BAMBOO AND NYLON FIBER REINFORCEMENT: AN ALTERNATIVE APPROACH TO PRODUCE INFILL WALL PANELS

Tayeba Islam*[1], Muhammad Harunur Rashid[2], Most. Mohosena Khatun[3] and Afifa Binte Shaheen[4]

[1] *Student, Department of Civil Engineering, KUET, Bangladesh, e-mail: lamia.tayeba@gmail.com*
[2] *Professor, Department of Civil Engineering, KUET, Bangladesh, e-mail: mhrashid@ce.kuet.ac.bd*
[3] *Student, Department of Civil Engineering, KUET, Bangladesh, e-mail: mostmohosenakhatun@gmail.com*
[4] *Student, Department of Civil Engineering, KUET, Bangladesh, e-mail: afifashaheen1@gmail.com*

***Corresponding Author**

ABSTRACT

Globally, conventional reinforced concrete structural elements such as steel have received discernible attention as an active component in the construction industry. However, its weight, cost volatility, and non-renewable nature weaken its feasibility in lightweight panels. Fueled by the imperatives of sustainable building practices, the purpose of this study is to utilize bamboo and nylon fiber reinforcement as cheaper alternatives to produce infill wall panels. A universal testing machine (UTM) was used to optimize the shape of bamboo strips and the diameter of nylon fiber, which exhibited the maximum tensile strength. The productivity and efficacy of bamboo strips and nylon fiber were assessed as reinforcement through experimental trials of wall panels. Three panels (Sample-1, Sample-2, and Sample-3) with two different design mixes of cement mortar and distinct reinforcement compositions were manufactured. Sample-1 utilized two layers of nylon as main reinforcements in both directions, while the others have bamboo strips longitudinally and nylon transversely. The composition included 0.2% nylon for Sample-1 and 1.8% bamboo with 0.12% nylon for Sample-2 and Sample-3 by volume. The compressive strength of the mortar was determined using 50mm cubes in a compression test. A cement-to-sand ratio of 1:2 was selected for the first two samples and 1:4 for the remaining one. Each panel has 1066 mm x 406 mm x 50 mm measurements and was tested as per ASTM C78 standards. In the construction industry, a variety of materials exists whose structural performance may or may not be influenced by temperature fluctuations. To ensure the fire safety of fiber-reinforced panels in various infrastructures, the samples were also observed under elevated temperatures to observe the cracking pattern of the samples. A heat transfer test was carried out on the reference samples to calculate the time required to heat the samples uniformly up to 375°C. From time to time, the samples were weighed to determine the consequent weight loss due to high temperatures. The experimental result shows the impact of fiber materials as the main reinforcements of the walls, encompassing load-deformation characteristics, crack patterns, failure modes, and fire resistance. Notably, wall panels' load-bearing and deformation capabilities exhibit better performance when utilizing the proposed bamboo strip coupled with nylon fiber as reinforcement and a cement sand ratio of 1:2 in mortar for the panels.

Keywords: *Infill wall panel, Bamboo, Nylon, Load-deformation, Fire resistance*

1. INTRODUCTION

In today's world, housing and infrastructure predominantly rely on traditional materials such as steel and concrete, and this reliance has significantly grown over the past two decades. The demand for these conventional construction materials has increased considerably (Mali et al., 2020). Although the materials enhance the concrete properties significantly, their heavy weight and cost volatility make them unfeasible for lightweight panels. Considering the limitations of conventional materials, this study solely focused on lightweight infill wall panels fabricated with bamboo and nylon fiber.

The search for alternative materials in the construction industry is not a new concept. Many researchers have explored the use of fibrous materials in strengthening concrete structures (Mali et al., 2018). As sustainability has become a topic of concern, materials demonstrating efficient use of renewable energy sources have received worldwide interest due to their eco-friendly nature and superior material properties (Sanal et al., 2019). Many naturally available materials have the potential to be utilized in construction and promote sustainable and eco-friendly concrete structures. One such natural material is bamboo (Anandamurthy et al., 2017).

According to the Guinness Book of World Records, bamboo is a giant grass with over 1200 species, some of which can even grow up to 91 centimeters a day. One of its significant advantages is its quick growth, reaching full size in just a few months. Moreover, bamboo is plentiful in tropical and sub-tropical regions worldwide (Puri et al., 2017). Although the durability of bamboo was questioned in Portland cement composite, Cordero and Lopez concluded that bamboo degradation occurs only when proper procedures are neglected in construction (Lima et al., 2008). Bamboo has been extensively utilized as the structural material for constructing both permanent and temporary construction projects. It has been recognized as a green alternative, offering a competitive and eco-friendly option compared to non-renewable and environmentally harmful materials like steel and concrete (Sharma & van der Vegte, 2020). In this paper, bamboo strips were utilized to fabricate infill wall panels, and the structural behavior of the samples was investigated. When bamboo is cut into small strips and meshed, it increases its flexural strength, making it conducive for wall panels (Ghavami, 2005). In one study by Paudel (2008), evaluating potential advantages and risks associated with advocating bamboo for housing, it has been claimed that bamboo can be used as an exceptional building material for various economic groups, providing a wide range of housing options. In contrast to modern concrete, bamboo walls were also found to offer better thermal comfort (Dash & Gupta, 2015).

