

# **Experimental Investigation On Sandwich Composite Made of Expanded Perlite/Epoxy to Enhance Mechanical Property**



## **Name of the Student**

Md. Kamrul Hasan  
Abu Niem Mohammad  
Arafat Hossain  
Jannat Ara  
Fatema Tuj Jannat

DEPARTMENT OF MECHANICAL ENGINEERING  
SONARGAON UNIVERSITY (SU)  
DHAKA, BANGLADESH

SEPTEMBER 2023

# **Experimental Investigation On Sandwich Composite Made of Expanded Perlite/Epoxy to Enhance Mechanical Property**

## **NAME OF THE STUDENTS, ID & SESSION**

**BME-2001020242 MD KAMRUL HASAN**

**BME-2001020260 ABU NIEM MOHAMMAD**

**BME-2001020259 ARAFAT HOSSAIN**

**BME-2001020212 JANNAT ARA**

**BME-2001020222 FATEMA TUJ JANNAT**

A Graduation Exercise Submitted to the Department of Mechanical Engineering in  
Partial Fulfillment of the Requirements for the Degree of Bachelor of Science in  
Mechanical Engineering

DEPARTMENT OF MECHANICAL ENGINEERING  
SONARGAON UNIVERSITY (SU)  
DHAKA, BANGLADESH

SEPTEMBER 2023

## **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. Kamrul Hasan (BME-2001020242), Abu Niem Mohammad (BME-2001020260), Arafat Hossain (BME-2001020259), Jannat Ara (BME-2001020212) Fatema Tuj Jannat (BME-2001020222) has been accepted as partial fulfillment of the requirement for the degree of bachelor of science in mechanical engineering on September 2023.

---

Prof. Md Mostofa Hossain  
Supervisor & Head in Mechanical Engineering  
Sonargaon University (SU), Dhaka-1215,  
Bangladesh

## 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.

---

Md. Kamrul Hasan

---

Abu Niem Mohammad

---

Arafat Hossain

---

Jannat Ara

---

Fatema Tuj Jannat

## **ACKNOWLEDGEMENT**

First and above all, we praise the Almighty Allah for providing us the opportunity, patience and allocating us the capability of completing the thesis for the degree of Bachelor of Science in Mechanical Engineering.

It is a great pleasure to acknowledge our profound gratitude and respect to our supervisor **Prof. Md Mostofa Hossain**, Head in Mechanical Engineering and all respected teachers in Sonargaon University for their continuous help and support in all stages of this thesis for their consistent guidance, encouragement, helpful suggestion, constructive criticism and endless patience through the progress of this work. The successful completion of this thesis would not have been possible without their persistent motivation and continuous guidance.

We would like to express cordial thanks to our loving parents, friends and well-wishers for their cooperation, during the course of this study. cheerfulness and inspiration.

[Authors]

Md Kamrul Hasan  
Abu Niem Mohammad  
Arafat Hossain  
Jannat Ara  
Fatema Tuj Jannat

## **ABSTRACT**

The abstract for an experimental investigation on a sandwich composite made of Expanded Perlite/Epoxy based core with JERP (Jute-Epoxy Reinforced Polymer) and CF (Carbon Fiber) as skin can be summarized. This study presents an experimental investigation into the mechanical properties and performance of a sandwich composite structure composed of an Expanded Perlite/Epoxy based core sandwiched between JERP and CF skins. The objective was to evaluate the feasibility of utilizing these materials for lightweight structural applications. A comprehensive series of tests, including tensile, flexural, and impact tests, were conducted to assess the mechanical behavior of the composite. The results revealed promising mechanical properties, with the composite demonstrating excellent strength-to-weight ratios. Additionally, the influence of different core thicknesses and skin configurations on performance was analyzed. The findings provide valuable insights into the potential use of this composite in aerospace, automotive, and other industries requiring lightweight and high-strength materials.

# Contents

|                           | <b>Page no.</b>                      |    |
|---------------------------|--------------------------------------|----|
| Certification of approval | iii                                  |    |
| Declaration               | iv                                   |    |
| Acknowledgment            | v                                    |    |
| Abstract                  | vi                                   |    |
| <b>CHAPTER I</b>          | <b>INTRODUCTION</b>                  | 1  |
|                           | 1.1 Overview                         | 1  |
|                           | 1.2 Objectives                       | 1  |
| <b>CHAPTER II</b>         | <b>LITERATURE REVIEW</b>             | 2  |
|                           | 2.1 Sandwich Composite               | 2  |
|                           | 2.2 Constituent Materials            | 2  |
|                           | 2.2.1 Expanded Perlite               | 2  |
|                           | 2.2.2 Jute Fiber                     | 4  |
|                           | 2.2.3 Carbon Fiber                   | 5  |
|                           | 2.2.4 Epoxy Resin and Hardener       | 6  |
|                           | 2.2.5 Acetone                        | 8  |
|                           | 2.3 Related Previous Work            | 9  |
| <b>CHAPTER III</b>        | <b>MATERIALS AND METHODOLOGY</b>     | 12 |
|                           | 3.1 Materials                        | 12 |
|                           | 3.1.1 Expanded Perlite               | 12 |
|                           | 3.1.2 Jute Fiber Mat                 | 13 |
|                           | 3.1.3 Carbon Fiber Mat               | 13 |
|                           | 3.1.4 Epoxy Resin and Hardener       | 14 |
|                           | 3.1.5 Acetone                        | 15 |
|                           | 3.2 Specimen Preparation             | 15 |
|                           | 3.2.1 Core Preparation               | 15 |
|                           | 3.2.2 Skin Preparation               | 17 |
|                           | 3.2.3 Sandwich Composite Fabrication | 19 |
|                           | 3.3 Physical and Mechanical Test     | 21 |
|                           | 3.3.1 Flexural Test                  | 21 |
|                           | 3.3.2 Compression Test               | 23 |
|                           | 3.3.3 Rockwell Hardness Test         | 25 |
|                           | 3.3.4 Impact Test                    | 26 |

