosen over ordinary plastics like polyethylene, polypropylene, aliphatic polyester, and so forth. Bioplastic materials are being considered as the efficient solution and are slowly occupying a major share in the polymers market (Sushmita et al. 2016). They are classified into two categories - bio based polymer and biodegradable polymer.

1.8 Classification of Bioplastics

1.8.1 Bio based polymer

The biobased polymer comes from agricultural and renewable sources. They are both biodegradable and non-biodegradable. The capacity of polymers to biodegrade is characterized by their structure and doesn't rely upon the crude material used to make them. All the bio based polymers are not biodegradable and not all the biodegradable polymers are bio based. Cellulose acetic acid derivation, bio based polyethylene and bio-PET, are few examples.

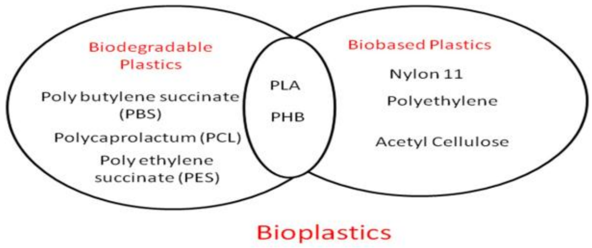


Fig 1.6. Classifications of Bioplastics (Source: Tokiwa 2009)

1.8.2 Biodegradable polymer

Biodegradable polymers, depending on the environmental conditions, can undergo aerobic and anaerobic degradations. In aerobic biodegradation, the microorganisms feed on the host material and release carbon di-oxide, water and biomass, where as in anaerobic condition the methane, mineral salt and biomass are released and this serves as an indicator for degradation. The biodegradation largely depends on the chemical and physical properties of the plastics such as surface condition and first order groups. The biodegradability depends on the chemical structure and not on the origin of the crude materials. Internationally, the mass production of biodegradable polymers has expanded as an alternative products to petroleum products. 540 million metric tonnes was expected to be produced by the end of the year 2020, before COVID19 came into picture. They have very efficient applications in different fields and thus the rate of production has increased significantly in the last few years. Gelatin, gluten, polyhydroxyalkonates are few examples

1.9 Polymer Materials

The biodegradable polymers might be fabricated naturally from rice, wheat, enzymes, lipids, and so on., or made artificially from renewable raw materials. In an appropriate compost environment, these biodegradable polymers may experience degradation and deliver non-poisonous products like carbon dioxide, soil, and humus. Aliphatic polyesters, for example, Polylactic corrosive (PLA), Polycaprolactone (PCL), Polybutylene adipate terepthalate (PBAT), and Polyhydroxybutyrate (PHB) are the most widely used biodegradable polymers.

The hydrolysable ester bonds found in the polyester play an important role in polymer biodegradability. PLA displays positive properties among the biopolymers, for example, tensile power, tensile modulus, biodegradability, clarity, eco-friendliness, and low toxicity.

It has certain drawbacks, however, for example, brittlesness, weak processability and low crystallization. Through filler or thread coating, plasticizing and blending in with different polymers, a few attempts have been made to improve the melt handling and properties of PLA bio composites.

1.10 POLYLACTIC ACID (PLA)

Polylactic acid is one of the organically degradable, aliphatic thermoplastic polyesters. As a result of its biodegradability, biocompatibility and solid mechanical properties, it has wide application in packaging and medicine fields. This is fomed by fermenting the starch into lactic acid in the presence of sugar, which can be additionally changed over into polylactic acid through polycondensation.

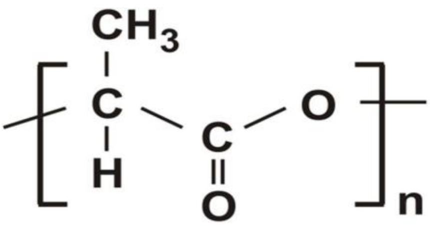


Fig 1.7 Structure of PLA

Properties and Applications of PLA

PLA shows positive properties, for example, transparency, environmental friendly and low toxicity. It has some disadvantages though, like brittleness and low crystallization quality. PLA's temperature for glass melting and transferring is 55-65 ° C and 145-155 ° C, individually. PLA is easily soluble in chloroform and dichloromethane.

PLA is organically degradable aliphatic polyester sourced completely from natural materials that can substitute artificially created polymers in a wide variety of uses.

It tends to be utilized in an assortment of uses, including food bundling, agro-industry and nonwovens. It is produced by a responsive expulsion polymerization technique that can be generally made at lower cost.

Table 1.3. Mechanical properties of PLA

Properties	***PLA***
Density (g/cm^3)	*1.21*
Melting point (^oC)	*177-180*
Tensile Strength (MPa)	*45*
Elongation (%)	*3*

Processing of PLA

The appropriate methods for producing polylactic bio composites are engineering processes such as extrusion, injection molding, and solvent casting. Furthermore, these approaches are easier for PLA production from upscale to large scale and for industry whereas twin screw extruder is the preferred method for PLA modification, such as the addition of master lots, impact modifiers, fibers, plasticizers, fillers and polymers.

