Mechanical and Durability Properties of Fly Ash Blended Concrete with Gi Fiber

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1 Introduction

Concrete is the most used product in the world after water and cement is the primary binding material for the concrete. With the growing demand for concrete as the most incorporated construction material, cement production is also increasing. In 2018, estimated global cement production was 4.1 gigatonnes [16]. In cement production, clinker is the major ingredients, and is the major source of carbon dioxide (CO_2) emission due to the production of CO_2 and consumption of fuel during the clinker production process. According to the World Business Council for Sustainable Development (WBCSD), cement production is the cause of nearly 7% of global CO_2 emissions [21]. In Bangladesh, cement production is rising on a daily basis with increasing demand resulting in increased toxic emissions causing environmental hazards.

Fly ash is one of the major by-products of coal based power plants of Bangladesh that needed to be stored and recycled for environmental concerns as it contains hazardous and radioactive metals like arsenic, lead, mercury, nickel, vanadium, beryllium, barium, cadmium, chromium, selenium and radium [15]. One of the attempts to manufacture more environment friendly concrete is to partly substitute the amount of cement in concrete with by-products such as fly ash. Inclusion of fly ash in the concrete has many advantages, such as increased workability, durability and long term compressive strength. Many researches have already been conducted using fly ash as pozzolan in concrete [10, 8, 9, 11, 12, 17]. Fly ash replacement level of 15–25% is recommended by ACI 211.4R for high strength concrete [1]. On the other hand, it can be used as more than 50% of the total binder for normal strength concrete [12, 9, 11]. However, inclusion of 50% of fly ash in concrete yielded lower compressive strength [11]. The test results indicate that concrete with high volume fly ash is more

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durable than control concrete without fly ash. Fly ash plays the role of an artificial pozzolan as a cement substitute, where its silicon dioxide content interacts from the cement hydration phase with calcium hydroxide to form the C-S–H gel.

Drawbacks of concrete includes its brittleness and weakness in tension. Concrete tensile strength usually one-tenth of the compressive strength. Over the years, different fibers are being used to improve the tensile strength and thus increase the ductility of concrete. Among the various fiber choices, steel fiber and polypropylene (PP) fiber are the most commonly used due to their material properties. Recently, more recognition was given to steel fiber reinforced concrete and used in many engineering applications such as in tunnel linings, slabs and airport pavements [18, 22]. However, additional costs have always been an issue to consider during the use of fiber in concrete. In this regard, galvanized iron (GI) wire can provide a viable low-cost substitute for steel fibers, especially for Bangladesh [13, 14]. In Bangladesh, GI wire is produced locally and available at a relatively low price.

The effect of high temperature on the compressive strength properties of concrete has been studied for many years [18, 20]. According to the study performed by [20], at high temperature concrete strength reduction is lower with added fly ash in the concrete. At high temperature, concrete lose its moisture and subjected to thermal cracks. Furthermore, due to the lower porosity of concrete, trapped moisture inside the concrete can cause explosive spalling. The inclusion of steel fibers in concrete improves its crack resistance as well as its fire resistance [18].

This study aims to evaluate the use of GI wire as a fiber reinforcement and fly ash as a partial substitute for cement in concrete. Performances of concrete will be determined through mechanical, and durability properties of concrete. Test results, such as compressive strength, splitting tensile strength, flexural strength, and durability at high temperature will be compared and benefits of adopting GI fiber and fly ash will be discussed.

2 Experimental Program

The form and composition of cement used in the preparation of fly ash cement concrete in this study was CEM-1 following ASTM C150 [6], which included 95–100% of clinker and 5–0% gypsum. Gradation of both fine and coarse aggregates were performed and the gradation curves of coarse aggregate and fine aggregate are shown in Fig. 1. As shown from the figure, fine aggregate was well within the ASTM upper and lower limits according to ASTM C33 [3]. On the other hand, coarse aggregate was close to the ASTM lower limit indicating coarser particle distribution. The fineness modulus of course aggregate was 6.85 and fine aggregate was 2.71.

