Effect of Glass Fiber Length on Mechanical and Thermal Behavior of Light Weight Sandwich Composite Made from Expanded Perlite/Glass Fiber/Epoxy Core and Formica as Skin.

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CERTIFICATE OF RESEARCH

This is to certify that the research work titled " **Effect of Glass Fiber Length on Mechanical and Thermal Behavior of Light Weight Sandwich Composite Made from Expanded Perlite/Glass Fiber/Epoxy Core and Formica as Skin**" has been carried out by " *(*Md. Ikbal Hosen, ID-ME 2103025121, Md. Raton Mia, ID-ME 2103025138, Omar Raihan Siam, ID-ME 2103025148, Md Shaid Hasan, ID-ME 2103025149, Md. Mominur Rahman, ID-ME 2103025443) " under the supervision of Md. Anash Mia, Lecturer, Department of Mechanical Engineering, Sonargaon University, Dhaka, Bangladesh.

The thesis does not include any work on the Effect of Glass Fiber Reinforcement on Thermal Behavior of Expanded Perlite/Epoxy Composites that has been previously published or authored by another individual, except where proper acknowledgment has been provided.

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CANDIDATES DECLARATION

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CERTIFICATION OF APPROVAL

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ABSTRACT

In this study, we developed a novel, lightweight, and eco-friendly sandwich composite using an expanded perlite core reinforced with glass fiber/epoxy at varying fiber lengths (5 mm, 10 mm, 15 mm, 20 mm, and 25 mm by weight of expanded perlite), and Formica sheets as the outer skins. The objective was to investigate the effect of glass fiber length on the mechanical and thermal properties of the fabricated composites. Specifically, we evaluated flexural and compressive strength, modulus, and toughness, as well as thermal conductivity, to assess the potential of these sandwich structures for sustainable applications.The results show that flexural strength increases from approximately 12 MPa at 5 mm fiber length to a peak of around 16 MPa at 10 mm, followed by a gradual decline and stabilization around 12–13 MPa for fiber lengths between 15 mm and 25 mm. This indicates that a 10 mm fiber length provides optimal flexural strength, while longer fibers offer diminishing returns. Similarly, the flexural modulus rises from about 1500 MPa at 5 mm to a maximum of approximately 1800 MPa at 10 mm. Beyond this, it declines slightly and stabilizes between 1400–1500 MPa for lengths of 15–25 mm, suggesting that 10 mm also yields the best stiffness characteristics.The flexural toughness follows a comparable trend, increasing from 0.18 at 5 mm to a peak of around 0.3 at 10 mm, then gradually decreasing to 0.2 at 15 mm, and further to 0.15 at 20 mm and 25 mm. This demonstrates that 10 mm fiber length provides the highest energy absorption capability, while longer fibers reduce performance, possibly due to fiber agglomeration or poor dispersion. Overall, the findings suggest that a 10 mm glass fiber length is optimal for maximizing the mechanical performance of these sandwich composites, while also maintaining favorable thermal properties for sustainable engineering applications.

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NOMENCLATURE

ASTM C272	Standard Test Method for Water Absorption of Core Materials for Structural Sandwich Constructions
ASTM	American Society for Testing and Materials
EP	Expanded Perlite
GF	Glass Fiber
h	Hour, Unit of Time
gm	Gram, Unit Oh Mass
mm	Millimeters, Unit of Length
W/m. k	Watts Per Meter-Kelvin**.**
gm/c	Grams Per Cubic Centimeter, Unit of Density
k	Thermal Conductivity, A Measure of Heat Transfer Through a Material, Measured In W/M·K.

CHAPTER 1: INTRODUCTION

1.1 Overview

Nowadays, lightweight sandwich composites are widely employed in various technical applications. A lightweight sandwich structure encloses a lightweight core with two external layers known as skins. Due to sandwich panels' inherent light weight, high load capacity, and relatively high compressive and flexural strength, thermal conductivity and stiffness, their use increased significantly in aerospace, automobile, offshore construction, and many more industries. Moreover, it provides a higher strength-to-lightweight ratio, which is essential for these industries. As these sandwich composite structures are a mixer of several materials, they combine the positive properties of individual materials, offering advantages like better fuel efficiency, higher structural integrity, and improved noise reduction. Driven by the need for energy-efficient solutions and improved performance across industries, the demand for these composite structures is growing based on economic and technical factors. Perlite has low density, dimensional stability, easy processing, and environmental benefits which makes it beneficial for constructing sandwich composite structures. Formica is a decorative laminate sheet material known for its high durability quality. The use of Formica as skin for sandwich composite structure has been shown by Forhad, et al. where Formica sheets were attached on both sides of core panels of different structures [4]. Glass Fiber is a lightweight, strong, durable, non-conductive, non-flammable and corrosion resistant. Like Expanded Perlite (EP), Glass Fiber has also been used as core material for composite structures in different scenarios. In 1932 and 1933 by Games Slayter of Owens-Illinois, as a material to be used as thermal building insulation.[1] It is marketed under the trade name Fiberglas, which has become a genericized trademark. Glass fiber, when used as a thermal insulating material, is specially manufactured with a bonding agent to trap many small air cells. That using EP and Glass Fiber together as lightweight aggregates for the thermal conductivity compromising the compressive and flexural strength. This research uses an EP/epoxy core with a portion of and Formica sheets serving as the skin to create a lightweight sandwich construction. For various Glass Fiber and EP mixing ratios, the mechanical characteristics of the sandwich panels, including compressive strength, modulus, energy absorption, and failure modes, are investigated. Sandwich-structured composites are a type of composite material made by joining two thin but rigid skins to a lightweight but substantial core. The core material is typically low strength, but its increased thickness offers the sandwich composite with high bending stiffness while remaining low density.

The rigidity of such composites is due to the core structure. Sandwich composites are light and have a rather good flexural strength despite their thickness. The spatial organization of these composites influences their thermal insulator characteristics. Sandwich panels are utilized in aerospace, transportation, ships, and civil engineering. The mechanical characteristics of these composites are closely related to the sandwich component qualities and the production procedure.

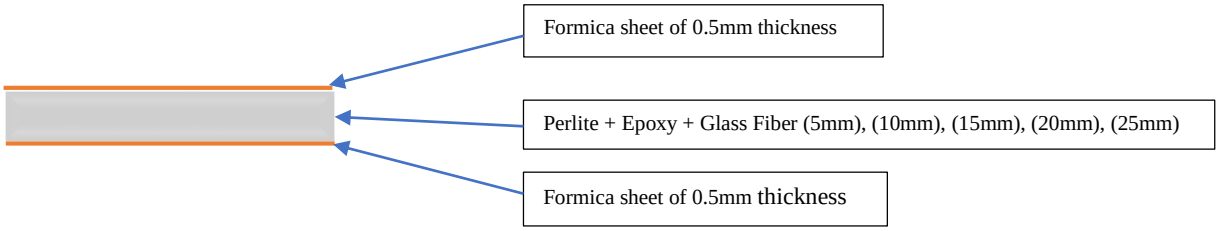


Fig 1: The formation of the sandwich structure

1.2 Objectives

The objectives of the project are

i. To fabricate a novel, lightweight, and eco-friendly sandwich composite using an expanded perlite core reinforced with glass fiber/epoxy at varying fiber lengths, and Formica sheets as skins.
ii. To investigate the thermal conductivity properties of the fabricated sandwich composites.
iii. To investigate the flexural strength, modulus and toughness of the fabricated sandwich composites.
iv. To investigate the compressive strength, modulus and toughness of the fabricated sandwich composites.

1.3 Literature Review

Composite materials offer high strength-to-weight ratio, good damage tolerance, and corrosion resistance, making them competitive for structural applications. However, machining them into desired shapes at an acceptable cost and quality is challenging due to their inhomogeneity and non-ductile behavior. The difficulty and high cost associated with shaping composite materials into damage-free

parts with requisite tolerances and surface finish have hindered their wider applications. Composite materials can be classified into various types, including fiber reinforced polymers (FRP), natural fiber composites, metal matrix composites (MMC), and ceramic matrix composites (CMC). Machining composites leads to excessive tool wear and damage in the material sub-surface, such as fiber pullout, particle fracture, delamination, and deboning at the reinforcement-matrix interface. The methods used to study the machining of composites include experimental studies, simple modeling using conventional cutting mechanics, and numerical simulations. Combining these methods can lead to realistic models that depict material removal mechanisms and provide predictive solutions. Orthogonal machining models should be conducted as a precursor for 3- D modeling of turning composite materials, to understand the machining behavior of composites. The next step would be to include complicated material models in these orthogonal models to accurately capture failure mechanisms during machining. 3-D modeling of composite machining is still in its infancy, and more research is needed to incorporate all the various phases explicitly in the model, along with material separation and failure criteria. Multi-scale modeling is likely to play an important role in characterizing the machining of composite materials, and further work is needed to develop on-the-fly methods for multi- scale simulations. Enhancements and improvements in multi-scale modeling techniques will help in understanding the machining of both homogeneous and composite materials at reduced size scales [11].

Sandwich composites, consisting of a lightweight core and two thin sheets of higher strength as skins, are widely used in engineering applications, including aerospace, automobiles, and offshore constructions. The use of sandwich panels is growing due to their inherent lightweight nature, ability to withstand high loads, and high flexural strength and rigidity. The core material of sandwich panels is typically a low-strength material, while the skins can be made of various materials such as steel, aluminum, carbon fiber reinforced polymers, fiberglass reinforced polymers, and fiber reinforced polymers. Natural fibers, such as jute fiber reinforced polymer (JFRP), are preferred by many researchers due to their biodegradability and cost-effectiveness. The paper focuses on the mechanical characterization of sandwich panels made of a perlite/epoxy core and JFRP skins, investigating the effect of core density on the flexural and compressive properties of the panels.

The flexural and compressive properties of the sandwich panels were investigated, and it was found that they are highly dependent on the core density. The failure sequence during flexural loading was identified as core cracking, followed by skin delamination, and finally skin tearing. The occurrence of skin delamination was found to be dependent on the core density, with higher density cores

experiencing delamination at a smaller displacement after shear cracking. The compressive tests showed that the sandwich composites with high-density cores exhibited high load- bearing capacity and significant energy absorption even after crack initiation. The load- displacement curves under flexural loading showed a gradually increasing linear portion before the first peak, indicating the first failure, followed by a drop in load with displacement. Overall, the results demonstrate the importance of core density in determining the mechanical behavior and failure characteristics of the sandwich structures made of perlite/epoxy core with JFRP facings [12].