2. METHODOLOGY

In the current work PLA material is utilized as sandwich material for both core and face sheets. The model is designed in the drafting software SolidWorks using the dimensions and importing it to ANSYS Workbench to perform analysis on Three point Bending. Later, the analytical calculations were made to validate the results, and to determine the error percentage.

2.1 Parameters considered for the design of sandwich panel:

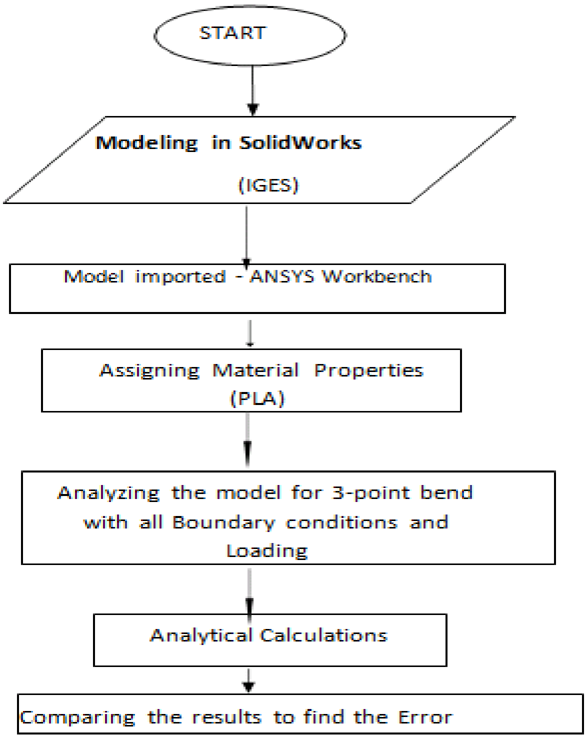
Flexural strength of sandwich structure is regarded as an important factor for efficient design. The design parameters effecting the flexural strength are face sheet and core materials.

2.2 Flow chart of work plan:

The different stages or stages in the Design of sandwich board are explained using a flowchart. The first stage starts with identifying the design parameters, for example, Material combination, Core shape, Face sheet gauge, Core height and shape of the panel. The Model is designed in SolidWorks using testing measurements.

In the second stage, the models generated are saved in IGES format and imported to ANSYS workbench. In the third stage, material properties are entered and saved for assigning purpose. In the fourth stage, the model is then analyzed for three point bending with right conditions and loads under model option. In the investigation, the model is created by considering face plate and core. A consistent or constant load of 5000N is applied to determine the stress and deflections. The objective of this examination work is to investigate the impacts of Flexural Strength and observe the deflection of the panel. In fifth stage, analytical calculations were made to find the percentage by comparing both the results.

Fig 2.1: Flow Chart for work plan sandwich panel



2.3 Introduction to Solid Works

Solid works is the leading product development solution for any manufacturing sector. The software is developed and funded by United States-based Parametric Technology Corporation (PTC). Solid works is innovative software designed for the manufacturing industry to meet the competitive demands of production efficiency, quicker time to market and increased quality of the goods.

Modules in Solid works:

Wildfire Solid works is a complete product development solution. We're able to get the best in class tools for product design, analysis, data processing, single device development. Solid works offers various packages to suit the needs of different customers.

Some of the important modules are as follows:

- *Solid works Machining Solid works*
- *NC sheet metal Solid works Tool design*
- *Solid works plastic Advisor*

Features of Solid works:

For any manufacturing industry Solid works is a one-stop store. It provides useful features which are integrated for a wide range of purposes.

Some important features are as follows

- ✓ *Simple and powerful tools*
- ✓ *Parametric design*
- ✓ *Feature-based approach*
- ✓ *Parent child relationship*
- ✓ *Associative model centric*

Simple and Powerful Tools:

Designs of Solid works are parametric. The term "Parametric" means the captured design operations can be stored as they occur. In future they can be used effectively to change and edit the template. Such modeling forms aid in quicker and simpler design modifications.

Feature Based Approach:

Features are the basic build blocks required to construct an object. Wild fire Solid works models are based on a range of features. To construct the model, each future builds upon the previous feature (only one single feature can be changed at a time). Could function can appear simple, individual but forms a complex part and assemblies collectively. The concept behind feature-based modeling is that if its dimensions change, the designer creates an object, composed of individual features that explain how he supports the object through geometry. The first feature was called future foundation.

Associative and Model Centric:

Wild fire drawings of Solid works are centric model. This means that Solid works models are associative, represented in assembly or drawings. When modifications are made in a single module, they will be changed in the referenced module automatically.

2.4 Introduction to ANSYS Workbench

ANSYS Work Bench can be viewed as a software platform or system where you carry out your research tasks (Finite Element Analysis). In other words, workbench helps you to arrange all the files and databases relevant to your research under the same frame work. That means you can use the same set of material properties for all your analyses, among other things.

