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A Study on Impact of Partial Replacement of Cement with Industrial By-Products in Concrete

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Abstract: This study investigates the effect of fly ash (FA) and ground granulated blast furnace slag (GGBS) as partial replacement of cement in the manufacture of concrete. Manufactured sand (M-sand) is used as fine aggregate in the place of scarce river sand. The grade of concrete used is M_{20}. The cube, cylindrical and prism specimens were cast and subjected to wet curing. The compressive strength, split tensile strength and flexural strength of concrete specimen was tested at 28 days. The experimental results indicated that replacement of cement by flyash resulted in decreasing the compressive strength and these strength values falls below 20 MPa after 30% partial replacement of cement by flyash. Further, the flyash is partial replaced by GGBS and then experimental tests were conducted. The cement concrete having binder proportions (50% cement, 30% flyash and 20% GGBS) provides better mechanical performance and optimum results in economical considerations. Hence the use of major industrial wastes such as fly ash and GGBS is found to be feasible in the production of new sustainable construction material.
Keywords: Flyash, GGBS, Compressive strength, Split tensile strength and Flexural strength

I. INTRODUCTION

Concrete is one of the most widely used reliable and effective construction material in all over the world. Rapid urban growth development leads to the usage of concrete in construction industry increases day by day. In recent years, the demand of concrete as a construction materials increases with increasing the demand of ordinary Portland cement. In order to meet the demand, the production of ordinary Portland cement (OPC) increases every year. During the production of OPC, an enormous amount of green house gas such as carbon dioxide (CO_2) will be emitted and it is responsible for global warming issues, then environment protection is greatly affected and it is under critical scenario. To overcome those issues, an alternative material is essentially needed and that material having effective and efficient usable manner and it also reduce the CO_2 emission. On the other hand, the continuous usage of river sand in construction industry declining the natural resources and its demand increases rapidly. Hence, the cost of construction material increases and economy is greatly affected. An alternative material is essentially needed to overcome those issues in terms of quantity, quality, cost and its essentially satisfying desirable mechanical properties of fine aggregates.

A. Fly ash

In present scenario, flyash and GGBS can be regarded as conventional cementitious constituent's material. Firstly, the production of fly ash increases in thermal power station due to high need of electricity in these generation and flyash disposal into the environment is a problem. Flyash, a heterogeneous by-product material produced in the combustion process of coal used in power stations. Fly ash particles are almost totally spherical in shape, allowing them to flow and blend freely in mixtures. That capability is one of the properties making fly ash a desirable binder for concrete. It greatly improve the durability of concrete through control of high thermal gradients, pore refinement, depletion of cement alkalis, resistance to chloride and sulphate penetration, and continued micro structural development through a long-term hydration and pozzolanic reaction. The utilization of by-products as the replacement of cement has important economical, environmental and technical benefits such as the reduced amount of waste materials, cleaner environment, reduced energy requirement, durable service performance during service life and cost effective structures.

B. GGBS

Secondly, the reinforced concrete structure demand the high quantity of rebar, and there is due to this production of iron in industries is more. From the industries, the slag is disposed and the slag is converted to ground granulated blast furnace slag. The GGBS is a by-product of iron manufacturing by heating iron ore, lime stone and coke at a temperature about 1500 degree Celsius. This process is carried out in a blast furnace slag. GGBS has better mobility characteristics arising from the consistent fineness and particle shape of the GGBS powder, and from its slightly lower relative density.

The smoother surface texture and glassy surface of GGBS particles also helps to improve workability. GGBS prevents the occurrence of efflorescence, the staining of concrete etc. Because of its superior performance, it replaces Sulphate Resisting Portland Cement (SRPC) and useful against chloride attack in reinforced concrete in marine environments.

C. Manufactured sand

Manufactured sand (M-sand) is one of the potential materials which is obtained from crushing rocks or quarry and subjected to series of crushing cycles to reduce the particles to the size of naturally occurring sand. The produced sand is then sieved and washed to remove fine particles and impurities and tested for various quality aspects to be fit as construction industry. M-sand is free of silt and clay particles, and has denser particle packing than natural sand. It also offers higher flexural strength, better abrasion resistance, higher unit weight and lower permeability.

Based on these above facts and problems, an attempt is going to made to evaluate the performance of concrete as a partial replacement of cement by flyash and GGBS under wet curing condition in order to find out the optimum percentage of flyash and GGBS in cement. By utilizing these two products as a replacement of cement in concrete, it may be a solution for reducing global warming issues and more eco-friendly material.

