Development of Mix Proportions for Different Grades of Metakaolin Based Self Compacting Concrete

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***Abstract*— This experimental study demonstrates that metakaolin (MK) can be successfully used as an admixture in the preparation of self-compacting concrete (SCC). In order to prepare suitable mix proportions for different grades of MK based SCC, investigations were undertaken replacing cement with 0%, 10%, 15%, 20%, 25% and 30% of MK and with different percentages of super plasticizer (Glenium B233). As per the European guidelines for Self-compacting concrete, slump flow test, V-funnel test and L-box test have been carried out on fresh properties of MK based SCC. The compressive strength, split tensile strength and flexural strength of the specimens have been analyzed for 7-days and 28 days curing. And finally mix proportions have been recommended for low, medium and high strength grades of MK based SCC. The fresh concrete test results revealed that by substituting different percentages of MK in SCC, satisfactory workability and rheological properties can be achieved, even though no viscosity modifying agent was needed. In general, it seems that MK can be considered as suitable replacement regarding to the economic efficiency, fresh and hardened properties of MK based SCC.**

Keywords—Self Compacting concrete, Metakaolin, Fresh and Hardened properties,super plasticizer,viscosity modifying ad mixture.

I. INTRODUCTION

The development of specifying a concrete according to its performance requirements, rather than the constituents and ingredients has opened innumerable opportunities for producers of concrete and users to design concrete to suit their specific requirements. One of the most outstanding advances in the concrete technology over the last decade is "self compacting concrete" (SCC). SCC is a high flowable concrete, which can be placed 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 super plasticizer admixture. To secure stability/cohesion of the mix, a large quantity of powder materials and/or viscosity-modifying admixture (VMA) is required. The hardened SCC is dense, homogeneous and has the same engineering properties and durability as that of traditional vibrated concrete. The use of SCC eliminates the need for compaction thereby saves time, reduces labour costs and conserves energy. Furthermore use of SCC enhances surface finish characteristics. According to EFNARC [1], the term powder is defined for materials of particle size smaller than 0.125 mm which includes fraction of aggregate, additions and cement. Portland cement is a highly energy-intensive product. On the other hand, CO2 emanations are produced by the cement industry. In addition, some disadvantages in the properties of concrete have been reported as the cement content exceeded a specified value [2]. To minimize these negative effects, the requirement to increase powder content in SCC is usually met by the use of additions. For this purpose, substantial studies have been performed on the usage of different additions for partially replacement of cement in SCC or self-compacted mortar such as marble powder, limestone powder, basalt powder, fly ash and slag. For instance, for fast track construction, early age compressive strength reduction may be unacceptable. The utilization of high pozzolanic activity materials seems to be an efficient choice to overcome this difficulty.

Metakaolin (MK) can also be considered as addition in the production of SCC. MK (commercially available since the mid-1990s [3]) is a thermally activated alumino-silicate material mostly produced by calcination of kaolin clay at temperature ranging from 700^0C to 850^0C [4] without production of CO2 [5, 6]. MK processing involves lower temperatures than Portland cement which may yield a lower cost on MK production. But, due to the low production of MK, the price will be raised up [6]. Nonetheless, the usage of MK in concrete can be reasonable due to its environmental benefits [5, 6] and positive effect on the both short and long terms strength of concrete.

In this respect, it has been reported that the use of MK in concrete can increase the compressive strength of mixtures especially during early ages of hydration. Poon et al. [7] showed that at early ages, the higher pozzolanic activity of MK results in a higher rate of strength development and pore structure refinement when compared to silica fume -or fly ash- blended cement pastes. However, at the same level of replacement, MK concrete had similar strength after 28 days with respect to silica fume concrete [8]. Kim et al. [9] measured the concrete strength with Korean MK and suggested that 10% replacement of MK is an appropriate replacement.

However, different aspects of normal concrete containing MK have been reported in literature but to the authors' knowledge, the performance of MK in SCC is not well documented, particularly over a wide range of grades. In particular, the effects of MK as a high surface area mineral addition on the workability as well as mechanical properties of SCC need to be fully recognized. So, the present study is an effort to characterize the fresh and hardened properties of SCC containing MK. For this purpose, several tests concerning slump flow, V-funnel and L-box were conducted to assess the workability of the matrix. Furthermore, hardened properties were evaluated by compressive strength, splitting tensile strength and flexural strength.