Nylon fiber is also used in this study, which is known to offer high tensile strength and good chemical resistance to the composite. Due to its small diameter, hydrophilic characteristics, and short length, it shows notable resistance to fire. In addition, it enhances workability in comparison to several alternative fibers (Vaishnavi et al., 2021). Previously, nylon fiber was used in concrete and the mechanical characteristics and cracking control of concrete with nylon fiber reinforcement were examined (Song et al., 2005). In a study by Spadea et al. (2015), recycled nylon from fishing nets was used in mortar and the structural behavior of mortar was investigated. The results showed a substantial improvement in both toughness and ductility when recycled fibers were introduced into the mortar. Moreover, the flexural strength experienced a notable improvement, reaching up to 35%. Saxena (2015) also investigated the application of nylon fiber to enhance the strength of conventional concrete and reported that the addition of nylon fiber can improve the structural performance of the concrete. They also noted that nylon fiber can provide additional benefits, such as reducing the permeability and shrinkage of the concrete. In another study, by examining the mechanical properties of cement-based mortar, Hanif et al. (2017) observed that the addition of nylon fiber positively affects both compressive and flexural strength, enhancing the overall performance of the mortar.

The above studies on the use of bamboo and nylon in structures indicate that both materials can provide significant benefits as construction materials. In this study, three panels were produced with different cement mortar mixes and distinct reinforcement compositions where nylon and bamboo were used as main reinforcements. To investigate the structural performance of wall panels reinforced with fibrous materials, a flexural strength test was conducted. The panels were also observed under elevated temperatures to evaluate fire resistance properties.

2. METHODOLOGY

The experimental program has been divided into four steps:

- Step 1: Selection of materials
- Step 2: Preparation of samples
- Step 3: Curing and casting of wall panels
- Step 4: Testing procedure

2.1 Step 1: Selection of materials

According to BNBC 2020, there are 21 types of bamboo species all over the country. The process of selecting bamboo type was not that challenging as the local region offered only three types of bamboo permitted by BNBC to be used for construction purposes. With the help of previous literature, *Bambusa balcooa* (locally called Borak) was chosen as it was suitable and more readily available than any other species. The characteristics of bamboo are influenced by the height and age of the bamboo stem. Research indicates that bamboo strength tends to rise with age, reaching its highest point between 2.5 and 4 years. However, In the later stages of its growth, the strength starts to decline (Amada and Untao, 2001). As the bamboo samples used in this study predominantly come from the lowest part of a well-developed bamboo stem, the density is noticeably high. For the selected bamboo specimens, the average density was found to be 850 kg/m3. It was ensured that the bamboo was sufficiently straight as well as free from any damage or fungal attack so that the resultant samples could present an even distribution of fibers. To prepare the samples, the bamboo was divided lengthwise into two sections and then subdivided into four pieces, each with a diameter of about 7mm. The pieces were then cleaned and shaped into a rod-like form.

Since the early 1980s, synthetic nylon fibers have been employed for reinforcing secondary temperature shrinkage in concrete (Menchaca-Campos et al., 2015). As nylon is a cheap material and easily available in Bangladesh, it was bought from a local market in different sizes and then cut into a specific length of about 6 ft. After the required cutting, these fibers were placed in wall panels as reinforcement based on their volume fraction. The diameter of the fiber was 1.19mm. In this context, three nylon specimens were immersed in an alkaline solution with a pH of approximately 13 to investigate the potential impact of cement mortar on nylon strength as shown in Figure 1. Following a 28-day exposure to wet conditions, the strength of the wet nylon samples was again analyzed. The tension test was performed for both nylon and bamboo fiber using a Universal Testing Machine (UTM) shown in Figure 2. The yield strength of bamboo was 98 MPa and that of nylon was 35 MPa.

