

*Experimental Investigation On Sandwich Composite
Made of Expanded Perlite/Epoxy Based Core And
JFRP & CF As Skin*

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DHAKA, BANGLADESH

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DECLARATION

We hereby declare that this thesis is our own work and to the best of our knowledge it contains no materials previously published or written by another person, or have been accepted for the award of any other degree or diploma at Sonargaon University or any other educational institution. We also declare that the intellectual content of this thesis is the product of our own work and any contribution made to the research by others, with whom I have worked at Sonargaon University or elsewhere, is explicitly acknowledged.

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CERTIFICATION OF APPROVAL

The thesis title “ Experimental Investigation On Sandwich Composite Made of Expanded Perlite /Epoxy Based Core And JFRP & CF As Skin ” submitted by Md. Moshiur Rahman Sikder (BME-1903019278), Md.Mahedi Hasan Kishor (BME-1903019105), Abu Rushd Md.Moydul Kadir (BME-1903019058), Khairul Islam (BME-1903019123) has been accepted as satisfactory partial fulfillment of the requirement for the degree of bachelor of science in mechanical engineering on 28 May 2023.

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ABSTRACT

A novel sandwich structure is fabricated consisting of an expanded perlite/epoxy-based core and jute fiber reinforced polymer (JFRP) & Carbon Fiber (CF) as skin. In situ sandwiching technique during compression molding was adopted for manufacturing the structure. JFRP & CF skin was made separately using the hand lay-up method and the core density of the sandwich composite was varied using various compaction ratio. The flexural and compressive properties are investigated along with the varying core to investigate the hardness & Energy absorption of the skin . The performance of the sandwich structure in flexure and compression is affected by the core density .The load-carrying capacity of the sandwich structure was increased about 1.5-1.91 times with an increasing to investigate the hardness & Energy absorption of the skin from 2 to 3. Hardness and Energy absorption The flexural failure of the sandwich composite was initiated from the core of the flexural specimen (core shear failure) and then delamination of the skin. During compression, the strength and the energy absorption are both enhanced significantly by the increment the of core density .

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Chapter 1 Introduction

1.1 Overview

Sandwich composite material and its structures are increasingly used in engineering applications in industries, building systems, and transporting composite sandwich materials. In automobile industries, aerospace and marine structures are mostly made of sandwich structures. Because the sandwich structures are lightweight in nature, can with stand heavy loads, and consists of relatively high flexural strength and stiffness. The sandwich core material is lightweight and mostly combined with skin materials. The skin materials can be of various types such as glass fiber reinforced polymer, carbon fiber reinforced polymer, steel, aluminum and fiber-reinforced polymer. Mostly, the composite skin materials are fabricated through hand lay-up methods or vacuum assisted resin transfer molding machines.

Expanded Perlite as core is mainly used because of its low density, light in weight, and JFRP & CF as skin because they are biodegradable comparatively higher strength than any other bio fiber. Aramid, balsa wood, Aluminum and Nomex core are mainly used as core materials. Corrugated cores are also used in mostly unidirectional support for structural applications. Some significantly higher strength fiber (carbon, glass, Kevlar) is being used as the skin of sandwich structure for better strength and stiffness of the composite structure. The prepared core materials are mostly covered with the two skin materials. Many researchers have carried out their work on sandwich composites focusing on different analysis techniques and using different types foams as core but the research on expanded perlite/epoxy-based core and JFRP& CF as skin by varying core density did not evokemuch attention, although it is a cheap material.

1.2 Objectives

The objectives of the project are

- i. To fabricate sandwich composites using expanded perlite/epoxy-based core and JFRP& CF as skin by varying the core density,
- ii. To Investigate the hardness & Energy absorption of the skin
- iii. To investigate the flexural and compressive properties of the manufactured composites, and
- iv. To analyze the failure behavior during the flexural and compression tests.

Chapter 2 Literature Review

2.1 Sandwich Composites

A sandwich-structured composite is a particular class of composite material fabricated by attaching two thin but stiff skins to a lightweight but thick core. The core material is usually low strength material, but its higher thickness provides the sandwich composite with high bending stiffness with overall low density. [1]

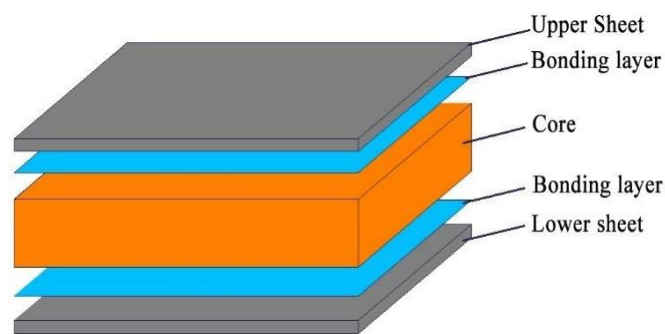


Figure:1 The formation of the sandwich structure

Owing to the core structure, such composites are distinguished by stiffness. Despite the thickness of the core, sandwich composites are light and have a relatively high flexural strength. These composites have a spatial structure, which affects good thermal insulator properties. Sandwich panels are used in aeronautics, road vehicles, ships, and civil engineering. The mechanical properties of these composites are directly dependent on the properties of sandwich components and the manufacturing method. The paper presents some aspects of technology and its influence on the mechanical properties of sandwich structure composites made of expanded perlite/epoxy-based core and JFRP& CF as skin [1].

2.2 Constituent Materials

2.2.1 Expanded Perlite

Perlite is an amorphous volcanic glass with a relatively high-water content, typically formed by the hydration of obsidian. It occurs naturally and has the unusual property of greatly expanding

When heated sufficiently. It is an industrial mineral and a commercial product useful for its low density after processing. It is a non-renewable resource, with about 700 million tons of perlite being stored in the current world.

Table 1: The chemical composition of perlite

Constituent	Percentage
SiO ₂	70-75%
Al ₂ O ₃	12-15%
Na ₂ O	3-4%
K ₂ O	3-5%
Fe ₂ O ₃	0.5-2%
MgO	0.2-0.7%
CaO	0.5-1.5%
LOI	3-5%

There are many advantages of perlite :

- It is very light in weight and has a low bulk density of about 30–150kg/m³.
- Extremely low thermal conductivity.
- It has extremely high insulation property temperature up to 650°C.
- Fireproof, rot proof, soundproof, impervious to damp.
- Environment friendly.
- Corrosion under insulation resistance.

Applications [4]

- It is used in high thermal insulation and heat protection.
- It is used in cryogenic applications like Non-combustible ultra-lightweight mineral aggregate with excellent insulation & adsorption properties.
- It is used in fireproofing and soundproofing systems.
- Swimming pools, cold storage, boilers, and some insulation projects with special requirements for water proofing.
- Perlite insulation is used in high-temperature applications in the steel and foundry industries, such as ladle topping, hot topping, and riser.
- Expanded Perlite is suitable for landscaping applications such as green roof construction, green golf renovation, planters, and drainage.
- Expanded perlite powder and board is a hydrophobic insulating aggregate.

2.2.2 Jute Fiber

Jute is one of the most affordable fibers, popularly known as "golden fiber". It is one of the cheapest and strongest all-natural fibers and is considered a future fiber. Jute is second only to cotton in the world's production of textile fibers. Jute fibers are composed primarily of the plant materials cellulose and lignin. Bangladesh, India, China, and Thailand are the leading producers of Jute. Jute is a significant textile fiber and a raw material for non-traditional and value-added non-textile products.