II. EXPERIMENTAL PLAN

A. Materials

The 53 grade ordinary Portland cement and MK (brought from 20 microns Ltd, Gujarat) were used as binder materials in the production of concrete mixes. The chemical compositions and physical characteristics of binders are given in Table 1. The fine aggregate was natural river sand. Limestone gravel a nominal maximum size of 12 mm was used as coarse aggregate. Poly carboxylic ether based admixture namely Glenium B233 (brought from BASF) with relative density 1.08 (at 25^{0}C) was used to enhance the flow ability of the mixtures. In addition, viscosity modifying agent namely Glenium stream2 was used for 0% replacement SCC.

Table 1: *Chemical compositions and physical characteristics of binders*

Chemical Composition (%)	Cement	MK
Silicon dioxide (SiO_2)	17-25	60-65
Aluminum oxide (Al_2O_3)	3-8	30-34
Iron oxide (Fe_2O_3)	0.5-6	1
Calcium oxide (CaO)	60-67	0.2-0.8
Magnesium oxide (MgO)	0.1 – 4.0	0.2-0.8
Sodium oxide (Na_2O)	0.4-1.3	0.5-1.2
Potassium oxide (K_2O)	-	0.5-1.2
Sulphur	1.3	-
Physical properties		
Specific surface(m^2/kg)	0.33	2.54
Specific gravity	3.15	2.6

B. Mixture proportions

SCC mixtures were designed in three groups which defined as M60, M40 and M20, respectively and were shown in Table 3, Table 4 and Table 5 respectively. In each group, the reference concrete was prepared by only Portland cement while in the remaining mixtures Portland cement was partially replaced with the MK. On the basis of preliminary experimental investigation, MK was partially replaced at 10%, 15%, 20%, 25% and 30% by weight of cement. Moreover, in the mixes without MK, VMA has been used to achieve proper viscosity and controlling the rheological properties of the concrete mixtures. In all mixes, the dosage of super plasticizer was adjusted in order to obtain suitable flow ability without segregation.

For mix preparation, the process for free-fall mixer stated in EFNARC [1] was employed to produce SCC with MK. In this way, approximately two thirds of the mixing water is added to the mixer. This is followed by the aggregates and cement. When a uniform mix is obtained, the remaining mixing water and the super plasticizer are added. Where VMA is used, this should be added after the super plasticizer and just prior to final consistence adjustment with water.

III. TEST PROCEDURE

A. Fresh concrete tests

In the present study, the slump flow, V-funnel and L-box tests were performed according to the procedure recommended by EFNARC committee [1]. Slump flow test has been proposed to assess filling ability of concrete in the absence of obstructions. According to EFNARC [1], there are typically three slump flow classes for a range of applications which are given in Table 2. Slump flow is not a suitable factor to exactly exhibit the fresh characteristic of SCC. But, if the slump flow is kept within a desirable range, it is possible to evaluate the requirements of SCC. SCC containing MK with slump flow values between 660 and 750 mm were proposed in the present study. Viscosity can be assessed by the T50 or V-funnel times. On the basis of EFNARC [1], there are two viscosity classes which determined by V-funnel and T50 flow times (Table 2). The L-box test is utilized to determine passing ability of SCC when flowing through confined or reinforced areas. The passing ability classifications according to EFNARC [1] were presented in Table 2. The workability test results were presented in Table 3, Table 4 and Table 5 respectively.

Table 2: Slump flow, viscosity and passing ability classes with respect to EFNARC [1].

Class	Slump flow (mm)	
Slump flow classes		
SF1	550–650	
SF2	660–750	
SF3	760–850	
Class	T50(sec)	V-funnel(sec)
Viscosity classes		
VS1/VF1	≤2	≤8
VS2/VF2	>2	9–25
Passing ability classes		
PA1	≥0.8 with two rebar	
PA2	≥0.8 with three rebar	

Table 3: Mixture proportions and fresh Properties of SCC-M60

	MIX No.	H-1	H-2	H-3	H-4	H-5	H-6
Mixture Proportions	MK %	0	10	15	20	25	30
	Cement kg	600	540	510	480	450	420
	C.A kg	660	660	660	660	660	660
	F.A kg	810	810	810	810	810	810
	Water kg	190	190	190	190	190	190
	MK kg	0	60	90	120	150	180
	S.P %	1.3	1.5	1.4	1.3	1.3	1.2
SLUMP TEST	SLUMP mm	725	690	710	705	700	685
	T-50 Sec	4.28	4.93	4.95	5.11	5.24	6.13
V-FUNNEL	T0 Sec	7.01	6.08	6.28	7. 95	10.54	12.02
	T5min Sec	8.56	8.86	8.90	10.12	12.67	14.14
L-BOX	H2/H1	0.86	0.84	0.97	0.95	0.96	0.98

