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EXPERIMENTAL INVESTIGATION ON COMPRESSIVE STRENGTH OF QUATERNARY CEMENT CONCRETE AND MORTAR

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Abstract— Cement manufacturing involves environmental degrade as it evolves CO2 in to atmosphere. The depletion of natural resource also causes environmental impact. One of the optimum methods to conserve the natural resources and reduce the environmental impact is to use supplementary cementitious materials. In the present study, the SCMs such as fly ash, ground granulated blast furnace slag, and silica fume were used as a partial replacement to cement at 30%, 40% and 50%. Seven concrete and mortar mixtures were designed to study the compressive strength of the quaternary blended mortar and concrete at 3, 7, 28, 56 days. The grade of concrete considered in this study is M40. Quaternary blended concrete mix C60F10G25S5 showed comparative strength in compare with control concrete at 56 days. The quaternary blended mortar mixes C60F10G25S5 and C50F15G30S5 showed higher compressive strength by 3.06% and 3.76% than control mix at the age of 56 days.

Keywords— Quaternary Cement Concrete, Compressive Strength, fly ash, ground granulated blast furnace slag, and silica fume

I. INTRODUCTION

Concrete is most used construction material in the world as it has some diverse properties like ease in casting, good compressive strength, versatility and good durability. The medium consumption of concrete in the world is one tonne by person by year. Cement places a major role in the production of concrete. From environment point of view cement has negative impact, since the manufacturing of cement emits about a tonne of greenhouse gas (CO2) into atmosphere for every tonne of cement manufactured. The cement industry requires lot of energy, exploitation of raw materials and quarrying & high cost for production, thus arising a need to find an effective way to reduce cement demand.

Over the past few decades cement manufacturers have been under increasing pressure to reduce the extent of their environmental hazards in particular harmful to the atmosphere. One of the effective ways to reduce the cement content in concrete is to use supplementary cementitious materials (SCMs) by replacing OPC in concrete. Thus the supplementary cementitious materials retain the same strength as that of normal concrete even after replacement to cement. Significant research has been done on binary and ternary blended concrete.
The results of blending of cement with SCMs have shown many advantages like reduction in cement content in the construction industry recycle and reuse of waste materials, increasing the strength and durability properties, finally reducing the green house gases and save the environment. In the present study the cement replacement is up to 50% by SCMs at different proportions and parameters studied were physical properties of cement mortar and compressive strength of quaternary blended concrete and compared with control concrete.

I. LITERATURE REVIEW

Naitik Patel et al, [2016], investigated the effects of using supplementary cementitious materials (SCM) in binary and quaternary blends on characteristic compressive strength of M40 grade concrete. A total of 8 concrete mixtures were designed having a constant water/cement ratio of 0.34 with a control mix in both binary and quaternary blends. They studied the compressive strength of binary and quaternary blended concrete at 7 and 28 days and compared with normal concrete. The results showed that 70% O.P.C. 15% F.A. 7.5% S.F. 7.5% GGBS has given more compressive strength than other replacements. The authors concluded that the quaternary mix gives better early strength than binary blend.

Niragi Dave et al [2016] studied the experimental analysis of strength and durability properties of quaternary cement binder and mortar. The fly ash, GGBS, silica fume, metakolin and lime stone powder were used as SCMs at 30% and 50% replacements.Water-binder ratio was kept constant as 0.5 for both binder and mortar. Normal consistency, setting time, density, water absorption and compressive strength (at ages of 3, 7, 28, 56 and 90 days) tests studied on quaternary binders. The quaternary cement mortars mixes considered for mortar were 1:3, 1:4, 1:5 and 1:6. The compressive strength of binary mortar (OPC 50% + FA 50%) in 1:3 and 1:4 at 90 days is higher than that of the control mortar. In quaternary cement mortar, the use of GGBS resulted significant increase in compressive strength by increasing the percentage of replacement and also there was a drop in compressive strength when 20% of SF was added with GGBS, MK and LP.

