IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 08, Issue 6 (June. 2018), ||V (II) || PP 69-76

Study on Strength and Durability Properties of GGBS-Fly Ash based Concrete

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Abstract: Concrete is the second most consumed material in the world after water. It is a combination of cement, coarse aggregates, fine aggregates, water and admixtures. Ordinary Portland Cement (OPC) is traditionally used as a binding material for concrete. It is estimated that when one tonne of OPC is manufactured, one tonne of carbon dioxide is released to the atmosphere. This emission during the manufacturing of cement contributes 7% of the global carbon dioxide emission. So it is important to introduce an alternate binder which will have less carbon footprint than cement. Efforts are made in the concrete industry to use waste materials as partial replacement of cement. Industrial waste material by products like GGBS and Fly Ash which are supplementary cementitious materials can be added to the concrete. In this study, experimental investigations were performed on the strength and durability properties of concrete with GGBS and Fly Ash as partial replacement of cement and M sand as fine aggregate. GGBS and Fly Ash together was replaced in the range of 0% to 30% with different percentage combinations between them. Various material tests were done on M20 grade concrete. Reduction in embodied energy and cost due to partial replacement of GGBS and Fly Ash was also investigated.

Keywords: Concrete, GGBS, Fly Ash, Material tests, Embodied energy

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Date of Submission: 28-05-2018 Date of acceptance: 11-06-2018

I. INTRODUCTION

Concrete is typically the most massive individual material element in the built environment. Concrete primarily comprises of Portland cement, aggregates and water. Cement is the vital ingredient of concrete. Although, Portland cement typically comprises only 12% of the concrete mass, it accounts for approximately 93% of the total embodied energy of concrete and 6% to 7% of the global CO_2 emissions. 1 tonne of CO_2 is estimated to be released to the atmosphere when 1 tonne of OPC is manufactured. Cement is energy intensive, so the embodied energy is high. If the embodied energy of concrete can be reduced without decreasing the performance or increasing the cost, significant environmental and economic benefits may be realized.

The usage of ground granulated blast furnace slag (GGBS) and Fly Ash as a partial replacement for OPC would provide environmental and economic benefits and the required workability, durability and strength necessary for the design of structures.GGBS is a byproduct from the manufacturing of pig iron and Fly Ash is one of the by-products of thermal power plants. Ground-granulated blast-furnace slag (GGBS) is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. Concrete made with GGBS cement sets more slowly than concrete made with Ordinary Portland Cement. However, it continues to gain strength over a longer period in production conditions. Fly Ash, also known as "pulverised fuel ash", is a coal combustion product composed of fine particles that are driven out of the boiler with the flue gases.Researchers all over the world are developing Ternary Blended Concretes by adding a super fine mineral admixture like GGBS to the binary blended concretes of Fly Ash. GGBS in the ternary blend improves the early age performance of concrete and Fly Ash improves the properties at the later age [17].In present work, an attempt is made to study the strength and durability properties of M20 concrete with GGBS and Fly Ash as partial replacement of cement.

II. MATERIALS PROPERTIES AND MIX PROPORTIONS

OPC 53 grade cementof specific gravity 3.15 was used for the study. Locally available M sand of specific gravity 2.82 and coarse aggregates of size less than 20 mm of specific gravity 3.128 were used. GGBS of specific gravity 2.88 and Fly ash of specific gravity 2.65 was used. Potable quality water was used for the mix.

Based on the properties of aggregates and cement, the mix proportion for M20 concrete was designed as per provisions in IS Code 10262-2009 for 0%, 10%, 15% and 20%, replacement of cement with GGBS and Fly Ash. No admixtures were used in this investigation. Four mixes were done for strength and durability tests.Control concrete (G0F0) with 0% GGBS, 0% Fly Ash, 100% cement.Mix 1 (G20F10) with 20% GGBS, 10% Fly Ash, 70% cement. Mix 2 (G15F15) with 15%GGBS, 15% Fly Ash, 70% cement. Mix 3 (G10F20) with 10% GGBS, 20% Fly Ash, 70% cement.The mix proportion is given in Table 1.