II. EXPERIMENTAL PROCEDURE

A. Materials

In this study, Class F flyash with a specific gravity of 2.3 is used. The Ground granulated blast furnace slag (GGBS) with a specific gravity of 2.1 is used. Manufactured sand (M-sand) with a specific gravity of 2.56 and water absorption 0.8% are used as a fine aggregate. Coarse aggregate of maximum size 20mm with a specific gravity of 2.6 and water absorption of 0.42% are used as coarse aggregate

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B. Concrete Mix Proportions and Specimen Preparation

The concrete including binder, fine aggregate, coarse aggregate and water. The materials were quantified before mixing. Firstly, the cement is partially replaced by fly ash from 0% to 50% .Totally six proportions of concrete(CC, C90F10, C80F20, C70F30, C60F40 and C50F50) is prepared including controlled concrete for 7days,14days and 28 days of curing. In addition to that, the flyash is further partially replaced by GGBS upto 20%. Totally four proportions of concrete (C50F45G5, C50F40G10, C50F35G15 and C50F30G20) is prepared for 7days, 14days and 28 days of curing. The nomenclature of specimen is presented in Table 1.Firstly, all solids like binder, fine aggregate and coarse aggregate are mixed by using mixer machine about three to four minutes. Then the water is poured over the dry mix concrete and mixing about four to five minutes to initiate the reaction. After preparing the concrete mix, they were cast into molds. The specimens were cured under wet curing for 7, 14 and 28 days.

Table 1 Nomenclature of specimen

Specimen (Indication)	Description
CC	Controlled concrete(100% Cement)
C	Cement
F	Fly ash
G	GGBS
M	Manufactured sand
5,10,15,20,30,40,50	% of binder

C. Test methods

To evaluate mechanical behaviour of cement concrete, a total of three kinds of analysis were used: Compressive strength, Split tensile strength and Flexural strength.

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D. Compressive Strength Test

The compressive axial load is applied at the rate of 1.2 N/mm^2 to 2.4 N/mm^2 according to IS code 5816:1999. The load is applied in such a way that the fracture plane will crossed the trowel surface. The compressive strength test of concrete specimen is shown in Fig.1.

Fig.1. Compressive strength test of cube specimen

E. Split tensile strength test

To measure the tensile strength of concrete, the specimen is placed centrally between the plates and the load is gradually applied in such a way that fracture plane will pass along its vertical diameter of specimen confirm to IS code 5816:1999.The split tensile strength test of concrete specimen is shown in Fig.2.

Fig.2. Split tensile strength test of cylinder specimen

F. Flexural Strength test

To measure the flexural strength of concrete specimen, the concrete specimen is placed in the Universal testing machine in such a manner that the load is applied to the uppermost surface as cast in the mould, along two lines spaced 150mm apart. The load is increased continuously until the specimen fails, and the maximum load withstand by each specimen before failure is recorded. The flexural strength test of concrete specimen is shown in Fig.3.

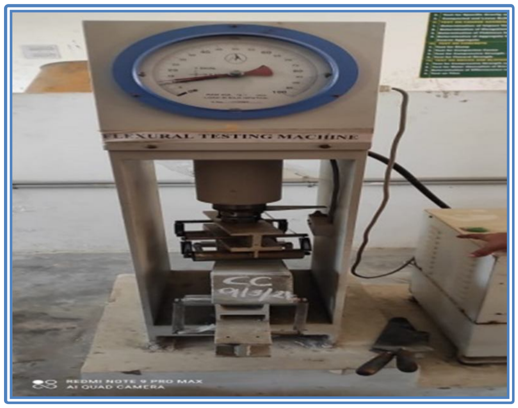

Fig.3. Flexural strength test of Prism

III. RESULTS AND DISCUSSION

A. Compressive Strength of Concrete

The concrete cube specimens were tested for compressive strength in a compression testing machine having 2000kN capacity in accordance with the bureau of Indian standard test procedure. The compressive strength after 28 days for mixes CC, C90F10, C80F20, C70F30, C60F40 ,C50F50, C50F45G5, C50F40G10, C50F35G15 and C50F30G20 are 26.66, 25.32, 22.31, 19.12, 18.45, 16.62, 17.45, 19.92, 20.05 and 22.45 respectively and these values are represented in Fig.4.