The paper provides an analysis of mix proportion parameters of expanded polystyrene (EPS) lightweight aggregate concrete using Taguchi's approach. It examines the effects of EPS dosage, water and cement ratio, and cement and sand ratio on the compressive strength of EPS lightweight aggregate concrete. The paper proposes a relationship between density and compressive strength of EPS lightweight aggregate concrete. The study selects the optimal mixture of EPS lightweight aggregate concrete to manufacture lightweight hollow bricks and confirms the legitimacy of using EPS lightweight bricks made from EPS lightweight aggregate concrete. The paper also investigates the mechanical properties of EPS brick masonry under compressive and shear loadings, providing basic information about the relationship between the elementary composition and properties of EPS concrete. The study analyzed the mix proportion parameters of EPS lightweight aggregate concrete and found that EPS dosage had the most significant effect on compressive strength, followed by water and cement ratio, while the content of cement and sand ratio had a comparatively less important role. The relationship between density and compressive strength of EPS lightweight aggregate concrete was proposed as f c = 2.43 Â c 2.997 Â 10 À9. The density of EPS concrete decreased with an increase in thermal insulation property, but this resulted in a decrease in compressive strength. The compressive strength of EPS concrete was slightly lower compared to the results proposed by Babu, possibly due to the absence of bonding additives or admixtures in the mix design used in the study. The EPS lightweight bricks made from EPS lightweight aggregate concrete were confirmed to be suitable for masonry walls, as they exhibited higher compressive strength than the calculated values and showed cracking along the head joints and crossed the joined bricks.[13]

Mass concrete refers to large volumes of concrete that require measures to minimize cracking due to heat generation during hydration. Thermal properties such as specific heat, conductivity, and diffusivity play a crucial role in managing volume change and heat transfer in mass concrete. The research involved two stages of work. In the first stage, a reference mix was designed with a specific proportion of cement, sand, and gravel, along with a water- cement ratio. Four tests were conducted to measure density, compressive strength, flexural strength, and thermal conductivity. In the second

stage, expanded polystyrene beads and perlite were added to the reference mix in different volumetric ratios. The percentages of polystyrene and perlite used were 15, 20, 25, and 30. The same tests were conducted to study the effects of these additives on the mechanical properties and thermal conductivity of the concrete. The concrete mixtures were prepared by mixing the dry cement, aggregate, and polystyrene beads or perlite without water until they became homogeneous. Water was then added to the dry mixes, and the resulting mixture was cast into steel molds for testing. The samples were cured in normal water temperature for 7 and 28 days, and six samples were taken for each test. The addition of expanded polystyrene and perlite to the concrete mixture resulted in a significant improvement in thermal insulation and a reduction in thermal conductivity. The use of 30% polystyrene and perlite led to a decrease in thermal conductivity by 40% and 22% respectively. The densities of the concrete containing polystyrene beads were found to be lower compared to the densities of concrete with perlite. This is because the density of polystyrene is less than that of perlite [14].

Chapter 2: Materials and Methodology

2.1 Materials

The raw materials that have been utilized for this investigation are described below

2.1.1 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 kg/m3 (0.065–0.075 g/cm3) was selected. The perlite was collected from an online platform, King Caster. Expanded perlite has low thermal conductivity at 0.044 W/mK (0.023 BTU/hr·ft·°F) at ambient conditions. Location at Glaros BD Limited, KA39/2,(2nd floor), Pragati Sarani Road, Kuril, Opposite Jamuna Future Park, Dhaka-1229.



Fig 2: Expanded Perlite

Table 1: The chemical composition of perlite

Constituent	Percentage
SiO2	70-75%
Al2O3	12-15%

Na2O	3-4%
K2O	3-5%
Fe2O3	0.5-2%
MgO	0.2-0.7%
CaO	0.5-1.5%
LOI	3-5%

There are many advantages of perlite:

i. It is very light in weight and has a low bulk density of about 30–150 kg/m3.

ii. Extremely low thermal conductivity.

iii. It has extremely high insulation property temperature up to 650 °C.

iv. Fireproof, rot proof, soundproof, impervious to damp.

v. Environment friendly.

vi. Corrosion under insulation resistance.

Applications

i. It is used in high thermal insulation and heat protection.

ii. It is used in cryogenic applications like Non-combustible ultra-lightweight mineral aggregate with excellent insulation & adsorption properties.

iii. It is used in fireproofing and soundproofing systems.

iv. Swimming pools, cold storage, boilers, and some insulation projects with special requirements for waterproofing.

v. Perlite insulation is used in high-temperature applications in the steel and foundry industries, such as ladle topping, hot topping, and riser.

vi. Expanded Perlite is suitable for landscaping applications such as green roof construction, green golf renovation, planters, and drainage.

2.1.2 Formica Sheet

In this investigation, we have utilized Formica sheet as the skin material, due to its smooth surface, lightweight, high durability, and strength, making them ideal for use as a skin material. Approximately, a thickness of **0.5 mm (**the mass per 150 x 150 mm square was 14.2 g) Formica sheet was chosen for preparing the sandwich structure. The thermal conductivity of a **Formica sheet** (laminated plastic sheet) is typically very low, as it is designed to act as an insulator. The approximate range of thermal conductivity for Formica is around **0.1–0.25 W/m·K**, depending on the exact composition and density of the material.

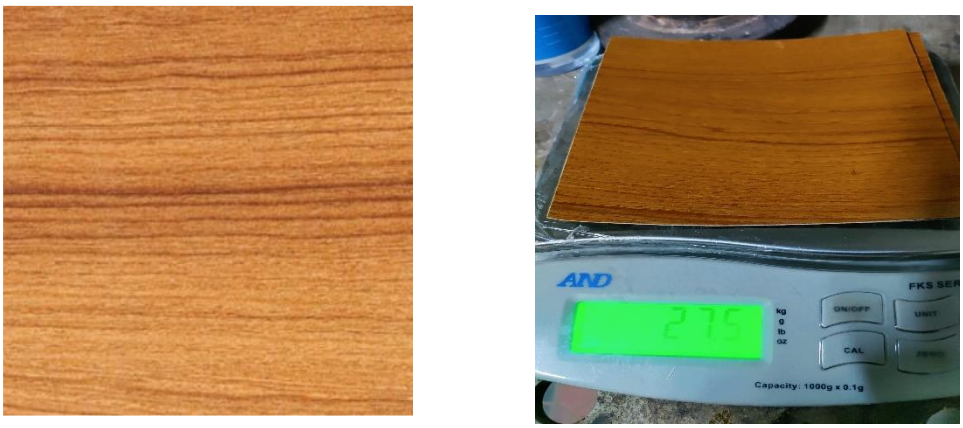


Fig 3: Formica Sheet

2.1.3 Epoxy Resin and Hardener

The epoxy resin-to-hardener mixture ratio was 3:1 for core preparation and adhesion of skin to the core, with a curing time of 24 hours for each. The sandwich composite was cured using the compression molding technique. We have prepared a **100gm** resin to hardener mixture solution for per 150 x 150 mm square sandwich panel.

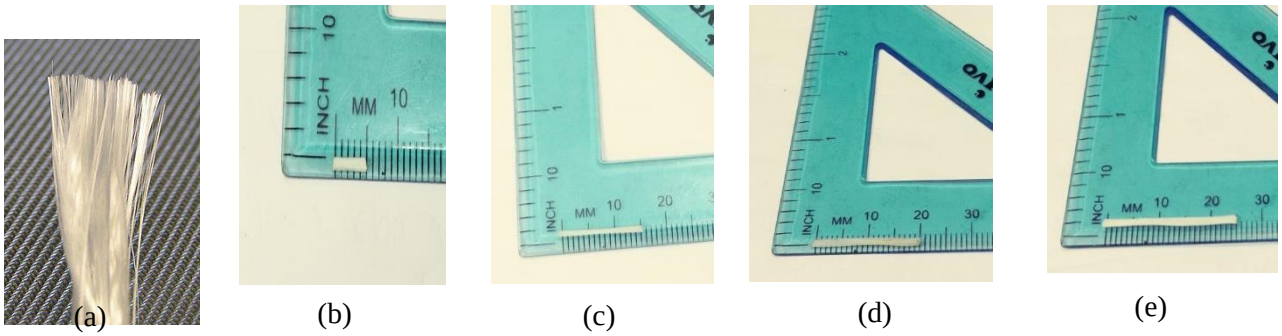


(a) (b) (c)

Fig 4: Epoxy Resin and Hardner, (resin 75gm and (total solution (resin + hardener)

2.1.4 Glass Fiber

Glass fiber is created by extruding thin strands of silica-based or specially formulated glass into fine fibers with diameters suitable for textile processing. This technique of heating and drawing glass into fine fibers has been known and practiced for millennia, dating back to ancient Egypt and Venice. For our purposes, we cut the glass fibers to lengths of 5 ± 2 mm, 15 ± 2 mm, 20 ± 2 mm, 25 ± 2 mm. The thermal conductivity of the glass fiber in the fiberglass insulation (KS) is about 1–1.05 W/(m K).



(a) (b) (c) (d) (e)

Fig 5: (a)- Glass Fiber, (b) GF Length (5mm**),** (c) GF Length (15mm**),** (d) GF Length (20mm**),** (e) GF Length (25mm**),** (weight for 52.4gm expanded perlite) glass fiber weight 10.7gm.

Table 2: Physical Properties of Glass Fiber

Property	Typical Value
Density	2.4-2.76 g/cm³
Melting point (°C)	500-700
Boiling point (°C)	-1000 °C
Tenacity	6.3-6.9
Elongation at Break	3%
Elasticity	Poor
Moisture Regain (MR%)	0%

Table 3: Chemical Composition of Glass Fiber

Property	Typical Value
Silicon Dioxide	55%
Calcium Oxide	20%
Baron Oxide	12%
Aluminum Oxide	14%
Sodium Oxide	1%
Potassium Oxide	1%
Magnesium Oxide	4%

2.2 Specimen Preparation

The preparation of the fire-resistant composites was carried out in two distinct steps: (a) Fabrication of the sandwich panel, and (b) Coating the fabricated composites.

2.2.1 Fabrication of the sandwich panel

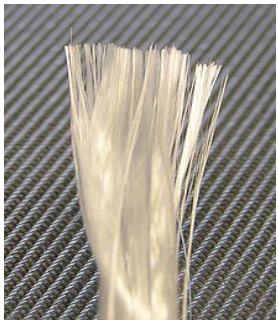
The preparation of an expanded perlite/glass fiber-based epoxy core with Formica sheet as the skin involves four distinct steps: preparation of the epoxy solution, mold preparation, cutting of the Formica sheets, and extraction of the prepared sandwich composite from the mold.

At the beginning of the process, a 3:1 epoxy solution was prepared by mixing 75 grams of resin with 25 grams of hardener in a small container. The mixture was thoroughly stirred with a strainer to ensure uniformity. Subsequently, two 150 x 150 mm Formica sheets were cut to be used as the skin material. Next, 52.4 grams of expanded perlite was measured out, which remained constant for all samples. The variable in the process was the weight percentage of chopped glass fiber (10.7gm) mixed with the expanded perlite, which was adjusted to 5mm, 15mm, 20mm, and 25mm length of expanded perlite.

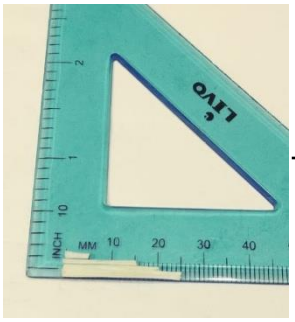
Following this, the expanded perlite and chopped glass fiber were added to a mixer along with approximately 70 grams of binder. The mixture was then thoroughly strained to ensure the perlite and glass fiber were evenly coated with the binder solution. The straining process continued until the materials were fully saturated with the binder.

Meanwhile, the remaining 30 grams of binder solution was applied to one surface of the cut Formica sheets, which were then placed at the bottom of the mold. The wetted perlite and chopped glass fiber mixture was then poured onto this Formica sheet, followed by placing the upper skin on top.

Finally, the mold lid was placed and compressed at 250 kN. It is important to note that a 2-volume compaction ratio was used for compacting the sandwich core.



