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# Effect of Lime Powder and Metakaolin on Fresh and Hardened properties of Self Compacting Concrete

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ABSTRACT

This study investigated the fresh and hardened properties of Self-Compacting Concrete (SCC) with different types and amounts of admixtures. Six mixes were prepared by replacing 30% of cement with different percentages of fly ash (FA), lime powder (LP) and metakaolin (MK). Water- Cement ratio was kept constant at 0.41 and superplasticizer dosage of 1% by weight of cement. The *filling* and *passing ability* were investigated through Slump Flow, J-Ring, V-funnel and L-box test before filling the moulds. The *compressive strength* of hardened SCC cubes was also measured after specified days of curing (7, 14, 28 & 60 days). The workability test results showed that as FA was replaced by increasing percentages of LP and MK, the mixes became dense and hence less workable. It was observed that the compressive strength showed an increase with increasing percentage replacement of FA with LP and MK. This increase was higher for mixes with MK than that of mixes with LP.

## 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 of 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

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achieved by increasing the solid fraction of paste phase of concrete that can be achieved by employment of some mineral admixtures [1].

The use of mineral admixtures, such as fly ash (FA), lime powder (LP) and metakaolin (MK) effects and improves the fresh and hardened properties of SCC. Fresh properties include filling and passing ability that define workability. Filling ability describes the ability of SCC to fill a formwork completely under its own weight. Passing ability is the ability to overcome obstacles like reinforcement, small openings etc under its own weight without any hindrance. SCC is tested for compressive strength to check its hardened property. Strength is one of the most important properties specified for concrete because it is a direct reflection of the capacity of the structure to resist forces and it is a reasonable indicator of other properties. Compressive strength is the capacity of a material or structure to withstand axially directed pushing forces.

Various researches have already been done in the past on SCC using various admixtures. FA has shown to be an effective addition for SCC providing increased cohesion and reduced sensitivity to changes in water content. It was investigated that the use of FA in concrete reduces the water demand for a given workability [2]. Therefore, concrete containing FA will cause an increase in workability at constant water to binder ratio. The use of FA provides benefits such as reduction in the water requirements with increased workability and increased strength at later ages of curing, which cannot be achieved through the use of additional Portland cement [3, 4]. Also, inclusion of FA leads to a reduction in the consistence retention and passing ability when the filling ability is kept constant [5]. LP additions to cements and concretes in the U.S. have developed along a much different path than that taken in Europe, where limestone/cement blends have been employed for many years. It was found that the improvement in compressive strength at 28 day is about 20% for a replacement of 20% of cement with LP [6, 7]. In cements with a high C3A content, on adding LP calcium carbo-aluminate is formed and has either a positive effect or no effect on cement properties [8]. MK has been introduced as a highly active and effective pozzolan for the partial replacement of cement in concrete. It is produced by the calcination of kaolin clay upon heating at 650–800°C. It was found that the relative strength of concrete containing MK increases with the increase in curing time up to 14 days before it begins to decline [9, 10]. The presence of MK in concrete containing ground granulated blast-furnace slag causes an increase in strength during the early ages of hydration [11]. MK gives maximum contribution to strength which is the result of an elementary change between the MK and calcium hydroxide reaction beyond 14 days [12]. The MK finesses is a very important factor to optimize the SCC production in terms of w/c and superplasticizer content [2].

In the present study, different mixes of SCC were prepared using varying percentages of FA, LP and MK. The mixes prepared were checked for their fresh and hardened properties. The effect of these mineral admixtures on workability and strength were studied.

## 2 Experimental Work

### *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 [13]. 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 [14-16]. 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 fresh and hardened 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 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. The moulds for casting the specimens were cleaned, brushed and oiled and placed on levelled surface.

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

| Mix Id | Cement | Fly ash (FA) | Lime (LP) | Powder | 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 |

The moulds were filled with SCC mix homogeneously, after doing the workability tests. Slump Flow Test (Abram's Cone), J-Ring test, V- Funnel test and L-Box test were conducted to determine workability of the mixes. After casting, the specimens were allowed to harden for 24 hours at room temperature. These were then removed from the moulds and were marked with their respective designations and placed in the curing tanks. The cubes were moist cured for 7, 14, 28 and 60 days under normal potable water. Compressive Strength test was carried out at 7, 14, 28 and 60 days of curing. The cubes of 150mm x 150mm x 150mm size were used in the present study.The determination of compressive strength was according to IS: 516 [17].