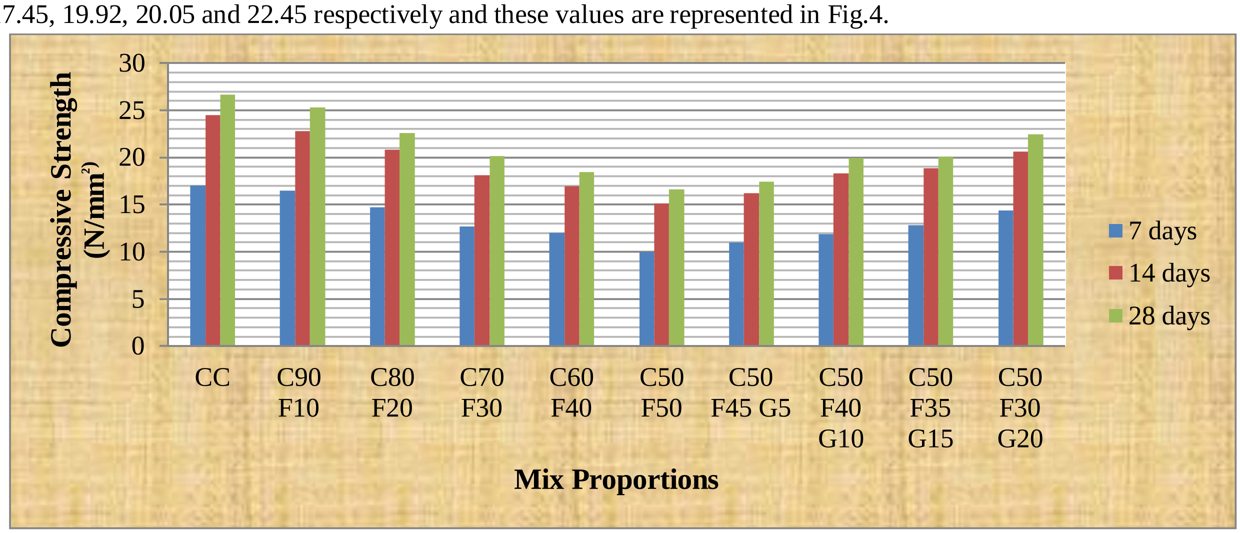

Fig.4. Compressive strength variation of different concrete mixes

The test results indicates that the replacement of cement by flyash decreases the compressive strength but the strength values fall below 20 N/mm² only after 30% replacement of cement by GGBS. Hence, the partial replacement of cement by flyash upto 30% achieved an optimum compressive strength. After 30% replacement of cement by flyash, the concrete achieved the minimum compressive strength of 18.45N/mm² (C60F40 MIX) and 16.62 N/mm² (C50F50 MIX) which is less than 20 N/mm². Hence this mix is not practically applicable. Hence, the optimum mix is C70F30 (70% cement and 30% flyash) having a compressive strength of 20.12 N/mm². In order to increase the compressive strength with minimum percentage of cement (50% binder content) and to obtain an optimum and economical concrete mix, the flyash is replaced by GGBS from 0% to 20%. On addition of GGBS, the compressive strength of concrete increases from 16.62 N/mm² (50%Cement&50%flyash) to 22.45 N/mm² (50%Cement&30% flyash and 20%GGBS).Hence, the replacement of flyash by GGBS upto 20% increases the compressive strength.

This is due to the fact the presence of calcium in high amount in GGBS and smoother surface texture and glassy surface of GGBS particles increases the compressive strength. After 20% replacement of flyash by GGBS, the workability of concrete was observed to be very stiff and it is very difficult in practical consideration.

B. Split tensile Strength of Concrete

The concrete cylinder specimens were tested in a compressive testing machine having 2000kN capacity for split tensile strength in accordance with the bureau of Indian standard test procedure. The split tensile strength after 28 days for mixes CC, C90F10, C80F20, C70F30, C60F40 ,C50F50, C50F45G5, C50F40G10, C50F35G15 and C50F30G20 are 2.86, 2.69, 2.38, 2.09, 1.90, 1.69, 1.87, 2.11, 2.08 and 2.33 respectively and these values are represented in Fig.5. After 30% replacement of cement by flyash, the concrete achieved the minimum split tensile strength of 1.90 N/mm² (C60F40 mix) and 1.69 N/mm² (C50F50 mix). Hence, the optimum mix is C70F30 (70% cement and 30% flyash) having a split tensile strength of 2.09 N/mm². In order to increase the split tensile strength with minimum percentage of cement (50% binder content) and to obtain an optimum and economical concrete mix, the flyash is replaced by GGBS from 0% to 20%. On addition of GGBS, the split tensile strength of concrete increases from 1.69 N/mm² (50%Cement&50%flyash) to 2.33 N/mm² (50%Cement&30% flyash and 20%GGBS).Hence, the replacement of flyash by GGBS upto 20% increases the split tensile strength.

