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Research Paper

Durability Properties of Self Compacting Concrete containing Fly ash, Lime powder and Metakaolin

Rizwan A. Khan, Atul Sharma*

Department of Civil Engineering, Dr. B. R. Ambedkar National Institute of Technology, Punjab, India

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ABSTRACT

This paper investigates the durability properties of Self-compacting concrete (SCC), with different amounts of fly ash (FA), lime powder (LP) and metakaolin (MK). A total of 6 mixes were prepared that have a constant water-binder ratio (w/b) of 0.41 and superplasticizer dosage of 1% by weight of cement. In addition to compressive strength, the durability properties of SCC mixes were determined by means of Initial surface absorption test (ISAT) and Capillary suction test. The test results indicated that the durability properties of the mixes appeared to be very dependent on the type and amount of the mineral admixture used; the mixes containing MK were found to have considerably higher permeability resistance. Good co-relation between strength and absorption were achieved.

1 Introduction

Self-compacting concrete (SCC) is a highly flow-able, non-segregating concrete that can spread into place, fill the formwork and encapsulate the reinforcement without any need for vibration. It is a modified product that flows and consolidates under the influence of its own weight. Not only will it, thus, reduce the exposure of workers to noise and vibration of the vibrating equipment, it can also reduce the technical cost of in-situ cast concrete constructions, due to improved casting cycle, quality, durability, surface finish and reliability concrete structures and eliminating some of the potential for human error. It is a sensitive mix, strongly dependent on the composition and characteristics of its constituents. It consists of the same components as of conventionally vibrated concrete, which are cement, aggregates and water, with the addition of chemical and mineral admixtures in different proportions. Stability and flow ability of SCC is achieved by increasing the solid fraction of paste phase of concrete that can be achieved by employment of some mineral admixtures [12]. The use of mineral admixtures improves the hardened and especially durability properties of the concrete.

* *Corresponding author. Tel.:* ++91 9876497242.
E-mail address: rizwan_iitd@yahoo.co.in

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SCC is tested for compressive strength to check its hardened property. Durability is a general analysis of the service life and the performance of concrete in an aggressive environment. Physical damage to concrete includes wetting/drying, freeze/thaw or heating/cooling cycles. Chemical damage consists of sulphate attack, acid attack, chloride attack and alkali-silica reaction (ASR) in which water acts as a carrier. The main durability properties are *permeability* and *sorptivity.* Permeability is a process in which water is transported under a hydrostatic pressure differential. The rate of water uptake by a porous material is defined as sorptivity.

Various researches have already been done in the past on SCC using various admixtures, such as fly ash (FA), lime powder (LP) and metakaolin (MK). The use of FA in concrete is known to increase the workability and contributes towards long-term strength. It was investigated that although the absorption increases with increasing FA content, the absorption values of SCC containing high volume (80%) of FA is below 2% at 56 days of curing [14]. For SCC incorporating FA not only possess required fresh properties but also develop adequate mechanical and durability characteristics, FA content in the mix may be limited to 40% [15,16]. It was also observed that the rate of gain in strength for different grades of SCC using FA is slightly more than the expected strength of conventional concrete of the same grades [4]. There may also be specialty cements that will benefit from the addition of LP [6]. The chloride penetration was found less sensitive to the lack of curing in concretes containing LP blended cements [2]. The LP made possible the formation of a denser cementitious matrix and interfacial transition zone in the SCCs. The increased rate of the hydration process and improved particle packing are probably responsible for increased density [3]. MK is recently being in much use in preparing SCC. It was found that at a low water to binder ratio of 0.3, the optimum replacement level to give maximum strength enhancement is 15% MK [13]. The main factors that affect the contribution of MK to strength are: 1) the filling effect; 2) the dilution effect; and 3) the pozzolanic reaction of MK with $Ca(OH)_2$ [17]. Regarding the water permeability of the concretes with quaternary blends, it was very interesting to note that the concretes with MK had water permeability less than or equal to 0.1968 in. (5 mm), irrespective of MK, FA, and ground-granulated blast-furnace slag content [5]. This led us to prepare SCC using these admixtures and analyze their effect on durability properties. The literature review shows that some papers are available on the strength properties of SCMs such as FA and MK but it is scanty on the durability characteristics of the same.