Figure 1: Nylon fiber in alkaline solution

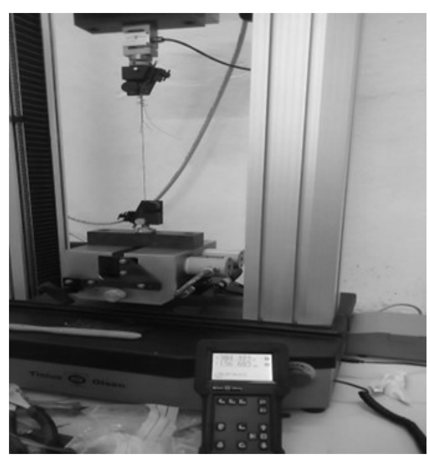


Figure 2: Tensile strength test using UTM

2.2 Step 2: Preparation of samples

To prepare the panels, formwork was built to support the newly poured mortar and the reinforcement. Key considerations included ensuring the design's accuracy in terms of length and shape, as well as the panel's overall appearance. 0.75-inch wood was utilized in constructing the formwork. The interior surface of the formwork was covered with plastic to make it watertight and to provide a smooth, clean surface for the cement mortar. A cork sheet was also used in the frame. Overall, three panels were prepared named "Sample-1", "Sample-2", and "Sample-3" with dimensions of 1066 mm x 406 mm x 50 mm. In the preparation of "Sample-1" (a panel with 0.2% nylon reinforcement), the volume percentage was first determined by measuring the average diameter of the nylon reinforcement. With a clear span of 306 mm in the transverse direction, the panel was supported 50 mm from each edge. The nylon was placed at an interval of 50 mm in both directions. The clear cover in both directions was 50 mm. The distance from the bottom of the panel to the fiber's center was 19 mm. The same was taken for the distance from the top to the center. About 21 nylon specimens in the transverse direction and 7 specimens in the longitudinal direction have been used in double layers, as illustrated in Figure 3.

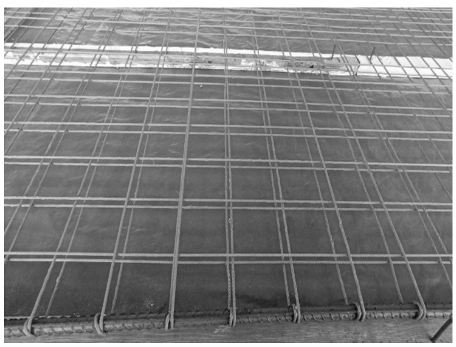


Figure 3: Sample-1 (reinforced with nylon in both direction)

Figure 4: Preparation of Sample-2 & Sample-3 (reinforced with bamboo and nylon)

To prepare Sample-2 and Sample-3 with bamboo and nylon reinforcement, firstly, the average diameter of nylon and bamboo reinforcement was calculated, which was then used to determine the percentage of reinforcement with respect to the total volume of the panel. The bamboo in the longitudinal direction and nylon in the transverse direction were placed at an interval of 50 mm. Two layers of nylon were placed in the transverse direction, whereas a total of 9 bamboo strips were placed in the longitudinal direction in between the nylon layers as shown in Figure 4. The alignment of the bamboo needed to be corrected repeatedly to give it a perfect form. The configuration of the reinforcements is also illustrated in Figure 5 & Figure 6.

