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Effect of Quaternary Binder Systems on Mechanical Properties of Concrete

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Abstract

This paper presents the results of an experimental study on the effect of mechanical behavior of quaternary cementitious system prepared from a mixture of cement additives. Fly ash (FA), blast furnace slag (BFS), metakaolin (MK) and silica fume (SF) were added simultaneously in different proportions by replacing 50% and 30% of Portland cement (PC) by weight. Tests were carried out to characterize the mechanical behavior of binary and quaternary blended concretes at 7, 28, 56, 90, 180 and 365 days. In this study the quantification parameters of strength of quaternary blended system are compressive strength test, tensile strength and flexural strength test. The synergistic action of the cement additives has a positive effect vis-a-vis the mechanical properties of the mix combinations with quaternary binders are better than that of the control concrete. Test results showed that the incorporation of FA, SF and BFS/MK as partial replacement to the PC resulted in improved mechanical properties of hardened concrete.

Keywords: cement additives, compressive strength, flexural, fly ash, metakaolin

1. INTRODUCTION

The use of mineral additives as partial replacement to Portland cement in concrete is a better step towards sustainable development because of their technological, economic, and environmental benefits. Inert and pozzolanic cement additives modify the properties of concretes by their physical and chemical activities. When the cement additives are added, three effects can be quantified including, filler, heterogeneous nucleation and pozzolanic reaction depending on the amount and solubility of amorphous silica. The filler action involves incorporating additives/mineral admixtures that are finer than the PC, so that these occupy small pores previously left vacant. Heterogeneous nucleation is a physical process leading to the chemical activation of hydration of PC such that the cement addition particles act as nucleation centers for the hydrates, thus enhancing cement hydration (1). Pozzolanic action takes place between the amorphous silica of the cement additive and the calcium hydroxide/portlandite (CH) produced by the cement hydration reactions to produce non-water-soluble calcium silicate hydrates (C-S-H). As the density of C-S-H is lower than that of CH and pure silica, a consequence of this reaction is a swelling of the reaction products. Concrete should be resistive from all weathering actions, therefore mechanical, durability and microstructure study of concrete should be considered [2-4]. The use of mineral additions such as limestone fillers, blast furnace slag and natural pozzolana improves the resistance of concrete to the attack of aggressive agents (sulfuric acid), because they reduce the presence of calcium hydroxide, which is the most vulnerable component to acid attacks (5).The slag has several advantages in the manufacture of cement. First, it has a relatively constant chemical composition compared to fly ash, silica fume, natural pozzolana etc. In addition, it has other advantages such as, low heat of hydration, resistance to acids and sulfates, better workability, and higher ultimate strength (6-8).

The cements standards allow only the introduction of only small quantities (less than 5%) of secondary components, in cements. The main objective of this research is to achieve information about the effect of the simultaneous incorporation of fly ash, blast furnace slag, metakaolin and silica fume as partial replacement to the Portland cement on the sulphate resistance and chloride ion resistance of concretes.

2. Materials and Methods

The properties of different materials used were determined in the laboratory as per relevant codes of practice. The materials used in this research programme are PC (53 Grade), crushed gravel as coarse aggregates and natural sand as fine aggregates. The cement additives, which were used as partial replacement of PC to produce binary and quaternary mixes, are FA, BFS, MK and SF. Ordinary Portland cement of 53 grade satisfying the requirements of IS: 8112-1989 was used in the study. The physical properties of the cement and cement additives as determined from various tests conducted are listed in Table-1. Figure-1presents the particle size distribution of all powders used in the study. Table 3 presents the slump test results of all fresh concretes prepared in this investigation.

Table 1 Physical and chemical properties of the PC, FA, SF, MK and BFS.

