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Effect of Fiber Content on the Mechanical Properties of Jute Fiber Reinforced Perlite/Gypsum Composites

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ABSTRACT

Fiber reinforcement is one of the ways for the improvement of the mechanical properties of composite materials. Previously, it was seen that the fiber content in composites played a vital role in the mechanical properties of fiber-reinforced composites. Considering the benefits of natural fiber, in this work, jute fiber reinforced perlite/gypsum composites were manufactured with five different fiber contents ranging from 2.41 % to 4.82 %. The ratios of gypsum to perlite and gypsum to water were kept constant, and only fiber content was varied. The compression and flexural tests were conducted to investigate the effect of jute fiber content on the mechanical properties of jute fiber-reinforced perlite/gypsum composites. Results showed that both the compressive and flexural properties were improved up to certain jute fiber content. The compressive strength, modulus, and energy absorption of the jute fiber-reinforced composite were found to be the maximum at 3.01 % fiber content. The compressive strength of the composite with 3.01 % jute fiber content was 35.23 % higher than the composite with 2.41 % fiber content. The flexural strength, modulus, and energy absorption were maximum at 3.61 % jute fiber content. This study demonstrated that the addition of jute fiber to perlite/gypsum composites results in improved mechanical properties up to a certain percentage of jute fiber, beyond which the properties deteriorate.

1. Introduction

Gypsum is a low-cost material and found its application in building industries as decoration, thermal barrier, fire resistance, etc. [1]. The major problems with gypsum-based wallboards are their high density, brittleness, lower strength, modulus, and energy absorption capacity (toughness) under compression and flexural loading [2]. The drawbacks of the gypsum plaster can be improved by

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reinforcing two types of materials *i.e.* particulate and fibrous fillers. Previous works showed that gypsum composites incorporating various lightweight fillers such as expanded perlite [3-6], vermiculate [4], polyurethane foam [7], waste rubber [8], etc. can reduce the density with the cost of strength although the modulus and energy absorption were increased. Many works have also been done to modify the mechanical characteristics of gypsum by introducing various fibers including glass [9, 10], polypropylene [11, 12], cork [13], hemp [14], rice husk [15], straw [16], jute [17, 18], seagrass [19], etc. The jute fabrics were also used to improve the mechanical properties and stability of gypsum composites [18]. A review article [2] provided a detailed overview of the fiber reinforced gypsum composites. They concluded that the fiber reinforcement in gypsum improved the performance of the gypsum composites and some economic and environmental benefits can also be found with the utilization of fibers in gypsum.

A recent work [6] showed that the utilization of expanded perlite particles up to a certain quantity in gypsum increased the specific compressive properties but the flexural properties were decreased. They have also shown that the jute fiber reinforcement increases the energy absorption (toughness) of the gypsum/perlite composites remarkably. However, the effect of jute fiber content on perlite/gypsum composites has not yet been studied. Therefore, in this work, jute fiber reinforced perlite/gypsum composites were manufactured using an open mold for various jute fiber contents for a fixed fiber length. The compression and flexural tests were conducted to obtain the optimum jute fiber content for various compressive and flexural properties.

2. Materials and Methodology

2.1 Materials

The raw materials used in this study were purchased from different sources to prepare the composites. Gypsum powder, collected from Shahinoor Corporation in Dhaka, Bangladesh, was used as the matrix material. According to the technical datasheet, gypsum powder comprises approximately 23.3% Calcium and 18.5% Sulphur. The filler material, expanded perlite was brought from Xinyang Caster New Material Co. Ltd. in Henan Province, China. The bulk density of the expanded perlite particles was 0.071 g/cm^3 and the composition, as stated by the manufacturer's datasheet, expanded perlite consists of approximately 71-75% Silicon Oxide, 12-16% Aluminium Oxide, 2.5-5% Sodium Oxide, 1-4% Potassium Oxide, 0.1-2% Calcium Oxide, 0.15-1.5% Ferric Oxide, and 0.2-0.5% Magnesium Oxide. Another major constituent, Jute fibers were obtained from Sonali Jute Mills Ltd., Khulna, Bangladesh. The fibers were cut to a length of 10-11 mm to be used as the reinforcing material in the composites.