## 3 Results and discussions

### *3.1 Workability*

All the mixes were found to be within the specified limits permissible for SCC according to EFNARC (2005) [18]. The horizontal spread of the SCC in Slump Flow test was found to lie between 650 to 800mm [10]. The mix M1 had the maximum slump value and the value showed a decrease in mixes having partial replacement with LP and MK. This is because of increase in the fineness content of binder with the addition of LP and MK. The difference in heights of the SCC at the centre and just outside the bars in J-Ring test was observed to be between 0 to 10mm. Flow time limits in V-Funnel test were from 6-12 seconds. The blocking ratio, $H_2/H_1$ in L-Box test should be greater than or equal to 0.8. All the workability tests results on M2, M3 and M4 showed that when LP is added, the mix becomes dense as compared to reference mix M1. Similarly, comparison of values of workability tests on MK mixes M5 and M6 showed the similar trend as in case of LP mixes. The mix M4 containing 15% FA and 15% LP was found to be the most dense and least workable mix. Although limestone powder is an inert material and can`t react with cement, many fine particles (less than 16μmexist in limestone powder and filled in the interface between cement and aggregate or cement particles, thereby, increasing the density.The workability test results are presented in Table 2.

**Table 2 Fresh properties test results for all SCC mixes**

| Mix ID | Slump Flow dia. (mm) | J-ring (mm) | V-Funnel Time (sec) | L-box ($H_2/H_1$) |
|---|---|---|---|---|
| M1 | 780 | 6 | 6.1 | 1.0 |
| M2 | 740 | 7 | 7.2 | 0.98 |
| M3 | 710 | 8 | 7.9 | 0.96 |
| M4 | 670 | 9 | 8.4 | 0.92 |
| M5 | 690 | 7 | 6.8 | 0.94 |
| M6 | 670 | 8 | 7.8 | 0.93 |

### *3.2 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 two samples is taken as the representative value of compression strength for each batch of SCC. The compressive strength test results are shown in Table 3. The compressive strength of different mixes varied with the age of curing. The general trend of strength variation of all the 6 mixes is shown in Fig. 1. 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 since, in general, the density tends to increase slightly with increasing amounts of MK in concrete, mainly resulting from the filling effect of MK particles [12]. It was also observed that compressive strength varied sharply when FA was replaced by varying percentages of MK as compared to when it was replaced by varying percentages of LP. Fig. 2 shows the comparison of compressive strength of mix M2 and mix M5 having replacement of FA with 5% LP and 5% MK, respectively, with mix M1 having 30% FA. It was found that the compressive strength increased up to 26.125%, 10.67%, 9.057% and 8.16% when FA was replaced by 5% LP while it increased up to 52.37%, 21.34%, 32.75% and 30.51 % when replaced by 5% MK. The limestone powder was helpful in improving the compressive strength. The reason is that the limestone powder can promote C3S early hydration, Ca2+ can be released when C3S which exist in cement begin hydrating, and the migration ability of Ca2+ is higher than SiO2- ion clusters.On similar basis, the compressive strength of mix M3 and mix M6 having 10% LP and 10% MK, respectively, is compared with that of mix M1 having 30% FA in Fig. 3. Also, it is observed that the compressive strength is increasing as percentage of LP and MK is increasing from 5% to 10% the change is slight (Fig. 4 and Fig. 5). This is due to the fact that at early ages, Metakaolin gives higher strength due to quick hydration process. But at later ages, the fly ash is more effective in giving higher strengths.

