Optimum Dose of Binary Admixtures in Self Compacting Concrete

Deep Tripathi, Rakesh Kumar, P. K. Mehta and **Amrendra Singh**

Abstract: Self Compacting Concrete (SCC) is a high performance concrete and is becoming popular day by day in the field of construction. Generally, the quantity of binder is more in SCC than the normal concrete. The application of pozzolanic material is found successful in such type of concrete. Generally, Ordinary Portland Cement (OPC) is replaced with Fly Ash (FA). In this paper, the results of an experimental programme to evaluate the performance of SCC are presented and optimum dose of binary admixture was found. For the determination of the optimum dose, concrete cubes of 100mm sizes were cast. The replacement level of OPC by FA was varied as- 5, 10, 15 and 20%, by mass. The OPC was also replaced separately by Metakaolin (MK) - 5, 10, 15 and 20%, by mass. Further, the OPC was replaced by the binary admixture (FA+MK). The workability and strength of SCC of grade M25 (Referral concrete- RC) and the concrete using the binary admixtures were studied. All SCC mixes were tested for workability as recommended by EFNARC i.e. Slump flow, T50 time flow, V-funnel, L-box, U-box and J-ring. The workability of SCC mix increases with FA and decreases gradually as MK content is increased. The optimum replacement level of OPC by binary admixture is 25% (FA-15% + MK-10%) with respect to compressive strength. The water absorption of cubes was also examined. It is concluded that a high strength and economical SCC could be developed by incorporation of FA and MK.

Index Terms*: *Binary Admixtures, Fly ash (FA), Metakaolin (MK), Self Compacting Concrete (SCC).

I. INTRODUCTION

Presently, concrete is most widely used building material. So it is an important area for further research. The SCC is a special type of concrete which flows under its own weight and there is no need of vibration for compaction. The SCC is developed to overcome workability problem, which is a commonly faced in congested reinforcement areas. Further, it enhances the durability of structures. SCC was first developed in Japan in 1983, and now it was used throughout the world due to its better flowability and self compaction properties. It is a concrete which gives better surface finish, requires less skilled man power, leads to faster construction and easier placing. FA is a waste material which is collected from hopper of a chimney after burning the coal in thermal power plants. It has pozzolanic properties due to which it is used in SCC preparation. FA gives adequate workability and durability to concrete structure and it also reduces the cost of construction. The use of FA and blast furnace slag in SCC reduces the superplasticizer dosage to obtain similar slump flow compared to concrete made with OPC only [1]. It is reported that it improves the rheological properties of SCC and reduces the cracking of concrete due to the less heat of hydration [2]. Ping Duan et al. [3] concluded that partial replacement of OPC by FA and MK improves the mechanical properties. Further, MK also optimizes the microstructure and reduces damage due to sulphate attack. MK is a highly reactive pozzolanic material which is produced by calcinations of kaolinite in air at moderate temperatures (600ºC-900ºC) [4]. In previous studies, it was found that workability, rheological properties and compressive strength of SCC improved satisfactorily by incorporating MK [5]. The micro and macro level properties of concrete improve due to inclusion of MK in control mix, micro level analysis of SCC was done by X-Ray Diffraction (XRD) [6]. It is reported that MK is a poorly crystallized white powder which has a specific surface of 12,000 m^2/kg and an average particle size between 1.5 and 2.5 micrometer [7]. The particle size of MK lies between fly ash and silica fume [8]. As the MK content increases, the corresponding 28 day compressive strength, the rheological parameters (plastic viscosity and yield stress), and the demand for high range water reducing chemical admixture also increases [9]. The behaviour of every material is related to its microstructure. Micro structure analysis is the best way to decide the performance of concrete because microstructure controls the properties of concrete and it also governs the behaviour of concrete. The XRD method is one of the techniques used for microstructural analysis. XRD is used to identify the compounds and minerals present in powdered specimen. The strength and permeability of the SCC specimens incorporating RHA were analysed by micro structural analysis. For 15% RHA, XRD and SEM analysis shows that increased formation of C-S-H gel which explains increase in compressive strength and improves pore structure of concrete specimen [10]. The main aim of this research is to optimize the binary admixtures i.e. FA and MK with respect to strength of the concrete mix and to study its effect on the properties of fresh and hardened concrete.