In the present study, different mixes of SCC were prepared using mineral admixtures FA, MK and LP as a partial replacement of Ordinary Portland Cement (OPC). The compressive strength and durability properties were determined. The relation between strength and absorption were obtained.

2 Experimental

2.1 Materials

The constituents of mixes were Ordinary Portland cement (OPC), FA, LP and MK, water, fine aggregate and coarse aggregate. OPC of 43 grade from a single lot was used throughout the course of investigation [11]. Sand made of crushed aggregates was used as fine aggregates and locally available crushed stone aggregates of 12.5 mm nominal maximum size were used as coarse aggregates [7, 8 and 10]. Class-F FA was used from Guru Gobind Singh super thermal plant, Ropar. LP having industrial name CARB 2 was used throughout the process. A single lot of MK named Metacem 85C was used in the study. The super-plasticizer used in the study was Sika Viscocrete 20-HE manufactured by Sika.

2.2 Mix proportions

Six different mixes (mixes M1–M6) were employed to examine the influence of different type and amount of admixtures on durability properties of concrete. Details of mixes are given in Table 1. The reference mix (M1) had 30 % FA as binder content and did not include LP and MK. In mixes M2–M4, FA was partially replaced with 5%, 10% 15% of LP respectively. In mixes M5-M6, FA was partially replaced with 5% and 10% of MK respectively. The water to binder ratio for all mixes was maintained constant at 0.41. A constant dosage of SP of 1% by weight of cement was used for all the mixes.

2.3 Casting, curing and testing

The casting of the various SCC specimens was done under laboratory conditions using standard equipment. Six batches of SCC were cast. Each batch consisted of 12 cubes for compressive strength and permeability tests and 3 cylinders for sorption tests. After casting, the specimens were allowed to harden for 24 hours at room temperature. These were then removed from the moulds, were marked with their respective designations and placed in the curing tanks. They were moist cured for 7, 14, 28 and 60 days under normal potable water.

Table 1 -Mix Proportions of all mixes in kg/m^3

Mix ID	Cement	Fly ash (FA)	Lime Powder (LP)	Metakaolin (MK)	Sand	Coarse aggregate	W/B ratio	SP
M1	420	180	0	0	882	530	0.41	4.20
M2	420	150	30	0	882	530	0.41	4.20
M3	420	120	60	0	882	530	0.41	4.20
M4	420	90	90	0	882	530	0.41	4.20
M5	420	150	0	30	882	530	0.41	4.20
M6	420	120	0	60	882	530	0.41	4.20

Compressive strength was determined at 7, 14, 28 and 60 days at 200 tonnes capacity Universal Testing Machine (UTM). Permeability and sorptivity tests were performed at 28 and 60 days of curing. The determination of compressive Strength was according to IS : 516, determination of initial surface absorption was according to BS 1881-208: 1996 and measurement of Rate of Absorption of Water was according to ASTM Standard C 1585 – 04 [1,4 and 9].

3 Results and discussions

3.1 Compressive strength

Compressive strength tests were conducted on SCC specimens of different mixes at 7, 14, 28 and 60 days of curing. The average of three samples is taken as the represented value of compression strength for each batch of SCC. The compressive strength test results are shown in Table 2.

It was observed that compressive strength increased as the FA was replaced by LP or by MK. The mix M1 having 30% FA showed the least compressive strength and the mix M6 having 20% FA and 10% MK showed the highest compressive strength at all curing ages. The density tends to increase slightly with increasing amounts of MK in concrete, mainly resulting from the filling effects of MK particles [13]. The general trend of strength variation of all the 6 mixes is also shown in Table 2.

Table 2-Compressive strength test results at different curing ages

Mix ID	Description	Compressive strength (MPa)			
		7D	14D	28D	60D
M1	70%OPC 30%FA	16.00	21.55	24.18	32.44
M2	70%OPC 25%FA 5%LP	20.18	23.85	26.37	35.09
M3	70%OPC 20%FA 10%LP	23.18	29.39	31.17	41.38
M4	70%OPC 15%FA 15%LP	23.41	31.34	34.50	44.39
M5	70%OPC 25%FA 5%MK	24.38	26.15	32.10	42.34
M6	70%OPC 20%FA 10%MK	24.02	33.56	41.54	46.20

3.2 Permeability

This test method provides data for assessing the uniaxial water penetration characteristics of a SCC [4]. ISAT was performed on SCC cubes after 28 and 60 days of curing. The results of 10, 30 and 60 minutes ISAT values of concrete mixes at different curing ages are shown in Fig. 1 and Fig.2. It was observed that the absorption values varied with different mixes and decreased with increase in period and curing age. The ISAT values (10 min) of SCC mixes at different curing ages are represented in Table 3.