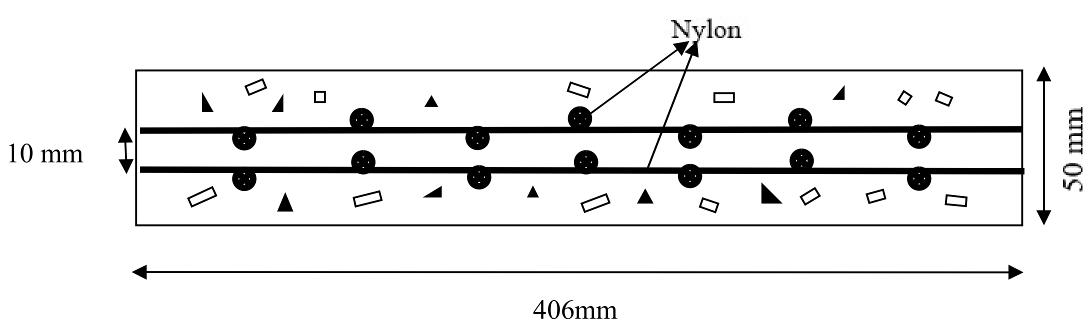


Figure 5: Schematic representation of Sample-1

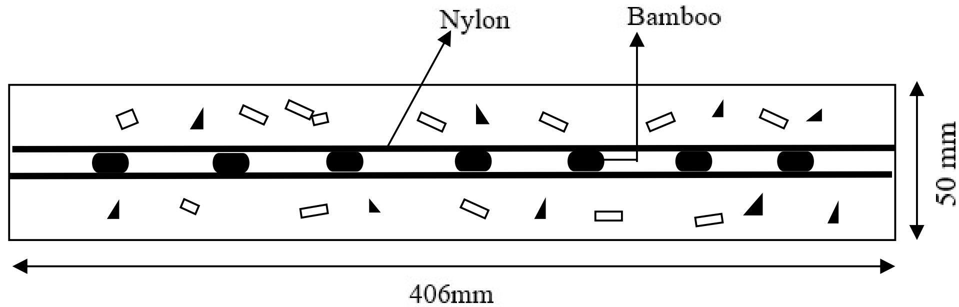


Figure 6: Schematic representation of Sample-2 & Sample-3

2.3 Step 3: Casting and curing of wall panels

2.3.1 Selection of mixing materials

According to BNBC 2020, Portland cement mortar is the principal component utilized in ferrocement production. So, In this study, Ordinary Portland Cement was utilized as the base material. It was also ensured that the cement was fresh, free of lumps and foreign particles, and had a uniform texture. The aggregate used in the panels was normal-weight fine aggregate (Sylhet sand). The sand was free of organic materials and harmful compounds, and a comparatively low percentage of silt and clay. Water-reducing admixture, Auramix 200 was used as a superplasticizer to achieve a decrease in water content. Sample-1 and Sample-2 had a cement-to-sand mix proportion of 1:2, while Sample-3 had a mix proportion of 1:4. The water-cement ratio was 0.45 for Sample-1 and 0.40 for both Sample-2 and Sample-3. After casting and a curing period of 28 days, these samples were tested to determine essential properties.

2.3.2 Casting and curing

The quantity of cement, sand, admixture, and water required for the mix ratio is shown in Table 1. The mortar was divided into three batches for three samples, mixed, and then poured into the formwork. Every batch includes three cube specimens to find out the compressive strength of the concrete. At the age of 28 days, the average cube strength for each batch was 42 MPa, 54 MPa, and 32 MPa, respectively. Mortar was applied using the conventional method of hand plastering. In this process, the mortar was forced through the mesh. A mortar mixer was used to make sure that the material was compacted effectively. Finally, the top surface was smoothed out to achieve a uniform finish. The wall panels were kept after casting for an initial settling for 24 hours. After that, the curing of the samples continued for 7 days.

Table 1: Properties of the Samples

Type of Samples	W/C Ratio	Cement(kg)	Sand (kg)	Admixture (Liter)	Water (Liter)
Sample-1	0.45	14	28	No admixture	6.3
Sample-2	0.40	17	34	0.17	6.8
Sample-3	0.40	9	36	0.14	3.6

2.4 Step 4: Testing Methodology

In this study, the flexural strength test of the wall panels has been selected to explore the possibilities of introducing nylon and bamboo for structural components. After 28 days had elapsed, the specimens were removed from their molds and tested as per ASTM C78 standard. The test arrangement is shown in Figure 7.

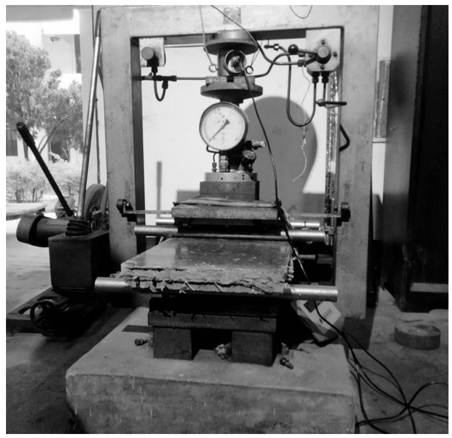


Figure 7: Flexural strength test arrangement

The Samples were also observed under elevated temperatures. The purpose of the heat transfer test was to find out how long it would take for three types of samples to uniformly heat up to 375 °C. It took nearly 6 hours to reach that temperature. To conduct the test, a furnace comprising three heaters was set up with a combined power of 9000 watts. The furnace had an opening on the top through which a thermocouple sensor was placed to monitor the temperature inside the furnace (Figure 8). A small opening was provided to allow for the circulation of heat on one side of the furnace.

