Experimental investigation of Lightweight Sandwich Structures Made of Expanded Perlite/Expanded Polystyrene/Epoxy Foam Core and Formica Sheet as Skin

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Declaration

This is to certify that the project and thesis work entitled "Experimental investigation of Lightweight Sandwich Structures Made of Expanded Perlite/Expanded Polystyrene/Epoxy Foam Core and Formica Sheet as Skin" has been carried out by *(MEHEDHI HASAN, Roll No. BME2001020092. Tareq Ahmmed, ID- BME2001020053, Farjana Khatun, ID- BME2001020093, Md Moynul Islam ID BME2001020089, Md Mahmudul Islam ID- BME2001020095)* in the Department of Mechanical Engineering, Sonargaon University (SU) , Dhaka , Bangladesh. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

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Abstract

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 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. The flexural and compressive properties are investigated along with the varying core density and different mixing ratio between EPS and EP. The performance of light weight the sandwich structure in flexure in compression is affected by the amount of perlite. The load-carrying capacity of the sandwich structure was increased about 3.26-4.26 times and 8.61-12.33 times in flexural strength and compressive strength respectively, with an increasing a density that ranged from 0.176 to 0.454 g/cm^3. The prepared samples' density seemed to somewhat increase with the addition of EP while decreasing with the addition of EPS. The density of the sample with an EPS core alone was found to be 0.176 g/cm3, which is 61.25% less dense than the sample with an EP core. The flexural failure of the sandwich composite was initiated from the core of the flexural specimen (core shear failure) and then delamination of the skin. During compression, the strength and the energy absorption are both enhanced significantly by the increment the of the amount of perlite and EPS.

This research uses an EP/epoxy core with a portion of EPS and Formica sheets serving as the skin to create a lightweight sandwich construction. For various EPS and EP mixing ratios, the mechanical characteristics of the sandwich panels, including compressive strength, modulus, energy absorption, and failure modes, are investigated.

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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 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. In 2017, M Arifuzzaman, et al. showed the flexural behavior of sandwich structures made of perlite composite foam with sodium silicate binder and brown paper as skin. The study demonstrated that perlite foam reinforced with brown paper had a load carrying capacity 3-7 times higher than the unreinforced structure [1]. Hossain, et al. manifested that the compressive and flexural properties of sandwich structures made of perlite/epoxy core and JFRP as skins are contingent on the core density[2]. The mechanical properties of these composite structures change with the variation of core density. It was observed in the work of A S M Aziz, et al. that while using expanded perlite/sodium silicate composite reinforced with nylon fiber, the energy absorption during flexural and compression test had improved despite the deterioration of the compressive and flexural properties [3]. 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]. Expanded Polystyrene (EPS) is a lightweight, thermoplastic foam with insulation and durability characteristics. Like Expanded Perlite (EP), EPS has also been used as core material for composite structures in different scenarios. Crameri, et al. investigated the mechanical behavior of EPS sandwich composites with varying fabric reinforcements[5]. In another study, EPS and perlite were used combined to get an improved thermal insulation and reduced thermal conductivity for mass concrete[6]. EPS has a good energy-absorbing characteristic, but the strength is lower than perlite. However, with the addition of steel fiber with EPS, the quality of it can be improved. D. Kioupis, et al. showed that using EP and EPS together as lightweight aggregates for the geo-polymers improved its overall density and thermal conductivity compromising the compressive and flexural strength [7].This research uses an EP/epoxy core with a portion of EPS and Formica sheets serving as the skin to create a lightweight sandwich construction. For various EPS and EP mixing ratios, the mechanical characteristics of the sandwich panels, including compressive strength, modulus, energy absorption, and failure modes, are investigated.

1.2 Objectives

The objectives of the project are

- To fabricated an EP/epoxy core with a portion of EPS and Formica sheets serving as the skin to create a lightweight sandwich.
- To investigate the flexural and compressive properties of the manufactured composites.
- To analyze the failure behavior during the flexural and compression tests.

2 LITERATURE REVIEW

2.1 Sandwich Composites

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.

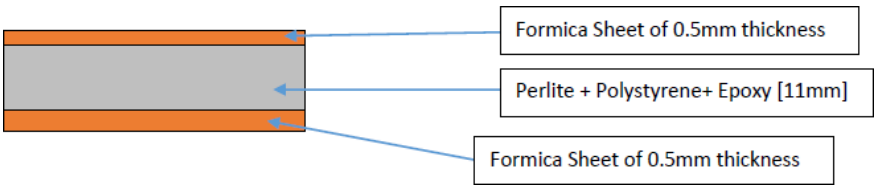

Figure 1 The formation of the sandwich structure

2.2 Constituent Materials

2.2.1 Expanded Perlite

Perlite is an amorphous volcanic glass with a high water content that is primarily created by the hydration of obsidian. It is found naturally and has the odd ability of substantially expanding when adequately heated. Because of its low density after processing, it is an industrial mineral and a commercial product. It is a nonrenewable resource, with approximately 700 million tons of perlite being stockpiled in the world.

Table 1: The chemical composition of perlite*[8]*

Constituent	Percentage
SiO_2	70-75%
Al_2O_3	12-15%
Na_2O	3-4%
K_2O	3-5%
Fe_2O_3	0.5-2%
MgO	0.2-0.7%
CaO	0.5-1.5%
LOI	3-5%

There are many advantages of perlite:

- It is very light in weight and has a low bulk density of about 30–150 kg/m^3.
- 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 [9]

- 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 waterproofing.
- 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 Expanded Polystyrene

Expanded polystyrene is solid foam or thermoplastic product that has characteristics such as low weight, insulation properties and durability. The thermal qualities of expanded polystyrene improve with its strength (density). EPS has a variety of applications such as for thermal insulation boards in building constructions and packaging products. EPS insulation foam is also used in closed cavity walls, roofs and floor insulation. It is the automatic choice

for electronic goods cushioning and packaging. Manufacturers rely heavily on EPS due to its insulation and shock absorption capacity, as well as its ability to prevent or minimize product damage during the transportation of sophisticated equipment.

Table 2 Properties of expanded polystyrene *[10]*

PHYSICAL PROPERTIES	
Molecular weight	300,00 g/mol
Density	17 kg/m^3
Thermal conductivity	0.040 W/mK
Flexural strength	24 N/cm^3
Compressive strength	10 N/cm^2
CHEMICAL COMPOSITION	
Carbon	92.34%
Hydrogen	6.93%
Nitrogen	0.51%
Oxygen	0.22%

Expanded Polystyrene (EPS) has several advantages that can be described
Here are some key advantages:

- Insulation properties: EPS is well-known for its excellent thermal insulation properties, which can be quantified using its thermal conductivity value. The thermal conductivity of EPS typically ranges from 0.032 to 0.040 W/(m·K). This indicates that EPS can effectively resist heat transfer, making it an efficient insulating material.

- Lightweight: EPS is a lightweight material, which is advantageous in various applications. The density of EPS foam ranges from 10 to 45 kg/m³, making it significantly lighter than many other materials with similar insulation properties. Its low weight makes it easier to handle and transport, reducing costs and facilitating construction and packaging processes.

- High compressive strength: EPS possesses high compressive strength, which measures its ability to withstand compressive forces without significant deformation. The compressive strength of EPS foam ranges from 70 to 700 kPa. This property makes EPS suitable for applications that require load-bearing capabilities, such as building foundations, road construction, and packaging.

- Moisture resistance: EPS has low moisture absorption properties, which helps to maintain its insulation performance over time. The moisture absorption of EPS foam is typically less than 5% by volume. This resistance to moisture is important in construction applications, as it helps prevent the degradation of insulation properties due to moisture infiltration.

- Versatility and design flexibility: EPS can be easily shaped and molded into various forms, allowing for versatile design possibilities. Its adaptability allows manufacturers to create customized products for specific applications, such as packaging inserts, insulation boards, and decorative shapes. The flexibility of EPS enables it to meet the specific needs of different industries.

- Chemical resistance: EPS exhibits excellent resistance to many chemicals, including alkalis and acids. This property makes it suitable for applications where exposure to chemicals is expected, such as in industrial settings or transportation of hazardous materials.

- Cost-effectiveness: EPS is a cost-effective material due to its relatively low production costs and widespread availability. Its affordability makes it a preferred choice in many industries, ranging from construction to packaging, as it offers a balance between performance and cost.

While these advantages can be described in terms of specific properties, it's important to note that the performance of EPS can vary depending on the specific product, manufacturing process, and application.

2.2.3 Formica sheet

Formica is a brand name that has become synonymous with high-pressure laminate (HPL) sheets. Basically, more than 60% of Formica Laminate consists of paper and the remaining 30 to 40% consists of cured phenol-formaldehyde resin for core layers and melamine-formaldehyde resin for the surface layer. These sheets are widely used for surfacing applications, such as countertops, furniture, cabinets, and wall panels. Here are the detailed properties of Formica sheets:

- **Material Composition:** Formica sheets are composed of multiple layers of materials, including kraft paper impregnated with resin, decorative paper, and a clear protective overlay. These layers are then bonded together under high heat and pressure to create a durable and rigid laminate.

- **Durability:** Formica sheets are known for their exceptional durability. They are resistant to scratches, impact, and general wear and tear, making them suitable for high-traffic areas and applications where surfaces might undergo frequent use.

- **Resistance to Stains:** Formica sheets have a non-porous surface that resists staining from various household items, including common liquids like water, coffee, tea, and even certain chemicals. This property makes them easy to clean and maintain.

- **Heat Resistance:** While Formica sheets are relatively heat-resistant, they can be damaged by excessive heat. Hot pots and pans should not be placed directly onto the surface. Using trivets or hot pads is recommended to prevent potential damage.

- **Design Options:** Formica sheets are available in a wide range of designs, colors, patterns, and textures. They can mimic the appearance of natural materials like wood, stone, and metal, providing versatile options for interior design projects.

- **Ease of Installation:** Formica sheets are relatively easy to work with and can be installed on various surfaces, including wood, particleboard, and MDF (medium-density fiberboard). They can be cut, shaped, and routed to suit specific design requirements.

- **Hygienic Properties:** The non-porous surface of Formica sheets inhibits the growth of mold, mildew, and bacteria, making them a suitable choice for kitchen and bathroom applications.

- **Versatility:** Formica sheets can be used in a variety of applications, from countertops and cabinets to furniture and wall panels. They offer a cost-effective way to achieve a desired aesthetic without the expense of using natural materials.

- **Maintenance:** Cleaning Formica surfaces is relatively simple. Regular wiping with a damp cloth and mild household cleaner is usually sufficient to keep the surface clean and looking its best.

- **Environmental Considerations:** Many Formica products are made using sustainable practices and eco-friendly materials. Always check for certifications like Forest Stewardship Council (FSC) certification to ensure that the product meets certain environmental standards.

- **Affordability:** Formica sheets are generally more affordable than natural materials they mimic, making them a budget-friendly option for achieving specific design aesthetics.

- **Applications:** Formica sheets find use in both residential and commercial settings. They are popularly used for kitchen and bathroom countertops, cabinetry, tabletops, shelving, wall panels, and furniture surfaces.

Therefore, the Formica sheet is very suitable. Advantages of Formica sheet include good insulating and antistatic properties and low thermal conductivity and moderate moisture regain. Other benefits of Formica include acoustic insulating properties and manufacture with no skin irritations.

2.2.4 Epoxy Resin and Hardener

Epoxy resin comes in two parts: a resin and a hardener. Mixing the resin and hardener prompts a chemical reaction between the two, transforming them from a liquid into a solid in 24 hours. The chemical formula of epoxy resin is $C_{21}H_{25}ClO_5$. Correctly measured and thoroughly mixed epoxy resin is required for perfect cures. Epoxy resins fall into two types based on their molecular structure and applications: glycidyl epoxy and non-glycidyl epoxy. These can be further divided into three types based on their configuration: glycidyl ether, glycidyl ester, and glycidyl amine.

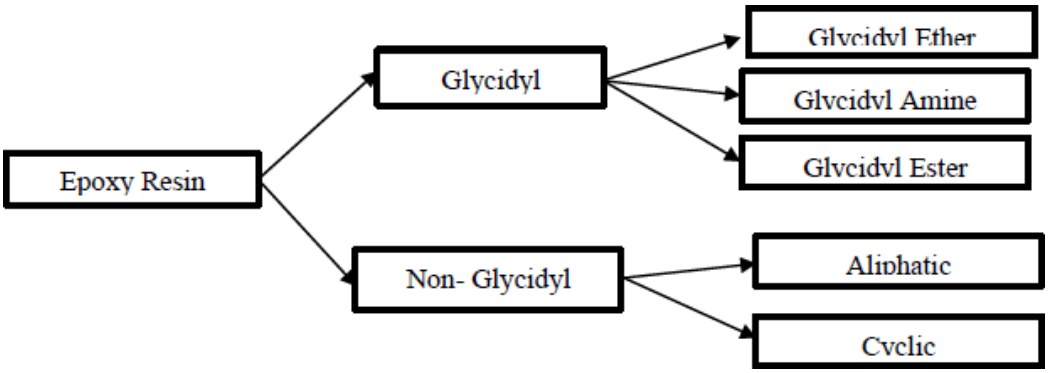

Figure 2 Classification of epoxy-resin

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,

- Excellent adhesion to various substrates.
- Low cost and low toxicity.
- Chemical and solvent resistance,
- High Strength.
- 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 composites 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.

2.3 Related Previous Works

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 10, 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].

The use of expanded polystyrene (EPS) and expanded perlite (ExP) as lightweight aggregates in geo-polymer composites reduced the total weight of the products and improved their thermal performance, but led to a decrease in mechanical performance. EPS achieved a better combination of physical, mechanical, and thermal properties due to its stability and better distribution within the geo-polymer matrix. The incorporation of 3 wt.% EPS resulted in a 40% reduction in thermal conductivity but also a 77% reduction in compressive strength and a 37% reduction in flexural strength. Fiber reinforcement with polypropylene (PP) fibers increased the flexural strength of the lightweight samples by 65% without affecting the compressive strength and density. The lightweight geo-polymer composites exhibited a density range of 1.0-1.6 g/cm3, compressive strength of 10-33 MPa, flexural strength of 1.8-6.3 MPa, thermal conductivity of 0.29-0.42 W/mK, 0.031-0.056 mm/min^0.5.[15]

The paper investigates the flexural behavior of a sandwich structure made of perlite composite foam core and brown paper skin, considering the properties of the constituents and manufacturing variables. The study finds that the performance of the brown paper is best when coated with undiluted sodium silicate binder, and the load carrying capacity of the perlite foam core is significantly increased when reinforced with brown paper. The failure initiation site in the flexural specimen shifts to the mid-plane when the foam core is sandwiched with the brown paper. The paper conducted tension tests on brown paper specimens coated with sodium silicate solutions to control binder content. The coated specimens were dried in an electric oven. The paper fabricated sandwich composites using brown paper as the skin and perlite foam/sodium silicate core. Different manufacturing variables of the foam core and properties of the constituent materials were investigated. The flexural behavior of the sandwich structure was studied using a three-point bending test. The dimensions and shapes of the test specimens were determined. The mechanical properties of the coated and uncoated skin paper were evaluated, including tensile strength. Scanning electron microscope (SEM) images were taken from failed specimens to analyze the effects of coating on the paper surface. Note: The methods used in the paper primarily involve tension tests, fabrication of sandwich composites, flexural testing, and evaluation of mechanical properties[16].

