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Binary, Ternary and Quaternary Blends in Self-Compacting Concrete

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Abstract*:- Experimental study on the effect of strength of binary, ternary and quaternary blends of self compacting concrete incorporating different mineral admixtures. In the present study Fly Ash (FA), Silica Fume (SF), ground granulated blast furnace slag (GGBS) and Limestone powder (LP) were blended in pre-determined proportions replacing 20-50% of Ordinary Portland Cement (OPC) by weight. SCC mix of M40 grade is developed by keeping water/binder ratio and total cementitious material constant for all mixes at 0.30 and 600 kg/m^3, respectively. Tests were carried out to characterize the compressive and flexural strength of binary, ternary and quaternary mixes at 7, 14, 28, 56 & 90 days and the obtained results were compared with the correspond values obtained for controlled concrete (100% OPC). The entire specimens were prepared, cured and tested as per Indian Standard code of practice. In addition to that homogeneity of entire specimens was determined via Ultrasonic Pulse Velocity (UPV). Strength of quaternary mix with GGBS was found better than that of the controlled mix concrete. Based on test results, optimum mixes of FA, SF and GGBS with appropriate dosage of superplasticizers (SP) at replacement levels of 30% & 50% of cement gave good results for fresh and hardened properties as compared to controlled concrete.

Keywords:- Self Compacting Concrete; Mineral Admixture; Quaternary Blends;

1. INTRODUCTION

Self – compacting concrete (SCC), also known as Self-consolidating concrete, is a fluid mixture, which is able to flow under its own weightand fill around congested reinforcement whilst maintaining homogeneity, without vibration. SCC was first introduced in the late 1980's by Japanese researcher named Okamura [3]. The main drive for the development of SCC and its research were the endangered durability of reinforced concrete structures, need for easier and high-quality fresh concrete placement and lack of skilled labour force. Self – compacting concrete is not being used in regular construction widely due to relatively high material costand also due to lack of research in the field.

The cost of materials used in preparing SCC is more due to the relatively high demand of cementitious materials and chemical admixtures which includes high – range water reducing admixtures (HRWRA) and viscosity enhancing admixtures (VEA). Adding a large volume of powdered material or viscosity modifying admixture can eliminate segregation. The powdered materials that can be added are fly ash, GGBS, limestone powder, silica fume, etc. Limestone filler also helps in controlling the heat of hydration during mixes that have high PC content. The cost of SCC can be reduced by partial replacement of cement and supplementary cementitious materials by readily available mineral admixtures/fillers. 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 of concrete by promoting, filling of micro pores, heterogeneous nucleation and pozzolanic reactions. 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 [8]. Concrete should be resistive from all weathering actions, therefore mechanical, durability and microstructure study of concrete should be considered [6,8,10-12]. 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 [13].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 [14-16]. The main objective of this research is to achieve information about the effect of the simultaneous incorporation of fly ash, blast furnace slag; limestone powder and silica fume as partial replacement to the Portland cement on the compressive and flexural strength of concrete compare to conventional concrete.

Our project focuses on creating a binary, ternary and quaternary blended Self Compacting Concrete (SCC) of M40 grade with better transport properties and strength similar or better to that when OPC is used. In the present work the initial mix proportion is determined by Indian Standard method of mix design because there is no Standard mix design of SCC mixes, and fine tuned by different guidelines to get the mix which satisfies the required fresh and hardened properties of SCC.

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2. MATERIALS AND METHODS

The basic constituent materials of SCC are similar to those of normal concrete i.e. cement, crushed gravel and sand. The materials used in this research are OPC (53 Grade), crushed gravel as coarse aggregates and natural sand as fine aggregates.The properties of different materials used were determined in the laboratory as per relevant codes of practice.The cement additives, which were used as partial replacement of OPC to produce binary, ternaryand quaternary mixes are FA, GGBS, LP and SF. Ordinary Portland cement of 53 grade satisfying the requirements of IS: 12269-1987 was used in the study. Superplasticizer used in present work is Master Glenium SKY 8784 which is based on second generation Polycarboxylic ether polymers (PCE). Mineral additives used in this project are obtained from local sources. The physical properties of the cement and cement additives as determined from various tests conducted are listed in Table-1.