Table2: Chemical constituents of jute fiber

Types	Cellulose (%)	Hemi-cellulose(%)	Lignin(%)	Fat and Wax (%)
1	61.2	23.2	13.7	0.5
2	61-73.2	13.6-20.4	12-16	-
3	61-71	14-20	12-13	-

Table3:Physico-mechanical properties of jute fiber

Types	Density(g/cm ³)	Tensile Strength(MPa)	Lignin(%)	Elongation at break(%)
1	1.3	393-773	26.5	1.5-1.8
2	1.3-1.46	393-800	10-30	1.5-1.8
3	1.3-1.45	393-773	13-26.5	1.16-1.5

The advantages of jute fiber are huge.

- Jute fiber is 100% biodegradable and recyclable, thus environmentally friendly.
- Jute has low pesticide and fertilizer needs.
- It is a natural fiber with a golden and silky shine and hence called the golden fiber.
- It is the cheapest vegetable fiber procured from the bast or skin of the plant's stem.
- It is the second most important vegetable fiber after cotton, in terms of usage, global consumption, production, and availability.
- It has high tensile strength and low extensibility and ensures better breathability of fabrics.

Therefore, in agricultural commodity bulk packaging, jute is very suitable. Advantages of jute fiber include good insulating and antistatic properties and low thermal conductivity and moderate moisture regain. Other benefits of Jute include acoustic insulating properties and manufacture with no skin irritations.

2.2.3 Carbon Fiber

Carbon fibers have diameters ranging from about 5 to 10 μ m and are composed primarily of carbon atoms. They are obtained by oxidation and carbonization in furnaces of poly acrylonitrile or PAN fibers. Their structure consists in a superposition of long and flat micro crystals aligned parallel to the fiber axis.

The main properties of carbon fibers are:

- high tensile and compressive strengths
- high modulus
- low density
- high chemical resistance
- high temperature tolerance
- electrically conductive

The variation of process parameters (temperatures, times etc.) can provides fibers with different characteristics: high or intermediate modulus, high tenacity etc.

Today's carbon fibers are nearly five times stronger than steel and three times lighter. These properties make carbon fiber extremely interesting for a range of industries, especially the automotive and aerospace industries

Table 4: Carbon fiber materials properties:

Tensile Strength (MPa)	5407
Tensile Modulus (GPa)	294
Elongation (%)	1.75
Density (g/cm ³)	1.79
Strength- to-weight ratio (MPa/g/cm ³)	3026

Applications:

- Hockey sticks, tennis racquets, archery bows, and golf clubs made from carbon fiber are often used.
- Even clothing and protective gear are made with carbon fiber, with racing sports often using carbon fiber helmets and shoes.
- Carbon fiber is expected to be used in components for mass-produced cars, such as housings and frames.

2.2.4 Epoxy Resin and Hardener

Epoxy resin comes in two parts: a resin and a hardener. Mixing the resin and hardener prompts a chemical reaction between the two, transforming them from a liquid into a solid in 24 hours. The chemical formula of epoxy resin is $C_{21}H_{25}ClO_5$. Correctly measured and thoroughly mixed epoxy resin is required for perfect cures.

Epoxy resins fall into two types based on their molecular structure and applications: glycidyl epoxy and non-glycidyl epoxy. These can be further divided into three types based on their configuration: glycidyl ether, glycidyl ester, and glycidyl amine. [6]

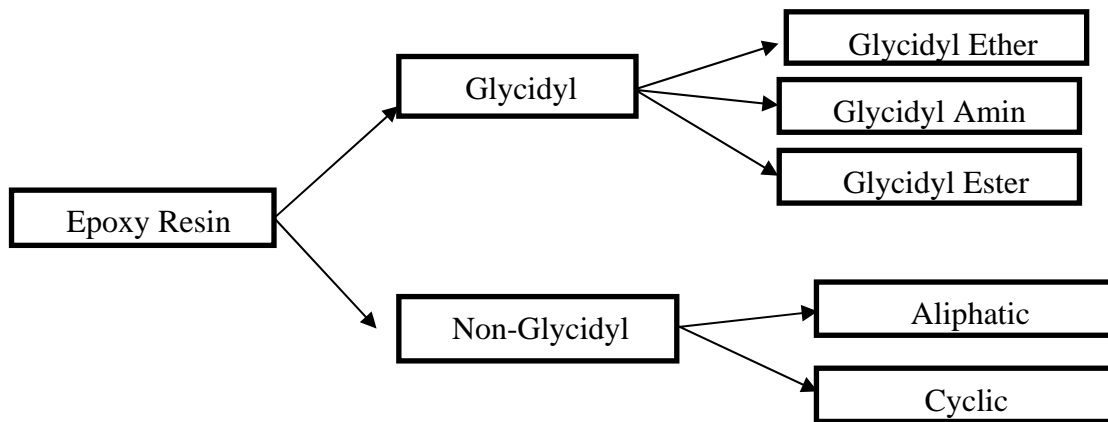


Figure 2:Classification of epoxy-resin

Epoxy resins are used to manufacture adhesives, plastics, paints, coatings, primers and sealers, flooring, and other products and materials used in building and construction applications. The properties of epoxy resin are:

- High Strength.
- Low Shrinkage.
- Excellent adhesion to various substrates.
- Effective electrical insulation.
- Chemical and solvent resistance, and.
- Low cost and low toxicity.

Epoxy resins are of particular interest in structural composite applications because they provide:

- A unique balance of chemical and mechanical properties
- As well as extreme processing versatility

Some of their most exciting applications are found in the aerospace and recreation industries, where resins and fibers are combined to produce complex composite structures. Epoxy resins satisfy a variety of non-metallic composite designs in commercial and military aerospace applications, including flooring panels, ducting, vertical and horizontal stabilizers, wings, etc.;

2.2.5 Acetone

Acetone is a clear, colorless liquid. It is a solvent that can dissolve or break down other materials, such as paint, varnish, or grease. It evaporates quickly into the air.

Acetone is naturally present in trees and other plants, as well as tobacco smoke, vehicle exhaust, and landfills. It also occurs in the body.

Other names for acetone include:

- ✓ dimethyl ketone
- ✓ 2-propanone
- ✓ propanone
- ✓ beta-ketopropane

❖ Table 5 General Properties of Acetone – C₃H₆O

Molecular Weight/ Molar Mass	58.08 g/mol
Density	0.784 g/cm ³
Boiling Point	56 °C
Melting Point	-94.7°C

❖ Application:

Companies use acetone in small amounts to create products that break down or dissolve other substances, such as:

- nail polish
- paint
- varnish

In industry, manufacturers use acetone for a variety of purposes, including:

- Removing grease or gum from textiles such as wool and silk
- Making lacquers for cars or furniture
- Making plastics

2.3 Related Previous Works

Krzyzak et al. [7] determined the influence of sandwich laminates' production technology on chosen mechanical properties, including structural characteristics occurring at the boundary of core stages and sandwich panel skins. They analyzed the process of developing cracks appearing after impact. The sandwich structures were fabricated in the following three methods, (a) hand lay-up (b) press, and (c) autoclave. The core was prepared by Polyurethane foam surrounded by a composite made of epoxy resin. Low viscosity epoxy resin with a CES R70 symbol based on Bisphenol A/F(modified using an active two-function diluter) and CES H71 hardener was used for outer skins. Mechanical properties (compressive strength and flexural strength) were calculated using a universal testing machine and the estimated results were found to be, the maximum compressive strength of 0.601 MPa using hand lay-up, 0.627 MPa for press and 0.610 MPa for Autoclave methods also the maximum flexural strength of 6.22MPa using hand lay-up, 7.26 MPa for press and 4.02MPa for Autoclave methods[7].

