International Research Journal of Engineering and Technology (IRJET) **e-ISSN: 2395-0056**
Volume: 09 Issue: 08 | Aug 2022 **www.irjet.net** **p-ISSN: 2395-0072**

Experimental Investigation on Mechanical Properties of Basalt-Core Reinforced Materials

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Abstract - *A composite material is a combination of two or more different materials; it gives superior quantity than its constituents. Composite materials not only used for structural applications but also in various other applications such as automobile, aerospace, marine, etc.*

This work describes an experimental mechanical characterization campaign on composite made out of unidirectional Basalt raw with 8 layers. The strength of the material is observed by performing mechanical tests. A core material is introduced in combination with basalt to check the mechanical properties of raw basalt with core as ingredient. In addition to that the influence of core on the strength and thickness of the material is also evaluated by knowing the percentage improvements in strength were the cost of the material also reduces due to the addition of core material. The work has used raw materials from commercial catalogues with no further modification. Compression mould is the manufacturing method used to prepare the sample. After mould process the sample is tailored to ASTM standards for testing

Key Words: Compression mould, Mechanical properties, Basalt, Core material.

1.INTRODUCTION

The ever growing request of lighter materials used in high speed train, ships, spacecraft and so on, is increasing more and more and the designers are challenged in the field of design and construction of composite materials. A crucial problem, which design engineers are facing in the aerospace industry, is how to attain better design ideas with the consideration of mechanical enactment and industrial cost. The development and application of original, efficient composite structure in an extensive range of industries are inspired by the continuing demands for reduced physical weight, superior effectiveness and enhanced performance. Composite structures are becoming a suitable alternative to metals in several industrial applications particularly for mass carriage where weight reduction is one of the key issues in design factors, owing to their superior advantages of specific mechanical properties and corrosion resistance. To build structures where the weight is a main concern, composite materials are predictably used. Composite structure with less amount of weight, in order to save energy, is primordial for all varieties of transportation industries such as aircraft, trains and cars (Zinno et al. 2010).

Nowadays, in the transportation area and particularly in aerospace machineries, the use of improved lightweight constructions is very common. The first use of composite structure in military aircraft was in the 1960s and then in the 1970s, it was used in civil aircrafts. Nevertheless, the manufacturers of civil aircraft were slow to use the composite structure for primary structural application in aircraft until the 2000s. In the 21st century, owing to their exceptional mechanical behaviors and multifunctional uses, composite materials are reflected as the most favorable multifunctional configuration resources. They meet design and qualifications necessities and provide notable weight benefits as well as substantial cost diminutions. Fiber reinforced plastic composite structures are extra outstanding for constructing ultra-lightweight multifunctional configurations mainly for spacecraft (Katnam et al. 2013).

The modern energy crisis of the world and weakening atmosphere have stimulated the fast improvement of new materials and structures such as composite materials and sandwich structures (Besant et al. 2001). Sandwich composite structures are widely used in aerospace, spacecraft, naval, marine vehicles, automobiles and other light weight structures due to their high stiffness, strength and energy absorption capacity. Sandwich structures are used not only to reduce the weight and cost but also to increase the structural performance. Typical sandwich composite is composed of two thin and strong face sheets separated from a lightweight core. They have distinct properties such as high specific modulus, lightness, strength and low coefficient of thermal expansion. Moreover, due to their design flexibility and light weight features, sandwich composites are used more in advanced aircraft components and marine structure (Meo et al. 2005).

In the midst of best favorable composite structures, due to their attractive characteristics such as massive weight reduction, capability of energy absorption and power resistance, the honeycomb core sandwich panels, particularly reinforced with composite structure, have been broadly utilized. Honeycomb sandwich structure is one of the dominant structures of the sandwich composite. The method of using honeycomb core between two faces

Sheets were first offered by Hugo Junkers in 1915 (Tijo Thomas et al. 2019). Honeycomb composite structures are widely utilized in aircraft, space structure, satellites, automobiles, boats and so on, because of their light density, high rigidity, good sound and high insulation capacity. Energy absorbing materials filled honeycomb sandwich panels can prevent or decrease the accumulation and trapping of water throughout use, which is a major problem especially in aeronautics. Honeycomb sandwich composite structures manifest static properties such as high buckling and high stiffness- to-weight ratio which are of great importance in the aeronautics field. The face sheet has a high strength and elastic modulus and the core has bending and high shear rigidity. Because of this, the moment of inertia of the structure will increase and thus, the rigidity of the structure will also increase (Castanie et al. 2008).

