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Mechanical behavior of sandwich structure made of perlite foam core and JFRP skin

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ABSTRACT

In this work, novel sandwich structures have been developed based on perlite/sodium silicate foam as core and jute fiber reinforced epoxy polymer composite (JFRP) as skin. The main objective is to fabricate the sandwich composites and investigate the mechanical behavior of the composites for varying core densities. Perlite/sodium silicate foam cores were consolidated by mixing with the sodium silicate solution. A mold was used to compact the mixer of the perlite and sodium silicate by hand pressing and the wet compact was dried for 24 hours in an electric oven for curing. The hand lay-up process was adopted to fabricate the JFRP. The sandwich formation was done by attaching JFRP skins to both sides of the foam cores. The flexural and compression tests were performed and the results were analyzed in terms of core density. The findings show that the sandwich structures made of high-density foam cores showed enhanced mechanical properties. The flexural and compressive strength increased by 71.75% and 211.86% respectively due to an increase in density of 9.26%. Analysis of the failure behavior during flexural tests indicates that the failure initiates at the core of the sandwich structures showing the direction for the future improvement of developed composites.

Keywords: perlite foam core, JFRP, sandwich structures, flexural properties, compressive properties.

1. Introduction

The global energy demand is increasing day by day and the energy crisis becoming prominent. Governments around the world are taking steps to mitigate energy consumption by applying various energy-saving methods. One of the effective ways to reduce energy consumption in buildings is the utilization of thermally insulating material for construction. The sandwich structures with heat-insulating composite materials as cores may be developed to be used in building interiors for the improvement of thermal insulation. A sandwich structure [1] consists of two skins made of thin but stiff material and a core that is comparatively lightweight and less stiff. The skins are used to protect the core material and to bear the load whereas the core constitutes a distance between two skins to provide a higher stiffness. The core can serve as a heat-insulating material to reduce energy consumption in the building cooling or heating.

The selection of materials for the fabrication of the sandwich structures depends on certain factors e.g., availability, cost, and properties of materials, etc. The expanded perlite-based particulate composites are known for their low cost, environmentally safe, lightweight, thermally resistant, and fire retardant. Many researchers have worked on the development of expanded perlite-based composites using various binder systems. For example, Shastri and Kim [2] have developed a perlite composite with potato starch and showed that the compressive strength of the material varies from 0.1 MPa to 1.45 MPa for a density range of 0.1 g/cm^3 to 0.4 g/cm^3, Arifuzzaman and Kim [3] consolidated the perlite particles using sodium silicate solution by dehydration method and found a compressive strength range from 0.12 MPa to 2.75 MPa for a density range of 0.15 g/cm^3 to 0.51 g/cm3. Arifuzzaman and Kim [4] also studied the bending strength and found that the bending strength of the composites ranged from 0.16 MPa to 1.17 MPa for a density range of 0.22 g/cm^3 to 0.41 g/cm^3. Other binder systems that have been successful in the development of expanded perlite-based composites include sodium silicate solution with corn starch [5], recycled polystyrene [6], epoxy resin [7], polyurethane [8], sodium silicate solution with boric acid [9], high-density polyethylene [10], etc. Therefore, the expanded perlite-based particulate composites may be an excellent candidate as a heat-insulating core material for the sandwich structure.

Limited research has been conducted on the development of sandwich structures made of perlite composite as the core of the structure. For example, Arifuzzaman and Kim [11] developed sandwich structures using kraft paper as skin, and Xie et al. [12] studied the electromagnetic shielding behavior of sandwich structures made of expanded perlite/carbon black with the cement-based core.