The addition of nylon fiber reinforcement in expanded perlite/sodium silicate composites improved the mechanical properties, such as flexural and compressive strength, as well as energy absorption during testing. The optimal percentage of nylon fiber reinforcement was found to be 1.62%, beyond which the properties deteriorated. The compressive strength and modulus increased by 12.38% and 119.18% respectively, compared to the composite without fiber, with the addition of 1.62% nylon fiber .The flexural strength and modulus increased by 34.15% and 12.46% respectively, for a nylon fiber content of 1.62% compared to the composite with 0% nylon fiber content .However, the flexural and compressive properties deteriorated with the further addition of nylon fiber to the composites .The decrease in properties with the addition of 2.41% nylon fiber was attributed to the lack of sodium silicate binder on the surface of the particles. The fiber content of 1.62% may be a threshold for the compressive and flexural properties of the composites studied in this work[17].

Lightweight concrete (LWC) is a promising modern construction material due to its lower density, higher specific strength, better thermal insulation, and greater energy absorption compared to ordinary concrete. Lightweight aggregate, which can be natural or artificial, is used to replace standard aggregate in LWC. Expanded polystyrene (EPS) is an artificial ultra-lightweight aggregate with a density of only 10-30 kg/m3. The paper aims to provide basic

information about the relationship between the elementary composition and properties of EPS concrete using the Taguchi method, a statistical and systematic approach. The density and compressive strength of EPS lightweight aggregate concrete were tested and discussed, with the objective of finding the optimal mixture proportioning. The density of EPS concrete showed an almost linear decrease as the volume of EPS and water/cement (W/C) parameters increased, but this resulted in a decrease in compressive strength. EPS lightweight concretes displayed good workability, but mixtures with higher EPS aggregate content showed a tendency of segregation and collapse, leading to a lower degree of compaction and reduction in strength. The density of EPS lightweight concrete varied from about 1700 kg/m3 to 2100 kg/m3, with a saving in dead-load between 10 and 30 compared to conventional normal weight concrete. The main factors affecting the density of EPS lightweight concrete were the volume of EPS, water-cement ratio, and cement content, while the sand ratio played a comparatively less important role. [7]

The use of modified waste expanded polystyrene aggregates (MEPS) as a replacement for natural aggregate in lightweight concrete can result in a significant reduction in density, making it a lightweight material suitable for various applications. MEPS concrete exhibits good workability and can be easily compacted and finished, although care must be taken during mixing, pouring, and compacting to minimize segregation of the concrete mixture. The addition of a superplasticizer to the concrete mixture can improve the workability of MEPS concrete, compensating for the reduced workability caused by the thermal treatment method applied to the MEPS aggregate particles. The strength of MEPS concrete is directly proportional to the concrete density, with an increase in strength observed as the natural coarse aggregate size increases. The compressive strength and ultrasonic pulse velocity (UPV) of MEPS concrete increase with the curing period, although MEPS can cause a reduction in both properties at all curing periods. The splitting-tensile strength of MEPS concrete also increases with increasing concrete density, reaching up to 64% higher when natural aggregates are used. The study investigated the effects of using modified waste expanded polystyrene aggregates (MEPS) as a replacement for natural aggregate in lightweight concrete. MEPS concrete exhibited a density range of about 900-1700 kg/m3, making it a lightweight material suitable for various applications. The compressive strengths of MEPS concrete ranged from 12.58 MPa to 23.34 MPa, satisfying the strength requirement of semi-structural lightweight concrete. The addition of MEPS aggregates resulted in a decrease in the slump values of the fresh concretes, with the highest decrease observed for a higher MEPS ratio. MEPS caused a reduction in both compressive strength and ultrasonic pulse velocity (UPV) during the early-age curing period, especially for samples with high volumes of MEPS. However, both properties increased with the increase of the curing period. The splitting-tensile strength of MEPS concrete increased with increasing concrete density, reaching up to 64% higher when natural aggregates were used[18].

The paper introduces a novel method to evaluate the homogeneity of concrete during setting, which is a significant contribution to the field. The paper explores the concept of partially replacing EPS beads with foam with a bubble diameter of 25-100 µm, which is relevant to builders interested in using lightweight concrete in their projects. The paper demonstrates that the segregation of EPS concrete can be significantly reduced by optimizing the foam content, leading to improved concrete quality. The introduction of a proper amount of foam enhances the strength of EPS concrete, making it more suitable for structural applications. The paper highlights that EPS foamed concrete exhibits ductility and has a high energy absorption capacity, which is valuable information for designers and engineers. The

workability of fresh EPS foamed concrete was evaluated in terms of slump, and the density and workability of each fresh concrete were measured immediately after mixing. Compressive strength tests were conducted on EPS foamed concrete using a servo hydraulic testing machine, and the mechanical properties were characterized. The thermal conductivity of the concrete was measured using a non-stationary method, and the thermal and mechanical properties of the concrete were determined. The segregation of EPS concrete was evaluated by testing the densities of different layers, and the influence of foam content on segregation was examined. Note: The paper provides detailed results on the workability, mechanical properties, thermal conductivity, and segregation of EPS foamed concrete[19].

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 kg/m3 (0.065–0.075 g/cm3) was selected.

Figure 3 Sieving of Expanded Perlite

3.1.2 Epoxy Resin and Hardener

The epoxy resin-hardener mixer density was 3:1 for skin and 3:1 for core, and the curing time was 24 hours for both. For the curing of sandwich composite, the compression molding technique was followed.

Figure 4 Epoxy Resin (3:1)

3.1.3 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. It used 20% for every sample according to weight.

Figure 5 Acetone for Dilution Epoxy Solution

3.1.4 Expanded Polystyrene Beads

Expanded Polystyrene (EPS) beads are lightweight, versatile, and widely used in various industries due to their unique properties and characteristics. EPS beads are a type of thermoplastic polymer derived from styrene monomer. The process of creating EPS involves expanding polystyrene through the application of heat and pressure, leading to the formation of small spherical beads. EPS beads come in a range of sizes, typically varying from 5 to 6 millimeters in diameter.

Figure 6 Sieving of Expanded Polystyrene (EPS).

3.1.5 Formica sheet

Formica sheets are widely known for their versatile use in interior design, furniture, and architectural applications. Formica is a brand name that has become synonymous with high-pressure laminate (HPL) sheets, which are made by layering various materials and applying heat and pressure. These sheets are commonly used to provide attractive and durable surfaces for countertops, cabinets, furniture, and wall panels. Formica sheets come in various sizes and thicknesses to cater to different applications.

The sheet sizes is 150 mm by 150 mm. The thickness of Formica sheets is 0.5mm.

Figure 7 Sized Formica Sheet (FS)

3.2 Specimen Preparation

The following steps are followed sequentially in specimen preparation as given below.

3.2.1 Elementary Process

First of all measure the amount of expanded polystyrene and expanded perlite as per the model. The quantities of perlite and expanded polystyrene used for the following samples are given:

Table 3 Amount of material in the samples

Sample code	Percentage of element	Perlite (ml)	Expanded polystyrene (ml)	Solution for core (gm) (Resin/hardener)	Solution for skin (gm) (Resin/hardener)
EPS-100,EP-0	EPS=100% EP=0%	0	400	30/10	12/4
EPS-75,EP-25	EPS=75% EP=25%	100	300	30/10	12/4
EPS-50,EP-50	EPS=50% EP=50%	200	200	30/10	12/4
EPS-25,EP-75	EPS=25 EP=75%	300	100	30/10	12/4
EPS-0,EP-100	EPS=0% EP=100%	400	0	30/10	12/4

Figure 10 Epoxy-Resin Solution (ERS) preparation.

Figure 9 Determining the weight of EPS.

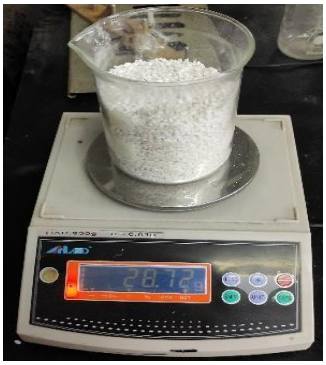

Figure 8 Determining the weight of EP.

Cover the mold plate with plastic to prevent the solution from sticking to the mold and to easily separate the sample from the mold. The mold should be twisted well.

3.2.2 Core preparation

Now in a container the measured perlite and expanded polystyrene along with the solution prepared for the core should be mixed well together in the container. Take about five minutes to mix well. When these three ingredients are completely mixed well. Then this mixture should be poured into the mold. After pouring, special care should be taken to ensure that the materials reach the corners of the mold properly. Then the upper layer should be leveled well so that there is no high and no low. That is why it should be leveled around with light pressure.

Each step is shown sequentially through figure:

Figure 12 Wrapping ladle Sheet

Figure 11 Wetting Dry EP & EPS with (ERS)

Figure 13 Wetted EPS and EP Pouring

Figure 14 Pressed EPS & EP

3.2.3 Skin preparation

From the solution that is made for the skin, take the solution well and wet it well on the skin. So that the skin gets thoroughly wet with the solution. Then the mold should be placed very carefully on the wet skin. So that the mold sits nicely around the skin. After placing the mold properly, the materials should be poured inside the mold.

Figure 16 Wetting Dry EP & EPS with (ERS)

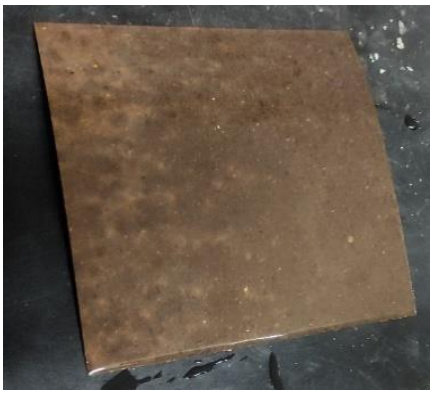

Figure 15 Wetted Skin

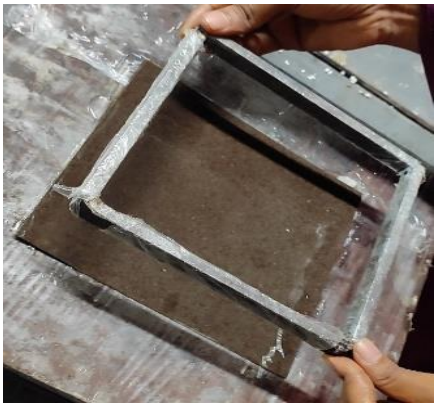

Figure 17 Placing Mold

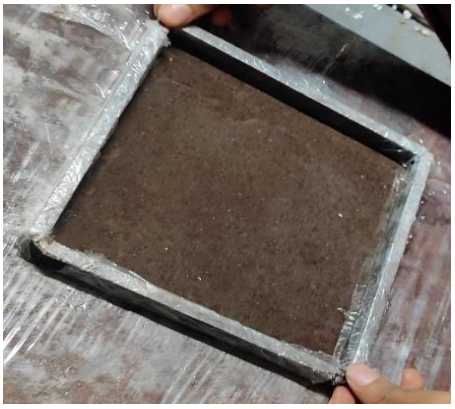

Figure 18 Placed Mold

3.2.4 Sandwich structure fabrication

After pouring the materials into the mold, after leveling it very well on the upper layer of the mold, the upper skin of the mold should be thoroughly moistened with the solution prepared for the skin. When the upper skin is thoroughly soaked with the solution. Then the upper skin should be held squarely on the mold. After the top skin is placed neatly on the core, the entire core is then pressed with a mold plate. Similarly another mold is prepared in the same way, another mold plate should be pressed on that mold. After that sample preparation should be started.

Figure 19 Placement of upper skin

Figure 20 Placement of upper skin

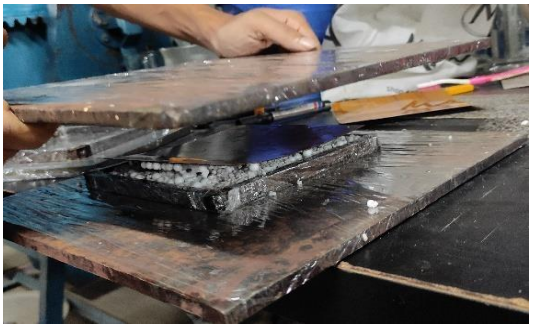

Figure 21 Placement of upper ladle

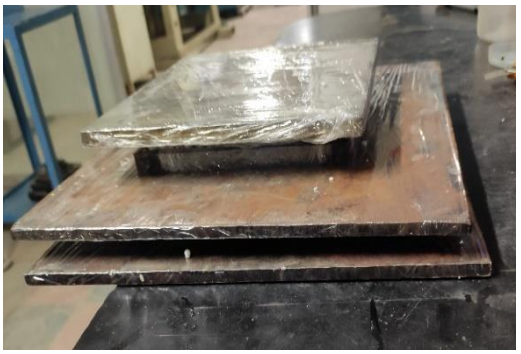

Figure 22 Placement of ladle on the mo

3.2.5 Sample preparation process

In the sample preparation process, the mold setup must first be left for 24 hours by applying pressure through a universal testing machine. Then take out the original setup from the universal testing machine. From there the sample has to be taken out very carefully. After taking out, the samples should be kept in an electric oven at 60 degrees Celsius for 24 hours. So that acetone evaporates easily from the sample. Then the sample should be taken out of the electric oven and stored. In this way the simple preparation process will be complete. [20]

Figure 23 Compression process

Figure 24 Drying in woven for evaporation of Acetone

Figure 25 Prepared sandwich structure

3.3 Physical and Mechanical Test

3.3.1 Flexural Test

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

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

Figure 26 Sandwich panel dimension

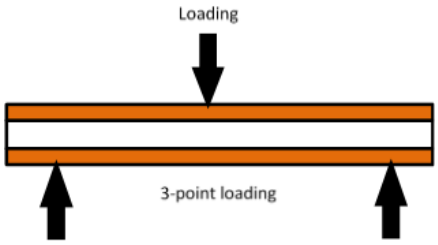

Figure 27 Three-point mid-span loading configuration

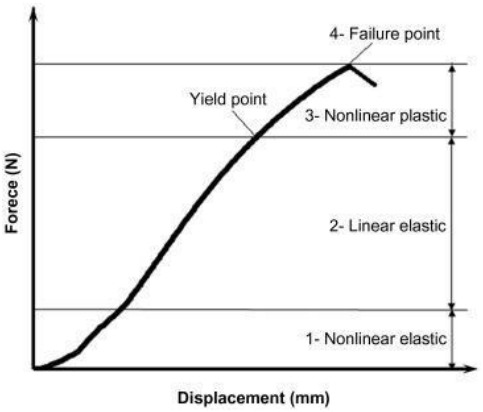

Figure 28 force displacement curve

Where,

Fs = Flexural strength, MPa [psi]

P_{max} = Force 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:

$$E = \frac{P2-P1}{\sigma 2-\sigma 1}$$

Where,

E = flexural modulus,

P_2 = Applied force corresponding.

P_1 = Applied force corresponding.

Ơ2= Value of deflection corresponding to P2

Ơ1= Value of deflection corresponding to P1

Universal Testing Machine was used to perform these tests and the speed of testing was 5 mm/min. Sandwich panels of dimension 150×150×12 mm from which samples for the flexural test were cut in 150×25×12mm and there were at least four test specimens per test condition.