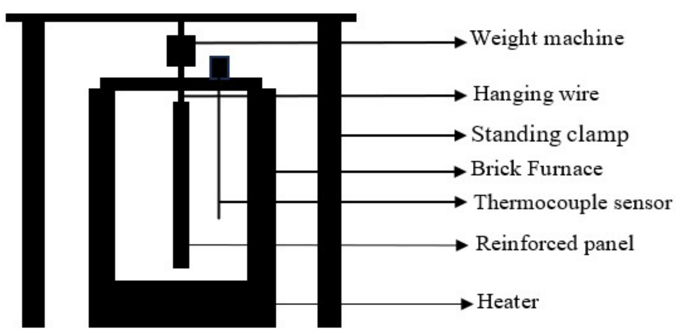


Figure 8: Test setup for fiber-reinforced panels in the furnace

The testing method for wall panels involves obtaining a single sample of each type of panel and drawing a small grid on it. The dimensions of the samples are provided as 42 inches in length, 15 inches in width, and 2 inches in thickness. The purpose of the grid is to evaluate the surface performance of the wall panels and to determine the pattern of cracks that occur on each panel. The level of fracture that occurred on each panel could be determined by taking snapshots of the grid. After observing the surface of the samples, it was possible to determine how well the wall panels could withstand external forces and stresses. This information can be used to identify any weaknesses or defects in the manufacturing process, as well as to ensure that the panels meet required specifications and standards. Overall, the testing method described provides a reliable way to evaluate the surface performance of the wall panels and ensure their quality. During the analysis, a probe thermometer and a thermocouple sensor were used to measure the temperature using a temperature controller. The weight of the samples was measured every 20 minutes. When the temperature reached 375℃, the specimens were removed from the furnace and put into a bucket full of water. The wet mass of each specimen was measured and compared to the weight before putting it into the furnace and the cracking pattern was also analyzed.

3. RESULTS AND DISCUSSION

3.1 Flexural Strength Test of fiber reinforced panels

The flexural strength tests of the samples have been carried out to determine the best performance of the samples among the three of them. The ultimate load, deflection, and flexural strength are shown in Table 2.

Table 2 : Strength properties of samples

Type of Samples	Load (kN)	Deflection (mm)	Flexural Strength (MPa)
Sample-1	3.4	0.32	4.56
Sample-2	4.4	0.41	5.28
Sample-3	4.2	0.54	5.04

The test results indicate that Sample-2 exhibited an ultimate load capacity of 4.4 kN, while Sample-3 demonstrated a capacity of 4.2 kN, and Sample-1 had a capacity of 3.8 kN. The load-deflection diagram is shown in Figure 9. The deflection curve of the samples indicates that the relationship between Load and Deflection possesses a nonlinear relationship.

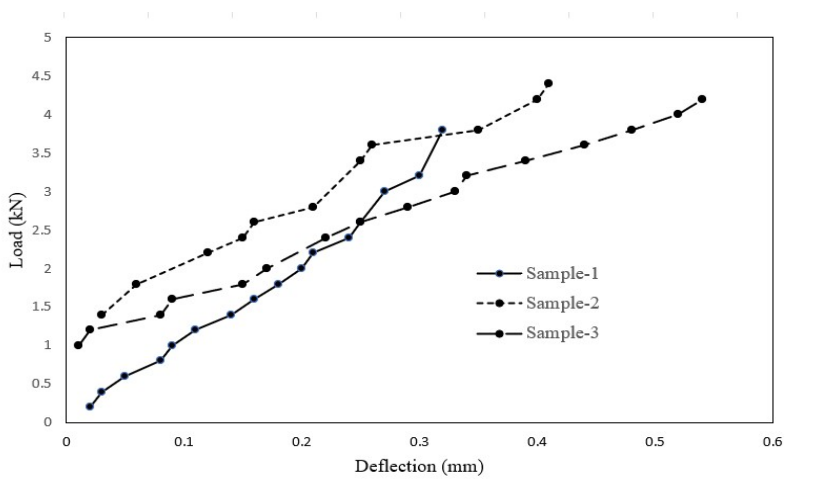
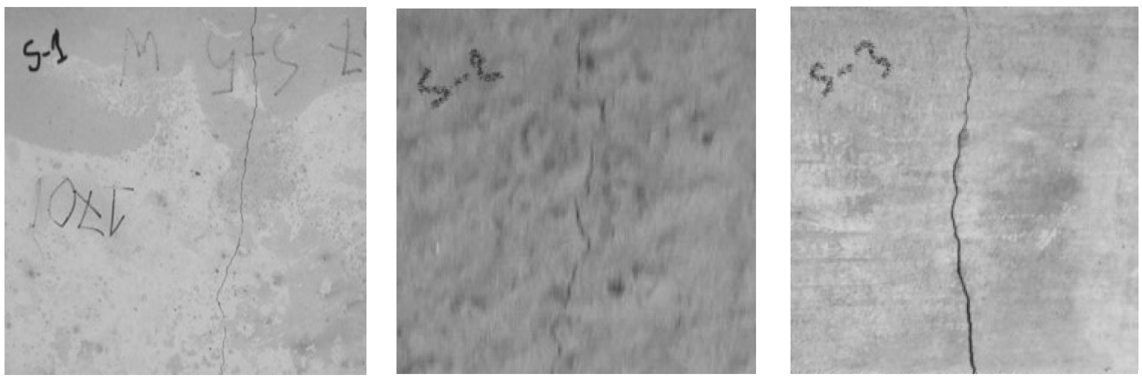


Figure 9 : Load-Deflection diagram of the samples

When the cement and sand ratio was 1:2 and both nylon and bamboo were used together, a little upgrade was noticed in the graph of Sample-2 which indicates the increased strength properties of the panel. The result of ultimate load-carrying capacity varies a little while nylon and bamboo were combined with a different mix ratio in Sample-3 as compared to Sample-2. On the other hand, Sample-1 possesses the lowest load-carrying capacity.