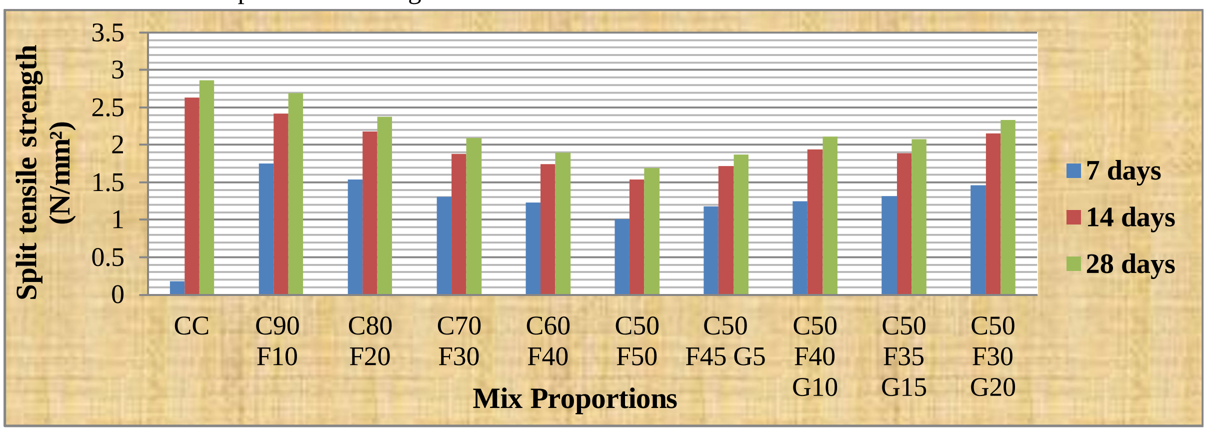

Fig.5. Split tensile strength variation of different concrete mixes

C. Flexural Strength of Concrete

The simply supported concrete prism was loaded by two point loads placed at third point along the span. The load was monotonically increased until flexure failure occurs. Based on the peak load, the peak flexural stress within the prism was calculated. The flexural strength after 28 days for mixes CC, C90F10, C80F20, C70F30, C60F40 ,C50F50, C50F45G5, C50F40G10, C50F35G15 and C50F30G20 are 5.85, 5.67, 5.32, 5.05, 4.81, 4.76, 4.78, 5.10, 5.04 and 5.30 respectively and these values are represented in Fig.6.

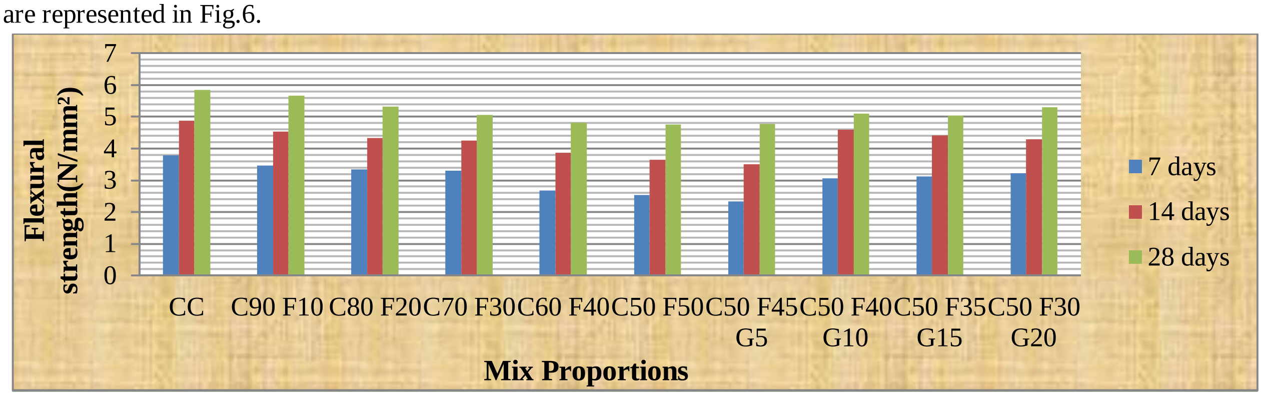

Fig.6. Flexural strength variation of different concrete mixes

The flexural strength test also yields the same inference that partial replacement of cement by flyash decreases the strength values but the replacement of cement by both flyash and GGBS increases the flexural strength of concrete. Hence, the optimum proportions of binder is 50% cement, 30% flyash and 20% GGBS.

IV. CONCLUSION

This project mainly focused on to find out the optimum percentage of flyash and GGBS in cement concrete. Based on the above test results, the following conclusions were arrived.