II. MATERIAL AND THEIR PROPERTIES

The 43 grade of OPC (Brand- M P Birla) was used in this experimental programme. The Physical properties of OPC i.e. normal consistency and specific gravity were found to be 27% and 3.14, respectively. The initial and final setting times were 45 and 480 minutes, respectively, which conforms to the

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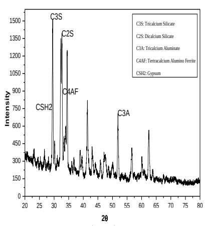
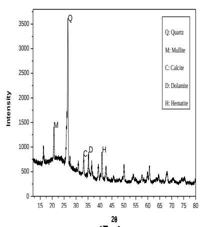
requirements of IS 8112-1989 [11]. The compressive strength of 50 cm^2 cement mortar cube at 28 days was found to be 51.95 N/mm^2. The natural river sand of rounded particle shape and smooth surface texture was used for making RC which conforms to zone II as per IS-383-1987 [12]. The specific gravity and bulk density were found to be 2.65 and 1680 kg/m^3, respectively. Coarse aggregate of sizes 10 mm and 20 mm, having specific gravity 2.66 and 2.7, respectively, and water absorption of 1.0% and 0.9%, respectively (conforming to IS 383-1987 [12]) were used. The fineness modulus of fine aggregate was 2.7 and for the coarse aggregates of sizes 10 mm and 20 mm it was 6.7 and 7.2, respectively. Class F- FA of grey colour having specific gravity 2.13 and confirming to IS 3812-2000 [13], procured from NTPC Unchahar, U.P., was used in this study. MK (Off-white colour) was procured from Kaolin Techniques Pvt. Ltd, Bhuj, Kutch, Gujarat. The specific gravity and bulk density of MK was reported as 2.5 and 0.9 gm/mm^2 respectively. A polycarboxylic ether based Master Rheobuild 817RL superplasticizer having density approximately 1.08 and pH approximately 5.0 was used. Tap fresh potable water was used in the mix design and curing of specimens. The chemical properties of OPC, FA, and MK are given in Table 1. The XRD analysis of all binders was also carried out and the results are presented in Fig. 1. From XRD analysis of OPC it was concluded that main products were C_3S and C_2S and for FA and MK main product is quartz.

Table I. Chemical Properties of OPC and Mineral Admixtures

S. No.	Chemical Composition (%)	OPC	FA	MK
1	Silicon dioxide (SiO_2)	20.05	55.40	51.46 36.05
2	Aluminum oxide (Al_2O_3)	05.28	19.98	2.21
3	Iron oxide (Fe_2O_3)	04.12	6.82	
4	Calcium oxide (CaO)	61.95	4.19	0.81
5	Magnesium oxide (MgO)	02.78	2.03	0.18
6	Sodium oxide (Na_2O)	0.24	0.61	0.28
7	Potassium oxide (K_2O)	0.95	1.92	0.74
8	Loss of ignition	3.12	2.41	0.96



(a)



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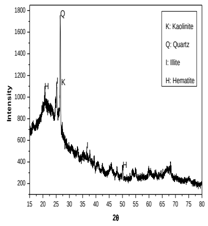

(c)

Fig.1. X- Ray Diffraction of (a) OPC, (b) FA and (c) MK

III. METHODOLOGY

In this experimental study, SCC concrete mix of grade M25 was prepared using 43 grade OPC (RC) confirming to EFNARC specifications [14]. Other mixes were also prepared in which OPC was replaced in part by FA and MK to find the optimum replacement percentage of OPC with respect to compressive strength. The flowability of concrete mixes was checked at different replacement levels. Slump flow, T50 slump flow, V-funnel, L- box, U- box and J-ring experiments were performed to find the properties of fresh concrete mixes to act as SCC. 100 mm cubes of different compositions were cast. The compressive strength of different mixes was determined at 7 days and 28 days to find the optimum dose of the binary admixtures.