Table 4: Mixture proportions and fresh Properties of SCC-M40

	MIX No.	M-1	M-2	M-3	M-4	M-5	M-6
Mixture Proportions	MK %	0	10	15	20	25	30
	Cement kg	500	450	425	400	375	350
	C.A kg	800	800	800	800	800	800
	F.A kg	800	800	800	800	800	800
	Water kg	190	190	190	190	190	190
	MK kg	0	50	75	100	125	150
	S.P %	1.3	1.5	1.4	1.4	1.2	1.1
SLUMP TEST	SLUMP mm	660	680	690	685	670	660
	T-50 Sec	3.22	3.89	3.95	4.00	4.65	5.05
V-FUNNEL	T0 Sec	11.95	9.34	10.25	12.01	12.60	12.99
	T5min Sec	14.26	12.95	13.50	15.24	15.67	16.14
L-BOX	H2/H1	0.89	0.81	0.83	0.90	0.81	0.80

Table 5: Mixture proportions and fresh Properties of SCC-M20

	MIX No.	L-1	L-2	L-3	L-4	L-5	L-6
Mixture Proportions	MK %	0	10	15	20	25	30
	Cement kg	400	360	340	320	300	280
	C.A kg	780	780	780	780	780	780
	F.A kg	844	844	844	844	844	844
	Water kg	180	180	180	180	180	180
	MK kg	0	40	60	80	100	120
	S.P %	0.80	0.85	0.82	0.76	0.70	0.62
SLUMP TEST	SLUMP mm	690	700	710	700	690	620
	T-50 Sec	3.33	3.68	3.55	4.22	5.92	6.84
V-FUNNEL	T0 Sec	6.36	6.94	7.81	9.84	12.64	13.64
	T5min Sec	8.95	9.65	11.24	12.63	16.01	16.73
L-BOX	H2/H1	0.96	0.94	0.97	0.96	0.89	0.86

B. *Hardened concrete tests*

After the completion of initial fresh concrete tests, the fresh concrete was poured into the molds. Specimens were de-molded one day after casting and were placed under water curing regime until the testing day. The average compressive strength, split tensile strength and flexural strength of cubes, cylinders and beam specimens at the age of 7 and 28 days were observed and tabulated in Table 6, Table 7 and Table 8.

Table 6: Hardened Properties of SCC-M60

Properties	H-1		H-2		H-3		H-4		H-5		H-6	
Curing age	7d	28d	7d	28d	7d	28d	7d	28d	7d	28d	7d	28d
Compressive Strength (N/mm^2)	55.2	61.2	54.2	61.6	59.3	64.7	47.5	56.2	45.0	50.3	43.6	48.7
Split tensile Strength (N/mm^2)	3.6	4.2	5.2	5.6	6.5	6.9	4.3	5.3	3.9	4.8	3.8	4.1
Flexural Strength (N/mm^2)	4.6	4.7	5.1	5.3	4.9	5.8	4.3	4.5	4.1	4.4	3.7	4.0

Table 7: Hardened Properties of SCC-M40

Properties	M-1		M-2		M-3		M-4		M-5		M-6	
Curing age	7d	28d	7d	28d	7d	28d	7d	28d	7d	28d	7d	28d
Compressive Strength (N/mm^2)	34.3	46.6	38.1	48.4	39.2	52.5	35.4	42.0	31.2	37.1	28.7	29.6
Split tensile Strength (N/mm^2)	3.0	4.8	4.2	6.3	4.6	6.8	3.9	4.6	3.7	4.9	3.5	4.5
Flexural Strength (N/mm^2)	5.2	7.7	7.9	9.2	8.5	9.9	6.9	8.5	5.4	7.3	5.1	6.8

Table 8: Hardened Properties of SCC-M20

Properties	L-1		L-2		L-3		L-4		L-5		L-6	
Curing age	7d	28d	7d	28d	7d	28d	7d	28d	7d	28d	7d	28d
Compressive Strength (N/mm^2)	20.1	29.4	29	33.2	30.5	34.3	21.3	24.0	20.4	22.7	19.7	20.1
Split tensile Strength (N/mm^2)	2.0	2.1	1.9	2.1	2.2	3.1	1.6	1.8	1.5	1.7	1.4	1.6
Flexural Strength (N/mm^2)	2.3	2.6	2.6	3.1	2.7	3.2	2.4	2.6	2.3	2.4	1.9	2.1

IV. RESULTS AND DISCUSSIONS

A. *Fresh concrete results*

The fresh characterizations of SCC containing MK were studied and the results were summarized in Tables (3, 4, 5).

