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Novel Expanded Perlite Based Composite using Recycled Expanded Polystyrene for Building Material Applications

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ABSTRACT

The present investigation aims to develop a novel composite material using expanded perlite particles as filler and recycled Styrofoam as binder to attain properties like lightweight, sound and thermal insulation to be used for building interior walls and ceilings. The developed material is expected to not only serve as a cost effective solution for building insulation or energy saving but also to mitigate the environmental pollution due to the waste Styrofoam plastics. Composites with various densities are produced for the purpose of comparison with the available building materials currently being used all over the world for building energy saving. Manufactured composites are characterized for compressive properties to assess the usability in the intended purpose. The composites are manufactured for various densities (0.50 to 0.72 g/cm^3) by varying the perlite content, Styrofoam content and the degree of compaction. The test results and the comparison with literature show that the compressive strength (1.32 MPa - 4.46 MPa) and specific compressive strength (3.03 MPa/(g/cm^3) to 6.43 MPa/(g/cm^3)) of the developed material are viable with the existing materials currently being utilized for the similar purpose. Additionally the stress – strain behavior and the failure mechanism during compression test has also been discussed which would be beneficial for the purpose of further development of this material.

Keywords: Expanded Perlite, Polystyrene, Recycling, Composite Building Material, Compressive Properties.

1. Introduction

Expanded perlite (EP) is available in a form of porous particles. It is cheap, light (0.032–0.4 g/cm^3), environment-friendly, and possesses good thermal insulation properties (0.04–0.06 W/mK) [1-3]. Expanded perlite has no known harmful effects on environment. Many researchers have reported their uses in manufacturing composites either as additives or as main constituent e.g. Expanded perlite was added as a filler with Portland cement to manufacture composites for building blocks by Grey [4] and Rodsky et. al [5], perlite as main constituent for building boards by Shepherd and Dolin [6], roof insulation panels made of perlite additive along with fibers/bituminous material by Hill [7], fibre reinforced composites using perlite as main constituent by Aglan et. al [8], building boards consisting of fiber/asphalt perlite coated with fiber/asphalt by Miscall and Rahr [9], or perlite board with urea–formaldehyde resin and other additives by Sherman and Cameron [10], fiber reinforced perlite and sodium silicate composites by Saybold [11], moisture resistant gypsum boards has also been modified using perlite, starch, boric acid, vinyl acetate by Luongo [12], gypsum/perlite composites by Vimmrova et. al [13], and clay brick with perlite additive by Topcu and Isikdag [14]. The expanded perlite has has not much been used as the principal constituent of composites because of their relatively poor mechanical properties. However perlite composites may have the potential to replace gypsum boards [15, 16] which are mainly used as non load bearing building insulation and decoration. Since perlite is a very low cost material it is likely to reduce the cost of building insulation. The development of new materials based on expanded perlite would therefore be advantageous in terms of cost and insulation properties.

It is important to carefully select the binder or matrix for consolidating the expanded perlite composites because they may increase the overall cost of the composites. Researchers have tried many different binder for perlite composites e.g. water-glass [17, 18], potato starch [19], bituminous materials [7], cement [8] etc. but nobody have considered using recycled plastic materials for the development of the perlite based composites. Therefore, by taking the advantage of recent development on expanded perlite based composite research, it would be great opportunity to accommodate recycled plastic in the development of perlite based insulation board to serve the purpose of building energy saving as well as consumption of harmful recycled plastic.

Expanded polystyrene (Styrofoam) is one of the widely used plastic material for packaging and insulation purpose. However the waste Styrofoam generated from the packaging causes severe health hazard not only for the human being but also affects the others animals in the world. Recently in Bangladesh, the use of Styrofoam based food serving or packaging dishes has increased significantly and the most of them ends up in the ponds, rivers, and cannels. Composite manufacturing by recycling Styrofoam is a way to reduce the environmental pollution as well as a better solution for building insulation may be obtained due to its low cost. It may also provide a long term solution for the Styrofoam waste.