Description	OPC	FA	GGBS	SF	LP
Physical Characteristics					
Specific gravity	3.17	2.26	2.77	2.17	2.73
Blaine's Fineness, cm^2/gm	2285	3720	3250	16018	4430
Compositions					
CaO	67.81	2.01	41.00	1.28	52.98
SiO_2	18.58	62.32	33.12	88.31	1.84
Al_2O_3	9.92	26.18	18.00	0.89	1.37
Fe_2O_3	3.01	3.40	1.30	1.60	-
MnO	0.03	0.02	0.04	0.00	-
MgO	1.34	2.70	11.60	0.15	0.42
K_2O	0.49	0.99	0.68	1.98	-
Na_2O	0.23	0.06	0.20	0.40	-
LOI	0.88	2.98	0.50	2.00	0.56

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

To summarize, we have taken a binary blend cement at the beginning, with minor replacement of cement by FA(30%), then so as to attain optimum strength which is achieved by standard vibration we added Limestone filler powder to the blend making it a ternary blend [1], and lastly, so as to compensate the lack of silica content we have added silica fume to the blend finally making it quaternary blend. Use of GGBS significantly reduces the risk of damages caused by alkali-silica reaction and also reduces the risk of reinforcement corrosion, providing higher protection against sulphate and chloride attacks [2,21-22]. Silica fume is a highly reactive pozzolana that converts all or most of the liberated calcium hydroxide to Calcium Silicate Hydrate (C-S-H) therefore blending with Silica Fume with increasing replacement shows higher strength than conventional concrete [9]. Limestone Powder acts as filler material which improves the hydration rate and increases the strength of cement compounds at early ages [4,6] and also enhances the transportation properties [7]. Fly Ash, an inorganic noncombustible, finely divided residue collected or precipitated from the exhaust gases from thermal furnace, consists of spherical glassy particles which acts like small balls to reduce inter particle friction hence reducing the heat of hydration, permeability and bleeding; thus, increasing the workability and long-term strength of concrete. The present investigation work on the strength performance of mix combinations containing FA, GGBS, SF and LP as cement additives in different proportions, involved preparing six mixes- Control mix (100% OPC); binary blended mix (80% OPC + 20% FA); ternary blended mix (70% OPC + 25% FA + 5% SF); quaternary blended mix-1 (70% OPC + 15% FA + 7.5% SF + 7.5% GGBS); quaternary blended mix-2 (50% OPC + 30% FA + 10% SF + 10% GGBS); quaternary blended mix-3 (70% OPC + 15% FA + 7.5% SF + 7.5% LP) and quaternary blended mix-4 (50% OPC + 30% FA + 10% SF + 10% LP). In the present work cement is replaced by cement additives by 20%, 30% and 50%.

Table-2 summarizes the mix proportions used in this investigation; Table-3 summarizes slump test and T_{500mm}measurements of all mix combinations.

Mix	Weight of constituents (kg) of concrete (M40)									
	OPC	FA	SF	GGBS	LP	Water	Admixture	FA	CA (10mm)	CA (20mm)
100% OPC	600	-	-	-	-	180	4.20	820	696	174
80% OPC + 20% FA	480	120	-	-	-	180	6.96	820	696	174
70 % OPC + 25 % FA + 5% SF	420	150	30	-	-	180	6.60	820	696	174
70%OPC + 15%FA + 7.5%SF + 7.5% GGBS	420	90	45	45	-	180	6.60	820	696	174
50% OPC + 30% FA + 10% SF + 10% GGBS	300	180	60	60	-	180	6.60	820	696	174
70% OPC + 15%FA + 7.5 % SF + 7.5% LP	420	90	45	-	45	180	6.60	820	696	174
50%OPC+ 30%FA + 10%SF + 10% LP	300	180	60	-	60	180	6.60	820	696	174

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

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After the specimens are casted,all the specimens are stored in laboratory at a room temperature for 24 hours. The specimens are then removed from the mouldsafter 24 hours and immediately submerged in clean, fresh water of curing water tank. The specimens are cured for 7 days, 14 days, 28 days, 56 days and 90 days in present investigation work.Compressive strength was measured as per I.S. 516-1959 using compressive 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.Flexural strength was measured using standard 150 X 150 X 700 mm beam specimens, simply supported on an effective span of 600 mm and loaded at the third points.

S.No.	SCC Mix	Composition	Slump	$T_{500\,mm}$
1.	Control	100% OPC	590 mm	4.9 sec
2.	Binary	80% OPC + 20% FA	662 mm	4.6 sec
3.	Ternary	70 % OPC + 25 % FA + 5% SF	725 mm	4.1 sec
4.	Quaternary	70%OPC + 15%FA + 7.5%SF + 7.5% GGBS	775 mm	3.9 sec
5.	Quaternary	50% OPC + 30% FA + 10% SF + 10% GGBS	783 mm	3.6 sec
6.	Quaternary	70% OPC + 15%FA + 7.5 % SF + 7.5% LP	778 mm	3.8 sec
7.	Quaternary	50%OPC+ 30%FA + 10%SF + 10% LP	790 mm	3.5 sec

Table-3: Slump and T_{500mm} results of all mix combinations.