|                   |  |    |
|-------------------|--|----|
| <b>CHAPTER IV</b> | <b>RESULTS AND DISCUSSION</b>                  | 26 |
|                   | 4.1 Physical Properties                        | 27 |
|                   | 4.2 Flexural Properties                        | 27 |
|                   | 4.2.1 Flexural Strength and Modulus            | 29 |
|                   | 4.3 Compressive Properties                     | 33 |
|                   | 4.3.1 Compressive Strength and Modulus         | 33 |
|                   | 4.3.2 Failure Behavior during Compression test | 35 |
|                   | 4.4 Hardness Test of Skin                      | 37 |
|                   | 4.5 Hardness Test of Block                     | 38 |
|                   | 4.6 Banding Test of Skin                       | 39 |
|                   | 4.7 Banding Test of Block                      | 40 |
|                   | 4.8 Test Report                                | 41 |
|                   | 4.9 Skin Impact Test                           | 42 |
| <b>CHAPTER V</b>  | <b>CONCLUSION AND FUTURE RECOMMENDATION</b>    |    |
|                   | 5.1 Conclusion                                 | 43 |
|                   | 5.2 Recommendations                            | 44 |
|                   | <b>REFERENCES</b>                              | 45 |



## TABLE OF CONTENTS

### List of Tables

| <b>Table No.</b> | <b>Table Name</b>  | <b>Page No.</b> |
|------------------|--|-----------------|
| Table 1          | The chemical composition of perlite  | 03              |
| Table 2          | Chemical constituents of jute fiber  | 04              |
| Table 3          | Physico-mechanical properties of jute fiber  | 04              |
| Table 4          | Carbon Fiber Materials Properties  | 06              |
| Table 5          | General Properties of Acetone  | 08              |
| Table 6          | Mechanical properties of jute core sandwich nanocomposites.  | 10              |
| Table 7          | Experimental results of sandwich composite testing   | 11              |
| Table 8          | Experimental data for density calculation for flexural test specimens where 2.0,2.5,3.0 indicates the compaction ratio, F as flexural and (1) as specimen number.  | 28              |
| 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 (1,2,3) as specimen number.  | 30              |
| Table10          | Flexural strength and modulus for the different specimens during the flexural test. Where sample code & element number 2.0, 2.5,and 3.0 indicates compaction ratio and F for flexural and (1) specimen number.           | 31              |
| Table 11         | Average Flexural strength and modulus for sandwich composite with different compaction ratio of the core.  | 31              |
| 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. | 33              |
| Table13          | Average Compressive strength and modulus for sandwich composite with differen compaction ratio.  | 34              |
| Table14          | Data of Rockwell Skin Test.  | 37              |
| Table 15         | Rockwell Block hardness test.  | 38              |
| Table 16         | Data of Block Banding Test.  | 40              |
| Table 17         | Data of impact test  | 42              |

## List of Figure

| <b>Figure No.</b>   | <b>Figure Name</b>  | <b>Page No.</b> |
|---------------------|---|-----------------|
| Figure 1            | The formation of the sandwich structure   | 2               |
| Figure 2            | Classification of epoxy-resin   | 7               |
| Figure 3            | Expanded Perlite  | 13              |
| Figure 4            | Jute Fiber Mat  | 13              |
| Figure 5            | Carbone Fiber Mat   | 14              |
| Figure 6            | (a) (10:1) Epoxy Resin and hardener and (b)Epoxy resin-hardener (10:1)  | 14              |
| Figure 7            | Acetone in bottle   | 15              |
| Figure 8<br>process | (a)Schematic view of the mold and(b),(c)and(d)core preparation  | 17              |
| Figure 9            | Line graph showing sample calculation for skin preparation  | 18              |
| Figure 10           | (a),(b) Preparation of skin by hand lay –up process and (c) Prepared JFRP & CF skin in dimension of (15*15) cm <sup>2</sup> | 19              |
| Figure 11           | (a) (e) Fabrication process of Sandwich composite and (f) Fabricated  | 20              |
| Figure 12           | Sandwich Panel Dimension  | 21              |
| Figure 13           | Force Displacement curve  | 22              |
| Figure 14           | Three –Point mid-span loading configuration   | 23              |
| Figure 15           | Load Displacement curve   | 24              |
| Figure 16           | Schematic diagram of flat wise compression test of the specimen   | 25              |
| Figure 17           | Rockwell Principle Diagram  | 26              |
| Figure 18           | (a) & (b) Schematic Diagram of Izod and Charphy Specimen  | 26              |
| Figure 19           | Flexural Strength versus Core density Curve   | 32              |
| Figure 20           | Flexural Modulus versus Core density Curve  | 32              |

|           |   |    |
|-----------|---|----|
| Figure 21 | Compressive Strength versus Core density Curve  | 34 |
| Figure 22 | Compressive Modulus versus Core density Curve   | 35 |
| Figure 23 | Failure pattern of a Sandwich Composite Specimen (2.0-C- 1&2)<br>Subjected to Compression Loading | 35 |
| Figure 24 | Failure pattern of a Sandwich Composite Specimen (2.5-C- 1&2)<br>Subjected to Compression Loading | 36 |
| Figure 25 | Failure pattern of a Sandwich Composite Specimen (3.0-C- 1&2)<br>Subjected to Compression Loading | 36 |
| Figure 26 | (a) & ( b) Rockwell Skin Hardness test  | 37 |
| Figure 27 | Rockwell Block Hardness test  | 38 |
| Figure 28 | Skining Banding Test  | 39 |
| Figure 29 | Block of Banding Test   | 40 |
| Figure 30 | Impact Testing Machine & Materials Condition after Testing  | 42 |