Some of the applications falling within the framework of the workbench are:

- *Design modeler Mechanical (simulation) Design Xplorer*
- *AUTODYNCFX Mesh FE Modeler*

Mechanical (simulation) – *We use this framework to carry out study of finite elements including structural, thermal and modal analyses.*

Design xplorer- *We use this framework to optimize design using the technique of Design of Experiments (DOE).*

AUTODYN – *We use this framework to model events of short duration involving significant deformations or complete material failure as well as interaction between fluid solids.*

CFX mesh – *We use these applications to create a mesh used by the CFX programme. Computational fluid dynamics was performed by CFX.*

FE Modeler – *We use these applications to import into Workbench a model of finite elements that was developed using the Nastran FEA software.*

Advantages of ANSYS Workbench

The ANSYS Workbench framework helps users to build new, quicker processes and communicate with external resources such as CAD systems in an efficient way. It provides a basis for easy simulation of multi physics and improved communication of simulation results around the business. For those conducting structural simulation, the graphical interface (called ANSYS Workbench Machinery) is used to represent all the parts of their simulation with a treelike navigation structure: geometry, connexions, mesh, loading, boundary conditions and results..

2.5 Sandwich Plate System

During the last 15 years Steel Sandwich Plate Systems (SPS) has been used for industrial applications. The primary application areas of metallic sandwich panels in cruise ships and other maritime applications are stairs & staircase landings, bulkheads, and floors. A wide range of applications of stainless steel sandwich panels have been used in recent years both in civil and mechanical engineering as well as in other manufacturing sectors. Those include bus decks, elevator floors and walls, work platforms in manufacturing applications, and shipyard balconies. The standard products may be replaced with alternatives because there are some benefits of this.

3.DESIGN AND ANALYSIS OF SANDWICH PANELS

3.1 Sandwich Structure in Three Point Bending Test

Sandwich structures behavior is evaluated using the finite element test. Models of isotropic material are considered for the present analysis. All strains are believed to be low due to the in-service loads. For both materials therefore, linear stress strain relationships may be used. It includes the use of only four parameters to explain the behavior of the material – the elastic moduli of the facings and the core (Ef and Ec) and the corresponding rations of the Poisson, (πf and ÿc). Simulations of the sandwich panel in 3-point bending process are carried out to investigate the characteristics of bending behavior of the sandwich panels and to analyze the shear effects of the core. Figure 4.1 displays a 3-point bending schematic model which is simulated using FEA. In all models of sandwich structures, the deflection analysis, Von-Misses stress and Shear stress are performed using three point bending process. The findings obtained are being analytically checked.

1) ***Table 3.1: Parameter details of First model***

Parameter	*Value*
Materials for Face sheet and core(MC)	*Polylactic acid (PLA)*
Core Shape (CS)	*R(Rectangle)*
Face sheet thickness(FS)	*1mm*
Core height(CH)	*10mm*
Panel Shape(PS)	*120×25×12 mm^3*
Lattice Strut Diameter of Unit Cell	*5mm*
Lattice Strut Height of Unit Cell	*5mm*

3.2 Modeling of Sandwich Structure

The solid models of the sandwich structure are created in Solid works. This model is then imported into Ansys workbench.

Designing

The SOLIDWORKS software is an automation program for mechanical design that allows designers to quickly sketch designs, experiment with features and measurements, and create models and detailed drawings.

Concepts

Parts are the fundamental building blocks within the program SOLIDWORKS. Parts have sections or other components, which are called subassemblies. A model of SOLIDWORKS consists of 3D geometry, which determines its sides, faces and surfaces. The SOLIDWORKS program lets you easily and accurately build models. SOLIDWORKS models are:

- *Defined by 3D design*
- *Based on components*

3.3 3D Design

SOLIDWORKS uses a 3D approach to the design. As you design a part, you create a 3D model from the initial sketch up to the final result. Using this model, to create 3D assemblies, you can build 2D drawings or mate modules that *consist of parts or subassemblies. You can also make 3D assembly drawings in 2D. When designing a model using SOLIDWORKS, you can display it in three dimensions, the manner in which the model exists once it is created.*

Design Process

The design process usually involves the following steps:

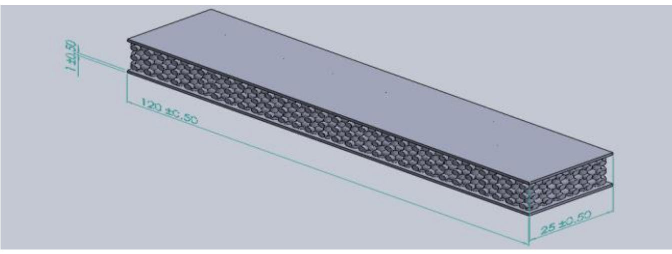
- *Identify the model requirements.*
- *Plan the model based on the needs that have been defined.*
- *Develop the model based on the concepts.*
- *Analyze the model.*
- *Prototype the model.*
- *Construct the model.*
- *Edit the model, if needed.*

Design Method

It's good to prepare a system on how to build the model before you actually design the model. You will design the model after defining needs and isolating the correct concepts: construct the drawings and determine how to scale and where to apply relationships.