More or less unnoticed by the majority of designers, engineers and architects, throughout the last 50 years, sandwich structure has industrialized typically into an inexpensive production method, which currently also fulfils high architectural necessities. Sandwich structure is recording a remarkable progress, as most of the engineers are using light metal towards a decreasing tendency at an alarming speed. An extensive investigation and progressive efforts are made in sandwich construction to use more and more of it in many areas, because the traditional cores that are used in sandwich construction are economically not feasible. Although there is an endless effort in the aerospace world for new materials improvements, there are several damaging aspects and substantial costs related to them and they are accepted at risk. Moreover, due to growing universal competition, a plenty of industries have a strong necessity to improve honeycomb cores for light weight sandwich panels. Particularly in terms of novelty, these cores should be extra cost effective to construct and preserve. This can offer a designer a comprehensive spectrum for selecting a core for light weight sandwich structure. All these phases and the requirement to know systematically the complex mechanism involved afforded a reasonable motivation to take up this topic for a doctoral study.

1.1 Face Sheets

Practically, all the bending and in-plane loads are carried by the facings. Facings also describe the flexural rigidity and flat wise compressive shear as well as compressive behaviors. Moreover, face sheets ought to have a comparatively high density, as they are proposed to offer almost all the tension, compression and bending confrontation. Also, they should be kept at an adequate distance from the midplane of the sandwich structure panel. Thus, the face sheets built with in-plane stiff as well as appropriate out-of- plane rigidity are significant. The layup and the thickness of the facings need to be designed to meet the particular requirement (Zinno et al. 2010)

1.2 Core

The chief objective of the core is to improve flexural stiffness of the whole structure with light weight. The low density core material plays a major role in offering high shear resistance and stabilizes the face sheet to get better adhesive bonding. Because, the face sheets and core interface is frequently the weakest part of the sandwich panels. Isotropic foam and anisotropic honeycomb are the two major sets for the core materials. Due to their lightweight, particular bending rigidity and strength in distributed loads, these two kinds of cores mainly utilized in sandwich composites for load-carrying purposes in aerospace, aeronautics, marine vehicles, transportation and military. In this regard, the density and core thickness need to be given importance in a design analysis to fulfil an explicit performance requirement (Victor Birman 2018).

1.3 Sandwich Panel

The overall characteristics of sandwich panels depend upon the material behaviour of the components such as face sheets, epoxy resin and core, symmetrical measurements and nature of loading. Under common bending, shear, and in-plane loading sandwich structures exhibit different failure mechanism. Main failure modes in the sandwich panels in bending are face/core interface de-bonding, core shear failure, face sheet delamination, fiber breakage and skin fracture. Damage mechanisms and their beginning can be identified by performing a systematic stress analysis and applying suitable failure principles in the dangerous areas of the structure. This analysis is highly challenging due to the nonlinear and inflexible performance of the constituent and the multifaceted interfaces of the damage mechanisms. Hence, it is significant to design the sandwich panels suitably and conduct the experiments carefully in illuminating the physical phenomena to support the analysis.

2.LITERATURE

2.1 Core Materials

Core material plays a major role to improve the properties of the sandwich structures. The material properties of the core profoundly control the damage behavior of sandwich structure. The core can be divided into four main groups. They are corrugated, honeycomb, balsa wood and foams. In addition, thermal and acoustical insulation properties of the sandwich composite based on the material of the core.