Jiang et al. [9] manufactured bio-composite sandwich structured mycelium-based cores. The materials were used in that bio-composite sandwich structure were natural textile reinforcement, mycelium-bound agricultural waste as core, and bio-resin. This manufacturing process was done in three specific steps of the seven-step manufacturing process: (a) filling prestamped textile shells with core mixture, (b) allowing the core material to grow, (c) thereby binding reinforcement particles, (d) textile skins into a unitized preform, and (e) oven drying said perform to drive off moisture and inactivate the mycelium. After preparing the composite three-point flexural strength and compressive strength were performed on the samples using a Universal testing machine. Three-point bending test results for biotex jute textile-reinforced sandwich panel specimens were an average of 762 kPa[9].

Daniel and Abot [10] fabricated and tested the composite sandwich beams of carbon/epoxy laminates as skin and aluminum honeycomb PAMG as core material by autoclave molding. Uniaxial tensile and compressive tests were conducted primarily in the longitudinal direction to obtain the appropriate constitutive behavior of the facing material. Failure was governed by the compressive strength of the face sheet, which in this case reached a value of 1930 MPa (280 KSI), which was higher than the compression strength for this material measured under direct compression, and the ultimate compressive strain recorded was 1.6% [10].

Hassan et al. [12] investigates the influence of varying core density on the blast resistance of sandwich panels based on cross-linked PVC cores and aluminium alloy as skins. Five cross-linked PVC foams, nominal densities ranging was between 60 and 200 kg/m³. Compression and single edge notch bend and shear tests were conducted on the prepared sandwich panels. On samples whose density was 200 kg/m³, the tested results were Compressive modulus 280 MPa, Tensile Strength 175 MPa, Shear strength 3.5 MPa, Plastic collapse stress 4.19 MPa [12].

Anbusagar et al. [13] investigate the influence of nano-clay content on sandwich composites under flexural and impact loading. Four different sandwich composite panels made of fiber glass/nano-modified polyester face sheets and jute core were prepared by hand lay-up manufacturing technique (H.L.). The core thickness was 6 mm, and the face sheets were made of one layer of woven fabric glass fibers and nano-modified polyester for sandwich panels. Composite samples were tested for flexural and impact behavior using universal testing machine standard ASTM-C393 & ASTM-D6110. The experimental results were found to be given in table 6.

Table 6: Mechanical properties of jute core sandwich nanocomposite.

Sample code	Measured failure load (N)	Skin bedding strength (MPa)	Core shear strength (MPa)	Bending modulus (GPa)	Impact strength (KJ/m ²)
SJ0	506.22	140	3.89	10.53	48.71
SJ2	586.66	162.81	4.51	13.63	50.35
SJ4	558.96	134.48	4.29	15.26	52.73
SJ6	449.65	113.67	3.45	16.35	59.63

Sridhar et al. [14] investigated the Mechanical Characterization of Polyurethane Foam and Hybrid Natural Fiber-Based sandwich Composite fabricated using vacuum bagging process. Polyurethane foam was used as a core with uniform thickness while varying the core density. Jute and glass fiber was used as the skin of the sandwich composite. The mechanical characterization of the specimens involves a tensile test, compression test, and three-point bending test were conducted on the sample according to ASTM standards using the universal testing machine. The results from the investigation revealed that the strength of natural fiber could be enhanced by partially combining it with synthetic fibers, and the mechanical properties of sandwich structures increase with the increase in the polyurethane foam density. The experimental results of sandwich composite were found to be given table 7.

Table7 :Experimental results of sandwich composite testing

Specimen	Compression strength (MPa)		Flexural strength (MPa)
	Flat wise	Edgewise	
Jute1	1.89	4.92	13.72
Jute2	2.4	6.9	19.54
Jute3	3.2	8.63	24.43
Glass1	2.14	7.92	27.28
Glass2	2.9	10.9	31.53
Glass3	3.7	13.73	39.41
Jute/Glass Hybrid1	2.4	13.87	23.65
Jute/Glass Hybrid2	3.1	19.14	30.58
Jute/Glass Hybrid3	3.8	23.43	38.23

Wangetal.[16]investigates the bending behaviors of three grid sandwich structures with wood facing and jute fabrics/epoxy composites cores. Three kinds of sandwich beams were prepared: cross, double-cross, and square sandwich structures (CSS, DCSS, and SSS), using spruce wood as face panels, KH-560 modified jute fabrics reinforced epoxy laminated composites (JFRELC) as cores. There were three steps to preparing a grid sandwich structure.

Step 1, the jute fabrics with the size of 33 cm × 27 cm were immersed in a 2 wt% silane coupling agent solution at room temperature ($22 \pm 2^\circ\text{C}$) for 60 min, and then they were dried at 80°C to a constant weight. In step2, two layers of modified fabrics were coated with the mixed resins, tiled between silicone cushions and placed in a drying oven. After curing for 1.5 h at 120°C , JFRELC was successfully prepared .A universal testing machine tested different types of tests like tensile, compressive, flexural properties, and in-plane shear response of raw and modified JFRELC. The flexural rigidity, shear rigidity ,shear modulus, and shear strength of SSS were $2.10 \times 10^8 \text{N}\cdot\text{mm}^2$, $1.97 \times 10^5 \text{N}$, and 143.94MPa , 0.948MPa , respectively, which were significantly better than that of DCSS and CSS.[16]

Thus, no clear picture exists about the investigation of sandwich composite made of expanded perlite/epoxy-based core and JFRP & CF as skin. Therefore, this study aimed to manufacture a sandwich structure made of JFRP & CF as skin and perlite as core and to investigate their mechanical properties.

Chapter 3 Materials and Methodology

3.1 Materials

The raw materials that were utilized for this investigation are described below.

3.1.1 Expanded Perlite

During this investigation, the core manufacturing was done using expanded perlite. It was a granular material produced by growing the volcanic rock perlite. Having low specific gravity, it provides excellent heat-insulating and sound-insulating qualities. The size of perlite, around (4-5.6) mm has a bulk density of $65\text{--}75 \text{ kg/m}^3$ ($0.065\text{--}0.075 \text{ g/cm}^3$) was selected. The perlite was collected from an online platform.



Figure 3: Expanded Perlite

3.1.2 Jute Fiber Mat

The two most common raw jute fiber mat types - White Jute and Tossa Jute- are available in Bangladesh. During this investigation, the Tossa jute fiber mat was selected for the preparation of skin because it is softer, silkier, and stronger than white Jute. Tossa Jute has a massive demand for industrial use and good sustainability in the climate. It is also known as the top-quality Jute from Bangladesh. Physical properties like mass per (150*150)square millimeters was 5.7 g.



Figure 4 : Jute Fiber Mat

3.1.3 Carbon Fiber Mat

Today's carbon fibers are nearly five times stronger than steel and three times lighter. These properties make carbon fiber extremely interesting for a range of industries, especially the automotive and aerospace industries. we collect it then measuring it .In every skin we use 3 layer from this 2 layer from jute fiber and 1 from Carbon fiber .Physical properties like mass per (150x150) square millimeters was 6.25 gm.

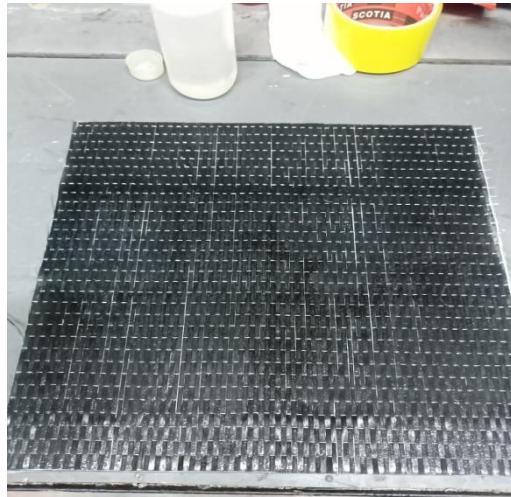


Figure 5 : Carbon Fiber Mat

3.1.4 Epoxy Resin and Hardener

10:1 Epoxy resin hardener was chosen for core preparation. The epoxy resin-hardener mixer density was 10:1 for skin and 10:1 for core, and the curing time was 24 hours for both.