Table 1: Mix proportion of M20 concrete

Water	Cement	Fine aggregate	Coarse aggregate
197 L	394 kg	726.544 kg	1314.88 kg
0.5	1	1.84	3.33

III. MECHANICAL BEHAVIOUR OF CONCRETE WITH GGBS AND FLY ASH

The mechanical behaviour of concrete with different percentage combinations of GGBS and Fly ash as replacement to cement was investigated. Tests were conducted to determine the workability, compressive strength, split tensile strength and flexural strength. The compressive strength test, split tensile strength test and flexural strength test of the specimens were tested on 28 days and 56 days.Workability test was carried as per IS 1199:1959 using a slump cone having 300mm height and base 200mm diameter and top cone diameter is 100mm.Cube specimens (150 mm x 150 mm x 150 mm), cylinder specimens (150 mm diameter and 300 mmheight), beam specimens (100 mm x 100 mm x 500 mm) were casted for all the 4 mixes. Durability tests like acid attack test and alkali attack test were done. These tests were performed on cube specimens. A cube was cast for acid and alkali attack test respectively. First concrete cubes were cast and cured in mould for 24 hrs for all mixes.Cubes were demoulded and cured for 7 days in water andkept in atmosphere for 2 days and were weighed.Later cubes were kept in 5% Sulphuric acid solution (for acid attack test) and 5% Sodium sulphate solution (for alkali attack test) separately for 60 days.The percentage weight loss was determined after exposing it to atmosphere for 2 days.

IV. RESULTS AND DISCUSSION

4.1 Effect on workability of concrete

The workability test results are shown in Table 2. From the test results, it is evident that workability of GGBS-Fly Ash concrete is slightly higher compared to control mix. Slump value is maximum for G15F15 which means slump value increases when GGBS and Fly Ash are used in same quantity in concrete. All the 3 mixes of GGBS-Fly Ash concrete has almost same slump value because in all these mixes 30 % of cement was replaced by GGBS and Fly Ash. Since GGBS and Fly Ash have pozzolanic properties similar to that of cement and are very fine, slump of GGBS-Fly Ash concrete and control concrete are nearly equal. The comparison of Slump vs Percentage Fly Ash is plotted as shown in Fig 1. From the chart it is clear that slump increases as the percentage of Fly Ash increases upto 15% replacement of cement. Further replacement reduces the workability. Hence optimum is found for 15 % replacement of GGBS and 15 % replacement of Fly Ash.

Table 2: Slump values

Sl No	Concrete Mix	Slump (mm)
1	G0F0	90
2	G20F10	102
3	G15F15	110
4	G10F20	105

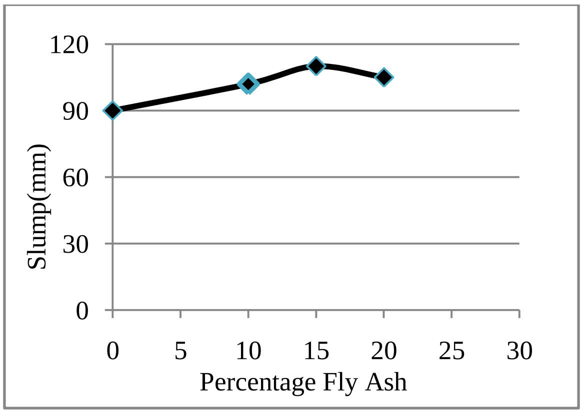

Fig 1. Slump vs Percentage Fly Ash

4.2Effect on compressive strength

The test results of the compressive strength test are shown in Table 3. It isfound that compressive strength is maximum for G20F10 (20% GGBS and 10% FA) both at 28days and 56 days age. The increase in strength of 39.5% was obtained for G20F10 compared to control specimen at 28 days and 46.3% increase in compressive strength at 56 days. Hence, it is clear that strength is maximum when GGBS content is maximum. As the percentage of GGBS content decreases from 20% to 10 %, strength also decreases. Maximum strength was obtained at 20 % GGBS content. It was found that later age strength is more for GGBS-Fly Ash concrete compared to control concrete. The presence of GGBS in concrete slow the pozzolanic reaction and the formation of calcium hydroxide $Ca(OH)_2$ requires time.