Corrugated cores that are prismatic in structures classically form open channels in one direction. The mechanical and structural characteristics of corrugated cores are studied to address the issues of isotropic design, core-face reinforcement and dynamic response to applied external loads. In order to enlarge the possible application of corrugated cores, numerous inventive designs of corrugated structure are offered (Jian Xiong et al. 2019). Honeycomb core sandwich structure that is usually closed cell configuration. Honeycomb cores that are hexagonally shaped structure are made up of aluminium alloy, titanium alloy, Nomex or composite materials. Nomex is the most used core, which is made with phenolic resin infused aramid fiber. Honeycomb core made up of metal are cheap but extra resistant. Honeycomb core made up of nonmetal are not delicate to decay but good thermal insulators. Due to its light density, high rigidity, good sound and high insulation capacity honeycomb core structure are widely utilized in aircraft, space structure, automobiles and so on.

Balsa wood that is highly anisotropic is made up of natural small pieces of sheets joined together. Due its extra density strength in through-thickness, balsa wood core finds special area of application and it is attractive against impact loadings. Foams are a solid on a macroscopic level and it is easy to prepare the surface, shaping and bonding to core blocks by adhesive. Polyurethane (PUR), polystyrene, polyvinylchloride (PVC) and polymethacrylimide (PMI) are the various kinds of foams. Among these, the most popular foams are polyvinyl chloride and polyurethane foams.

Polyvinylchloride foam is a combination of air bubbles and high volume polymer with less weight. Due its low water absorption capacity, PVC is preferable than polyurethane foam. Through the action between isocyanate and polyol while using carbon dioxide as a blowing agent, the polyurethane foam is formed. Many varieties of PUR foams are formed from soft foam from open cells to rigid types with predominantly closed cells.

Honeycomb core sandwich structure is one of the dominant structures of the sandwich composites. The foam filled honeycomb core provides coupled advantages of the foam and the honeycomb core, because the cell walls offer the strength and the foam absorb high impact energy (Vaidya et al. 1998).

2.2 Applications of Sandwich Panels

Sandwich composites with their stability and ease of repairs, find increasing use in many applications such as aerospace, automotive, water turbine industries, satellite launch vehicles, missiles and transportation engineering. And also these materials, because of their lightweight and favourable cushioning properties, are used as shock absorbers in air planes and high speed trains. They have distinct properties such as high specific modulus, lightness, strength and low coefficient of thermal expansion. Moreover, due to their design flexibility and light weight features, sandwich composites are used more in advanced aircraft components and marine structure. In addition, sandwich structures have better bending stiffness, strength, and capable of absorbing high energy (Kang et al. 2006).

In order to obtain more stiffness, strength and combined thermal insulation, sandwich composite also used in portions of the structure of GRP terrain vehicles. One of the features of this vehicle is to obtain low structural weight so that it is able to function in deep snow environments. There are also a series of pleasure boats, hulls, cars, ships and train made up of sandwich design with an aim of reducing weight, emissions and costs (Ye et al. 1988).

Honeycomb core sandwich structures can be used for several applications, in particular for aircraft structural applications such as airplane floors, doors, wings flaps, rudders and helicopter fuselages (Herrmann et al. 2005). Other advantages of sandwich structure are fire retardation, comfort of forming, simplicity of machining, high explicit strength, isolation, good weariness behaviours and erosion resistance. The sandwich materials are also used in building construction such as walls, ceilings, floor panels and roofing. Also they can be used in damped structures to reduce the vibrational problems. Various degrees of damping can be solved based on the properties of core as well as wavelength of the vibration mode by using a visco-elastic core sandwich structures (Rizov et al. 2006).

2.3 Manufacturing Methods

There are different methods used in the manufacture of composites sandwich. The methods are hand lay-up, Resin Transfer Moulding method, Vacuum-Assisted Resin Transfer Moulding (VARTM) and vacuum bag moulding methods (Daniel B Miracle & Steven 2001).