In this study, cement was partially replaced with low calcium (Class F) fly ash, which was collected from the Boropukuria coal burnt power station near Durgapur, Dinajpur, Bangladesh. Fly ash is part of the solid waste produced from the thermal power station. Replacement percentage of fly ash varied between 0 and 15%. The chemical composition of fly ash was measured using an energy dispersive X-ray

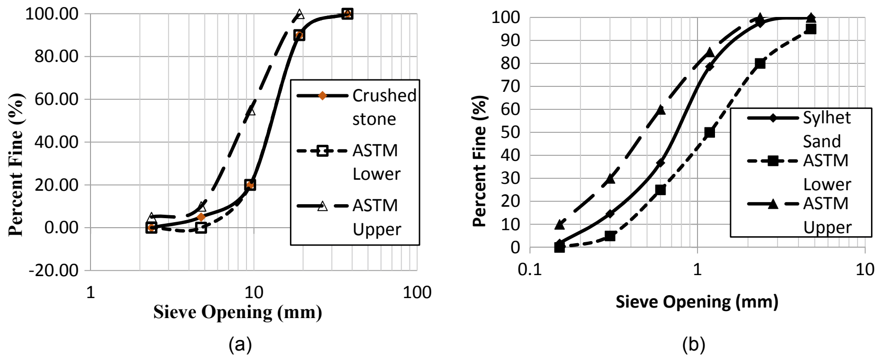

Fig. 1 Gradation curve of **a** coarse aggregate and **b** fine aggregate

Table 1 Chemical analysis of fly ash

Composition	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	K_2O	CaO
Result (%)	58.72	30.33	5.75	2.08	1.11	0.82

Table 2 Properties of galvanized iron (GI) fiber

Yield strength, F_y (MPa)	Ultimate strength, F_u (MPa)	Elongation (%)
223	365	18

fluorescence (EDXRF) and shown in Table 1. Galvanized iron (GI) fiber was incorporated in concrete for the present study. The 15.3 mm length (L) galvanized iron (GI) fiber was added by 0.5% (by volume) in the concrete mixture. The properties of GI fiber are shown in Table 2.

The mechanical and durability properties of concrete determined in this study include compressive strength, splitting tensile strength, flexural strength, stress strain response under axial compression, Young's modulus and compressive strength at a high temperature (500 °C). The compressive strength and tensile strength were determined at 7, 28, 56, and 84 days; the flexural strength, stress–strain response and durability at high temperature (500 °C) were determined at 28 days and the Young's modulus was determined at 56 days. For compressive strength, splitting tensile strength, Young's modulus and durability tests 100 mm × 200 mm cylinders were prepared. For the test of flexural strengths, beams of 100 mm × 100 mm × 500 mm dimensions were prepared. The mix design of the concrete was performed according to ACI 544.3R [2] and the mix proportion for 1 cum of concrete is given in the Table 3.

Table 3 Mix proportion for 1 m^3 concrete

Designation	W/C ratio	Water (kg)	Cement (kg)	Fly ash (kg)	Fiber (kg)	Coarse Agg (kg)	Fine Agg (kg)	Admixture (kg)
Control (FCF0F0)	0.4	148	370	0	0	1296	589	3.7
FCF5F0	0.4	148	370	0	38.5	1296	589	3.7
FCF5F5	0.4	148	351.5	18.5	38.5	1296	589	3.515
FCF5F10	0.4	148	333	37	38.5	1296	589	3.33
FCF5F15	0.4	148	314.5	55.5	38.5	1296	589	3.145

Note FCFxFx: FC = fiber reinforced concrete with fly ash; Fx = percentage of GI fiber used multiplied by 10 (e.g. for 0.5%, 5); and Fx = percentage of fly ash (e.g. for 5%, 5)

