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A Study on Strength Properties of Fly Ash and Ground Granulated Blast Furnace Slag based Geopolymer Concrete

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***Abstract*—The need to reduce the global anthropogenic carbon dioxide has encouraged researchers to search for sustainable building material. The second most consumed product in the world is concrete. Cement contributes 7% of the global carbon emission. Geopolymer Concrete (GPC) which is manufactured using industrial waste like fly ash, Ground Granulated Blast Furnace Slag (GGBS) is becoming a more eco-friendly alternative to Ordinary Portland Cement (OPC) concrete. The objective is to study the fly ash and GGBS on the mechanical properties of geopolymer concrete at full replacement of cement. Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solution have been used as alkaline activators. The effect of replacement of cement with fly ash and GGBS at varying percentage on strength of geopolymer concrete is studied. Additionally, the feasibility of production of geopolymer concrete using fly ash and GGBS is also evaluated in this study. In the present investigation, it is proposed to study the mechanical properties viz. compressive strength and split tensile strength of fly ash-GGBS based geopolymer concrete. These properties have been determined at curing periods 7 & 28 days and at ambient room temperature. From this study it is concluded that full replacement of cement with fly ash and GGBS gives good strength properties. The maximum compressive strength is observed to be attained at full replacement of cement by fly ash and GGBS having a proportion ratio of 1:1 which is more than the optimum mix in full replacement had an increase in cost than the conventional mix. However, with respect to its strength characteristics it still economical. From these conclusions we can say that, it will be a good initiative to give a solution for solid waste disposal as well as to reduce the CO_2 emission generated during the process of cement manufacturing.**

***Index Terms*— Fly ash, Ground Granulated Blast Furnace slag, Sodium silicate solution, Sodium hydroxide, compressive strength, tensile strength.**

I. INTRODUCTION

Ordinary Portland Cement (OPC) is conventionally used as the primary binder to produce concrete due to the availability of its raw materials all over the world. The amount of the carbon dioxide released during the manufacture of OPC due to the calcinations of limestone and combustion of fossil fuel is in the order of one

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ton for every ton of OPC produced. In addition, the extent of energy required to produce OPC is only next to steel and aluminum [1].

When used as a partial replacement of OPC, in the presence of water and in ambient temperature, fly ash reacts with the calcium hydroxide during the hydration process of OPC to form the calcium silicate hydrate (C-S-H) gel. The development and application of high volume fly ash concrete, which enabled the replacement of OPC up to 60% by mass is a significant development [2].

Palomo et al (1999) suggested that pozzolans such as blast furnace slag might be activated using alkaline liquids to form a binder and hence totally replace the use of OPC in concrete. 80% to 90% reduction in CO_2 emission can be achieved by the replacement of Ordinary Portland Cement (OPC) with geopolymer concrete as well as a solution to disposal of industrial wastes such as fly ash, GGBS etc. [3].

II. MATERIALS USED

In this experimental study, cement is completely replaced by combinations of fly ash and GGBS in concrete. For this study, the materials used are GGBS, fly ash, fine aggregate, coarse aggregate, alkaline liquid and water.

A. Ground Granulated Blast Furnace Slag (GGBS)

Ground Granulated Blast Furnace Slag (GGBS) is obtained by quenching molten iron slag from a blast furnace in water or stream. The material properties of GGBS are determined by collecting random samples and testing as per Indian standards confirming to IS 383-1970.

B. Fly Ash

Fly ash also known as pulverized fuel ash in UK, is a coal combustion product that is composed of the particulates that are driven out of coal-fired boilers together with the flue gases. It is used in many ready mix concrete due to less cost and increase in compressive strength.

C. Fine Aggregate

Manufactured sand (M sand) is used as fine aggregate of uniform gradation confirming to the requirements of IS 383-1970. Specific gravity obtained is 2.5.