3. RESULTS AND DISCUSSION

3.1 Compressive Strength Test

The average compressive strength results of cube specimens of each batch of different mix carried out at 7, 14, 28, 56 and 90 days are shown in Fig-1.

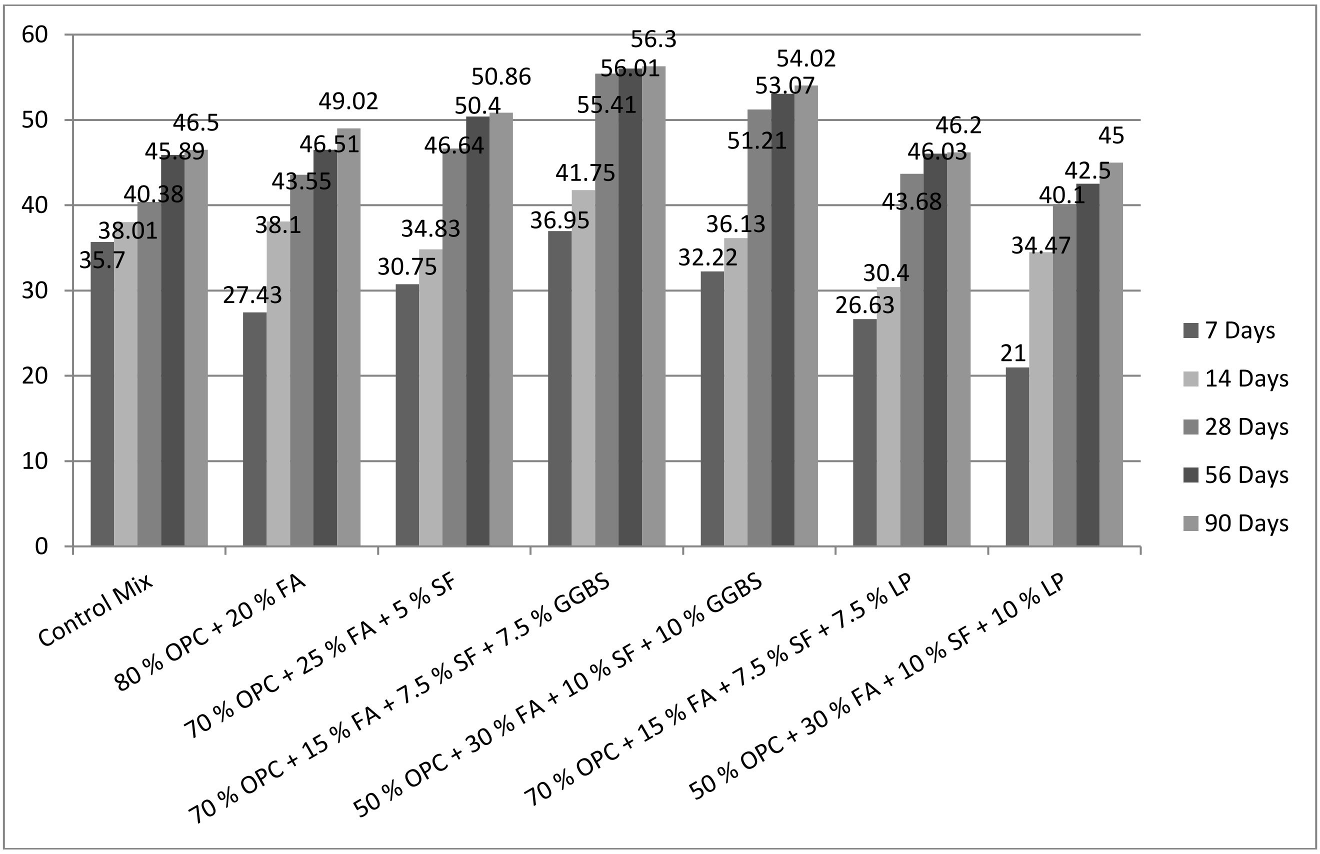

Fig-1 Compressive strength results of SCC mixes (M-40)

