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STUDY ON EARLY AGE STRENGTH DEVELOPMENT OF MULTI BLENDED CONCRETES CONTAINING FLY ASH AND SILICA FUME

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Abstract— It is of significant interest to produce high performance multi blended mix concretes by using supplementary cementatious materials (SCM). In this research an attempt is made to compare the performance of multi blended mix concretes i.e. both binary and ternary mixes with ordinary Portland cement (OPC) concrete. In binary mixes cement was partially replaced by low calcium fly ash (LCFA) or silica fume (SF) and in ternary mixes both LCFA and SF were combined to partially replace OPC. The class F fly ash is used in different proportions of 20%, 30%and 40% and silica fume of 5% and 10% by weight of cement. A constant water binder ratio of 0.42 was maintained. Super plasticizer of required quantity was added to achieve the required degree of workability. The specimens were tested for compression at both 7 and 28 days. The multi blended mix concretes exhibited slightly higher compressive strength than OPC mix concrete and also better performance in short term strength development. The ultra-sonic pulse velocity was also carried out on all the multi blended mixes to assess the homogeneity of concrete.

Index Terms—**Binary mix, Compressive strength, Low calcium fly ash, Silica fume, Ternary mix, ultra-sonic pulse velocity**

INTRODUCTION

Supplementary cementitious materials (SCM) are widely used in mortars and concrete in various proportions for reducing the amount of cement required, which lead to lower initial and life-cycle costs of concrete structures. SCMs are by-product materials and the use of these materials in mortar and concrete leads to a reduction in waste and savings in energy consumption during the production of cement and multi blended mixes. Most recently blended and multi-blended concretes produced with the addition of industrial by-products/pozzolanic materials are becoming an active area of research due to their improved performance in both strength and durability. The common SCM used are fly ash (FA), rice husk ash (RHA), slag, silica fume (SF), calcined clay etc. The improved properties such as rheology and cohesiveness, lower heat of hydration, lower permeability, control of the ASR are reported by many authors (Khan et al., X. Cong et al., M.H. Zhang et al., J.A. Larbi et al., Goldman et al., Shannag et al., [1,7,8,9,10,11]). The multi blended concerts reported to exhibit higher resistance against chemical attack (Mehta P.K. [2]).

In general, each of SCMs possesses different properties and reacts differently in the presence of water at early age. Toutanji et al. [3] achieved optimum compressive strength by adding 8% SF in concrete and reported that the addition of silica fume content beyond 10% decreased the compressive strength. The amount of cement replaced by fly ash (class C) increased beyond 30%, the compressive strength decreased at early ages and usually has limitations while some have contrasting influences on properties of concrete [1]. The combination of two or more kinds of SCMs has emerged as a better choice over single admixture to improve concrete properties and (Bagel et al. [4], Pandey et al. [5]) found that the addition of 8–12% SF as cement replacement yielded the optimum strength and less permeability. The concrete mixes containing FA beyond 30% with or without SF were not able to achieve the strength of OPC concrete (Khan et al., 6].

T K Erdem et al. [12] studied the effect of blending of OPC, SF, slag and FA on the strength of concrete and reported that these ternary blends exhibited significant increase at 7 and 28 days than at 3 days. Radlinski et al. [13] reported that ternary cementitious systems containing of 20% fly ash (class C) and 5 %silica fume exhibited the synergistic effect at later ages, resulting in increased compressive strength, resistance to chloride ion Penetration and reduced rate of water absorption compared to binary mixes consisting FA or SF.

Recently there has been a growing trend towards the use of supplementary cementitious materials in India and Bhutan for water resources structures. In this research work an attempt has been made to study the effect of the use of low calcium Indian fly ash and silica fume on the short term strength development and homogeneity of multi blended concretes and compare with that of normal strength concrete mix, the binary mixes containing each cementitious separately.

INGREDIENTS

The concrete mix was designed as per IS 10262-2004 [14] and it was prepared by using the following ingredients.