D. Coarse Aggregate

Crushed angular shaped aggregates are used. Size of aggregate is generally 10mm to 20mm. Coarse aggregate shall comply with the requirements of IS 383-1970. Aggregate should be having uniform quality with respect to shape and grading. Specific gravity obtained is 2.67.

E. Alkaline Activator

Sodium silicate and sodium hydroxide were used as activators to react with the aluminum and the silica in the fly ash and GGBS. Commercially available sodium silicate was used for this experimental work. Sodium hydroxide solution of 8 M concentration was prepared by dissolving sodium hydroxide flakes with 97% purity in the water. The ratio of sodium silicate to sodium hydroxide solution was fixed as 2.5. The alkaline solution was prepared by mixing both sodium silicate solution and sodium hydroxide solution together at least one day prior to use [4]. Alkaline activator to binder ratio, by mass, was taken as of 0.35 [5].

F. Water

Locally available test for potable water is used for the preparation of concrete.

III. MIXING AND CASTING

The material tests were carried out in the laboratory and the results from those tests motivated to go for mix design and further tests on concrete. Mix design for the water cement ratio, 0.5, is prepared to know the quantity of materials required. Trials with various water contents were done in order to get the required slump in the slump test.

Geopolymer concrete was prepared by dry mixing of fly ash, GGBS, fine aggregate and coarse aggregate manually and then water was added immediately after the alkali activators were added to the dry mix for getting the required workability. The prepared fresh concrete was casted immediately after mixing into moulds of 150 mm x 150 mm x 150 mm cubes and 150 mm x 300 mm cylinders to find the compressive and tensile strength. These specimens were then cured in water. The proportions of fly ash and GGBS taken for the study are given in Table I.

TABLE I. PROPORTIONS OF BINDER TAKEN FOR STUDY

Sl. No.	Fly ash (%)	GGBS (%)
1	100	0
2	60	40
3	50	50
4	40	60
5	0	100

IV. RESULTS AND DISCUSSIONS

From the experimental study conducted, the following results were obtained.

A. Compressive Strength Test

Compressive strength test is conducted as per IS: 516-1959. The compressive strength of 7 days and 28 days of curing is tabulated below in Table II for various proportion of fly ash and GGBS combination and Fig. 1 shows the respective bar chart. From the study it is understood that strength increases as proportion of GGBS increases and reaches an optimum value and decreases. It is clear from the analysis that the maximum compressive strength which is greater than the plain concrete is obtained at Combination III, which is the full replacement of cement by 50% fly ash and 50% GGBBS.

TABLE II. COMPRESSIVE STRENGTH FOR 7 DAYS AND 28 DAYS OF CURING

Specimen	Cement (%)	Fly ash (%)	GGBS (%)	7 day test (N/mm^2)			Average (N/mm^2)	28 day test (N/mm^2)			Average (N/mm^2)
M 25	100	0	0	27.02	23.73	25.78	25.51	31.64	29.51	30.71	30.62
I	0	100	0	9.78	14.84	12.44	12.36	22.67	21.78	23.56	22.67
II	0	60	40	32.00	28.89	30.84	30.58	36.00	37.78	37.15	36.98
III	0	50	50	42.67	43.55	43.11	43.11	52.44	54.31	53.11	53.29
IV	0	40	60	39.11	35.20	37.29	37.20	46.93	48.00	47.87	47.60
V	0	0	100	29.78	26.22	28.00	28.00	37.78	40.44	39.38	39.20