On the other hand, Jute is a natural fiber known for its high strength and low cost. Jute fiber as a reinforcement [13, 14] in polymer matrix composites has been studied by many researchers and found highly effective in strength enhancement. Jute mat or woven jute fiber-reinforced epoxy composites [15, 16] are easy to manufacture and can be cured at room temperature. Jute mat-reinforced epoxy composites may be a good candidate for the development of the skin of the sandwich structure considering the easy availability, cost, and mechanical properties of the constituent materials. Therefore, by considering the potential of the expanded perlite composite-based cores and the jute fiber mat-reinforced epoxy composites, the sandwich structures may be developed to find new applications in the construction industry.

In this work, a novel sandwich structure is developed using the jute fiber mat-reinforced epoxy composites as skins and the perlite/sodium silicate composite foam as heat insulating core. Since expanded perlite composites are known for their high thermal performance [8, 17], the flexural and compressive behavior of the novel sandwich structures for varying core density were investigated to

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understand the effects of perlite/sodium silicate foam core density on mechanical performance and failure behavior.

2. Experimental Details

2.1 Materials

The expanded perlite particles was bought from King Caster Perlite, China. The particles that are 3-4 mm in size were separated using sieves containing 3 mm holes and used in this work. The two principal components of expanded perlite are aluminum oxide and silicon dioxide. The bulk density of expanded perlite is measured to be 0.072 g/cm^3. Sodium Silicate Solution was taken from Silica-Solution, Chittagong, Bangladesh which consists of a density of 1.382 g/cm^3, solid content range of 37-38 wt%, and modulus (SiO_2/Na_2O) 3.21 according to the manufacturer's datasheet. A jute fiber mat was purchased from a local store with 253.33 GSM. Epoxy (Araldite AW-106) and hardener (HV-953) were sourced from a local market and the recommended mixing ratio of epoxy and hardener was 5:4.

2.2 Specimen preparation

Perlite and binder sodium silicate were mixed with a mass ratio of 1:3 by hand in a mixing container, and the mixture was inspected to ensure that all perlite particles were wet with the binder. The wet mix was placed in a mold with inside dimensions of 150 mm x 150 mm x 100 mm for manual compaction. The final size of the specimen was 18 mm in thickness after compaction. The compact was placed in an electric oven and dried at 120°C until no mass loss occurs which took approximately 48 hours. Various amounts of particles were taken initially before compaction to vary the density of the composite and for each density, three specimens were prepared. Fig. 1(a) shows a prepared perlite/sodium silicate core.

The jute mats were cut into 150 mm x 150 mm sizes. First, a layer of prepared epoxy was placed in a steel plate then the first layer of jute woven mat was placed. Similarly, another two mats were placed. After placing each layer of the mat a roller was used to remove air bubbles. Finally, a metal plate of 5 mm thickness along with 10 kg mass above it was placed on top of the arrangement. After 24 hours of curing at room temperature, the JFRP skin was removed. The manufactured jute fiber reinforced sheet is shown in Fig. 1(b).

Both of the skins for making the sandwich were coated with prepared epoxy resin uniformly and the foam core is pressed in the middle of the coated skins. The stacked sandwich structure was placed on a plane steel surface and a load of 10 kg was positioned at the top of the structure. After 24 hours of curing at room temperature, the sandwich structure was ready for testing. The fabricated sandwich panels as shown in Fig. 1(c) with a 24 mm thickness were bent-saw cut into (25 x 25 x 24) mm^3 sizes for compression testing, while sandwich composites were cut into (150 x 25 x 24) mm^3 sizes using band saw.

