PRELIMINARY STUDY ON GREEN CEMENTITIOUS COMPOSITES WITH JUTE FIBRE

Md. Atiqur Rahman*[1], Md. Imran Kabir [2]

[1] *M.Sc. Student, Islamic University of Technology (IUT), Bangladesh, e-mail: atiqur@iut-dhaka.edu*
[2] *Assistant Professor, Islamic University of Technology (IUT), Bangladesh, e-mail: imran.kabir@iut-dhaka.edu*

***Corresponding Author**

ABSTRACT

This paper outlines a preliminary study aimed at developing a new type of green cementitious composites by smartly combining locally available ingredients (i.e. portland cement, sand, jute fibre, and superplasticizer) and industrial by-products (i.e. fly ash). In this study mixing parameters of cementitious composites were arbitrarily chosen where four mixing parameters were varied which include the water-to-binder ratio (0.23 to 0.36), cement-to-fly ash ratio (1.2 to 2.0), sand-to-binder ratio (0.30 to 0.50), length of the jute fibre (10 mm and 20 mm) but volumetric content of jute fibre was fixed to 0.5% for all mixes. Raw jute fibres were treated by immersing in 0.5% of NaOH solution for 24 hours and then dried jute fibre was chopped into a length of 10 mm and 20 mm for using in the cementitious composite. 150 µm of fine sand was prepared by sieving from locally available sylhet sand which was used in the cementitious composite. For each batch of casting, three cubes (50 mm x 50 mm x 50 mm) and two cylinders (100 mm x 200 mm) were prepared as a testing specimen. Then, specimens were tested on different curing days to understand the effects of the mixing parameters on the compressive strength. This study notes noticeable effects on the compressive strength due to variations in those mixing parameters. At water/binder ratio of 0.23, better compressive strength was observed than other water/binder ratios. A significant effect of 10 mm length of jute fibre was noticed on the compressive strength of the cementitious composite. There was an effect of sand/binder ratio on compressive strength when the fly ash/cement ratio of 1.2 was maintained. However, the optimum mix ratio couldn't be determined to achieve the highest compressive strength. Therefore, the subsequent phase of the study will comprise a comprehensive statistical analysis of the mixing parameters, aiming to develop cost-effective jute fiber-reinforced cementitious composites.

Keywords: *Jute fibre, cementitious composites, local ingredients, cost effective, industrial by-products*

1. INTRODUCTION

Concrete is the second most consumed material on Earth and the yearly consumption of concrete is increasing swiftly due to rapid economic growth. It was reported by Huda & Alam in 2014 that global concrete production is more than 15 billion tons. Gradually, the consumption of concrete has been increasing and thereby the global aggregate production and consumption have also been increased. As per Shen et al., 2015, cement industries are responsible for nearly 8 percent of worldwide carbon dioxide emissions because of the combustion of limestone into clinker, a primary component of cement. Therefore, declining the environmental impact caused by its production processes is a pertinent and timely challenge for modern technology. As a consequence, the incorporation of recycled, industrial by-products, natural resources, and unconventional construction materials in concrete technology has become widely appealing to both industry stakeholders and researchers in recent years.

Establishing a sustainable construction material is a challenge for construction industry considering environmental and economical perspectives. Although synthetic fibre reinforced cementitious composite has many advantages over conventional concrete in terms of sustainability but in the last couple of years, natural fibres like coir, sisal fibre, jute fibre etc. are getting more consideration than synthetic fibre in respect to environmental and economical aspects (Onuaguluchi & Banthia, 2016) and jute fibre reinforced samples show higher tensile and flexural strength compared to synthetic fibre i.e., polypropylene reinforced samples (Deb et al., 2020).