Hand Lay-Up Method

This is an open molding method which can be used for the manufacture an extensive variability of composites products. Hand lay-up method is a simple processing with low cost tooling method. By using this method, good production rates and reliable quality are achieved. There are four phases in this process such as mold preparation, get coating, lay-up and curing. First of all, the waste from the mold surface is removed to avoid the sticking of polymer to the surface. Then, the reinforcements are applied by hand on the mold. The reinforcement may be any preferable material such as aramid, carbon or glass. To apply the resin on to the fibers, brushes are used. Consequently, to confirm the enriched interaction between the fibers and the resin, rollers are used to roll the wet composite. Finally, the laminates are kept to cure at room temperature. Without the external heat, the fiber reinforced composite is cured to get hardening. The hand lay-up technique is mostly utilized in marine as well as aerospace structures. However, more workers and time are required for this method than advanced fabricating methods.

Vacuum Bagging Processing Method

In this process, the fiber with the resin is impregnated in the open mould tool and the core is located in between the mats. Then, the whole lay-up is covered, sealing around the edges. For the composite to consolidate, the vacuum bag process is activated by sucking all the air inside. Without crushing the laminate part, the pressure is added by the vacuum bag. Pressure supplied by the vacuum bag to eliminate the entrapped air, excess resin and compresses the laminate. Continuously this is done to assist with the curing of the resin. When the composite part is fully cured, the vacuum pump can be removed in order to remove the manufactured composite part.

2.4 Materials and Methods

Preamble

From the literatures, it is found that most of the cores are made with metals and the enhancement of properties through sandwich is better when compared with solid laminates. Since applications of basalt fiber is found much in many applications such as boat hulls, an attempt has been made to develop a hybrid honeycomb sandwich panel with basalt fiber and core for structural applications. Also to improve the characteristics and to develop the innovative and novel light weight structures, it is proposed to incorporate the core material in between the fiber. Core also acts as Energy absorbing materials, and also profoundly controls the damage behavior of sandwich structure, increases the impact resistance and absorbs high impact energy.

Flow chart of the research

Basalt fabric as the reinforcement and LY 556 epoxy resin and HY 961 hardener as the matrix material are used to fabricate the sandwich composite. The core material having regular hexagonal cell configuration with cell size of 6 mm is used in the fabrication of composite. The physical and mechanical properties of the face sheet have been determined as per the ASTM standards. As per ASTM standard, flat wise compression, three-point bending and charpy impact tests are conducted to determine the elastic constants of the core and maximum load capability of the sandwich panels.

3. MATERIALS

Core material plays a major role to improve the mechanical properties of composite sandwich structures. Also, when the weight is reduced, it is easy to increase the payload and reduce the cost. Hence, it is very significant to select the correct material to minimize the weight with high quality. Therefore, the bidirectional fiber of 210 GSM with a thickness of 0.2 mm as a reinforcing material and Epoxy resin LY 556 mixed with HY 951 hardener in the ratio of 100:10 as binding materials are used to fabricate both face sheet as well as the core. In order to obtain the optimum strength, the fiber and resin ratio 65:35 is taken to make the sandwich panel. The split molding tool dimensions are 310 mm in length, 300 mm in width, 30 mm in height and it contained 30 half hexagonal inserted rows of core with the cell size of 6 mm. The bidirectional hybrid fiber is shown in Figure.

Fig -1: Basalt Fiber

To analyze the effect of fillers on the core, two different samples are prepared with different compositions. Both are prepared with different stacking sequences. The study is to know the mechanical characteristics of the samples with the addition of core material and comparing the same with raw basalt sample.

Development of sandwich structure

The Vacuum bag molding technique, in which the improvement of the hand lay-up uses the vacuum to remove the captured air and extra resin, is used to fabricate the hybrid fiber honeycomb core sandwich material.

There are many advantages in vacuum bag hand lay-up process when it is compared with conventional hand lay-up techniques. Since the process takes place within the closed atmosphere, it virtually removes the unsafe Volatile Organic Compound (VOC) emissions. Vacuum bagging process is used to add pressure without damaging the part and the vacuum is run into the sealed area. The resulting vacuum pressure pushes out the extra resin. Moreover, by using this method higher structural strength and efficiency is gained against the traditional methods. This method also offers better resin distribution and stronger bonding of the laminate. As a result, the mechanical behaviors of the sandwich panels are remarkably higher than the case of hand laminating panels.