Cement

43 grade Ordinary Portland cement (OPC) conforming to IS 8112-1989 [15] was used. The physical and chemical properties of the cement are tabulated in Table. 1.

Coarse aggregate

Coarse aggregate from crushed Quartzite rock was used. Flakiness and Elongation Index were maintained well below 15%. Coarse aggregate with a nominal maximum size of 20 mm and a specific gravity of 2.649 was used.

Fine aggregate

Badarpur sand (local crushed sand) was used as fine aggregate with a fineness modulus of 2.39 and a specific gravity of 2.679. Fine aggregate is classified as zone III as per IS 2386 (I, III), 1963 [16].

Table 1: Physical properties and chemical compositions of cementitious materials

Parameters	OPC (43 Grade)	LCFA	SF
Physical Properties			
Base exchange capacity (meq/.100gm.)	11.50	11.50	-
Specific Gravity	3.16	2.21	2.2
Initial setting time (ml)	45	-	-
Final setting time (ml)	325	-	-
Bulk Density (Kg/m^{3})	1440	721	601
Specific Surface Area (m^2/g)	0.33	0.45	21
Consistency (ml)	33		
Compressive strength at 3, 7,and28 days (MPa)	31.7, 43.2 and 51.6	-	-
chemical compositions			
SiO_2 (% by wt)	19.55	57.90	89.7
Al_2O_3 (% by wt)	7.27	30.80	1.4
Fe^2O_3 (% by wt)	4.39	3.20	0.35
CaO (% by wt)	59.53	0.87	2.3
MgO (% by wt)	1.14	0.51	1.6
Na_2O (% by wt)	0.12	0.0068	0.6
K_2O (% by wt)	0.77	0.0122	0.6
SO_3 (% by wt)	2.46	0.0262	0.4
Moisture	-	0.18%	0.5%
Pozz activity	-	75%	137%
Loss on ignition (LOI) (% by wt)	4.71	4.76	2.8

Insoluble residue, % by wt	2.24	-	-
Mix Oxide (as R_2O_3), % by wt.	11.56	-	-

Fly ash

LCFA is categorized as a normal pozzolan, a material consisting of silicate glass, modified with aluminium, iron and alkalies. The particles are in the form of solid spheres with sizes ranging from less than 1 µ to 100 µ and an average diameter of 20 µ (Mehta, 1993 [17]). LCFA requires $Ca(OH)_2$ to form strength-developing products (pozzolanic reactivity), and therefore is used in combination with Portland cement, which produces $Ca(OH)_2$ during its hydration. It lowers the heat of hydration and improves the durability when used in concrete as a cement replacement. It also contributes to development of strength due to filler effect in addition to pozzolanic reactivity.

The fly ash used in this research is produced from Badrapur Thermal power plant in New Delhi, India. This fly ash conforms to the requirement of IS 3812 (Part I) 2003 [18] and also ASTM C-618 [19] type F fly ash (LCFA). It has the total sum of SiO_2, Al_2O_3 and Fe_2O_3 is >90% but with quite a low CaO content (0.87%). Test results of fly ash are summarized in Table 2.

Silica Fume

Silica fume is a highly reactive material that is used in relatively small amounts to enhance the properties of concrete. It is a by-product of silicon metal and ferrosilicon alloy production. The SF is a very fine powder with spherical particles about 100 times smaller in size than those of Portland cement or fly ash. The particles are extremely fine and having diameter ranging between 0.03 and 0.3µm, with more than 95% of the particles being less than 1µm. Particle size is extremely important for both physical and chemical contributions (ASTM 1240 [20]) of silica fume in concrete. The specific surface of SF is 13 to 20 times higher than other pozzolans. Because of its very high amorphous silicon dioxide content it is very reactive pozzolanic material in concrete. The silica fume reacts with calcium hydroxide to form additional binder material called calcium silica hydrate.