Bangladesh is one of the largest producers of jute all over the world and approximately 1.0 million tons jute are produced in Bangladesh annually (Akter et al., 2020). As jute has high tensile strength ranging from approximately 300-579 MPa and jute fibre is lighter than other steel fibre (Kundu et al, 2012), hence jute fibre could be one of the most efficient construction materials. Over the past years, several studies were conducted on enhancing the mechanical properties of conventional concrete through the inclusion of jute fibres of varying lengths and volumes (Zakaria et al., 2015). Mechanical properties of jute fibre reinforced concrete depend on length of jute fibre and quantity of jute fibre as because balling formation and high porosity is experienced in composites due to large length of jute fibre and excess amount of jute fibre resulting reduce the mechanical properties of composite (Zakaria et al., 2016).

Fly ash, an environmentally harmful substance, is prevalent in abundance within Bangladesh which may cause many environmental threats. A large amount of fly ash was dumped annually from the thermal power plants in Bangladesh. Fly ash production was predicted to be approximately 2.0 million metric tonnes by 2025 (Sultana et al., 2021). The effect of fly ash (Yang et al., 2017) and natural fibres were studied in cementitious composites separately but the effects of the combined uses of these two materials on the mechanical behaviour of the composites are yet to be studied.

Motivated by these facts, this study aimed to develop jute fibre-reinforced cementitious composites (JFRCCs) by combining locally available ingredients (i.e., portland cement, sand, jute fibre, and superplasticizer) and industrial by-products (i.e., fly ash). As certain amount of cement is replaced by fly ash, this JFRCC would play a vital role in reducing CO_2 emissions which will allow to meet SDG 13 (climate action) to some extent. Hence, JFRCC would be an eco-friendly construction material that mitigates the environmental effects of fly ash. In addition, as coarse aggregate is not being used to make JFRCC, huge amounts of natural resources will be saved for future generations to make other infrastructures. Till now, research is absent in the existing literature concerning the experiment of mechanical behaviours in JFRCC. With this background, the main purpose of this study was to investigate the effects of different parameters i.e., length of the jute fibre, cement-to-fly ash ratio, water-to-binder ratio, and sand-to-binder ratio of JFRCC on compressive strength at different curing ages.

2. METHODOLOGY

In this study, Ordinary Portland Cement (OPC) and fly ash as a binding material, fine sand of 150 µm size, treated jute fibre of different length (10 mm and 20 mm), polycarboxylic based superplasticizer and water were used to prepare JFRCC. OPC and fly ash were collected from the local cement industry whereas locally available fine sand and jute fibre were prepared through some procedure and polycarboxylic based superplasticizer was sourced from local market. Subsequent sections provide the details about raw material preparation, sample mixing, and testing.

2.1 Jute Fibre Preparation

Locally produced jute fibre was collected from the local market and treated with NaOH solution. Treatment with NaOH solution helps to remove impurities like vegetable lipids and pectin on the fibre surface (Zhang et al., 2019). For alkali treatment, the required quantity of raw jute fibres was immersed in 0.5% of NaOH solution for 24 hours (Jo et al, 2015). To prepare this solution, 5 gm of NaOH pellets were mixed with 1 liter of water to maintain 0.5% of NaOH solution. After 24 hours of immersion, jute fibre was squeezed and then dried with sunlight. After that, dried jute fibre was chopped into a length of 10 mm and 20 mm which were used in cementitious composite. The process involved to prepare the jute fibre is shown in Figure-1.

Raw jute fibre

Jute fibre treatment

Treated jute fibre

Chopped jute fibre

10 mm length jute fibre

20 mm length jute fibre

Figure 1: Jute fibre preparation

2.2 Sand Preparation

150 µm of fine sand was used in the cementitious composite which was prepared from locally available Sylhet sand. To prepare this, fine sand was dried with sunlight then sieve analysis was performed and retained sand in a 150 µm sieve was kept for using in cementitious composite. Note that, the sieved sand was oven-dried at 150 ºC for 24 hours before using it in the mixing. Figure-2 shows the raw and processed Sylhet sand.

