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Study on quaternary concrete micro-structure, strength, durability considering the influence of multi-factors

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HIGHLIGHTS

- Quaternary concrete micro-structures.
- Quaternary concrete strength and durability.
- Supplementary cementitious materials like silica flume, GGBS, Metakaolin, Fly ash.
- Rapid Chloride Permeability Test (RCPT) and sulfate attack.
- Development of new quaternary concrete.

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ABSTRACT

Experimental study on the effect of mechanical behavior of quaternary binders, prepared using various supplementary cementitious materials was performed. Fly ash (FA), Ground Granulated Blast furnace Slag (GGBS), Metakaolin (MK) and Silica Fume (SF) were blended in pre-determines proportions by replacing 30–50% of Ordinary Portland Cement (OPC) by weight. The water/binder ratio and total cementitious materials for pre-decided M40 grade quaternary mix were kept constant for all mixes at 0.40 and 440 kg/m^3, respectively. Tests were carried out to characterize the mechanical behavior of quaternary blended concretes at 7, 28, 56, 90, 180 and 365 days and results obtained were compared with the corresponding values obtained for controlled concrete (100% OPC) as well as binary mixes (70% OPC:30% FA and 50% OPC: 50% FA). The entire specimen were prepared, cured and tested as per the Indian standard code of practice. In addition to that durability of the quaternary mix was determined via Rapid Chloride Permeability Test (RCPT) and sulfate attack test. The synergistic action of the cement with the addition of supplementary cementitious materials has a positive effect vis-a-vis the durability and in few combinations of mixes strength of the concrete with quaternary binders was found better than that of the controlled and binary mix concrete. Based on the test results, optimum mixes of FA, SF and GGBS/MK as partial replacement to the OPC as quaternary binder would be a better option compare to 100% controlled concrete.

1. Introduction

The use of supplementary cementitious materials as partial replacement to Portland cement in concrete is a better step towards sustainable development because of their technological, economic, and environmental benefits. Addition of inert and pozzolanic materials modifies the physical and chemical properties of concrete by promoting, filling of micro pores, heterogeneous nucleation and pozzolanic reactions which depends on the amount and solubility of the amorphous silica. The filler action involves incorporating supplementary materials that are finer than the OPC, so that these occupy small pores previously left vacant. Heterogeneous nucleation is a physical process leading to the chemical activation of hydration of OPC 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

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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 [1–4].

The use of mineral additions, such as, limestone fillers, ground granulated 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]. By adding pozzolanic materials in concrete, it increases the volume of hydrates and makes structure dense [2,9,10]. Reduction in permeability is that addition of supplementary cementitious materials cause pore refinement which transform the bigger pores into smaller one due to their pozzolanic reaction concurrent with cement hydration [11–13].

The existing standards on cements allow the introduction of small quantities of secondary components, in cements. The main objective of the present study is to achieve information about the effect of simultaneous incorporation of fly ash (FA), ground granulated blastfurnace slag (GGBS), MetaKaolin (MK) and silica fume (SF) as partial replacement to the Ordinary Portland cement (OPC) on the strength and durability of concretes and based on the results to propose an optimum proportion of quaternary mix.

2. Materials and methods

The constituting materials of concrete used in the present study are OPC (53 Grade), crushed gravel as coarse aggregates (with specific gravity 2.67 and aggregate size 10 mm–20 mm) and natural sand as fine aggregates (specific gravity of 2.63 and maximum size of 4.75 mm) confirming to IS:456–2000. The supplementary cementitious materials, which were used as partial replacement of OPC (53 Grade as per IS:8112-1989) to produce binary and quaternary mixes, are FA, GGBS, MK and SF and the relevant properties of these materials were determined in the laboratory as per relevant codes of practice. The physical properties and chemical composition of the cement and supplementary materials, as determined from various tests conducted, are listed in Table 1. Fig. 1 presents the particle size distribution of all mixtures in the binder used in the study. The higher specific surface of GGBS, MK and SF in quaternary concrete will fill all the voids in quaternary concrete and make it denser. Moreover such mix will also help in enhancing the strength and durability of quaternary concretes manifold.

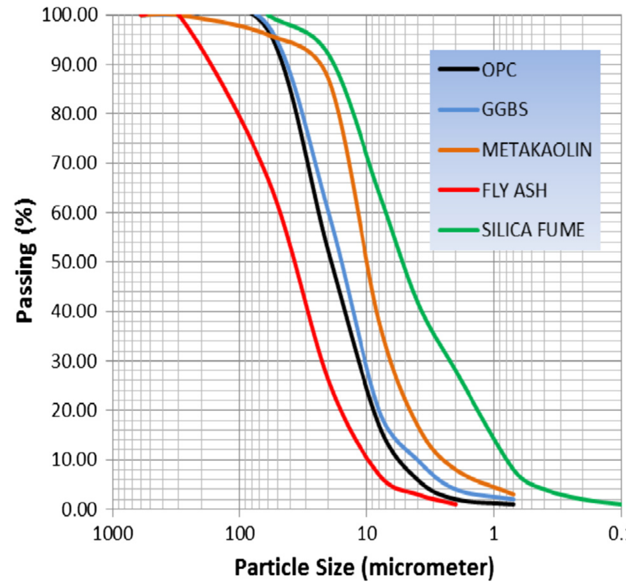

Fig. 1. Particle size distribution of all powders used in the study.

Table 2 presents different various proportions of constituents in controlled, binary and quaternary mixes containing GGBS, FA, MK and SF. The mix combinations incorporating supplementary materials were prepared by replacing 30% and 50% of OPC by weight with these additions in binary and quaternary mode. Table 3 presents slump test measurements of all mix combinations.

Total 936 concrete specimens were casted with each batch comprising of 312 cube specimens of size $150 \times 150 \times 150$ mm for static compressive strength tests, 312 cylinder specimens of size150 X 300 mm for tensile strength and 312 beam specimens of size $100 \times 100 \times 500$ mm for flexural strength tests, respectively. Also, for each mix type, three additional beam specimens were casted for conducting the ultrasonic pulse velocity (UPV), RCPT and sulfate attack tests. All the specimens were demoulded after 24 h and cured under water curing tank.

Compressive strength was measured as per I.S. 516-1959 using 200 T capacity universal testing machine using standard $150 \times 150 \times 150$ mm cubes. The load was applied at the rate of 14 N/mm^2/minute, approximately. The average of three specimens was taken as the representative value of compressive strength of each batch of concrete.

Table 1
Physical and chemical properties of the OPC, FA, SF, MK and GGBS.

Description	FA	OPC	GGBS	MK	SF
Physical characteristics					
Specific gravity (gm/cm^3)	2.26	3.13	2.86	2.51	2.23
[as per IS 4031-11(1988) for OPC and IS 1727-1967 for FA, GGBS, SF and MK]					
Blaine's Fineness, (cm^2/g)	2285	3720	4258	8735	16,018
[as per IS 4031-1(1996) for OPC and IS 1727-1967 for FA, GGBS, SF and MK]					
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