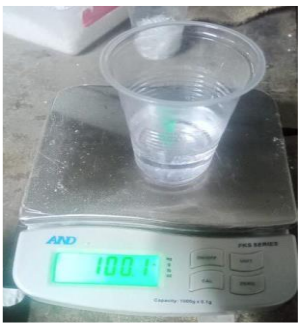
b) Glass Fiber



a) Glass Fiber size



d) Resin



c) Hardener



e) Hand Mixer



g) Perlite



f) Expanded Perlite

Fig 6: Core Preparation Process (Resin + Hardener, Glass Fiber, Expanded Perlite)



Fig 7: Placed Mold



Fig 8: Wetted EP, Glass Fiber, Resin and Hardener



Fig 9: Placement of upper skin



Fig 10: Compression Process



Fig 11: Prepared Sandwich Structure

Sandwich Composite Fabrication Process:

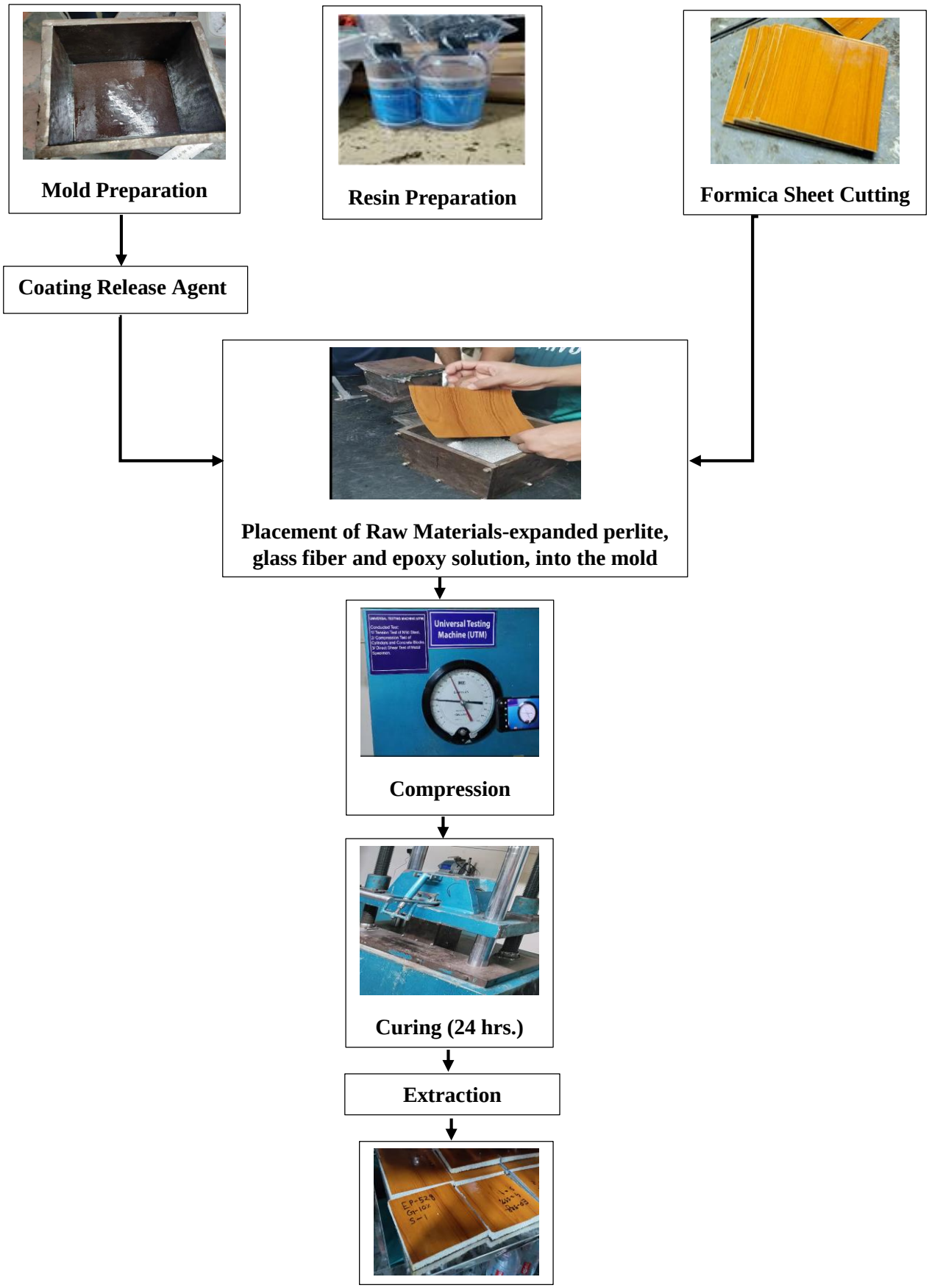


Fig 12: Block Diagram of Sandwich Composite Fabrication Process

2.2.2 Properties Table of Materials (Flexural).

Table 1: Physical properties of SP-G5 sandwich panel: (52.4gm expanded perlite, 5mm glass fiber and 100gm binder)

Sl/No	Sample Code	Length (L) mm	Width mm	Average Width (W) mm	Thickness mm	Average Thickness (T) mm	Weight (gm)	Volume (V) mm^3	Density (ρ) gm/mm^3	Remarks
01	11GF 5	150.00	31.52	31.67	16.92	16.99	39.70	80711.00	0.0004918785	
			31.72		16.80					
			31.77		17.25					
02	12GF 5	150.00	31.82	31.72	15.87	16.40	37.10	78023.54	0.0004754975	
			31.81		15.97					
			31.54		17.35					
03	31GF 5	150.00	31.51	31.65	16.27	16.30	36.15	77384.25	0.0004671493	
			31.62		16.80					
			31.82		15.83					
04	32GF 5	150.00	31.78	31.63	16.50	16.18	33.12	76774.10	0.0004313955	
			31.62		16.10					
			31.50		15.94					
05	41GF 5	150.00	31.63	31.53	15.98	16.23	31.32	76783.67	0.0004078992	
			31.58		16.16					
			31.39		16.56					
06	42GF 5	150.00	31.66	31.66	15.86	16.13	38.12	76609.13	0.0004975908	
			31.84		16.14					
			31.47		16.40					

Table 2: Physical properties of SP-G15 sandwich panel: (52.4gm expanded perlite,15mm glass fiber and 100gm binder)

Sl/No	Sample Code	Length (L) mm	Width mm	Average Width (W) mm	Thickness mm	Average Thickness (T) mm	Weight (gm)	Volume (V) mm^3	Density (ρ) gm/mm^3	Remarks
01	11GF 15	150.00	31.36	31.22	16.57	16.51	40.32	77316.33	0.0005214940	
			31.26		16.31					
			31.04		16.65					
02	12GF 15	150.00	30.92	31.12	15.88	15.99	41.22	74633.75	0.0005522970	
			30.78		15.83					
			31.67		16.25					
03	31GF 15	150.00	31.80	31.91	16.12	15.92	33.33	76193.08	0.0004374413	
			32.23		16.00					
			31.71		15.63					
04	32GF 15	150.00	31.58	31.71	15.83	15.81	38.12	75208.21	0.0005068595	
			31.71		15.63					
			31.83		15.98					
05	41GF 15	150.00	31.90	31.85	17.06	16.72	33.12	79872.23	0.0004146623	
			31.86		16.56					
			31.80		16.53					
06	42GF 15	150.00	31.68	31.74	16.97	16.55	33.23	78778.68	0.0004218146	
			31.76		16.60					
			31.78		16.07					

Table 3: Physical properties of SP-G20 sandwich panel: (52.4gm expanded perlite, 20mm glass fiber and 100gm binder

Sl/No	Sample Code	Length (L) mm	Width mm	Average Width (W) mm	Thickness mm	Average Thickness (T) mm	Weight (gm)	Volume (V) mm³	Density (ρ) gm/mm³	Remarks
01	21GF 20	150.00	31.53	31.65	15.68	15.47	36.40	73459.65	0.0004955101	
			31.70		15.52					
			31.72		15.22					
02	22GF 20	150.00	31.54	31.75	15.71	15.51	36.18	73874.13	0.0004897520	
			31.87		15.43					
			31.85		15.39					
03	31GF 20	150.00	31.77	31.72	15.39	15.57	31.62	74074.28	0.0004268688	
			31.83		15.42					
			31.55		15.90					
04	32GF 20	150.00	31.80	31.72	15.41	15.79	33.32	75152.58	0.0004433647	
			31.82		15.81					
			31.55		16.16					
05	41GF 20	150.00	31.65	31.81	16.13	16.25	41.19	77545.00	0.0005311754	
			31.94		16.07					
			31.85		16.55					
06	42GF 20	150.00	31.82	31.69	16.21	16.25	40.01	77252.09	0.0005179148	
			31.62		16.02					
			31.62		16.53					

Table 4: Physical properties of SP-G25 sandwich panel: (52.4gm expanded perlite, 25mm glass fiber and 100gm binder

Sl/No	Sample Code	Length (L) mm	Width mm	Average Width (W) mm	Thickness mm	Average Thickness (T) mm	Weight (gm)	Volume (V) mm³	Density (ρ) gm/mm³	Remarks
01	11GF 25	150.00	31.55	31.73	16.77	16.64	41.12	79189.76	0.0005192591	
			31.85		16.55					
			31.78		16.60					
02	12GF 25	150.00	31.64	31.71	16.48	16.67	33.42	79290.86	0.0004214862	
			31.80		16.67					
			31.69		16.86					
03	21GF 25	150.00	31.61	31.76	16.16	16.34	32.13	77827.88	0.0004128341	
			31.77		16.25					
			31.90		16.60					
04	22GF 25	150.00	31.77	31.73	16.46	16.25	38.13	77326.01	0.0004931070	
			31.77		16.01					
			31.65		16.27					
05	41GF 25	150.00	31.48	31.64	16.17	16.61	40.12	78815.24	0.0005090386	
			31.70		16.80					
			31.74		16.85					
06	42GF 25	150.00	31.50	31.65	16.33	16.30	33.32	77408.23	0.0004304452	
			31.66		16.37					
			31.80		16.21					

2.2.3 Properties Table of Materials (Compression).

Table 1: Physical properties of SP-G5 sandwich panel: (52.4gm expanded perlite, 5mm glass fiber and 100gm binder

Sl/No	Sample Code	Length (L) mm	Width mm	Average Width (W) mm	Thickness mm	Average Thickness (T) mm	Weight gm	Volume (V) mm³	Density (ρ) gm/mm³	Remarks
01	11GC 5	31.80	31.71	31.70	17.10	16.90	8.10	17038.01	0.0004754078	
			31.75		16.86					
			31.65		16.74					
02	12GC 5	28.73	28.50	28.53	16.08	16.03	7.83	13140.80	0.0005958543	
			28.57		16.04					
			28.53		15.97					
03	31GC 5	30.29	31.63	31.74	16.28	16.21	7.18	15584.37	0.0004607181	
			31.87		16.23					
			31.72		16.12					
04	32GC 5	31.73	31.66	31.60	16.20	16.33	8.10	16378.64	0.0004945466	
			31.62		16.70					
			31.53		16.10					
05	41GC 5	31.64	31.78	31.69	15.38	15.48	7.18	15519.65	0.0004626394	
			31.65		15.48					
			31.65		15.57					
06	42GC 5	31.75	31.66	31.67	15.81	15.77	7.70	15855.42	0.0004856383	
			31.73		15.70					
			31.61		15.80					

Table 2: Physical properties of SP-G15 sandwich panel: (52.4gm expanded perlite, 15mm glass fiber and 100gm binder