Table 3: Compressive strength values

Sl No	Concrete Mix	Compressive strength (N/mm²)	
		28 days	56 days
1	G0F0	29.77	36.44
2	G20F10	41.55	53.33
3	G15F15	40	51.11
4	G10F20	37.33	47.77

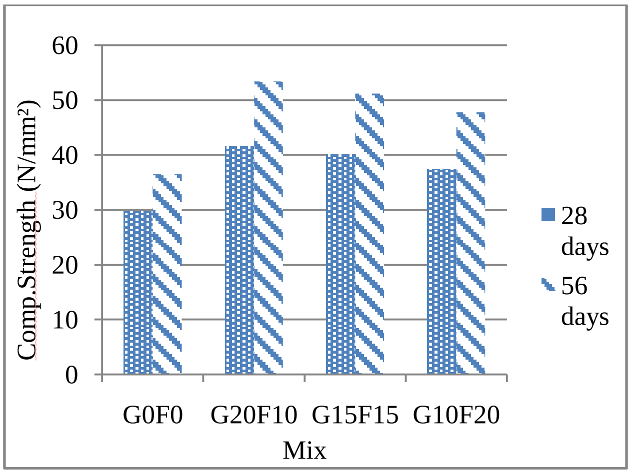

Fig 2. Compressive Strength vs Mix

4.3 Effect on split tensile strength

The split tensiletest results are shown in Table 4.The maximum split tensile strength was obtained for G15F15 mix. The split tensile strength of G15F15 mix at 28 days is 37.7% greater than the control mix and 13.88% greater at 56 days. Hence considering the tensile strength criteria 15 % GGBS and 15 % Fly Ash is the optimum that can be used in the concrete.

Table 4: Split tensile strength values

Sl No	Concrete Mix	Split tensile strength (N/mm^2)	
		28 days	56 days
1	G0F0	3.11	3.89
2	G20F10	4.1	4.43
3	G15F15	4.3	4.64
4	G10F20	3.53	4.16

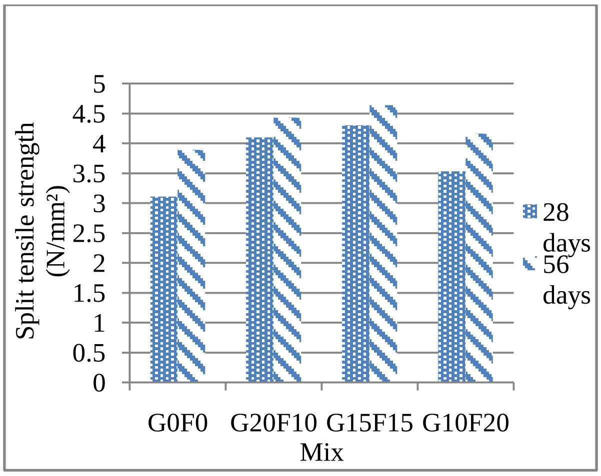

Fig 3. Tensile strength vs Mix

4.4Effect on flexural strength

Flexural strength results are shown in Table 5. Flexural strength is found to be maximum for G20F10 mix both at 28 days and 56 days. Flexural strength increases by 34.6 % compared to the control mix for 28 day strength and for 56 day strength, an increase of 14.2 % in strength is found compared to the control mix. Hence, considering flexural criteria, 20% GGBS is found to give optimum results. The flexural strength of various mixes for 28 days and 56 days is shown in Fig 4.

Table 5: Flexural strength values

Sl No	Concrete Mix	Flexural strength (N/mm^2)	
		28 days	56 days
1	G0F0	6.5	8.75
2	G20F10	8.75	10
3	G15F15	7.75	9.5
4	G10F20	7	9