A. Mix Proportion

M25 grade SCC mixes were prepared using constant Water/Binder ratio (W/B) of 0.43 and the total binder content was kept constant (450 Kg/m^3). The quantity of fine aggregate, coarse aggregate and dosage of superplastisizer were 890 Kg/m^3, 750 Kg/m^3 and 4.95 Kg/m^3, respectively. The final mix proportion was 1:1.98:1.66 (Binder: Fine aggregate: Coarse aggregate). Total 150 cubes were cast for different replacement levels of OPC by FA, MK, and FA+MK. The replacement level of OPC with FA was- 5, 10, 15and 20%, by mass. The replacement level of OPC with MK was- 5, 10, 15and 20%, by mass. For each replacement level of OPC with FA, replacement level of MK was also varied from 0-20%, at an interval of 5%.

B. Fresh Concrete Properties

The properties of different fresh concrete mixes of SCC were determined. For this, different types of concrete mixes, specific tests were performed to check the flowability, filling ability and passing ability. Slump flow test was performed to check the flowability of concrete mix. Diameter of slump and T_{50} time was measured as per EFNARC [14] guidelines/recommendations. The photo graph is shown in Plate-1. V-Funnel test was performed to check the filling ability of SCC [14]. The test apparatus is shown in Plate-2. L-box, U-box and J-ring tests were performed to check the passing ability of SCC and the photographs are shown in Plates-3, 4 and 5, respectively. The various mix proportions and the workability parameters are presented in Table 2.

C. Hardened Concrete Properties

The 7 and 28-days compressive strength of concrete cubes were determined on compression testing machine of capacity 2000 KN. The load was applied at a rate of approximately 140 kg/cm^2/min, as per IS: 14858-2000 [15].

D. Water Absorption Test

The water absorption tests were carried out of all concrete mixes to determine the change in weight (%), as given by equation (1). If A is the weight of concrete cube at 7 or 28 days curing and B is the weight after demoulding,