Manufacture parameters

The bidirectional fiber as reinforcement and LY 556 resin mixed with HY 951 hardener as the matrix materials are used to fabricate the basalt/ core laminate. The ratio of mixing of the epoxy resin and the hardener is 100:10. When the surface is cleaned and remaining particles of molding tool are removed, the process could be started.

Fig -2: Core Material

After confirming a thorough wetting of the hybrid fiber and applying the resin mixture on the molding surfaces, the hybrid fiber is impregnated in the hexagonal split molding tool by placing hexagon mandrel, To improve the joining, the load is applied onto the wet laid-up laminate. After this, a bag with a Vacuum Valve (returnable) is attached and taped up, which institutes the vacuum bagging process. To merge and to increase the inter-laminar shear strength of the layers, a port for the vacuum is organized at one corner of the bag with subjected to 450-500 Hg/mm2 of pressure for 120 minutes.

Manufacture of Sandwich laminates

In order to make the sandwich panel, three layers of the fiber which are joined by resin mixture with the core material, When compared with hand lay-up process, the vacuum bag technique offers greater reinforcement absorptions, better adhesion between layers and control extra resin/hybrid ratio. Two different varieties of panels are prepared one with raw basalt and the other with basalt and the core material. In order to improve the mechanical properties and to control the premature bending, shear failure and buckling of cell walls. The core material having regular hexagonal cell configuration of 6 mm cell size is used to increase the stiffness and loading capacity. The wall thickness of the core is 3mm.

Experimental test of laminate

A detailed understanding of the mechanical behaviors of a material that is used to develop the sample is important to know whether the material is correct and the best material for particular application. The mechanical behaviors of the samples are examined as per ASTM standards. By performing tensile, flexural and compression tests.

Tensile Test

To determine the tensile strength of the composite, using universal testing machine, tensile test is conducted at a cross head speed of 1 mm/min as per the ASTM D 3039M-08. Test specimens are cut from the composite panels with the dimension of 25 mm width, 2 mm thickness and 220 mm length. Figure 3.8 shows the specimen (face sheet) during the tensile test. An average of three specimens is reported in each type of sandwich composite structures.

Fig -3: Tensile Test Arrangement

Compression Test

To determine the compression strength of the composite face sheets, using universal testing machine, compression test is conducted at a cross head speed of 1 mm/min as per the ASTM D 3410M-03. Test specimens are cut from the composite panels with the dimension 20 mm width, 2 mm thickness and 20 mm length. The compressive strength is found out by dividing the breaking load with the cross-sectional area of the face sheet specimen.

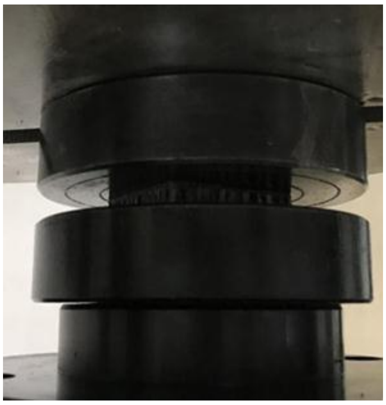

Fig -4: Compression Test

4. RESULTS AND DISCUSSION

Tensile testing

The tension test is generally performed on flat specimens. The standard test method as per ASTM D 3039 has been used; length of the test specimen used is 250mm. The tensile test is performed in universal testing machine. The tests were performed with a cross head speed of 10mm/min. For each test composite of four samples were tested and average value was taken for analysis. The results obtained from the tests is presented in table 4.1

Fig -5: Tensile Specimen

Table -1: Tensile Test outcomes of samples

S No	Samples	Gauge Width (mm)	Thickness (mm)	Tensile Modulus (N/Sq. mm)	Tensile Strength (N/sq.mm)
1.	S1	25	1.5	82.75	137.93
2.	S2	25	3.5	65.0	130.78

S1: 6 layers of Basalt S2: 2-Basalt 1-core

4.1 Flexural Testing

Flexural test was conducted on UTM machine in accordance with ASTM Standards. Specimens of 150mm length and 20mm wide were cut and were loaded in Three Point Bending. The test was conducted on the same machine used for tensile testing using a load cell of 5kN at 2mm/min rate of loading. The flexural stress in a three point bending test is found out by using equation (4.3). The results obtained from the tests are presented in table 4.2.