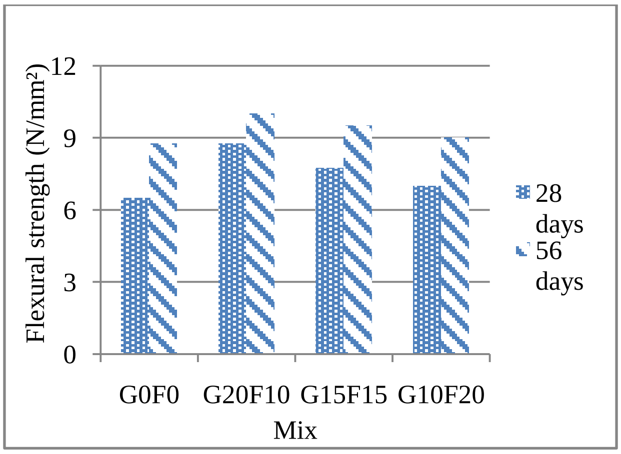

Fig 4. Flexural strength vs Mix

4.5 Durability tests

The durability of the specimen is measured by percentage weight loss in cubes after immersing in acidic and alkali solutions.

4.5.1 Acid attack test:

Fig 5. Eroded cube after immersion

Table 6: Percentage weight loss in acid attack test

Concrete mix	Weight before placing in Acidic Solution (kg)	Weight after placing in Acidic Solution (kg)	% weight loss
G0F0	8.899	8.880	0.212
G20F10	8.454	8.412	0.49
G15F15	8.378	8.349	0.35
G10F20	8.320	8.283	0.44

Percentage weight loss for control specimen is found to be 0.212. The maximum percentage weight loss is found for G20F10 mix of value 0.49. Minimum weight loss is for G15F15 mix. Compared to control mix, percentage weight loss is more for GGBS-Fly Ash concrete.

4.5.2 Alkali attack test:

Alkali attack test was performed on the cubes and the test results are presented in the Table 7. The weight of the concrete cubes before placing in alkaline solution was noted and weight of the cubes after immersing in alkaline solution was noted to find out the weight loss. Percentage weight loss of control mix was found to be 0.118. Higher weight loss is found for G15F15 mix. The GGBS-Fly Ash mixes have nearly same percentage weight loss. Hence we can conclude that alkali attack resistance of GGBS-Fly Ash concrete is nearly same as that of the control concrete.

Fig.6 Eroded cubes after immersion

Table 7: Percentage weight loss in alkali attack test

Concrete mix	Weight before placing in Alkaline Solution (kg)	Weight after placing in Alkaline Solution (kg)	% weight loss
G0F0	8.993	8.985	0.118
G20F10	8.572	8.56	0.14
G15F15	8.487	8.472	0.17
G10F20	8.304	8.29	0.16

4.6 Embodied energy calculation

Embodied energy is the energy consumed by all of the processes associated with the production of a material. It is expressed in megajoules (MJ) or gigajoules (GJ) per unit weight (kg or tonne) or area (m^2). The individual material used in concrete has its own embodied energy coefficient.Details of energy values of materials are given in Table 8. Embodied energy of GGBS-Fly Ash based concrete is compared with that of control concrete. Hence, embodied energy required for producing 1 cube is calculated for GGBS – Fly Ash concrete and control concrete. Considering the quantity of materials required for casting 1 cube, the total embodied energy of GGBS- Fly Ash concrete cube is found to be 24 % lesser (for G10F20) than the control concrete.

Table 8: Embodied energy coefficient of materials

Type of material	EmbodiedEnergy (MJ/kg)
Cement	4.53
GGBS	0.31
Fly Ash	0
Water	0
Fine Aggregate (M sand)	0.12
Coarse Aggregate	0.22