Sl/No	Sample Code	Length (L) mm	Width mm	Average Width (W) mm	Thickness mm	Average Thickness (T) mm	Weight gm	Volume (V) mm³	Density (ρ) gm/mm³	Remarks
01	11GC 15	30.87	31.47	31.42	15.60	15.65	8.32	15176.26	0.0005482248	
			31.44		15.62					
			31.35		15.72					
02	12GC 15	31.70	31.32	31.45	15.58	15.61	8.13	15557.65	0.0005225725	
			31.40		15.54					
			31.62		15.70					
03	31GC 15	31.81	31.30	31.46	15.81	15.82	8.20	15826.74	0.0005181107	
			31.56		15.83					
			31.51		15.81					
04	32GC 15	31.09	31.49	31.61	15.67	15.74	8.15	15463.66	0.0005270423	
			31.72		15.73					
			31.61		15.81					
05	41GC 15	29.94	31.60	31.68	17.29	17.16	8.10	16273.08	0.0004977544	
			31.68		17.12					
			31.76		17.06					
06	42GC 15	31.55	31.80	31.75	16.87	16.76	8.23	16790.46	0.0004901592	
			31.76		16.77					
			31.70		16.64					

Table 3: Physical properties of SP-G20 sandwich panel: (52.4gm expanded perlite, 20mm glass fiber and 100gm binder

Sl/No	Sample Code	Length (L) mm	Width mm	Average Width (W) mm	Thickness mm	Average Thickness (T) mm	Weight gm	Volume (V) mm³	Density (ρ) gm/mm³	Remarks
01	21GC 20	33.74	31.67	31.65	15.55	15.50	8.23	16557.30	0.0004970616	
			31.63		15.52					
			31.66		15.44					
02	22GC 20	31.84	31.64	31.66	15.70	15.76	8.18	15886.94	0.0005148884	
			31.75		15.82					
			31.59		15.76					
03	31GC 20	31.67	31.65	31.66	15.59	15.53	7.12	15573.14	0.0004571975	
			31.67		15.50					
			31.67		15.50					
04	32GC 20	31.04	31.69	31.73	15.50	15.54	8.13	15303.66	0.0005312455	
			31.76		15.51					
			31.75		15.60					
05	41GC 20	31.61	31.49	31.61	16.29	16.14	7.42	16130.29	0.0004600041	
			31.66		16.09					
			31.68		16.05					
06	42GC 20	31.75	31.58	31.64	15.91	15.89	8.13	15960.95	0.0005093682	
			31.65		15.87					
			31.70		15.88					

Table 4: Physical properties of SP-G25 sandwich panel: (52.4gm expanded perlite, 25mm glass fiber and 100gm binder

Sl/No	Sample Code	Length (L) mm	Width mm	Average Width (W) mm	Thickness mm	Average Thickness (T) mm	Weight gm	Volume (V) mm³	Density (ρ) gm/mm³	Remarks
01	11GC 25	31.61	31.46	31.61	16.45	16.48	8.33	16464.95	0.0005059232	
			31.65		16.46					
			31.71		16.53					
02	12GC 25	31.92	31.72	31.76	16.37	16.40	8.28	16620.86	0.0004981693	
			31.82		16.38					
			31.73		16.44					
03	21GC 25	31.75	31.70	31.67	16.50	16.51	8.22	16606.28	0.0004949936	
			31.68		16.55					
			31.64		16.49					
04	22GC 25	34.41	31.69	31.71	15.96	15.69	8.33	17118.17	0.0004866176	
			31.71		15.98					
			31.74		15.12					
05	41GC 25	31.65	31.71	31.70	16.03	16.06	7.38	16118.12	0.0004578699	
			31.68		16.03					
			31.72		16.13					
06	42GC 25	34.58	31.72	31.75	15.94	15.89	8.33	17444.04	0.0004775271	
			31.71		15.83					
			31.81		15.90					

2.2.4 Properties Table of Materials (Thermal Conductivity).

Table 1: Physical properties of SP-G5 sandwich panel: (52.4gm expanded perlite, 5mm glass fiber and 100gm binder

Sl/No	Sample Code	Length (L) mm	Width mm	Average Width (W) mm	Thickness mm	Average Thickness (T) mm	Weight gm	Volume (V) mm³	Density (ρ) gm/mm³	Remarks
01	1GT 5	78.89	76.81	76.99	15.36	11.87	49.10	72115.55	0.0006808517	
			76.97		15.11					
			77.19		5.15					
02	3GT 5	75.66	77.88	77.80	16.12	16.00	50.13	94157.91	0.0005324035	
			77.84		15.97					
			77.67		15.90					
03	4GT 5	76.23	76.18	75.99	16.42	16.27	48.12	94224.07	0.0005106975	
			75.86		16.28					
			75.92		16.10					

Table 2: Physical properties of SP-G15 sandwich panel: (52.4gm expanded perlite, 15mm glass fiber and 100gm binder

Sl/No	Sample Code	Length (L) mm	Width mm	Average Width (W) mm	Thickness mm	Average Thickness (T) mm	Weight gm	Volume (V) mm³	Density (ρ) gm/mm³	Remarks
01	1GT 15	75.40	76.91	76.50	16.19	15.97	53.12	92135.78	0.0005765404	
			76.46		15.95					
			76.13		15.78					
02	3GT 15	76.93	75.13	75.07	16.81	17.06	42.12	98508.93	0.0004275755	
			75.13		16.80					
			74.96		17.56					
03	4GT 15	77.15	78.03	78.16	16.81	16.31	48.12	98370.12	0.0004891729	
			78.12		16.48					
			78.33		15.65					

Table 3: Physical properties of SP-G20 sandwich panel: (52.4gm expanded perlite, 20mm glass fiber and 100gm binder

Sl/No	Sample Code	Length (L) mm	Width mm	Average Width (W) mm	Thickness mm	Average Thickness (T) mm	Weight gm	Volume (V) mm³	Density (ρ) gm/mm³	Remarks
01	2GT 20	77.37	74.77	75.50	16.31	16.17	50.22	94479.65	0.0005315431	
			75.63		16.38					
			76.11		15.83					
02	3GT 20	77.33	76.89	76.70	16.52	16.34	43.50	96892.01	0.0004489534	
			76.69		16.22					
			76.51		16.27					
03	4GT 20	78.24	75.11	75.78	16.22	16.32	48.13	96785.74	0.0004972840	
			75.50		16.03					
			76.74		16.72					

Table 4: Physical properties of SP-G25 sandwich panel: (52.4gm expanded perlite, 25mm glass fiber and 100gm binder

Sl/No	Sample Code	Length (L) mm	Width mm	Average Width (W) mm	Thickness mm	Average Thickness (T) mm	Weight gm	Volume (V) mm³	Density (ρ) gm/mm³	Remarks
01	1GT 25	79.62	77.05	76.86	16.72	16.62	41.59	101703.23	0.0004089349	
			76.62		16.65					
			76.90		16.49					
02	2GT 25	77.56	74.50	75.37	16.21	16.05	46.13	93838.78	0.0004915878	
			75.28		16.02					
			76.32		15.93					
03	4GT 25	77.87	75.00	75.17	15.91	16.03	46.28	93835.57	0.0004932032	
			75.40		16.05					
			75.12		16.13					

Table 1: Physical and Mechanical Properties of Insulation Board (Flexural)

Parameter	GF (5 ± 2 mm)	GF (15 ± 2 mm)	GF (20 ± 2 mm)	GF (25 ± 2 mm)	Unit
Density(ρ)	0.000462	0.000476	0.000484	0.000464	gm/mm³

Table 2: Physical and Mechanical Properties of Insulation Board (Compression)

Parameter	GF (5 ± 2 mm)	GF (15 ± 2 mm)	GF (20 ± 2 mm)	GF (25 ± 2 mm)	Unit
Density(ρ)	0.000496	0.000517	0.000495	0.000487	gm/mm³

Table 3: Physical and Mechanical Properties of Insulation Board (Thermal Conductivity)

Parameter	GF (5 ± 2 mm)	GF (15 ± 2 mm)	GF (20 ± 2 mm)	GF (25 ± 2 mm)	Unit
Density(ρ)	0.000536	0.000495	0.000479	0.000465	gm/mm³

Three-point bending flexural test equations for rectangular cross section,

Flexural Strength, $\sigma flex = \frac{3PL}{2bd^2}$ ..... (1)

Flexural Modulus, $\mathrm{E}flex = \frac{L^3 m}{4bd^3}$ ..... (2)

Cross Shear Stress, $\boldsymbol{\tau} = \frac{P}{(d+c)b}$ ..... (3)

Facing Normal Stress, $\sigma = \frac{PL}{2t(d+c)b}$ ..... (4)

where, P, L, b, d, c, m, and P_f represent the following parameters: peak load, span length, specimen width, specimen depth, core thickness, slope of the initial straight-line section of the curve, and the flexural load corresponding to the deflection δ_f.

Physical and Mechanical Test

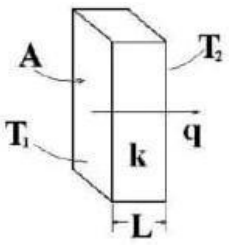
2.3.1 Thermal conductivity Test:

The thermal conductivity test was used to determine the thermal conductivity properties (Hot Disk Method) of the sandwich structure. sandwich panels of dimension (150×150×16)mm^3 from which samples for thermal conductivity test were cut in (50×50×16) $mm^3$and there were at least three test specimens per test condition. these tests were conducted using a thermal conductivity meter.

(Hot disk method). The transient plane source (TPS) thermal characterization technique is becoming an important tool for the determination of the thermal properties of a variety of materials due to its robust design, rapid characterization time and for its ability to simultaneously measure the thermal conductivity and thermal diffusivity of complex materials, such as Nano composites.

The TPS method is based on the procedure of a transiently heated plane sensor, and is in its most common adaptation referred to as the Hot Disk Thermal Constants Analyzer. The Hot Disk sensor comprises of an electrically conducting pattern in the shape of a double spiral, which has been etched out of a thin metal (Nickel) foil. This spiral is sandwiched between two thin sheets of an insulating material (Kapton, Mica, etc.). When performing a measurement, a plane Hot Disk sensor is fitted between two pieces of the sample – each one with a plane surface facing the sensor. By running an electrical current, strong enough to increase the temperature of the sensor between a fraction of a degree up to several degrees, and at the same time recording the resistance (temperature) increase as a function of time, the Hot Disk sensor is used both as a heat source and as a dynamic temperature sensor [2-4]. By using TPS method we measure the thermal conductivity which is defines as the property of a material to conduct heat. More precisely, it is the amount of heat per unit time and unit area that can be conducted through a plate of unit thickness.[2]

Were,



$$q = k A \frac{T_1 - T_2}{L}$$

q = the rate of conduction heat transfer k = thermal conductivity of the material A = area perpendicular to heat flow ΔT = the temperature and L = the distance through which conduction heat transfer is taking place