Description	**PC**	**FA**	**BFS**	**SF**	**MK**
Physical Characteristics					
Specific gravity	3.13	2.26	2.86	2.23	2.51
Blaine's Fineness, cm^2/gm	2285	3720	3250	16018	8735
Compositions					
CaO	67.81	2.01	36.80	1.28	1.56
SiO_2	18.58	62.32	41.55	88.31	51.48
Al_2O_3	9.92	26.18	16.21	0.89	47.83
Fe_2O_3	3.01	3.40	0.69	1.60	0.39
MnO	0.03	0.02	0.04	0.00	0.00
MgO	1.34	2.70	3.56	0.15	0.10
K_2O	0.49	0.99	0.68	1.98	0.19
Na_2O	0.23	0.06	0.20	0.40	0.07
LOI	0.88	2.98	1.09	2.00	0.56

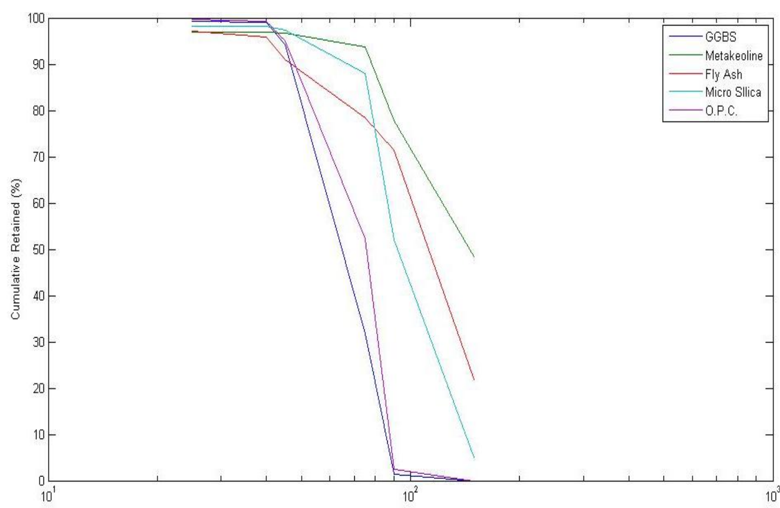

Figure-1 Particle size distribution of all powders used in the study.

The present investigation on the strength performance of mix combinations containing BFS, FA, MK and SF as cement additives in different proportions, involved preparing twelve mixes - control concrete (100% PC); binary blended mix combinations (70% PC + 30% FA) and (50% PC + 50% FA)'; quaternary blended mix combinations (70% PC + 20% FA + 5% SF + 5% BFS); (70% PC + 15% FA + 7.5% SF + 7.5% BFS); (50% PC + 30% FA + 10% SF + 10% BFS) and (50% PC + 20% FA + 15% SF + 15% BFS); (50% PC + 15% FA + 20% SF + 15% BFS); (70% PC + 20% FA + 5% SF + 5% MK); (70% PC + 15% FA + 7.5% SF + 7.5% MK; (50% PC + 30% FA + 10% SF + 10% MK); (50% PC + 20% FA + 15% SF + 15% MK) and(50% PC + 15% FA + 20% SF + 15% MK). The mix combinations incorporating cement additives were prepared by replacing 30% and 50% of PC by weight with these additives in binary and quaternary mode.

Table-2 summarizes the mix proportions used in this investigation. Table-3 presents slump test measurements of all mix combinations.

Table-2: Concrete mix combinations used in the present investigation.

MIX	Weight of constituents (kg) of concrete (M40)								
	OPC	PFA	SF	BFS	Water	Admixture	FA	CA (10mm)	CA (20mm)
100% Control	440	-	-	-	167	2.64	677	391	839
70% OPC + 30% FA	308	132	-	-	167	2.64	621	394	838
50 % OPC + 50 % FA	220	220	-		167	2.64	647	374	803
70%OPC + 20%FA + 5%SF + 5% GGBS	308	88	22	22	167	2.64	613	419	851
70% OPC + 15% FA + 7.5% SF + 7.5% GGBS	308	66	33	33	167	2.64	613	420	850
50% OPC + 30%FA + 10% SF + 10% GGBS	220	132	44	44	167	2.64	603	419	851
50%OPC+ 20%FA + 15%SF + 15% GGBS	220	88	66	66	167	2.64	603	419	851
50%OPC + 15%FA + 20% SF + 15% GGBS	220	66	88	66	167	2.64	603	419	851
70%OPC + 20%FA + 5%SF + 5%MK	308	88	22	22	167	2.64	568	409	880
70%OPC + 15%FA + 7.5% SF + 7.5% MK	308	66	33	33	167	2.64	577	415	893
50%OPC + 30%FA + 10% SF + 10%MK	220	132	44	44	167	2.64	560	403	867
50%OPC + 20%FA + 15%SF + 15% MK	220	88	66	66	167	2.64	560	403	867
50%OPC + 15%FA + 20% SF + 15% MK	220	66	88	66	167	2.64	560	403	867

Compressive strength was measured as per I.S. 516-1959 using 200 T capacity universal testing machine using standard 150 X 150 X 150 mm cubes. The load was applied at the rate of14 N/mm2/minute, approximately. The average of three specimens was taken as the representative value of compressive strength of each batch of concrete.