$$\sigma_{\max} = \frac{(3P_{\max} L)}{(2bh^2)} \quad (4.3)$$

Where Pmax is the maximum load at failure (N), L is the span (mm), b and h is the width and thickness of the specimen (mm), respectively. The flexural modulus is calculated from the slope of the initial portion of the load-deflection curve which is found out by using equation (4.4)

$$E = \frac{(mL^3)}{(4bh^3)} \quad (4.4)$$

Where m is the initial slope of the load deflection curve for each stacking sequence, five specimens are tested and average result is obtained.

Flexural specimen dimensions: Span = 160 mm, Width =20 mm, Thickness=2mm

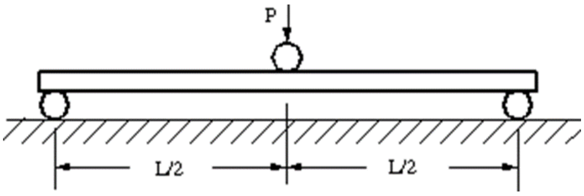

Fig -6: Flexural Specimen

Table -2: Flexural Test outcomes of samples

S No	Specimen Specification	Gauge width (mm)	Thickness (mm)	Flexural Strength (N/Sq.mm)
1.	S1	25	1.2	209.86
2.	S2	25	3.4	202.03

S1: 6 layers of Basalt S2: 2-Basalt 1-core

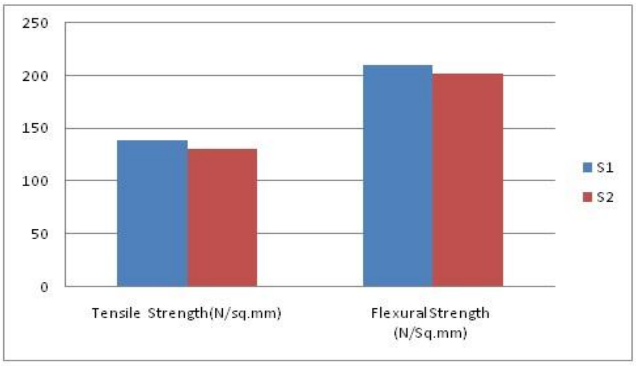

Fig -7: Graphical Representation of Outcomes

Flat wise Compression Properties

To study the effect of energy-absorbing materials under the flat wise compression test sandwich panels, at crosshead displacement rate of 1 mm/min. It is noted that after reaching the maximum load, it drops and this denotes failure initiation in the sandwich specimens.

Table -3: Experimental Results of Compression Test

Samples	Load (kN)	Load/Weight (N/N)	Compressive Strength (MPa)	Compressive modulus (MPa)
S2	89.82	287.28×10^3	34.72	283.13
S1	90.58	295.26×10^3	37.43	298.24

5. CONCLUSIONS

Mechanical behavior of the hybrid core sandwich panels have been experimentally investigated under static mechanical testing's such as Tensile strength, Flat-wise compression, Three-point bending. The obtained conclusions from the above experiments are mentioned below.

Tensile behavior

- The average tensile strength achieved by S2 is 7.15 N/mm2 less than S1, Which is within the permissible limits.

- The 6-layers of raw basalt are exhibiting 137.93 N/mm2. The same strength can be achieved by adding core material to 2-layers of basalt as shown in Table 1.
- By adding core material, strength of the sample S2 is increased at the same time thickness is also increased up to 2mm, S1 is maintaining a thickness of 1.5mm.

Compression Properties

- Experimental results indicated that the hybrid core sandwich panel improved the high strength, specific stiffness, critical load and rigidity more than raw basalt sample.
- S1 is achieved 37.43 Mpa whereas S2 is 34.72Mpa from experimental results.

Three-point Bending Properties

- Due to the strong interface between the fiber and core provided, the sandwich specimen improved the three-point bending properties significantly.
- There is a big difference in bending properties between basalt and e-glass reinforced with core material.

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