$$\text{Water Absorption (\%)} = \frac{A-B}{B} \times 100 \qquad (1)$$

IV. RESULT AND DISCUSSION

The results of all the tests are presented in Table. II

Table II. Mixture Proportioning and Workability Parameter

Mixture details	W/B	OPC (Kg/m^3)	FA (Kg/m^3)	MK (Kg/m^3)	Water (Kg/m^3)	Slump Flow (mm)	T_{50} time (sec)	V-funnel (sec)	L-box (mm)	U-box (mm)	J-ring (mm)
RC	0.43	450.0	0.0	0.0	198	670	4.5	11.5	0.85	16.0	6.0
FA0MK5	0.43	427.5	0.0	22.5	198	660	4.8	12.0	0.83	17.0	6.5
FA0MK10	0.43	405.0	0.0	45.0	198	650	4.9	12.1	0.82	18.0	6.9
FA0MK15	0.43	382.5	0.0	67.5	198	640	5.0	12.2	0.81	19.0	7.0
FA0MK20	0.43	360.0	0.0	90.0	198	630	5.1	12.3	0.80	20.0	7.6
FA5MK0	0.43	427.5	22.5	0.0	198	680	3.0	11.0	0.90	15.0	5.4
FA5MK5	0.43	405.0	22.5	22.5	198	670	3.2	11.5	0.89	16.5	5.9
FA5MK10	0.43	382.5	22.5	45.0	198	650	3.4	11.7	0.86	17.0	6.0
FA5MK15	0.43	360.0	22.5	67.5	198	640	3.5	12.0	0.85	17.4	6.8
FA5MK20	0.43	337.5	22.5	90.0	198	630	3.6	12.5	0.83	18.0	7.0
FA10MK0	0.43	405.0	45.0	0.0	198	700	2.5	10.0	0.95	14.8	5.0
FA10MK5	0.43	382.5	45.0	22.5	198	680	2.8	10.5	0.91	15.0	5.9
FA10MK10	0.43	360.0	45.0	45.0	198	670	3.0	10.8	0.89	15.9	6.0
FA10MK15	0.43	337.5	45.0	67.5	198	650	3.2	11.0	0.86	16.0	7.0
FA10MK20	0.43	315.0	45.0	90.0	198	640	3.4	11.2	0.82	16.6	7.4
FA15MK0	0.43	382.5	67.5	0.0	198	720	2.3	09.5	0.98	13.0	4.4
FA15MK5	0.43	360.0	67.5	22.5	198	700	2.5	11.0	0.96	14.0	5.0
FA15MK10	0.43	337.5	67.5	45.0	198	690	2.9	12.0	0.94	15.0	5.7
FA15MK15	0.43	315.0	67.5	67.5	198	660	3.0	12.2	0.92	16.0	6.2
FA15MK20	0.43	292.5	67.5	90.0	198	650	3.4	12.5	0.90	17.0	7.5
FA20MK0	0.43	360.0	90.0	0.0	198	730	2.0	09.0	1.00	12.0	4.0
FA20MK5	0.43	337.5	90.0	22.5	198	700	2.3	11.0	0.98	12.6	5.0
FA20MK10	0.43	315.0	90.0	45.0	198	680	2.5	11.3	0.95	13.0	6.0
FA20MK15	0.43	292.5	90.0	67.5	198	670	3.0	12.0	0.92	13.8	7.0
FA20MK20	0.43	270.0	90.0	90.0	198	650	3.6	12.1	0.90	14.0	8.0

A. Fresh concrete Properties

The results of fresh SCC mixtures are given in Table 2 and shown in Figs.2-3. It is evident from Fig.2 that slump-flow is in the range of 650-800 mm, which satisfies the flowability requirements as per standards of EFNARC. The maximum slump flow was found at 20% FA + 0% MK i.e. 730 mm. The slump was 690 mm at the optimum replacement level (15%FA + 10%MK). The T50 time is the time taken by concrete to reach a diameter of 50 cm. It was in the range of 2-5 sec, satisfying the EFNARC guidelines (Fig.2). The V-funnel time of different mixes was in the range of 6-12 sec (Fig.3). L-box values i.e. blocking ratio (h2/h1) was found in the range of 0.8-1.1, satisfying the EFNARC standards [14] (Fig. 3). The values of U- box (0-30mm) and J-ring (0-10mm) were also within the desirable limits of EFNARC [14] (Fig.4). All the SCC mixes were found to satisfy the EFNARC limits [14].