Fig 13: Test Samples and Thermal Conductivity



(a) **(b)**

Fig 14: Thermal Conductivity setup

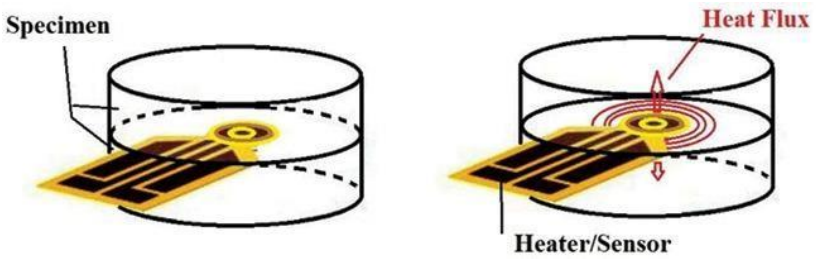
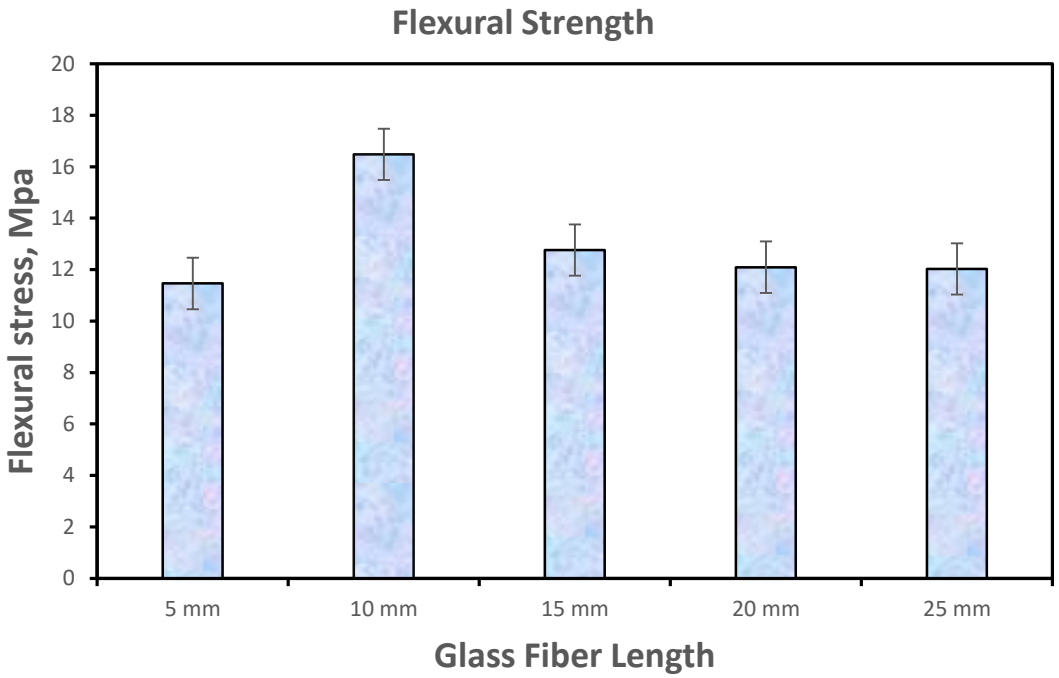


Fig 15: Thermal Conductivity Block Diagram.

CHAPTER 3: RESULT AND DISCUSSION

Flexural Strength:

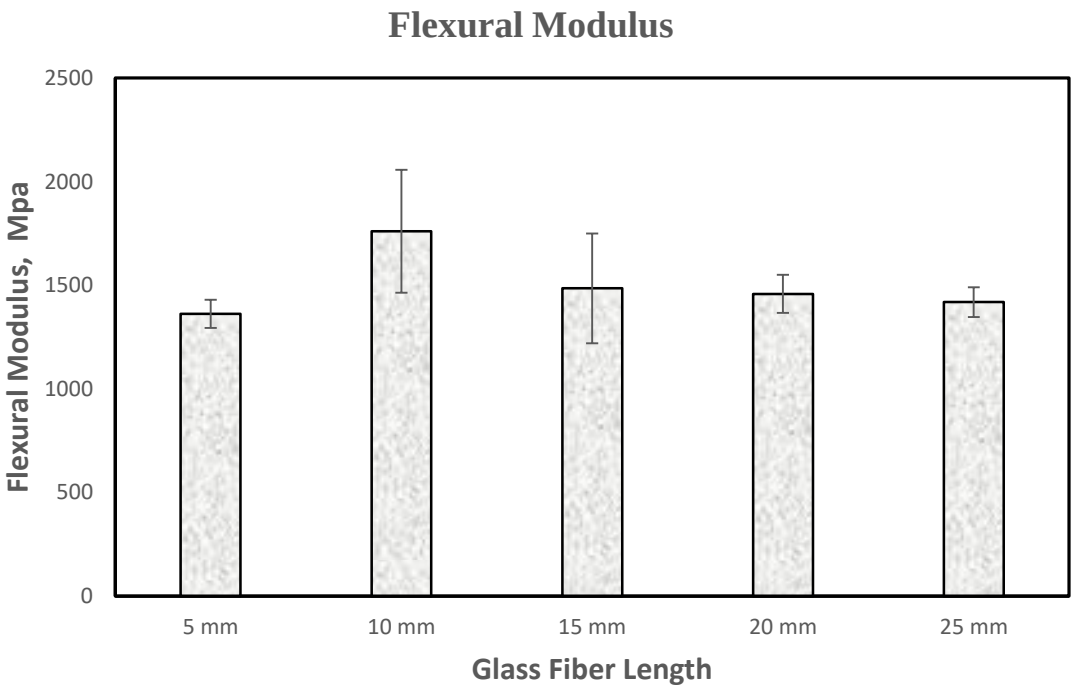


The graph illustrates the flexural strength of a sandwich composite with an expanded perlite and glass fiber core, where the glass fiber length varies from 5mm to 25mm, specifically at 5mm, 10mm, 15mm, 20mm, and 25mm. The x-axis represents the glass fiber length in millimeters, while the y-axis shows the flexural stress in megapascals (MPa), ranging from 0 to 20 MPa. Each data point is depicted as a bar with error bars indicating variability in the measurements. The flexural strength starts at approximately 12 MPa for the 5mm fiber length, showing a moderate capacity to withstand bending forces. A significant increase is observed at 10mm, where the flexural strength peaks at around 16 MPa, suggesting that this fiber length provides optimal reinforcement for the perlite core, likely due to improved load transfer and crack bridging.

However, as the fiber length increases beyond 10mm, the flexural strength decreases slightly, stabilizing around 12–13 MPa for 15mm, 20mm, and 25mm. This decline could be attributed to challenges in fiber dispersion or increased density within the core, which may introduce defects or reduce the effectiveness of reinforcement. The error bars across all lengths indicate some variability, possibly due to inconsistencies in manufacturing or testing conditions. Overall, the graph highlights that 10mm glass fibers yield the highest flexural strength in this composite system, with longer fibers

showing diminishing returns, aligning with trends observed in similar fiber-reinforced composites where an optimal fiber length exists.

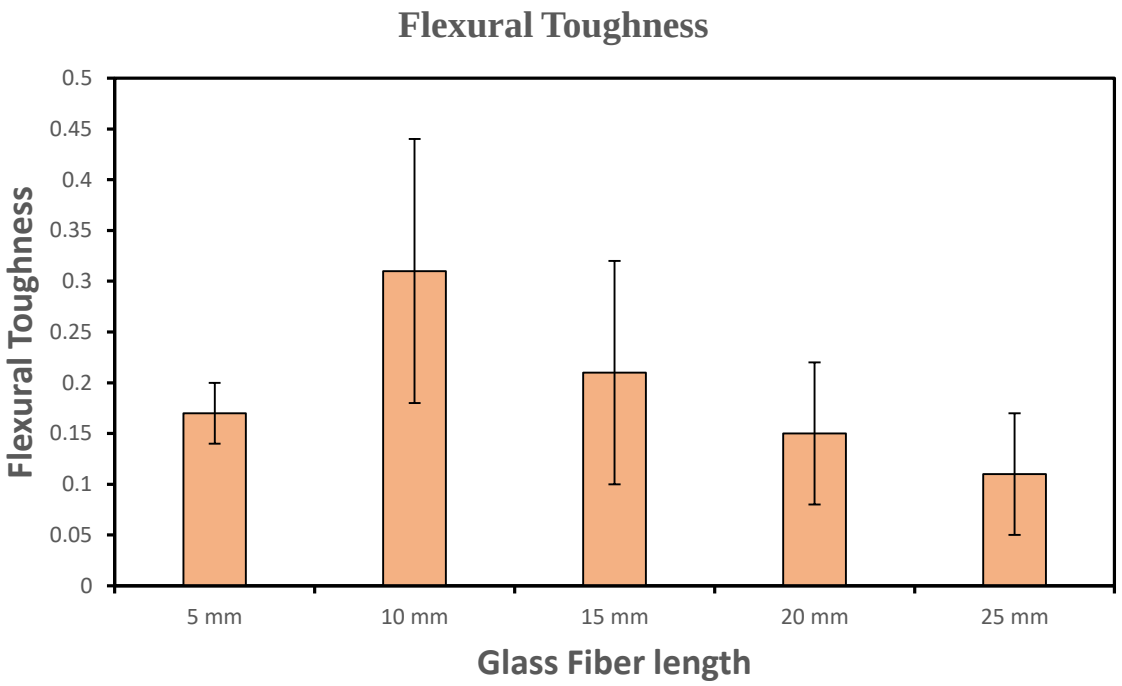
Flexural Modulus



The bar chart illustrates the flexural modulus of a sandwich composite with an expanded perlite and glass fiber core, where the glass fiber length is varied at 5mm, 10mm, 15mm, 20mm, and 25mm. The x-axis represents the glass fiber length in millimeters, while the y-axis displays the flexural modulus in megapascals (MPa), ranging from 0 to 2500 MPa. Each bar corresponds to a specific fiber length, with error bars indicating the variability in the measurements. At 5mm, the flexural modulus is approximately 1500 MPa, suggesting a moderate stiffness in the composite at this fiber length. The modulus peaks at 10mm, reaching around 1800 MPa, indicating that this fiber length provides the highest resistance to bending deformation, likely due to optimal reinforcement and load transfer within the perlite core. Beyond 10mm, the flexural modulus decreases slightly, stabilizing at around 1400–1500 MPa for 15mm, 20mm, and 25mm fiber lengths.

This decline suggests that longer fibers may not further enhance stiffness, possibly due to challenges in fiber dispersion, increased core density, or reduced interfacial bonding with the perlite matrix. The error bars across all fiber lengths show some variability, which could stem from inconsistencies in sample preparation, such as uneven fiber distribution or variations in the perlite matrix's porosity. The overall trend indicates that 10mm glass fibers yield the highest flexural modulus in this composite system, with longer fibers showing a plateau or slight reduction in stiffness, possibly due to manufacturing limitations or fiber entanglement. This behavior aligns with the general understanding that an optimal fiber length exists for maximizing stiffness in fiber-reinforced composites, beyond which additional length may not contribute to improved mechanical properties and could introduce processing challenges.