# 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 withstand heavy loads, and consist 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 evoke much 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 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]

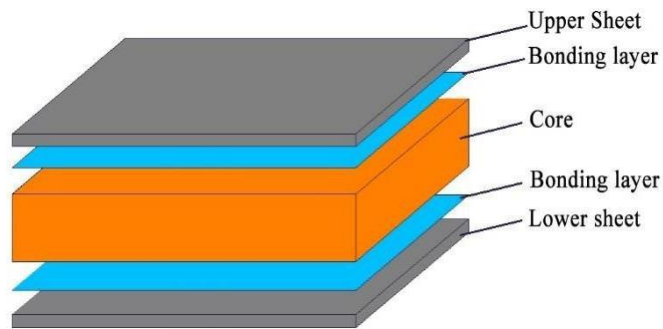


Figure:1 The formation of the sandwich structure

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 <sub>2</sub>               | 70-75%     |
| Al <sub>2</sub> O <sub>3</sub> | 12-15%     |
| Na <sub>2</sub> O              | 3-4%       |
| K <sub>2</sub> O               | 3-5%       |
| Fe <sub>2</sub> O <sub>3</sub> | 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/m<sup>3</sup>.
- 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 <sup>3</sup> ) | 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 $\mu$ 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 <sup>3</sup> )                          | 1.79 |
| Strength- to-weight ratio<br>(MPa/g/cm <sup>3</sup> ) | 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 24hours.The chemical formula of epoxy resin is C<sub>21</sub>H<sub>25</sub>ClO<sub>5</sub>. 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]

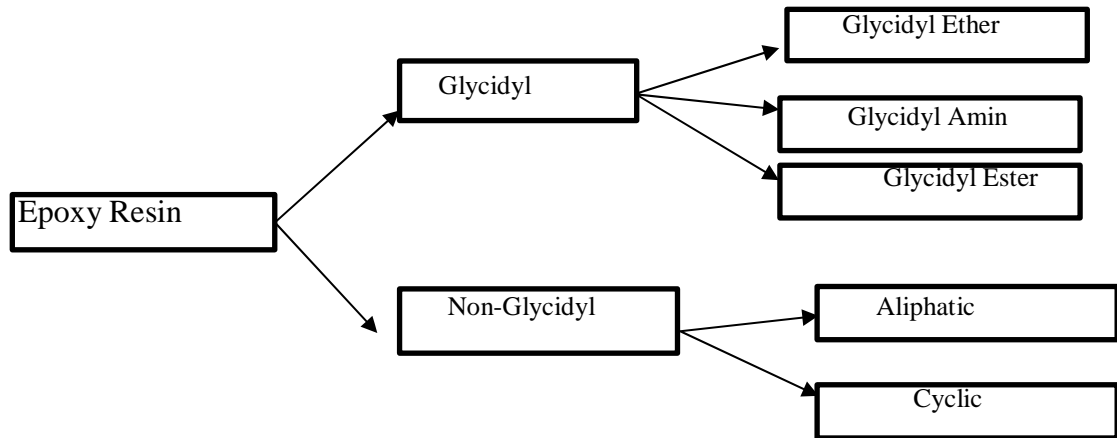


Figure 2:Classification of epoxy-resin

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 – C<sub>3</sub>H<sub>6</sub>O

|                              |                         |
|------------------------------|-------------------------|
| Molecular Weight/ Molar Mass | 58.08 g/mol             |
| Density                      | 0.784 g/cm <sup>3</sup> |
| 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/m<sup>3</sup>. Compression and single edge notch bend and shear tests were conducted on the prepared sandwich panels. On samples whose density was 200 kg/m<sup>3</sup>, 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 <sup>2</sup> ) |
|-------------|---------------------------|-----------------------------|---------------------------|-----------------------|--------------------------------------|
| 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.

❖ Table 7 :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  $80^\circ\text{C}$  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  $120^\circ\text{C}$ , 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  $143.94 \text{MPa}$ ,  $0.948 \text{MPa}$ , 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 65–75  $\text{kg}/\text{m}^3$  ( $0.065\text{--}0.075 \text{ g}/\text{cm}^3$ ) 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.

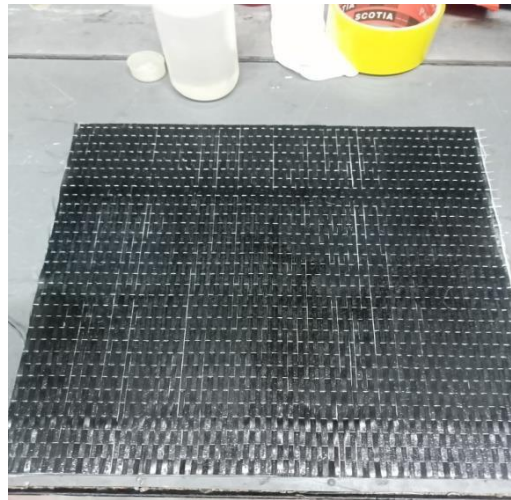


Figure 4 : Jute Fiber Mat

### 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.





### 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)



(b)

Figure 6: (a)Epoxy resin and hardener (10:1) (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  $\rho = 0.08\text{g/ml}$