A. The partial replacement of cement by flyash upto 30% achieved an optimum compressive strength. After 30% replacement of cement by flyash, the concrete achieved the minimum compressive strength which is less than 20 N/mm².
B. Both split tensile and flexural strength of concrete achieved an optimum strength at 30% replacement of cement by flyash. Hence, the optimum percentage of flyash in cement is 30%.
C. The replacement of flyash by GGBS increases the compressive, split and flexural strength upto 20% including workability of concrete is good but thereafter the workability of concrete was observed to be stiff. Therefore, the optimum percentage of GGBS in flyash is 20%. Hence, the binder content proportions of 50% cement, 30% flyash and 20% GGBS achieved an optimum mix and strength.
D. Both flyash and GGBS is found to be feasible alternative binder materials for cement upto 50% partial replacement.

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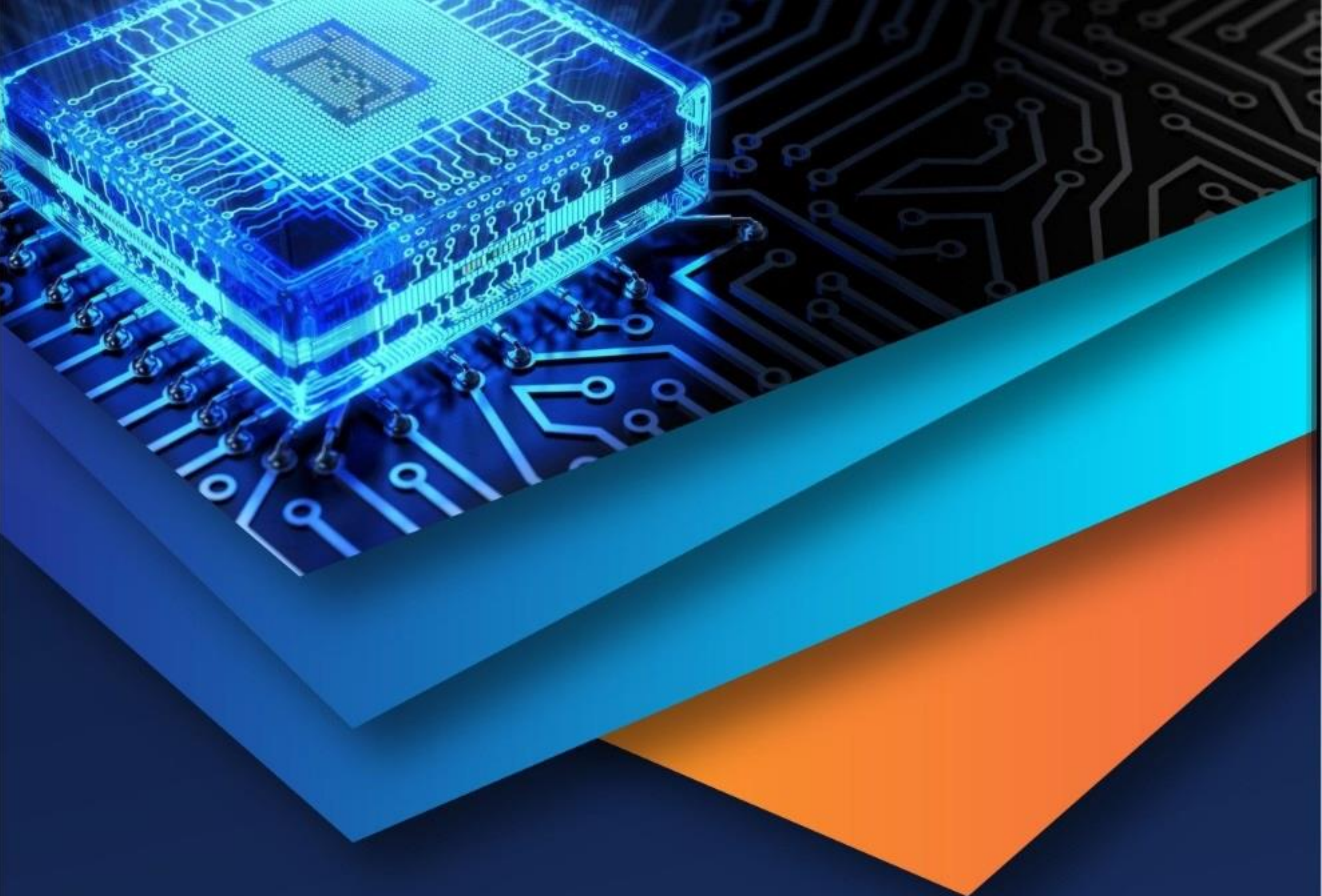

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