3.3.2 Compression Test

The ASTM C365 test method was used to determine the flatwise compression properties (compressive strength and modulus) of the sandwich structure. Sandwich panels of dimension (150×150×12) mm^3 from which samples for compression test were cut in (25×25×12) mm^3 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,

$$F = \frac{P}{A}$$

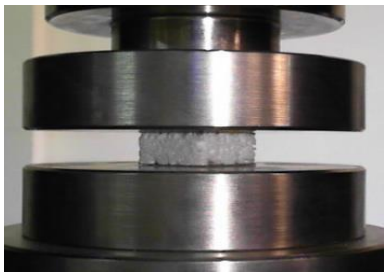

Figure 29 Compression test arrangement

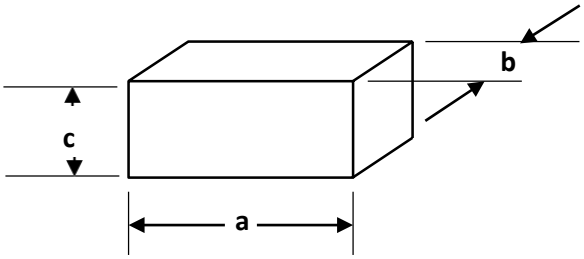

Figure 30 a conceptual illustration of the sandwich cross-section

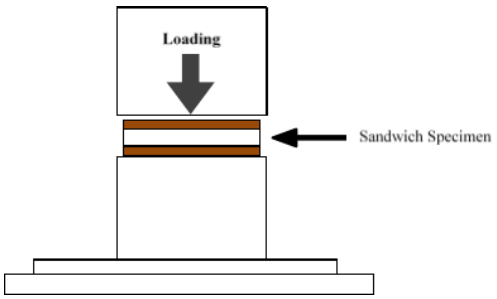

Figure 31 Schematic diagram of compression test

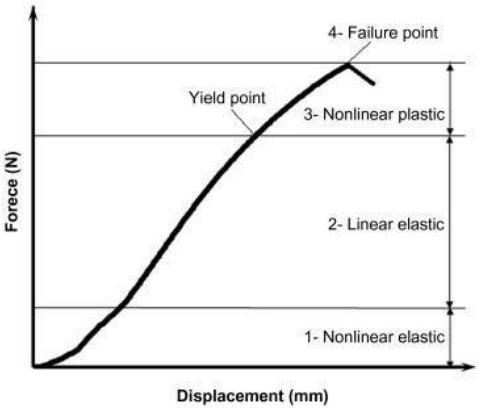

Figure 32 Force-displacement curve

Where,

F = Ultimate flatwise compressive strength, (MPa)

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

A = Cross sectional Area, (mm^2)

Flatwise compressive modulus was calculated using the following equation,

$$E = \frac{P2 - P1}{\sigma 2 - \sigma 1}$$

Where,

E = flexural modulus,

P_2 = Applied force corresponding to ✿2

✿1= Value of deflection corresponding to P1

4 RESULTS AND DISCUSSION

4.1 Physical Properties

Material characterization is the method of measuring and ascertaining the microstructural, 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 4 Experimental data for density calculation for compression test specimens where PS-100 (percentage of polystyrene) P-0 (percentage of perlite) and (1.1) as specimen number for sample variation 01.

SL No	Sample Code & Element Number	Length (mm)	Avg.1	Width (mm)	Avg.2	Thickness (mm)	Avg.3	Mass (g)	Avg.4	Volume (cm^3)	Density (g/cm^3)	Avg. Density (g/cm^3)
1	PS-100,P-0,(1.1)	25.23	25.35	25.27	25.48	12.35	12.08	1.44	1.44	7.80	0.18	0.18
		25.95		25.76		11.54		1.40				
		24.86		25.42		12.34		1.47				
2	PS-100,P-0,(1.2)	24.85	25.46	24.79	25.22	12.45	12.60	1.33	1.38	8.09	0.17	
		25.56		25.65		12.48		1.43				
		25.96		25.21		12.87		1.37				
3	PS-100,P-0,(2.1)	25.45	25.22	24.89	25.38	12.45	12.06	1.35	1.34	7.72	0.17	0.18
		25.64		25.41		11.78		1.38				
		24.56		25.83		11.96		1.30				
4	PS-100,P-0,(2.2)	25.52	25.35	24.69	25.01	12.64	12.64	1.41	1.41	8.01	0.18	
		24.79		24.71		12.53		1.43				
		25.73		25.62		12.74		1.40				

Table 5 Experimental data for density calculation for compression test specimens where PS-100 (percentage of polystyrene) P-0 (percentage of perlite) and (1.1) as specimen number for sample variation

SL No	Sample Code & Element Number	Length (mm)	Avg.1	Width (mm)	Avg.2	Thickness (mm)	Avg.3	Mass (g)	Avg.4	Volume (cm^3)	Density (g/cm^3)	Avg. Density (g/cm^3)
5	PS-75,P-25,(1.1)	25.23	24.93	25.71	25.23	12.35	11.95	2.22	2.12	7.51	0.28	0.29
		24.45		24.83		11.54		2.12				
		25.12		25.14		11.95		2.02				
6	PS-75,P-25,(1.2)	25.38	25.26	25.51	25.05	12.45	12.60	2.30	2.32	7.97	0.29	
		25.92		25.12		12.48		2.35				
		24.49		24.51		12.87		2.30				
7	PS-75,P-25,(2.1)	25.18	25.17	25.46	25.26	12.45	12.52	2.25	2.25	7.96	0.28	0.29
		24.84		25.20		12.43		2.25				
		25.50		25.13		12.67		2.25				
8	PS-75,P-25,(2.2)	25.65	25.43	25.56	25.38	12.89	12.83	2.46	2.44	8.28	0.29	
		25.40		25.44		12.67		2.46				
		25.25		25.13		12.94		2.40				

Table 6 Experimental data for density calculation for compression test specimens where PS-100 (percentage of polystyrene) P-0 (percentage of perlite) and (1.1) as specimen number for sample variation 04.

Sl No	Sample Code & Element Number	Length (mm)	Avg.1	Width (mm)	Avg.2	Thickness (mm)	Avg.3	Mass (g)	Avg.4	Volume (cm^3)	Density (g/cm^3)	Avg. Density
9	PS-50,P-50,(1.1)	25.74	25.56	25.84	25.47	12.45	12.54	3.42	3.47	8.16	0.43	
		25.43		24.94		12.29		3.56				
		25.51		25.63		12.87		3.44				0.44
10	PS-50,P-50,(1.2)	25.67	25.29	25.52	25.36	12.40	12.52	3.74	3.61	8.03	0.45	
		24.87		25.54		12.50		3.63				
		25.34		25.03		12.67		3.47				
11	PS-50,P-50,(2.1)	25.93	25.21	25.34	24.96	12.30	12.45	3.73	3.71	7.83	0.47	
		25.12		25.42		12.85		3.68				
		24.57		24.12		12.20		3.71				0.44
12	PS-50,P-50,(2.2)	25.12	25.12	24.63	25.18	11.78	12.28	3.47	3.10	7.77	0.40	
		25.45		25.15		12.64		2.71				
		24.78		25.75		12.42		3.12				

Table 7 Experimental data for density calculation for compression test specimens where PS-100 (percentage of polystyrene) P-0 (percentage of perlite) and (1.1) as specimen number for sample

Sl No	Sample Code & Element Number	Length (mm)	Avg.1	Width (mm)	Avg.2	Thickness (mm)	Avg.3	Mass (g)	Avg.4	Volume (cm^3)	Density (g/cm^3)	Avg. Density (g/cm^3)
13	PS-25,P-75,(1.1)	25.41	25.12	25.34	24.99	11.95	11.97	3.44	3.49	7.52	0.46	
		25.83		25.19		12.32		3.44				0.44
		24.13		24.45		11.65		3.60				
14	PS-25,P-75,(1.2)	24.71	25.35	25.52	25.56	11.95	12.46	3.44	3.42	8.08	0.42	
		25.62		25.74		12.62		3.40				
		25.71		25.43		12.82		3.42				
15	PS-25,P-75,(2.1)	24.83	25.16	25.51	25.35	12.82	12.46	3.47	3.46	7.95	0.44	
		25.14		25.67		12.73		3.46				0.44
		25.51		24.87		11.84		3.45				
16	PS-25,P-75,(2.2)	25.12	25.12	25.34	25.46	12.93	12.47	3.44	3.56	7.97	0.45	
		24.51		25.93		12.12		3.47				
		25.73		25.12		12.35		3.78				

variation 03.

Table 8 Experimental data for density calculation for compression test specimens where PS-100 (percentage of polystyrene) P-0 (percentage of perlite) and (1.1) as specimen number for sample variation 05

SL No	Sample Code & Element Number	Length (mm)	Avg.1	Width (mm)	Avg.2	Thickness (mm)	Avg.3	Mass (g)	Avg.4	Volume (cm^3)	Density (g/cm^3)	Avg. Density (g/cm^3)
17	PS-0,P-100,(1.1)	25.76	25.32	24.57	25.05	12.12	12.11	3.62	3.62	7.68	0.47	
		25.42		25.12		12.32		3.63				0.46
		24.79		25.45		11.88		3.60				
18	PS-0,P-100,(1.2)	25.65	25.25	24.78	25.22	11.79	12.19	3.43	3.42	7.76	0.44	
		25.21		25.75		12.32		3.41				
		24.89		25.12		12.47		3.42				
19	PS-0,P-100,(2.1)	25.41	25.12	24.91	25.32	12.45	12.08	3.38	3.58	7.69	0.47	
		24.68		25.71		12.42		3.68				0.45
		25.27		25.34		11.38		3.69				
20	PS-0,P-100,(2.2)	25.71	25.28	25.25	25.24	12.56	12.51	3.36	3.48	7.98	0.44	
		24.75		25.35		12.45		3.56				
		25.37		25.12		12.51		3.53				

Table 9 Experimental data for density calculation for flexural test specimens where PS-100 (percentage ofpolystyrene) P-0 (percentage of perlite) and (1.1) as specimen number for sample variation 01

SL No	Sample Code & Element Number	Length (mm)	Avg.	Width (mm)	Avg.2	Thickness (mm)	Avg.3	Mass (g)	Avg.4	Volume (cm^3)	Density (g/cm^3)	Avg. Density (g/cm^3)
		150.75		25.42		12.54		9.64				
1	PS-100,P-0,(1.1)	150.54	150.54	25.12	25.35	12.43	12.61	9.62	9.63	48.13	0.20	
		150.32		25.52		12.86		9.64				0.20
		150.42		25.74		12.43		9.30				
2	PS-100,P-0,(1.2)	149.87	150.31	25.43	25.56	12.78	12.48	9.30	9.31	47.96	0.19	
		150.63		25.51		12.24		9.32				
3	PS-100,P-0,(2.1)	149.87		25.67		12.67	12.48	8.94	8.94	47.27	0.19	
		149.03	149.78	24.87	25.29	12.31		8.93				0.19
		150.45		25.34		12.45		8.94				
4	PS-100,P-0,(2.2)	149.69		25.93	25.21	12.45	12.60	8.77	8.76	47.77	0.18	
		150.76	150.39	25.12		12.92		8.76				
		150.73		24.57		12.43		8.76				

Table 10 Experimental data for density calculation for flexural test specimens where PS-100 (percentage of polystyrene) P-0 (percentage of perlite) and (1.1) as specimen number for sample variation 02

SL No	Sample Code & Element Number	Length (mm)	Avg.	Width (mm)	Avg.2	Thickness (mm)	Avg.3	Mass (g)	Avg.4	Volume (cm^3)	Density (g/cm^3)	Avg. Density (g/cm^3)
5	PS-75,P-25,(1.1)	150.47		24.87	25.22	11.98	11.97	13.66	13.66	45.30	0.30	0.30
		149.78	150.06	25.84		12.45		13.66				
		149.94		24.94		11.48		13.67				
6	PS-75,P-25,(1.2)	150.47		25.63	25.56	12.98	12.72	14.75	14.74	48.73	0.30	
		149.12	149.81	25.52		12.54		14.73				
		149.85		25.54		12.65		14.75				
7	PS-75,P-25,(2.1)	150.52	150.15	25.03	25.26	12.78	12.58	13.94	13.94	47.72	0.29	0.30
		149.70		25.34		12.56		13.93				
		150.24		25.42		12.40		13.96				
8	PS-75,P-25,(2.2)	149.63	149.92	25.74	25.17	12.50	12.49	14.82	14.82	47.14	0.31	
		150.18		24.63		12.67		14.81				
		149.94		25.15		12.30		14.82				

Table 11 Experimental data for density calculation for flexural test specimens where PS-100 (percentage of polystyrene) P-0 (percentage of perlite) and (1.1) as specimen number for sample variation 03.

SL No	Sample Code & Element Number	Length (mm)	Avg.	Width (mm)	Avg.2	Thickness (mm)	Avg.3	Mass (g)	Avg.4	Volume (cm^3)	Density (g/cm^3)	Avg. Density (g/cm^3)
9	PS-50,P-50,(1.1)	150.47	150.23	25.75	25.23	12.85	12.28	19.01	18.95	46.53	0.41	0.40
		149.48		25.34		12.20		18.83				
		150.73		24.59		11.78		19.01				
10	PS-50,P-50,(1.2)	150.59	149.98	24.97	25.38	12.64	12.34	18.05	18.28	46.95	0.39	
		149.71		25.73		12.42		18.76				
		149.63		25.43		11.95		18.03				
11	PS-50,P-50,(2.1)	150.83	149.81	25.94	25.26	12.32	11.97	18.62	18.61	45.30	0.41	0.41
		149.02		24.34		11.65		18.63				
		149.58		25.49		11.95		18.58				
12	PS-50,P-50,(2.2)	149.53	150.02	25.45	25.11	12.76	12.17	18.46	18.45	45.83	0.40	
		150.12		24.75		11.78		18.45				
		150.42		25.12		11.96		18.44				

Table 12 Experimental data for density calculation for flexural test specimens where PS-100 (percentage of polystyrene) P-0 (percentage of perlite) and (1.1) as specimen number for sample variation 04.

SL No	Sample Code & Element Number	Length (mm)	Avg.	Width (mm)	Avg.2	Thickness (mm)	Avg.3	Mass (g)	Avg.4	Volume (cm^3)	Density (g/cm^3)	Avg. Density (g/cm^3)
13	PS-25,P-75,(1.1)	150.34	150.07	25.45	25.03	12.64	12.64	15.82	15.85	47.46	0.33	0.37
		149.12		25.12		12.53		15.87				
		150.74		24.51		12.74		15.86				
14	PS-25,P-75,(1.2)	150.73	149.96	24.75	25.13	12.35	11.95	18.60	18.64	45.02	0.41	
		149.42		24.97		11.54		18.68				
		149.72		25.67		11.95		18.65				
15	PS-25,P-75,(2.1)	150.28	149.85	24.53	24.93	12.45	12.60	19.76	19.76	47.07	0.42	0.40
		148.89		25.14		12.48		19.74				
		150.38		25.12		12.87		19.78				
16	PS-25,P-75,(2.2)	150.53	150.38	25.86	25.59	12.45	12.47	17.96	17.96	48.00	0.37	
		150.62		25.63		12.43		17.98				
		149.98		25.28		12.54		17.95				

Table 13 Experimental data for density calculation for flexural test specimens where PS-100 (percentage of polystyrene) P-0 (percentage of perlite) and (1.1) as specimen number for sample variation 05.