2.2 Sample Preparation Process

The jute fiber reinforced perlite/gypsum composites were prepared by mixing expanded perlite particles, gypsum powder, water, and jute fibers. The ratios of gypsum to perlite and gypsum to water were kept constant at 26.67 and 1.14, respectively. Five different jute fiber contents were studied e.g. 2.41 %, 3.01 %, 3.61 %, 4.22 %, and 4.82 %.

Table 1
Mix proportion of the constituent materials

Sample No.	Gypsum (g)	Water (g)	Perlite (g)	Jute Fiber (g)	Jute Fiber (%)
1.	400	350	15	10.0	2.41
2.	400	350	15	12.5	3.01
3.	400	350	15	15.0	3.61
4.	400	350	15	17.5	4.22
5.	400	350	15	20.0	4.82

The dry perlite particles were firstly dry mixed with gypsum, then jute fiber was added to the mixture using a strainer (a small amount at a time to avoid agglomeration). The required amount of water was then added to the mixture and stirred by hand for at least 2 minutes. The mixture was transferred to an open mold (the cavity size for the compression test specimens was 130 mm × 130 mm × 25 mm and 200 mm × 200 mm × 10 mm for flexural test specimens) and left for two hours for initial curing. After that, the mold was transferred to an electric oven (Gallenkamp OHG097 XX.2.5 Size 2) for drying at a temperature of 80 °C. The sample was removed from the oven after 24 hours and cut to the required size for testing. A schematic diagram of the sample manufacturing process is given in Figure 1.