It was observed that the ISAT – 10 values at 60 days are less than ISAT – 10 values at 28 days for all mixes except for M4 mix having 15% replacement of FA by LP. The highest ISAT – 10 value was for mix M4 while mix M6 having 20% FA and 10% MK had the least value. It was found that mixes M2, M3 having 5%, 10% replacement of FA by LP, respectively, showed a decrease in ISAT–10 value. Similarly mixes M5 and M6 having 5%, 10% replacement of FA by MK, respectively, showed a decrease which is much more than that of mixes M2 and M3. Mix M4 showed an exceptional increase in ISAT–10 value at 28 as well as 60 days.

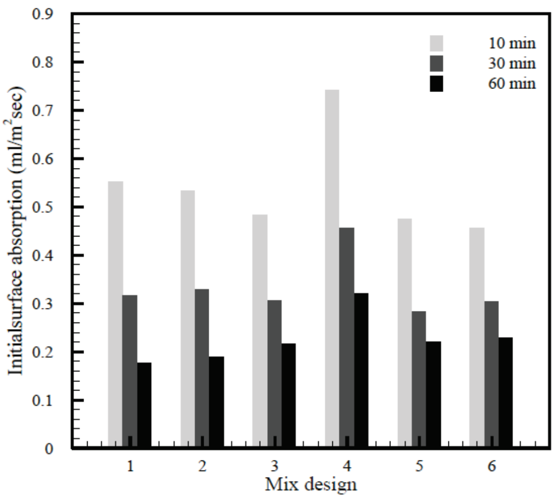

Fig. 1- ISAT values at 28 days of curing

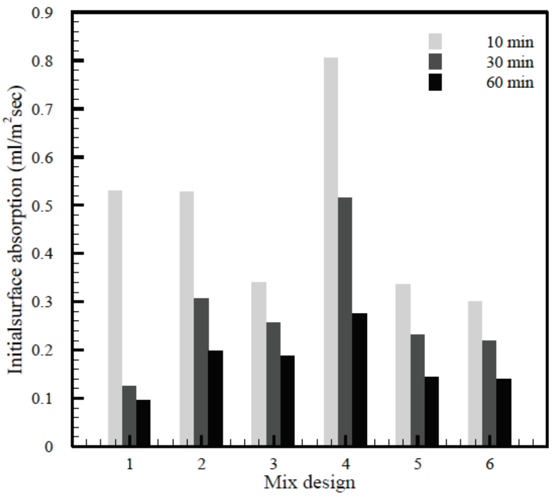

Fig. 2- ISAT values at 60 days of curing

Table 3 -ISAT-10 values of different mixes at 28 and 60 days of curing

Mix ID	Description	Initial Surface Absorption [ml/(m^2.sec)]	
		28D	60D
		10 Min	10 Min
M1	70%OPC+ 30%FA	0.552	0.530
M2	70%OPC +25%FA+ 5%LP	0.533	0.527
M3	70%+OPC +20%FA+ 10%LP	0.483	0.341
M4	70%OPC + 15%FA +15%LP	0.741	0.805
M5	70%OPC+ 25%FA+ 5%MK	0.475	0.336
M6	70%OPC+ 20%FA+ 10%MK	0.457	0.301