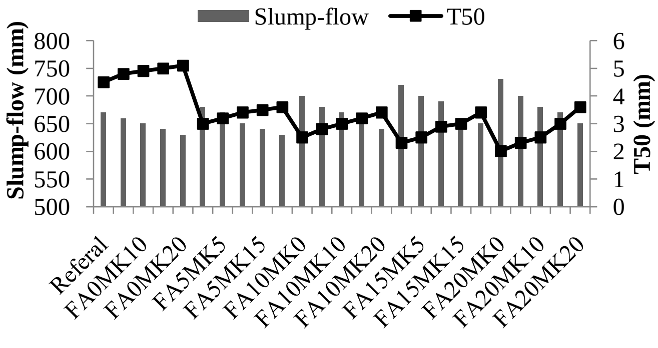

Fig.2. Slump-flow and T50 time of SCC mixtures

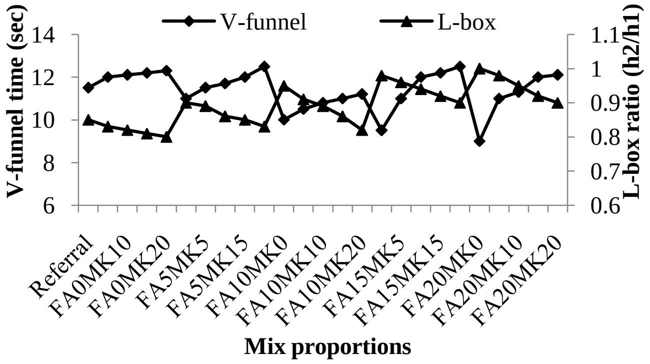

Fig.3. V- Funnel time and L-Box ratio of SCC

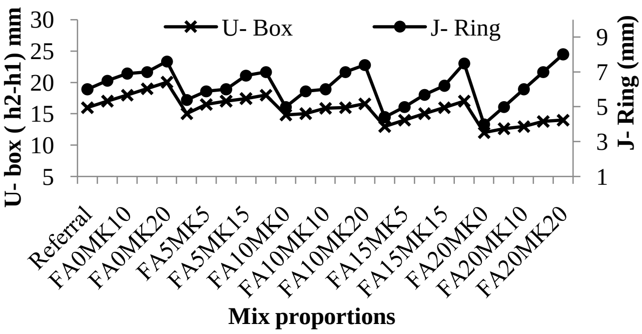

Fig.4. U- Box and J-Ring values of SCC mixtures

B. Hardened Concrete Properties

The compressive strength of different mixtures was found after 7 and 28 days of curing (as per IS: 516-1959 [16]). The maximum strength of SCC mix was found at the optimum replacement level of OPC by 25% by binary admixtures (15% FA+10 % MK). The compressive strength of samples of different mixes are presented in Fig.5.

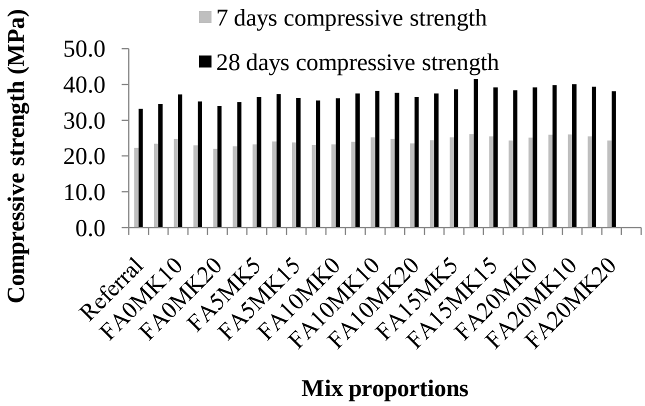

Fig.5. Compressive strength of different SCC

V. WATER ABSORPTION TEST

The water absorption test results at 7 days and 28 days are shown in Fig.6. It is observed that as FA content increases, the saturated water absorption decreases in comparison to RC.The change in the slump flow is: +60mm when 20% of OPC is replaced by FA; -40mm when 20% of OPC is