Silica Fume used in this study was obtained from Corniche India Pvt. Ltd., Mumbai, Maharashtra, India. This Silica Fume conforms to the requirement of ASTM C1240. Test results of Silica Fume are summarized in Table 2.

Superplasticizer (SP)

A new generation Poly Carboxylic Ether (PCE) based super-plasticizer, CEMWET SP-3000 (PCE-2) was used. This super -plasticizer is available as a medium brown coloured aqueous solution with standard specifications of ASTM C 494 [21] Type G. The specific gravity and pH value of the super plasticizer is 1.1 and 7, respectively.

Mix Proportions

This paper reports the results of an experimental investigation of short term (early age) compressive strength of multi blended mix concretes. Twelve concrete mix proportions of M30 grade concrete consisting of control, binary and ternary mixes were considered for this investigation as shown in table 2. The total cementitious material content was kept as 365 kg/m^3 and a constant W/B of 0.42 was adopted. In order to get homogeneous samples, the super plasticizer was added to maintain the same slump for all the multi blended concrete mixes.

- In CF series, cement (C) was replaced partially with low calcium fly ash (LCFA) by 20%, 30% and 40% for getting CF20, CF30 and CF40 mixes respectively.
- In CS series the cement was replaced with silica fume (SF), by (5% and 10%) for getting CS5 and CS10 mixes respectively.
- In CFS series cement was partially replaced by both silica fume at (5%, 10%) and fly ash (20%, 30%, 40%) for getting CFS725, CFS635, CFS545 and CFS721, CFS631, CFS541 mixes respectively. For example CFS635 indicates 65% cement, 30%fly ash, 5% silica fume and CFS631

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indicates 60% cement, 30%fly ash, 10% silica fume.

Table 2 Mixes Proportions for multi blended concrete mixtures studied

S. No	Mix designation	W/B	Cement (Kg/m^3)	LCFA (Kg/m^3)	SF (Kg/m^3)	SP (Kg)	CA (Kg/m^3)	FA (Kg/m^3)	Slump (mm)
1	Control Mix (M30)	0.42	365	0	0	1.83	1237	704	50
2	CF20	0.42	292	73	0	2.19	1219	694	50
3	CF30	0.42	255.5	109.5	0	2.56	1210	689	60
4	CF40	0.42	219	146	0	2.74	1202	684	70
5	CS5	0.42	346.75	0	18.25	2.92	1231	701	50
6	CS10	0.42	328.5	0	36.5	3.65	1226	698	50
7	CFS725	0.42	273.75	73	18.25	2.92	1214	691	50
8	CFS635	0.42	237.25	109.5	18.25	3.29	1206	686	50
9	CFS545	0.42	200.75	146	18.25	3.65	1197	681	70
10	CFS721	0.42	255.5	73	36.5	4.8	1208	687	50
11	CFS631	0.42	219	109.5	36.5	4.01	1200	683	50
12	CFS541	0.42	182.5	146	36.5	4.38	1191	678	70

Casting and testing of specimens

Initially cement, fly ash and SF were mixed to get the total cementitious material. This cementitious material in dry state was mixed with the mixture of fine aggregate and coarse aggregate to produce homogeneous mix. The mixture of water and SP was then added to the dry mix of cementitious and aggregate. Slump cone test was performed as per IS 1199-1959[22] to measure the slump of the concrete. 150 mm x150 mm x150 mm Cube specimens were used to determine both the compressive strength as per IS: 10086-1982[23] and UPV as per IS: 13311 (Part I) 1992[24]. A set of six cubes were cast as per procedure laid down in IS 516-1959 [25] for each mix of concrete. After casting, the moulds specimens were air dried for 24 h as shown in figure 1. The cube specimens were cured for both 7 and 28 days period for conducting compression and UPV tests as shown in Fig 1, 2, & 3.

Fig 1: Casting of Concrete cubes

Fig 2: UTM Testing Machine

Fig 3: UPV Testing in Progress

results and discussions

The compressive strength and UPV test results of binary mixes (C+LCFA and C+SF) and ternary mixes (C+LCFA+SF) of varies combinations of cementitious materials at both 7 and 28 days are shown in Table 3.