Shrihari et al, [2016] studied the cementing efficiency of binary, ternary and quaternary blended high strength self-compacting concrete. By using the OPC was kept constant as 52% and the remaining 48% replaced with SCMs such as fly ash, metakaolin and micro silica in binary & quaternary blended concretes. The authors work also includes the experimental study to evaluate the synergic effects of Metakaolin, Micro Silica and Fly ash combinations on compressive strength of hardened Quaternary blended high strength SCC of M80 grades at 3, 7, 28, 60, and 90 days. The results revealed that FA based binary, ternary, and quaternary blended SCC systems achieved almost the same compressive strength at 90 days as that of 100% OPC concrete. In ternary blended M80 grade SCC system, for OPC+FA+MS and OPC+ FA+MK combinations, compressive strengths comparable to that of 90 days target strength of 100% OPC high strength grade SCC can be achieved.

Hassan et al,[2013] investigated the performance of high-strength flowable concrete (HSFC) made with binary, ternary, or quaternary binder and with up to 70% of Portland cement replaced by supplementary cementitious materials (SCMs). Class C and class F fly ash, ground granulated blast furnace slag, and silica fume were used as alternative materials. A total of sixteen concrete mixtures were prepared and tested for compressive strength of concrete at the age of 1, 7, 28 and 90days and shrinkage of concrete at the age of 7, 28 and 90 days. One set was cured under normal curing conditions (i.e. in a conventional curing room until the day of testing or in the curing room for the first 7 days and air cured for the remaining of the study) with a water binder ratio of 0.3 and the second set was cured in the curing room for the first 7 days and then exposed to a temperature of 46^0C (115^0F) in the oven on a 12-h based cycles until testing with a water binder ratio of 0.33. They concluded 28-day compressive strength of concrete.

III. MATERIAL CHARACTERIZATION

A. *Cement*

Ordinary Portland cement (OPC), 53 Grade confirming to Indian standard IS: 12269-1987[8]was used in making cement concrete and mortar. The physical properties of cement are shown in Table 1.

TABLE 1: Physical Properties of OPC 53 Grade Cement

S.No	Properties	Test Results
1	Standard Consistency	33%
2	Initial Setting Time	120min
	Final Setting Time	240min
3	Soundness	2.33
4	Specific Gravity	3.15
5	Fineness	7.9%
6	Compressive strength, MPa	
	3 days	30.10
	7 days	38.20
	28 days	50.23

B. *Fine aggregate*

The fine aggregate used for this investigation confirms to grading zone-II as per IS: 383-1970 [10]. The specific gravity was found to be as 2.62 and water absorption was 0.4%.

C. *Coarse aggregate*

The Coarse aggregate used for this investigation confirming to Indian standard IS: 2386-1963.The specific gravity of CA was found to be 2.64 and 2.76 for 20mm and 10mm aggregates respectively. The water absorption was found to be 0.3% and 0.4% for 20mm and 10mm aggregates respectively.

D. *Ground Granulated blast furnace slag*

Ground Granulated blast furnace slag used in this project from Vizag Steel Plant, Visakhapatnam. The specific gravity of GGBS was found to be as 2.1 and fineness was 4%.(IS 3812-2003).

E. *Fly Ash*

Fly ash used in this experimental work was obtained from National Thermal Power Corporation (NTPC), Visakhapatnam.The specific gravity of fly ash was found to be as 2.2 and fineness was 5%.(IS 3812-2003).

F. *Silica Fume*

The Silica Fume used in this work was supplied from BTL industries, Autonagar, Visakhapatnam. The specific gravity of GGBS was found to be as 2.2 and fineness was 4%.(IS 15388 – 2003).

G. *Water*

Fresh potable water confirming to IS: 456-2000[12] was used for casting and curing.