For the curing of sandwich composite, the compression molding technique was followed.



(a)

Figure 6: (a)Epoxy resin and hardener (10:1)



(b)

(b)Epoxy resin-hardener(10:1)

3.1.5 Acetone

Acetone is a clear, colorless liquid. It is a solvent that can dissolve or break down other materials. It evaporates quickly into the air. we used it for decrease density of resin and hardener mixer .we used 5gm acetone for 2.0 compaction,7gm for 2.5 compaction and 8gm for 3.0 compaction in every mixer.



Figure 7: Acetone Bottle

3.2 Specimen Preparation

The preparation of the sandwich structure composites was carried out in three different steps as follows(a) Core preparation, (b)Skin preparation and(c) Sandwich structure fabrication

3.2.1 Core Preparation

The core was prepared using the following methods.

In step 1: The epoxy-hardener solution was prepared in the ratio of 10:1 by weight percentage in a container.

Step 2:Then, the expanded perlite was poured into the container and mixed it properly so that the perlite could wet properly with epoxy-hardener.

Step3: Then the wetted perlite was sucked with a filter from the container and placed into the mold. Before placing the wetted perlite into the mold, plastic paper was used on the lower parts and walls of the mold for easy removal of the prepared core.

Step4:After placing the wetted perlite in proper quantity (129-6g,162g,194-4g),the puncher was placed over the wetted perlite with a sufficient weight so that the curing process cloud occurred under compressive stress for good bonding & high density of the material. The core thickness was maintained at around 15mm for all compaction ratio.

Step5:The compression process was maintained on the core for 24hours for better curing and then extracted the prepared core from the mold. The sample calculation was as follows to estimate the perlite required,

Epoxy-Perlite mixing ratio(1:2)

The Weight of $v = 200\text{ml}$ perlite was , $w = 16\text{g}$

According to the formula $\rho = w/v$

The Density of perlite $\rho = 0.08\text{g/ml}$

$$\begin{aligned} \text{Finite Volume required of the core} &= \{\text{length}(15\text{cm}) * \text{width}(15\text{cm}) * \text{Thickness}(1.8\text{cm})\} \\ &= 405\text{cm}^3 \end{aligned}$$

1.Compaction ratio=2

$$\begin{aligned} \text{Required Perlite Mass} &= (2 * 405 * \rho)\text{g} \\ &= 64.8 \text{ g} \end{aligned}$$

I. Compaction ratio=2.5

$$\begin{aligned} \text{Required Perlite Mass} &= (2.5 * 405 * \rho)\text{g} \\ &= 81 \text{ g} \end{aligned}$$

II. Compaction ratio=3

$$\begin{aligned} \text{Required Perlite Mass} &= (3 * 405 * \rho)\text{g} \\ &= 97.2\text{g} \end{aligned}$$



(a) Constructed Mold



(b) Pouring perlite mixture inside the mold



(c) Prepared core

Figure 8: (a) Constructed mold and (b) and (c) core preparation process

3.2.2 Skin Preparation

After preparing the core, skin of the sandwich structure composites was prepared in the hand lay-up method in the following manner,

In step1: A plastic paper was placed on the bottom part to easily extract the prepare skin and then prepare the epoxy-hardener solution in a ratio of 10:1 by weight percentage.

Step2: After preparing the epoxy-hardener solution, It was poured on the paper and rolled it with a paint roller.

Step 3: Then a size of (150*150) mm²Carbon fiber mat was placed over this epoxy-hardener layer and rolled it with a roller for removing bubbles from it. After that again the epoxy-hardener solution was applied top of the order.

Step4: Then a size of (150*150) mm² jute fiber mat was placed over this carbon fiber epoxy-hardener layer and rolled it with a roller for removing bubbles from it. In this way, the epoxy-hardener solution was applied by placing three successive layers in the same order, one on top of the other. The three-tiered mat was covered with plastic sheeting and re- rolled with a roller so that maximum air could escape from inside.

Step 4: After placing plastic paper, the top of the mold kepted it on UTM Machine and give pressure on it then it remove from there and was placed on top of the plastic for 24hours.

Step5:After 24hours, the skin was removed from the mold. And subsequent skins were created in exactly the same way. The sample calculation is as follows,

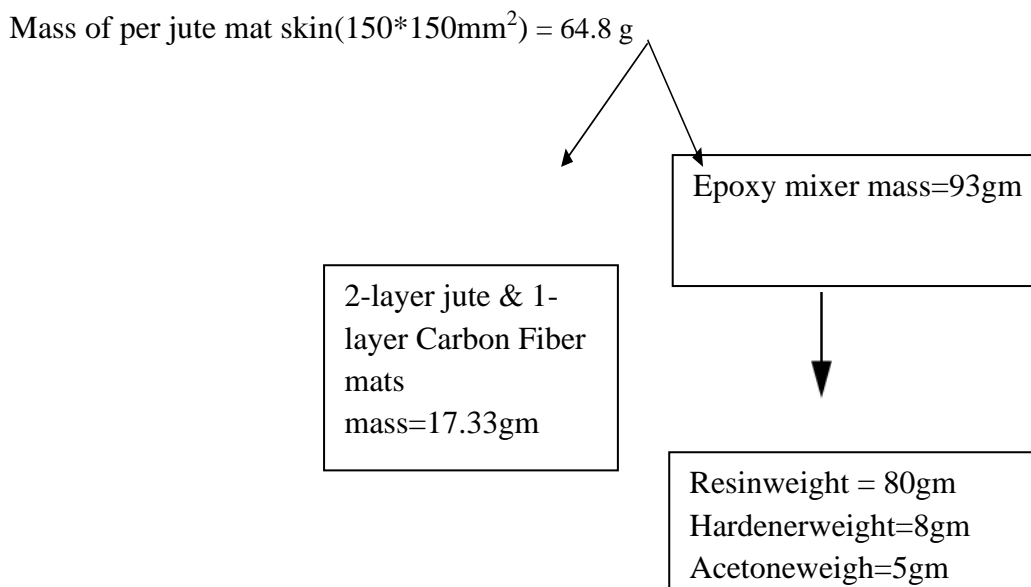


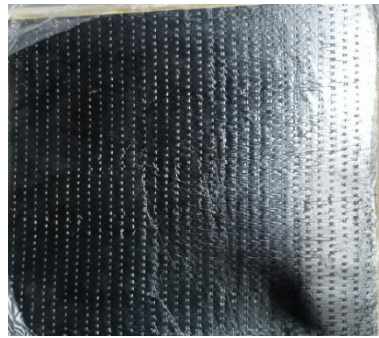
Figure 9:Line graphs showing sample calculation for skin preparation



(a)



(b)



(c)

Figure 10 (a), (b) Preparation of skin by hand lay-up process and (c) prepared JFRP&CF skin in dimension of $(15*15) \text{ cm}^2$

3.2.3 Sandwich Composite Fabrication

After preparing the skin and core individually the sandwich composite of expanded perlite/epoxy-based core and JFRP & CF as the skin was prepared in the following steps.

In step1:A plastic paper was placed on top of the bottom surface of the mold so that the fabricated sandwich composites could not be attached to the surface of the mold.

Step 2: After placing the plastic, adhesive was added to the skin of JFRP& CF with a roller.

Step3:Then, the skin was placed inside the mold and the core on it.