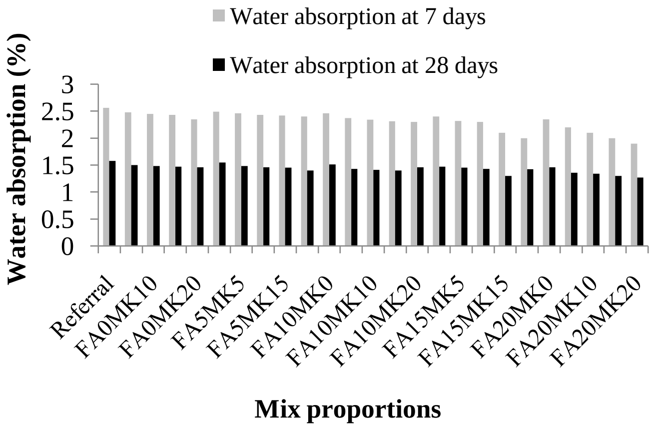

Fig.6 Water Absorption of different SCC

replaced by MK; +20mm when 25% of OPC is replaced by binary admixtures (15% FA+10% MK). The change in the T50 time is: -2.5 sec when 20% of OPC is replaced by FA; +0.6 sec when 20% of OPC is replaced by MK; -1.6 sec when 25% of OPC is replaced by binary admixtures (15% FA+10% MK). The change in the V-funnel value is: -2.5 sec when 20% of OPC is replaced by FA; +1.0 sec when 20% of OPC is replaced by MK; +0.6 sec when 25% of OPC is replaced by binary admixtures (15% FA+10% MK). The change in the L-box value is: +0.15 mm when 20% of OPC is replaced by FA; -0.05 mm when 20% of OPC is replaced by MK; +0.09 mm when 25% of OPC is
replaced by binary

admixtures (15% FA+10% MK). The change in the U-box value is: -4.0 mm when 20% of OPC is replaced by FA; +4.0 mm when 20% of OPC is replaced by MK; -1.0 mm when 25% of OPC is replaced by binary admixtures (15% FA+10% MK).The change in the J-ring value is: -2.0 mm when 20% of OPC is replaced by FA; +1.0 mm when 20% of OPC is replaced by MK; -0.3 mm when 25% of OPC is replaced by binary admixtures (15% FA+10% MK).

The replacement level of OPC by FA was varied from 0-20%. At 20% replacement level, the increase in compressive strength was maximum and the increment was found to be 2.8 MPa (12.56%) and 6 MPa (18.07%), as compared to the RC at 7 and 28 days, respectively. The replacement level of OPC by MK was varied from 0-20%. At 10% replacement level, the increase in compressive strength was maximum and was found to increase by 2.5 MPa (11.21%) and 4.0 MPa (12.04%), as compared to the RC, at 7 and 28 days, respectively. Lastly, the replacement of OPC by the binary admixtures (FA+MK) was varied as given in Table 2 and plotted in Fig 5. The optimum replacement level of OPC by the binary admixtures was obtained at 15%FA+10%MK. The increase in compressive strength was 3.8 MPa (17.04%) and 8.3 MPa (25%), as compared to the RC, at 7 and 28-days, respectively.

The water absorption values decrease with inclusion of FA from 0-20%. At 20% replacement level of OPC by FA, the water absorption was found minimum i.e. -0.23 (10.19%) and -0.15 (9.49%), as compared to the RC, at 7 and 28 days, respectively. It was also found to decrease with inclusion of MK from 0-20%. At 20% replacement level of OPC by MK, the water absorption was minimum i.e. -0.21 (8.2%) and -0.12 (7.59%), as compared to the RC at 7 and 28 days, respectively. At the optimum replacement level of OPC by binary admixtures (15%FA+10%MK), its value was found -0.26 (10.15%) and – 0.15 (9.49%), at 7 and 28 days, as compared to RC. Water absorption values tends to decreases with increase in percentage of FA replacement in SCC mixes [17]. With inclusion of MK in SCC water absorption values decreases with higher percentage of replacement [18].

VI. CONCLUSIONS

The following conclusions are drawn from the present study:

1. The use of FA and MK improves the performance of SCC.
2. The workability of SCC also improves upto an optimum replacement level of OPC with FA and MK.
3. Slump flow values increases as FA content increases; however, there is a gradual fall as MK content increases in the mix.
4. The use of MK increases the cohesion of the concretes due to which V-funnel flow time of SCC increases. The use of FA and MK in combination over-comes this negative effect of MK.
5. The compressive strength of SCC cubes with FA+MK were increased upto 25 % with respect to RC.
6. The optimum replacement level of OPC is 25% (15%FA+10% MK), by mass.
7. The increase in FA content decreases the water absorption in comparison to RC.

Overall, It was concluded that with incorporation of binary admixture (i.e. FA+MK) at an optimum level, the fresh and hardened properties of the concrete were improved and water absorption was also reduced in comparison to RC which may be due to improved pore structure of the concrete. A high performance SCC is developed which can be used in congested reinforcement easily.

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