Locally available sylhet sand　　150 microns of fine sand

Figure 2: Sand preparation

2.3 Mix Proportion and Mixing of JFRCC

For this preliminary study, range of mixing parameters were chosen arbitrarily where water to binder ratio changed within 0.23-0.36; fly ash to cement ratio varied from 1.2-2.0; sand to binder ratio were taken 0.3 and 0.5; 10 mm and 20 mm length of treated jute fibre were used. However, jute fibre content (% of total volume) was fixed to 0.5% for each case. Mix proportions for different batch of casting are listed in Table-1. For each batch of casting, three cubes (50 mm x 50 mm x 50 mm) and two cylinders (100 mm x 200 mm) were prepared.

Table 1: Mix proportion for different batch of cementitious composites.

Water to Binder ratio	Fly Ash to Cement ratio	Sand to Binder ratio	Length of the jute fibre, mm
0.23	1.2	0.5	20
0.23	1.2	0.3	20
0.27	1.2	0.5	20
0.27	2	0.5	20
0.27	2	0.3	10
0.27	2	0.3	20
0.30	1.4	0.3	10
0.36	1.2	0.5	20
0.36	1.2	0.5	10
0.36	1.2	0.3	10
0.36	1.2	0.3	20

For each batch of casting, mixing was done in three phases. In 1st phase of mixing, all the dry materials i.e., cement, fly ash, and sand were placed into the mixing bowl of a mixture machine of 20 litre capacity, then the mixture machine was run for 5 minutes at low speed (100 rpm) to completely mix all the dry materials. In next phase of mixing, a solution was prepared by adding the calculated superplasticizer into 80% of measure water. The solution was then slowly added into the mixing bowl. As soon as a uniform paste of the added materials was achieved, chopped jute fibre (0.5% of total volume) was included very steadily. 2nd phase of mixing took approximately 10-15 minutes and throughout the period machine was run at low speed (100 rpm). In 3rd phase of mixing, the rest amount of the water was added and then the mixture machine was run for 5 minutes to complete the mixing. After that, the fresh cementitious composite was poured into cube and cylinder moulds. Because of the high bonding strength between jute fibre and the metal surface of the moulds, demoulding of the specimen was done at 7 days of casting. Afterwards, specimens were placed into the curing chamber till the testing date. The mixing process of the proposed composites is shown in Figure-3.

Mixture machine (capacity-20 litre)

Fresh cementitious composites

Cylinder specimen

Figure 3: Sample mixing

2.4 Testing of JFRCC Samples

The compressive strength of specimens was tested in a compression machine. Samples were tested randomly on different days from the casting date. Some samples were tested on 28 days of the casting date and other samples were tested on 42 days, 160 days, and 170 days from the casting date respectively.

Compression machine

Sample failure pattern

Bridging action of jute fibre

Figure 4: Specimen testing and sample failure pattern

3. ILLUSTRATIONS/ RESULTS AND DISCUSSIONS

3.1 Effect of Water/Binder Ratio

Table-2 represents the compressive strength for different mixing parameters where only water/binder ratio was changed from 0.23 to 0.36 but other mixing parameters were remained same. Figure-5 demonstrates that compressive strength of cementitious composite was increased at water/binder ratio of 0.23 than water/binder ratio of 0.36. Also, it illustrated that there was a good effect of curing days in compressive strength increasing. At 170 days of curing, compressive strength was increased by approximately 150% than 28 days of curing.