Step 4: In addition, adhesive was applied to both sides of the core and skin. After that, the upper skin was placed on this core and it was kept compressed for 24 hours.

Step 5:Then the fabricated sandwich composites were remove from the mold



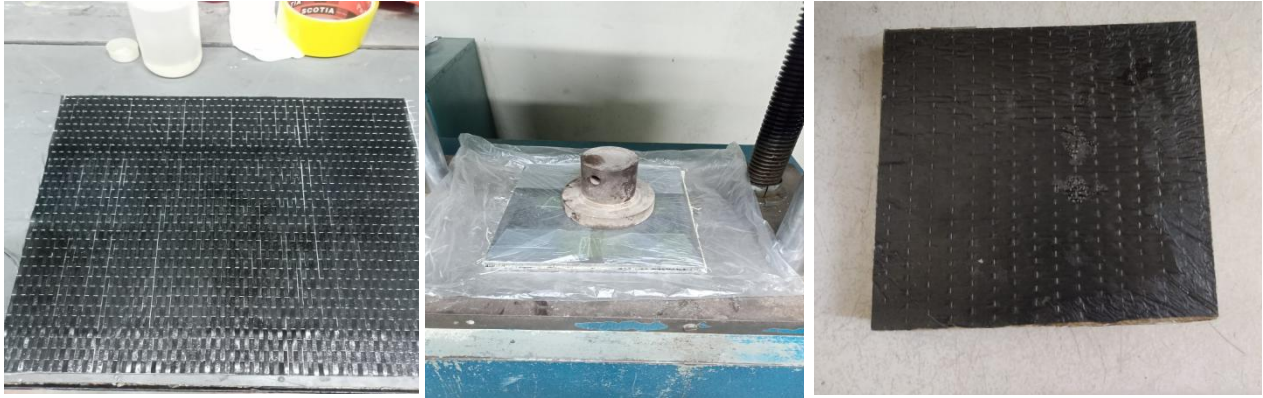
(a) Adding adhesive to the skin



(b) Placing the skin into the mold



(c) Placing the core up on the lower skin



(d)Placing the upper skin

(e)Compression process

(f)Fabricated Sandwich Composites

Figure11 : (a)-(e) Fabrication process of sandwich composite and (f) fabricated sandwich composite

3.3 Physical and Mechanical Tests

3.3.1 Flexural test

The ASTM C393 test method was used to determine the flexural properties (flexural strength and modulus) of the sandwich structure. The equation for calculating flexural strength,

$$F_s = \frac{P_{max}}{(d + c)b}$$

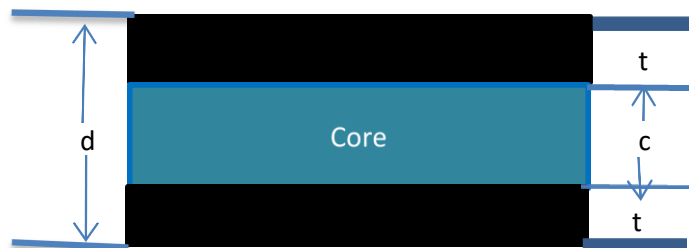


Fig 12: Sandwich Panel Dimension

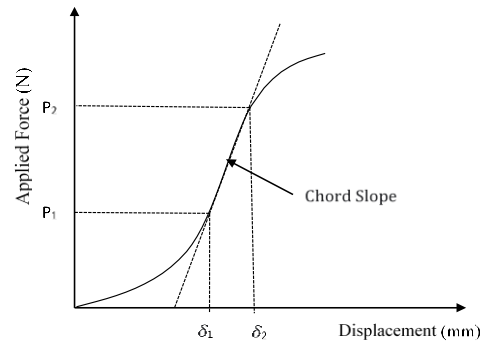


Figure13: Force-displacement curve

Where,

F_s =flexural strength MPa[psi]

P_{max} =Force facing prior to failure, (N)

t = nominal facing thickness, mm[in.]

d = sandwich thickness, mm [in.]

c = core thickness, mm[in.], ($c = d - 2t$)

b = Sandwich Panels width ,mm [in.].

Flexural modulus was calculated using the following equation,

$$E = \frac{P_2 - P_1}{\delta_2 - \delta_1}$$

Where,

E =flexural modulus,

P_2 = Application force corresponding to δ_2

P1= Application force corresponding to δ_1

δ_2 = Value of deflection corresponding to P2

δ_1 =Value of deflection corresponding to P1

Universal Testing Machine was used to perform these tests and the speed of testing was 5mm/min. Sandwich panels of dimension 150×150×22 mm from which samples for the flexural test were cut in 150×20×22 mm and there were at least three test specimens per test condition.

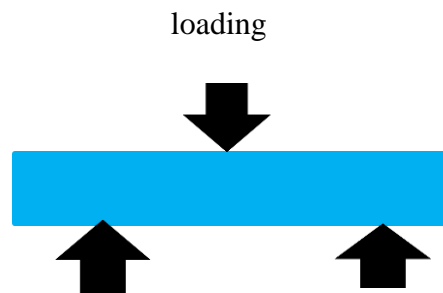


Figure14: Three-point mid-span loading configuration

3.3.2 Compression Test

The ASTM C365 test method was used to determine the flat wise compression properties (compressive strength and modulus) of the sandwich structure. Sandwich panels of dimension (150×150×22) mm³ from which samples for compression test were cut in (20×20×22) mm³ and there were at least four test specimens per test

condition. These tests were conducted using a Universal Testing Machine with a stroke speed of testing was 5 mm/min.

The equation for calculating compression strength,

$$FZ = \frac{P_{max}}{A}$$

Where,

F_z = Ultimate flat wise compressive strength, (MPa)

P_{max} = Ultimate force prior to failure, (N)

A = Cross sectional Area, (mm^2)

Flat wise compressive modulus was calculated using the

Following equation,

$$E = \frac{P_2 - P_1}{\delta_2 - \delta_1}$$

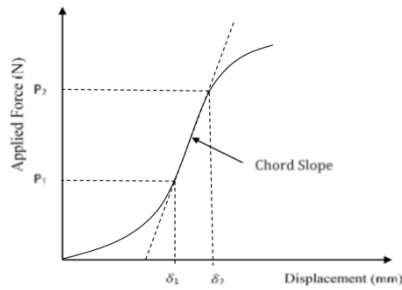


Figure 15 : Load Displacement curve

Where,

E = Flat wise compressive modulus

P_2 = Application force corresponding to δ_2

P_1 = Application force corresponding to δ_1

δ = Application force corresponding to P_2

δ_2 = Value of deflection corresponding to P_2

δ_1 = Value of deflection corresponding to P_1

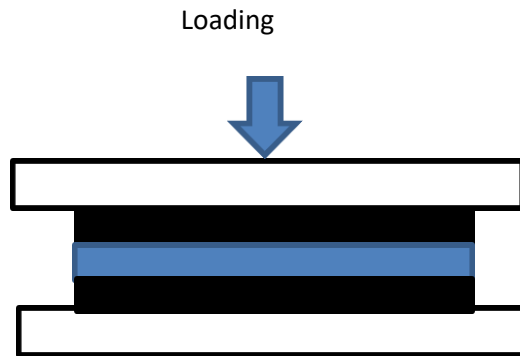


Figure16:Schematic diagram of flat wise compression test of the specimen

3.3.3 Rockwell Hardness Test:

Hardness number depends on The applied load, the shape of the indentation and the depth to which the indenter penetrates the specimen.