Split tensile test was carried out as per IS: 5816-1999. Concrete cylinders of size 150 mm diameters and 300 mm height were casted. During casting, the cylinders were mechanically vibratedusing a table vibrator. After 24 h, the specimens were removedfrom the mould and subjected to water curing for 28 days. After the specified curing period was over, the concrete cylinders were subjected to split tensile test by using universal testing machine. Tests were carried out on triplicate specimens and the average split tensile strength values were recorded.

Flexure strength was measured using standard 100 X 100 X 500 mm beam specimens, simply supported on an effective span of 400 mm and loaded at the third points after 90 days of curing. The test was carried out as per IS: 516-1959 (Reaffirmed 2004).

Table-3: Slump results of all mix combinations

Mix Combinations	Slump (mm)
100% Control	110
70% OPC + 30% FA	130
50 % OPC + 50 % FA	140
70%OPC + 20%FA + 5%SF + 5% GGBS	102
70% OPC + 15% FA + 7.5% SF + 7.5% GGBS	115
50% OPC + 30%FA + 10% SF + 10% GGBS	175
50%OPC+ 20%FA + 15%SF + 15% GGBS	170
50%OPC + 15%FA + 20% SF + 15% GGBS	190
70%OPC + 20%FA + 5%SF + 5%MK	140
70%OPC + 15%FA + 7.5% SF + 7.5% MK	145
50%OPC + 30%FA + 10% SF + 10%MK	143
50%OPC + 20%FA + 15%SF + 15% MK	142
50%OPC + 15%FA + 20% SF + 15% MK	145

3. RESULTS and DISCUSSION

3.1 Compressive Strength Test

The averaged compressive strength results of cube specimens of each batch of different concrete cubes were measured at 7, 28, 56, 90, 180 and 365 days of curing are presented in Figs. 2 and 3. It was observed that the compressive strength of all mix combinations increases continuously over time. At all ages, the strength of quaternary concretes is more than that of the control concrete. Quaternary mix combinations (50% PC +30% FA+ 10% SF+ 10% MK), (50% PC +30% FA+ 10% SF+ 10% BFS), (70% PC +15% FA+ 7.5% SF+ 7.5% MK) and (70% PC +20% FA+ 5% SF+ 5% MK) has shown best performance amongst others at higher ages. The increase in the strength of concretes containing cement additives is attributed to the reaction of silicates of mineral additives with released lime to form additional C–S–H that contribute to the development of compressive strength.

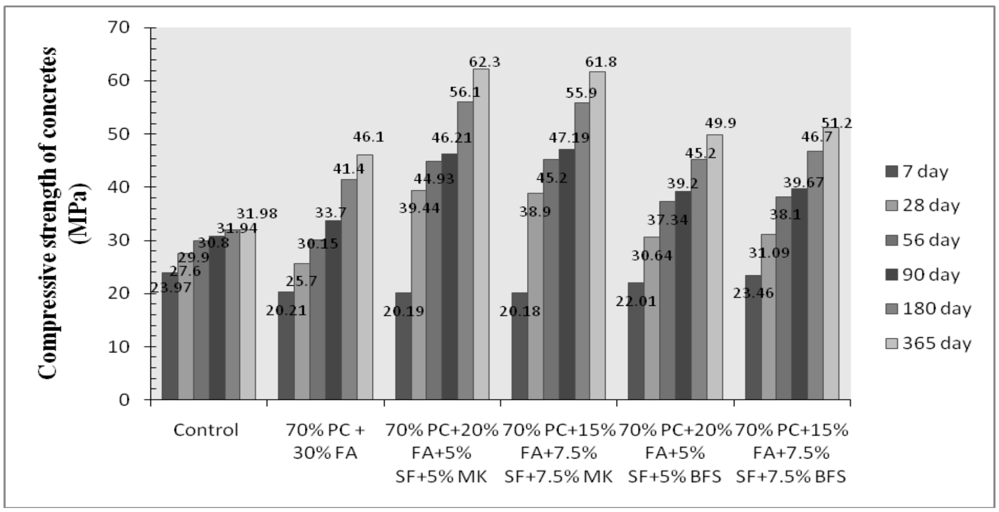

Fig: 2. Compressive strength results of (M 40) concretes containing 30% of mineral admixtures