Table 2: Effect of water/binder ratio on compressive strength

Water to Binder ratio	Fly Ash to Cement ratio	Sand to Binder ratio	Length of the jute fibre, mm	Curing Age, Days	Compressive Strength, MPa
0.23	1.2	0.5	20	28	15.61
0.36	1.2	0.5	20	28	12
0.23	1.2	0.5	20	170	27.08
0.36	1.2	0.5	20	170	17.33

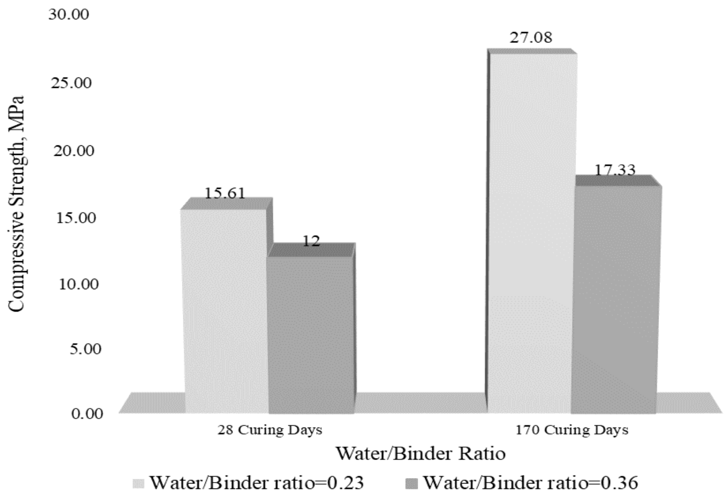

Figure 5: Effect on compressive strength due to water/binder ratio changes

3.2 Effect of Sand/Binder Ratio

Table-3 shows the compressive strength at different mixing parameters where only sand/binder ratio was changed from 0.5 to 0.3 but other mixing parameters were remained same. Figure-6 describes that almost same compressive strength was observed due to sand/binder ratio changes from 0.5 to 0.3 when W/B=0.27, FA/C=2 and 20 mm length of jute fibre were used in cementitious composites as mixing parameters.

Table 3: Effect of sand/binder ratio on compressive strength at W/B=0.27 and FA/C=2

Water to Binder ratio	Fly Ash to Cement ratio	Sand to Binder ratio	Length of the jute fibre, mm	Compressive Strength, MPa
0.27	2	0.5	20	21.00
0.27	2	0.3	20	19.48

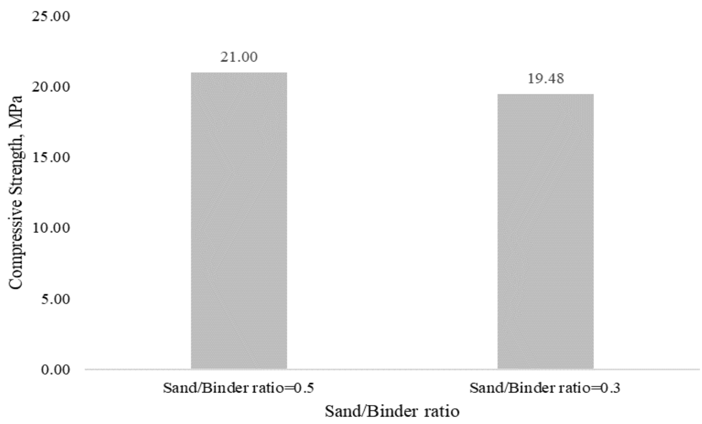

Figure 6: Effect on compressive strength due to sand/binder tatio changes at W/B=0.27 and FA/C=2

However, when the cementitious composites were prepared with W/B=0.23 and FA/C=1.2, compressive strength of the test specimens was higher for a sand/binder ratio of 0.5 than a sand/binder ratio of 0.3 as listed in Table-4 and shown in Figure-7. Similar trend was observed in Figure-7 for changing sand/binder ratio when W/B=0.36, FA/C=1.2 and 20 mm length of jute fibre were used in the cementitious composite.