H. *Mix proportions*

TABLE 2: Mix proportions for quaternary blended concrte

Mix No.	Mix Designation	Cement Kg/m^3	GGBS Kg/m^3	Fly ash Kg/m^3	SF Kg/m^3	FA Kg/m^3	CA Kg/m^3	W/c ratio
1	C100	365	0	0	0	704	1237	0.42
2	C70 FA10 GGBS15 SF5	255.5	36.5	54.75	18.25	704	1237	0.42
3	C70 FA15 GGBS10 SF5	255.5	54.75	36.5	18.25	704	1237	0.42
4	C60 FA10 GGBS25 SF5	219	36.5	91.25	18.25	704	1237	0.42
5	C60 FA25 GGBS10 SF5	219	91.25	36.5	18.25	704	1237	0.42
6	C50 FA10 GGBS30 SF5	182.5	36.5	109.5	18.25	704	1237	0.42
7	C50 FA30 GGBS10 SF5	182.5	109.5	36.5	18.25	704	1237	0.42

IV EXPERIMENTAL PROGRAMME

COMPRESSIVE STRENGTH TEST OF CONCRETE

In this investigation, the concrete specimens of size 150 mm x 150 mm x 150 mm and mortar cube specimens of size 70.6 mm x 70.6 mm x 70.6 mm of all the multi blended mixes are tested in accordance with IS: 516- 1959. The testing was done on an automatic compression testing machine of 2000 KN capacity. The specimens which are casted are tested on 3, 7, 28 and 56 day

Figure 1: Compressive strength test machine

V RESULTS AND DISCUSSION

Compressive strength of quaternary blended concrete

Table 3shows the compressive strength of OPC concrete and quaternary blended concrete at 3, 7, 28 and 56 days. At early ages of 3 and 7 days, the mix C70F10G15S5 showed the30% & 17% lower strength than the control concrete, but

at 56 days the strength of mix C70F10G15S5 reached 98% of control concrete. Also the mix C70F15G10S5 showed decrease in strength of 32% and 18% at the age of 3 and 7 days when compared to control concrete, but at 56 days the strength of mix C70F15G10S5 is 98% of control concrete.

Mix C60F10G25S5 (60%OPC, 10%FA, 25%GGBS, 5%SF) reached same strength as that of control concrete at the age of 56 days. From all different mixture proportions made of quaternary blended concrete, C60F10G25S5 is found to be optimum mix. At early age, all the mix proportions quaternary mixes showed the lesser strength when compared with control concrete.

Figure 2: failure of 100% OPC concrete and quaternary blended concrete with 30% replacement