3 Results and Discussions

3.1 Mechanical Properties of Concrete

3.1.1 Compressive Strength

The compressive strength values of the specimens at 7, 28, 56, and 84 days are plotted in Fig. 2. From the figure, it is observed that the compressive strength of concrete increased with the age of concrete. It also shows that the compressive strength increased with the addition of GI fiber. Contrarily, with the increasing percentage of fly ash replacement, the compressive strength increased initially and is maximum for 5% fly ash replacement but then gradually decreased with a higher percentage of

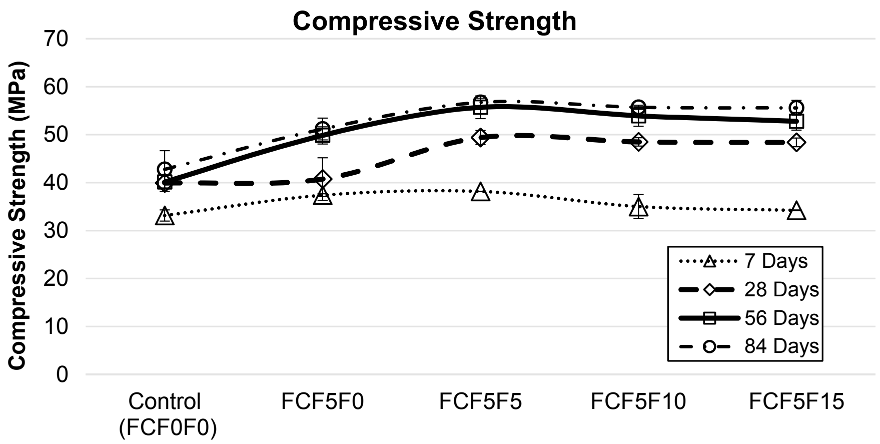

Fig. 2 Influence of GI fiber and fly ash on compressive strength of concrete at 7, 28 and 56 days

Fig. 3 Failure pattern of **a** control concrete cylinder with 0% fiber and 0% fly ash, and **b** FCF5F0 with 0.5% fiber and 0% fly ash at 56 days

fly ash replacement. The strength variation with respect to the control specimen was significant at later days. At 7 days, compared to the control specimen the compressive strength increased 12.8% for adding 0.5% GI fiber and 15.2, 5.6, and 3.3% with the increasing percentage of fly ash, respectively. On other hand, the compressive strength of concrete increased 24% by the addition of GI fiber and 39%, 34%, and 32%, respectively with the increasing percentage of fly ash replacement at 56 days. All the combinations of concrete were found with higher compressive strength than the compressive strength of the control specimen. The failure patterns of concrete specimens are shown in Fig. 3. It is observed from the failure patterns that the control specimen with no fiber was explosive in nature (Fig. 3a); whereas, concrete with fiber failed after the formation of a good number of small cracks as depicted in Fig. 3b.

3.1.2 Splitting Tensile Strength

The influence of the addition of GI fiber and fly ash on concrete split tensile strength at 7, 28, 56, and 84 days is described in Fig. 4. As shown in the figure, the addition of GI fiber and fly ash increased the tensile strength of concrete. The strength variation with respect to the control specimen increased with increasing fly ash content as observed from the figure. The tensile strength of the concrete specimen with 0.5% fiber increased 16.7% compared to the tensile strength of the control specimen at 56 days. With the increasing percentage of fly ash replacement, the tensile strength of concrete increased 18%, 19%, and 22% respectively, compared to the tensile strength of the control specimen at 56 days. Concrete specimens with 0.5% fiber and 15% fly ash showed the highest tensile strength for all combinations of concrete specimens. Figure 5 shows the failure patterns of concrete cylinders after the splitting tensile strength test at 56 days. The fibers tend to hold the concrete together and resist crack formation, resulting in improved tensile strength with the addition of GI fiber. Furthermore, the addition of fly ash reduced crack growth by filling internal voids in the concrete and making it denser.