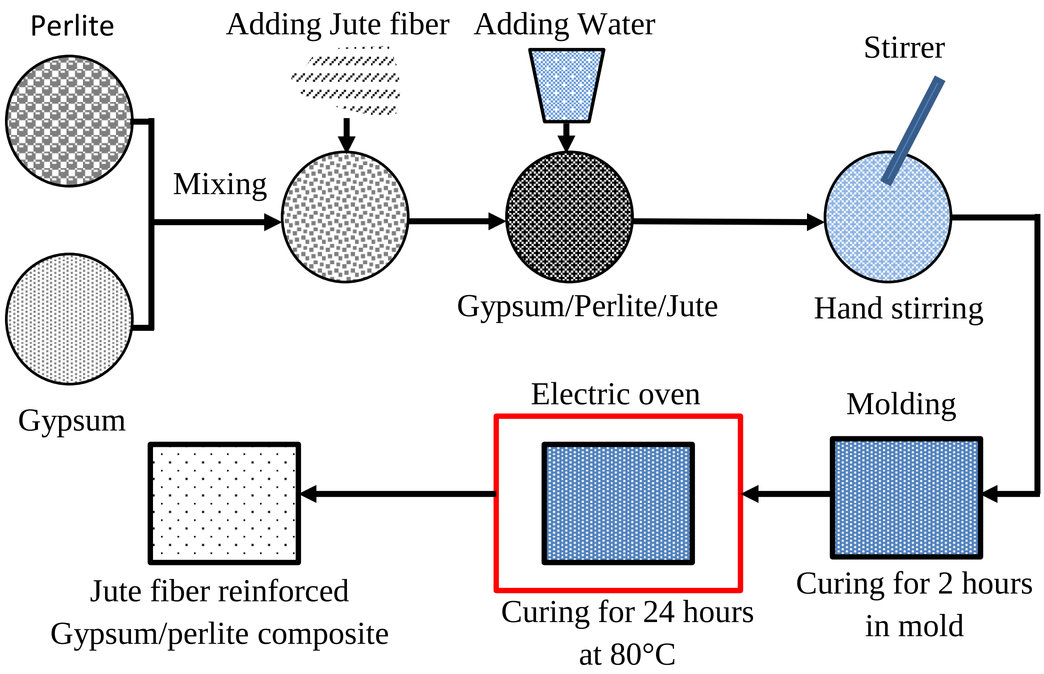

Fig. 1. Schematic diagram for sample preparation

2.3 Mechanical Tests

Compression and flexural tests were performed on the Universal Testing Machine (Shimadzu AGX-300kN, Japan) by following ASTM C365/C365M and ASTM D790 standards respectively at a 5 mm/min crosshead speed. The test setups are shown in Figure 2. The strength, modulus, and energy absorption for compression and flexural loading were calculated using the standard from the test results of at least 4 specimens for each jute fiber content. The specimen size was 30 mm × 30 mm × 25 mm for the compression test and 200 mm × 25 mm × 10 mm for the flexural test.

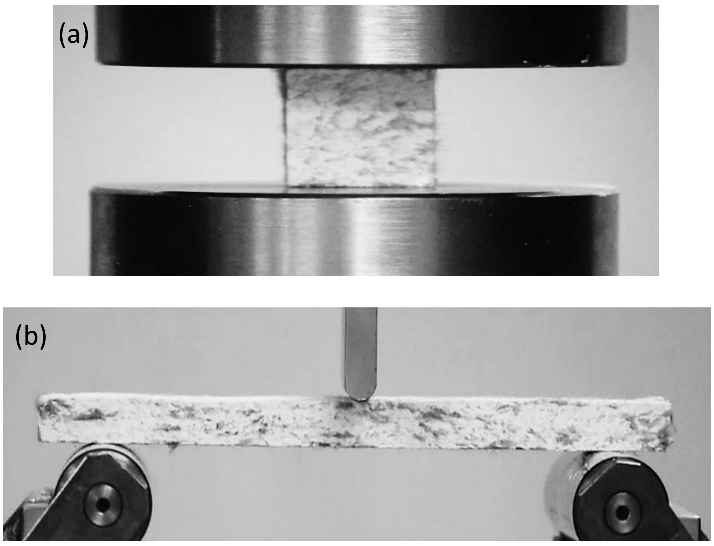

Fig. 2. (a) Compression and (b) Flexural test setup

3. Results and Discussion

The average densities of the prepared specimens are plotted and shown in Figure 3. The density increased gradually with the addition of 3.61 wt.% jute fiber, and then a decreasing trend followed. With the addition of jute content, the total volume of the whole mixture increased. Since the mold size was fixed, excess material could not be accommodated in the mold, resulting in a decrease in density when the jute fiber content is more than 3.61 wt.%.

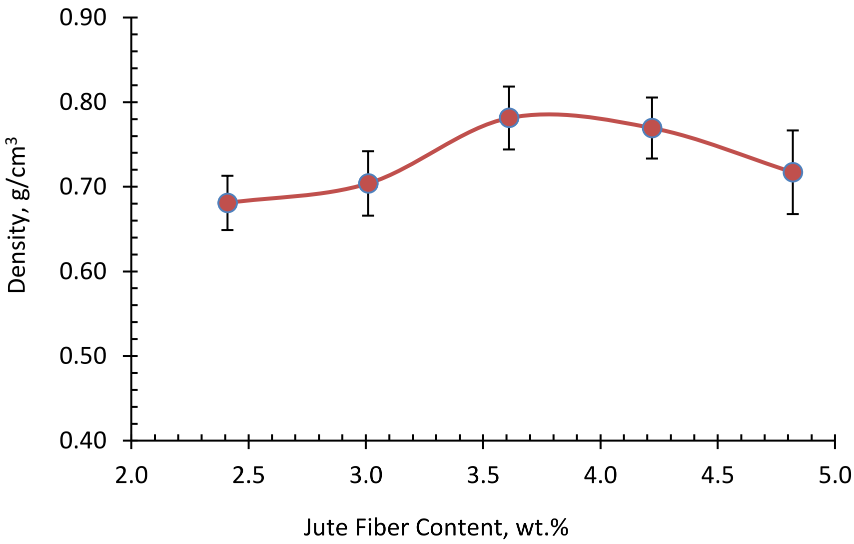

Fig. 3. The density of composites for different wt.% of jute fiber contents (Standard deviations are given as error bars)