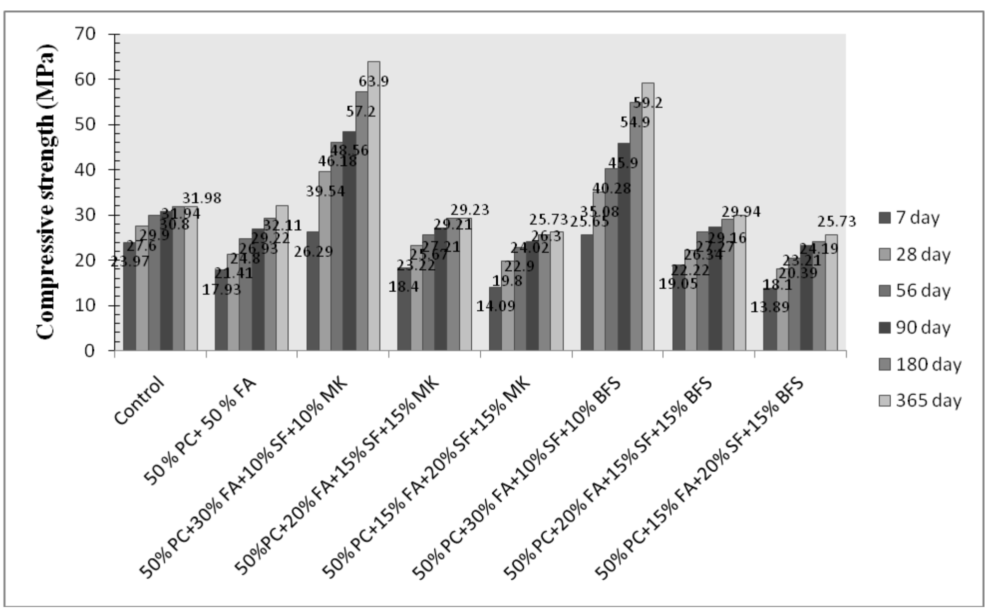

Fig: 3. Compressive strength results of (M 40) concretes containing 50% of mineral admixtures

3.2. Tensile Strength Test

It was also observed that the tensile strength of all mix combinations increases over time as evident in Figs. 4 and 5. In few cases, i.e. (70% PC +20% FA+5%SF+5%MK), (70% PC +15% FA+7.5% SF+ 7.5% MK), (50% PC +30% FA+10%SF+10%MK) and (50% PC +30% FA+10%SF+10%GGBS) shown good tensile strength. From the observed test results the effect of using mixcombinations of supplementary cementitious materials in quaternary mixtures on the tensile strength is clear, almost similar behavior was observed with the 30% replacement of OPC with supplementary cementitious materials.

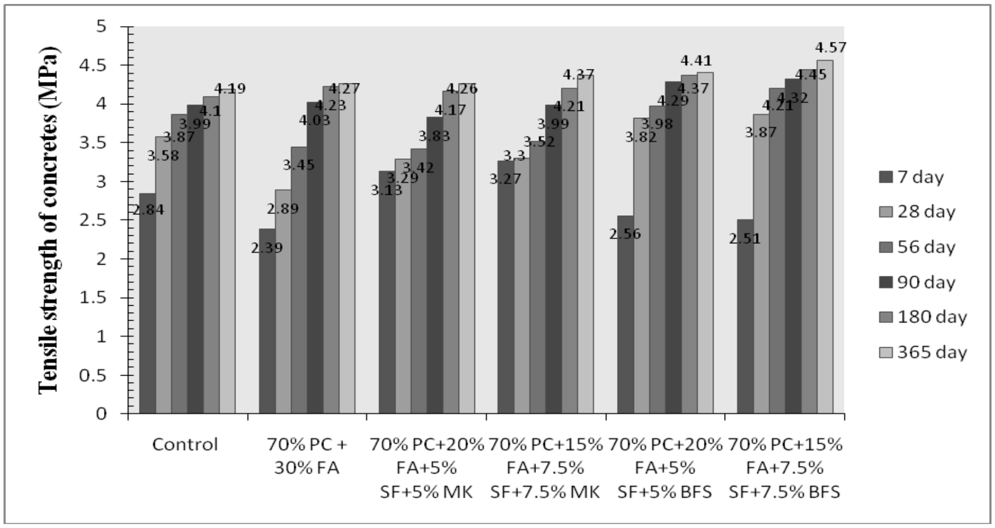

Fig: 4. Tensile strength results of (M 40) concretes containing 30% of mineral admixtures