Therefore in this study, an attempt has been taken to find a way to recycle the Styrofoam waste for manufacturing expanded perlite based composites. The compressive properties of the manufactured composites are investigated along with the available data from the literature to assess its usability as a potential building material.

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2. Constituent materials

2.1 Expanded perlite

Perlite is a lightweight particle processed from perlite ore. The water content of solid perlite evaporates and creates cellular structured expanded perlite of very low bulk density (0.03-0.40 g/cm^3) [2-3]. Main components of perlite are Silicon Dioxide (70-75%), Aluminum Oxide (12-15%), Sodium Oxide (3-4%), Potassium Oxide (3-5%), Iron Oxide (0.5-2%), Magnesium Oxide (0.2-0.7%), Calcium oxide(0.5-1.5%), others (3-5%) [3]. In this study the expanded perlite particles were bought from China (Henan Blider Mining Product Co., Ltd.) with a particle size range 1-5 mm but after sieving the particle size range from 1-4 mm was used. The bulk density of the EP particles were measured to be 0.167 g/cm^3.

2.2 Polystyrene foam, Acetone and Thinner

Expanded polystyrene (Styrofoam) is mainly used for packaging and insulation purpose. It is a polymer of styrene with a chemical formula of $(C_8H_8)_n$. Expanded polystyrene from computer packaging was used in this research and recycled to manufacture expanded perlite based composites.

Acetone is also known as propanone which is an organic compound ($(CH_3)_2CO$). It is a member of ketone group and is the smallest ketone. Its characteristics are colorless, volatile, flammable and a special odor. Thinner was a T-6 organic mixture and the chemical name of it is Isopropyl alcohol. A mixture of acetone and thinner was used to dilute expanded polystyrene to manufacture the composites. The ratio of acetone to thinner 8:9 was found to be the best ratio for diluting Styrofoam at room temperature after many trial and error.

3. Experimental details

3.1 Specimen manufacturing

The compression moulding technique was used to manufacture the cylindrical specimen of the composites. Acetone and thinner were mixed together at a ratio of 8:9 and Styrofoam pieces are poured into the solution for dilution and stirred with a glass rod. The mass of the Styrofoam was used as 1.5g, 1.25g and 0.8g per 100g of the acetone solution to examine the behaviour of the composites for different Styrofoam content. The perlite particles were poured into the prepared Styrofoam solution and mixed thoroughly for at least 2 minutes for proper mixing. The mixer was transferred into a cylindrical mould with 35 mm inside diameter. The mixture was compressed into a height of 15 mm. As a result the excess Styrofoam solution came out of the mould which was discarded and cleaned. The cylindrical form of the wet composite was taken out carefully and left to cure until the weight loss became zero due to the evaporation of acetone and thinner.

3.2 Density and compression test

The mass of the composite was measured using a precision digital scale and the dimension of the cylindrical specimen was measured using a digital slide calipers. The density of the composite was calculated as the mass per unit volume of the composite.

The Uni-axial compression test was conducted to evaluate the compressive properties of the manufactured composites. A Hydraulic Universal Testing Machine (Time Group Inc, China) with precision load cell of 50kN was used to carry out the test at a cross head speed of approximately 5 mm/min. A digital data acquisition system was used to capture the load and cross head displacement data. The cross head displacement data was captured using a calibrated displacement sensor. The ASTM standard ASTM C365/C365M-16 was used as a guide for compression test. The peak load on the force displacement curve was used to calculate the compressive strength and the gradient of the initial linear part of the stress-strain curve was considered as the compressive modulus.