Sketches

Select the correct features, such as extrudes and filets, evaluate the best features to add, and decide in which order to implement those features.



3.4 FEATURES

Assemblies

Pick the mate components and the mate forms to be included.

Sketches

In most 3D models the sketch is the foundation. Usually the development of a model starts with a sketch. You can build features from the sketch. One or more features can be combined to form a part. Then you can add the correct parts and fuse them together to create an assembly. You can then make sketches from the pieces or the assemblies. A sketch is a 2D or cross-sectional image. You use an airplane or a planar face to create a 2D drawing. You can also build 3D sketches which include a Z axis, as well as the X and Y axes, in addition to 2D sketches.

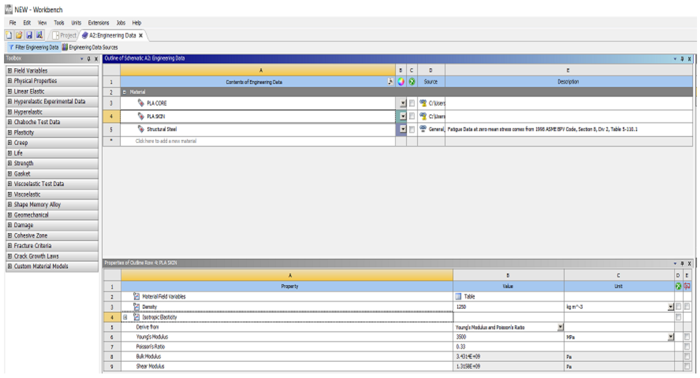


Fig 3.2. Assembly of sandwich structure

4. RESULTS AND DISCUSSIONS

Sandwich structures are having wide applications as opposed to conventional structures due to their improved properties. Sandwich structures have a high weight resistance ratio and provide improved resistance properties. The present work was performed to investigate the bending behavior of sandwich structures for various application areas. The main aim is to replace the conventional sandwich structures. ANSYS workbench is used for understanding the sandwich structure 's three-point bending behavior and validating the finding with analytical results.

*Modeling of the structure is carried out according to **the** necessary dimensions in Solid Works. The developed is stored in iges format to be imported into the ANSYS workbench for analysis where the structure is determined by three point bending, and also by-mises and shear stresses are calculated. Finally empirical analyses are conducted to verify the findings.*

4.1 Analysis of sandwich structure using ANSYS Work Bench

ANSYS workbench Geometry imports the CAD model produced in solid works in IGS format. The sheets of the heart and face are made of polylactic acid. Simulation process of the ANSYS Workbench in the Geometric Modeler with the adoption of the material properties for face sheet and core and the type of element is selected automatically and meshing is performed using mesh choice. The selected element type is a solid element with mid-nodes. On the center of the panel is applied a static charge of 5000 N. Analytical findings are shown in figures.