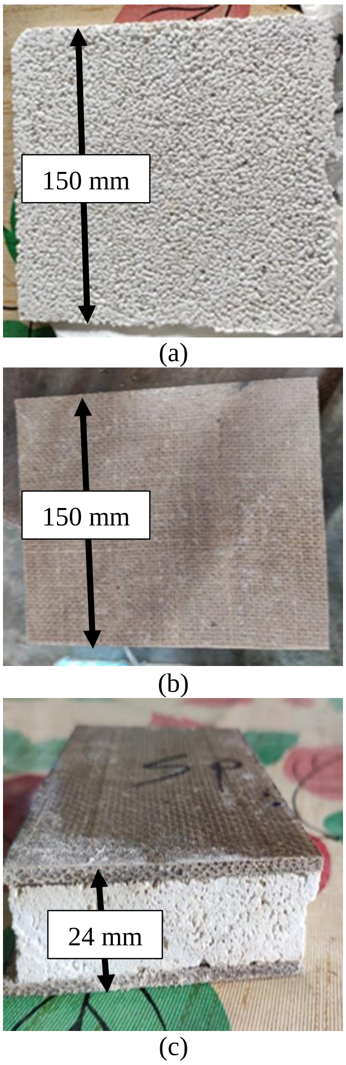


Fig. 1 (a) Prepared perlite/sodium silicate core; (b) JFRP sheet; and (c) Sandwich structure.

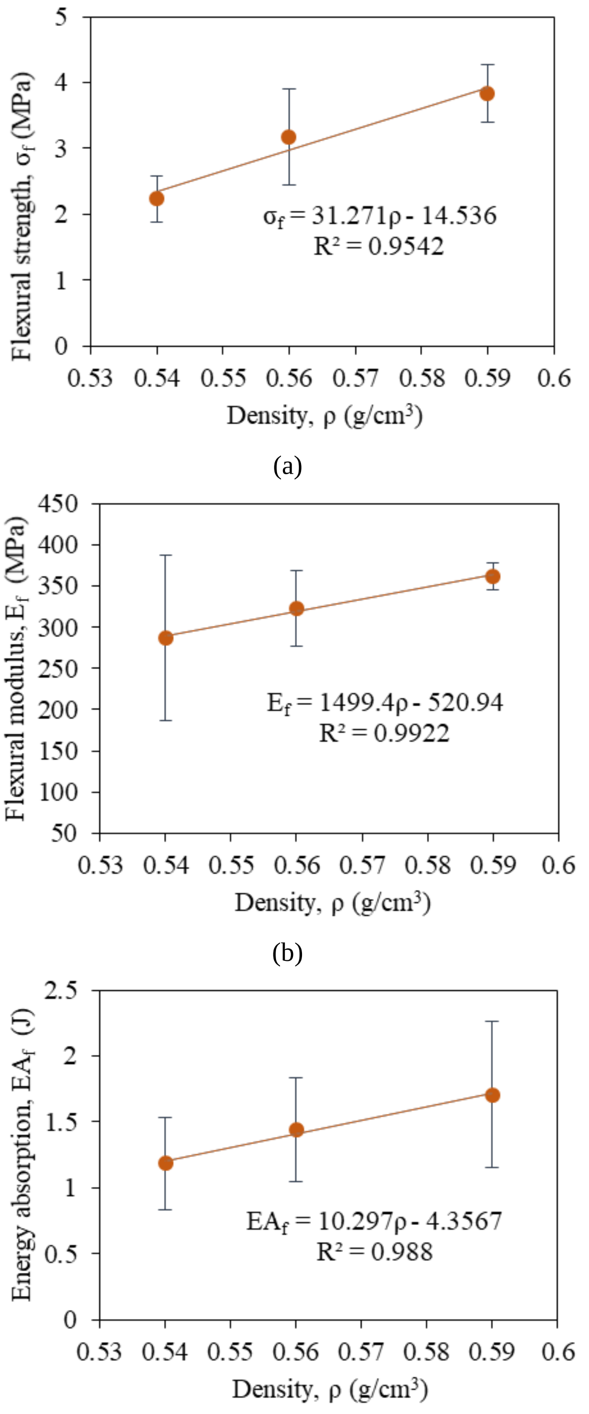
2.3 Mechanical Tests

The flexural and compressive test was conducted on a universal testing machine (Shimadzu AGX 300kN) at a crosshead speed of 5 mm/min by following ASTM standards C393 and C365 respectively. At least three specimens for each density were tested for both flexural and compression tests.

