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Research Paper

Experimental Study on Flexure Behavior of Reinforced Concrete Beams using Fly Ash and Slag

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ABSTRACT: *In this paper, presents the fresh and hardened concrete properties with fly ash and slag. M60 grade of concrete has been designed with a constant water–cement ratio as 0.4. Ten concrete mixtures are arrived by cement is partially replaced by fly ash from 0 to 30% with 10% increment and slag is replaced from 10 to 50% at 20% increment. The compressive strength of the concrete was verified at 7, 14, and 28 days curing periods. Three reinforced concrete beams of size 150 mm × 250 mm × 2000 mm were cast based on the optimum mix proportion and flexural behavior of reinforced concrete beams was monitored by a three-point bending test. From the experimental results, the slump vales indicated that workability of concrete increased by partial cement replacement, however the compressive strength, and split tensile strength were decreased.*

KEYWORDS: *Fly ash, Ground granulate blast furnace slag, Cement replacement, Mechanical properties, Flexural behavior*

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I. INTRODUCTION

Cement is the third most energy-intensive material to produce. The cement production leads to the rapid depletion of natural resources and emission of greenhouse gasses as well as other harmful pollutants in environment. Such pollutants are responsible for quick climate changes and create a threat to human lives, ecology, and environment. One of the most effective methods to reduce environmental impact associated with the production of cement is to widen the use of supplementary cementitious material other than Portland cement clinker [1]. The use of supplementary cementitious material for cement replacement has recently increased along with the development of concrete industry, due to the consideration of cost saving, energy saving, environmental protection [2]. Mineral admixtures generally used are fly ash, rice husk ash, metakoline, silica fume etc. Addition of such materials improves the strength and durability of concrete [3].

Granulated blast furnace slag and fly ash are the most known and widely used supplements of Portland clinker [4]. The world-wide production of these industrial by-products is fly ash around 1000 million tons [5] and blast furnace slag about 140–330 million tons [6]. Both discussed components are obtained, similarly to Portland clinker, in a high-temperature process and commonly used as main constituents of cement and as concrete components. The degree of granulated blast-furnace slag utilization in the composition of cement and concrete is over 90%, whereas the fly ash is about 30% [1]. From this, the aim of this study is to achieve green concrete in the category of high compressive strength up to 50 MPa by using fly ash and slag with different percentages. This paper, an experimental study has been carried out on the industrial by-products such as fly ash and slag to find the possibility of suitable alternative materials for cement. The experimental study includes nine different mixtures using different replacement percentages, the cement was replaced by percentages of 10%, 30% and 50% for slag replacement as well as 10%, 20% and 30% for fly ash. And three reinforced concrete beams were cast based on the optimum mix proportion and flexural behavior of reinforced concrete beams was monitored by a three-point bending test.

II. MATERIALS

Concrete mixtures examined were made in the laboratory using the following materials: cement, gravel, sand, cement, fly ash and slag. The experimental study includes 9 different mixtures using different replacement percentages, the cement was replaced by percentages of 10%, 30% and 50% for slag replacement as well as 10%, 20% and 30% for fly ash.

The cement used in this study is normal Portland cement N42.4, where its properties are conforming to ASTM C150-07. The Blaine fineness is 3154.5 cm^2/gm and specific gravity is 3.15. The coarse aggregates used in the concrete mixture is a crushed 20 mm size. The coarse aggregate used, its specific gravity is 2.65 and the absorption capacity equals 1.90%. Natural sand (5 mm) maximum size, with 0.9% passing the 75 μm (No. 200 ASTM) sieve was used. Its specific gravity is 2.5, and its SSD condition water absorption of 0.98%. The low calcium class F fly ash is acquired from Sika company, which has specific gravity equals 2.2. Ground granulated blast furnace slag was got from reinforcing steel factory. It was tested and the specific gravity found to be 3 and the value of Blaine fineness is 4100 cm^2/gm.

Figure 1: Blast furnace slag and the fly ash

III. MIXTURE PROPORTIONS

In this study, ten series of concrete mixtures are shown below in Table 2. the cement was replaced by percentages of 10%, 30% and 50% for slag replacement as well as 10%, 20% and 30% for fly ash. The produced concrete series are coded according to the reduction percent ratio in the concrete mix and using water-cement ratio equals to 0.45, as given in Table 1. In addition to a control mixture with no replacement.