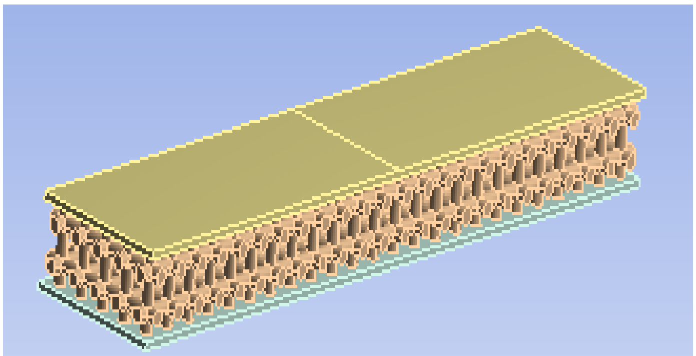


Fig 4.1: Geometry modeled in Solid Works and imported to

ANSYS Workbench

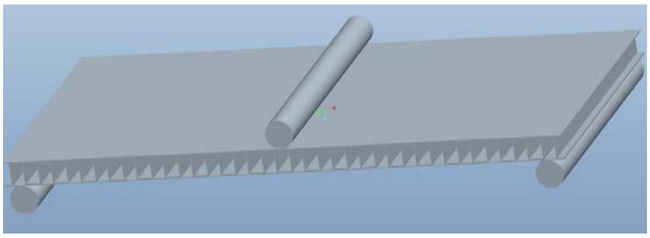


Fig 4.2. Material Properties

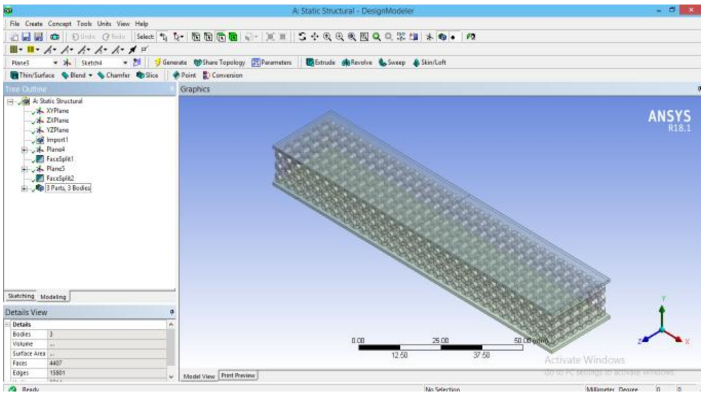


Fig 4.3. Transparent Model in ANSYS workbench geometry

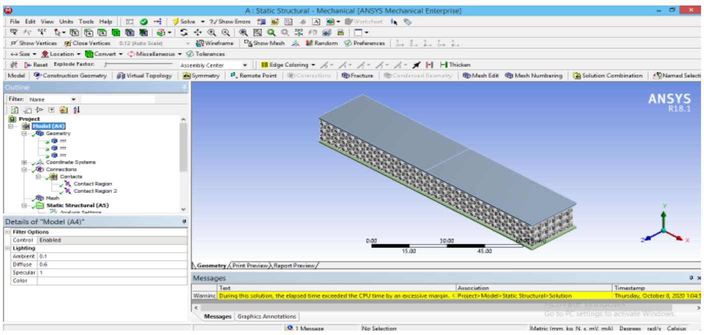


Fig 4.4. Model in Design Modeller

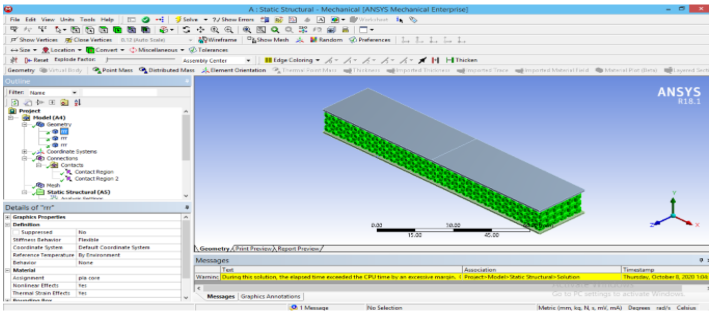


Fig 4.5.1 Assigning Material properties to core

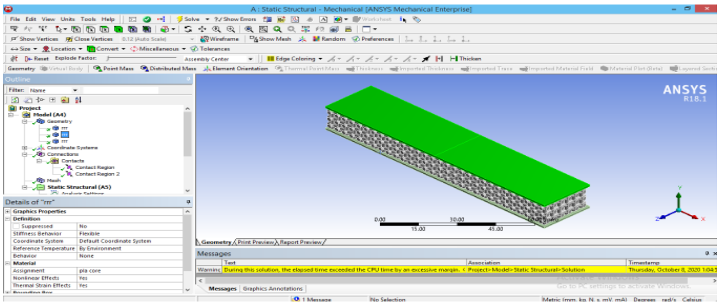


Fig 4.5.2 Assigning Material properties to top face sheet

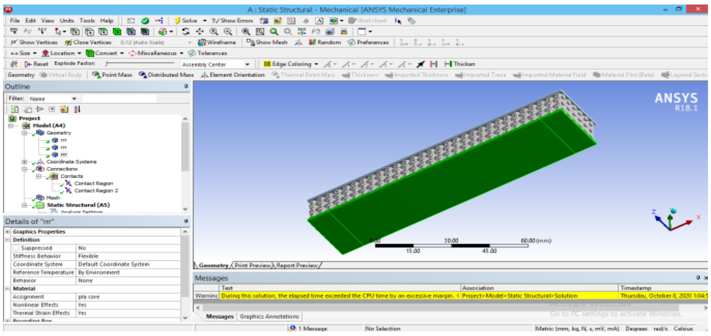


Fig 4.5.3 Assigning Material properties to bottom face sheets

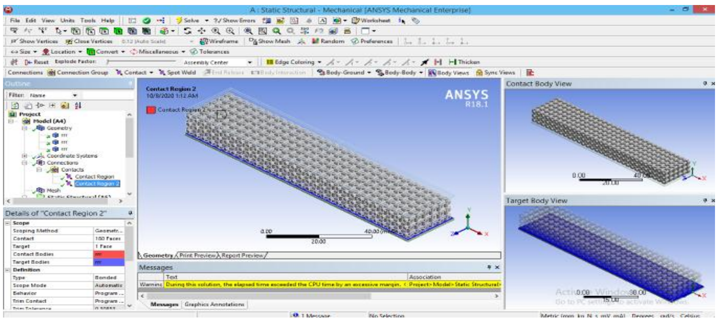


Fig 4.6.1 Contact Region 1

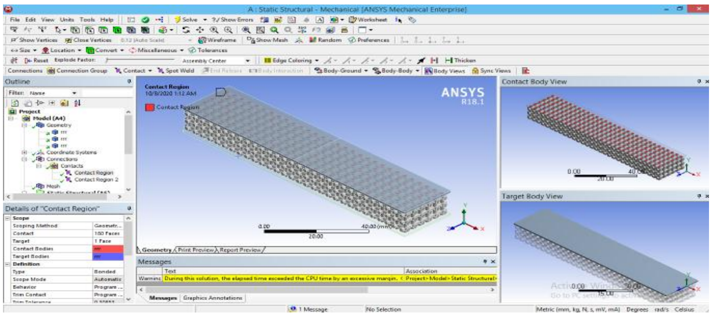


Fig 4.6.2 Contact Region 2

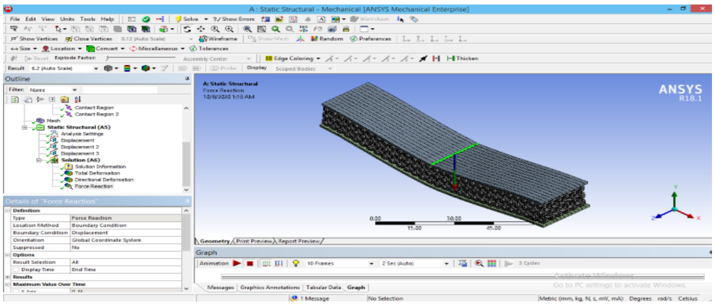


Fig 4.7. Mesh model

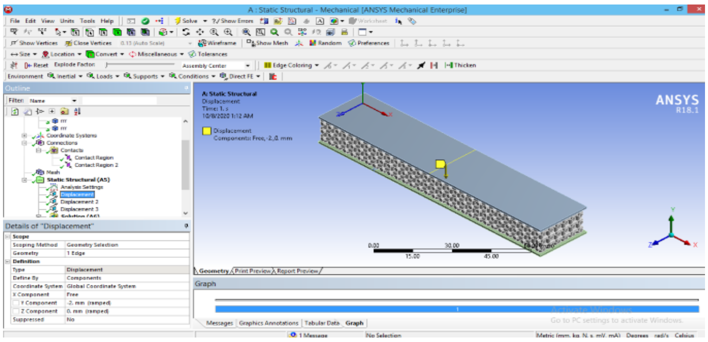


Fig 4.8. Displacement-1

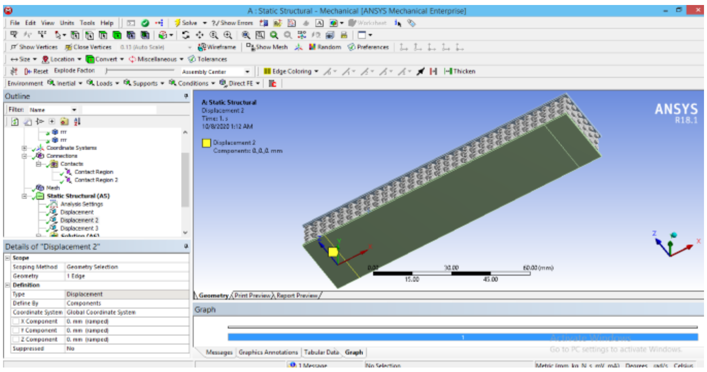


Fig 4.9. Displacement-2

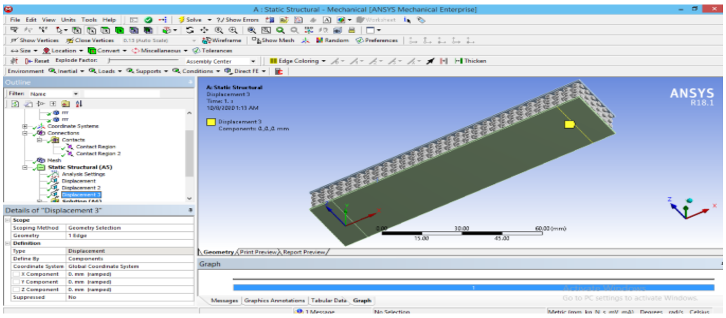


Fig 4.10. Displacement-3

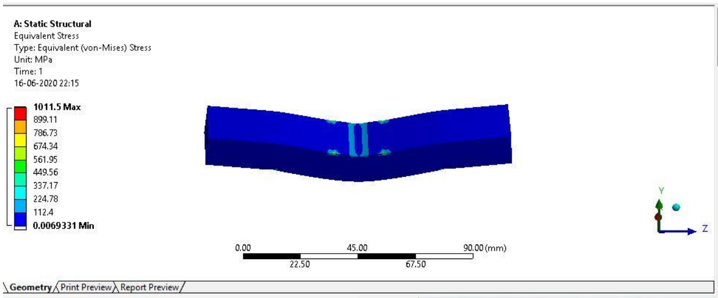


Fig 4.11. Equivalent stress (von-mises) stress

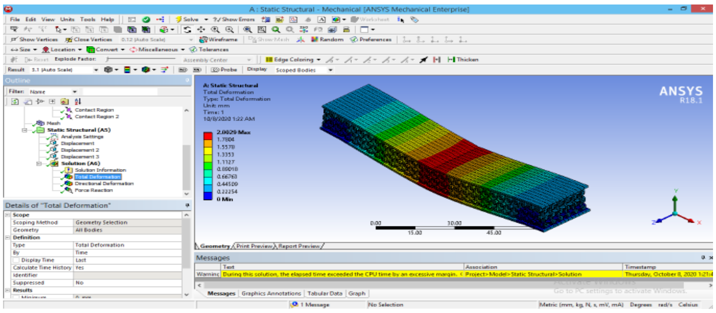


Fig 4.12. Total deformation

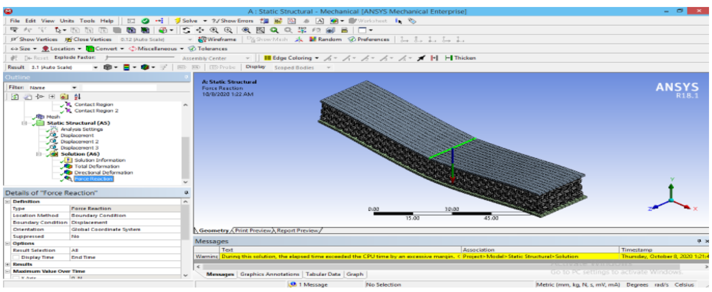


Fig 4.13. Force Reaction

4.3 Analytical Method