3. Results and Discussions

3.1 Flexural Properties

The flexural strength, modulus, and energy absorption of the sandwich structures are plotted as a function of the density of the sandwich core in Fig. 2(a), Fig. 2(b) and Fig. 2(c), respectively. The standard deviations are shown as error bars at the data points. It is seen that the strength, modulus, and energy absorption increased linearly with increasing the core density. The high linearity is reflected by the higher correlation coefficients (R^2) as shown in Fig. 2. The flexural strength is increased by 71.75% due to an increase in density of 9.26% only. On the other hand, the flexural modulus is increased by 26.44% for the same density change.



(a)

(b)

(c)

Fig. 2 Flexural (a) strength, (b) modulus, and (c) energy absorption as a function of the density of the sandwich core.

Flexural stress versus strain curves are plotted in Fig. 3 for three density groups. The stress appears to be increased linearly up to a peak where the first failure occurred. The first failure was initiated at the core as shear cracking [See Fig.4] for all density groups. The sandwich with higher density showed a higher first peak [See Fig.3].

After the first failure the load is carried by the JFRP skins and the stress starts to rise again due to the interlocking of the failed surfaces between the skins. The second catastrophic failure of the sandwich also occurred due to shear cracking. As the deflection propagates the third major failure was found to be skin delamination.

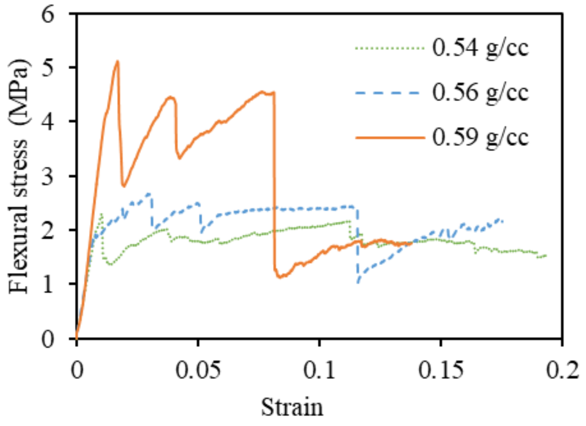
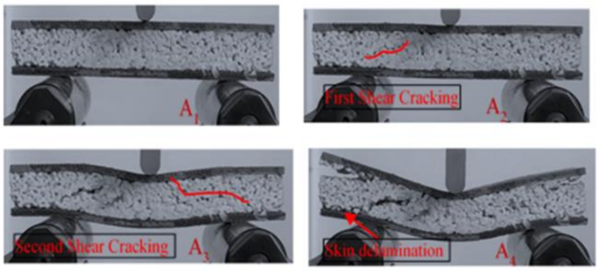
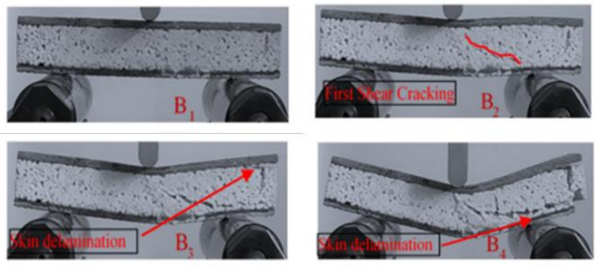