Finite Volume required of the core = {length(15cm)\*width(15cm)\*Thickness (1.8cm)}

$$= 405\text{cm}^3$$

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

$$\text{Required Perlite Mass} = (3 * 405 * \rho)\text{g}$$

$$= 97.2\text{g}$$



(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) mm<sup>2</sup>Carbon 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) mm<sup>2</sup> 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 kept 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,

$$\text{Mass of per jute mat skin}(150*150\text{mm}^2) = 64.8 \text{ g}$$

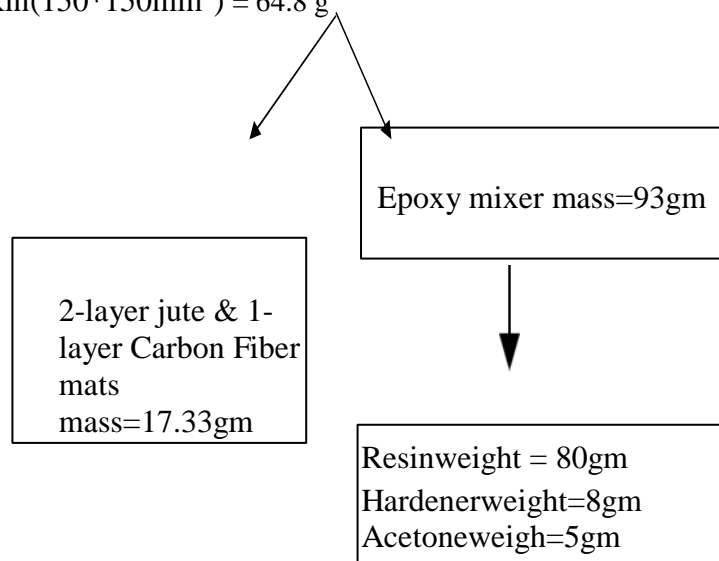


Figure 9:Line graphs showing sample calculation for skin preparation

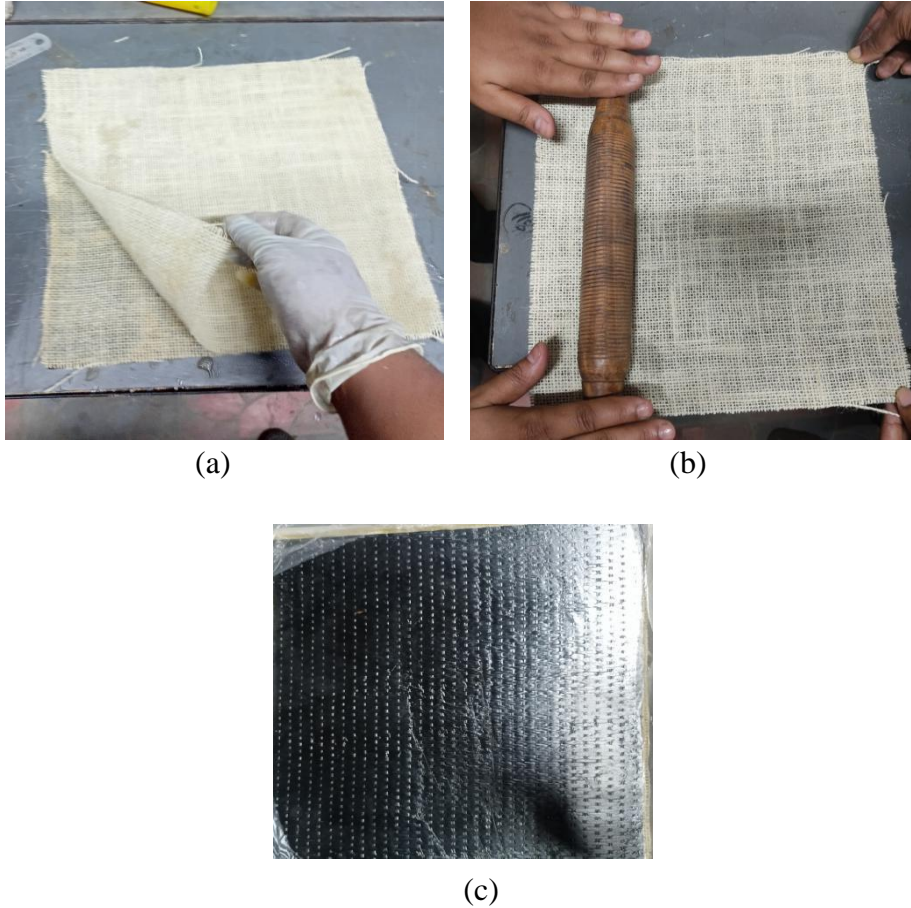


Figure 10 (a), (b) Preparation of skin by hand lay-up process and  
(c) prepared JFRP&CF skin in dimension of  $(15*15) \text{ cm}^2$

### 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,

$$F_s = \frac{Pm \cdot x}{(b + \frac{1}{2} \cdot \frac{Pm \cdot x}{E_s})}$$

**Fig 12: Sandwich Panel Dimension**



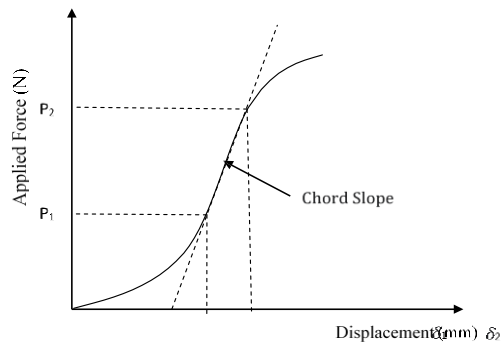


Figure13: Force-displacement curve

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  $\delta_2$

$P_1$  = Application force corresponding to  $\delta_1$   
 $\delta_2$  = Value of deflection corresponding to  $P_2$   
 $\delta_1$  = Value of deflection corresponding to  $P_1$

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.