The results of the deformation obtained through FEA are checked using analytical methods and discussed below. It presents sample calculations for the model. In this session, the formulations for linear response under static charge are described. The sandwich panel is known as beam of width (b) and span (l.) defined by deflection (ð) consisting of both bending and shear components.

$$\delta = (\frac{pl^3}{48(EI)_{eq}})$$

Where δ is deflection of Beam in mm

P is Load in N,

E=Young's Modulus of Sandwich Structure in MPa,

I= Moment of Inertia in mm^4

l = Length of Beam in mm

$$(EI)_{eq} = [(E_f bt^3/6) + ((E * bc^3)/12) + ((E_f btd^2)/2]$$

Where Ef = Young's Modulus of Skin,

t = thickness of Skin,

b = width of Sandwich Structure,

c = thickness of Core,

d = thickness of Sandwich Structure.

$$(E^*/E) = c_1(1 - (V_s/V_t)^2$$

Where E= Young's Modulus of lattice sandwich Structure,*

E= Young's Modulus of Sandwich Structure in MPa,

C1 = Gibson and Ashby's Constant.

Vs= Volume of Lattice Core,

Vt= Volume of solid Core.

$$V_s = (3\pi \times r^2 l) - (8\sqrt{2}\, r^3)$$
$$V_t = l \times b \times h$$

Where l = length of Core,

b = Width of Core,

h = thickness of Core.

Where k_b *&* k_s *are defined in Table,* E_f *&* E_c *are Young's moduli of facing and corematerial respectively, d is the distance between the center lines facings (d □* h_c *□* t_f*).*