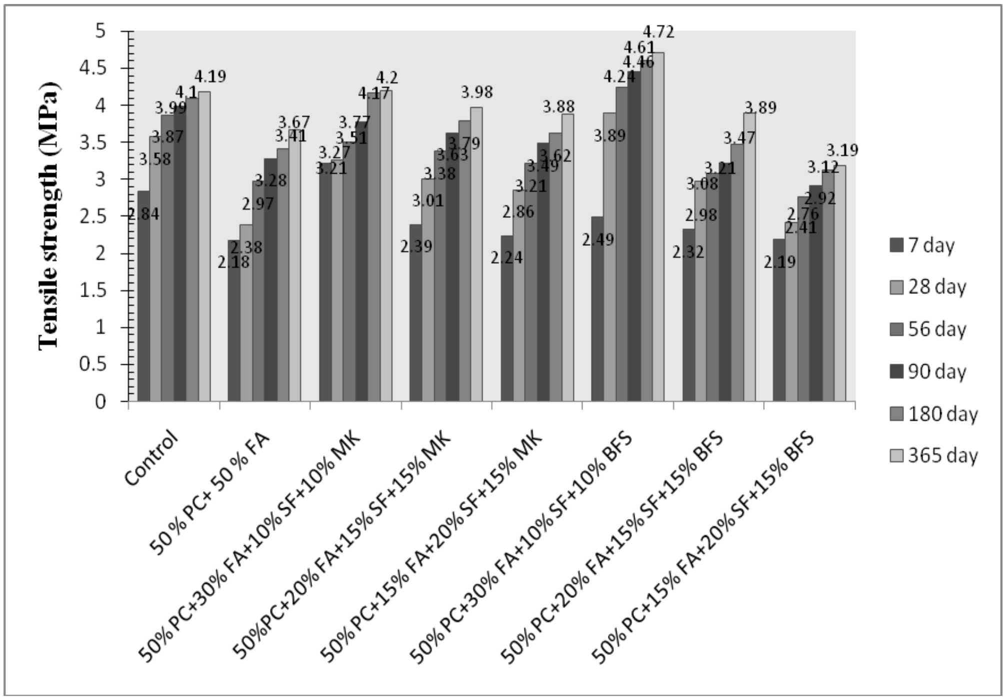

Fig: 5. Tensile strength results of (M40) concretes containing 50% of mineral admixtures

3.3. Flexural Strength Test

Figs. 6 and 7 shows the static flexural strength test results of allquaternary concretes at given test days. Quaternary mix combinations containing FA, SF and MK have shown best performanceamongst others at higher ages at 30% of mineral admixtures. Mix8 and mix 11 (50% OPC + 30% FA + 10% SF + 10% MK/GGBS) hasshown best flexural strength among other proportions. Also, it was observed that 50% replacement of OPC with supplementary cementitious materials shows better performance as compare to 30% replacement.