SL No	Sample Code & Element Number	Length (mm)	Avg.	Width (mm)	Avg.2	Thickness (mm)	Avg.3	Mass (g)	Avg.4	Volume (cm^3)	Density (g/cm^3)	Avg. Density (g/cm^3)
17	PS-0,P-100,(1.1)	150.45	150.02	24.87	25.31	12.48	12.41	20.89	20.88	47.11	0.44	0.43
		149.34		25.47		11.98		20.86				
		150.27		25.59		12.76		20.89				
18	PS-0,P-100,(1.2)	149.43	150.08	25.65	25.42	12.23	12.17	19.50	19.59	46.41	0.42	
		150.54		25.85		12.48		19.58				
		150.26		24.75		11.79		19.68				
19	PS-0,P-100,(2.1)	150.82	149.99	24.84	25.36	12.84	11.96	18.92	18.95	45.49	0.42	0.43
		149.38		25.64		11.36		18.96				
		149.78		25.61		11.67		18.98				
20	PS-0,P-100,(2.2)	150.63	150.42	24.73	25.04	11.78	12.19	19.91	19.95	45.90	0.43	
		149.92		25.92		12.33		19.96				
		150.72		24.46		12.45		19.97				

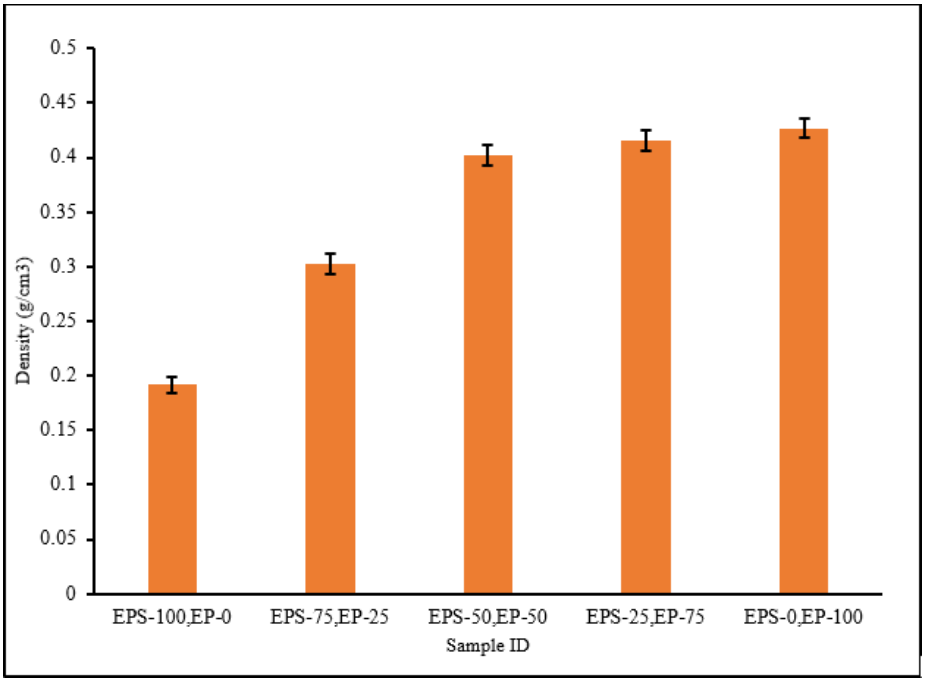

Figure 33 density vs sample id for flexural

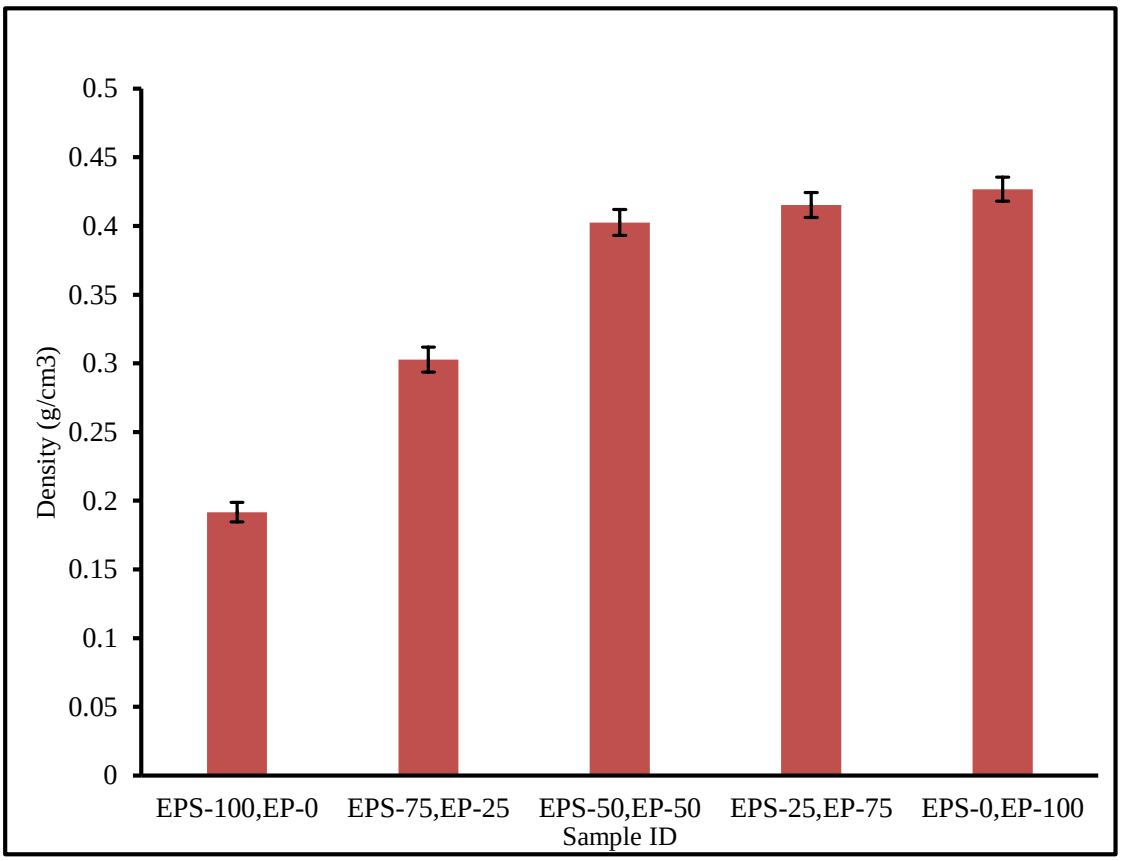

Figure 34 Dencity vs Flexural for compression

4.2 Flexural Properties

After conducting the three-point flexural test for sandwich composite on a universal testing machine at a speed of testing 5 mm/min with a span length of 100 mm for different mixing ratio between EP and EPS, flexural properties were calculated from the raw data produced during the test period.

4.2.1 Flexural Strength and Modulus

Flexural strength and modulus are dependent on density of EPS and EP. As shown in figure 26 gives the maximum strain and maximum modulus of each sample, it can be seen that the maximum strength increases with the increase of pearlite in each sample as shown in *Figure 19*,*Figure 20*,*Figure 21*, and *Figure 22*. It can be seen from these figures that the maximum strength increased gradually as the perlite was added in the samples (EP-0 to 100%), starting from 2.8 MPa to 11.94, similarly the flexural modulus increased in the samples (EP-0 to 100%) as well as expanded pearlite. With increasing, for example, from 0.3 MPa to 1.2 Mpa. As seen in *Figure 25*, finally, *Figure 26* shows how the flexural strength and flexural modulus of the samples increase as density increases.

However, the highest flexural strength and modulus found in the sample (EPS-0, EP-100) in *Figure 22*, is 11.94 MPa similarly, the highest flexural modulus found in the sample (EPS-0, EP-100) is 1.2 MPa in *Figure 25* . As shown at *Figure 23* that the stress and strain curves. Also show that A negative aspect is that 100% pearlite sample (EPS-0, EP-100) showed the highest stress gain but destructive failure was found in 100% pearlite sample (EPS-0,EP-100) . But the highest maximum strength and highest modulus are found in this sample which can be considered as an advantage. Separate figures are given from *Figure 18* to *Figure 22* to see how the maximum stand and maximum modulus of each sample behaved.