After performing the test, the crack pattern of three samples was observed as shown in Figure 10. The first crack appeared in Sample-1 at 3.8 kN due to the action of bending and the deflection was 0.32mm. Its location was at the center of the panel. The crack was noticed in Sample-2 while the load was about 4.4 kN and the deflection was 0.42 from the top of the panel. Its position was slightly left from the center of the panel. Sample 3 developed a crack as a result of an ultimate load of 4.2 kN and a 0.55 mm deflection.



(a) (b) (c)

Figure 10: Crack Pattern in (a) Sample-1; (b) Sample-2 and (c) Sample-3

The failure load was characterized as crack propagation up to about 90% of the panel's depth, and the maximum load measured was 4.4 kN. As seen by the crack pattern, the samples failed suddenly after the initial crack, exhibiting a brittle failure mode.

3.2 Samples under elevated temperature

The samples were tested under elevated temperatures. The rate of weight loss of the samples can be observed in Figure 11. In this test, initially, Sample-3 experienced greater weight loss compared to Sample-1 and Sample-2, but the gap between them decreased with increasing temperature.

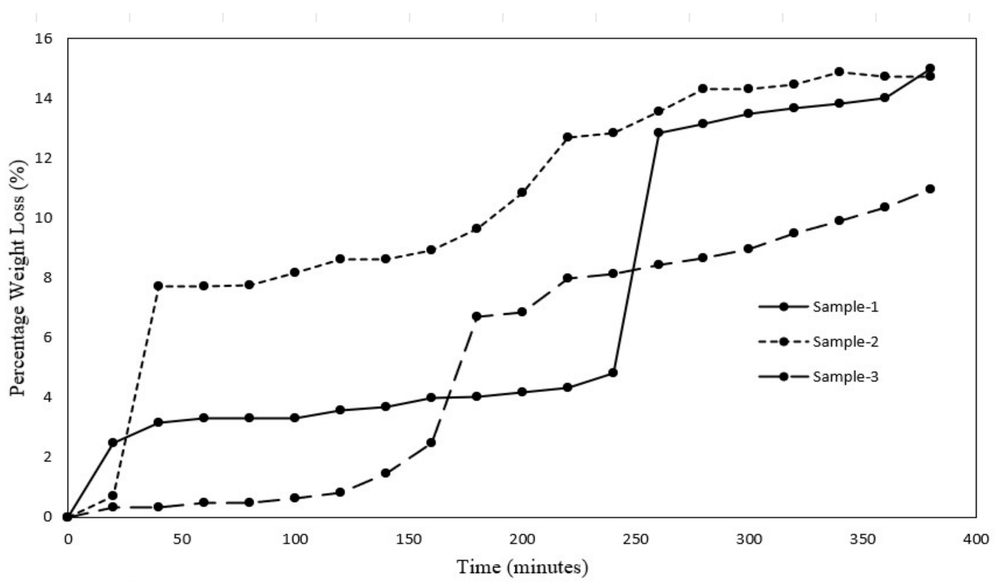


Figure 11: Relationship between percentage weight loss and time of fiber-reinforced samples

At different temperatures up to 200°C, a slight increase in weight loss can be noticed. However, after 200°C, all types of the samples experienced a major increase in the rate of weight loss. The percentage weight loss of Sample-1, which comprises nylon fiber reinforcement, was much higher than the other two samples. After removing the samples from the furnace, no crack was observed on the surface of the grid samples.