Rockwell B Scale : For softer materials ,a 1/16 inch diameter steel ball is used, the major load load and t is 90 kg and minor is 10kg (100 kg load in total) and the hardness is

$$\text{HRB} = 130 - \frac{d}{0.02}$$

Rockwell C Scale : For Harder materials ,a conical-shaped diamond of 120 apex angle is used, the major load is 140kg and minor load is 10kg (150 kg load in total) and the hardness is

$$\text{HRC} = 100 - \frac{d}{0.02}$$

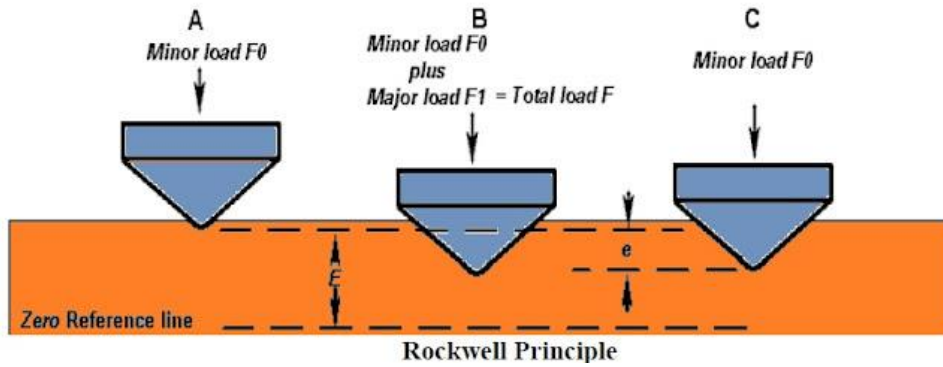


Figure 17: Rockwell Principle

3.3.4Skin Impact Test:

ASTM E23 standard test method for Notched Bar Impact Testing of materials. We can do Charpy Impact test and Izod Impact test by Impact Testing Machine. Specimen dimension for Charpy impact test is (55x10x10) mm and for Izod Impact test is (75x10x10) mm.

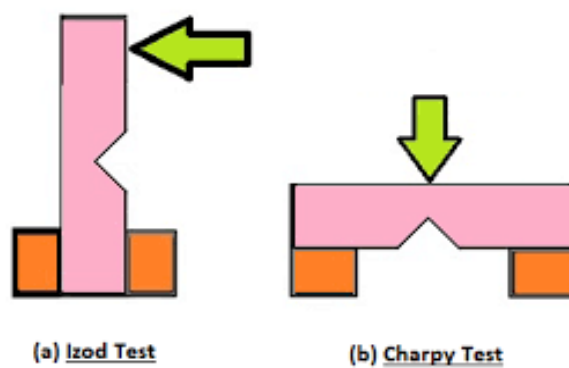


Figure 18 : (a) & (b) Schematic diagram of Izod and Charpy Specimen

Where,

Depth at notch = Specimen depth - depth of notch

Cross sectional area at notch = Depth of notch X Specimen width

Energy required to break the specimen = Absorbed Energy, E

Chapter 4 Results and Discussion

4.1 Physical Properties

Material characterization is the method of measuring and ascertaining the micro structural, physical, and mechanical properties of a material from which it is easy to find the causes of failure and problems related to the manufacturing process. Further, it helps the manufacturer to make critical materials decisions.

Table 8 : Experimental data for density calculation for flexural test specimens where 2.0 indicates the compaction ratio, F as flexural and(1) as specimen number.

Sample Code& Element Number	Length (mm)	Avg.	Width (mm)	Avg.	Thickn ess (mm)	Avg.	Mass (g)	Avg.	Volume (cm ³)	Densit y (g/cm ³)	Density (g/cm ³)
2.0 F-(1)	148.12	148.1	19.80	19.57	21.03	21.12	37.1	37.23	61.21	0.61	.61
	148.32		19.85		21.20		37.28				
	148.08		19.08		21.13		37.31				
2.0 F-(2)	148.16	148.21	19.32	19.67	22.05	22.16	40.1	40.05	64.6	0.62	
	148.08		19.81		22.14		40.21				
	148.41		19.88		22.29		39.85				
2.5 F-(1)	145.87	145.98	21.89	21.33	22.0	21.51	44.00	44.16	65.4	0.67	0.68
	146.02		20.64		21.05		44.2				
	146.06		21.64		21.50		44.3				
2.5 F-(2)	146.22	146.2	20.05	20.83	22.00	22.1	45.15	45.1	65.6	0.68	
	145.90		20.08		22.12		45.12				
	146.13		20.16		22.3		45.10				
3.0 F-(1)	149.60	149.68	21.64	21.4	21.85	21.99	53.30	53.3	70.4	0.75	
	149.87		21.65		21.78		53.20				
	149.62		21.07		22.35		53.40				
3.0 F-(2)	150.00	149.94	21.67	21.80	22.38	22.69	55.6	55.6	74.01	0.75	0.75
	150.12		21.74		22.90		55.76				
	149.70		21.80		22.80		55.54				

4.2 Flexural Properties

After conducting the three –point flexural test for sandwich composite on a universal testing machine at a speed of testing 5mm/min with a span length of 100 mm for the different compaction ratio of 2.0-3.0, flexural properties were calculated from the raw data produced during the test period

4.2.1 Flexural Strength and Modulus

Flexural strength and modulus as a function of core density for various compaction ratio (but without distinguishing particle sizes) are shown in table(9,10) and figure (19). As expected, they increased with increasing the sandwich core density (compaction ratio 2.0-3.0),

.The least-square lines for flexural strength-core density relationship were found to be from the graph: $y = x - 100x - 45.597$, $R^2 = 0.9982$ (Figure 19). Further, the nature of flexural modulus for various density of core was estimated and were found to be the least-square lines $y = 1411x + 377.3$, $R^2 = 0.867$ (Figure 20). It was also observed that as the core density was increased, the flexural strength and modulus was also increased (Figure 19,20) due to high density of the core, as expected.

Table 9 :Experimental data for density calculation for Compression test specimens where 2.0 ,2.5, 3.0 indicates the compaction ratio, C as Compression and(1)as specimen number.

Sample Code & Element Number	Length (mm)	Avg.	Width (mm)	Avg.	Thickness (mm)	Avg.	Mass (g)	Avg.	Volume (cm ³)	Density (g/cm ³)	Density (g/cm ³)
2.0 C(1)	19.60	19.80	20.25	20.24	22.25	22.24	5.6	5.6	8.91	0.63	0.6
	19.55		20.59		22.30		5.9				
	20.26		19.89		22.18		5.4				
2.0-C-(2)	20.30	20.34	20.34	20.4	22.39	22.51	5.3	5.3	9.34	0.57	0.6
	20.47		20.19		22.21		4.9				
	20.26		20.67		22.95		5.8				
2.5 C-(1)	20.34	20.18	20.34	20.21	22.17	22.09	6.1	6.26	9.009	0.69	0.68
	19.97		19.86		21.98		6.3				
	20.23		20.42		22.13		6.4				
2.5 C-(2)	20.45	20.58	20.12	20.12	23.07	22.81	6.6	6.5	9.44	0.68	0.68
	21.04		20.45		22.79		6.3				
	20.26		19.78		22.58		6.6				
3.0 C-(1)	20.50	20.23	20.34	20.43	23.25	22.92	7.1	7.1	9.47	0.75	0.75
	20.32		20.29		22.75		7.3				
	19.87		20.65		22.78		7.0				
3.0 C-(2)	20.36	20.47	20.75	20.39	23.25	23.14	7.1	7.2	9.66	0.74	0.75
	20.60		20.19		23.39		7.3				
	20.47		20.25		22.78		7.2				

Table10 : Flexural strength and modulus for the different specimens during the compression test. Where sample code & element number 2.0, 2.5, and 3.0 indicates compaction ratio and F for compression and (1) specimen number.