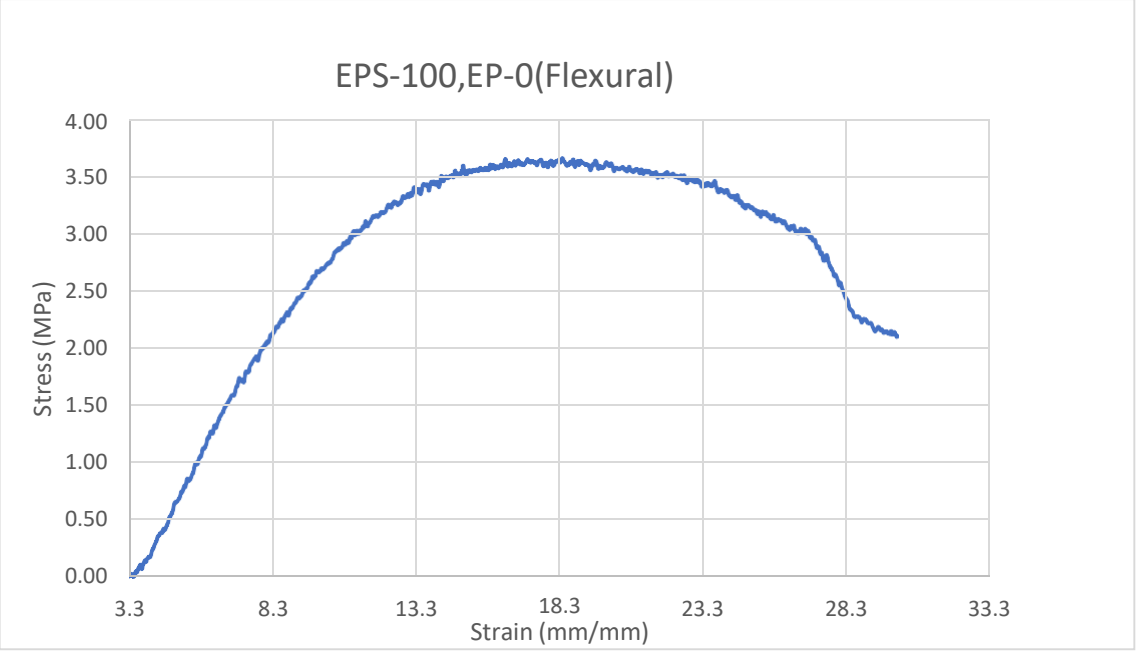

Figure 18 Flexural stress vs strain curve for EPS-100,EP-0

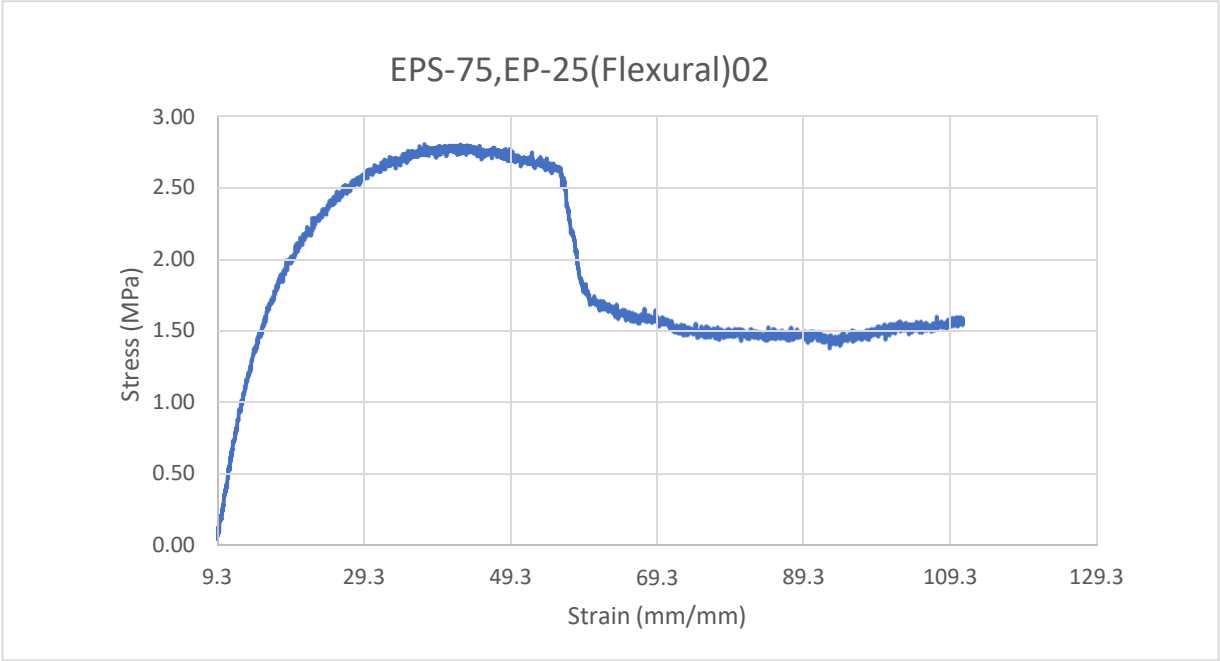

Figure 19 Flexural stress vs strain curve for EPS-75,EP-25

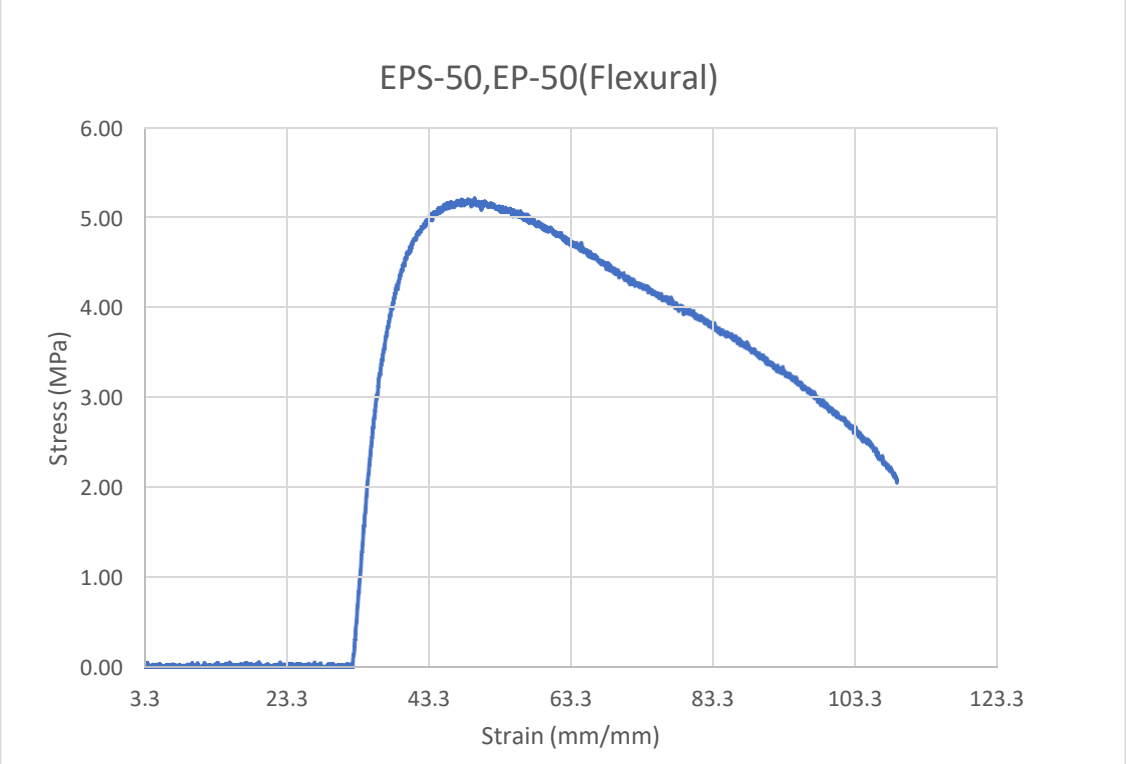

Figure 20 Flexural stress vs strain curve for EPS-50,EP-50,

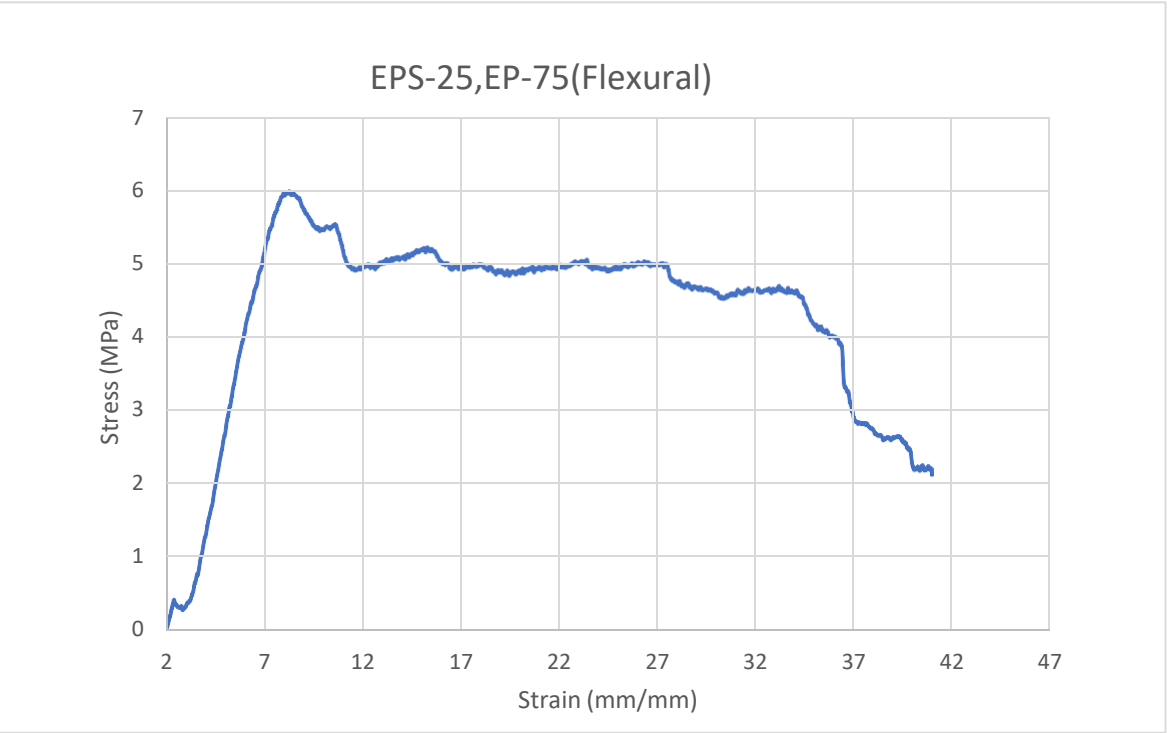

Figure 21 Flexural stress vs strain curve for EPS-25,EP-75

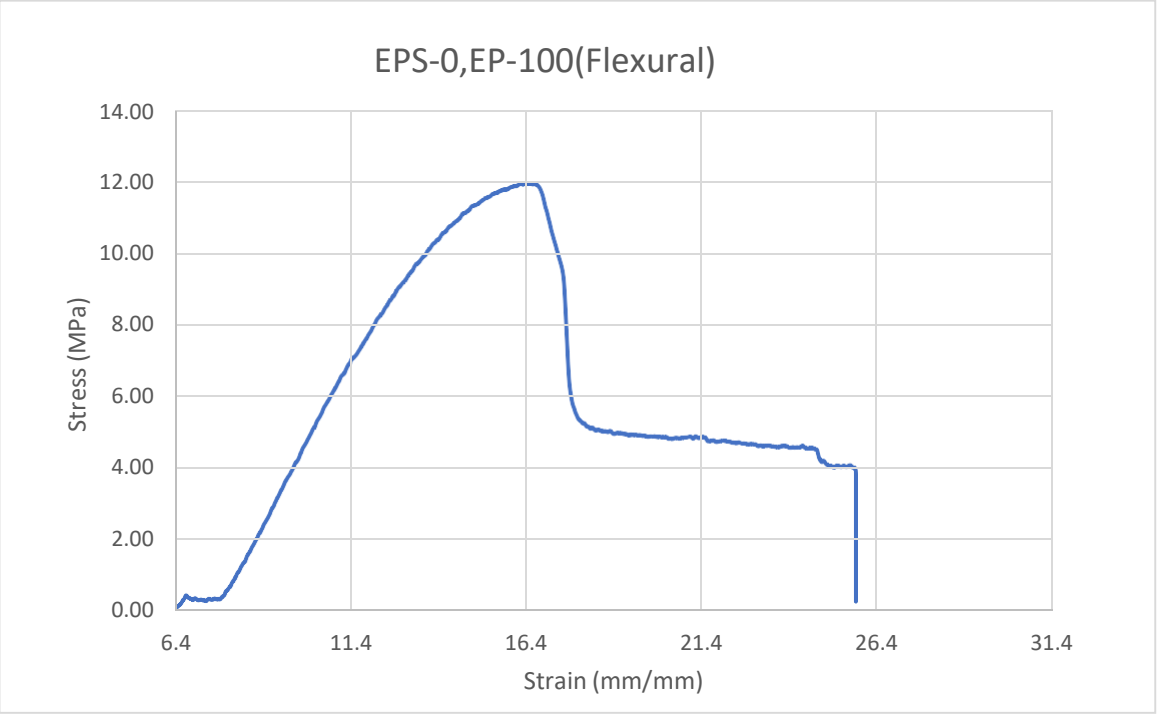

Figure 22 Flexural stress vs strain curve for EPS-0,EP-100

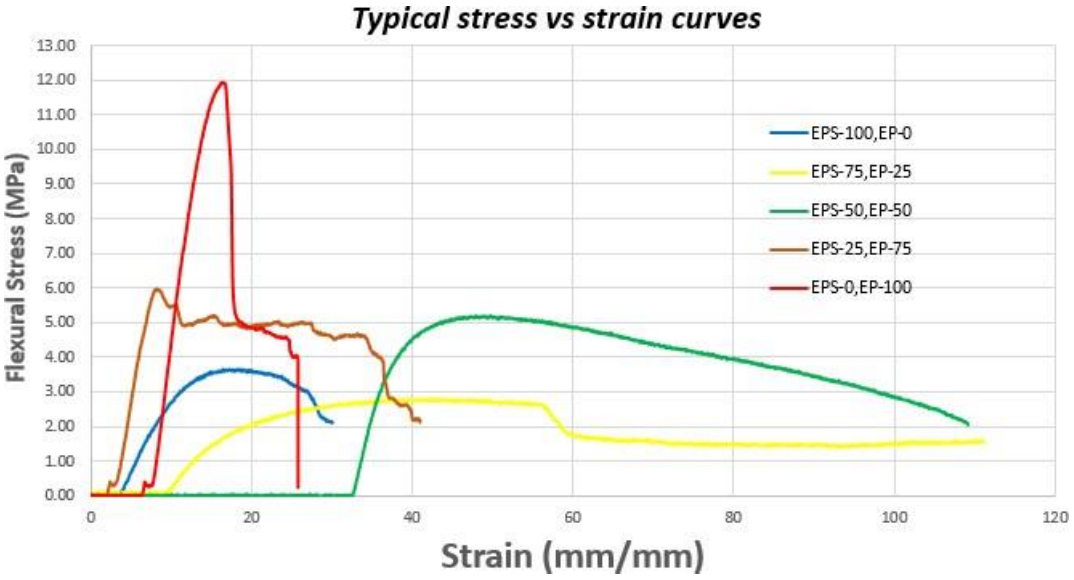

Figure 23 Typical stress vs strain curves for flexural

Table 14 Strength and SD of strength for flexural

Sample id	strength	SD of strength
EPS-100,EP0	3.66	0.36
EPS-75,EP-25	2.8	0.28
EPS-50,EP-50	5.21	0.21
EPS-25,EP-75	5.98	0.32
EPS-0,EP-100	11.94	0.21

Table 15 Modulus and SD for flexural

sample id	modulus	SD of modulus
EPS-100,EP0	0.4	0.05
EPS-75,EP-25	0.3	0.02
EPS-50,EP-50	0.56	0.04
EPS-25,EP-75	0.64	0.05
EPS-0,EP-100	1.2	0.03

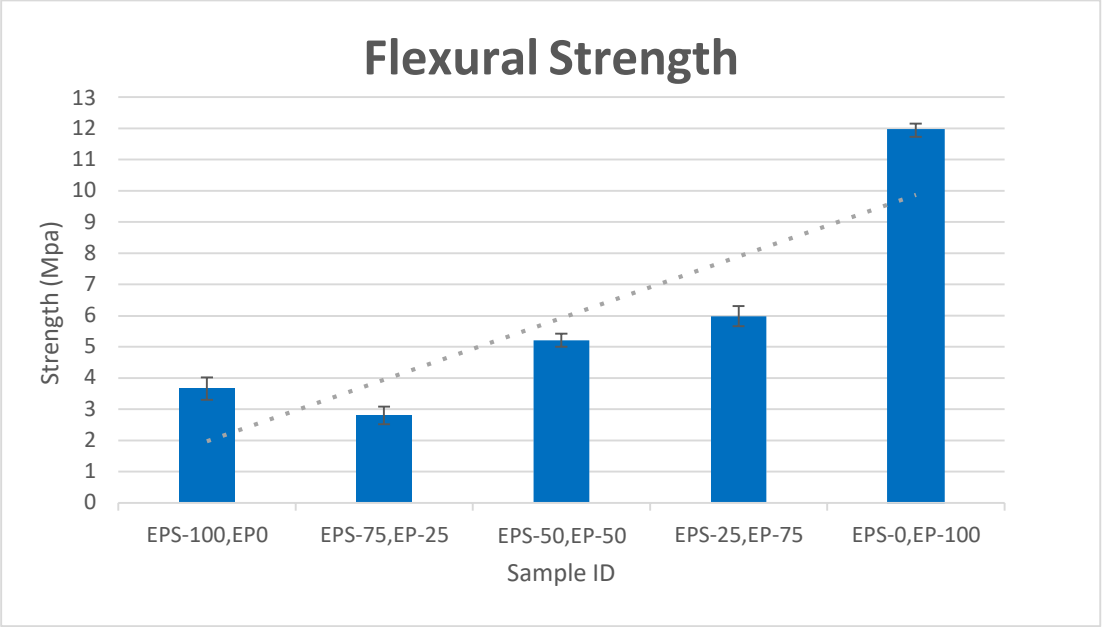

Figure 24 Strength VS Sample Id Graph

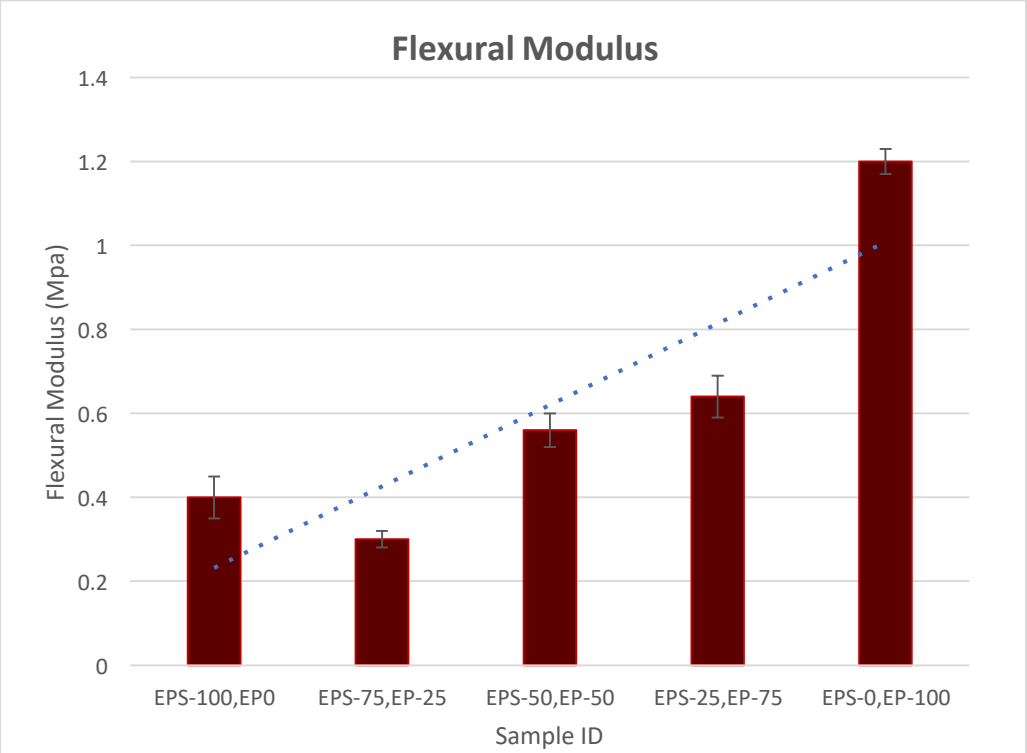

Figure 25 flexural Modulus vs sample id

Table 16 combined strength and modulus

sample id	strength	SD of strength	modulus	SD of modulus
EPS-100,EP0	3.66	0.36	0.4	0.05
EPS-75,EP-25	2.8	0.28	0.3	0.02
EPS-50,EP-50	5.21	0.21	0.56	0.04
EPS-25,EP-75	5.98	0.32	0.64	0.05
EPS-0,EP-100	11.94	0.21	1.2	0.03