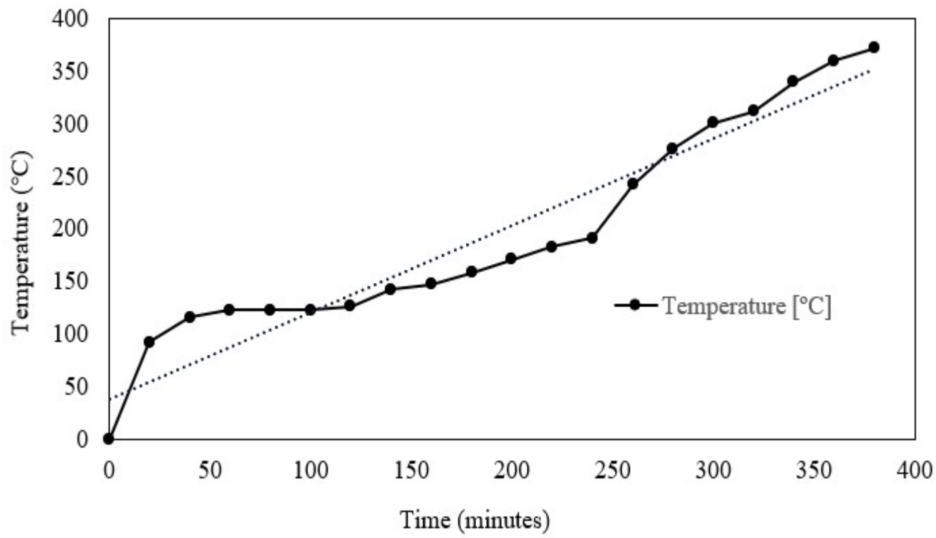
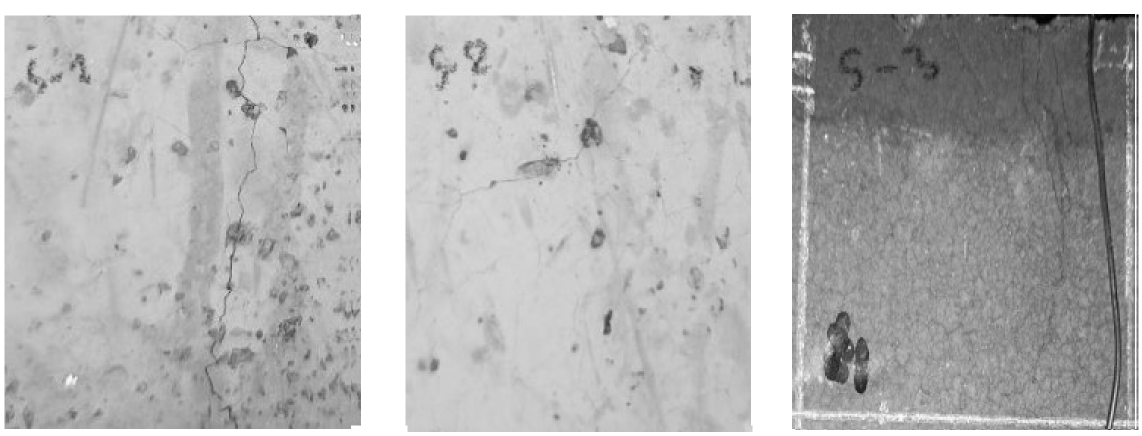


Figure 12: Relationship between temperature and time

From Figure 12, it can be observed that the relationship between temperature and time is not linear. At some points, the temperature remains constant and after a while, it starts to increase gradually. To ensure the accuracy of temperature measurements, it is important to calibrate the instruments being used. In this scenario, a traditional thermometer was used as a reference to calibrate a temperature controller. To do this, a heater was used to generate heat, and the temperature controller was adjusted to match the temperature shown on the traditional thermometer. After adjusting the temperature controller, the two instruments were compared again, and no noticeable difference in the readings was found, indicating that the calibration was successful.

The experiment involved subjecting samples to a process of heating and cooling. Typical images of samples after cooling samples are shown in Figure 13.



(a) (b) (c)

Figure 13: Crack pattern of samples under elevated temperature (a) Sample-1; (b) Sample-2 and (c) Sample-3

When the temperature inside the furnace reached 375°C, the samples were taken out and soaked in a solution. This cycle of heating, submerging in water, and cooling was repeated several times. As a result of this process, surface fine hairline cracks were found in Sample-1 and Sample-2. No visible cracks were found in Sample-3.

4. CONCLUSIONS

In conclusion, this research investigated the possibility of utilizing bamboo along with nylon as reinforcement for lightweight panels experimentally. Several tests on tensile strength, flexural strength, compressive strength, and fire resistance of the reinforced panels have been conducted. From the tension tests, it was found that nylon fibers as well as bamboo strips possess good tensile strength. The flexural strength test results showed that the panel composites made from a combination of bamboo and nylon with a cement-sand ratio of 1:2 demonstrated greater performance with an ultimate load capacity of 4.4 kN and flexural strength of 5.28 MPa compared to other samples. It implies that this combination of materials and cement-sand ratio resulted in a stronger panel composite. The compressive strength test results indicated that a sand and cement ratio of 1:2 was optimal for creating a strong and durable material. In the fire resistance tests, it was observed that the percentage weight loss of panels at higher temperatures is greater than at lower temperatures, and panels with a higher reinforcement ratio exhibited better performance. However, all the panels showed hairline cracks at 375°C, except Sample-3. Showing little to no cracking at elevated temperatures is also an indication of good fire resistance properties. Overall, it can be stated that Sample-2 displayed more promising results than the other samples. While the proposed method for using nylon and bamboo can be used in lightweight infill wall panels, the durability of such members requires further investigation into adverse weather conditions.