The following situations are observed with respect to the compressive strength behavior of the SCC mixtures in the investigation. As we can see from the table, the 7-day strengths of all the proportions, the quaternary replacements with GGBS (70% OPC + 15% FA + 7.5%SF + 7.5% GGBS) gave a slightly more strength than the control mix. The binary mix with fly ash (80% OPC + 20% FA) replacement and quaternary replacements with LP (70% OPC + 15% FA + 7.5 % SF + 7.5% LP) shows similar strength to the control mix. The ternary mix (70 % OPC + 25 % FA + 5% SF) and quaternary mix with GGBS (50% OPC + 30% FA + 10% SF + 10% GGBS) shows similar strength to the control mix. At 14 days of testing, results shows that the binary mix (80% OPC + 20% FA) gave strength similar to that of the control mix whereas strength of quaternary mix with LP (50%OPC+ 30% FA + 10% SF + 10% LP) showed much improved strength. Quaternary mix with GGBS (70% OPC + 15% FA + 7.5%SF + 7.5% GGBS) gave the highest strength amongst all the mixes and even better than that of the control. At 28 days of testing, quaternary mix with GGBS (70% OPC + 15% FA + 7.5%SF + 7.5% GGBS) shows higher strength than control and others. Quaternary mix with GGBS replacing 30% (70% OPC + 15% FA + 7.5%SF + 7.5% GGBS) & 50% (50% OPC + 30% FA + 10% SF + 10% GGBS) cement shows slightly same strength. Large improvements in the strengths of ternary mix (70 % OPC + 25 % FA + 5% SF) and quaternary mixes (70% OPC + 15% FA + 7.5%SF + 7.5% GGBS), (50%OPC+ 30% FA + 10% SF + 10% LP) and (70% OPC + 15% FA + 7.5 % SF + 7.5% LP) were seen. The LP quaternary mix (50%OPC+ 30% FA + 10% SF + 10% LP) shows similar strength that compared to the control (100% OPC). The binary mix (80% OPC + 20% FA) and LP quaternary mix (70% OPC + 15% FA + 7.5 % SF + 7.5% LP) showing similar strength to the control. At 56 days of testing, there was a slight increase in the strength of all the mixes. Quaternary mix with GGBS (70% OPC + 15% FA + 7.5%SF + 7.5% GGBS) and (50% OPC + 30% FA + 10% SF + 10% GGBS) shows similar strength however (70% OPC + 15% FA + 7.5%SF + 7.5% GGBS) quaternary mix shows the highest strength amongst all the mixes. The binary (80% OPC + 20% FA) and quaternary mix (70% OPC + 15% FA + 7.5 % SF + 7.5% LP) shows similar strength as that to the control. Quaternary mix (50%OPC+ 30% FA + 10% SF + 10% LP) shows slightly less level of strength of that of the control at this stage. The final testing for compressive strength was done for 90 days of curing. Among all the mixes, the quaternary mix (50% OPC + 30% FA + 10% SF + 10% GGBS) shows the highest compressive strength. (80% OPC + 20% FA) and (70 % OPC + 25 % FA + 5% SF) mix gave strength higher to that of the control. Literature also support that with continuing curing at long time, the replacement of cement with pozzolanic materials gives best compressive strength and it is significantly higher than the control concrete [17-20].

3.2 Flexural Strength Test

The average flexural strength results of beam specimens of each batch of different mix carried out at 7, 14, 28, 56 and 90 days are shown in Fig-2.