3.1 Compressive Properties

Figure 4 shows the variation of compressive strength (CS) and specific compressive strength (sp. CS) with the addition of jute fiber in the samples. The CS and sp. CS increased with the increase in jute fiber content up to 3.61 wt.%, but they decreased with further addition of jute fiber in the composites. The highest CS and sp. CS was found to be 1.16 MPa and 1.64 MPa/(g/cm^3) respectively for the samples prepared with 3.01 wt.% of jute fiber. Comparing the sample made with 2.41 wt.%

of jute fiber to the sample made with 3.01 wt.%, the increase in CS was 35.23%. The samples prepared with 4.22 wt.% and 4.82 wt.% of jute fiber contents showed significantly lower CS and sp. CS compared to the sample with 2.41 wt.% of jute fiber content. The high jute fiber content results in an increase the voids and fiber agglomeration in the sample and decrease in the amount of binder (gypsum) in the composites which may be the reason for the lower strength of the composites with high jute fiber content.

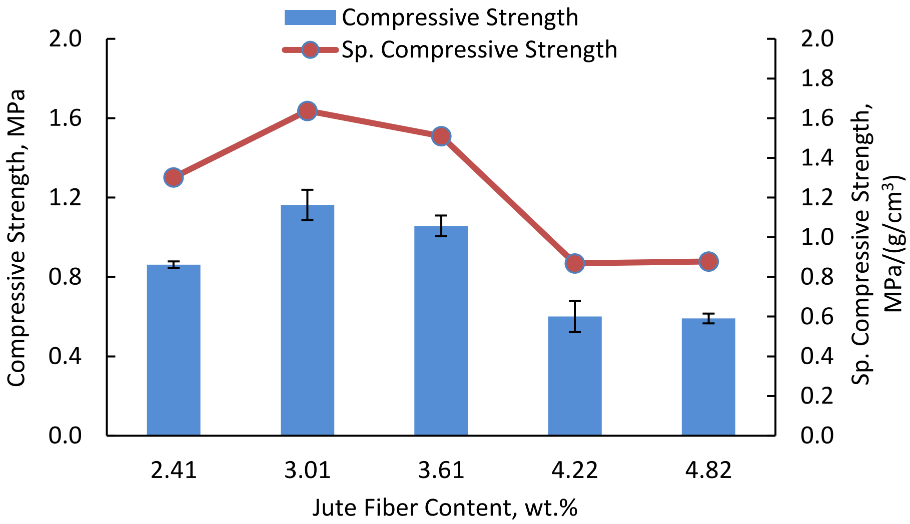

Fig. 4. Compressive strength and specific compressive strength of composites for different wt.% of jute fiber contents (Standard deviations are given as error bars)

The variation of compressive modulus (CM) and specific compressive modulus (sp. CM) for five different wt.% of jute fiber is shown in Figure 5. The CM increased from 81.76 MPa to 83.81 MPa for the sample prepared with 3.01 wt.% of jute fiber compared to the sample with 2.41 wt.% of jute fiber, whereas sp. CM decreased slightly. The further addition of jute fiber caused a gradual decrease in both CM and sp. CM because of the increase in void, fiber agglomeration and decrease in gypsum content. In the case of the sample prepared with 4.82 wt.% of jute fiber, the CM and sp. CM decreased to 38.87 MPa and 57.80 MPa/(g/cm^3) respectively.