The materials chosen for face sheet and core for the present case are PLA. Clearly assisted ends and center point loading are the conditions considered for further analysis. The constants kb and ks are chosen from Table 4.1.

Table 4.1. Constant definition

Both Simple	*Uniformly Distributed*	*5/384*	*1/8*
Both Fixed	*Uniformly Distributed*	*1/384*	*1/8*
Both Simple	*Centre Point*	*1/48*	*1/4*
Both Fixed	*Centre Point*	*1/192*	*1/4*
One Fixed (Cantilever)	*Uniformly Distributed*	*1/8*	*1/2*
One Fixed (Cantilever)	*End Point*	*1/3*	*1*
End Supports	***Loading***	***kb***	***ks***

4.4 Sample calculations:

Based on the material selected we have,

Young's Modulus of face material (E_f*)= 3500 MPa*

Young's Modulus of core material (E_c*)= 1000 MPa*

Length of the panel (l)= 120 mm

Width of the panel (b)= 25 mm

Face sheet thickness (t_f*)= 1 mm*

Core height (h_c*)= 10 mm*

Load (P)= 100 N

Distance between center lines of opposite facings (d) = h_c *□* t_f *= 12mm from equation, we have Flexural Rigidity (D) given by*

$$K_b = 1/48$$

$$K_s = 1/4$$

$$\delta = (\frac{pl^3}{48(EI)_{eq}})$$

= 2.8mm

The deflection obtained from numerical simulation for the same configuration is

□$_{sim}$ *□ 2.0mm*

Fig.4.14Graphs of Simulation

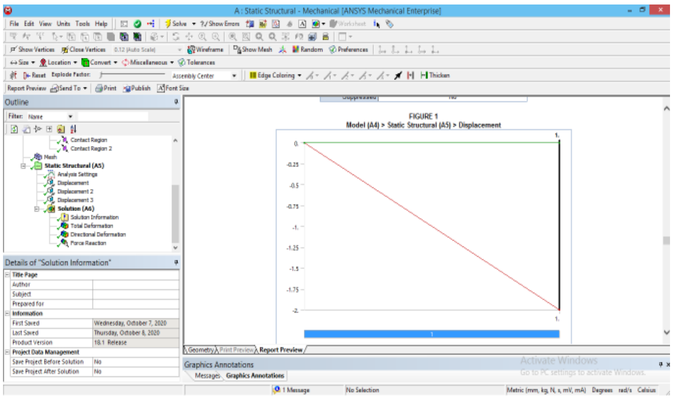


Fig.4.14.1Displacement

Displacement is used to define the movement of the Lattice Sandwich Structure so that Load can be finded.