Table 4: Effect of sand/binder ratio on compressive strength at W/B=0.23 and FA/C=1.2; W/B=0.36 and FA/C=1.2

Water to Binder ratio	**Fly Ash to Cement ratio**	**Sand to Binder ratio**	**Length of the jute fibre, mm**	**Compressive Strength, MPa**
0.23	1.2	0.5	20	27.08
0.23	1.2	0.3	20	10.72
0.36	1.2	0.5	20	20.15
0.36	1.2	0.3	20	13.98

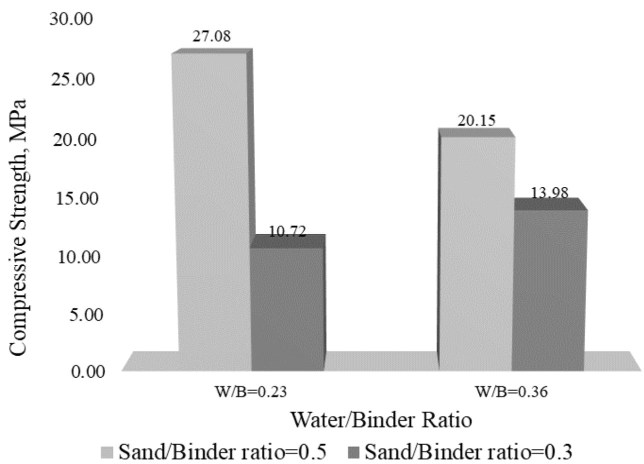

Figure 7: Effect on compressive strength due to sand/binder ratio changes at W/B=0.23 and FA/C=1.2; W/B=0.36 and FA/C=1.2

Nonetheless, when the length of jute fibre was changed from 20 mm to 10 mm in a cementitious composite resulting in a contrasting trend. In this case, the compressive strength exhibited superior performance at a sand/binder ratio of 0.3 compared to a sand/binder ratio of 0.5, as illustrated in Table-5 and Figure-8.

Table 5: Effect of sand/binder ratio on compressive strength at W/B=0.36, FA/C=1.2 and fibre length=10mm

Water to Binder ratio	**Fly Ash to Cement ratio**	**Sand to Binder ratio**	**Length of the jute fibre, mm**	**Compressive Strength, MPa**
0.36	1.2	0.5	10	30.75
0.36	1.2	0.3	10	39.09

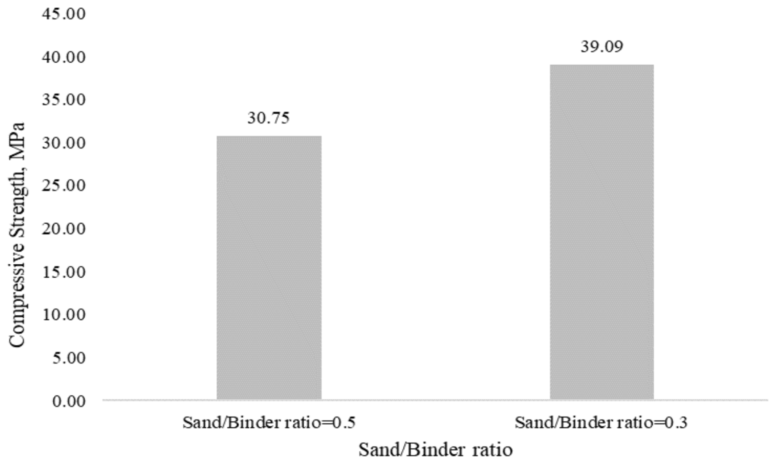

Figure 8: Effect on compressive strength due to sand/binder ratio changes at W/B=0.36, FA/C=1.2 and fibre length=10mm

3.3 Effect of Fly Ash/Cement Ratio

Following Table-6 presents the compressive strength under different mixing parameters where only the fly ash/cement ratio was changed from 2 to 1.2. Figure-9 describes that the compressive strength was increased at a fly ash/cement ratio of 1.2 compared to a fly ash/cement ratio of 2.0 (see Table-6 and Figure-9).