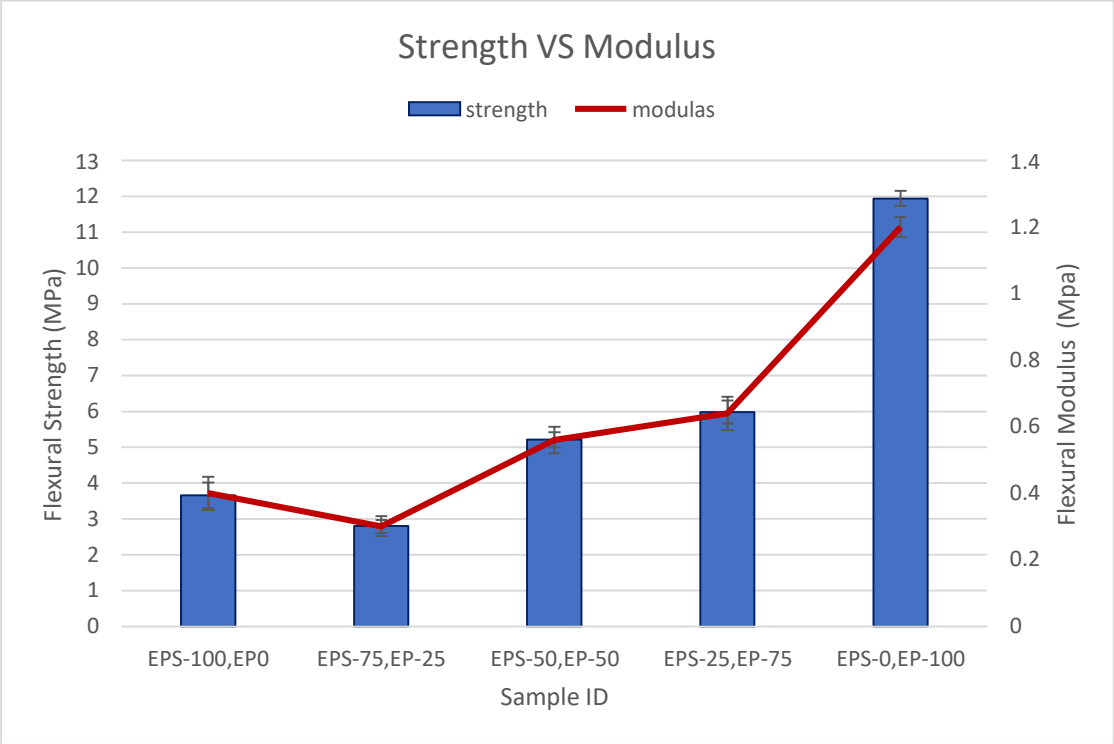

Figure 26 Strength vs Modulus graph

4.2.2 Energy Absorption During Flexural Test

Similarly, energy absorption is observed to increase similarly to Flexural strength and flexural modulus. From *Figure 27*. Sample number five (EPS-0,EP-100) has the highest energy absorption but sample number two(EPS-75,EP-25) has some less energy absorption and from sample number two (EPS-75,EP-75) to sample number five (EPS-0EP-100) there is a very rapid increase in energy absorption.

Table 17 Energy and SD of energy

sample id	Energy	SD of energy
EPS-100,EP0	40	3
EPS-75,EP-25	30.45	4
EPS-50,EP-50	50	2
EPS-25,EP-75	65.32	3
EPS-0,EP-100	78.98	2

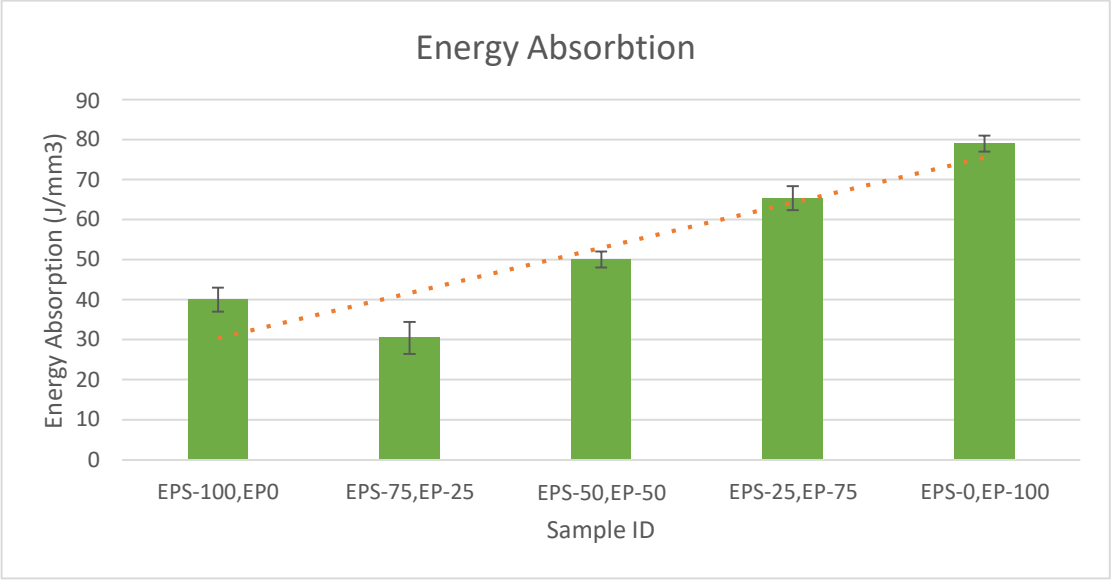

Figure 27 Energy absorption vs sample id

4.2.3 Failure Behavior During Flexural Test

In the case of 100% EPS, no deboning is observed during the test. But as the perlite content increases, deboning occurs and destructive failure occurs as the perlite increases, which is a disadvantage, but as the perlite increases, flexure increases. Generally, the top skin fails first, then the core shares, and then the entire sample is destroyed.

As evidenced by the failed specimens of various samples, the sandwich construction made entirely of EPS did not deboned after compression and rebounded to 20mm after 12mm compression. Sandwich composites with 100% EP showed excellent load-bearing properties. The specimen under compressive load showed notable core bulging before many cracks with irregular orientations began to appear for 100% EP core.

Figure 28 EPS-100,EP-0 sample no deboning appeared

Figure 29 EPS-50,EP-50 sample Deboning appeared

Figure 30 Core share and cracking EPS-25,EP-75 sample

Figure 31 core share and cracking sample EPS-0,EP-100

Table 2 combined strength and modulus data table

sample id	strength	SD of strength	modulus	SD of modulus
EPS-100,EP0	3.66	0.36	0.4	0.05
EPS-75,EP-25	2.8	0.28	0.3	0.02
EPS-50,EP-50	5.21	0.21	0.56	0.04
EPS-25,EP-75	5.98	0.32	0.64	0.05
EPS-0,EP-100	11.94	0.21	1.2	0.03

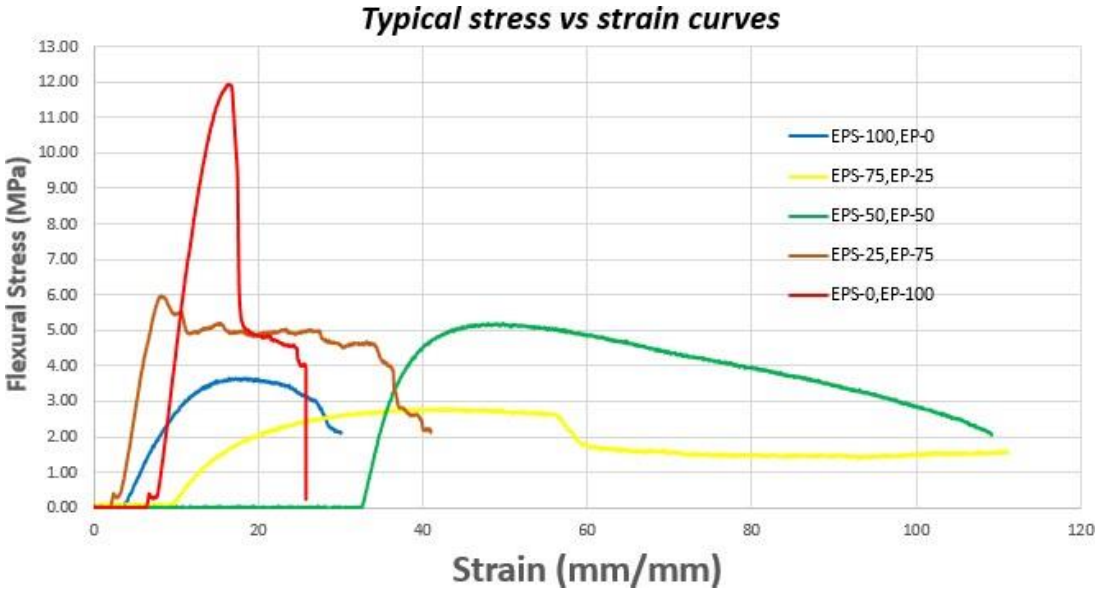

Figure 32 typical stress vs strain curves

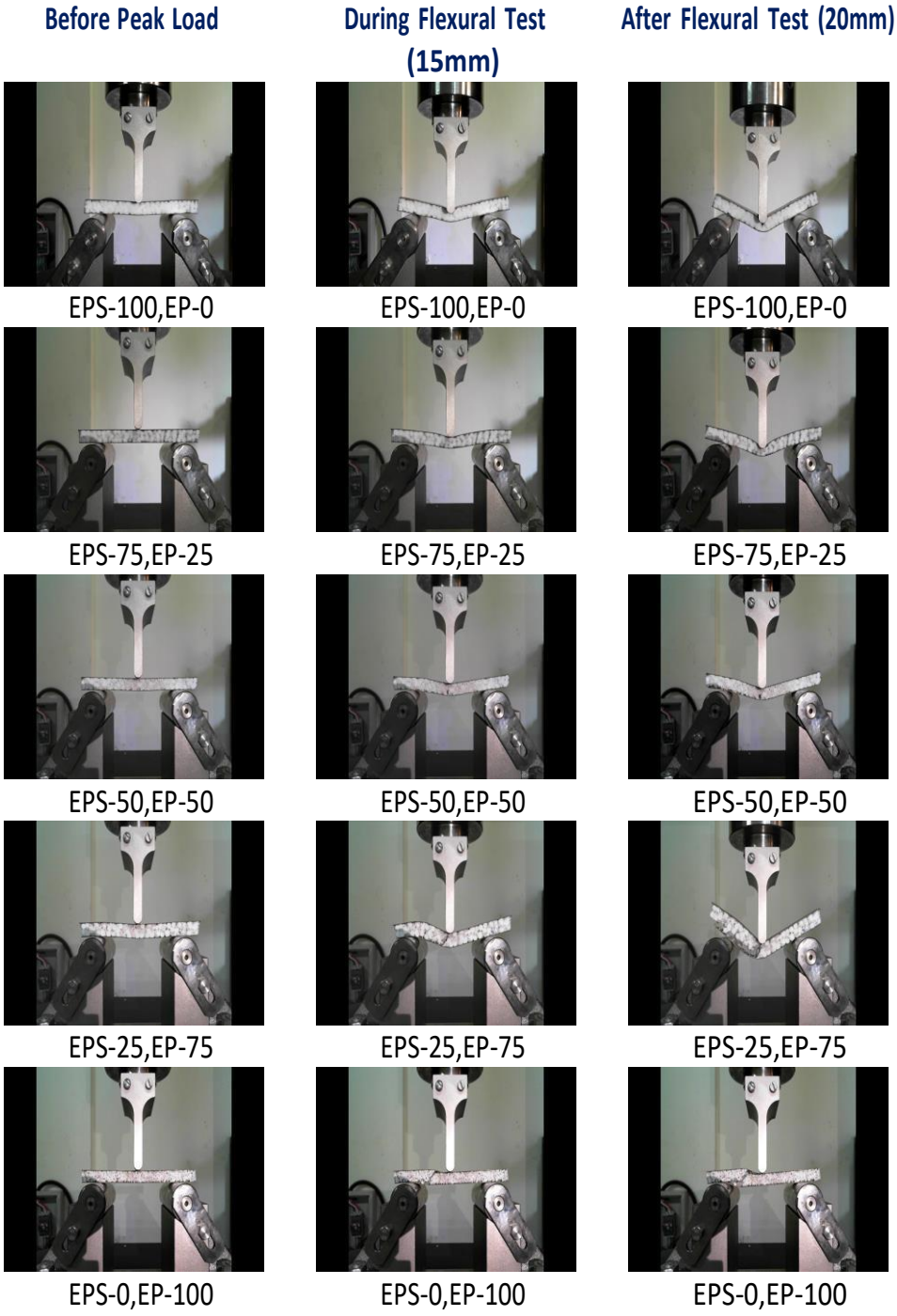

Figure 35 Typical snapshots of the failed sandwiches during flexural test

4.3 Compressive Properties

After performing the flatwise compression test for sandwich composite at a testing speed of 5 mm/min with a sample size of (25*25*12) mm3 on a universal testing equipment. The density of sandwiches produced from Formica sheets was found to range from 0.176 to 0.454 g/cm3. With the addition of EP, the prepared samples' density appeared to slightly rise, but the addition of EPS caused it to somewhat decrease. In comparison to the sample with an EP core, the sample with an EPS core alone has a density of 0.176 g/cm3, which is 61.25 percent less dense.

Table 18 Sandwich structures' compressive properties

SL No.	Sample Code	Density (g/cm^3)	Compressive Strength (MPa)	Compressive Modulus (MPa)	Energy Absorption (J/mm^3) (Stroke 0-8mm)
1	EPS100-EP0	0.176 ± 0.006	0.18 ± 0.03	6.58 ± 1.42	1.83 ± 0.18
2	EPS75-EP25	0.287 ± 0.006	0.83 ± 0.03	21.80 ± 1.60	7.71 ± 0.64
3	EPS50-EP50	0.370 ± 0.008	1.02 ± 0.23	33.18 ± 2.20	15.27 ± 2.97
4	EPS25-EP75	0.443 ± 0.018	2.22 ± 0.08	59.16 ± 3.41	23.47 ± 2.82
5	EPS0-EP100	0.454 ± 0.018	1.55 ± 0.15	32.55 ± 8.06	12.83 ± 2.12

4.3.1 Compressive Strength and Modulus

The typical compressive stress-strain curves of the sandwich structure for different sample ratios are shown in the graph in *Figure 38*. The curves share comparable features, including a linear component that progressively increases, a failure indicator that appears as a little drop, and then a prolonged plateau before densification. Over the strain period 0-0.022 (mm/mm), the compressive stress of samples 2 *Figure 34*, sample 3*Figure 35*, sample 4 *Figure 36*, and sample 5 *Figure 37* dramatically increased; however, the stress of sample 1 (EPS100-EP0) *Figure 33* increased slightly. It can also be observed that, after reaching the peak load, all the samples have a declining tendency with regard to the stress value. Even though sample 4 (EPS25-EP75) *Figure 36* had the highest stress-bearing capacity, it failed catastrophically because its strength was far lower than sample 5 (EP100-EPS0) *Figure 37*. Since the EP percentage was low, the stress was similarly low, but signs of slight brittleness were found compared to 75% EPS. The information regarding the compressive strength and modulus of various sample compositions between EPS100-EP0 *Figure 33* and EPS0-EP100 *Figure 37* is shown in the bar chart figure 3 (b) *Figure 42*. Overall, throughout the sample variation, the compressive strength and modulus showed an upward trend in Figure 40. There are some variations in both features. Although modulus had a greater value at the beginning of the period, compressive strength had surpassed it by the end. As the percentages of EPS decreased and EP increased, the compressive strength increased steadily from 0.18 MPa in the first sample to 0.83 MPa, 1.02 MPa, and 2.22 MPa in the second, third, and fourth samples, respectively in *Figure 42* . However, due to EP's brittleness, the figure indicates a rose-shaped decline in compressive strength in the fifth sample from about 2.22 MPa to 1.55 MPa. In the sample of 100% EPS, the compressive modulus was 6.58 MPa, and when perlite was added to the sample, the compressive modulus significantly changed. The modulus increased by almost three times due to the inclusion of 25% EP and 75% EPS, reaching 59.16 MPa for the EPS25-EP75 ratio.