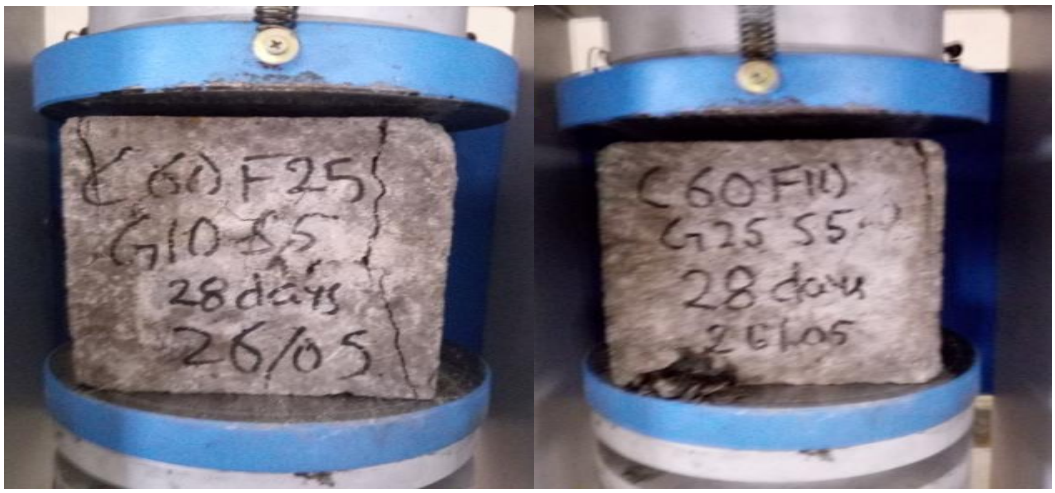
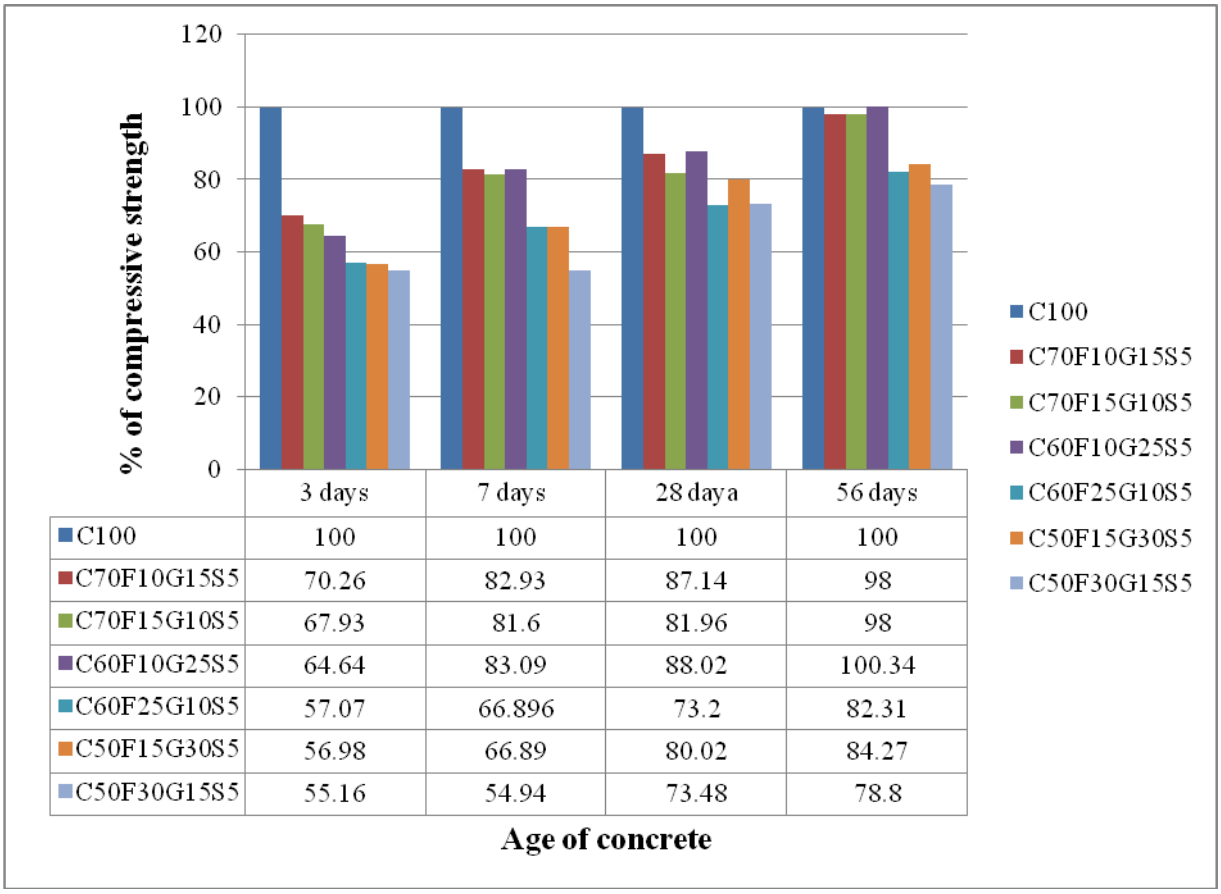