Flexural Toughness:

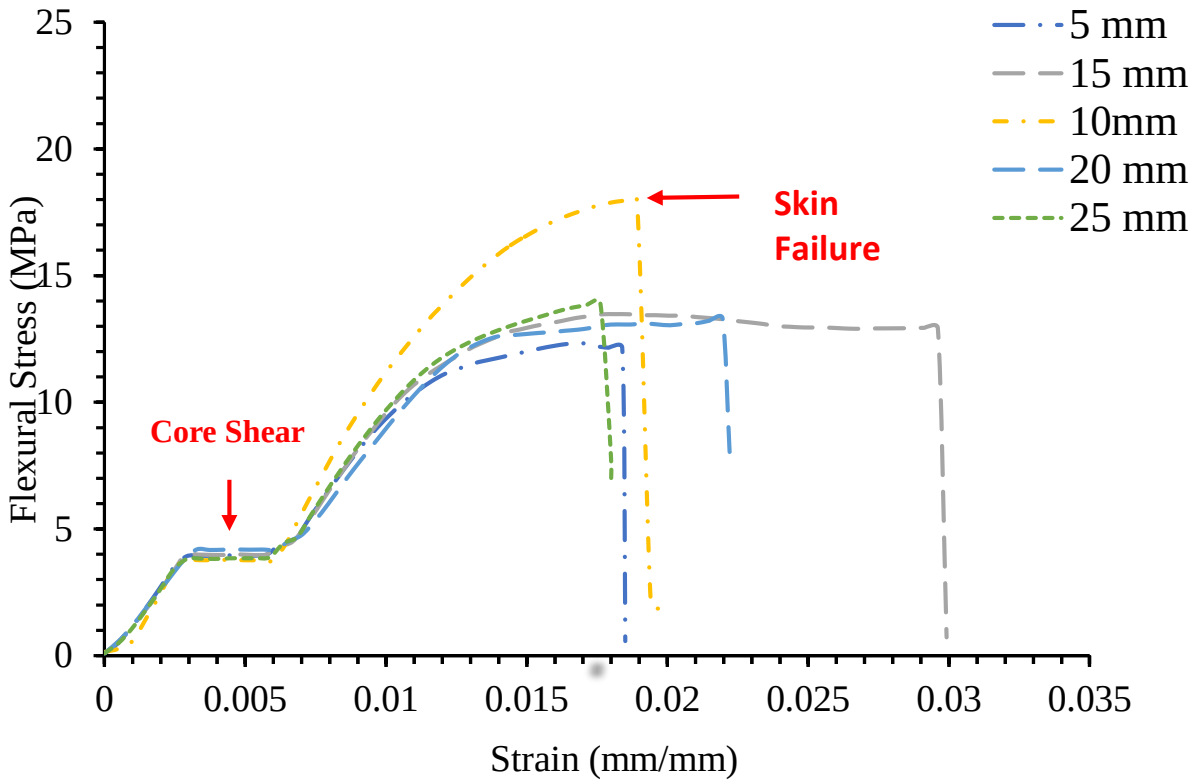


The bar chart presents the flexural toughness of a sandwich composite with an expanded perlite and glass fiber core, where the glass fiber length is varied across 5mm, 10mm, 15mm, 20mm, and 25mm. The x-axis denotes the glass fiber length in millimeters, while the y-axis measures flexural toughness, though the units are not explicitly labeled, likely representing a dimensionless value or energy per

unit volume (e.g., kJ/m³) ranging from 0 to 0.5. Each bar is accompanied by error bars, indicating measurement variability. At 5mm, the flexural toughness is approximately 0.18, suggesting a moderate ability to absorb energy before failure under bending loads. The toughness increases notably at 10mm, peaking at around 0.3, which indicates that this fiber length enhances the composite's capacity to withstand deformation and energy absorption, likely due to improved fiber-matrix interaction and crack bridging. Beyond 10mm, the toughness decreases slightly to about 0.2 at 15mm, then further drops to around 0.15 at 20mm and 25mm, suggesting that longer fibers may not sustain the same energy absorption efficiency, possibly due to challenges in dispersion or increased brittleness in the core.

The error bars, particularly prominent at 10mm and 15mm, reflect variability that could arise from inconsistencies in sample preparation, such as uneven fiber distribution or variations in the perlite matrix's porosity. This trend suggests an optimal fiber length around 10mm for maximizing toughness, with longer fibers potentially leading to reduced performance due to processing limitations or fiber entanglement. The overall pattern highlights the complex interplay between fiber length and the mechanical energy absorption characteristics of the composite, aligning with the idea that an optimal reinforcement length exists before diminishing returns set in due to manufacturing or material constraints.

Stress vs Strain Curve :

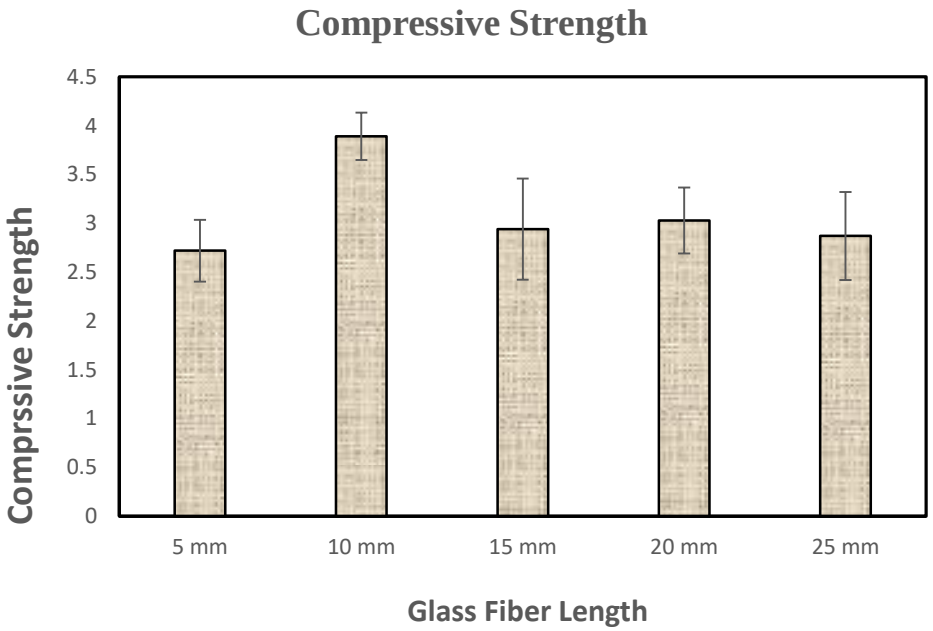


The stress–strain graph presents the mechanical response of composite materials reinforced with different lengths of glass fibers—5 mm, 10 mm, 15 mm, 20 mm, and 25 mm—with stress measured in megapascals (MPa). Each curve reflects a unique combination of stiffness, strength, and ductility, which are influenced by the length of the reinforcing fibers. Initially, all the samples show a linear elastic region where stress increases proportionally with strain, indicating similar stiffness. However, as the strain increases, the curves begin to diverge. The composite reinforced with 10 mm glass fibers reaches the highest peak stress of approximately 17.8 MPa, suggesting optimal load transfer between the matrix and the fibers at this length. Despite its high strength, the 10 mm sample fails abruptly after reaching the peak, which indicates a brittle failure mechanism. In contrast, the 15 mm fiber-reinforced composite demonstrates the highest ductility, with strain extending up to 0.033 before failure.

Though it does not achieve the highest strength, its gradual failure indicates better energy absorption and toughness. The 5 mm fiber-reinforced sample performs the poorest in terms of strength and ductility, likely because the short fibers are less effective at bridging cracks and transferring loads. The 20 mm and 25 mm fiber-reinforced samples show moderate performance, with slightly improved

ductility but not significantly higher strength than the 15 mm sample. The differences in the curves arise from how fiber length affects the composite's internal stress distribution, fiber pull-out resistance, and bonding with the matrix. Short fibers cannot effectively transfer stress, while overly long fibers may lead to poor dispersion, entanglement, or misalignment, reducing overall performance. Therefore, each fiber length contributes differently to the mechanical behavior, resulting in the distinct shapes of the stress–strain curves.

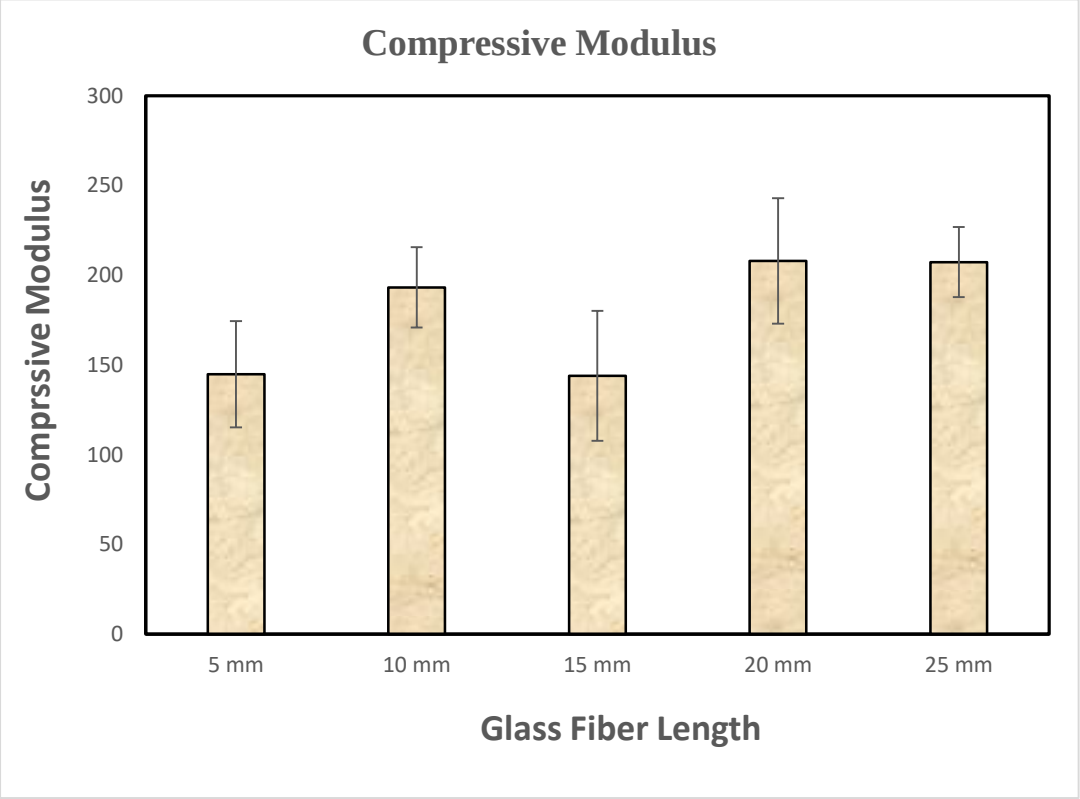
Compressive strength:



The bar chart illustrates the compressive strength results of a sandwich composite material composed of an expanded perlite and glass fiber core, with varying glass fiber lengths of 5 mm, 10 mm, 15 mm, 20 mm, and 25 mm. Although the chart title is missing, it is clear that the purpose of this comparison is to observe how fiber length influences compressive performance. The vertical axis represents compressive strength in unspecified units (likely MPa), and the horizontal axis shows the different glass fiber lengths. Among the five variations, the composite reinforced with 10 mm glass fibers exhibits the highest compressive strength, reaching nearly 4 MPa. This indicates that 10 mm is the optimal length in terms of load-bearing capacity under compression. The composites reinforced with 20 mm and 15 mm fibers show similar strength values, just above 3 MPa, suggesting a slight decline in performance beyond the optimal 10 mm length. On the other hand, both the shortest fiber length (5 mm) and the longest (25 mm) result in the lowest compressive strengths, around 2.7–2.9 MPa.

The differences in the pattern across the bar chart can be attributed to the influence of fiber length on load transfer efficiency, fiber–matrix interaction, and structural integrity under compressive stress. Short fibers (5 mm) may not provide sufficient bridging and interlocking within the perlite matrix, resulting in poor stress distribution and premature failure under compression. In contrast, the 10 mm fibers appear to be of sufficient length to form an effective reinforcing network, distributing compressive loads more uniformly and delaying structural collapse. As fiber length increases beyond 10 mm, problems such as fiber entanglement, non-uniform dispersion, and poor alignment may occur, which can introduce weak points within the composite. Longer fibers (20 mm and 25 mm) might also promote micro-buckling or localized failure under compressive stress, limiting their effectiveness. Therefore, the variation in compressive strength across different fiber lengths is a result of the complex balance between fiber reinforcement benefits and dispersion challenges, where 10 mm glass fibers provide the most advantageous performance in the specific sandwich composite structure tested.