Table 3: Result of Compressive Strength and Ultra Pulse Velocity of all mix combinations

S.No	Mix	Compressive Strength (N/mm^2)		UPV (Km/sec)	
		7d	28d	7d	28d
1	M30	24.6	31.16	5.05	5.23
2	CF20	22.9	30.25	5.28	5.41
3	CF30	18.75	28.81	5.56	5.59
4	CF40	17.03	25.49	5.17	5.17
5	CS5	25.83	33.31	5.23	5.23
6	CS10	26.5	34.26	5.36	5.41
7	CFS725	24.75	31.64	5.65	5.56
8	CFS635	25.15	32.43	5.82	5.73
9	CFS545	17.99	26.73	5.13	5.33
10	CFS721	19.74	30.05	5.54	5.55
11	CFS631	18.99	29.01	5.61	5.62
12	CFS541	16.2	24.92	5.02	5.10

Fly ash binary mixes (OPC + LCFA)

Variation of compressive strength of cement +fly ash binary concrete mixes at 7 and 28 days is shown in Fig 4. The strength of concrete decreased with the increase of fly ash at both ages (7d, 28 d) for all the mix combinations.

The compressive strength decreased by 6.91%, 23.78% and 30.77% at 20, 30 and 40% replacement levels of fly ash respectively compared to control mix at 7 days. The decrease in compressive strength at 28 days with 20, 30 and 40% replacement was 2.9%, 7.5% and 11.2% respectively compared to that of control mix. The reduction in the compressive strength of CF mixes at early ages is considered to be the result of lower activity of the fly ash particles.

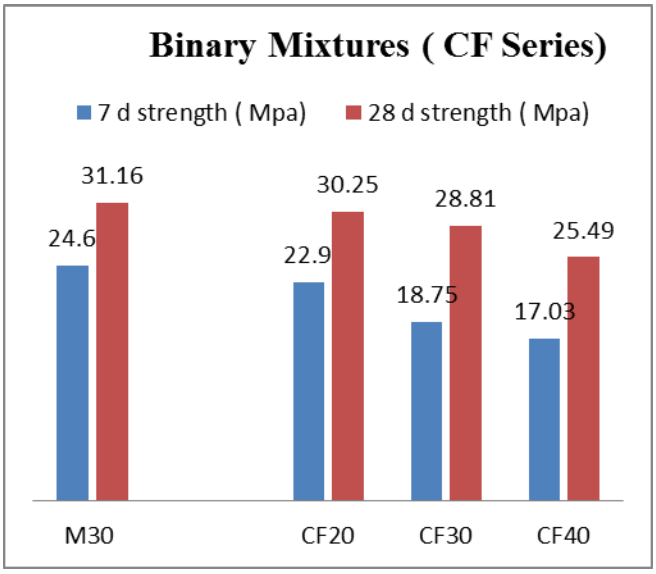

Fig 4: Comparison of compressive strength (control mix) with binary mixtures

Variation of UPV of cement +fly ash binary concrete mixes at 7 and 28 days is shown in Fig 5. It was observed that the addition of fly ash up to 30% enhanced the quality of concrete by exhibiting increased velocity. CF20 and CF30 mixes showed increased velocity at both ages whereas the CF40 mix showed decreased velocity as that of control mix. The small and spherical fly ash particles filled the voids or air spaces. The addition of fly ash also improved the pozzalanic reaction up to 30% replacement due to its higher surface area and glassy phase content. The low calcium fly ash made the blended cement paste more homogeneous and impermeable resulting in the increased UPV values.