Table 6: Effect of fly ash/cement ratio on Compressive strength at W/B=0.27, S/B=0.5 and fibre length=20mm

Water to Binder ratio	**Fly Ash to Cement ratio**	**Sand to Binder ratio**	**Length of the jute fibre, mm**	**Compressive Strength, MPa**
0.27	2	0.5	20	21.00
0.27	1.2	0.5	20	28.70

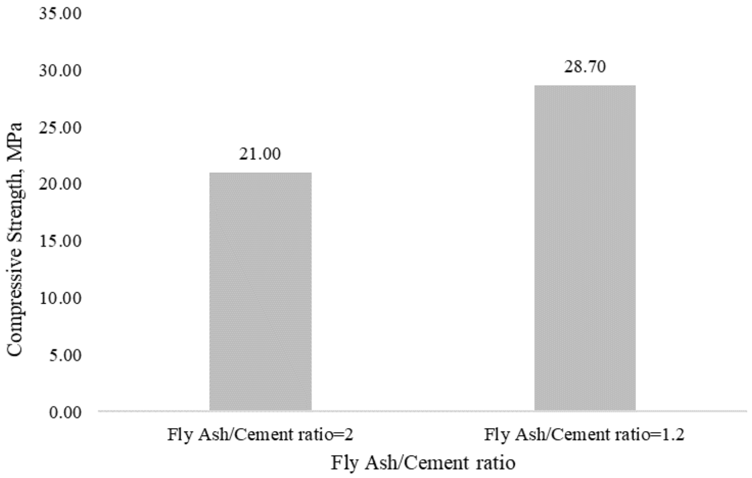

Figure 9: Effect on compressive strength due to fly ash/cement ratio changes at W/B=0.27, S/B=0.5 and fibre length=20mm

3.4 Effect of Jute Fibre Length Changes

This section discusses the influence of jute fibre length on the compressive strength of cementitious composites. Table-7 presents three distinct sets of mixing parameters to observe the impact of jute fibre length on compressive strength. In each set of mixing, only length of jute fibre was varied from 10 mm to 20 mm while keeping other mixing ingredients constant. Figure-10 demonstrates that the compressive strength was consistently increased when the jute fibre length was 10mm, in contrast to those specimens where 20 mm jute fibre was utilized (see Table-7 and Figure-10). Similar results were observed by Islam & Ahmed, 2018 and Zakaria et al., 2015. Due to the long fibre length, the balling effect arises in cementitious composites, and lots of porous space remains in composites made by long fibre than short fibre. Thus, the compressive strength increases in cementitious composite produced by 10 mm fibre than 20 mm fibre.

Table 7: Effect of jute fibre length on compressive strength

Water to Binder ratio	Fly Ash to Cement ratio	Sand to Binder ratio	Length of the jute fibre, mm	Compressive Strength, MPa
0.36	1.2	0.3	10	39.09
0.36	1.2	0.3	20	13.98
0.36	1.2	0.5	10	30.75
0.36	1.2	0.5	20	20.15
0.27	2	0.3	10	29.41
0.27	2	0.3	20	19.48

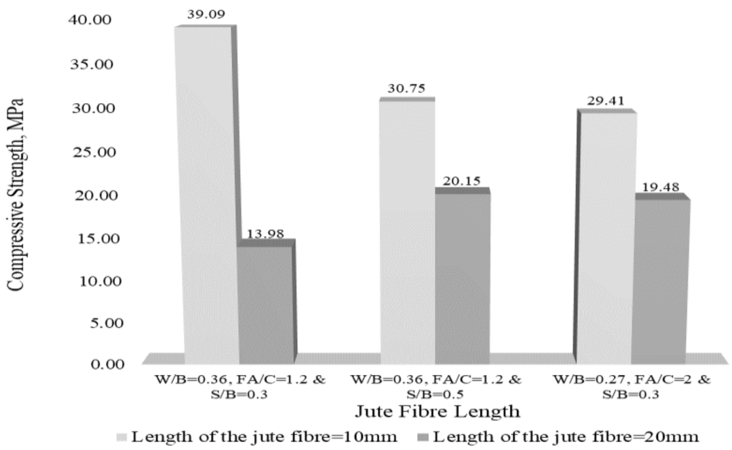

Figure 10: Effect on compressive strength due to jute fibre length changes

3.5 Effect of Curing Days

This section explores how the duration of curing days impacts the compressive strength of cementitious composites. As depicted in Table-8 and Figure-11, there was a positive correlation between the curing days and compressive strength. In particular, the compressive strength was increased substantially with a percent increase of about 180% when the curing duration was changed from 28 days to 42 days. This result clearly indicates that the proposed cementitious composites would gain higher strength after the 28 days unlike the conventional concrete.