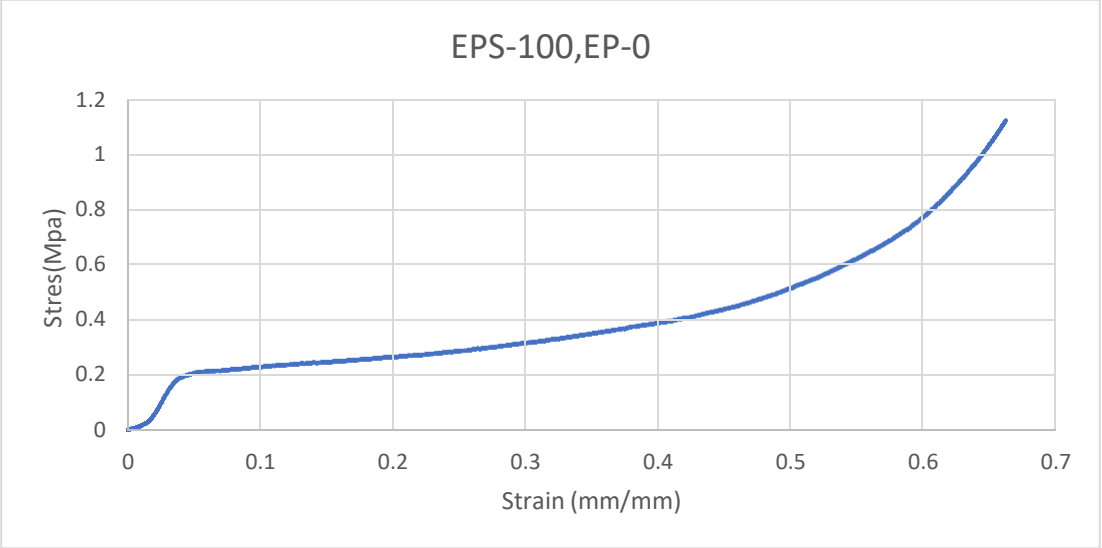

Figure 33 stress vs strain curve for compression (EPS-100,EP-0)

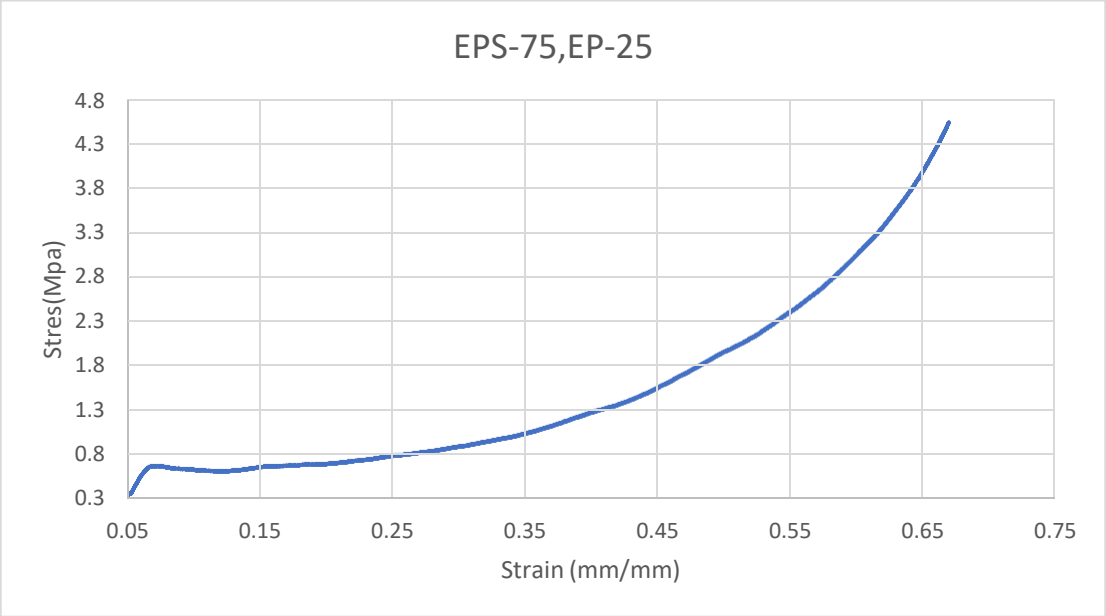

Figure 34 stress vs strain curve for EPS-75,EP-25 (compression)

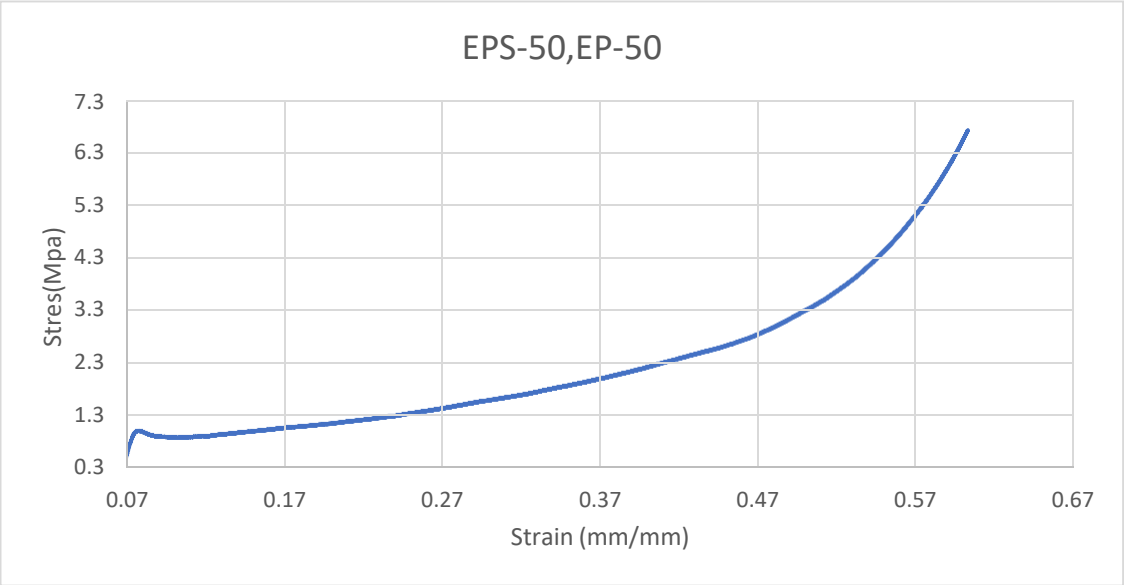

Figure 35 stress vs strain curve for compression (EPS-50,EP-50)

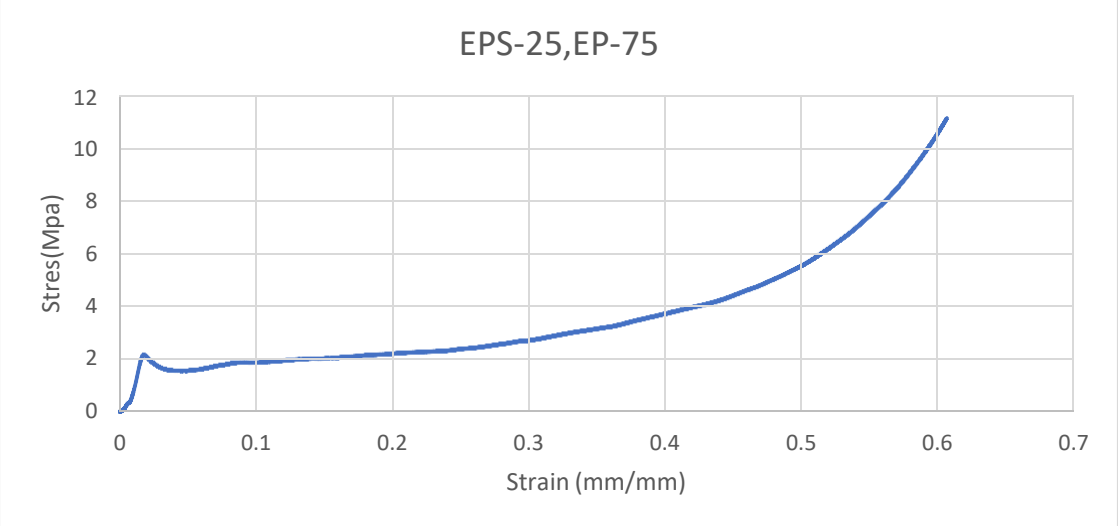

Figure 36 stress vs strain curve for compression (EPS-25,EP-75)

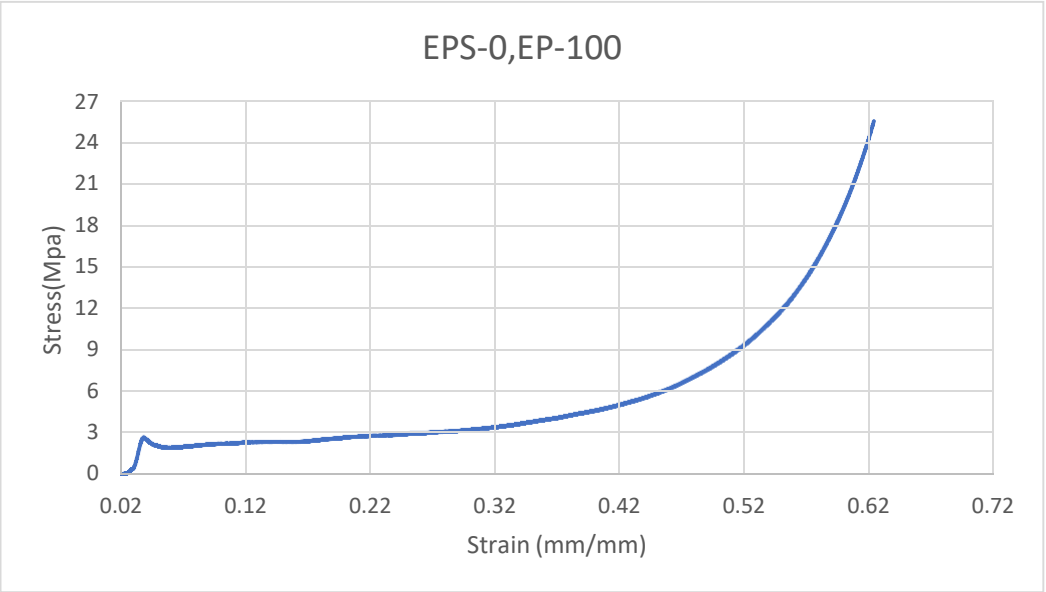

Figure 37 stress vs strain curve for compression (EPS-0,EP-100)

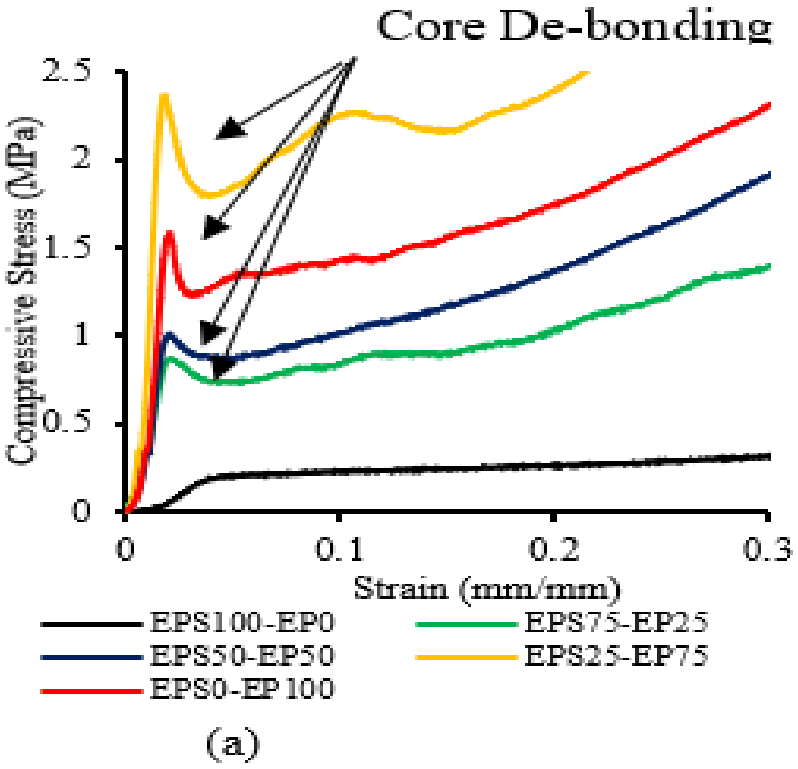

Figure 38 compressive stress vs strain curve

Table 19 compressive strength vs SD of strength

Sample ID	Compressive Strength (Mpa)	SD
EPS100-EP0	0.18	0.03
EPS75-EP0	0.83	0.03
EPS50-EP50	1.02	0.23
EPS25-EP75	2.22	0.08
EPS0-EP100	1.55	0.15

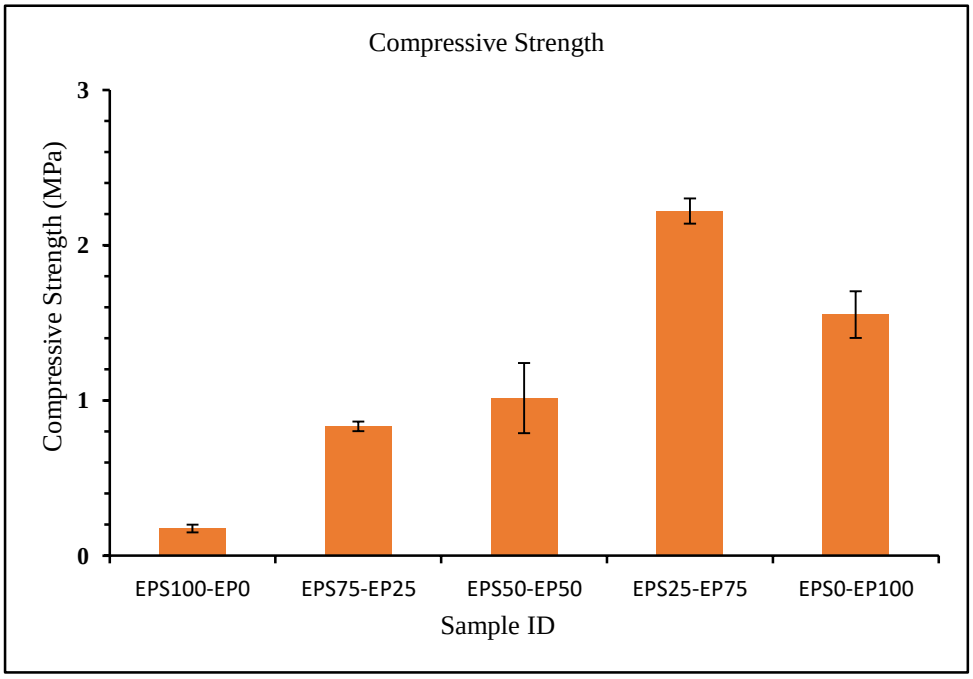

Figure 39 compressive strength vs sample id

Table 20 compressive modulus vs SD

Sample ID	Compressive Modulus (Mpa)	SD2
EPS100-EP0	6.58	1.422788712
EPS75-EP0	21.80	1.603757152
EPS50-EP50	33.18	2.19705148
EPS25-EP75	59.16	3.408500259
EPS0-EP100	32.55	8.055926137