4. Results and discussion

4.1 Compressive properties

The compressive strength of the composites for various Styrofoam content is plotted as a function of the density as shown in Fig. 1. It should be noted that the variation of density was obtained using the mixture of various particle sizes from 1-4 mm and the mass of perlite particles. It is seen that the compressive strength increased linearly with the increase in the density of the composites for all Styrofoam contents (SC). The fitted equations and the coefficients are $y = 13.328x - 4.7622$ and $R^2 = 0.9956$ for SC = 1.50; $y = 13.282x - 4.5351$ and $R^2 = 0.9347$ for SC = 1.25; $y = 5.8072x - 1.1853$ and $R^2 = 0.9747$ for SC = 0.80. The high correlation coefficients indicate high linearity. It is a well-established fact that the compressive strength increases with increasing density of the composites [15, 17, 19, 20].

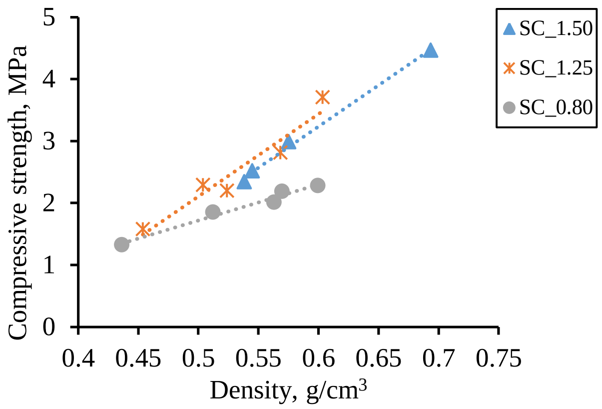


Fig.1 Compressive strength as a function of the density of the composites

The range of compressive strength obtained from this work are 1.32 MPa to 2.28 MPa for SC=0.8, 1.58 to 3.70 MPa for SC=1.25 and 2.34 MPa to 4.46 MPa for SC=1.5. The reported range of compressive strength in the literature for the building materials are approximately 0.20 MPa to 2.80 MPa by Arifuzzaman and Kim [17], 0.1 MPa to 1.45 MPa by Shastri and Kim [19], 0.2 MPa to

0.9 MPa by Ai et. al [21]. 0.34 MPa to 0.82 MPa by Gao et. al [22], 0.3 MPa to 2.7 MPa by et. al. [13], 0.2 MPa to 0.75 MPa by Tian et. al [23]. Besides the foamed gypsum, an widely used material for building insulation, has a compressive strength range from 0.31 MPa to 2.22 MPa studied by Colak [24]. Petrone, Magliulo and Manfredi has investigated compressive properties of various commercial gypsum plasterboard and obtained a compressive strength rage of 3.02 MPa to 8.13 MPa [25]. Adhikary et. al [26] has reported expanded perlite composites made of sodium silicate solution along with starch as reinforcement which showed a compressive strength range from 1.93 to 3.25 MPa So, the compressive strength obtained for expanded perlite and recycled Styrofoam composite in this work is well comparable with already available building materials in terms of compressive strength.

The specific compressive strength which is calculated as compressive strength per unit desity of the composite is an excellent parameter to identify the lightweight characteristics of the any material. The range of specific compressive strength found to be 3.03 MPa/(g/cm^3) to 6.43 MPa/(g/cm^3) while the reported specific compressive strength in the literature for similar type of materials alike this study are 0.62–2.03 MPa/(g/cm^3) [24], 0.8–5.37 MPa/(g/cm^3) [17], 1–3.86 MPa/(g/cm^3) [13], 4.27 to 5.08 MPa/(g/cm^3) [26] and 1.1–3.1 MPa/(g/cm^3) [16]. The specific compressive strength range for the commercial gypsum plasterboards is 4.19-8.84 MPa/(g/cm^3) [25]. So, it can be observed that the developed material in this study has excellent compatibility in terms of specific compressive strength.

