

Effect of Metakaolin Developed from Local Soorh on Fresh Properties and Compressive Strength of Self-Compacted Concrete

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Abstract—This paper presents the fresh properties of Self-Compacting Concrete (SCC) containing metakaolin (MK) produced by calcination of the natural material soorh of district Thatta Sind in Pakistan. Five mixes were tested, including four MK mixes replacing 5-20% of cement, with 0.38 water/binder (W/B) ratio. The fresh properties of the SCCs were evaluated using slump flow, T50, V-funnel, J ring, L-box and sieve segregation tests. Compressive strength of the control and the MK SCC was also investigated. The fresh concrete test results revealed that SCC could be developed by substituting cement with local MK, using 2% superplasticizers and without using a viscosity-modifying amplifier. The SCC with 15% replacement of cement with local MK showed maximum compressive strength, which was 10.39% higher than the control specimen's without MK.

Keywords—metakaolin; self-compacting concrete; soorh

I. INTRODUCTION

Self-compacting concrete (SCC) is a highly flowable concrete, which can be installed and compacted without any vibration in complex or dense reinforced formworks. In order to achieve such behavior, the main requirements of fresh SCC are filling ability, passing ability and very high segregation resistance. The first two properties can be achieved by using a high-range water reducer (HRWR) admixture. To secure the stability/cohesion of the mix, a large quantity of powder materials and/or viscosity-modifying admixture (VMA) is required. According to [1], the term powder is defined for materials of particle size smaller than 0.125mm, which include a fraction of aggregate additions and cement. Portland cement is a high energy-intensive product. On the other hand, about 7% of total CO₂ emissions are produced by the cement industry [2]. In addition, some disadvantages in the properties of

concrete have been reported as the cement content exceeded a specified value [3]. To minimize these negative effects, the requirement to increase powder content in SCC is usually met by using additions. For this purpose, various studies have been conducted on the usage of different additions for partially replacing cement in SCC or self-compacted mortar such as marble powder [4, 5], limestone powder [6], basalt powder [5, 6], fly ash [7–9], slag [10, 11], MK [12-16], and other materials [17-22]. Today global warming and energy crisis are major issues. The manufacture of one ton of cement emits approximately 0.8 tons of CO₂ into the atmosphere, which accounts about the 5-8% of worldwide CO₂ emissions [23, 24]. Moreover, cement production emissions include also SO₃ and NO_x [24, 25]. Cement production requires huge energy, as it needs temperatures of 1600-1900°C, adding up to the energy crisis in many countries, such as Pakistan, where the cost of cement is rising resulting in an overall rise in the construction cost. This study proposes a method that increases the properties of SCC and reduces the cement production, reducing consequently both CO₂ emissions and construction cost, by replacing cement with local MK.

II. MATERIALS USED

A. Cement

Ordinary Portland cement (OPC) from a brand named Lucky, has been used in this research. Its chemical composition and physical properties are shown in Table I.

B. Fine Aggregates

The aggregates used are composed of hill sand passing from 4.75mm, crushed stone passing from 12mm and retained on 4.75mm sieves.

C. Local Metakaolin

Local metakaolin (MK) was produced from local natural material soorh available at district Thatta Sindh in Pakistan, by calcination at 800°C for 2 hours. The MK was used as cement replacement at various dosages, after sieving it from a sieve No 325. The chemical composition and physical properties comparison of OPC, soorh and developed MK are presented in Table I.

TABLE I. CHEMICAL COMPOSITION OF MATERIALS [26]

Constituents	Percentage by cement weight	Percentage by soorh weight	Percentage by MK weight
SiO ₂	20.78	55.89	62.18%
Al ₂ O ₃	5.11	23.51	21.67 %
CaO	60.89	-	3.01%
MgO	3	3.53	3.41%
Fe ₂ O ₃	3.17	8.15	6.05%
K ₂ O	-	5.89	1.85%
Na ₂ O ₃	-	1.89	1.03%
TiO ₂	-	1.14	1.03%
In ₂ O ₃	-	-	0.8%
LOI (%)	1.71	7.4	0.5
Blaine specific surface area (cm ² /g)	3008	2101	2339

III. MIXTURE PROPORTION

Based on the W/B ratio of 0.38, SCC mixtures were prepared following [1]. The reference concrete was prepared by only OPC while in the other mixtures OPC was partially replaced by MK at 5%, 10%, 15% and 20% of the cement's weight. Details of mix proportions are exhibited in Table II.

TABLE II. MIX PROPORTIONS

Concrete mix	Cement (kg/m ³)	MK (kg/m ³)	Total binder (kg/m ³)	Water (kg/m ³)	FA (kg/m ³)	CA (kg/m ³)	SP (%)
CM	500	-	500	190	900	650	2
MK5	475	25	500	190	900	650	2
MK10	450	50	500	190	900	650	1
MK15	425	75	500	190	900	650	3
MK20	400	100	500	190	900	650	3

M/B=0.38

IV. TEST PROCEDURE

The fresh properties of SCC have been studied out by using the method specified in [1]. The filling ability tests respected slump flow using V-funnel and T₅₀ flow time test, while passing ability tests, such as J-Ring and L-box, were also carried out. Moreover, sieve segregation test was carried out. Various trial mixes with and without superplasticizers were prepared to develop the SCC. Twenty eight days after the development of the control and the modified MK SCC, the compressive strength of concrete was evaluated using BS EN 12390-3.

