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EFFECTS OF BORIC ACID CONTENT ON WATER ABSORPTION AND FLEXURAL PROPERTIES OF PERLITE/SODIUM SILICATE COMPOSITES

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Abstract-*Expanded perlite particles are one of the lightweight materials that are used in the construction industry because of their excellent insulation and fire-resistant characteristics. These particles are usually bonded using various binders to manufacture building wall and ceiling insulation boards. In this study, expanded perlite-based composites were prepared with a new binder system of sodium silicate solution with boric acid. The prepared composites were characterized for density, water absorption, and flexural properties. The failure behavior during the flexural test was also analyzed in relation to load vs displacement curves. It is seen that the increment in density reaches 4.83 % with the addition of 8 g boric acid as compared to the sample having 0 g boric acid. The water absorption by the composites was seen to decrease with increasing boric acid content. The flexural test results showed an improvement in the flexural modulus and bending energy absorption when 2 g boric acid is used in the perlite/sodium silicate composites when compared with the specimens with no boric acid.*

Keywords: Expanded Perlite, Sodium Silicate Solution, Boric Acid, Water Absorption, Flexural Properties

1. INTRODUCTION

The importance of lightweight materials in building insulation has become a major issue in construction sites. With the increasing demand for resisting fire accidents and temperature control, the utilization of lightweight composites is growing rapidly. In addition to this, lightweight composites show significant energy conservation. Considering such criteria, the researchers introduced wood-aluminum [1] and different fiber-reinforced composites [2] for insulation purposes. To minimize costs, some researchers showed interest in expanded perlite-based composites having excellent sound absorption and insulation properties [3]. Rashad [4] has reviewed the pros and cons of expanded perlite as a building material. Many researchers have worked with expanded perlite-based composites with various binder systems e. g. potato starch [5], sodium silicate solution [6, 7], recycled polystyrene [8], sodium silicate solution reinforced with corn starch [9] etc. But there are still scopes to improve the binder system to overcome the drawbacks of the existing binder system. Expanded perlite composites with dehydrated sodium silicate solution as a binder have a high affinity to water because of the high water absorption capability of sodium silicate solution [10]. Recently Li et. al. [11] showed that the addition of boric acid to the sodium silicate solution can improve the compressive properties of the adiabatic foam. Therefore, in this work, we are suggesting a new binder system comprised of sodium silicate solution with boric acid for manufacturing expanded perlite-based composite foam for the application as a building material. The manufactured composites were characterized for density, water absorption, and flexural properties. The failure behavior of the manufactured composites has also been discussed along with the load-displacement curves for future development.

2. MATERIALS

2.1 Expanded Perlite

Expanded perlite was bought from Xinyang Caster New Material Co. Ltd. in Henan Province, China. Dust and powders were sieved out of the particles. To preserve uniformity, the particles with diameters of 2-3 mm were separated using sieves. The expanded perlite comprises 71-75% Silicon Oxide, 12-16% Aluminum 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, according to the manufacturer's catalog. The measured bulk density of expanded perlite was 0.071 g/cm^3.

2.2 Binders

Sodium silicate solution was purchased from SilicaSolution in Chittagong, Bangladesh. The weight ratio of SiO_2 and Na_2O is 3.2:1, with a density of 1.381

g/cm^3 at 20°C and solid content of 36.3 ± 1.2%, according to the manufacturer's datasheet (by weight). Gypsum powder and boric acid were purchased in powder form from local construction stores in Khulna. According to the technical datasheet, gypsum powder contains 23.3 % Calcium and 18.5 % Sulfur; and boric acid contains 4.89 % Hydrogen, 17.48 % Boron and 77.63 % Oxygen. Gypsum was used to ease the molding process of the sample. The mass of perlite and gypsum were kept constant while the mass of boric acid was varied from 0 to 8 g, as illustrated in Table 1.