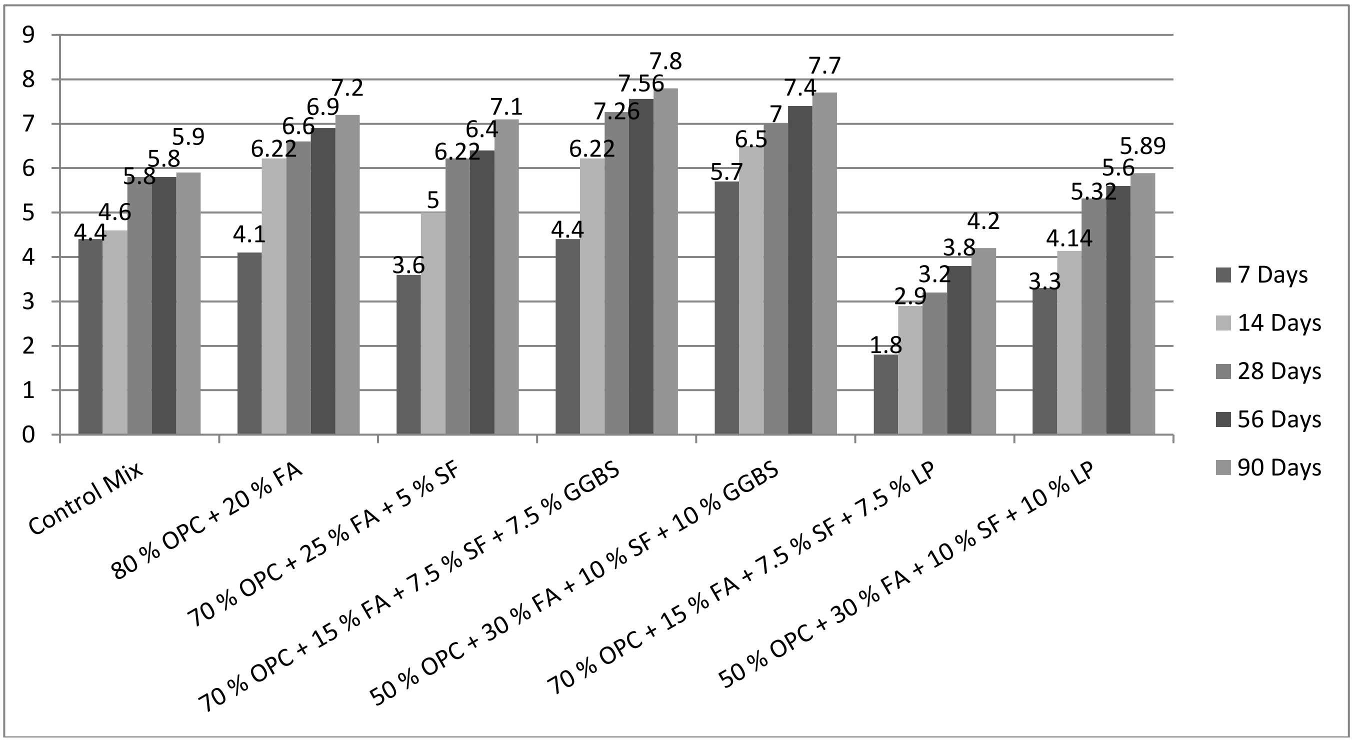

Fig-2 Flexural strength results of SCC mixes (M-40)

The following situations are observed with respect to the flexural strength behavior of the SCC mixtures in the investigation. As we infer from the Fig-2 the first test on the 7-day strength was carried out. The binary mix (80% OPC + 20% FA) and quaternary mix (70% OPC + 15% FA + 7.5%SF + 7.5% GGBS) shows similar strength to that of the control (100% OPC). Quaternary mix (50% OPC + 30% FA + 10% SF + 10% GGBS) shows highest strength amongst all the other mixes. Quaternary mix (70% OPC + 15% FA + 7.5%SF + 7.5% GGBS) gives slightly higher strength to the control mix. The ternary mix (70 % OPC + 25 % FA + 5% SF) and quaternary mix (50%OPC+ 30% FA + 10% SF + 10% LP) shows similar strength to the other mixes but lesser than the control. The next test was carried out at 14 days of curing which shows that quaternary mix (50% OPC + 30% FA + 10% SF + 10% GGBS) gives highest strength amongst all the mixes. The binary mix (80% OPC + 20% FA) and quaternary mix (70% OPC + 15% FA + 7.5%SF + 7.5% GGBS) show similar strength to that of the control. The ternary mix (70 % OPC + 25 % FA + 5% SF) and quaternary mix (50%OPC+ 30% FA + 10% SF + 10% LP) shows similar strength to the other mixes but lesser than the control. Quaternary mix (70% OPC + 15% FA + 7.5 % SF + 7.5% LP) gave the least strength among all other mixes. The tests were then carried out after 28 days of curing and the trends in the results were exactly similar to the 14 days test. All the mixes gained slightly higher strength than their 14 days equivalent. The tests were then carried out for 56 days of curing. Quaternary mix (70% OPC + 15% FA + 7.5%SF + 7.5% GGBS) gave the highest strength whereas quaternary mix (50%OPC+ 30% FA + 10% SF + 10% LP) gave strength slightly less than that of the control mix. Tests were then carried out for 90 days of curing. Quaternary mixes (70% OPC + 15% FA + 7.5%SF + 7.5% GGBS) and (50% OPC + 30% FA + 10% SF + 10% GGBS) have showed similar strength to each other, however the quaternary mix (70% OPC + 15% FA + 7.5%SF + 7.5% GGBS) gave the highest strength amongst all the mixes. The quaternary mix (50%OPC+ 30% FA + 10% SF + 10% LP) gave strength similar to that of the control (100% OPC).

3.3 Ultrasonic Pulse Velocity Test

Ultrasonic Pulse Velocity test (UPV) primarily gives the homogeneity of the material being tested. As per IS 13311 Part 1 1992, if a pulse velocity of more than 4 km/s is achieved in the specimen being tested, it is proved to be homogeneous. The output graph of the test has the interpretation that if there are large variations in amplitude then the specimen has cracks or air voids and in general is not homogeneous. As shown in Table-4 the entire testedspecimens gave pulse velocity greater than 4kmps thus, as per code, are excellent specimen and also, through graph (Fig-3toFig-8), we observe that none of the specimen show large variations in their amplitude output thus all the specimens are homogeneous. This gives us an important result that the SCC maintain their homogenous nature even when there is no external vibration provided and also, they do not allow formation of cracks or air voids that will deviate the specimen from homogeneity.