Table 8: Effect of curing time on compressive strength

Water to Binder ratio	Fly Ash to Cement ratio	Sand to Binder ratio	Length of the jute fibre, mm	Curing Age, Days	Compressive Strength, MPa
0.30	1.4	0.3	10	28	17.44
0.30	1.4	0.3	10	42	31.78

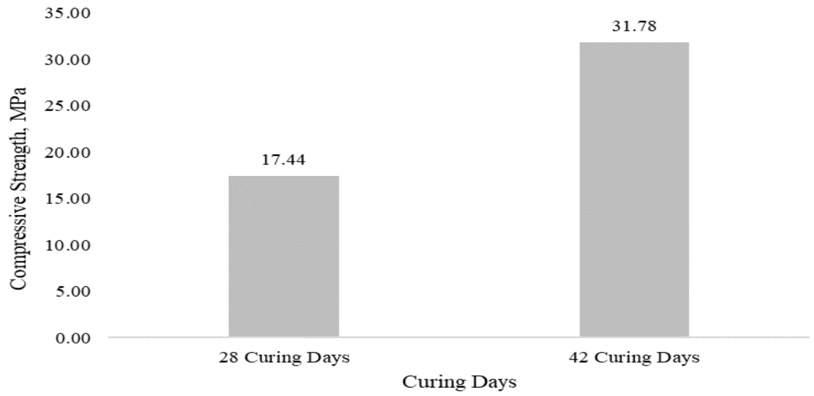

Figure 11: Effect on compressive strength for curing days

4. CONTRIBUTION OF JUTE FIBRE AND COMPARISON WITH ALTERNATIVE FIBRE

In this study it was seen that jute fibre has a greater contribution to achieve compressive strength of cementitious composites. Gupta et al., 2020 found that due to inclusion of 15 mm length of jute fibre compressive strength was increased 6.5% - 12.4% compared to plain concrete. Moreover, from the previous study, jute fibre exhibited better performance for mechanical properties compared to other types of fibres. As per Deb et al., 2020, better tensile & flexural strength was observed in jute fibre reinforced sample than polypropylene fibre reinforced samples. Also, Bheel et al., 2021 was observed that 11.71 % compressive strength increased when 1 % of nylon and jute fibres together was mixed with concrete. Hence, the incorporation of jute fibre might be a prominent construction material in the future.

5. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be made from the above discussion:

- Jute fibre has high potential to use in developing fibre reinforced cementitious composites as it significantly influences the compressive strength of cementitious composites.
- Industrial by-products (i.e., fly ash) also had a good contribution on improving the compressive strength of cementitious composites. Thus, an eco-friendly construction material (i.e., JFRCC) could be developed by replacing cement partially with fly ash.
- Improved compressive strength of the developed cementitious composites was observed at a water/binder ratio of 0.23 compared to other water/binder ratios.
- Compressive strength exhibited superior performance at a sand/binder ratio of 0.5 compared to a sand/binder ratio of 0.3, specifically when the fly ash/cement ratio was set at 1.2 in cementitious composites.

From this study it can be concluded that each mixing parameters like water-to-binder ratio, cement-to-fly ash ratio, sand-to-binder ratio, length of the jute fibre had significant effect on compressive strength of cementitious composites. However, the optimum mix ratio of different parameters couldn’t be achieved in terms of higher compressive strength and material cost. Therefore, comprehensive statistical analysis of mixing proportions can be conducted in future study to develop an economical jute fibre-reinforced cementitious composite.