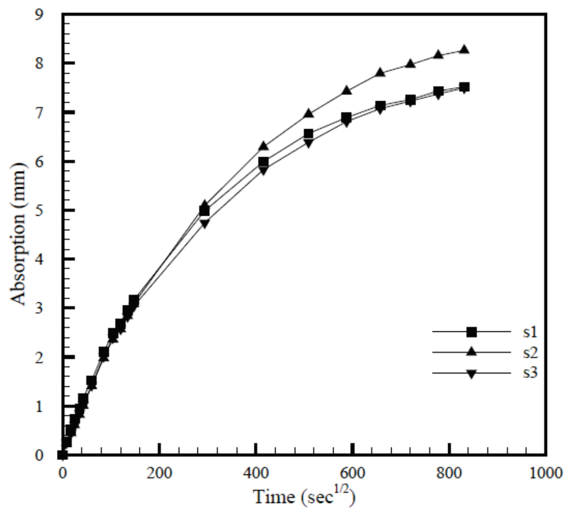

Fig. 3 Absorption values for M1 at 28 days

3.3 Sorptivity

Capillary suction test is used to determine the rate of absorption (sorptivity) of water by SCC by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water [1]. Typical plots of cumulative water absorption against the square root of time, where each set of plot referred to the three specimens for different SCC mixes obtained by different OPC replacement levels by LP, MK and LF at different curing ages, were drawn. Fig. 3 and Fig. 4 show these absorption values for reference mix M1. Since the relationship between cumulative water absorption and the square root of time of exposure begins to deviate from linearity after about 360 minutes (6 hours) therefore calculations were based on the first 6 hours of elapsed test time which gave the initial rate of absorption (IRA). IRA (mm/sec$^{1/2}$) is defined as the slope of the line that is the best fit to absorption (I) plotted against the square root of time (sec$^{1/2}$).