Figure 3: Failure of quaternary blended concrete with 40% replacement

TABLE 3: Compressive strength of quaternary blended concrete

Mix designation	Compressive strength, MPa			
	3 days	7 days	28 days	56 days
C100	42.17	44.3	54.22	56.69
C70F10G15S5	29.63	36.74	47.26	55.56
C70F15G10S5	28.65	36.15	44.44	55.56
C60F10G25S5	27.26	36.81	47.72	56.89
C60F25G10S5	24.07	29.63	39.7	46.67
C50F15G30S5	22.04	29.63	43.41	47.78
C50F30G15S5	23.26	24.33	39.85	44.67



	3 days	7 days	28 daya	56 days
C100	100	100	100	100
C70F10G15S5	70.26	82.93	87.14	98
C70F15G10S5	67.93	81.6	81.96	98
C60F10G25S5	64.64	83.09	88.02	100.34
C60F25G10S5	57.07	66.896	73.2	82.31
C50F15G30S5	56.98	66.89	80.02	84.27
C50F30G15S5	55.16	54.94	73.48	78.8

Figure 4: Variation in Percentage of Compressive Strength with respect to Control Concrete

Compressive strength of quaternary blended mortar

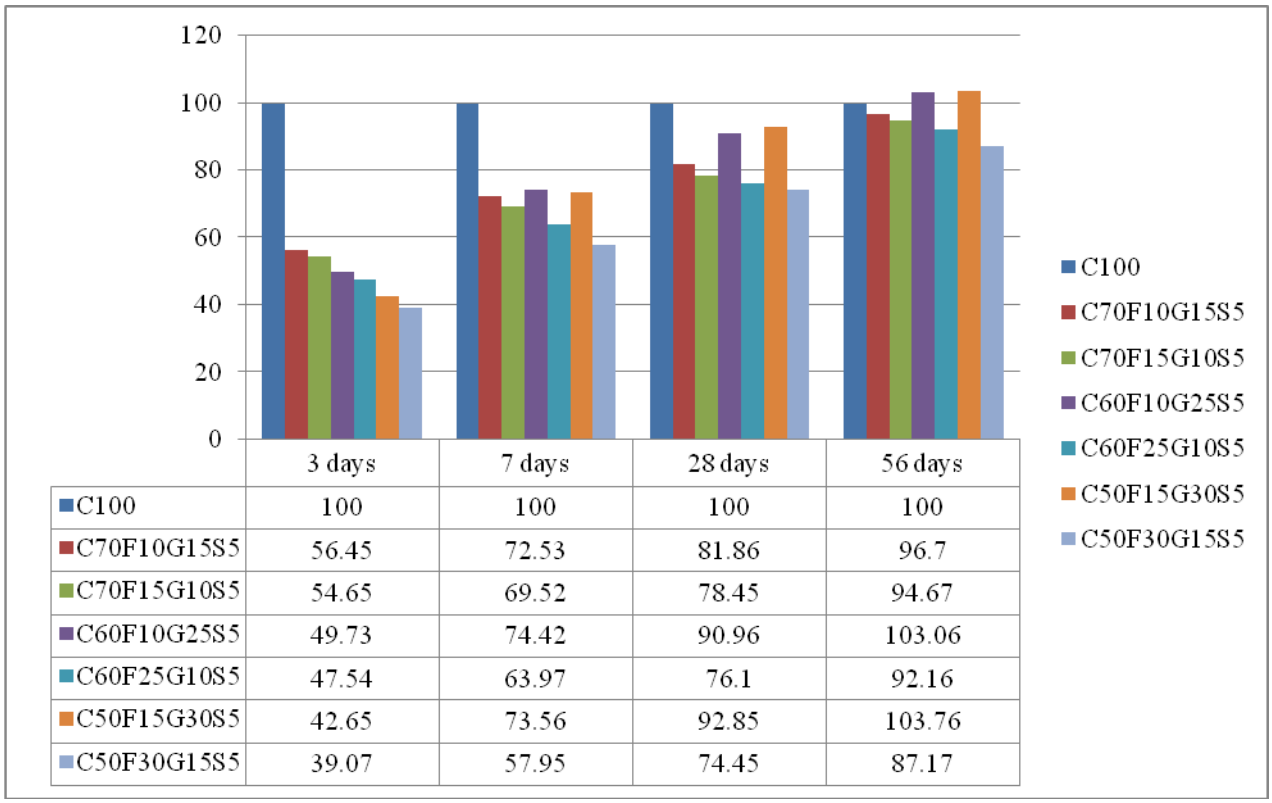
The compressive strength of all the mixes at all ages was found to decrease with increase in percentage of fly ash. Fly ash is generally known to decrease the mechanical properties of mortar at early age. At all ages (i.e, 3, 7, 28 and 56 days), the mixesC60F25G10S5 and C50F30G15S5 found to have lower strengths than all other mixes. At the age 28 days it was observed that the mix C60F25G10S5 and C50F30G15S5 showed decrease in compressive strength about24% and 26% to that of control concrete but at 56 days both the mixes showed increase in strength about 8% and 13% to that of control concrete.