Table 1: Concrete mixture description

Mixtures	Description		
	Cement%	Slag%	Fly ash%
Control	100	0	0
Mix 1	80	10	10
Mix 2	70	10	20
Mix 3	60	10	30
Mix 4	60	30	10
Mix 5	50	30	20
Mix 6	40	30	30
Mix 7	40	50	10
Mix 8	30	50	20
Mix 9	20	50	30

IV. EXPERIMENTAL TESTING PLAN

4.1 Slump Test

Concrete mixing was done in a laboratory pan mixer following ASTM C192/192M-06 [7]. Slump tests were performed on the mixes to measure consistency as described in ASTM C1611 / C1611M [8]. The mixes were then prepared and cured according to ASTMC192/192M-06 [9] as shown in Figure 4. 150x150x150mm molds were used for casting the concrete cubes. Nine specimens were tested for each mix and compacted on a vibrating compactor and the curing method described in the standard was made where all cubes and cylinders were immersed in water tank and then kept in shaded area before the test day. The experimental plan included three reinforcement concrete beams, the size of the beam specimen is 150mm width, 250mm depth and 2 m span length.

Figure 2: Specimen preparation for testing

Values of slump are shown in Figure 3 that evidences a noticeable change of the slump value from reference mixture Control because of the amount of fly ash and slag, the fly ash increase slump values and the slag decreases slump of the concrete mixes. The values varied from 3 cm to 8 cm according to the percentages of fly ash and slag used in the concrete mixes.

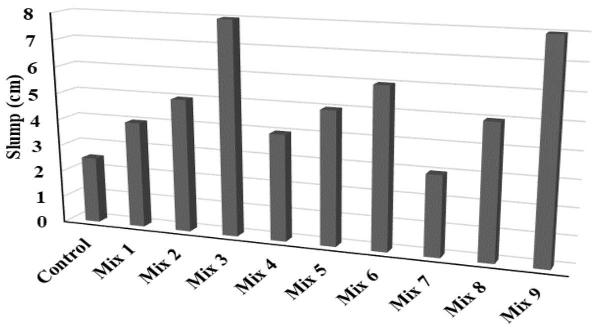

Figure 3: Slump values for the designed concrete mixtures

4.2 Compressive Strength Test

Compressive strength tests were conducted on concrete cubes of size 150x150x150 mm according to BS EN 12390-3:2019 [10] using ELE international ADR auto v2.0 3000 BS EN Compression Machine, as shown in Figure 4. The concrete cubes were tested at 7, 14, and 28 days and the results are tabled in Table 2. Test three cubes for compressive strength for each curing period mentioned under the relevant specifications (7 days, 14 days, 28 days).

Figure 4: Compressive strength testing of concrete cubes

Figure 5 present the compressive strength results of designed mixtures. It is observed from the results, presented at Table 2, that the compressive strength decreases by using fly ash and slag as a partial replacement with cement but there is an increase in the reduction of the cementious materials that represent a reduction in the cost and carbon emissions from the manufacturing of cement. Using 20% cement replacement by 10% fly ash and 10% slag leads to a decrease in the compressive strength by 10% and the meanwhile the reduction of the cost reached to 17%. 30% cement replacement, 20% fly ash and 10% slag, gives compressive strength at 28 days equals to 59 MPa presenting 14.5 % decrease. Increasing the replacement ratio to 40% by 10% slag and 30% fly ash, the compressive strength decreased by 28% at 28-days. With more cement replacement ratios up to 50% the compressive strength reached to 44 MPa. Mix 6 and Mix 7 that represent 60% cement replacement with 30% fly ash - 30% slag and 10% fly ash - 50% slag, its compressive strength reached to 40 MPa and 32 MPa that present a cost reduction 51% and 57%. Mixtures with large replacement values up to 70%, 80% cement replacement, the compressive strength reached to 23 and 21 MPa.

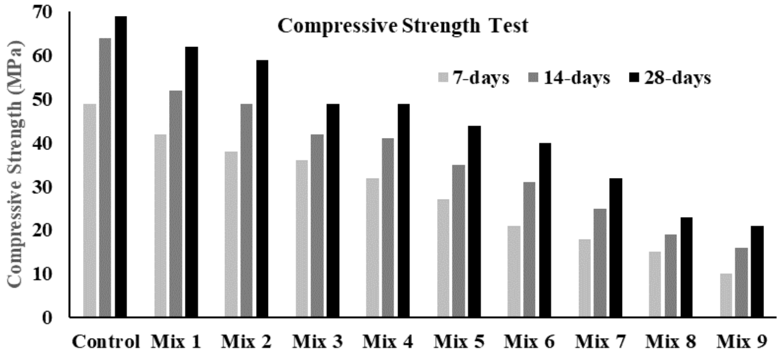

Figure 5: Cube compressive strength values for the concrete mixtures at different ages