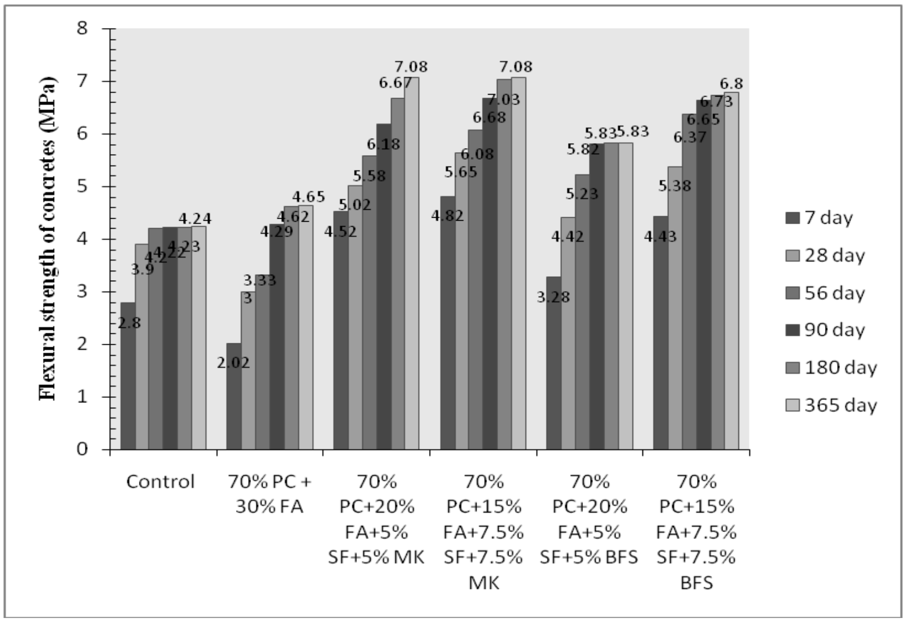

Fig: 6. Flexural strength results of (M 40) concretes containing 30% of mineral admixtures

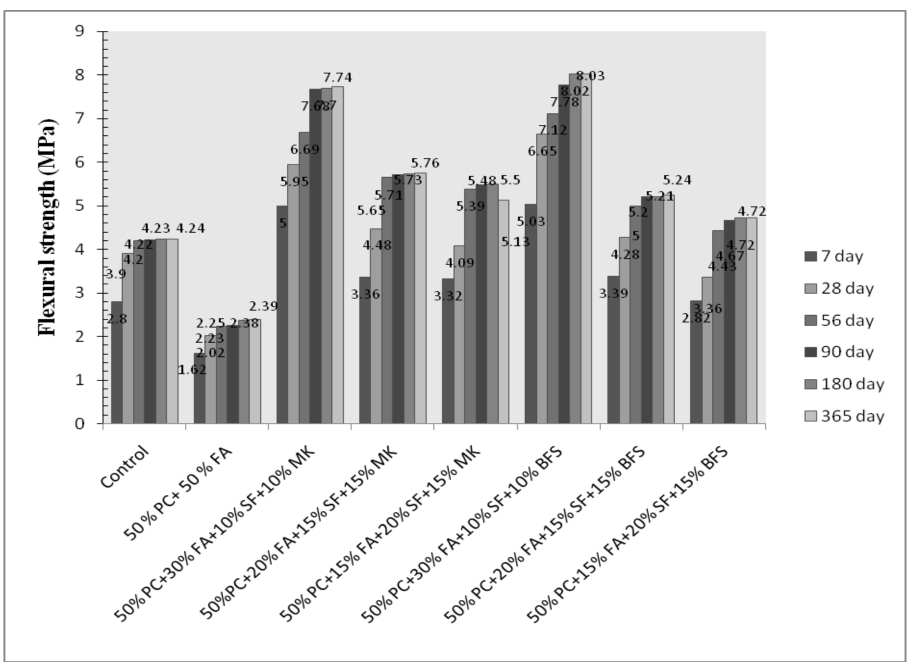

Fig: 7. Flexural strength results of (M40) concretes containing 50% of mineral admixtures.

4. Conclusion

This study investigates the behavior of quaternary concrete after incorporating FA, SF, GGBS and MK. The experimental results revealed that the addition of supplementary cementitious materials, such as, FA, SF, GGBS and MK in cement affects the properties of concrete. Based on the test results, the following conclusions can be drawn:

1. The compressive strength of quaternary concrete increases with the addition of pozzolanic materials and the improvement of strength indicates that the pozzolans are more effective with low water/binder ratio. The quaternary concrete with (50% OPC + 30% FA + 10% SF + 10% MK) and (50% OPC + 30% FA + 10% SF + 10% GGBS) have shown the best results in terms of a good compressive strength.
2. In all cases, the flexural strength and tensile strength of quaternary concrete have shown acceptable results. The optimum Mix 8 and Mix11 have shown 25% and 10% higher flexural strength as compare to control mix and around 11.9% and 11.2% higher tensile strength than control mix at the age of 365 days.
3. Quaternary concrete could be the best substitute of OPC concretes. It's utilization in construction may help in reducing the burden on natural raw materials used in OPC and promote the utilization of waste materials in construction.

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