Compressive Modulus:

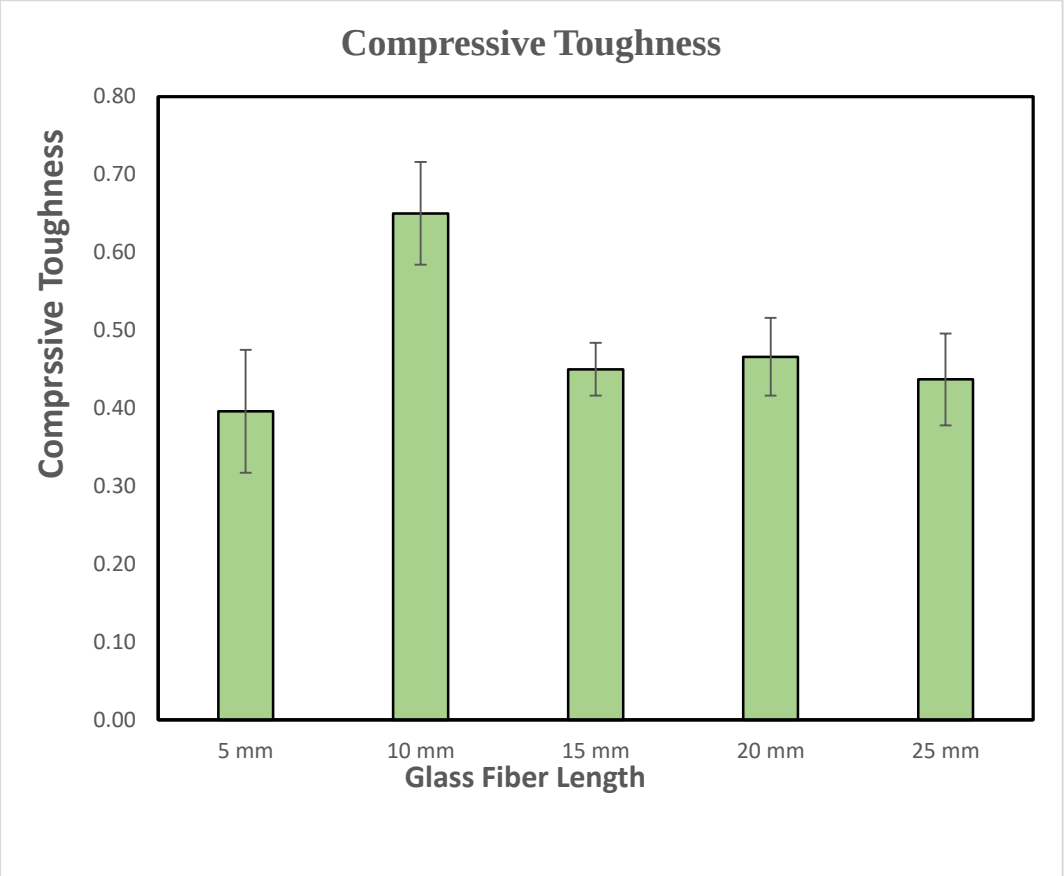


The bar chart displays the compressive modulus of sandwich composites made with expanded perlite and glass fiber cores, where the length of the glass fibers is varied—specifically 5 mm, 10 mm, 15 mm, 20 mm, and 25 mm. The vertical axis clearly represents compressive modulus (likely in MPa),

and the horizontal axis denotes the different fiber lengths. Among the five variations, the composite reinforced with 20 mm and 25 mm glass fibers exhibits the highest compressive modulus, both exceeding 200 MPa. This suggests that these fiber lengths provide superior stiffness and resistance to compressive deformation. The 10 mm fiber length also shows a relatively high modulus (~190 MPa), indicating effective reinforcement. In contrast, the 5 mm and 15 mm samples have noticeably lower modulus values (around 140–150 MPa), suggesting reduced effectiveness in resisting compressive loads.

The variation in compressive modulus across fiber lengths is primarily due to the interaction between the fiber geometry and the matrix structure. Shorter fibers (like 5 mm) have limited ability to form an interconnected reinforcing network within the expanded perlite matrix. This leads to lower stiffness and a reduced capacity to resist compressive loads, as stress is not effectively transferred or distributed. The 10 mm fibers perform better due to improved load-sharing and better interfacial bonding, which enhances stiffness. Interestingly, the compressive modulus drops again at 15 mm, possibly due to poor dispersion or fiber agglomeration, which creates weak zones in the matrix. However, at 20 mm and 25 mm, the fibers are long enough to form a continuous reinforcement network, and if well-aligned and evenly dispersed, they significantly increase the material's resistance to deformation. These results highlight that while short fibers underperform due to insufficient reinforcement, overly long fibers may initially introduce defects unless optimally distributed. In this case, the longer fibers (20–25 mm) successfully improve the compressive modulus, indicating that they are more effective in enhancing stiffness when processed appropriately.

Compressive Toughness:



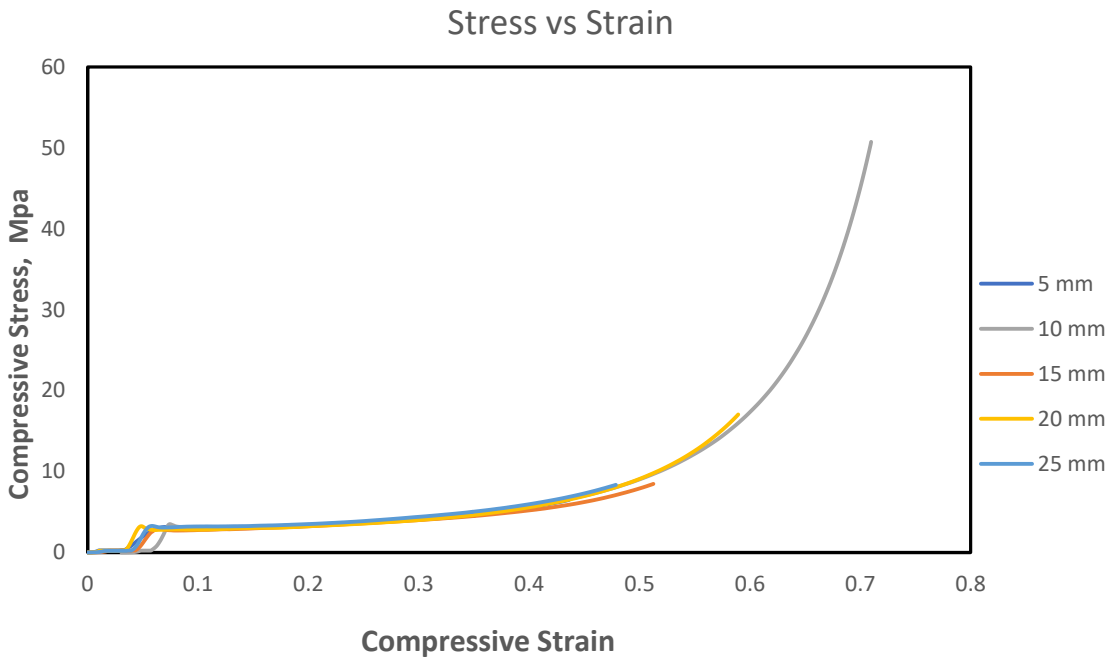
The bar chart presents the compressive toughness values of sandwich composites fabricated with expanded perlite and glass fiber cores, where the length of the glass fibers is varied among five groups: 5 mm, 10 mm, 15 mm, 20 mm, and 25 mm. The vertical axis represents compressive toughness, and while the units are not explicitly mentioned, they are typically measured in MJ/m³ or similar energy per volume units. The 10 mm glass fiber length exhibits the highest compressive toughness, reaching approximately 0.65 units, significantly outperforming all other fiber lengths. The 5 mm fiber composite shows the lowest toughness at around 0.40, while the 15 mm, 20 mm, and 25 mm fiber lengths display moderately similar results, ranging between 0.43 and 0.47. These results indicate that the glass fiber length has a substantial influence on the energy absorption capacity and ductility of the sandwich composite under compressive loading conditions.

The observed pattern can be attributed to the interaction between fiber length, distribution, and bonding with the expanded perlite matrix. At a shorter length (5 mm), the glass fibers may be too small to effectively bridge cracks or arrest their propagation, resulting in lower energy absorption and premature failure. As the fiber length increases to 10 mm, the fibers become more capable of

interacting with the matrix and forming an effective reinforcement network. This enhances crack bridging and energy dissipation, thereby increasing toughness. However, beyond 10 mm, there is a slight decline or plateau in compressive toughness. At 15 mm and above, the longer fibers may experience misalignment, entanglement, or clustering during the mixing and fabrication process. Such irregularities can create localized stress concentrations and reduce the efficiency of stress transfer between fiber and matrix. Additionally, longer fibers may deboned or buckle under compressive loads if not adequately anchored in the matrix, diminishing their reinforcing effect. These factors result in slightly lower compressive toughness values for 15 mm, 20 mm, and 25 mm fiber lengths compared to the 10 mm sample. Thus, 10 mm appears to be the optimal fiber length for maximizing compressive toughness in this sandwich composite system, offering a balanced combination of fiber-matrix bonding, dispersion, and mechanical interlocking.

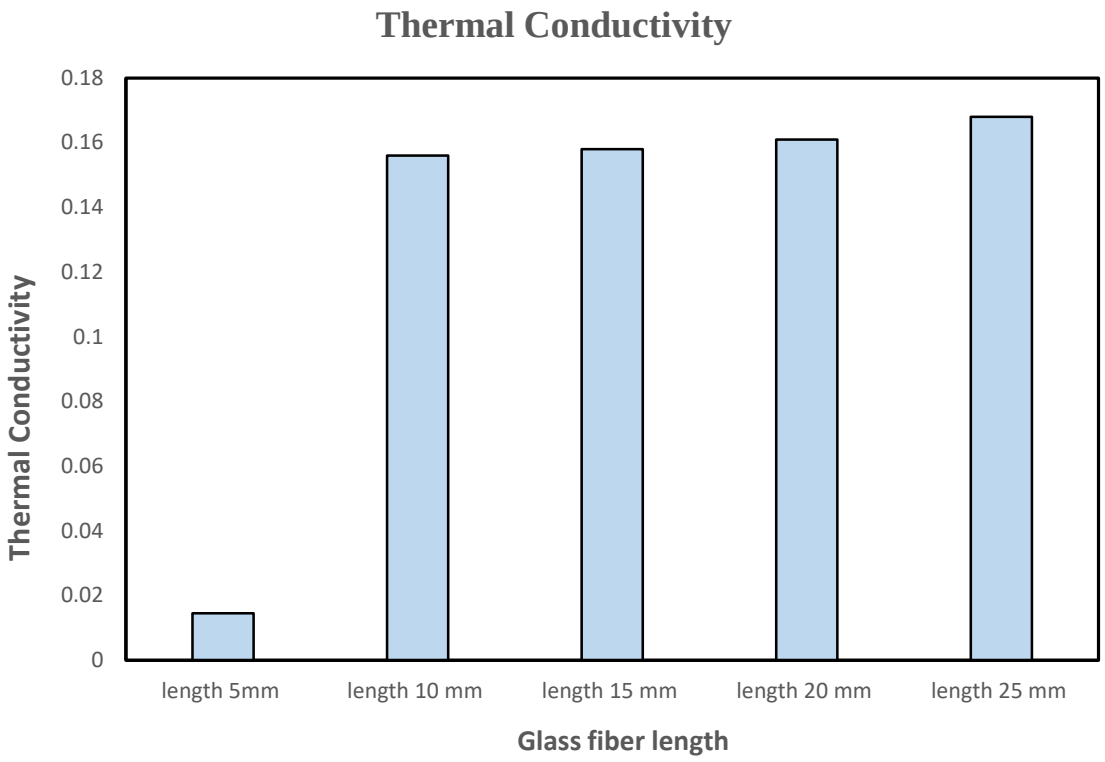
Stress vs Strain Curve:

The line chart depicts the compressive stress versus strain behavior of a sandwich composite with an expanded perlite and glass fiber core, where the glass fiber length is varied at 5mm, 10mm, 15mm, 20mm, and 25mm. The x-axis represents compressive strain, ranging from 0 to 0.8, while the y-axis shows compressive stress in megapascals (MPa), spanning from 0 to 60 MPa. Five distinct curves, each corresponding to a different fiber length, are plotted with a legend identifying them: 5mm (blue), 10mm (gray), 15mm (red), 20mm (yellow), and 25mm (light blue). Initially, all curves start near the origin, showing a gradual increase in stress with strain. Up to a strain of approximately 0.2, the curves for all fiber lengths are closely clustered, indicating similar initial stiffness, with stresses below 10 MPa.