ACKNOWLEDGEMENTS

The authors would like to express their heartfelt gratitude and appreciation to the Department of Civil Engineering, KUET for their invaluable assistance and support in facilitating the successful execution of this work.

REFERENCES

Mali, P. R., & Datta, D. (2020). Experimental evaluation of bamboo reinforced concrete beams. *Journal of Building Engineering*, *28*, 101071.

Mali, P. R., & Datta, D. (2018). Experimental evaluation of bamboo reinforced concrete slab panels. *Construction and Building Materials*, *188*, 1092-1100.

Sanal, I., & Verma, D. (2019). Construction materials reinforced with natural products. In *Handbook of ecomaterials* (pp. 2119-2142). Springer International Publishing.

Anandamurthy, A., Guna, V., Ilangovan, M., & Reddy, N. (2017). A review of fibrous reinforcements of concrete. *Journal of Reinforced Plastics and Composites*, *36*(7), 519-552.

Sharma, B., & van der Vegte, A. (2020). Engineered bamboo for structural applications. In *Nonconventional and vernacular construction materials* (pp. 597-623). Woodhead Publishing.

Puri, V., Chakrabortty, P., Anand, S., & Majumdar, S. (2017). Bamboo reinforced prefabricated wall panels for low-cost housing. *Journal of Building Engineering*, *9*, 52-59.

Ghavami, K. (2005). Bamboo as reinforcement in structural concrete elements. *Cement and concrete composites*, *27*(6), 637-649.

Paudel, S. K. (2008). Engineered bamboo as a building material. *Modern Bamboo Structures (Xiao Y, Inoue M and Paudel SK (eds)). CRC Press (Taylor and Francis Group), London, UK*, 33-40.

Dash, A. K., & Gupta, S. (2015). A scientific approach to bamboo-concrete house construction. In *Advances in Structural Engineering: Materials, Volume Three* (pp. 1933-1942). Springer India.

Vaishnavi, M., Aswathi, A., Saarani, S. S., Varghese, A., Sathyan, D., & Mini, K. M. (2021). Strength and workability characteristics of coir and nylon fiber reinforced self-compacting mortar. *Materials Today: Proceedings*, *46*, 4696-4701.

Lima, H. C., Willrich, F. L., Barbosa, N. P., Rosa, M. A., & Cunha, B. S. (2008). Durability analysis of bamboo as concrete reinforcement. *Materials and Structures*, *41*, 981-989.

Song, P. S., Hwang, S., & Sheu, B. C. (2005). Strength properties of nylon-and polypropylene-fiber-reinforced concretes. *Cement and concrete research*, *35*(8), 1546-1550.

Spadea, S., Farina, I., Carrafiello, A., & Fraternali, F. (2015). Recycled nylon fibers as cement mortar reinforcement. *Construction and Building Materials*, *80*, 200-209.

Saxena, J., & Saxena, A. (2015). Enhancement the strength of conventional concrete by using nylon fibre. *Int. J. Eng. Sci*, *5*(2), 56-59.

Hanif, I. M., Syuhaili, M. N., Hasmori, M. F., & Shahmi, S. M. (2017, November). Effect of nylon fiber on mechanical properties of cement based mortar. In *IOP Conference Series: Materials Science and Engineering* (Vol. 271, No. 1, p. 012080). IOP Publishing.

BNBC (2020). Bangladesh National Building Code. (2020). Retrieved from https://www.dpp.gov.bd/upload_file/gazettes/39201_96302.pdf

Amada, S., & Untao, S. (2001). Fracture properties of bamboo. *Composites Part B: Engineering*, *32*(5), 451-459.

Menchaca-Campos, C., Uruchurtu, J., Hernández-Gallegos, M. Á., Covelo, A., & García-Sánchez, M. Á. (2015). Smart protection of polymer-inhibitor doped systems. In *Intelligent Coatings for Corrosion Control* (pp. 431-459). Butterworth-Heinemann.

Guru, S. S., & Kumar, S. (2020). BEHAVIOUR OF FIBER REINFORCED FERROCRETE WALL PANEL. *irjmets*, *2*(08), 1102-1107.