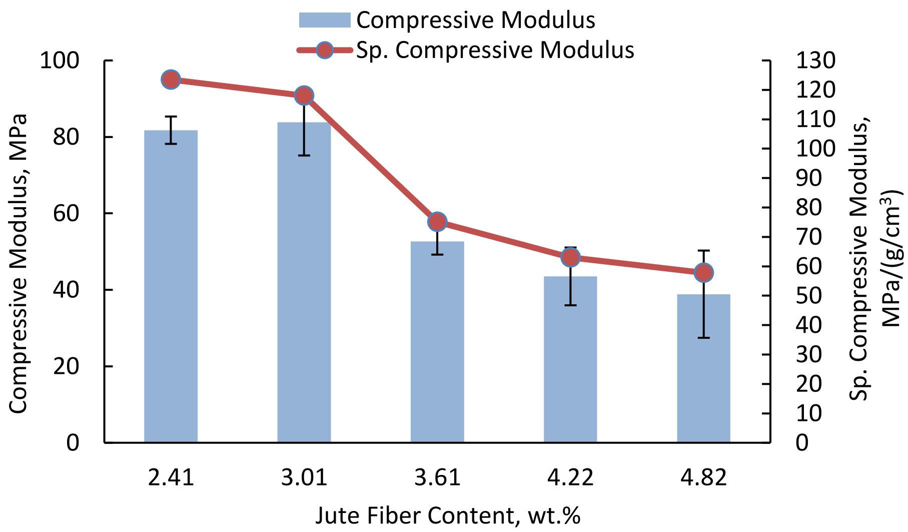

Fig. 5. Compressive modulus and specific compressive modulus of composites for different wt.% of jute fiber contents (Standard deviations are given as error bars)

The compressive energy absorption (CEA) and specific compressive energy absorption (sp. CEA) up to 50 % deformation during the compression test for different wt.% of jute fiber is shown in Figure 6. The CEA and sp. CEA are found to be the maximum for a jute fiber content of 3.01%. Further increase in jute fiber content gradually decrease the energy absorption capacity of the composite however the CEA and sp. CEA are higher than the composite with 2.41wt.% of jute fiber up to a jute fiber content of 4.82%. The higher energy absorption capacity of the composite with higher jute fiber content is primarily due to arresting the rapid crack propagation during compression.

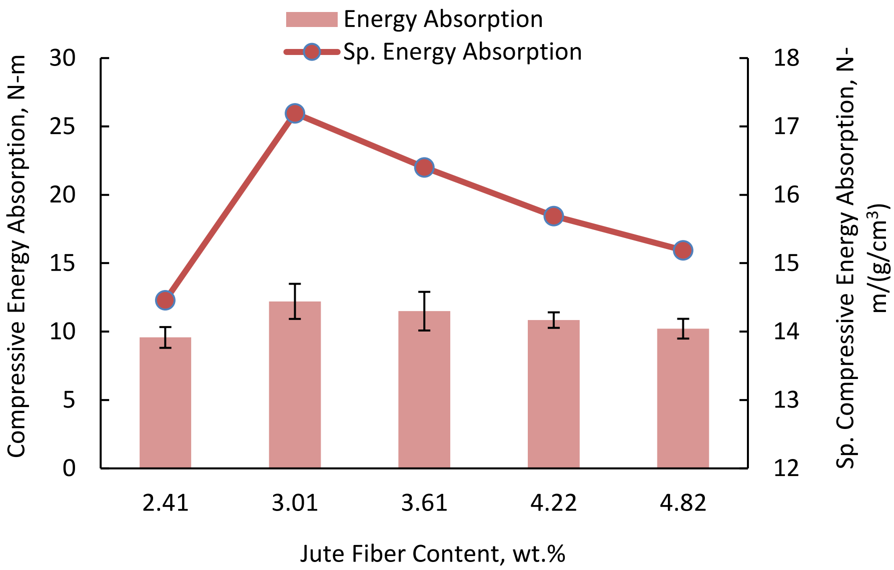

Fig. 6. Energy absorption and specific energy absorption during compression of composites for different wt.% of jute fiber (Standard deviations are given as error bars)

3.2 Flexural Properties

Figure 7 shows the variation of flexural strength (FS) and specific flexural strength (sp. FS) for composites with 2.41-4.82 wt.% of jute fiber contents. Though sp. FS decreased gradually with raising the jute fiber contents, the FS showed an increasing trend up to 3.61 wt.% of jute fiber embedded samples. In that case, the FS reached to a maximum of 0.64 MPa. The percentage increase in FS was 8.75 % compared with that of 2.41 wt.% of jute fiber content. Further addition of jute fiber reduced the FS and dropped to 0.56 MPa, slightly below the FS of 2.41 wt.% jute fiber content.