S.No.	Mix	Time (µs)	Distance (mm)	Velocity (km/s)	Quality as per IS: 13311 (Part I)
1.	80% OPC + 20% FA	31.9	150	4.697	Excellent
2.	70 % OPC + 25 % FA + 5% SF	33.1	150	4.529	Excellent
3.	50%OPC+ 30%FA + 10%SF + 10% LP	35.1	150	4.279	Excellent
4.	50% OPC + 30% FA + 10% SF + 10% GGBS	34.2	150	4.389	Excellent
5.	70% OPC + 15%FA + 7.5 % SF + 7.5% LP	33.6	150	4.462	Excellent
6.	70%OPC + 15%FA + 7.5%SF + 7.5% GGBS	33.5	150	4.473	Excellent

Table-4 Ultrasonic Pulse Velocity Results of Specimens

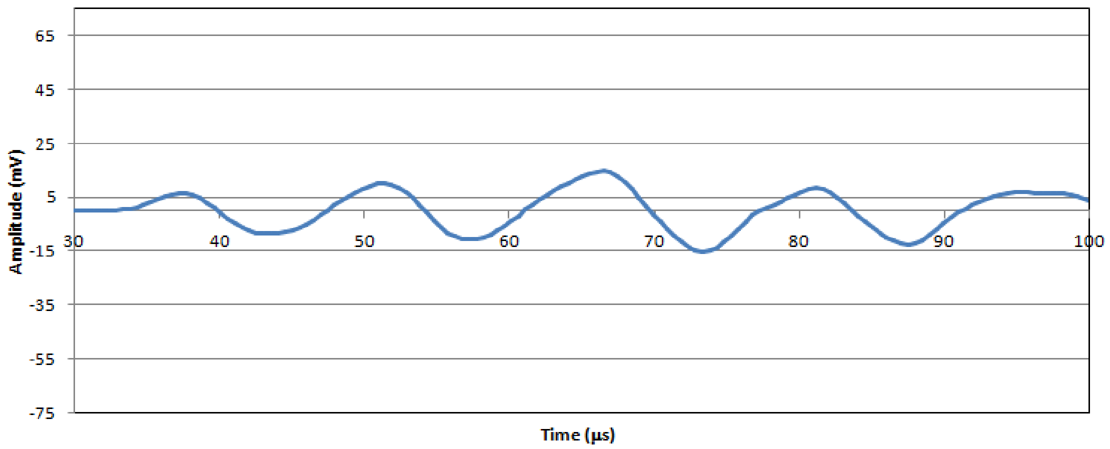

Fig-3 UPV Analysis for SCC Binary Mix(80% OPC + 20% FA)

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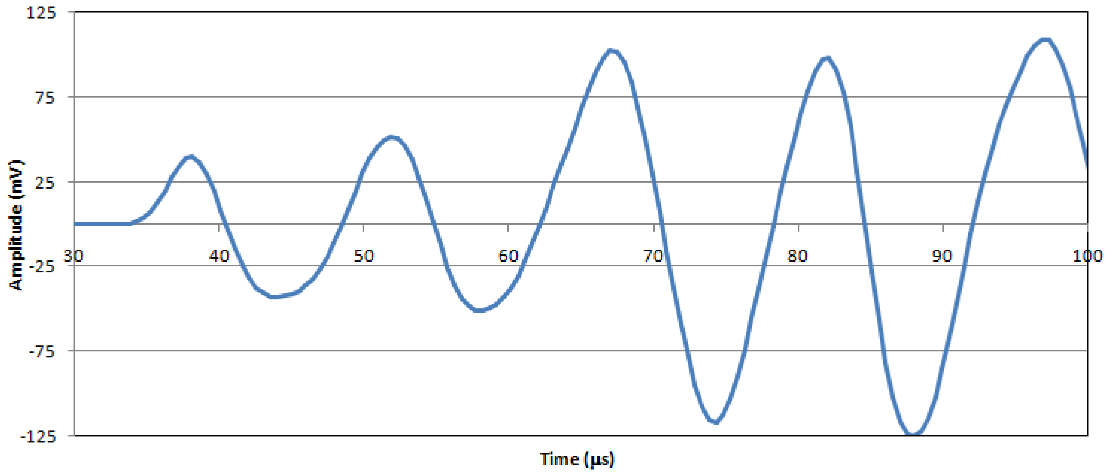

Fig-4 UPV Analysis for SCC Ternary Mix(70 % OPC + 25 % FA + 5% SF)