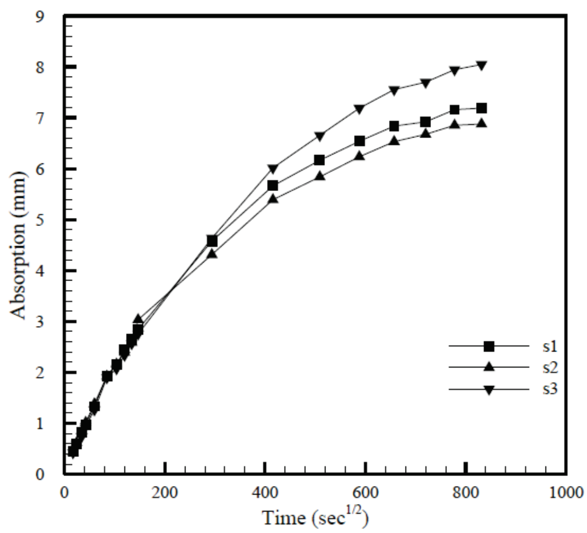

Fig. 4- Absorption values for M1 at 60 days

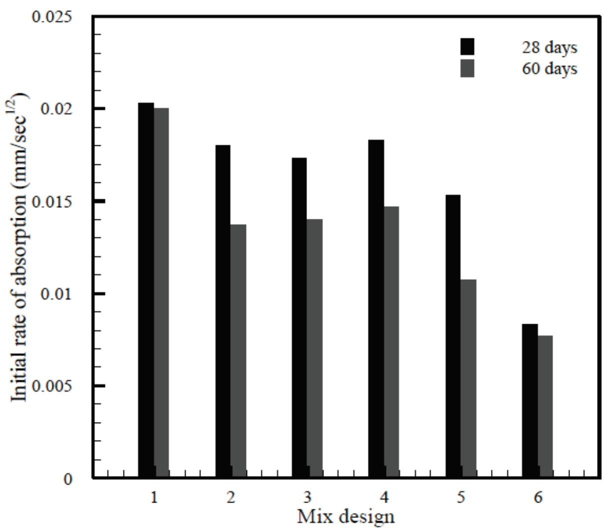

Fig. 5- Average IRA values for all mixes at different curing ages

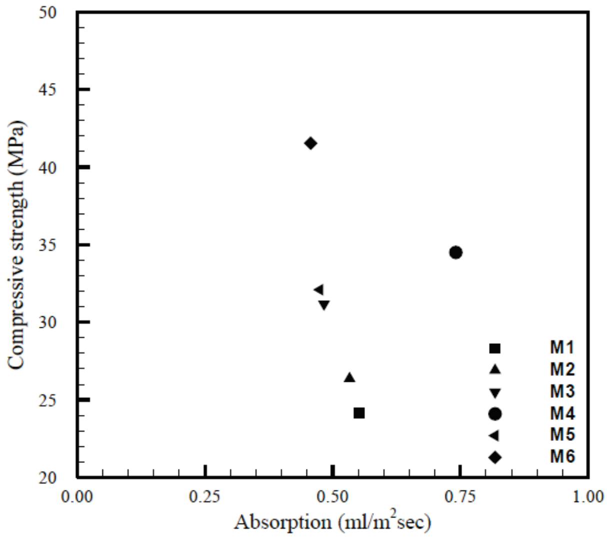

Fig. 6- Comparison of compressive strength ISAT-10 values at 28 days of curing

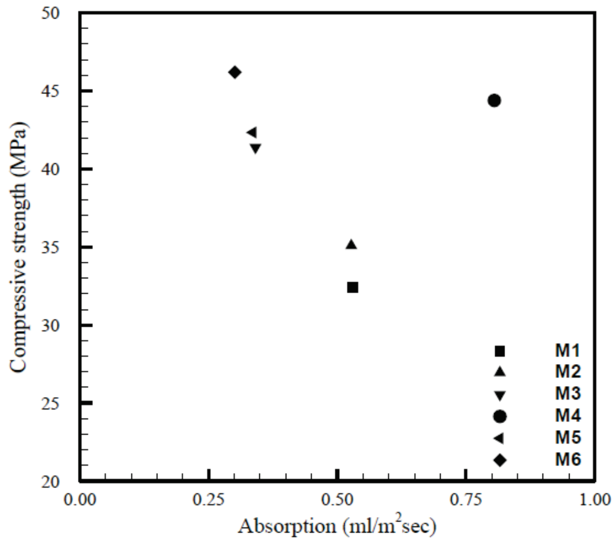

Fig. 7- Comparison of compressive strength with with ISAT-10 values at 60 days of curing

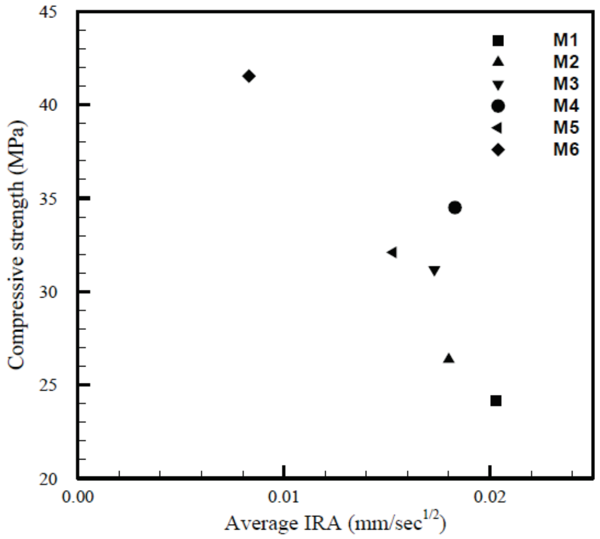

Fig. 8- Comparison of compressive strength IRA values at 28 days of curing with

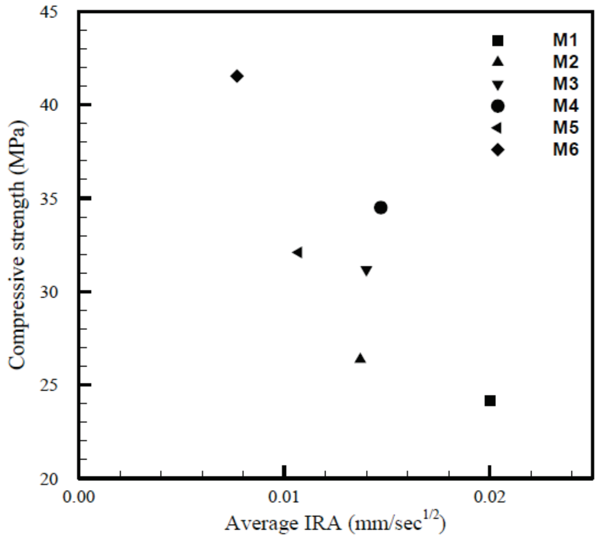

Fig. 9- Comparison of compressive strength with IRA values at 60 days of curing

Average IRA values for different mixes at different curing ages are plotted in Fig. 5. It was observed that average IRA values of mixes M2, M3 having 5% and 10% replacement by LP, respectively, were less as compared to mix M1 having 30% FA at both curing ages. The mixes having 5% and 10% MK replacement showed more decrease in average IRA value than those of same percentage replacement of LP. The mix M6 having 10% MK replacement has the least average IRA value i.e. 0.0077. The use of MK appeared to be much more effective in reducing the sorptivity due to the reduced pore volume. The mix M4 having 15% replacement of FA by LP shows a slight increase in average IRA value at both curing ages.