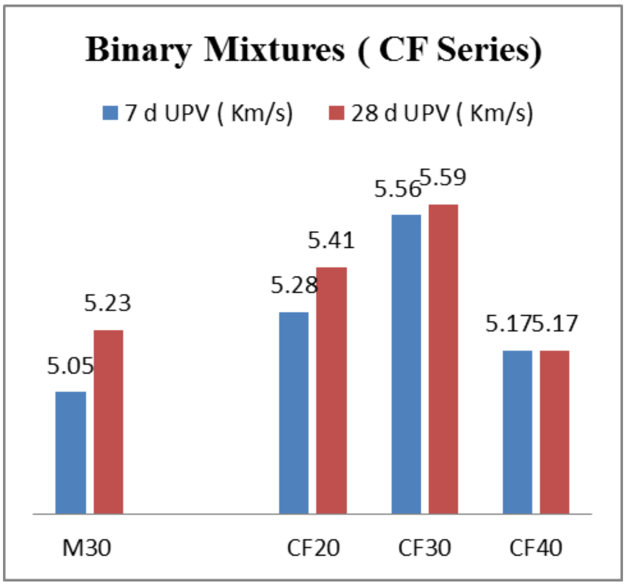

Fig 5: Comparison of UPV (control mix) with binary mixtures of fly ash

Silica fume binary mixes (OPC + SF)

As presented in the experimental program, Cement was partially replaced with SF by 5% and 10% mass to produce CS binary mixes. Variation of compressive strength of cement +silica fume binary concrete mixes at 7 and 28 days is shown in Fig 6. The strength of concrete increased with the increase of silica fume at both ages (7d, 28 d) for all the mix combinations.

The compressive strength increased by 5%, and 7.72% at 5, and 10% replacement levels of silica fume respectively compared to control mix at 7 days. The increase in compressive strength at 28 days with 5, and 10% replacement was 6.9% and 9.95% respectively compared to that of control mix. Increase in the compressive strength of the concrete containing SF is mainly due to the filler effect and pozzolanic reactions between the amorphous silica of SF and calcium hydroxide (CH) produced by the cement hydration to form calcium-silicate-hydrates. SF has extremely fine particle size (0.1– 0.3 µm) compared to that of LCFA (10–20 µm) leading to dense packing of the solid materials by filling the spaces between the cement grains. All these mechanisms make the microstructure of the paste more homogeneous and denser (ACI Committee 234., 1995 [26]).

Variation of UPV of cement +silica fume binary concrete mixes at 7 and 28 days is shown in Fig 7. It was observed that the addition of fly ash up to 10% enhanced the quality of concrete by exhibiting increased velocity. CS10 mix showed increased velocity at both ages whereas the CS5 mix showed almost same velocity for both ages as that of control mix at 28 days. It can be attributed to the fact that the filler effect of silica fume reduces the porosity of the transition zone and leads to a denser microstructure and impermeable, resulting in the increased UPV values of the system at 28 days.

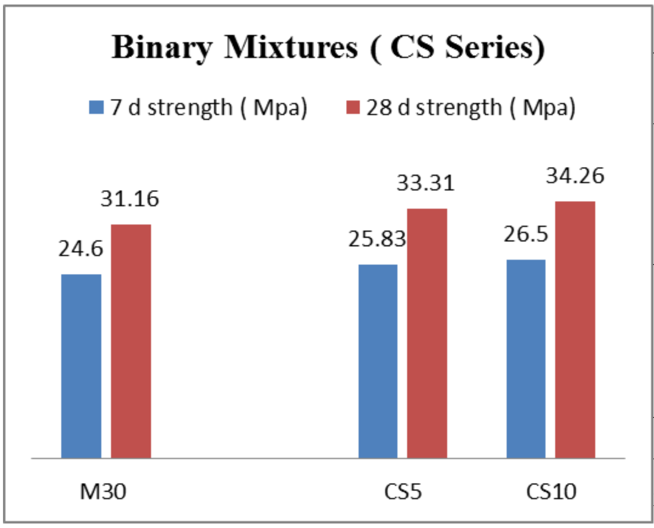

Fig 6: Comparison of compressive strength (control mix) with binary mixtures of Silica Fume