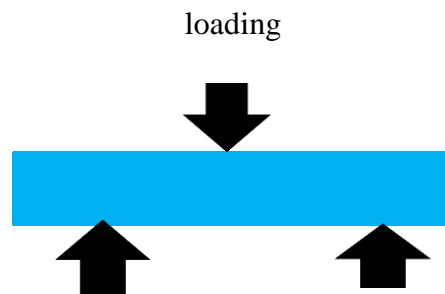


Figure14: Three-point mid-span loading configuration

### 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) mm<sup>3</sup> from which samples for compression test were cut in (20×20×22) mm<sup>3</sup> 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,

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

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,

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

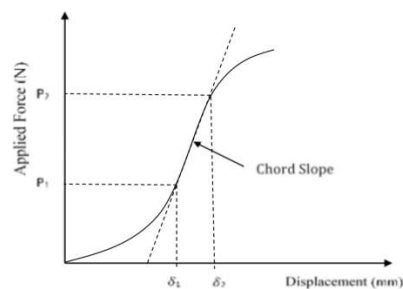


Figure 15 : Load Displacement curve

Where,

$E$  = Flat wise compressive modulus

$P_2$  = Application force corresponding to  $\delta_2$

$P_1$  = Application force corresponding to  $\delta_1$

$\delta$  = Application force corresponding to  $\delta$

$\delta_2$  = Value of deflection corresponding to  $P_2$

$\delta_1$  = Value of deflection corresponding to  $P_1$

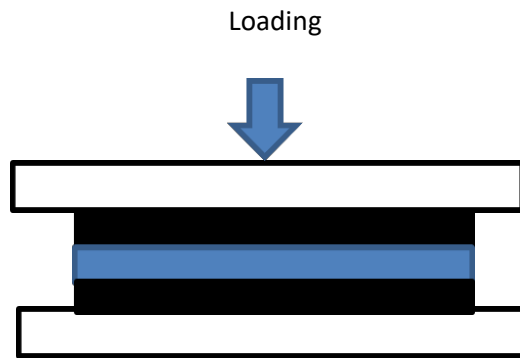


Figure16:Schematic diagram of flat wise compression test of the specimen

### 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 and t is 90 kg and minor is 10kg ( 100 kg load in total) and the hardness is

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

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

$$HRC = 130 - \frac{d}{0.02}$$

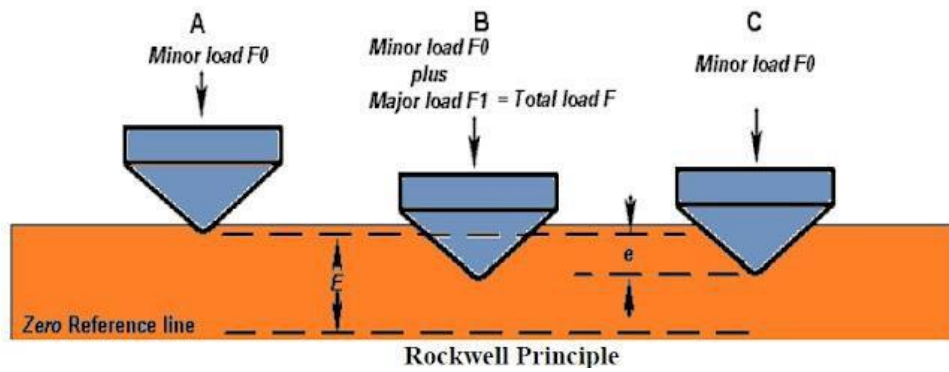


Figure 17: Rockwell Principle

### 3.3.4 Skin 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.

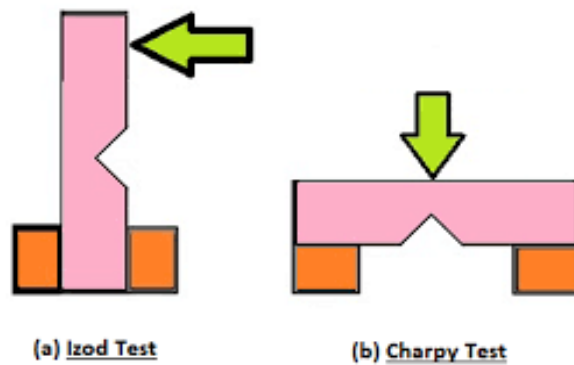


Figure 18 : (a) & (b) Schematic diagram of Izod and Charpy Specimen

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.  | Thickness (mm) | Avg.  | Mass (g) | Avg.  | Volume (cm <sup>3</sup> ) | Density (g/cm <sup>3</sup> ) | Density (g/cm <sup>3</sup> ) |
|-----------------------------|-------------|--------|------------|-------|----------------|-------|----------|-------|---------------------------|------------------------------|------------------------------|
| 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 <sup>3</sup> ) | Density (g/cm <sup>3</sup> ) | Density (g/cm <sup>3</sup> ) |
|------------------------------|-------------|-------|------------|-------|----------------|-------|----------|------|---------------------------|------------------------------|------------------------------|
| 2.0 C(1)                     | 19.60       | 19.80 | 20.25      | 20.24 | 22.25          | 22.24 | 5.6      | 5.6  | 8.91                      | 0.63                         |                              |
|                              | 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                         |                              |
|                              | 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                         |                              |
|                              | 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 of 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                     |