Table 1: Proportion of the constituent materials

Sample No.	Weight of Perlite (g)	Weight of SSS (g)	Weight of Gypsum (g)	Weight of Boric Acid (g)
1.	50	200	20	-
2.	50	200	20	2
3.	50	200	20	4
4.	50	200	20	6
5.	50	200	20	8

3. METHODOLOGY

3.1 Sample Preparation

Perlite foams were prepared by mixing expanded perlite particles of size 2-3 mm with sodium silicate solution (SSS), gypsum, and boric acid in the proportions listed in Table 1. The preparation was done in stages following the compression molding technique. Firstly, the gypsum powder was poured into the SSS solution and mixed for 10 minutes, then the boric acid was added and swirled for another 15 minutes. After that, the prepared mixture was placed into a container containing perlite particles and hand-mixed to ensure uniformity. The wet mixture of porous perlite particle and binder was then transferred into a mold of cavity size 130 mm × 130 mm × 25 mm and compacted to 20 mm height using a plunger. After that, the foam was kept inside Gallenkamp OHG097 XX.2.5 Size 2 oven for drying at a temperature of 120 °C until the weight loss becomes constant. Two foam panels for each boric acid content were manufactured and test samples were cut to the required size (130 mm × 25 mm × 20 mm).

3.2 Density Test

Two specimens from each manufactured panel were taken to measure the density for each boric acid content. All of the specimens' dimensions (length, width, and height) and mass were measured, and the density was calculated by dividing the mass of the specimen by the volume of the specimen.

3.3 Water Absorption Test

Three specimens were used for each boric acid content for the hygroscopic test according to ASTM D5229/D5229M standard. The mass of all specimens was measured before immersing into the distilled water for 48 hours. The percentage increase in mass after 48 hours of immersion was calculated.

3.4 Flexural Test

The flexural tests were performed on the Universal Testing Machine (Shimadzu AGX-300kN) by following the ASTM D790 standard at a crosshead speed of 5 mm/min. The flexural strength, flexural modulus, and energy absorption up to 50% deformation were calculated using ASTM D790 standard from the test results of four specimens for each boric acid content. The failure behavior during flexural tests was recorded using a video camera for analysis.

4. RESULTS AND DISCUSSION

4.1 Density

Average densities of the prepared five types of foams are plotted in Fig. 2. Density increases gradually with the addition of boric acid and the trend line equation shows the linearity in increment of densities. The density range found is from 0.40 to 0.42 g/cm^3. The percentage increase in density with the addition of 2 g boric acid is 1.92 %, which reaches up to 4.83 % for 8 g boric acid content.

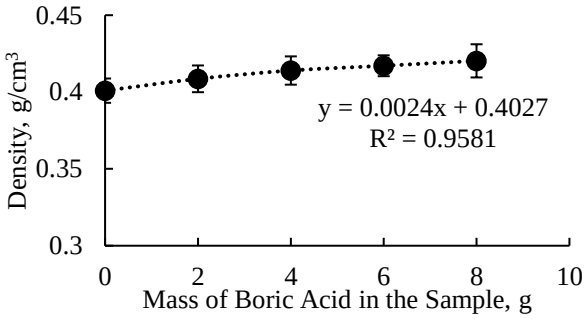

Fig. 1: The density of the prepared foams for various boric acid contents (Standard deviations are given as error bars).

4.2 Water Absorption

Table 2 indicates the percentage of water absorption after 24 hours and 48 hours for the samples prepared with different boric acid contents. After 24 hours and 48 hours, the highest water absorption was found 103.13% and 106.98% respectively in the control sample with no boric acid. Water absorption was decreased gradually up to sample prepared with 4 g boric acid content in the foam. In the rest of the samples, an anomaly is found in the percentage absorption of water due to high boric acid content. It may be because excessive boric acid has changed the kinetics of water absorption.

Table 2: Water absorption by the foams for various boric acid content

Boric Acid Content, g		0	2	4	6	8
Water absorbed, %	24 hrs	103.13	99.89	89.27	94.91	90.40
	48 hrs	106.97	102.92	95.02	100.63	94.57

4.3 Flexural Properties

Fig. 2 shows flexural strength (FS) and specific flexural strength (sp. FS) for various boric acid contents

in the composite foams. The highest value of FS and sp. FS (1.26 MPa and 3.09 MPa/(g/cm^3) respectively) are found when no boric acid was added in the binder. The FS and sp. FS decreased linearly with a high correlation coefficient with the addition of boric acid as shown in Fig. 2. The addition of 8 g boric acid caused a decrease in both FS and sp. FS more than 50%. In the literature [11] it is found that the compressive strength of the sodium silicate adiabatic foam increased due to the addition of boric acid. However, the FS decreased with the increase in boric acid content in the perlite/sodium silicate foam. One of the reasons for the decrease in FS may be the formation of agglomerate due to the chemical activity between sodium silicate and boric acid. Further microstructural and chemical analysis needs to be conducted to evaluate the exact cause of the decrease in the FS.