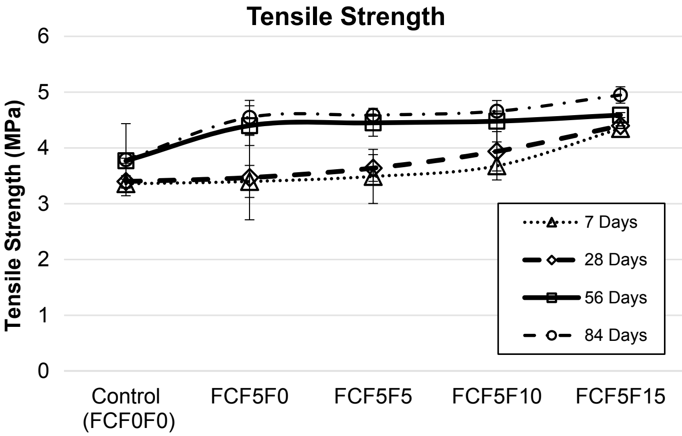

Fig. 4 Influence of GI fiber and fly ash on splitting tensile strength of concrete at 7, 28 and 56 days

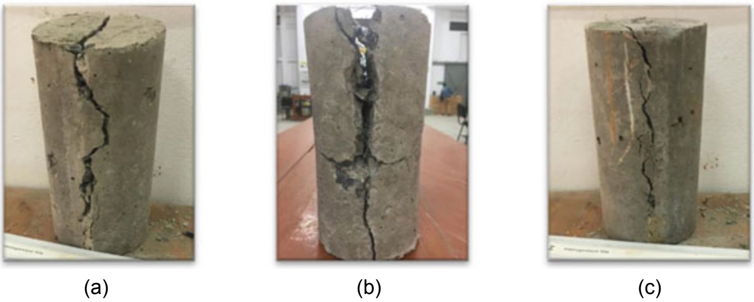

Fig. 5 Failure pattern of concrete cylinder subjected to splitting tensile test at 56 days **a** control (0% fly ash and 0% fiber), **b** FCF5F0 (0% fly ash and 0.5% fiber), and **c** FCF5F10 (10% fly ash and 0.5% fiber)

3.1.3 Flexural Strength

Beams were tested for the flexural strength at 28 days with third point loading following the ASTM C78 [5]. The load vs deflection curves for all the combinations are shown in Fig. 6. According to the load vs deflection curve, the control specimen had a very limited post-peak region, indicating brittle failure. The addition of GI fiber increased the load carrying capacity of concrete after crack formation, as concrete with 0.5% fiber and 0% fly ash had a longer post-peak region than the plastic region of the control specimen. It is also observed that as the percentage of fly ash increased, so did the load taking capacity after peak stress and the failure of members were also delayed. Concrete with 0.5% GI fiber and 5% fly ash showed the highest peak stress and the longest plastic region.

Table 4 presents the peak load, deflection at peak load, flexural strength, and

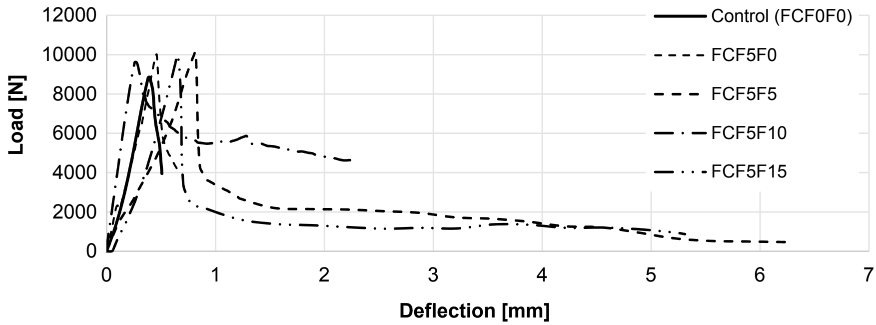

Fig. 6 Load versus extension curve for concrete beams with different percentages of fly ash and GI fiber