ACKNOWLEDGEMENTS

Firstly, we would like to extend cordial gratitude to the laboratory staff of the Concrete Laboratory of Civil and Environmental Engineering, Islamic University of Technology (IUT) for their unconditional support during specimen preparation and casting. Also, we are very much thankful to Basundhara Cement for providing fly ash.

REFERENCES

Akter, S., Sadekin, M. N., & Islam, N. (2020). Jute and Jute Products of Bangladesh: Contributions and Challenges. *Asian Business Review, 10(3), 143-152.*

Bheel, N., Tafsirojjaman, T., Liu, Y., Awoyera, P., Kumar, A., & Keerio, M. A. (2021). Experimental Study on Engineering Properties of Cement Concrete Reinforced with Nylon and Jute Fibers. *Buildings, 11(10), 454.*

Deb, S., Mitra, N., Maitra, S., & Majumdar, S.B. (2020). Comparison of Mechanical Performance and Life Cycle Cost of Natural and Synthetic Fiber-Reinforced Cementitious Composites. *Journal of Materials in Civil Engineering, Vol. 32, No. 6.*

Gupta, S. D., Aftab, S. M., Zakaria, M. H., & Karmakar, C. (2020). Scope of improving mechanical characteristics of concrete using natural fiber as a reinforcing material. *Malaysian Journal of Civil Engineering, UTM, e ISSN, 2600-9498.*

Huda, S.B., & Alam, M.S. (2014). Mechanical behavior of three generations of 100% repeated recycled coarse aggregate concrete. *Journal of Construction and Building Materials 65 (2014) 574–582.*

Islam, M.S., & Ahmed, S.J. (2018). Influence of jute fiber on concrete properties. *Journal of Construction and Building Materials 189 (2018) 768–776.*

Jo, B.W., Chakraborty, S., & Kim, H. (2015). Efficacy of alkali-treated jute as fibre reinforcement in enhancing the mechanical properties of cement mortar. *Journal of Materials and Structures (2016) 49:1093–1104.*

Kundu, S.P., Chakraborty, S., Roy, A., Adhikari, B., & Majumder, S.B. (2012). Chemically modified jute fibre reinforced non-pressure (NP) concrete pipes with improved mechanical properties. *Journal of Construction and Building Materials 37 (2012) 841–850.*

Onuaguluchi, O., & Banthia, N. (2016). Plant-based natural fibre reinforced cement composites: A review. *Journal of Cement and Concrete Composites, 68 (2016) 96-108*.

Shen, W., Cao, L., Li, Q., Zhang, W., Wang, G., & Li, C. (2015). Quantifying CO_2 emissions from China's cement industry. *Journal of Renewable and Sustainable Energy Reviews 50 (2015) 1004–1012.*

Sultana, S., Ahsan, S., Tanvir, S., Haque, N., Alam, F., & Yellishetty, M. (2021). Coal Fly Ash Utilisation and Environmental Impact. *Clean Coal Technologies, Chap.-15, 381–402.*

Yang, E., Yang, Y., & Li, V. (2007). Use of High Volumes of Fly Ash to Improve ECC Mechanical Properties and Material Greenness. *Journal of ACI Materials 104(6):620-628.*

Zakaria, M., Ahmed, M., Hoque, M.M., & Islam, S. (2016). Scope of using jute fiber for the reinforcement of concrete material. *Journal of Textiles and Clothing Sustainability (2016) 2:11*.

Zakaria, M., Ahmed, M., Hoque, M.M., & Hannan, A. (2015). Effect of jute yarn on the mechanical behavior of concrete composites. *Journal of SpringerPlus (2015) 4:731*.

Zhang, T., Yin, Y., Gong, Y., & Wang, L. (2019). Mechanical properties of jute fiber-reinforced high-strength concrete. *Structural Concrete. 2019;1–10.*