Figure 40 Bar chart to demonstrate the compressive strength of different variant sample configuration during compressive loading

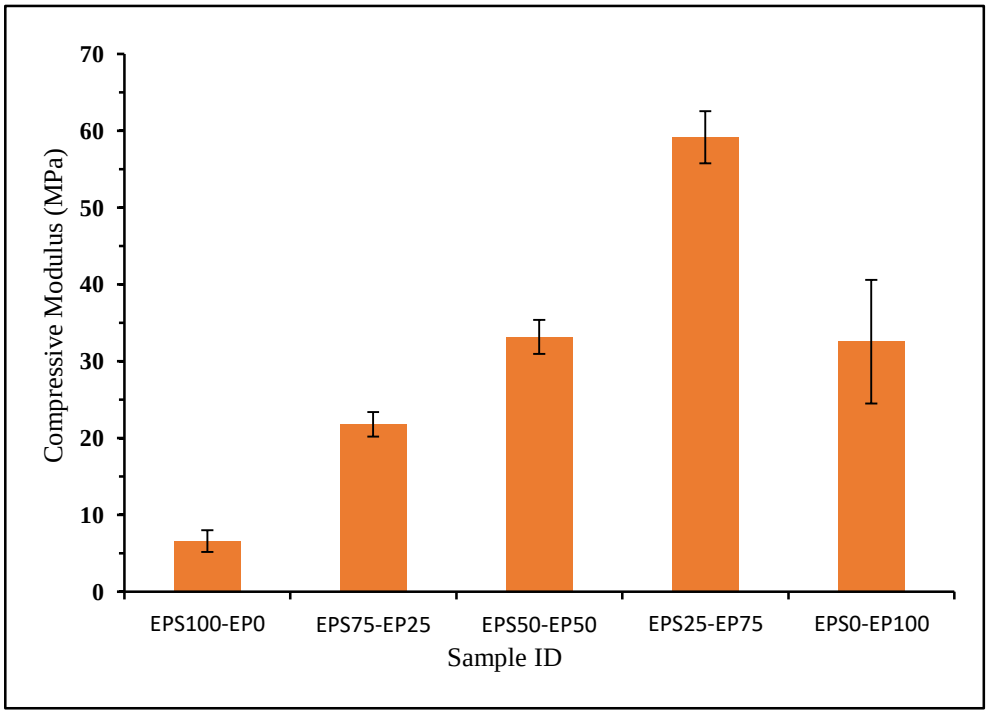

Figure 41 compressive modulus vs sample id

Table 21 compressive strength and compressive modulus

Sample ID	Compressive Strength (Mpa)	SD	Compressive Modulus (Mpa)	SD2
EPS100-EP0	0.18	0.03	6.58	1.422788712
EPS75-EP0	0.83	0.03	21.80	1.603757152
EPS50-EP50	1.02	0.23	33.18	2.19705148
EPS25-EP75	2.22	0.08	59.16	3.408500259
EPS0-EP100	1.55	0.15	32.55	8.055926137

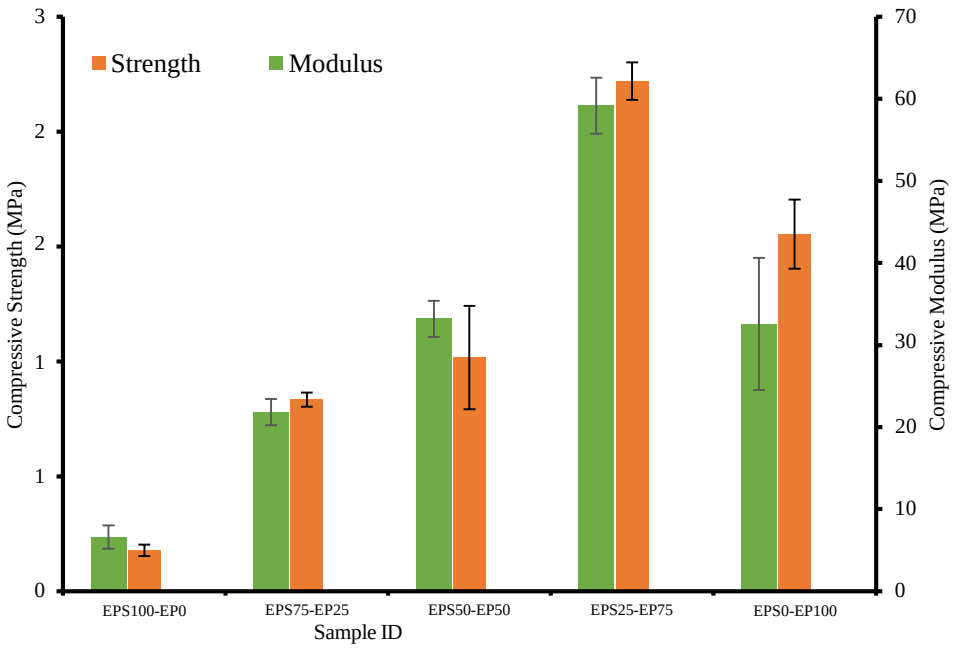

Figure 42 combined strength and modulus bar chart

Table 22 Elastic Force vs SD

Sample	Avg Elastic Force N/mm²	SD
EPS100EP0_1	6.58	1.42
EPS75EP25_1	21.80	1.60
EPS50EP50_1	33.18	2.20
EPS25EP75_1	59.16	3.41
EPS0EP100_1	32.55	8.06

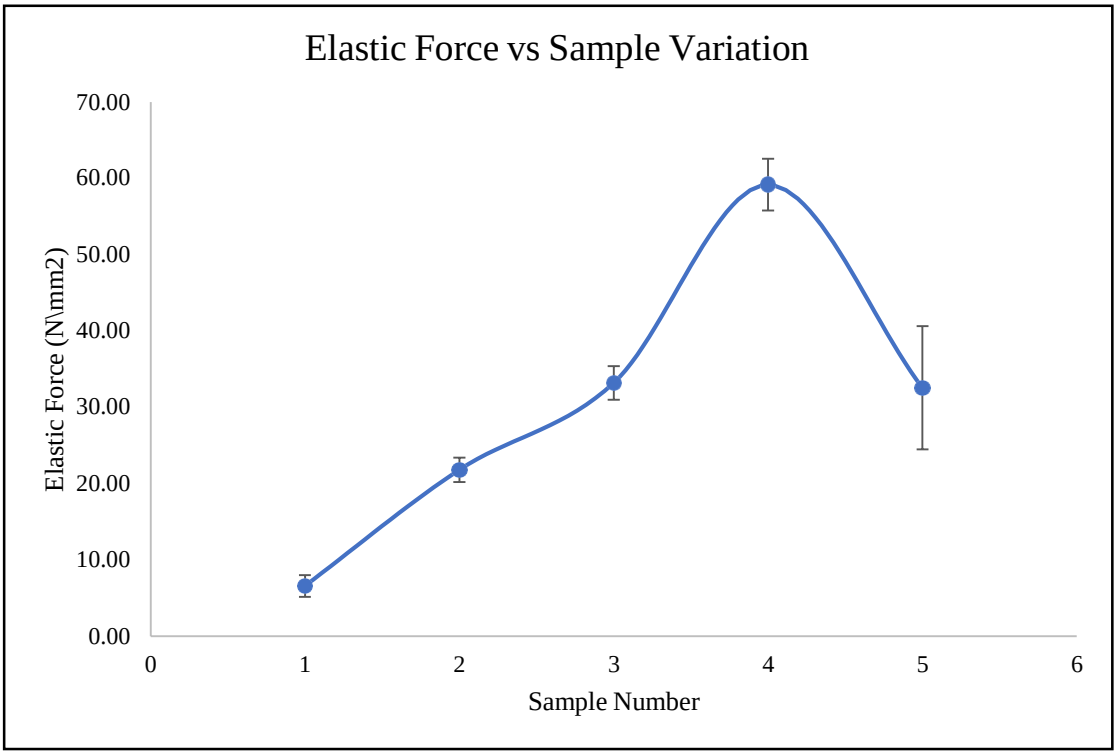

Figure 43 Elastic Force vs Sample Variation

4.3.2 Energy Absorption During Compression Test

Similarly, energy absorption is observed to increase similarly to compressive strength and compressive modulus. From *Figure 45*. Sample number four (EPS-25, EP-75) has the highest energy absorption and suddenly sample number five (EPS-0,EP-100) has some less energy absorption and from sample number one (EPS-100,EP-100) to sample number four (EPS-25, EP-75) there is a very rapid increase in energy absorption.

Table 23 Energy Absorption vs SD

Sample	**Avg Energy Absorption Stroke (0mm-8mm)**	**SD**
EPS100EP0_1	1.83	0.18
EPS75EP25_1	7.71	0.64
EPS50EP50_1	15.27	2.97
EPS25EP75_1	23.47	2.82
EPS0EP100_1	12.83	2.12

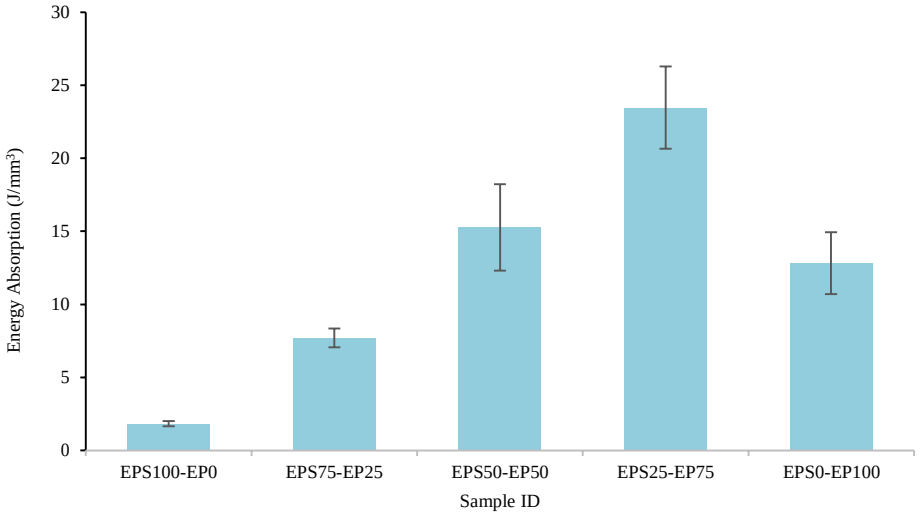

Figure 45 Bar chart illustrating the energy absorption during compressive loading

4.3.3 Failure Behavior During Compression Test

As evidenced by the failed specimens of various samples, the sandwich construction made entirely of EPS did not deboned after compression and rebounded to 10mm after 4mm compression. Sandwich composites with 75% EPS showed excellent load-bearing properties. The specimen under compressive load showed notable core bulging before many cracks with irregular orientations began to appear for 100% EP core.

In the case of 100% EPS, no deboning is observed during the test. But as the perlite content increases, deboning occurs and destructive failure occurs as the perlite increases, which is a disadvantage, but as the perlite increases, flexure increases. Generally, the top skin fails first, then the core shares, and then the entire sample is destroyed.

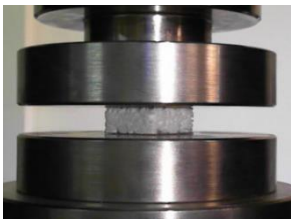

Figure 36 Compression test arrangement

Figure 37shows images of specimens that failed the compression test EPS-100,EP-0

Figure 38 shows images of specimens that failed the compression test EPS-0,EP-100

Figure 39 shows images of specimens that failed the compression test, ranging from EPS100-EP0 (on the left) to EPS0-EP100 (on the right

Figure 40 Failure Behavior During Compression Test each variant sample respectively

Table 23 compressive strength and compressive modulus combined

Sample ID	Compressive Strength (Mpa)	SD	Compressive Modulus (Mpa)	SD2
EPS100-EP0	0.18	0.03	6.58	1.422788712
EPS75-EP0	0.83	0.03	21.80	1.603757152
EPS50-EP50	1.02	0.23	33.18	2.19705148
EPS25-EP75	2.22	0.08	59.16	3.408500259
EPS0-EP100	1.55	0.15	32.55	8.055926137

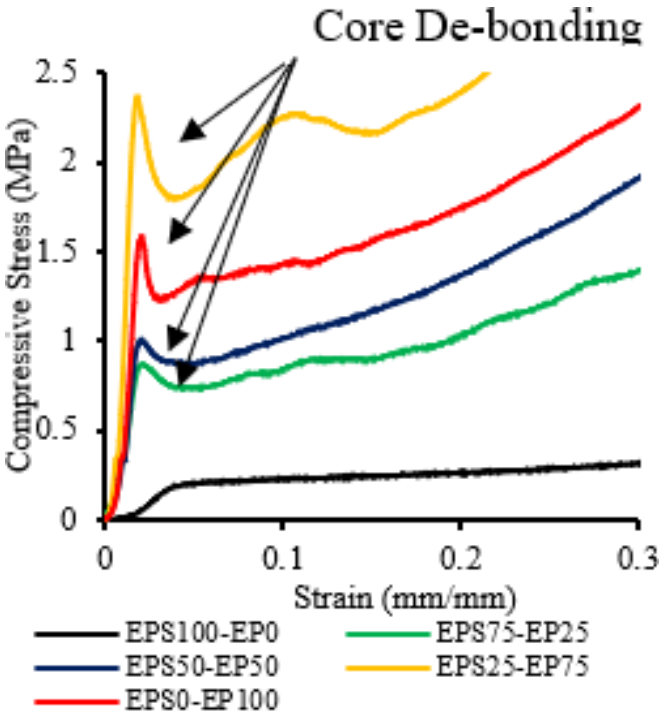

Figure 42 compressive stress vs strain curve

5 CONCLUSION AND FUTURE RECOMMENDATIONS

5.1 Conclusion

In this study, a light weight sandwich composite was created consisting of Formica sheet as skin and an expanded perlite/epoxy core with various EPS ratios. Flexural and Compressive characteristics and failure modes of the produced composites were both characterized. The main conclusions of the study can be summed up as follows: –

- The proportional amount of EPS and ES has a considerable impact on the flexural and the compressive parameters of sandwich panels, including strength, modulus, and energy absorption.
- Core shear cracking and core de-bonding have been demonstrated as the flexural and the compressive failure sequence.
- The mode of failure during flexural and compression gives a clue as to the sample's significant capacity for load bearing even after fracture onset.
- The flexural and compressive behavior of the sandwich structure is highly dependent on the amount of perlite and core density.
- Crack initiated in the core of the sandwich structure during the flexural test and delamination is found to be the catastrophic failure.
- Some local indentation failure of the core was noticed due to skin distortion during the flexural test.
- The load-carrying capacity of the sandwich structure was increased about 3.26-4.26 times for flexural and 8.61 -12.33 times for compression due to a change in core density.
- Energy absorption during flexural test was increased with increasing the amount of perlite and 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,

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

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