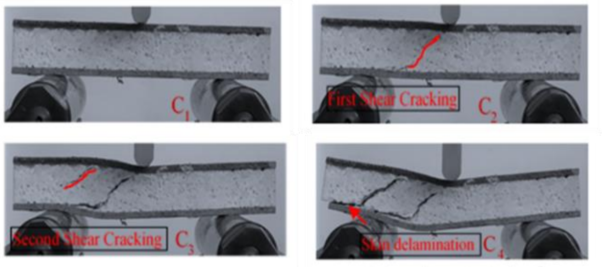
Fig. 3 Flexural stress vs strain curves



(a) For density- 0.54 g/cm^3

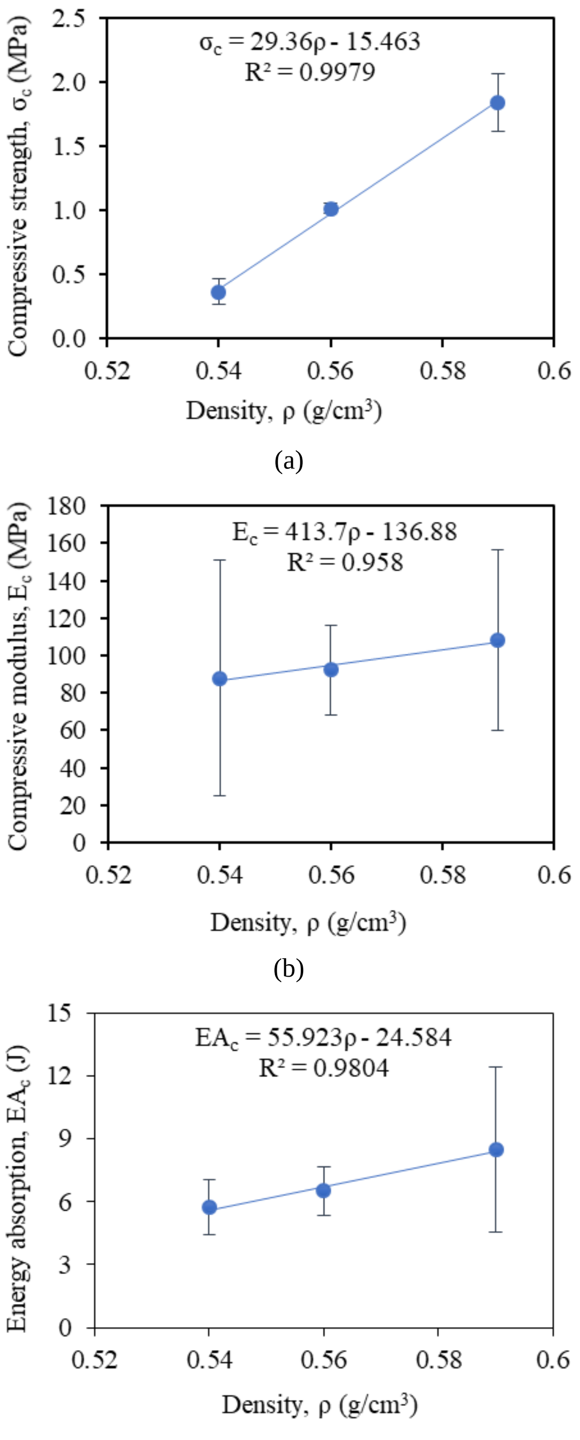


(b) For density- 0.56 g/cm^3



(c) For density- 0.59 g/cm^3

Fig. 4 Typical photographs of the failure sequence for various densities



(a)

(b)

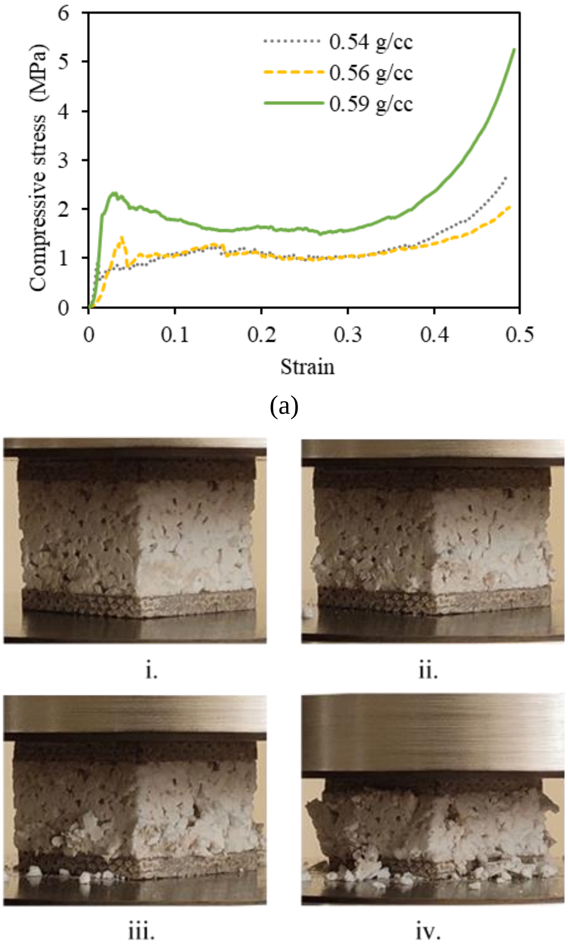
(c)