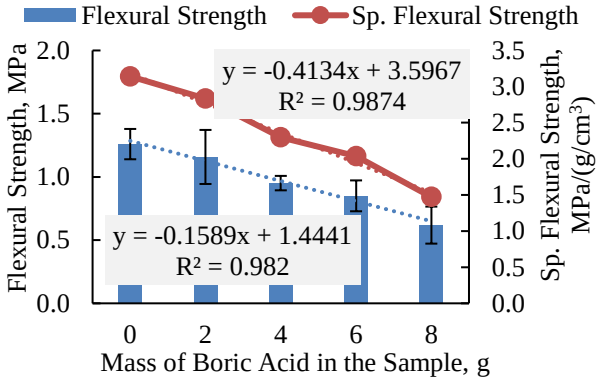

Fig. 2: Flexural strength for various boric acid contents (Standard deviations of FS are given as error bars).

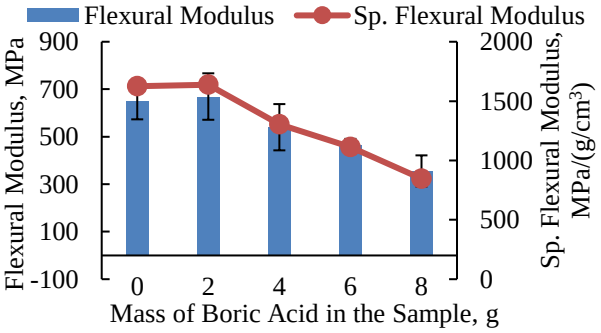

Fig. 3: Flexural modulus for various boric acid contents (Standard deviations of FM are given as error bars).

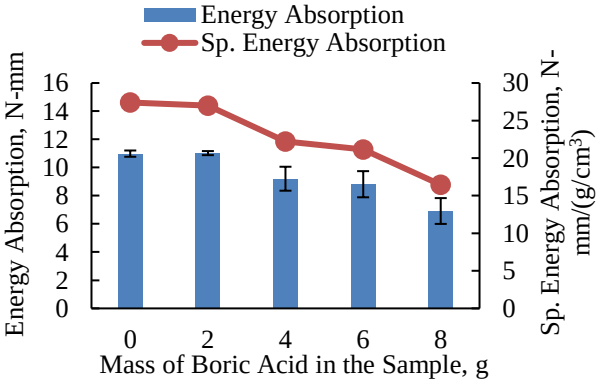

Fig. 4: Total energy absorption up to 1.2 mm deflection for various boric acid contents (Standard deviations are given as error bars).

The flexural modulus (FM) and specific flexural modulus (sp. FM) are plotted for various boric acid contents in Fig. 3. It is interesting to see that the maximum FM and sp. FM (669.26 MPa and 1637.93 MPa/(g/cm^3) respectively) were found in the foam having 2 g boric acid. The percentage increase in FM and sp. FM with the addition of 2 g boric acid were 2.75 % and 0.81 % respectively. Nonetheless, further addition of boric acid in the composite foam decreased FM and sp. FM gradually as shown in Fig. 3. The foam with 8 g boric acid showed the minimum FM and sp. FM valued 355.96 MPa and 846.91 MPa/(g/cm^3) respectively and the percentage decrease in FM and sp. FM from the foam with no boric acid were 45.35% and 47.88% respectively. In Fig. 4, total energy absorption (EA) and specific energy absorption (sp. EA) up to 1.2 mm deflection for various boric acid contents are plotted from the results of the flexural test. The sample prepared with 2 g boric acid showed the highest EA valued 11.02 N-mm, whereas the maximum sp. EA (27.40 N-mm/(g/cm^3)) was seen for the samples having 0 g boric acid because of low density (See Fig. 1). Further addition of boric acid in the samples decreased the EA and sp. EA significantly as shown in Fig. 4. The decrease in EA and sp. EA were found to be 37.06 % and 39.97 % respectively for the samples having 8 g boric acid as compared to the maximum value.

In summary, it may be noted that the addition of 4 g and 2 g boric acid in sodium silicate has shown improvement in water absorption and flexural modulus respectively.