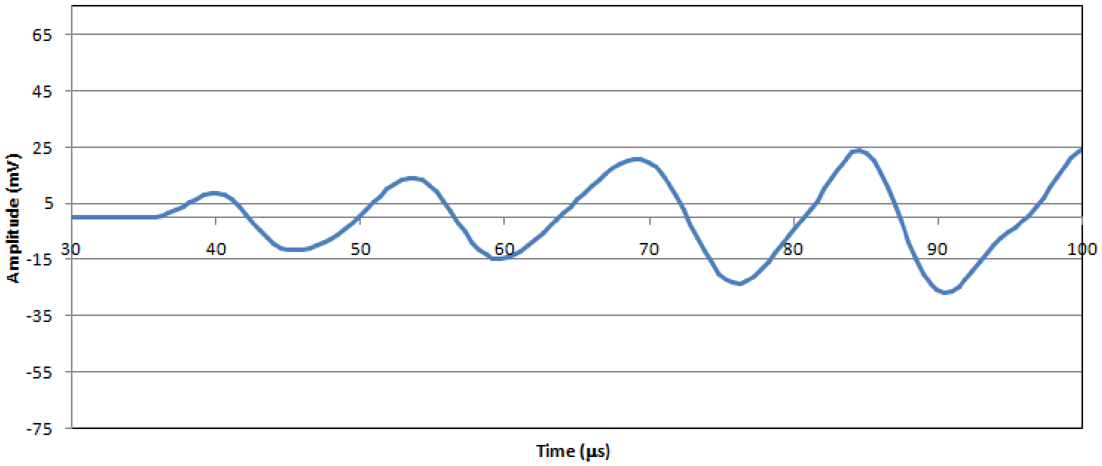

Fig-5 UPV Analysis for SCC Quaternary Mix (50%OPC+ 30% FA + 10% SF + 10% LP)

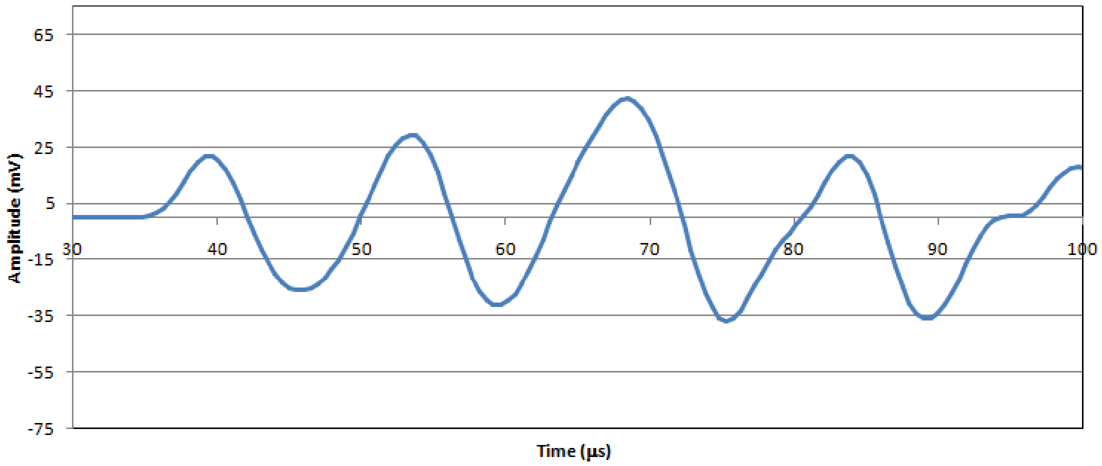

Fig-6 UPV Analysis for SCC Quaternary Mix (50% OPC + 30% FA + 10% SF + 10% GGBS)

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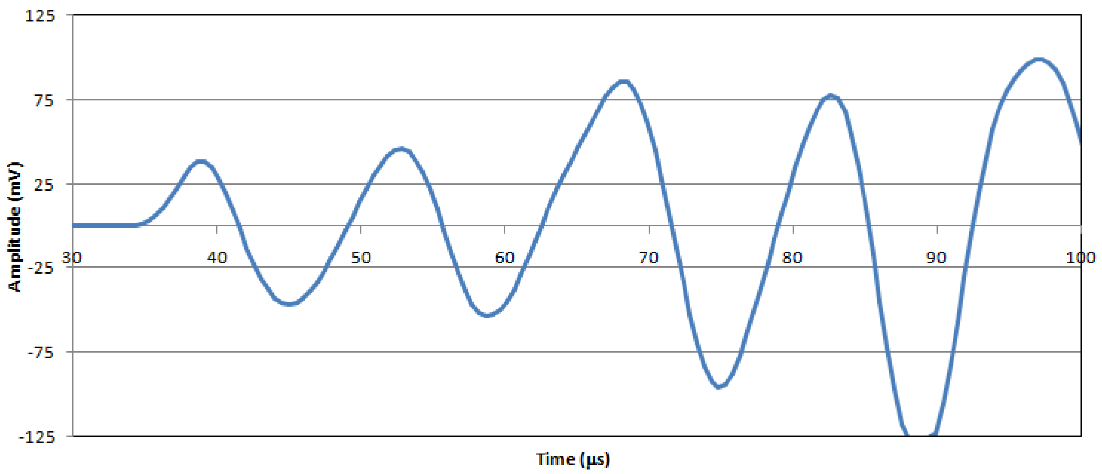