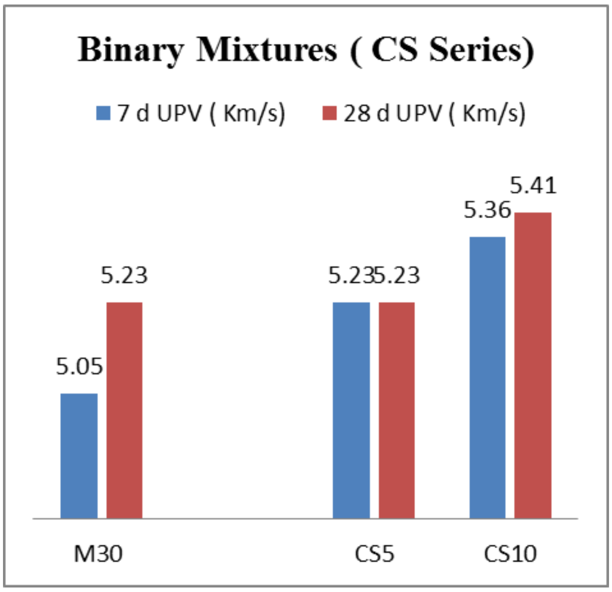

Fig 7: Comparison of UPV (control mix) with binary mixtures of Silica Fume

TERNARY MIXTURES (OPC+LCFA +SF))

In the ternary systems, cement was replaced partially with a combination of FA (20%, 30%, and 40%) and SF (5% & 10%) to produce CFS ternary mixes. Variation of compressive strength of CFS mixes at 7 and 28 days is shown in Fig 8. It was observed that ternary mixtures consisting of 5%SF with 20%, 30% and 40% fly ash at early age compressive strength (7d, 28d) exhibited higher than that of ternary mixtures of 10% silica fume series. The percentage increases in compressive strength of ternary mixes up to 40% and 5%SF at 28 days were 5.29%, 11.79%, 7.2% as compared with the ternary mixes up to 40% and 10%SF.

It can be concluded that ternary mixes exhibited better compressive strength at both ages with 5%SF up to 30% addition of fly ash. The percentage increase in compressive strength were 1.54%, 4.08% with 5%SF at 28 days compared to the control mix. The percentage increases in compressive strength were 0.61%, 2.24% with 5%SF at 7 days compared to the control mix. The combination of 5%SF and 30% fly ash exhibited almost same strength at both ages as that of control mix. The strengths obtained with 5% SF+20% FA blends at the end of 7days and 28 days were 24.75 and 31.64 MPa respectively and the strengths obtained with 5% SF+30% FA blends at the end of 7days and 28 days were 25.15 and 32.43 MPa respectively. This increase in early age compressive strength (7d, 28d) of ternary mixes upto 30% FA with 5% SF is due to the balancing effect in reactivity and water demand.

Variation of UPV of ternary blends consisting of 5% and 10% silica fume with fly ash upto 40% at 7 and 28 days is shown in Fig 9. It was observed that the addition of 5% SF and fly ash upto 30% (CFS725, CFS635) enhanced the quality of concrete by exhibiting higher velocity as compared to other ternary mixes. This enhanced quality can be attributed to the homogeneous and impermeable blended paste resulting from the combination LCFA and SF.

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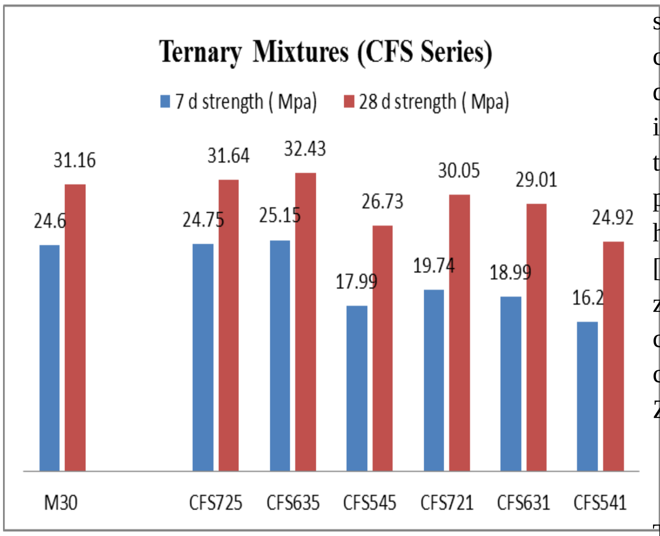