The compressive modulus of the composites is plotted in Fig. 2 as a function of the density for different Styrofoam contents. The compressive modulus increased with increasing the density of the composites for all Styrofoam contents (SC) linearly. The fitted lines and the coefficients are $y = 86.171x - 18.364$ and $R^2 = 0.9721$ for SC = 1.50; $y = 114.5x - 28.198$ and $R^2 = 0.9442$ for SC = 1.25; $y = 73.395x - 13.569$ and $R^2 = 0.9455$ for SC = 0.80. Similar to the compressive strength, the compressive modulus also disclosed high dependency on the density of the composites as indicated by the high value of the correlation coefficients. The range of compressive modulus obtained from this work are 18.90 MPa to 30.35 MPa for SC=0.8, 23.66 MPa to 40.26 MPa for SC=1.25 and 27.67 MPa to 57.03 MPa for SC=1.5. It can also be noted from Fig. 2 that the compressive modulus of the composites are higher for Styrofoam content 1.25 than that for Styrofoam content 1.50. This may be due to the variation of the quality of the expanded perlite particles as well as the compaction during the specimen manufacturing which is reflected by the higher density of the composites for Styrofoam content 1.50.

The density of the composites has a considerable effect on the compressive properties of the developed composites. However the density is also dependent on the volume fraction of the constituents of the composites, the degree of compaction for manufacturing the composites. It is also necessary to investigate the effects of these parameters on the compressive properties which may be investigated in future.

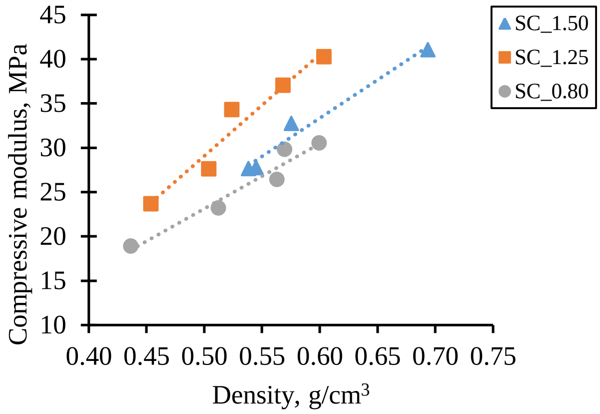
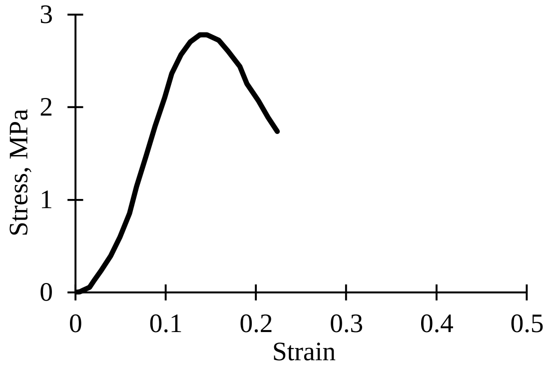


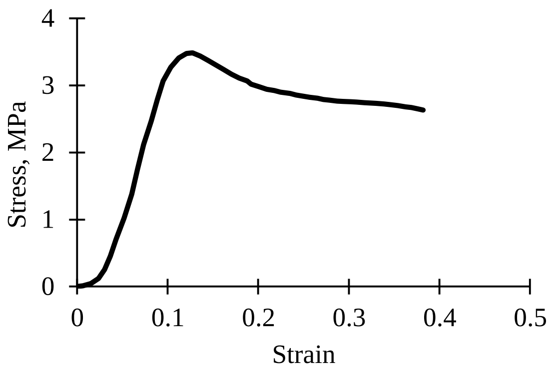
Fig.2 Compressive modulus as a function of the density of the composites

4.2 Failure mechanism

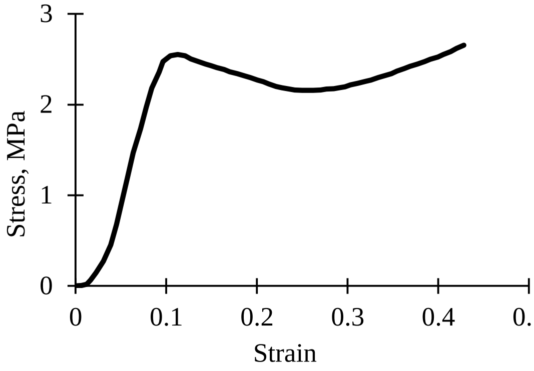
Some typical stress-strain curves for developed composites are shown in Fig. 3. It is observed that the stress increased linearly with strain until a peak where the failure of the composite takes place for all tested specimens. The nature of the curve changes with the density after the peak load.