Table 2: Compressive strength of the designed concrete mixtures

Mixtures	Compressive Strength (MPa)			Compressive Strength Reduction (%)	Cost Reduction for Cementitious Materials (%)
	7-days	14-days	28-days		
Control	49	64	69	-	-
Mix 1	42	52	62	10.1	17
Mix 2	38	49	59	14.5	24
Mix 3	36	42	49	28.9	31
Mix 4	32	41	49	28.9	37
Mix 5	27	35	44	36.2	44
Mix 6	21	31	40	42.0	51
Mix 7	18	25	32	53.6	57
Mix 8	15	19	23	66.7	64
Mix 9	10	16	21	69.6	71

4.3 Split Tensile Strength Test

A Split tensile strength test on the concrete cylinder size 150x300 mm is a method to determine the concrete's tensile strength. The procedure is based on the ASTM C496 / C496M-17 Standard Test [11], using ELE international ADR auto v2.0 3000 BS EN Compression Machine. Split strength test results are given in Table 3. Split strength decreased by 2.3% using 20% cement replacement by 10% fly ash and 10% slag. 30% cement replacement, 20% fly ash and 10% slag, gives split tensile strength at 28 days equals to 4.2 MPa presenting 4.7% decrease. Increasing the replacement ratio to 40% by 10% slag and 30% fly ash, the strength decreased by 7% at 28-days. With more cement replacement ratios up to 50% the compressive strength reached to 3.7 MPa. Mix 6 and Mix 7 that represent 60% cement replacement with 30% fly ash - 30% slag and 10% fly ash - 50% slag, its strength reached to 3.6 MPa and 3.5 MPa. Mixtures with large replacement values up to 70%, 80% cement replacement, the split tensile strength reached to 3 and 2 MPa.

Table 3: Split tensile strength of the designed concrete mixtures

Mixtures	Split Tensile Strength (MPa)
Control	4.3
Mix 1	4.2
Mix 2	4.1
Mix 3	4.0
Mix 4	3.9
Mix 5	3.7
Mix 6	3.6
Mix 7	3.5
Mix 8	3.0
Mix 9	2.0

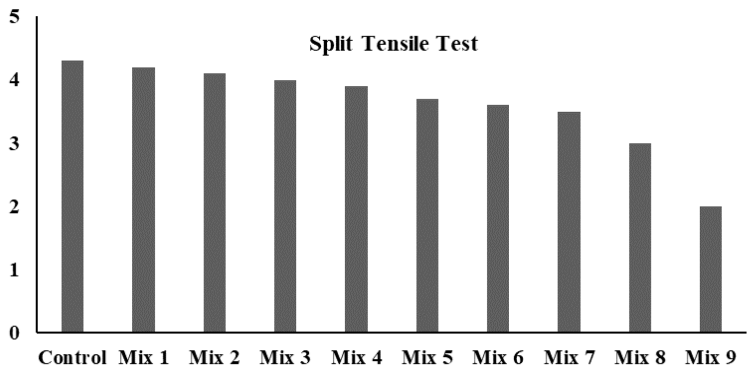

Figure 6: Split tensile strength of the designed concrete mixtures at 28 days

4.4 Flexure Strength Test

In this experimental study, a conventional reinforced concrete beam and modified concrete beams prepared with partial replacement of cement by marble powder and fine aggregate by marble powder were considered. Six full-scale beams were tested in total using Computer Controlled Servo Hydraulic Universal

Testing Machine 600KN. The first beam was casted with control mix with no replacement. Two beams were casted with concrete mixtures made by replacing cement by ratio 40% with different fly ash/slag ratios; 10% - 30% and 30% - 10%, as presented in Table 4. All the beams had a rectangular cross-section of 150mm wide, 250mm depth, and a span of 2 m, illustrated in Figure 7. They had the same structure, size, and reinforcement (2ø12 top rft and 2ø16 bottom rft). The beams were loaded using a concentrated three-point load setup, a concentrated load was applied directly at the center of the supported beams with clear span 1.6 m. The beams were loaded in constant load steps, and concrete strain gauges were installed to measure the concrete's strains, while beam deflections were measured by displacement meters as in Figure 8.