V. RESULTS AND DISCUSSION

A. Slump Flow

Slump flow test was used to assess the horizontal free flow of SCC in the absence of obstructions. The diameter of the concrete circle is a measure of the filling ability of concrete [1].

The results of slump flow test for the mixtures are shown in Figure 1.

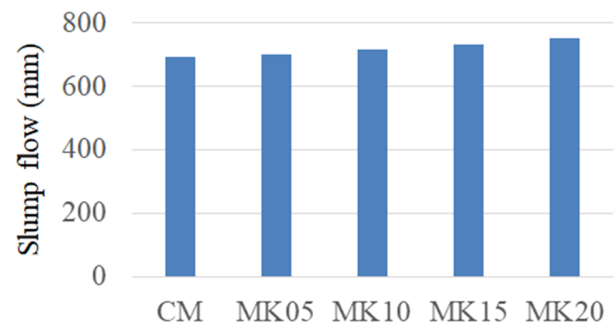


Fig. 1. Slump flow of control and metakaolin SCC

The recommended values of slump flow in [1] are 650-850mm. Without using superplasticizers and using only 1% superplasticizers, the observed slump flow of control and MK SCC was less than the recommended. By using 2% superplasticizers the slump flow of control and MK SCC was within the recommended range. As the quantity of MK increased the slump flow increased due to MK's less specific surface area as compared to cement.

B. V-Funnel

This test was developed in Japan and used in [27]. The V-funnel test is used to determine the filling ability (flowability) of the concrete with a maximum aggregate size of 20mm. The results of the V-Funnel test are shown in Figure 2.

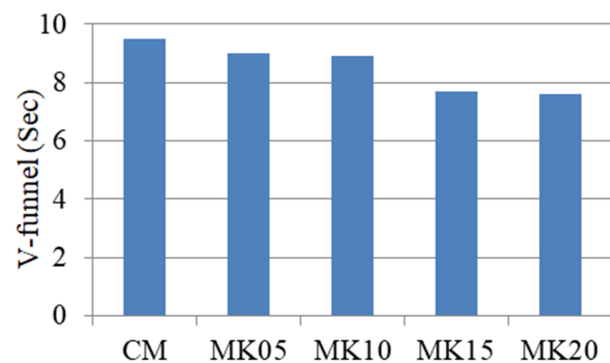


Fig. 2. V-funnel of control and metakaolin self compacted concrete

The recommended values [1] of the V-funnel are 6-12sec [1]. Without using superplasticizers and using 1% superplasticizers, the observed V-funnel flow of the control and the MK SCCs exceeded the recommended range. By using 2% superplasticizers the V-funnel of the control and the MK SCC were within the recommended range. As the quantity of MK increased, the V-funnel time decreased.

C. T50 Flow

T50 flow test was used to assess the horizontal free flow of SCC in the absence of obstructions. The results of the T50 flow tests are shown in Figure 3.

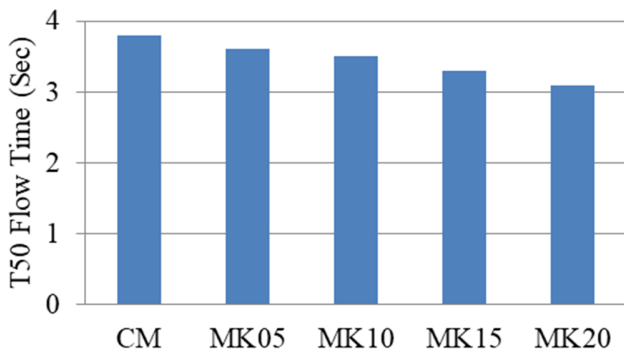


Fig. 3. T50 flow of control and metakaolin SCC

The recommended values of T50 flow time are 2-5sec [1]. Without using superplasticizers and using 1% superplasticizers, the observed T50 flow time of the control and the MK SCC exceeded the recommended. By using 2% superplasticizers, the T50 values of the control and the MK SCC were observed within the recommended range. As the quantity of MK increased the T50 flow decreased.

D. J-Ring

The J-Ring test was developed at the University of Paisley and it is used to determine the passing ability of the concrete. The results J-Ring tests are shown in Figure 4.