3.4 Relation between Strength and Absorption

The results obtained from compressive strength tests, Initial Surface absorption tests and capillary suction tests were used to compare compressive strength with ISAT-10 values and average IRA values at different curing ages as shown in

Fig. 6-9. It was found that with the increase in compressive strength, the ISAT-10 and IRA values of different SCC mixes decreased. The mix M6 having 10% MK replacement had highest compressive strength while lowest ISAT – 10 and average IRA value.

4 Conclusions

- The compressive strength showed an increase with increasing percentage replacement of FA with LP and MK. The mix M6 having 10% replacement of FA with MK has highest compressive strength than all mixes at all ages of curing. This is because of increase in density resulting from the filling effect of MK particles.
- Average IRA value was less for mixes with MK replacement than with LP replacement. The mix M6 had least value of IRA at both curing ages. As discussed previously, this is due to the reduction in pore volume.
- Good correlation between strength and absorption properties of concretes was found. With increase in strength, initial surface absorption and sorptivity values were found to decrease.
- It can be concluded from the results that SCC mix containing 20% FA and 10% MK can be considered as the most appropriate mix for compressive strength, initial surface absorption and capillary suction taken together.

REFERENCES

[1]- ASTM C 1585 – 04. Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic - Cement Concretes. ASTM International.
[2]- V. Bonavetti, H. Donza, V. Rahhal, E. Irassar, Influence of initial curing on the properties of concrete containing limestone blended cement. Cement Concrete Res. 30 (2000) 703-708.
[3]- V.B. Bosiljkov, SCC mixes with poorly graded aggregate and high volume of limestone filler. Cement Concrete Res. 33(2003) 1279–1286.
[4]- BS 1881-208. Recommendations for the determination of the initial surface absorption of concrete. 1996.
[5]- E. Güneyisi, M. Gesoglu, E. Özbay, Permeation Properties of Self-Consolidating Concretes with Mineral Admixtures. ACI Mater. J. 102(2) (2011).
[6]- K.D. Ingram, KE. Daugherty, A Review of Limestone Additions to Portland Cement and Concrete. Cement Concrete Comp. 13(1991) 165-170.
[7]- IS: 383. Indian Standard specification for coarse and fine aggregates from natural sources for concrete; 1970.
[8]- IS: 456. Indian Standard Plain and Reinforced Concrete-Code of Practice; 2000
[9]- IS: 516. Methods of Test for Strength of Concrete; 1959.
[10]- IS: 2430. Indian Standard methods for sampling of aggregates for concrete; 1986
[11]- IS: 8112. Indian Standard 43 grade Ordinary Portland Cement Specification; 1989.
[12]- IS: 9103. Indian standard concrete admixtures – specification; 1999.
[13]- J.M. Khatib, Metakaolin concrete at a low water to binder ratio. Constr. Build. Mater. 22(2008) 1691–1700.
[14]- J.M. Khatib, Performance of self-compacting concrete containing fly ash. Constr. Build. Mater. 22(2008) 1963–1971.
[15]- M. Liu, Self-compacting concrete with different levels of pulverized fuel ash. Constr. Build. Mater. 24(2010) 1245–1252.
[16]- B. Sukumar, K. Nagamani, R.S. Raghavan, Evaluation of strength at early ages of self-compacting concrete with high volume fly ash. Constr. Build. Mater. 22(2008) 1394–1401.
[17]- S. Wild, J.M. Khatib, A. Jones, Relative Strength, Pozzolanic Activity and Cement Hydration in Superplasticised Metakaolin Concrete. Cement Concrete Res. 26(10) (1996) 1537-1544.