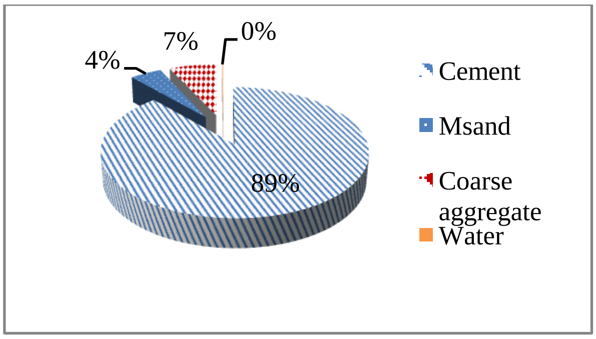

Fig 7. Embodied energy contribution of each material on control concrete

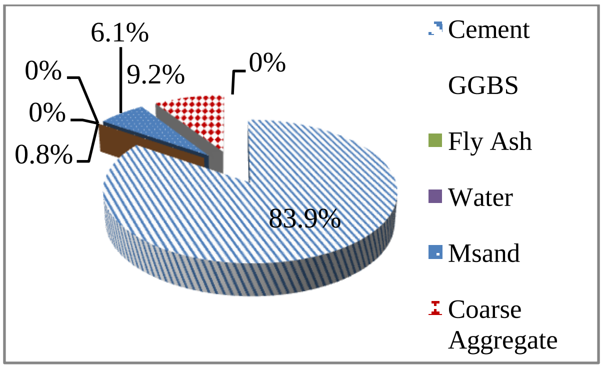

Fig 8. Embodied energy contribution of each material onGGBS-Fly Ash concrete

4.7 **Cost analysis**

In cost analysis, total cost of producing control concrete (which includes 8 cubes, 6 cylinders and 6 beams) for this project is compared with that cost of producing GGBS-Fly Ash concrete (includes 24 cubes, 18

cylinders and 18 beams). Cost of cement, GGBS, Fly Ash, M sand and coarse aggregates are taken into consideration. Transportation charges are excluded in this analysis. The total cost for producing control concrete is Rs.546. From the test results, 20% GGBS gives optimum results. So considering G20F10 mix, total production cost is Rs. 472 only. So cost reduction is possible by using GGBS and Fly Ash in concrete.
Cost - Benefit analysis is also done considering compressive strength of a cube. A single cube is considered. Total cost of producing one cube is then analysed with the compressive strength attained by that cube at 28 days and 56 days. This analysis is done for both control concrete and GGBS-Fly Ash concrete which is shown in Fig 9.

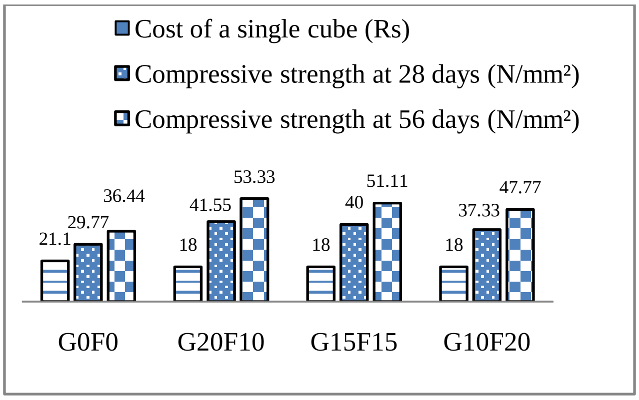

Fig 9. Cost-Benefit analysis

V. CONCLUSIONS

Experimental investigations were performed on the strength and durability properties of M20 concrete with GGBS and Fly Ash as partial replacement of cement and M sand as fine aggregate. GGBS and Fly Ash together were replaced in the range of 0% to 30% with different percentage combinations between them. Various material tests were done on M20 grade concrete.Based on experiments and test results on this ternary blended concrete, the following conclusions were drawn:

- Partial replacement of cement by FA and GGBS in concrete increases strength properties. Therefore the utilization of waste materials like FA and GGBS in concrete as cement replacement is possible.
- Compressive strength and flexural strength increases maximum for 20% GGBS and 10% Fly Ash replacement (G20F10 mix) both for 28 days and 56 days age.
- Split tensile strength is found maximum for 15% GGBS and 15% Fly Ash replacement (G15F15) both for 28 days and 56 days age.
- The increase in strength was higher for GGBS-Fly Ash concrete compared to control concrete beyond 28 days. Hence later age strength is more for GGBS-Fly Ash concrete.
- Durability characteristics of GGBS-Fly Ash concrete is nearly the same as that of control concrete
- The adverse environmental effects like global warming caused due to usage of energy intensive cement can be reduced by incorporating GGBS and Fly Ash in concrete.
- Cost reduction is possible by effectively using GGBS and FA as Cost –Benefit analysis shows higher strength with lesser cost can be achieved. The utilisation of GGBS and Fly Ash holds promising prospects in the country because it is easily available all over the country at much lower rates than cement and due to the fact that it reduces the impact on environment and capital cost of structure.

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