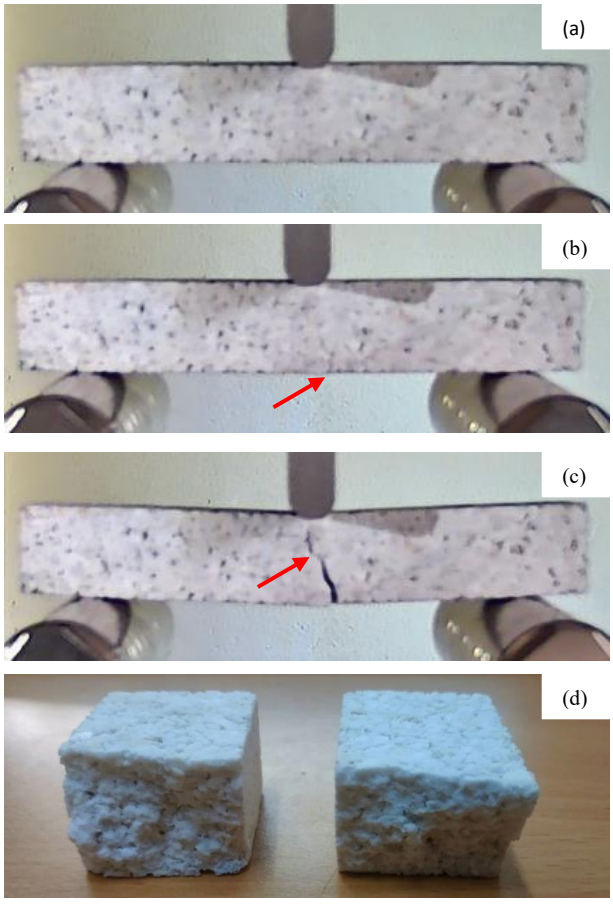

Fig. 5: Failure sequences of the sample during flexural

test (a) specimen setup before the test starts; (b) with the application of bending load crack initiates; (c) crack growth leads to fracture; (d) specimen after failure.

4.3 Failure Behavior

The sequences of failure during the flexure test are shown in Fig. 5. During the test, crack initiates at the tension side of the specimen (Fig. 5(b)) and propagates to the compression side (Fig. 5(c)). No mark of indentation was seen in the compression side of the specimen. A similar type of failure is also found in Ref. [12]. The load vs displacement curves shown in Fig. 6 shows that the load increased with the increase in displacement linearly until a sudden drop indicating the crack initiation. The propagation of the crack can be identified from the load-displacement curves because the load does not drop to zero after failure and some energy absorption after the failure can be seen by the gradual decrease of load with deflection after failure. The energy absorption after failure appears to be prominent for specimens made with boric acid content 6 g and 8 g (Fig. 6). One of the reasons for the energy absorption after failure is the mechanical interlocking between the expanded perlite particles because of their irregular porous surfaces [12]. It can also be observed from Fig. 5 (d) that the crack propagation has occurred through the interface between the particles which indicates the future direction of improvement of perlite based composites.

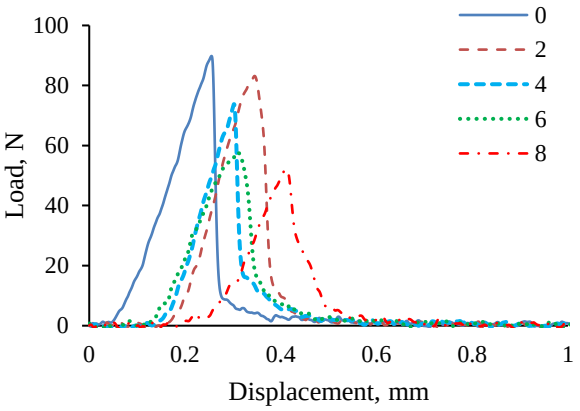

Fig. 6: Load vs displacement curve for samples prepared with different boric acid contents

5. CONCLUSION

The effects of boric acid content on the water absorption and flexural properties of the perlite/sodium silicate composites were investigated experimentally. The density increased with the addition of boric acid in the perlite/sodium silicate foam and the water absorption decreased with increasing boric acid content in the foam. Although an 8.07 % drop in flexural strength was found in the sample prepared with 2 g boric acid the flexural modulus and energy absorption increased by 2.75 % and 3.4 % respectively. The failure analysis showed the crack initiation at the tension side of the specimens and the evidence of the crack propagation was found in the photographs taken during the test and the load vs displacement curves.

6. ACKNOWLEDMENT

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