Sample code & Element Number	Flexural Strength (MPa)	Avg.(MPa)	Flexural Modulus (MPa)	Avg. (MPa)
2.0-F-(1)	15.30	15.23	1215.80	1215.86
2.0-F-(2)	15.16		1215.92	
2.5-F-(1)	22.67	22.75	1381.37	1381.67
2.5-F-(2)	22.83		1381.97	
3.0-F-(1)	29.27	29.23	1413.20	1413.43
3.0-F-(2)	29.19		1413.63	

Table11: Average Flexural strength and modulus fo sandwich composite with different compaction ratio.

Compaction Ratio	Flexural strength avg.(MPa)	Flexural Modulus avg. (MPa)
2.0 -F-(1&2)	15.23	1215.86
2.5-F-(1&2)	22.75	1381.67
3.0-F-(1 & 2)	29.23	1413.43

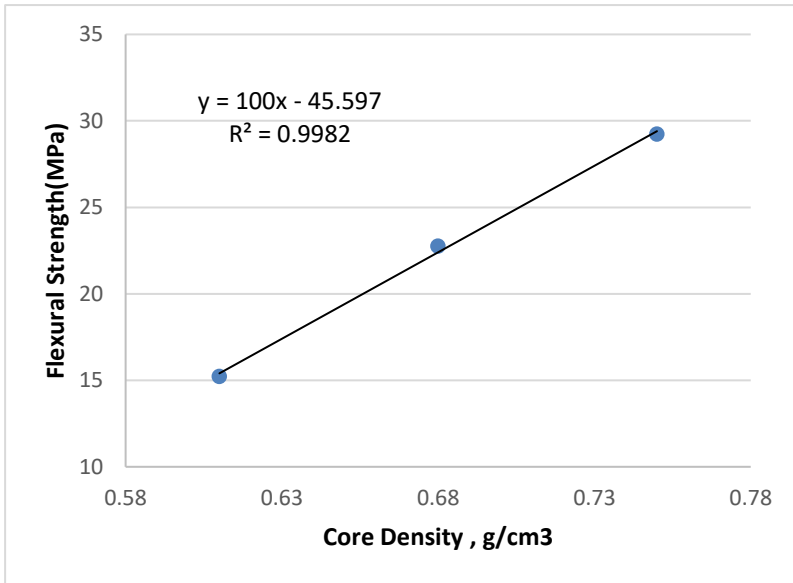


Figure 19 : Flexural strength versus core density curve

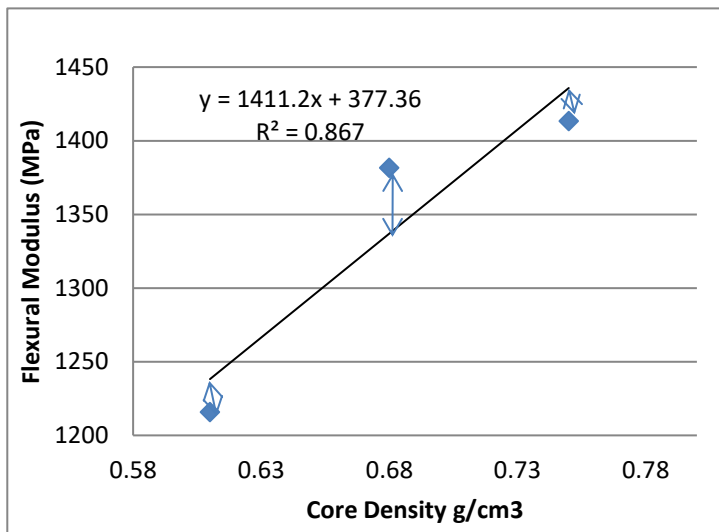


Figure 20 : Flexural Modulus versus Core Density Curve

4.3 Compressive Properties

After conducting the flat wise compression test for sandwich composite on a universal testing machine at a speed of testing 5mm/min with a sample size(20*20*22) mm³ compaction ratio ranges of 2.0-3.0, compression properties were calculated from the raw data produced during the test period.

4.3.1 Compressive Strength and Modulus

Compressive strength and modulus as a function of core density for various core density (but without distinguishing particle sizes) are given in table (21, 22). As expected, they increase with increasing the sandwich core density (compaction ratio 2.0-3.0), The least-square lines for compressive strength-core density relationship were found to be from the graph : $y = 45.57x - 24.83$ $R^2 = 0.998$ (Figure 21) and the nature of compressive modulus for various core density was estimated and were found to be the least-square lines $y = 1449.x - 584.8$, $R^2 = 0.0.804$ (Figure 22). As expected, it was observed that as the core density was increased, the flexural strength and modulus was also increased (Figure21,22)

Table 12 :Compressive strength and modulus for the different specimens during the compression test. Where sample code & element number 2.0, 2.5, and 3.0 indicates compaction ratio and C for compression and (1) specimen number.

Sample code & Element Number	Compressive Strength (MPa)	Avg.(MPa)	Compressive Modulus (MPa)	Avg. (MPa)
2.0-C-(1)	2.81	2.89	270.184	270.285
2.0-C-(2)	2.97		270.386	
2.5-C-(1)	6.29	6.31	458.22	458.44
2.5-C-(2)	6.34		458.66	
3.0-C-(1)	9.09	9.27	473.07	473.17
3.0-C-(2)	9.45		473.27	

Table 13: Average Compressive strength and modulus for sandwich composite with different compaction ratio.

Compaction Ratio	Compressive strength avg.(MPa)	Compressive Modulus avg.(MPa)
2.0 -C-(1&2)	2.89	270.285
2.5-C-(1&2)	6.31	458.44
3.0-C-(1&2)	9.27	473.17