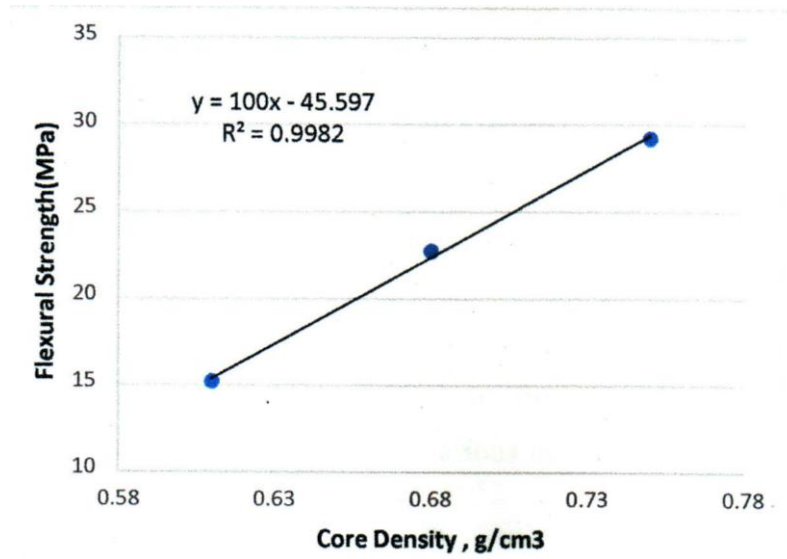


Figure 19: Flexural strength versus core density curve

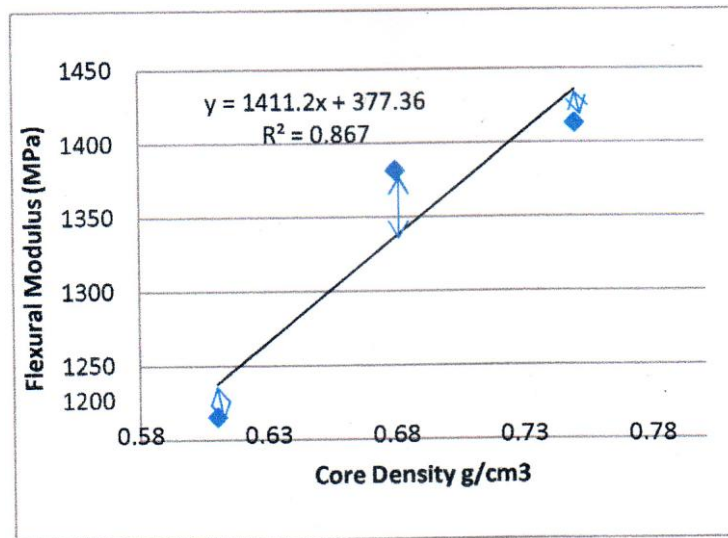


Figure 20 : Flexural Modulus versus Core Density Curve

### 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) mm<sup>3</sup> 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                        |

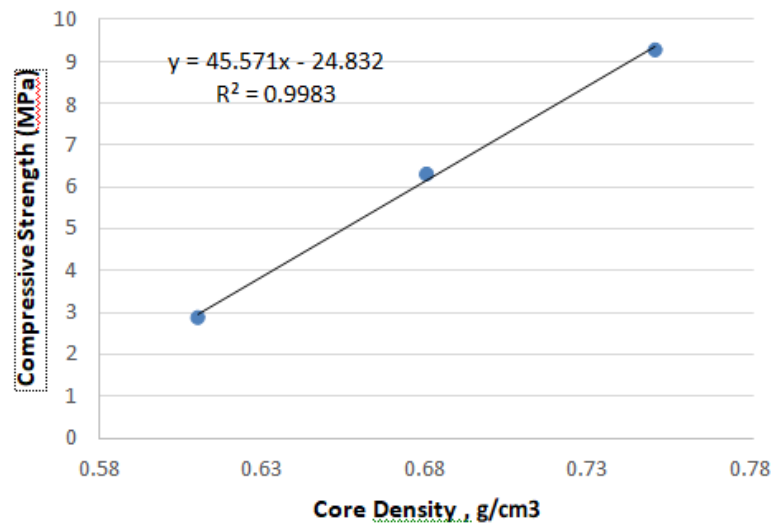


Figure 21: Compressive Strength Versus Core Density

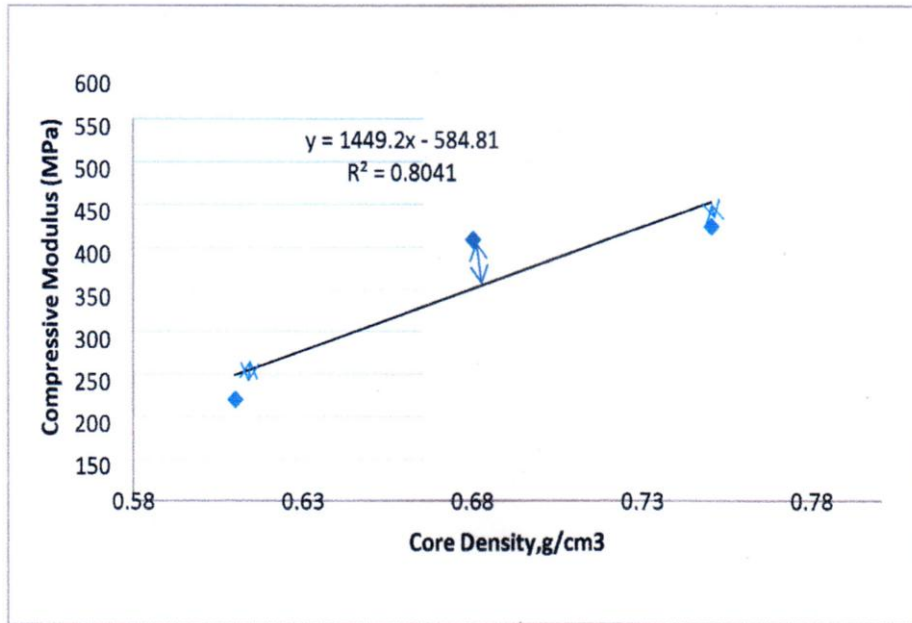
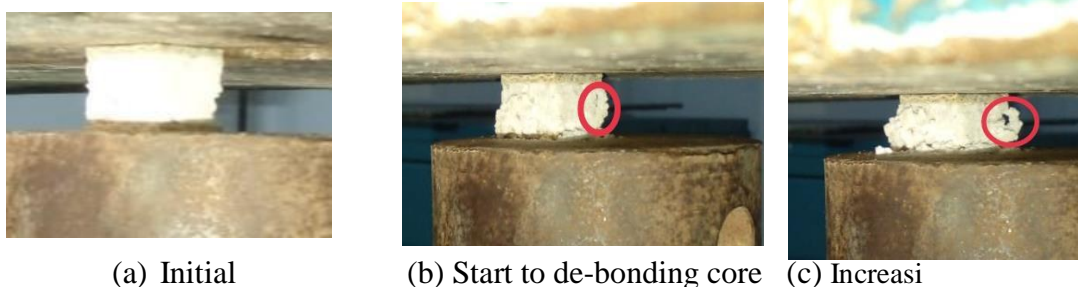