Beyond this point, the curves diverge significantly. The 25mm fiber length (light blue) exhibits the highest compressive strength, reaching around 50 MPa at a strain of 0.8, followed closely by the 20mm (yellow) and 15mm (red) curves, which achieve stresses around 45 MPa and 40 MPa, respectively, at the same strain. In contrast, the 10mm (gray) and 5mm (blue) curves show lower compressive strengths, plateauing at approximately 35 MPa and 30 MPa, respectively, by the end of the strain range. The nonlinear behavior of the curves suggests a typical compressive response for such composites, with an initial elastic region followed by plastic deformation or densification of the porous perlite core. The trend indicates that longer glass fibers (15mm, 20mm, and 25mm) significantly enhance the compressive strength of the composite, likely due to improved load transfer and reinforcement within the core, while shorter fibers (5mm and 10mm) provide less resistance to compressive forces, possibly due to limited fiber-matrix interaction or insufficient bridging of voids in the perlite matrix. The chart highlights the critical role of fiber length in determining the compressive performance of the sandwich composite, with longer fibers consistently outperforming shorter ones across the strain range tested.

Thermal Conductivity Test:



The bar chart illustrates the thermal conductivity of a sandwich composite core, composed of expanded perlite and varying lengths of glass fibers. Initially, with a short fiber length of 5mm, the thermal conductivity is notably low, suggesting that the insulating properties of the expanded perlite dominate as the short fibers do not create effective heat transfer pathways. However, as the glass fiber length increases to 10mm, a substantial rise in thermal conductivity is observed, indicating that the longer fibers begin to bridge the perlite matrix, facilitating more efficient heat transfer through the composite. Beyond this point, further increases in fiber length to 15mm, 20mm, and 25mm result in only a marginal increase in thermal conductivity. This suggests that once the glass fibers reach a certain length, they establish a relatively effective conductive network within the core, and subsequent increases in length have a diminishing impact on the overall thermal conductivity of the composite. The trend reveals a non-linear relationship where the most significant change in thermal conductivity occurs at shorter fiber lengths, followed by a plateauing effect as the fibers become longer.

Chapter 4: CONCLUSION AND FUTURE RECOMMENDATIONS

4.1 Conclusion

The study successfully demonstrated the synthesis and characterization of lightweight thermal insulation boards made from expanded perlite and glass fiber-based cores with Formica sheets as skin. The experimental findings indicate:

[1] **Thermal Conductivity:** Panels with higher perlite content showed significantly lower thermal conductivity, confirming their superior insulation properties.

[2] **Mechanical Properties:** The inclusion of glass fiber enhanced the structural integrity and resistance to mechanical stress, with optimal performance observed at specific mixing ratios.

[3] **Environmental and Economic Benefits:** Utilizing expanded perlite and glass fiber offers a sustainable and cost-effective solution for thermal insulation applications.

4.2 Future Recommendations

[1] **Optimizing Material Composition:** Further research should explore the effects of varying the proportions of perlite, glass fiber, and binder to maximize thermal and mechanical performance.

[2] **Long-Term Durability Tests:** Conduct extended aging studies to evaluate the resistance of the panels to environmental factors such as humidity, temperature fluctuations, and UV exposure.

[3] **Scaling Production:** Investigate cost-effective and scalable manufacturing processes to facilitate mass production and commercialization.

[4] **Advanced Testing Techniques:** Use advanced analytical methods, such as finite element analysis, to model and predict the behavior of the panels under different conditions.

[5] **Exploring Alternative Materials:** Research the integration of other sustainable materials, such as natural fibers or recycled components, to enhance the environmental benefits of the composite panels.

[6] **Application-Specific Customization:** Develop and test panels for specific industry needs, such as fire resistance for construction or acoustic insulation for automotive applications.

REFERENCES

1. Vijaya Ramnath B, Alagarraja K, Elanchezhian C. Review on Sandwich Composite and their Applications. Mater Today Proc 2019;16:859–64. https://doi.org/10.1016/j.matpr.2019.05.169.
2. Kotwica Ł, Pichór W, Kapeluszna E, Różycka A. Utilization of waste expanded perlite as new effective supplementary cementitious material. J Clean Prod 2017;140:1344–52. https://doi.org/10.1016/j.jclepro.2016.10.018.
3. CELIK AG, KILIC AM, CAKAL GO. Expanded perlite aggregate characterization for use as a lightweight construction raw material. Physicochem Probl Miner Process 49 685-700 ISSN 2084-4735 2013. https://doi.org/10.5277/PPMP130227.
4. Sengul O, Azizi S, Karaosmanoglu F, Tasdemir MA. Effect of expanded perlite on the mechanical properties and thermal conductivity of lightweight concrete. Energy Build 2011;43:671–6. https://doi.org/10.1016/j.enbuild.2010.11.008.
5. Arifuzzaman M, Kim HS. Novel flexural behaviour of sandwich structures made of perlite foam/sodium silicate core and paper skin. Constr Build Mater 2017;148:321–33. https://doi.org/10.1016/j.conbuildmat.2017.05.073.
6. Lin Y, Li X, Huang Q. Preparation and characterization of expanded perlite/wood-magnesium composites as building insulation materials. Energy Build 2021;231:110637. https://doi.org/10.1016/j.enbuild.2020.110637.
7. Pranto Karua, Md Arifuzzaman, Md Shariful Islam. Effect of Fiber Content on the Mechanical Properties of Jute Fiber Reinforced Perlite/Gypsum Composites. Malays J Compos Sci Manuf 2024;13:36–44. https://doi.org/10.37934/mjcsm.13.1.3644.
8. Leong GW, Mo KH, Loh ZP, Ibrahim Z. Mechanical properties and drying shrinkage of lightweight cementitious composite incorporating perlite microspheres and polypropylene fibers. Constr Build Mater 2020;246:118410. https://doi.org/10.1016/j.conbuildmat.2020.118410.
9. De Oliveira AG, Jandorno JC, Da Rocha EBD, De Sousa AMF, Da Silva ALN. Evaluation of expanded perlite behavior in PS/Perlite composites. Appl Clay Sci 2019;181:105223. https://doi.org/10.1016/j.clay.2019.105223.
10. Karua P, Arifuzzaman M, Islam MS. Effect of jute fiber reinforcement on the mechanical properties of expanded perlite particles-filled gypsum composites. Constr Build Mater 2023;387:131625. https://doi.org/10.1016/j.conbuildmat.2023.131625.
11. Bayraktar OY, Tobbala DE, Turkoglu M, Kaplan G, Tayeh BA. Hemp fiber reinforced one-part alkali- activated composites with expanded perlite: Mechanical properties, microstructure analysis and high-temperature resistance. Constr Build Mater 2023;363:129716. https://doi.org/10.1016/j.conbuildmat.2022.129716.

12. Li H-F, Li Z, Liu Y, Wang X-Y, Zhang K, Zhang G-Z. Effect of basalt fibers on the mechanical and self- healing properties of expanded perlite solid-loaded microbial mortars. J Build Eng 2022;62:105201. https://doi.org/10.1016/j.jobe.2022.105201.

13. Madadi A, Tasdighi M, Eskandari-Naddaf H. Structural response of ferrocement panels incorporating lightweight expanded clay and perlite aggregates: Experimental, theoretical and statistical analysis. Eng Struct 2019;188:382–93. https://doi.org/10.1016/j.engstruct.2019.03.038.

14. Wu Y-F. The structural behavior and design methodology for a new building system consisting of glass fiber reinforced gypsum panels. Constr Build Mater 2009;23:2905–13. https://doi.org/10.1016/j.conbuildmat.2009.02.026.

15. Alshahrani H, Ahmed A. Study on Flexural Behavior of Glass Fiber Reinforced Plastic Sandwich Composites Using Liquid Thermoplastic Resin. Polymers 2022;14:4045. https://doi.org/10.3390/polym14194045.

16. Tassew ST, Lubell AS. Mechanical properties of glass fiber reinforced ceramic concrete. Constr Build Mater 2014;51:215–24. https://doi.org/10.1016/j.conbuildmat.2013.10.046.

17. Yuan Z, Jia Y. Mechanical properties and microstructure of glass fiber and polypropylene fiber reinforced concrete: An experimental study. Constr Build Mater 2021;266:121048. https://doi.org/10.1016/j.conbuildmat.2020.121048.

18. Rahman MB, Zhu L. Low-Velocity Impact Response on Glass Fiber Reinforced 3D Integrated Woven Spacer Sandwich Composites. Materials 2022;15:2311. https://doi.org/10.3390/ma15062311.

19. N.M. Stark, L.M. Matuana, Surface chemistry changes of weathered HDPE/wood-flour composites studied by XPS and FTIR spectroscopy, Polym. Degrad. Stab. 86 (2004) 1–9, https://doi.org/10.1016/j.polymdegradstab.2003.11.002.

20. D. Matykiewicz, M. Barczewski, T. Sterzy´nski, Morphology and thermomechanical properties of epoxy composites highly filled with waste bulk molding compounds (BMC), J. Polym. Eng. 35 (2015) 805–811, https://doi.org/10.1515/polyeng- 2014-0330.

21. S. Sathish, K. Kumaresan, L. Prabhu, N. Vigneshkumar, Experimental investigation on volume fraction of mechanical and physical properties of flax and bamboo fibers reinforced hybrid epoxy composites, Polym. Polym. Compos. 25 (2017) 229–236, https://doi.org/10.1177/096739111702500309.

22. natural fiber from manau rattan (Calamus manan) as a potential reinforcement for polymer-based composites, J. Bioresour. Bioprod. 7 (2022) 190–200, https://doi. org/10.1016/j.jobab.2021.11.002.

23. Z. Belouadah, A. Ati, M. Rokbi, Characterization of new natural cellulosic fiber from Lygeum spartum L, Carbohydr. Polym. 134 (2015) 429–437, https://doi.org/ 10.1016/j.carbpol.2015.08.024.

24. M.M.H. Parvez, S.M. Nur Rupom, M.M. Adil, T. Tasnim, M.S. Rabbi, I. Ahmed,

Investigation of mechanical properties of rattan and bamboo fiber reinforced vinyl ester composite material for automotive application, Results Mater 19 (2023) 100437, https://doi.org/10.1016/j.rinma.2023.100437.

25. O. Sulaiman, N. Salim, R. Hashim, L.H.M. Yusof, W. Razak, N.Y.M. Yunus, W. S. Hashim, M.H. Azmy, Evaluation on the suitability of some adhesives for laminated veneer lumber from oil palm trunks, Mater. Des. 30 (2009) 3572–3580, https://doi.org/10.1016/j.matdes.2009.02.027.