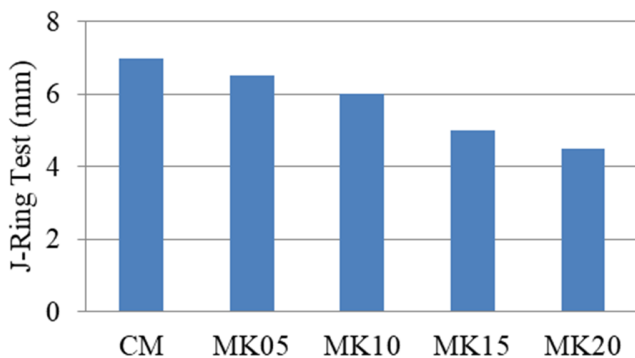


Fig. 4. J-Ring of control and metakaolin self compacted concrete

The recommended values of J Ring test [1] are 0-10mm. Without using superplasticizers and using 1% superplasticizers, the observed values of the control and the MK SCC exceeded the recommended. By using 2% superplasticizers the observed J-Ring values of the control and the MK SCC were within the recommended range. As the quantity of MK increased, J-Ring decreased.

E. L-Box

L-Box test is used to assess the flow of the concrete and the extent to which it is subject to blocking by reinforcement. The results of L-Box tests are shown in Figure 5. The recommended values for the L-Box test are 0.8-1.0. Without using superplasticizers and using 1% superplasticizer, the observed values of control and the MK SCC exceed the recommended range. By using 2% superplasticizers the L-box value of control and the MK SCC were observed within the recommended

range. Again, as the quantity of MK increased the L-box is decreased.

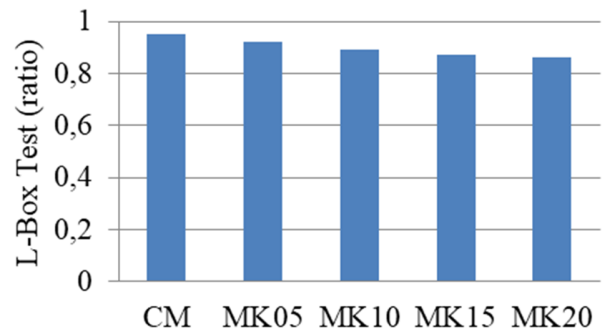


Fig. 5. L-Box ratio of control and metakaolin self compacted concrete

F. Sieve Segregation Test

The sieve segregation test was developed by GTM to assess segregation resistance (stability). The results of the sieve segregation tests are shown in Figure 6.

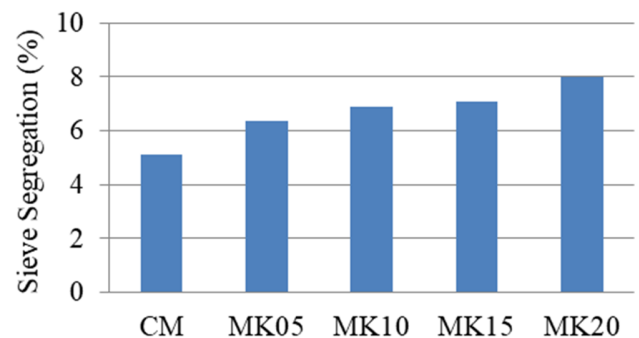


Fig. 6. Sieve segregation of control and metakaolin self compacted concrete

The recommended range of sieve segregation is 0-12% [1]. Without using superplasticizers and using 1% superplasticizers, the observed values of the control and the MK SCC exceeded the recommended range. By using 2% superplasticizers, the J-Ring values of control and MK SCC were within the recommended range. As the quantity of MK increased the sieve segregation increased.

G. Compressive Strength

The results of compressive strength tests are shown in Figure 7. The test results show that the compressive strength of 5-15% MK SCC increased compared to the control or the other MK SCCs. The 15% MK mixture exhibited maximum compressive strength, being 10.39% higher than the one of the control mix.

VI. CONCLUSION

This study evaluated the fresh properties of SCC containing local MK. Results showed that all the fresh properties of SCC containing local MK with 2% superplasticizers like passing ability, filling ability, and sieve segregation tests are within the recommended range. The fresh concrete test results revealed

that SCC could be developed substituting cement with local MK up to 20%, by using 2% superplasticizers, without using any viscosity-modifying admixture. Compressive strength of 5-15% MK mixtures was increased, while in higher MK mixtures the compressive strength decreased. The 15% MK SCC had the maximum compressive strength, which was 10.39% higher than the control mix without MK.

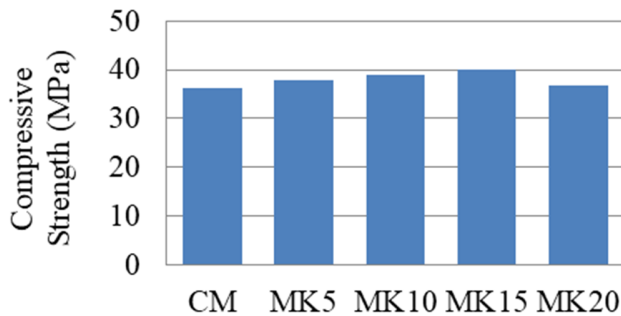


Fig. 7. Compressive strength of control and metakaolin Self compacted concrete

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