Table 4 Effect of adding fly ash and GI fiber on flexural strength of concrete at 28 days

Designation	Peak load (KN)	Deflection at peak load (mm)	Flexure stress (MPa)	Maximum deflection (mm)
Control (FCF0F0)	8.86	0.391	3.99	0.507
FCF5F0	10.03	0.267	4.51	0.85
FCF5F5	10.13	0.816	4.56	6.276
FCF5F10	10.00	0.266	4.5	2.234
FCF5F15	9.99	0.65	4.49	5.309

deflection at failure for all five types of concrete at 28 days of age. According to the data, the addition of GI fiber increased the flexural strength of the FCF5F0 concrete specimen by 13% when compared to the flexural strength of the control specimen. On the other hand, with the increasing percentage of fly ash replacement, the flexural strength also increased and was maximum for 5% fly ash replacement; but gradually decreased with the higher percentage of fly ash replacement.

3.1.4 Young's Modulus and Stress–Strain Response

The stress–strain relationship for all five combinations of concrete were documented at 56 days following the ASTM C469 [4] and presented in Fig. 7. From the stress–strain relationships, Young's modulus was calculated for all five combinations and tabulated in Table 5. As shown in the figure and table, the modulus of elasticity decreased with the addition of GI fiber content. This result was consistent with findings from previous study [7]. Furthermore, failure strain also decreased with inclusion of GI fiber content. However, incorporation of fly ash in concrete resolved this problem. Young's modulus of concrete with 5% fly ash and 0.5% GI fiber showed comparable value with the control specimen. Although the failure strain increased with increasing fly ash content, the Young's modulus in the concrete decreased.

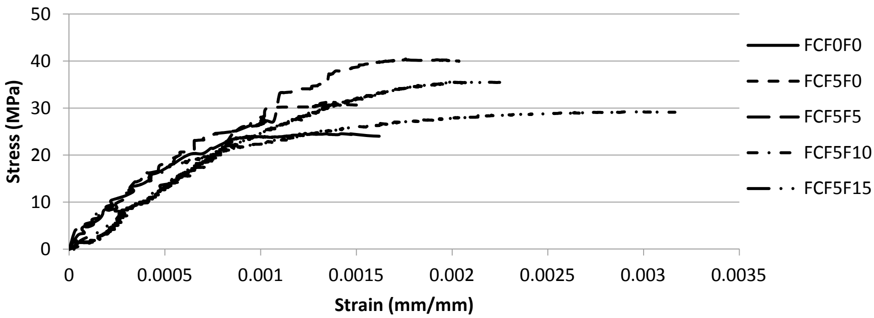

Fig. 7 Stress–strain relationship for different percentage of fly ash and GI fiber at the age of 56 days

Table 5 Elastic modulus of concrete for different percentage of fly ash and GI fiber

Designation	Modulus of elasticity (GPa)	Failure strain × 10^{-3} (mm/mm)
Control (FCF0F0)	37.13	1.619
FCF5F0	26.03	1.510
FCF5F5	34.08	2.035
FCF5F10	28.73	3.163
FCF5F15	26.18	2.213

3.1.5 Compressive Strength After Exposed to High Temperature

In order to investigate the compressive strength of concrete specimens after being subjected to high temperature, a test setup was devised. After 28 days of water curing, concrete cylinders were heated in an electric furnace at 500C° temperature. The temperature remained constant for an hour and then samples were allowed to cool down. A compressive strength test was performed after the samples cool down to room temperature. The average compressive strength determined from the concrete specimens with different combinations at room temperature (25 °C) and at high temperature (500 °C) are shown in Fig. 8. It is observed from Fig. 8 that, with the addition of GI fiber the strength reduction between compressive stresses at room temperature and high temperature increased. The compressive strength reduction between room temperature and high temperature for the control specimen is 12% which is increased to 25% by the addition of 0.5% GI fiber at 28 days. With the increasing percentages of fly ash replacement, the strength reduction also increased and is maximum for 5% fly ash replacement but then gradually decreased with a higher percentage of fly ash replacement. The compressive strength reduction is 29%, 22%, and 19%, respectively, for concrete specimens with 5%, 10%, and 15% fly ash replacement, respectively. The loss of moisture during heating is one of the reasons for the loss of compressive strength associated with the temperature increase. An increase in strength with increasing fly ash content is attributed to the formation