Figure 8 shows the variation of flexural modulus (FM) and specific flexural modulus (sp. FM) with the jute fiber reinforcement of 2.41-4.82 % by weight. Both the FM and the sp. FM increased gradually with increasing jute fiber contents up to 3.61 wt.%. Even while the FM began to fall as more jute fiber was added, the sp. FM maintained its linear increment up to 4.82 wt. of jute fiber. The highest FM and sp. FM were found to be 3.22 GPa and 4.40 GPa/(g/cm^3) respectively. The FM dropped at 4.82 wt.% of jute fiber content but remained higher (3.16 GPa) than the sample made of 2.41 wt.% jute fiber. Thus, a significant improvement in flexural modulus is found with the additional reinforcement of jute fiber in the perlite/gypsum composites.

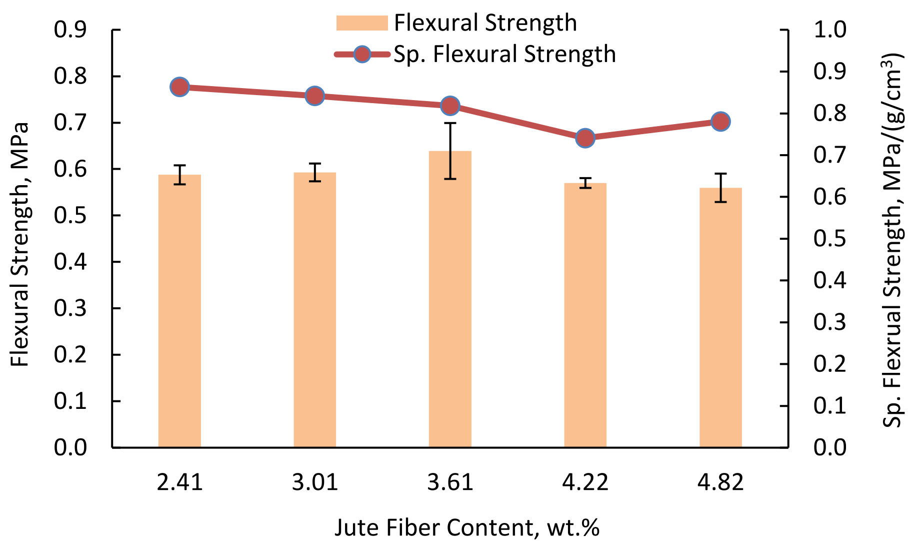

Fig. 7. Flexural strength and specific flexural strength of composites for different wt.% of jute fiber contents (Standard deviations are given as error bars)