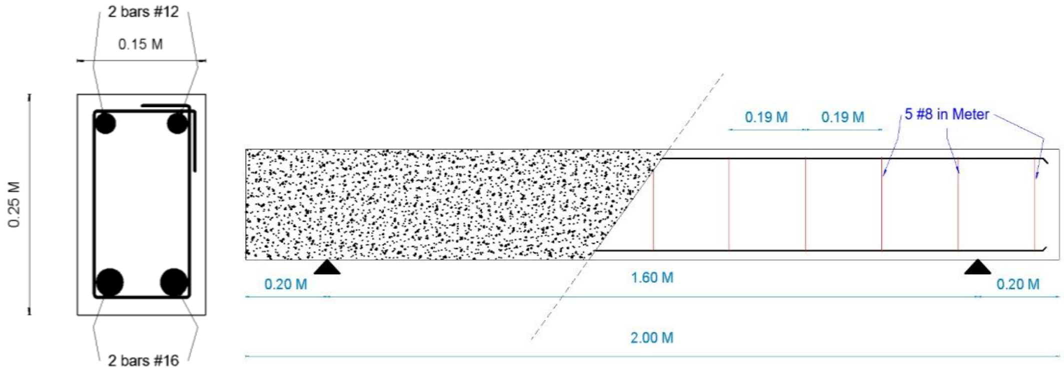

Figure 7: Cross-sectional view of beam specimen

Table 4: Reinforced Concrete beams mixture description

Beam	Description		
	Cement%	**Slag%**	**Fly ash%**
B1	100	0	0
B2	60	10	30
B3	60	30	10

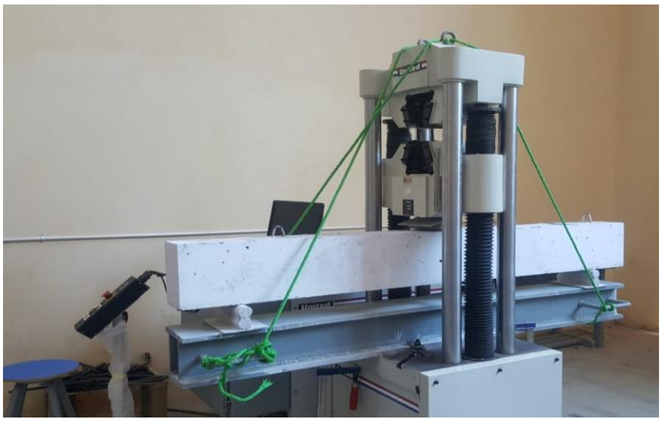

Figure 8: Three-point bending test setup for the beams

The load-deflection curves of each beam are shown in Figure 9. From the results shown, the ultimate load of all beams is relatively close and the beams B1 and B2 casted with 40% cement replacement showed a ductility compared to the beam B1 casted with the control mix.

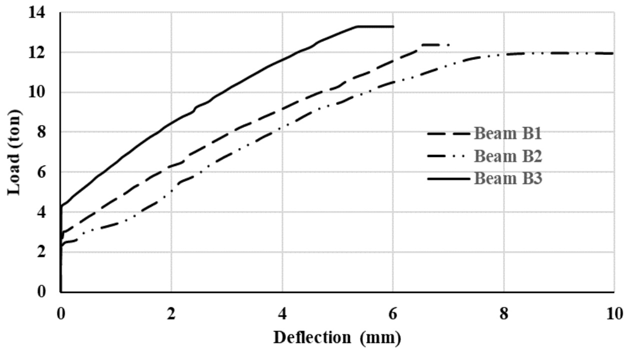

Figure 9: Load deflection curve for the reinforced concrete beams

V. CONCLUSION

This research offers a detailed study through an experimentally approaches that can be utilized to implement the effect of using waste fly ash and slag on the response of reinforced concrete beams. Also, the study determines the effect of using this waste in the design mix of concrete and its effect on the concrete mechanical properties such as compressive, split tensile, and flexure strength. An experimental investigation where three specimens were casted and tested. An experimental investigation is performed on concrete mixtures to study the effect of using waste fly ash and slag as a partial replacement of cement with different percentages, the cement was replaced by percentages of 10%, 30% and 50% for slag replacement as well as 10%, 20% and 30% for fly ash. The results show that 40% replacement of cement with fly ash and slag achieve the maximum optimum compressive strength that reached to 50 MPa, and split tensile strength reached to 3.9 MPa.

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