Fig. 5 Compressive (a) strength, (b) modulus, and (c) energy absorption as a function of the density of the sandwich core.

Another interesting thing to be mentioned is that the angle of the shear crack with the horizontal is higher for the high-density foam [See Fig.4(c)]. Again, the delamination failure of the sandwich with high-density foam core took place at a lower strain as seen in Fig.3 whereas the low-density sandwiches showed a larger strain for the delamination failure. There is no visible failure of skins is noticed for all density groups. This analysis indicates that with a high strength skin i.e., JFRP with perlite/sodium silicate foam the failure of the sandwich occurs at the core due to shear cracking followed by skin delamination. Therefore, it can be said that the increase in the density of the core is not sufficient to improve the performance of the sandwich structure rather an improvement in the shear resistance of the core would enhance the flexural performance of the sandwich structure.

3.2 Compressive Properties

The compressive strength, modulus, and energy absorption of the sandwich structures as a function of the density of the sandwich core are shown in Fig. 5(a), Fig. 5(b), and Fig. 5(c) respectively. Again, the standard deviations are presented as error bars at the data points. It is observed that the strength, modulus, and energy absorption increased linearly (with high correlation coefficients i.e., R^2) with increasing the core density which is similar to the observation mentioned for the flexural properties in section 3.1. In this case, the compressive strength and modulus are increased by 211.86% and 163% due to an increase in density of 9.26% only.



(a)

(b)

Fig. 6 (a) Compressive stress-strain curves and (b) the photographs of the failure sequence at different strains.

The compressive stress vs strain curves are given in Fig. 6 (a) and the photograph of the typical failure sequence is shown in Fig. 6(b). It is observed that the compressive stress increased with increasing the strain linearly up to a peak where the failure is initiated as the localized crashing of the core. The sandwich structure with a higher-density core showed a higher peak. The crashing of the core initiated at the support side (bottom side) of the specimen near the bottom skin [See Fig. 6(b)-ii]. As the deflection of the loading plate (top plate) continues the core crashing propagates towards the top plate [See Fig. 6(b)-iii] and until the densification starts. Before the densification stage begins, the longitudinal splitting of the core was noticed. A long plateau region is observed for all samples indicating the high energy absorption capacity of the sandwich structures under compression loading. However, the plateau is smaller for the sandwiches with a high-density foam core which is because of the longitudinal splitting of the core instead of the localized crashing at the later stage of the compression test.

4. Conclusion

The sandwich structures consisting of expanded perlite/sodium silicate composite foam and JFRP were manufactured and their flexural and compressive properties were investigated experimentally. The following conclusions may be drawn from the work:

- As the density of the expanded perlite/sodium silicate composite foam core increases, both the flexural and compressive properties were improved i.e. the strength, modulus, and energy absorption increased.
- Flexural failure was found to be core shear cracking whereas compression failure was the localized crashing for all samples.
- Because of the higher strength of the JFRP skin, a further improvement in the load-carrying capacity of the sandwich structures may be possible by enriching the expanded perlite/sodium silicate composite foam shear resistance.

5. Acknowledgement

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