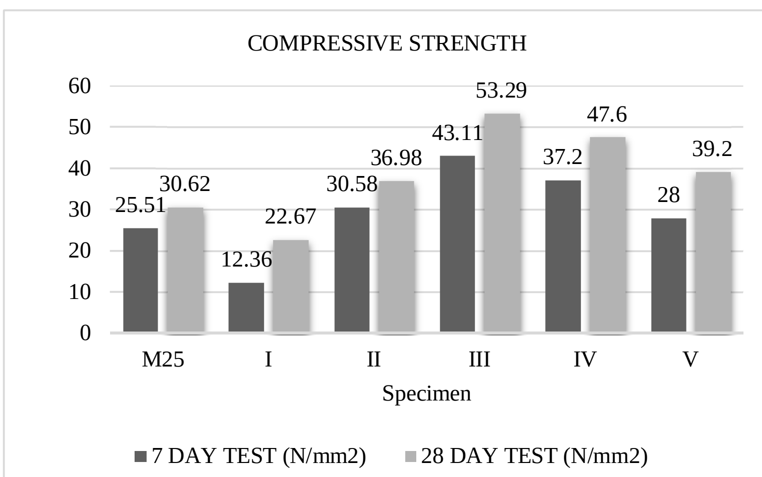

Figure 1. Bar chart of 7 day and 28 day compressive strength test

B. Split tensile strength test

Split tensile strength test is conducted as per to IS: 10086-1982. The split tensile strength of 7 days and 28 days of curing is tabulated below in Table III for various proportions of fly ash and GGBS combination and their respective bar chart is depicted in Fig. 2. From the study it is understood that strength increases as proportion of GGBS increases and reaches an optimum value and decreases. It is clear from the analysis that the maximum split tensile strength which is greater than the plain concrete is obtained at Combination III, which is the full replacement of cement by 50% fly ash and 50% GGBS.

TABLE III. SPLIT TENSILE STRENGTH FOR 7 DAY AND 28 DAY CURING

Specimen	Cement (%)	Fly ash (%)	GGBS (%)	7 day test (N/mm^2)			Average (N/mm^2)	28 day test (N/mm^2)			Average (N/mm^2)
M25	100	0	0	1.88	1.95	1.81	1.88	2.69	3.11	3.07	2.96
I	0	100	0	1.30	1.33	1.36	1.33	2.12	1.98	2.43	2.19
II	0	60	40	2.53	2.57	2.62	2.57	3.39	3.48	3.27	3.38
III	0	50	50	2.66	2.94	2.76	2.79	3.62	3.96	3.75	3.77
IV	0	40	60	2.55	2.29	2.38	2.40	3.05	3.47	3.15	3.22
V	0	0	100	1.67	2.35	2.05	2.02	2.97	3.25	3.03	3.08

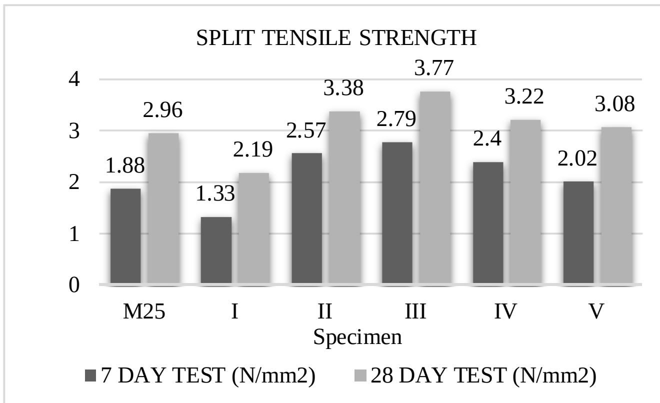

Figure 2. Bar chart of 7 day and 28 day split tensile strength test

V. CONCLUSIONS

From this experimental study, following conclusions were made:

- The results from compressive strength test of cement replaced with different proportions of combination of fly ash and GGBS showed an initial decrease in strength compared to nominal strength and then attained an optimum value and finally decreased.
- The maximum compressive strength was observed to be attained at full replacement of cement by fly ash and GGBS having a proportion ratio of 1:1, which is 70% more than the conventional mix compressive strength.
- In full replacement, the tensile strength was found to be higher in a ratio of 1:1 of fly ash and GGBS having an increase of 15% than that of conventional mix.
- By going through the results we have obtained, it will be an initiative to give a solution for solid waste disposal and also reduces the emission of CO_2 by cement.
- We can also come to a conclusion that the by product from factories such as fly ash and GGBS can be effectively used for replacing cement in concrete.

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