The percentage compressive strength increases with increases in percentage replace of cement with GGBS. The compressive strength of mix C60F10G25S5 with 25% GGBS, showed decrease in strength up to 50%, 25%, and 9% at 3, 7, and 28 days respectively when compared to control concrete and at 56 days, the compressive strength increased by 3.06% in comparative to control concrete.

At 3, 7, and 28 days the compressive strength of the quaternary mix C50F15G30S5 with 30% GGBS replacement showed decrease in strength by 58%, 26%, and 7%respectively to that of control concrete. At 56 days the margin reduced to 3.76%. At early ages the 30% replacement mixes is performed as same as 40% and 50% replacements. At long term the strength of mortar C70F10G15S5 andC70F15G10S5 is similar to control mortar.

Figure 5: Compressive strength and failure of 40% replacement of cement with SCMs in quaternary mortar

Table 4: Compressive strength of 1:3 binder - sand mortars				
Mix designation	**Compressive strength, MPa**			
	3 days	7 days	28 days	56 days
C100	30.1	38.2	50.23	53.1
C70F10G15S5	16.99	27.71	41.12	51.35
C70F15G10S5	16.45	26.56	39.41	50.27
C60F10G25S5	14.97	28.43	45.69	54.73
C60F25G10S5	14.31	24.44	38.23	48.94
C50F15G30S5	12.84	28.1	46.64	55.1
C50F30G15S5	11.76	22.14	37.40	46.29



	3 days	7 days	28 days	56 days
C100	100	100	100	100
C70F10G15S5	56.45	72.53	81.86	96.7
C70F15G10S5	54.65	69.52	78.45	94.67
C60F10G25S5	49.73	74.42	90.96	103.06
C60F25G10S5	47.54	63.97	76.1	92.16
C50F15G30S5	42.65	73.56	92.85	103.76
C50F30G15S5	39.07	57.95	74.45	87.17

Figure 6: Variation in Percentage of Compressive Strength with respect to Control Mortar

VI CONCLUSIONS

This study investigated the behaviour of quaternary blends after incorporating FA, GGBS and SF. The experimental results shown that the addition of supplementary cementitious materials, such as, FA, GGBS and SF in cement affects the properties of concrete mortar. Based on the test results, the following conclusions were be drawn

1. The compressive strength of quaternary blended concrete increased with the addition of pozzolanic materials at long term durations. The mixes C70F15G10S5 and C70F10G15S5 performed better than other mixes.
2. The compressive strength of quaternary concrete with mix C60F10G25S5 was increased by 0.34% at 56 days. From the results it was concluded that the cement replaced between 30- 40% with SCMs is performed better at long term durations.
3. The compressive strength of quaternary blended mortar decreased with increase in fly ash replacement.
4. Based on the compressive strength results, the ordinary portland cement can be better replaced with C60F10G25S5 or C50F15G30S5.
5. The percentage increase in strength for C60F10G25S5 and for C50F15G30S5 are 3.06% and 3.76% respectively at 56 days.
6. Quaternary blend is a very good option, which has some limitations. And there is substantial saving in quantity of cement, through which the environmental degradation is reduced.

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