Fig-7 UPV Analysis for SCC Quaternary Mix (70% OPC + 15% FA + 7.5 % SF + 7.5% LP)

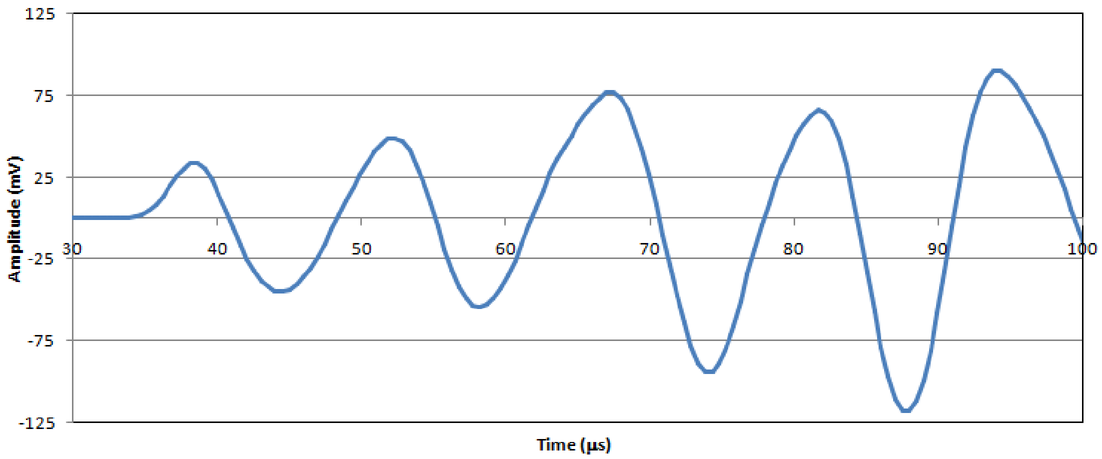

Fig-8 UPV Analysis for SCC Quaternary Mix (70% OPC + 15% FA + 7.5%SF + 7.5% GGBS)

4. CONCLUSION

From the experimental study so far carried out, following conclusions can be drawn;

1. Development of M40 grade SCC is possible by following the European guidelines of mix design and by incorporating mineral admixtures in binary, ternary and quaternary blends. As there is limited literature is available on the design of quaternary blends in SCC, it can be now recommended that the use of quaternary blends of M40 grade SCC by incorporating a specific combination of mineral admixture is satisfactorily possible.
2. The workability properties determined by slump flow test for all the mixes prepared by varying the replacement levels of binary, ternary and quaternary blends have been found to be within the specific range of EFNARC. However, the mix prepared by incorporating quaternary blends of FA(30 %), SF (10 %) and GGBS (10 %) or LP (10 %) (i.e. 50 % cement replacement) have indicated better workability results.
3. The developed M40 grade SCC satisfies the workability specifications and the 28 day compressive requirement of the mix is found to be higher than the control mix for two combinations of quaternary blend of mineral admixtures namely FA, GGBS and SF (51.21 N/mm^2) at 30 %, 10 %, 10 % respectively (i.e. 50 % cement replacement) and FA, GGBS and SF (55.41 N/mm^2) at 15 %, 7.5 %, 7.5 % respectively (i.e. 30 % cement replacement) thus replacing the cement content by 30 % and 50 % at a constant w/c ratio of 0.3 and at 1.1 % SP content by weight of cement. The 28 days compressive strength of the mix thus obtained by incorporating quaternary blend is found to be higher than that of the control mix (40.38 N/mm^2) while all the other SCC mixes has shown similar strengths as compared to control mixes. Also 28 days flexural strength requirement of these mixes are found to be higher than control mixes and all other SCC mixes have shown slightly better results than control mix except quaternary blend incorporating LP has shown lesser strength than control mix.

4. The UPV tests that were conducted for checking the homogeneity of the blends gave excellent results. A peak velocity of greater than 4 Km/s assures the quality of the concrete to be homogenous (IS 13311: Part – I – 1992). The entire specimen showed a peak velocity larger than 4 Km/s proving the entire specimen to be homogeneous, without vibration.
5. During our study of various other works related to self compacting concrete we found that a lot of other materials can also be used in the mix designs and one can even go for even complex mixes such as Pentanary or more blends.
6. Quaternary concrete could be the substitute of OPC concrete. Its 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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