**Table 3-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 |

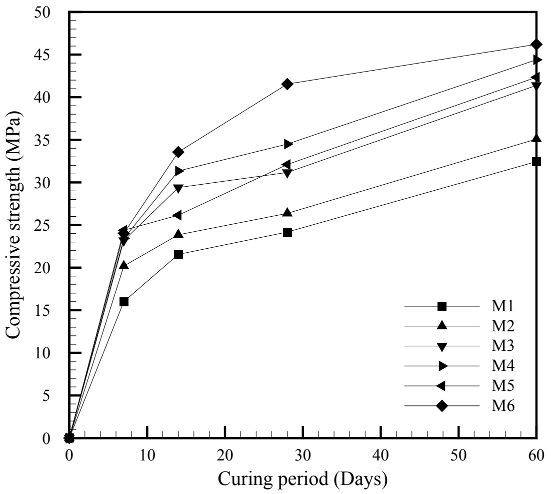


*Fig. 1 Compressive strength for all mixes at different curing ages*

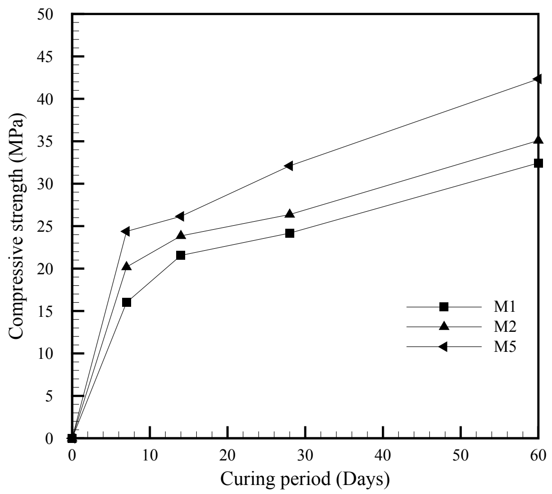


*Fig. 2 Compressive strength comparison of M1, M2 and M5*

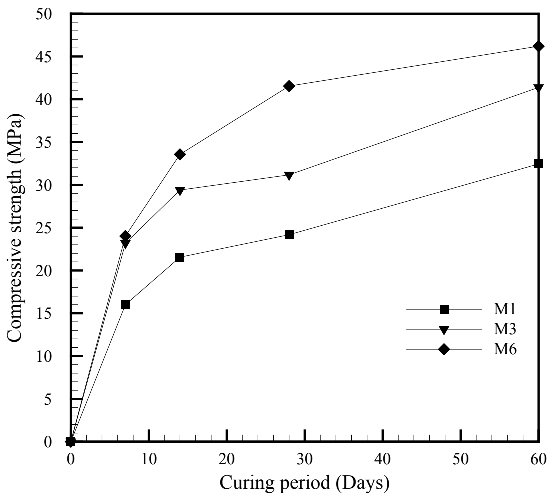


*Fig. 3 Compressive strength comparison for M1, M3 and M6*

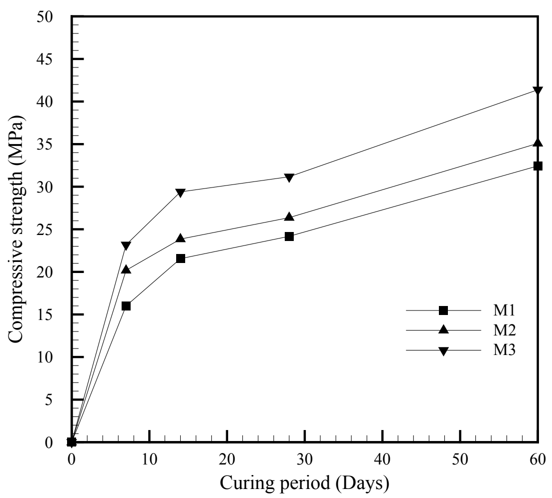


*Fig. 4 Compressive strength comparison forM1, M2 and M3*

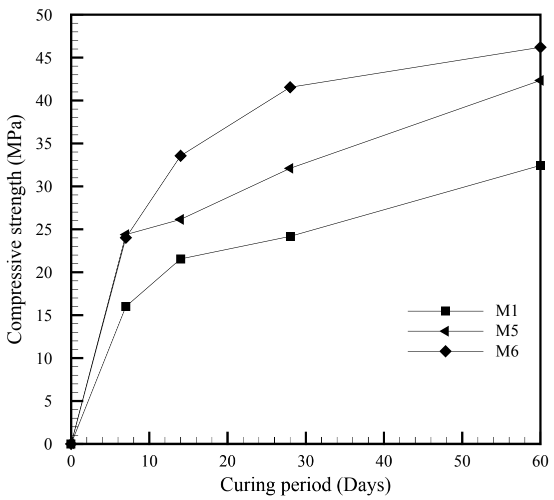


*Fig. 5 Compressive strength comparison for M1, M5 and M6*

## 4 Conclusions

SCC mixes containing different replacement levels of different admixtures were found to comply with all the workability requirements as per EFNARC (2005). The mixes had good workability and consistency at a constant w/b ratio of 0.41 and constant SP dosage of 1.0% of weight of cement. The comparison of workability test values of mixes showed that as FA was replaced by increasing percentages of LP and MK, the mixes become dense and hence less workable. This is because LP and MK which are finer than FA. The compressive strength showed an increase with increasing percentage replacement of FA with LP and MK. The effect of increase in compressive strength by replacement of FA with MK was much more than with LP. 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.

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