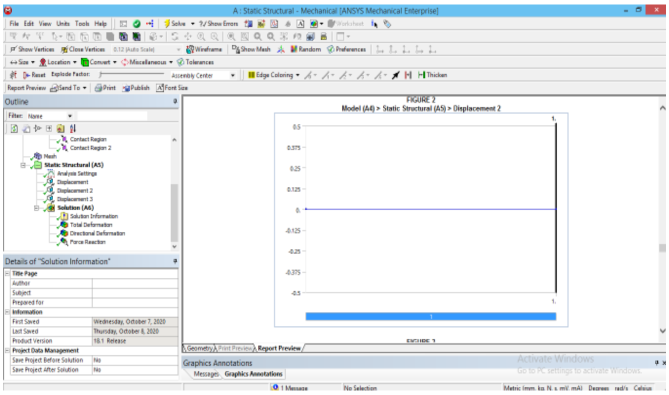


Fig.4.14.2Displacement 2

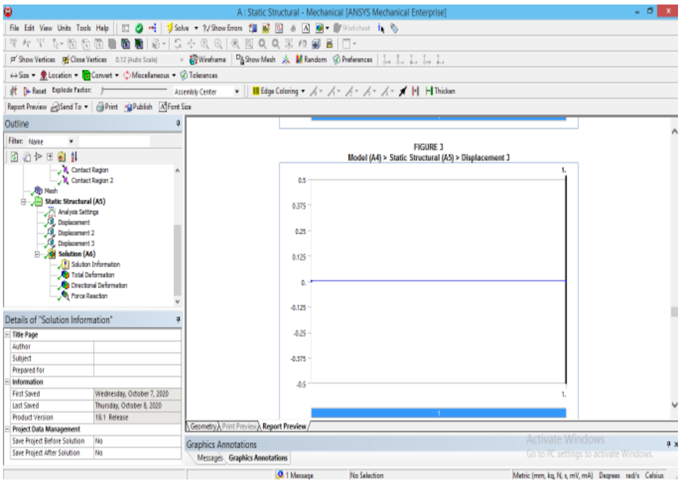


Fig.4.14.3Displacement 3

Here in the graph we can see that initial displacement of Sandwich Structure is 0mm and the final displacement of Sandwich Structure is 2mm. Also the graph is indicating that Sandwich Structure is loaded gradually. In the graphs of Displacement 2 and 3 we can see that there is no displacement of Lattice Sandwich Structure. These are used as Fixed Supports.

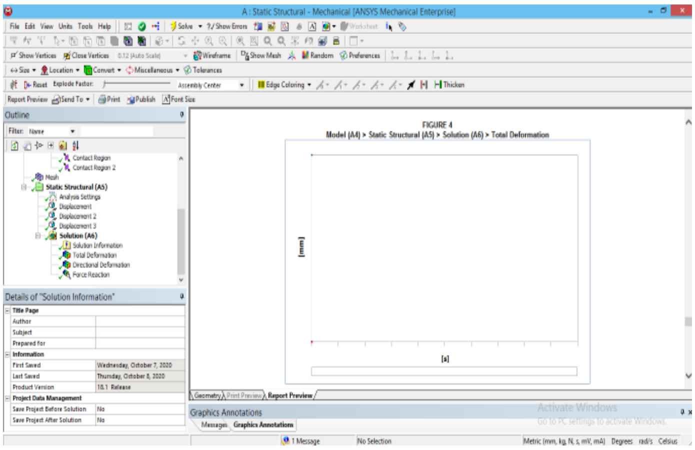


Fig.4.14.4 Total Deformation

The above graph is indicating Total Deformation of Sandwich Structure.

The percentage error is calculated as = $\underline{(Difference\ of\ values/Analytical\ value) \times 100}$ = ((2.8-2.71) /2.8) × 100 = 3.2%

4.5 SUMMARY

In this chapter Numerical simulation was performed for model using Ansys Workbench and Von-misses stress, Maximum shear stress and deformations were measured under three point bending test. In order to verify the computational simulation of the sandwich structure made of analytical calculations with polylactic acid, the error between the results was found as 3.2%.

S. No	*Load*	*Analytical Deflection*	*Simulation Deflection*	*Error*
1	*100 N*	*2.8 mm*	*2.71 mm*	*3.2%*

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11) L. Valdevit, Z. Wei, C. Mercer, F.W. Zok, A.G. Evans, 2006, "Structural performance of near-optimal sandwich panels with corrugated cores", International Journal of Solids and Structures, 43(16), 4888–4905.

BIOGRAPHY

N.Rohit Reddy is a Mechanical Engineer working in the field of Design Engineering. He was awarded M.Tech Degree in CAD CAM with distinction at Vidya Jyothi Institute of Technology.