Figure 22 : Compressive Modulus versus core Density

#### 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.





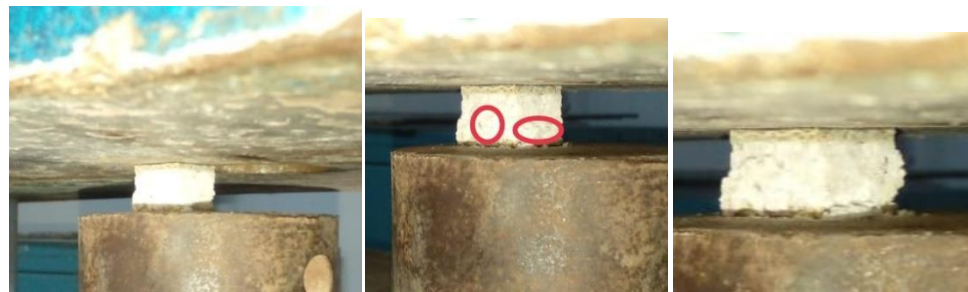
(d) Final failure

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

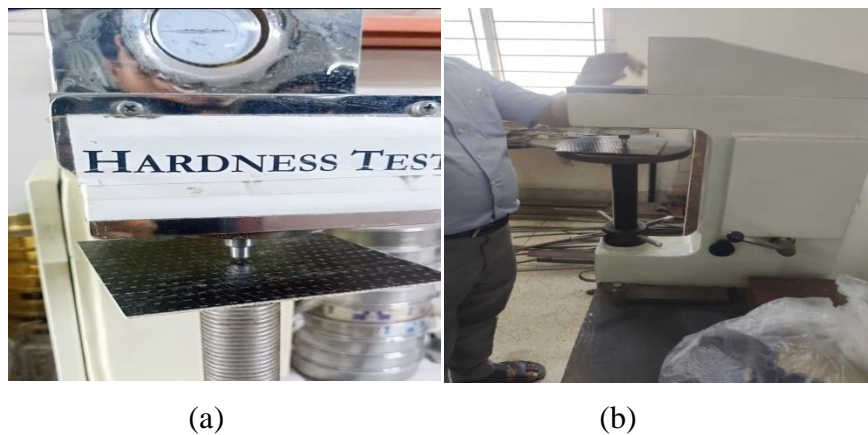


Figure 26 : (a) & (b) Rockwell Skin hardness test

Table 14 : Data of Rockwell Skin hardness test :

| Test no. | scale | Material used  | Indentor used              | Load Applied/kg |       | RHN | Avg. RHN |
|----------|-------|----------------|----------------------------|-----------------|-------|-----|----------|
|          |       |                |                            | Minor           | Major |     |          |
| 1        | C     | JFRP & CF Skin | Diamond – 120 <sup>0</sup> | 10              | 150   | 76  | 60.34    |
| 2        | C     |                |                            | 10              | 150   | 65  |          |
| 3        | C     |                |                            | 10              | 150   | 40  |          |



## Block Specimen



A



B

### Block composite :

Machine Capacity 150kg  
 Count Load 100.5kg  
 Block Area: 145 cm<sup>2</sup>



C

Figure 27

Table 15 : Data of Rockwell Block hardness test :

| Test no. | scale | Material used  | Indentor used              | Load Applied/kg |       | RHN | Avg. RHN |
|----------|-------|----------------|----------------------------|-----------------|-------|-----|----------|
|          |       |                |                            | Minor           | Major |     |          |
| 1        | C     | JFRP & CF Skin | Diamond – 120 <sup>0</sup> | 10              | 150   | 99  | 100.5    |
| 2        | C     |                |                            | 10              | 150   | 108 |          |
| 3        | C     |                |                            | 10              | 150   | 95  |          |

## Banding Test : Skin

Machine Name: Banch Press Machine  
Machine Capacity :12000kg  
Skin Load Capacity : 300kg



A



B

Figure 28

It bends but does not break when a load is applied to the skin. It is capable of carrying a load of 1.72kg per square cm and can withstand a maximum load of 300 kg, which can be determined based on the test results.

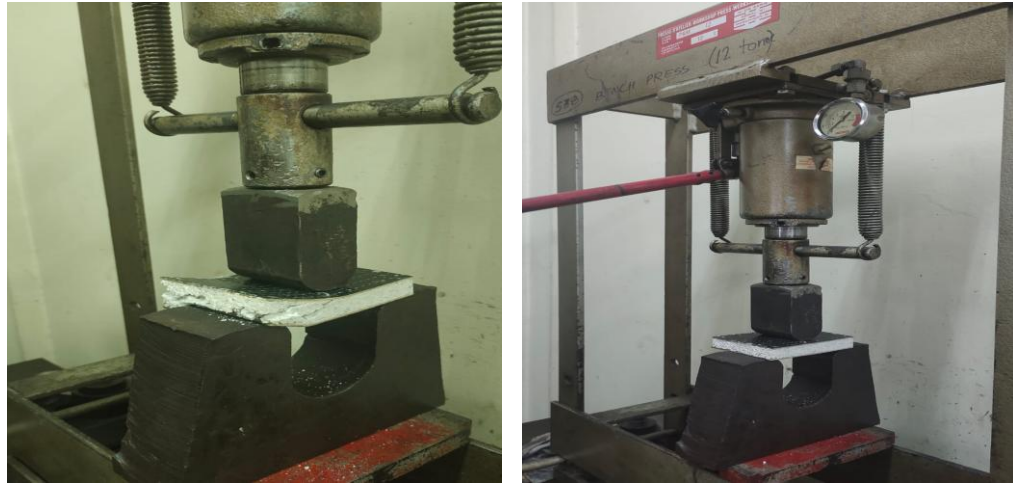


Figure 29

**Banding Test : Block**

Machine Name : Banch Press Machine  
 Machine Capacity :12000kg

Table 16 Data of Block Banding Test

| Sample    | Size mm          | Load kg | Avg Load |
|-----------|------------------|---------|----------|
| Block-3   | 145 x 100 x 15   | 300kg   | 260kg    |
| Block-2.5 | 145 x 100 x 16.5 | 280kg   |          |
| Block-2   | 145 x 100 x 18   | 200kg   |          |