(a)



(b)



(c)

Fig.3 Typical stress versus strain curve obtained from the compression test of the composites: (a) For low density specimens (SC = 0.80, Density = 0.45 g/cm^3), (b) for high density specimens (SC = 1.25, Density = 0.60 g/cm^3) and (c) with densification stage (SC = 1.50, Density = 0.69 g/cm^3)

For low density composites, stress decreased gradually with strain after the peak is reached (see Fig. 3(a)) but for high density composites the rate of decrease in stress is low compared to low density composites and a plateau region is noticed as shown in Fig. 3(b). The densification after the plateau is also noticed in some high density specimens as shown in Fig. 3(c). The plateau region indicates the high energy absorption capacity of the developed composites. The high density composites showed high amount of energy absorption but for low density composites due to the less volume fraction of Styrofoam expanded perlite particles debonded quite easily.

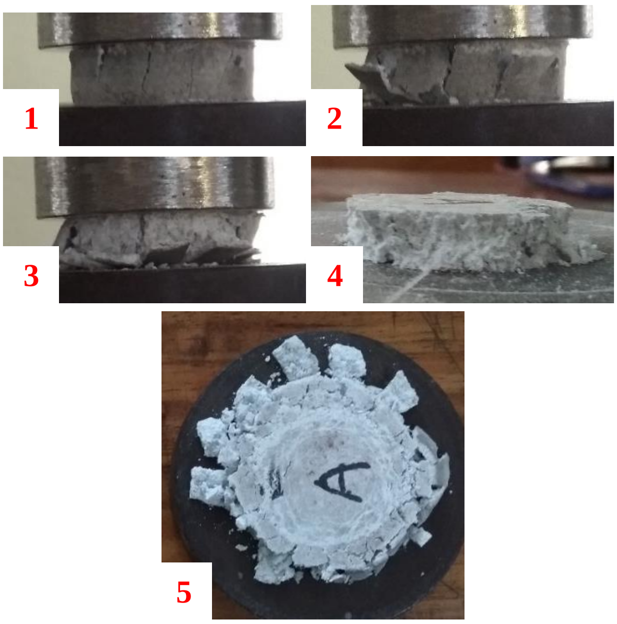


Fig. 4 Photograph of the failed composite specimens during (1-3) and after (4 and 5) compression test to illustrate the failure mechanism.

A typical failure behavior of the developed composite is shown in Fig. 4. The failure mechanism reported in the literature for expanded perlite composites are 45° shear, debonding, vertical splitting etc. [17, 19, 20]. In this work the failure mechanism for all composites are found to be the vertical splitting as shown in Fig. 4.

5. Conclusion

In this study the lightweight composite building materials are manufactured to investigate the compatibility in terms of compressive strength with the available building materials in the literature. The expanded perlite particles are embedded into the Styrofoam matrix to develop the composites. A density range obtained is from 0.50 g/cm^3 to 0.72 g/cm^3 by varying the degree of compaction and Styrofoam content. The compressive strength and modulus showed a strong dependence on the density of the material i. e. the compressive strength and modulus display a linear trend with increasing the material density. The range of compressive strength (1.32 MPa to 4.46 MPa) and specific compressive strength (3.03 MPa/(g/cm^3) to 6.43 MPa/(g/cm^3)) attained were found to be well comparable with the existing building materials in the literature. Therefore further research can be conducted to explore other essential properties such as thermal conductivity, energy absorption capacity, impact behavior etc. to fully understand the developed material for application in construction and building industries in future.

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7. References

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