Fig 8: Comparison of compressive strength (control mix) with ternary

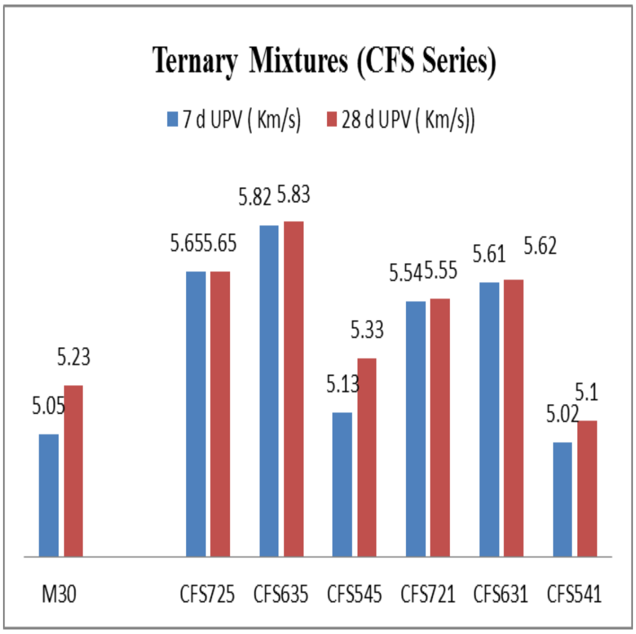

Fig 9: Comparison of UPV (control mix) with ternary mixtures

BINARY V/S TERNARY MIX CONCRETES

The performance of ternary mixes containing silica fume and fly ash was observed to be better than their binary mixes with 5%SF and FA upto 30%. The percentage increase in compressive strength of ternary mix of CFS635 is 12.57%, compared to that of the binary mix of CF30 at 28 days and the percentage increase in compressive strength of ternary mix of CFS 725 is 4.59%, compared to that of the binary mix of CF20 at 28 days. The use of SCMs reduce the porosity of the interfacial transition zone (ITZ) in concrete due to their ability to fill the pores in ITZ with fine silica particles and reduction of the amount of calcium hydroxide (CH) in the ITZ (X. Cong et al.1992 [7]). The densification of the interfacial transition zone allows for efficient load transfer between the cement mortar and the coarse aggregate, contributing to the strength of the concrete (M.H. Zhang et al.1990 [8]).

The ternary mixes also exhibited higher velocity than that of binary mixes up to 30% fly ash replacement. CFS635, CFS725 exhibited higher velocities (5.82, 5.65) than that of CF30 (5.56), CS5 (5.23) and CF20 (5.28), CS5 (5.23) respectively.

CONCLUSIONS

The following conclusions can be drawn from the above discussions:

- It can be concluded that the binary mix produced with the addition of fly ash up to 30% exhibited enhanced quality of concrete by showing increased velocity.
- The binary mix produced with the addition of SF up to 10% the exhibited improved compressive strengths at all ages as compared with binary mix produced with fly ash.
- It can be concluded that the compressive strengths of ternary mixes produced with the addition of fly ash up to 30% along with 5% silica fume were higher than that of binary mixes.
- It can be concluded that the UPV values of ternary mixes produced with the addition of fly ash up to 30% along with 5% silica fume were higher than that of binary mixes.
- It can be concluded that the ternary mixes consisting of 5%silica fume with the addition of fly ash upto 30% at early ages (7d & 28d) performed better than control and other ternary blended mixes.

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