Shown in figure are three blocks. which have different densities and different volumes. Due to this different density, the load obtained is different. Due to the difference in the material used in the block, the load obtained is less or more. It is determined based on the results obtained in the test.



**TTTC**

Department of Mechanical Engineering  
Technical Teachers Training College  
Tejgaon Industrial Area, Dhaka-1208.



**TEST REPORT**

**Root Bend & Hardness Test Result**

| Sample              | Size                      | Bend<br>(at 180°)     | Hardness HRC |     |    |
|---------------------|---------------------------|-----------------------|--------------|-----|----|
|                     |                           |                       | 1            | 2   | 3  |
| Composite Block-3   | 100 mm x 145 mm x 15 mm   | No crack was observed | -            | -   | -  |
| Composite Block-2.5 | 100 mm x 145 mm x 16.5 mm | No crack was observed | -            | -   | -  |
| Composite Block-2   | 100 mm x 145 mm x 18 mm   | No crack was observed | 99           | 108 | 95 |
| Composite Sheet     | 147 mm x 147 mm x 2 mm    | No crack was observed | 76           | 65  | 40 |

*Shah Ansan Habib*  
**Shah Ansan Habib**  
Craft Instructor (Mech)  
Technical Teachers Training College  
Tejgaon, Dhaka-1208

*10-9-2023*  
Engr. Abu Hena Md. Ghannim Hossain  
B.Sc. Engg. (Mechanical), DUET  
BCS (Technical Education)  
Assistant Professor (Mechanical)  
Technical Teachers Training College  
Tejgaon Industrial Area, Dhaka-1208

#### 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 30 : Impact Testing Machine & Materials Condition after testing

Table 17: 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 Matrix Cracking.
- 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.



## References

- [1] Zenker and Dan, "An Introduction to Sandwich Structures," in An Introduction to Sandwich Structures, 1995, pp. 1.2-1.3.
- [2] Z. Li and J. Ma, "Experimental Study on Mechanical Properties of the Sandwich Composite Structure Reinforced by Basalt Fiber and Nomex Honeycomb," MDPI, p.1870, 2020.
- [3] A.Rekaandet.al, "Chemical, mineralogical and structural features of native and expanded perlite from Macedonia," *Geologia Croatica*, vol.72, no. 3, pp. 215-221, 2019.
- [4] "Perlite Insulation Boards & Pipe Sections," Wedge India, [Online]. Available :<https://www.wedge-india.com/perlite-insulation-boards>.
- [5] H. Chandekar, V. Chaudhari and S. Waigaonkar, "A review of jute fiber reinforced polymer composites," Elsevier Ltd., pp. 2214-7853, 2020.
- [6] S. Pradhanandet .al, "Insight on the Chemistry of Epoxy and Its Curing for Coating Applications: A Detailed Investigation and Future Perspectives," *Polymer-Plastics Technology and Engineering*, pp. 862-877, 2016.
- [7] Krzyhak and et.al, "Sandwich Structured Composites for Aeronautics: Methods of Manufacturing Affecting Some Mechanical Properties," Hindawi Publishing Corporation, vol. 2016, no. 7816912, p. 10, 2016.
- [8] M. Mohamed and et.al, "Manufacturing and characterization of polyurethane-based sandwich composite structures," Elsevier, vol. 123, pp. 169-179, 2015.
- [9] "A new approach to manufacturing biocomposite sandwich structures: mycelium-based cores," *International Manufacturing Science and Engineering Conference*, p.8864, 2016.
- [10] J.L.A. Isaac M.Daniel, "Fabrication, testing and analysis of composite sandwich beams," *ELSEVIER*, pp. 2455-2463, 2000.
- [11] P.W.et.al, "Experimental and numerical evaluation of the flexural properties of a stitched foam-core sandwich structure," *ELSEVIER*, pp. 243-248, 2013.
- [12] M. Hassan and et.al, "The influence of core density on the blast resistance of foam-based sandwich structures," Elsevier, vol. 50, pp. 9-16, 2012.

- [13] N. R. R. Anbusagar, P. K. Giridharan, and et.al, "Mechanical Behavior of Glass-Jute Sandwich NanoPolyester Composites to Flexural and Impact Loading," *European Journal of Scientific Research*, vol. 84, no.2, pp. 148-155, 2012.
- [14] S.B.S,S.A.R and et.al, "Mechanical Characterization Of Polyurethane Foam And Hybrid Natural Fiber Based Sandwich Composite," *Palarch's Journal Of Archaeology Of Egypt/Egyptology*,vol. 17, no. 9, pp. 5588-5604, 2020.
- [15] M. Arifuzzaman and H.S.kim,"Novel Flexural behavior of sandwich structures made of perlite foam/sodium silicate core and paper skin " *Construction and building materials*, Elsevier ,vol.148,pp.321-333-2017.
- [16] X.Wang ,X.-I .Shi and et.at, "Bending behaviors of three grid sandwich structures with wood facing and jute fabrics/epoxy composite cores,"*composite structures*,vol,252,p.