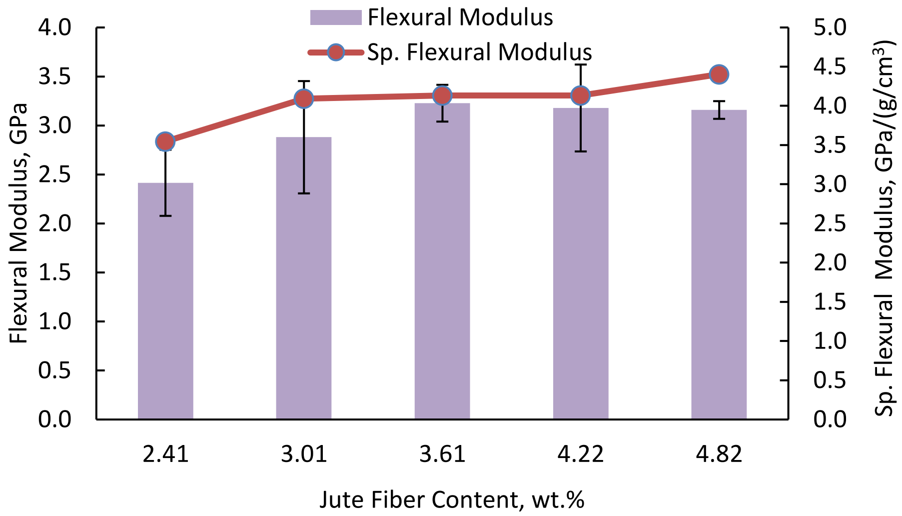

Fig. 8. Flexural modulus and specific flexural modulus of composites for different wt.% of jute fiber contents (Standard deviations are given as error bars)

The flexural energy absorption (FEA) and specific energy absorption (sp. FEA) up to 10 mm deflection during the flexural test for different wt.% of jute fiber contents is shown in Figure 9. The FEA and sp. FEA increased gradually up to a maximum at 3.61 wt.% of jute fiber content and then dropped with further addition of jute fiber in the perlite/gypsum composite, but never fell below the FEA and sp. FEA of sample prepared with 2.41 wt.% of jute. The maximum values of FEA and sp. FEA were 107.28 N-mm and 137.32 N-mm/(g/cm^3) respectively. The percentage increase in FEA was 63.45 % for the sample prepared with 3.61 wt.% of jute compared to the sample with the lowest wt.% of jute fiber content. The increased energy absorption due to jute fiber reinforcement is because of the fiber pull out after the initial gypsum cracking.

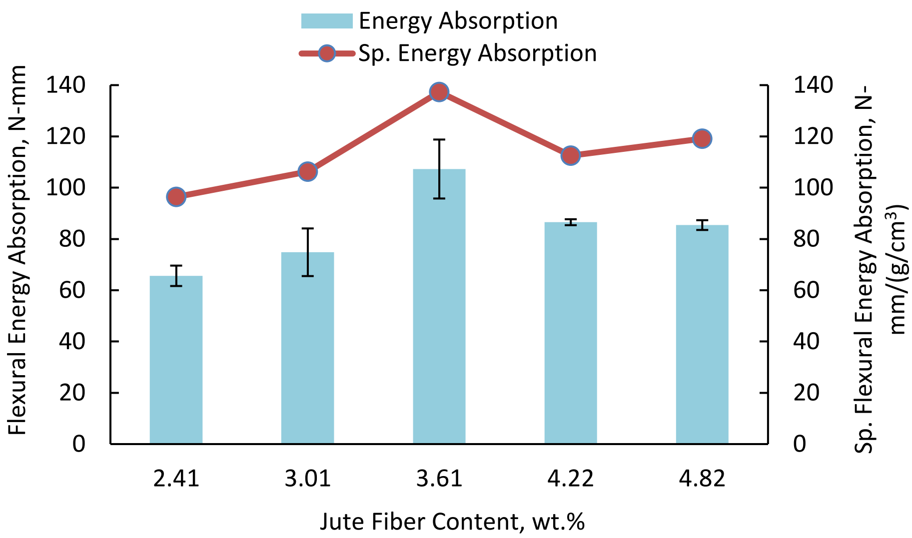

Fig. 9. Flexural Energy absorption and specific flexural energy absorption of composites under flexural loading for different wt.% of jute fiber contents (Standard deviations are given as error bars)

4. Conclusions

Jute fiber reinforced perlite/gypsum composites were prepared with 2.41-4.82 wt.% of jute fiber contents and the mechanical properties were investigated in this work. The compressive and flexural properties of the perlite/gypsum composites is dependent on the jute fiber content. Compressive strength, modulus, and energy absorption during compression were found to be the maximum for a 3.01 wt. % jute fiber content in the perlite/gypsum composites; whereas flexural strength, modulus, and energy absorption during flexural test were found to be maximum for 3.61 wt. % of jute fiber. It is seen that high jute fiber content degrades the compressive and flexural properties of the composites. This work showed the effect of jute fiber content in the gypsum/perlite composites and the sandwich structures may be investigated using the proposed composites in the future.

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