A1. Slump flow diameter and T50 time

As can be seen in Tables (3, 4, 5), the slump flow values for different concrete mixes were measured in the range of 660–750 mm. According to EFNARC (Table 2), all concrete mixtures under investigation can be categorized as slump flow class 2 (SF2). The concrete mixture at this class of slump flow is suitable for many normal applications such as walls and columns. The flowability of the mixtures was reduced with the higher proportion of MK replacement, as indicated in Tables (3, 4, 5). For instance, at a given superplasticiser dosage, the slump flow of SCC-M20 was measured to be 690 mm while this could be decreased to 620 mm when MK introduced to 30%. This could be explained by the higher surface area of the MK particles compared to Portland cement.

During the slump flow test, the aggregate segregation and bleeding was visually inspected. In addition, uniformity in the distribution of coarse aggregate can be visually observed by inspecting the broken split tensile test specimens which indicate proper segregation resistance of mixtures. As presented in Tables (3, 4, 5), the T50 flow times was measured in the range of 3–7 s. The incorporation of MK increased T50 flow time of the SCC.

A2. *V-funnel time*

The V-funnel times of different concrete groups were presented in Tables (3, 4, 5). From this table, it can be seen that the V-funnel times for M60, M40 and M20 concrete groups were in the range of 6.08–12.02 s, 9.34–12.99 s and 6.94–13.64 s, respectively.

Regarding to the EFNARC [1], a V-funnel flow time higher than 25 s did not recommended (Table 2). As presented in Tables (3, 4, 5), the V-funnel flow times of all mixtures satisfy this requirement. The results presented in Tables (3, 4, 5), the V-funnel time shows a distinct tendency to increase with increasing MK content. From the results, it can be concluded that in the SCC based MK, no viscosity modifying agent was needed.

A3. *Blocking ratio (L-box test)*

From Tables (3, 4, 5), SCC mixtures containing MK were mostly shows satisfactory blocking ratio as per EFNARC recommendation (Table 2).

An overview on the fresh properties of SCC containing MK of low(M20), medium(M40) and high(M60) grade SCC reveals that MK replacement generally satisfy the fresh-state behavior requirements related to high segregation resistance, deformability, passing and filling abilities.

B. Hardened concrete results

The hardened concrete tests like compressive strength, splitting tensile strength and flexural strength were performed for all mixtures since they were molded without any compaction and tabulated in Tables (6, 7, 8)

B1. *Compressive strength*

The compressive strength for M60, M40 and M20 concrete groups respectively shown in Tables (6, 7, 8). As can be expected the compressive strength of all mixtures enhanced by the age of concrete. Among different MK replacement level at M60, M40 and M20 SCC groups, the most remarkable strength development was found to attain for MK replacement at the levels of 10–15%. Nonetheless, concerning the economic efficiency, it seems that 10% MK can be regarded as a suitable replacement.

B2. *Splitting tensile strength*

In a similar trend to that observed in compressive strength, SCC mixtures containing 10–15% MK provided better performance in terms of splitting tensile strength for for M60, M40 and M20 concrete groups respectively shown in Tables (6, 7, 8).

B3. *Flexural strength*

The same tendency as observed in compressive strength and split tensile strength, SCC mixtures containing 10–15% MK provided better performance in terms of flexural strength for M60, M40 and M20 concrete groups respectively shown in Tables (6, 7, 8).

V. CONCLUSION

This study was carried out to evaluate the fresh and hardened properties of SCC containing MK for developing different grades of SCC. The following conclusions can be drawn:

(1) SCC containing MK with slump flow values between 660 and 750 mm can be produced by adjusting the high range water reducer dosage. SCC with this range of slump flow can practically be used in many applications.

(2) SCC with MK can be produced with proper stability without using viscosity modifying agent.

(3) The presence of MK improved both early ages and long term compressive strength of SCC.

(4) Splitting tensile strength and flexural strength development followed the same pattern as compressive strength, though the tensile and flexural strengths development is rather small.

(5) Based on the overall effects of MK, it seems that 10% to 15% replacement of MK can be regarded as a suitable replacement and have been recommended for low, medium and high strength grades of MK based SCC.

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