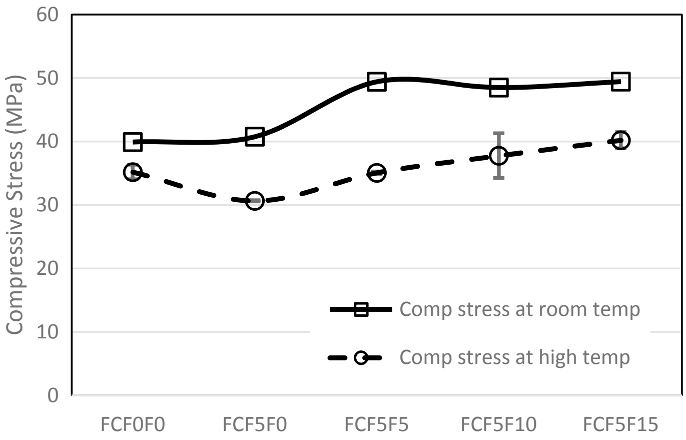

Fig. 8 Comparison between compressive strength for different percentage of fly ash and GI fiber at room temperature (25 °C) and high temperature (500 °C)

of tobermorite [19]. Under high temperature, tobermorite is formed from the reaction between lime and fly ash.

4 Conclusion

In this study, the cement was partially replaced (0, 5, 10 and 15%) by fly ash and GI fiber reinforcement, with 0.5% by volume, was used in concrete. Number of experiments were conducted to analyze and assess the hardened properties of concrete and compared with the control concrete without any fly ash and GI fiber. Following conclusion can be drawn from the interpretation of the test results:

I. The compressive strength increased with the addition of GI fiber and fly ash. The maximum strength was obtained for 5% fly ash and 0.5% GI fiber at 84 days. It is more sustainable to use 15% fly ash because the strength variation was only 2% as compared to the maximum strength.

II. The tensile strength increased with the addition of GI fiber and fly ash. The maximum tensile strength was obtained for 15% fly ash and 0.5% GI fiber at 84 days.

III. The flexural strength of concrete also increased with the addition of GI fiber and fly ash. The maximum flexural strength was obtained for 5% fly ash and 0.5% GI fiber. However, it will be more economical to use 15% fly ash replacement as its flexural strength varied only 2% than the maximum flexural strength. Post peak region was lengthened by the addition of GI fiber and fly ash than the control specimen with no fly ash and no fiber. This indicates an increment in load carrying capacity with the addition of fly ash and fiber.

IV. The elastic modulus decreased with the increasing percentages of fly ash replacement. The maximum value of elastic modulus was obtained for 5% fly ash replacement. The elastic modulus of 15% fly ash replacement differed by 16% from the maximum value. However, as the fly ash content in concrete increased, the failure strain increased; and for 15% fly ash replacement, the variation was 31% compared to the control concrete.

V. The reduction in strength between compressive stresses at room temperature (25 °C) and high temperature (500 °C) increased with the inclusion of GI fiber and decreased with the increasing percentages of fly ash. The minimum strength reduction was obtained for 15% fly ash replacement.

VI. Inclusion of fly ash increases mechanical strength with age and at the age of 84 days concrete with fly ash shows higher strength than the control concrete. Furthermore, 15% fly ash replacement with 0.5% GI fiber can be a more efficient option to be used as a structural concrete.

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