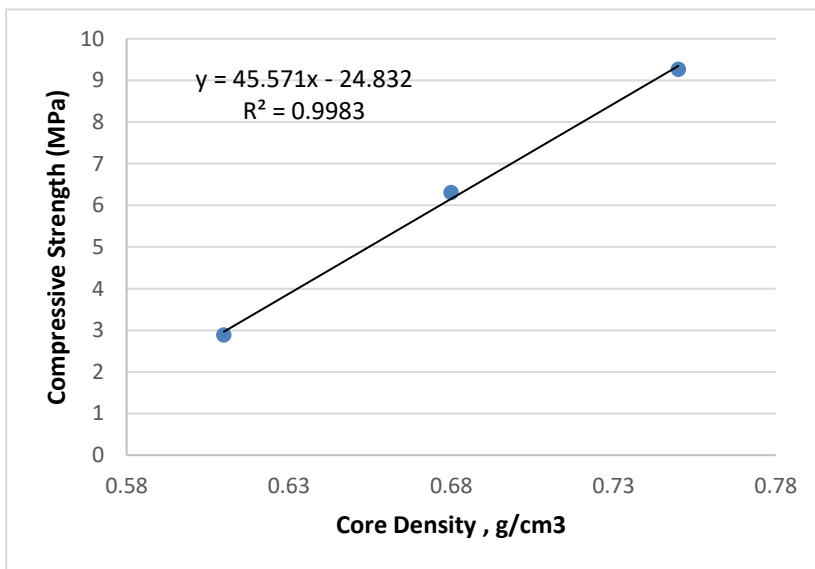


Figure 21: Compressive Strength Versus Core Density

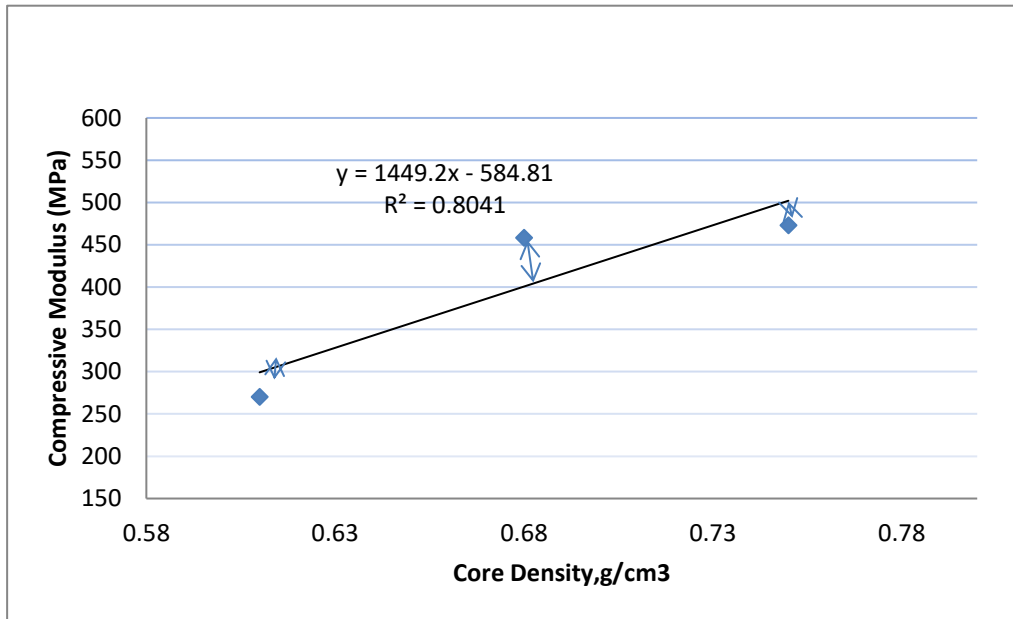


Figure 22 : Compressive Modulus versus core Density

4.3.2 Failure Behavior during Compressive test

Typical flexural load versus displacement with photographs (Figure 23, 24, and 25) captured from the testing videos show failure sequences for several specimen configurations with compaction ratio of 2.0, 2.5, and 3.0. In general, the curves appear to have similar characteristics, each displaying a linearly increasing part before the peak point, then a sudden drop due to core failure at the outer edge. The first peak indicates before the cracking of the core. After the peak load, the core material is started to de-bonding and lose in carrying the load. It was also observed that, as the core density was increased compressive strength of the sandwich composite was also increased (Figure 21) because of the high density of the core, as expected.



(a) Initial

(b) Start to de-bonding core

(c) Increasing de-bonding



(d) Final failure

Figure 23 : failure pattern of composite specimen (2.0-C-1)

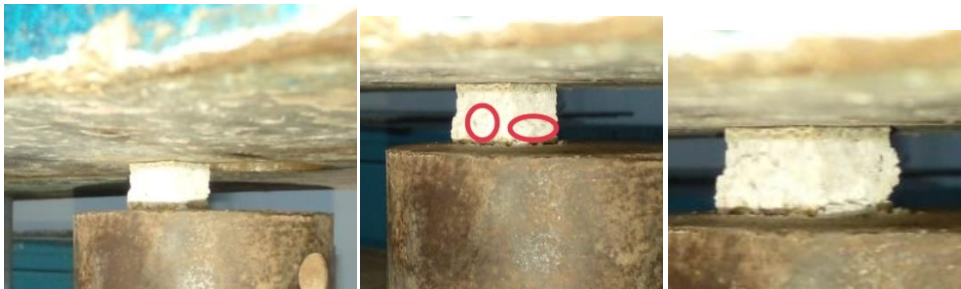


(a) Initial

(b) Start de-bonding core

(c) Final Failure

Figure 24 : failure pattern of composite specimen (2.5-C-1)



(a) Initial

(b) Start cracking core

(c) Final Failure

Figure 25 :failure pattern of composite specimen (3.0-C-1)

4.4 Rockwell hardness test :

The hardness test of materials by the Rockwell hardness test method is measured by the depth of penetration of the indenter. at first select the load by rotating the knob and fix the suitable indenter .clean the test-piece and place n the special anvil or work table of the machine .turn the capstan wheel to elevate the test specimen into contact with the indent point .further turn the wheel for three rotations forcing the test specimen against in indenter .This will ensure that the minor load of 10 kg has been applied .Set the pointer on the scale dial at the appropriate position .Push the leveler to apply the major load .A dash pot provided in the loading mechanism to ensure that the load is applied gradually. As soon as the pointer comes to rest pull the handle in the reverse direction slowly .This release the Major, But not minor load .The pointer will now rotate in the reverse direction .The Rockwell hardness can be read off the scale dial .on the appropriate scale ,after the pointer comes to rest



(a)

(b)

Figure 26 : (a) & (b) Rockwell hardness test

Table 14 : Data of Rockwell hardness test :

Test no.	scale	Material used	Indentor used	Load Applied/kg		RHN	Avg. RHN
				Minor	Major		
1	C	JFRP & CF Skin	Diamond	10	140	75	76
2	C			10	140	78	
3	C			10	140	75	

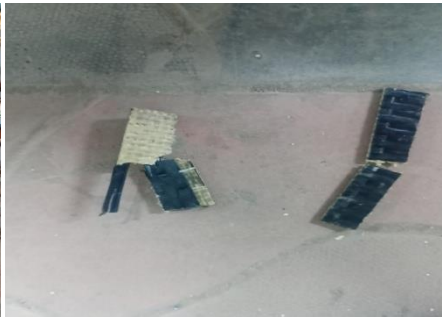
4.5 Skin Impact Testing :

Impact test is a test used in studying the toughness of materials. The definition of toughness is defined as the capacity of materials to absorb energy and deform plastically before fracturing. Toughness is associated with both ductility and strength of materials.

At First the dimensions of the unnotched length and the thickness of specimen are measured. Then pendulum is raised to the left unit it indicates the maximum energy range on the upper indicator unit. The specimen is placed horizontally across support with the notch away from the pendulum .then pendulum released. The indicated value from the indicator unit is recorded. Then brake is applied until the pendulum has returned to its stable hanging vertical position. At last specimen is removed from the testing area and failure surface is observed.



(a) Impact Testing Machine



(b) Condition After Testing

Figure 27 : Impact Testing Machine & Materials Condition after testing

Table 15: Data of impact test :

Materials	Energy absorbed for Charphy (J)	Average (J)	Energy absorbed for Izod (J)	Average (J)
JFRP & CF Skin	14.5	14.63	10.2	10.2
	14.6		10.6	
	14.8		10.0	

Chapter 5 Conclusion and Future Recommendations

5.1 Conclusion

Sandwich composites using expanded perlite/epoxy-based core and JFRP & CF as skin by varying the core density were fabricated. The manufactured composite's flexural and compressive properties were investigated along with the failure mechanism. The findings of the work can be summarized as -

- The flexural and compressive behavior of the sandwich structure is highly dependent on the core density.
- Crack initiated in the expanded perlite core of the sandwich structure during the flexural test and delamination is found to be the catastrophic failure.
- Some local indentation failure of the core was noticed due to skin distortion during the flexural test. Skin failure was noticed during Hardness and Skin Impact Test.
- The load-carrying capacity of the sandwich structure was increased about 1.5- 1.91 times for flexural and 2.35-3.20 times for compression due to a change in core density.
- Energy absorption during flexural test was decreased with increasing core density and it increased with increasing core density during compression test.

5.2 Future Recommendations

Further research could be done on these types of sandwich composites are,

- i. The skin's strength could be improved by adding some high-strength fiber mat, including glass, and Kevlar, instead of JFRP & CF..
- ii. Adding some high-strength constituent materials with the expanded perlite could enhance the stiffness and reduce the tendency of catastrophic failure of the core.
- iii. Better compaction and air removal techniques could be used to improve core density and reduce skin bubble formation.

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