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 crystalized white powder which has a specific surface of 12,000 m²/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
Optimum Dose of Binary Admixtures in Self Compacting Concrete

requirements of IS 8112-1989 [11]. The compressive strength of 50 cm² cement mortar cube at 28 days was found to be 51.95 N/mm². 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/m³, 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/mm² 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 C₃S and C₂S and for FA and MK main product is quartz.

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/m³). The quantity of fine aggregate, coarse aggregate and dosage of superplastizizer were 890 Kg/m³, 750 Kg/m³ and 4.95 Kg/m³, 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 T₅₀ 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/cm²/min, as per IS: 14858-2000 [15].

D. Water Absorption Test

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

\[
\text{Water Absorption (\%) } = \frac{A-B}{B} \times 100
\]

IV. RESULT AND DISCUSSION

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

| Mixture details | W/B | OPC (Kg/m³) | FA (Kg/m³) | MK (Kg/m³) | Water (Kg/m³) | Slump Flow (mm) | T₅₀ 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.4). All the SCC mixes were found to satisfy the EFNARC limits [14].
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.

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 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; -40mm 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 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 BA 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.

VI. CONCLUSIONS

The following conclusions are drawn from the present study:
1. The use of BA and MK improves the performance of SCC.
2. The workability of SCC also improves up to an optimum replacement level of OPC with BA and MK.
3. Slump flow values increase 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 overcomes this negative effect of MK.
5. The compressive strength of SCC cubes with FA+MK were increased up to 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.

ACKNOWLEDGEMENT

The authors acknowledge the Motilal Nehru National Institute of Technology Allahabad, Prayagraj for providing their support.

REFERENCES

1. Yahia A., Tanimura M., Shimabukuro A. and Shimoyama Y.: Effect of rheological parameters on self compactability of concrete containing various mineral admixtures. In Proceedings of the first RILEM International symposium on self-compacting concrete, pp. 523-35, Stockholm, (1999).
2. Kurita M. and Nomura T.: Highly-flowable steel fiber-reinforced concrete containing ash fly. Special Publication 178, 159-176 (1998).
3. Duan, Png, Chunjie Yan, and Wei Zhou.: Influence of partial replacement of fly ash by metakaolin on mechanical properties and microstructure of fly ash geopolymer paste exposed to sulfate attack. Ceramics International 42 (2), 3504-3517 (2016).
4. Sabir B.B., Wild S. and Bai J.: Metakaolin and calcined clays as pozzolans for concrete: a review. Cement and concrete composites 23 (6), 441-454 (2001).
5. Madandoust R., and Mousavi S.Y.: Fresh and hardened properties of self-compacting concrete containing metakaolin. Construction and building materials 35, 752-760 (2012).
6. Kavitha O.R., Shanthy V.M., Arulraj G.P., and Sivakumar P.: Fresh, micro-and macrolevel studies of metakaolin blended self-compacting concrete. Applied Clay Science 114, 370-374 (2015).
7. Caldarone M.A., Gubker A.A., and Burg R.G.: High reactivity metakaolin (HRM): a new generation mineral admixture for high performance concrete. Concrete International 16, 37-41. (1994).
8. Fras M., Rojas M.I.S., and Cabrera J.: The effect that the pozzolanic reaction of metakaolin has on the heat evolution in metakaolin-cement mortars. Cement and Concrete Research 30 (2), 209-216 (2000).
9. Hassann A.A.A., Larcheni M., and Hossain K.M.A.: Effect of metakaolin on the rheology of self-consolidating concrete: In Design, production and placement of self-consolidating concrete, pp. 103-112. Springer, Dordrecht, (2010).
10. Chopra, Divya, and Rafat Siddique.: Strength, permeability and microstructure of self-compacting concrete containing rice husk ash. Biosystems engineering 130, pp. 72-80 (2015).
11. IS: 8112 (1989). : Specification for 43 grade ordinary Portland cement. Bureau of Indian standards, New Delhi, India (1989).
12. IS: 383 (1987). : Specification for coarse and fine aggregate from natural sources for concrete. Bureau of Indian Standards, New Delhi, India (1987).
13. IS: 3812-2000.: Specification for Pulverized Fuel Ash, Part 1: For Use as Pozzolana in Cement. Cement Mortar and Concrete (2002).
14. EFNARC.: Specification and guidelines for self-compacting concrete. UK: EFNARC: (2005).
15. IS: 14859-2000.: Requirements for compression testing machine used for testing of concrete and mortar. Bureau of Indian Standards, New Delhi, India (2002).
16. IS: 516 (1959). : Specification for methods of test for strength of concrete. Bureau of Indian standards, New Delhi, India (1959).
17. Brabha H Nagaratnam, Ahmed Faheem, Muhammad Ekhsalsur Rahman, Mohammad: Mechanical and Durability Properties of Medium Strength Self Compacting Concrete with High-Volume Fly Ash and Blended Aggregates. R Periodica Polytechnica Civil Engineering 59(2), pp. 155-164 (2015).
18. Lenka, S., and K. C. Panda.: Effect of metakaolin on the properties of conventional and self compacting concrete. Advances in concrete construction.5 (1), pp. 31-48 (2017).
Optimum Dose of Binary Admixtures in Self Compacting Concrete

AUTHORS PROFILE

Deep Tripathi is a Research scholar in Civil Engineering Department, MNNIT Allahabad, Prayagraj, India. He was completed his B. Tech. in Civil Engineering from REC, Ambedkar Nagar, U.P., India in 2014. His area of research includes concrete technology, composite materials, building materials, microstructural analysis of materials and structural engineering. He has attended more than 5 short term courses and worked as a volunteer in summer training programme organized by Department of Civil Engineering, MNNIT Allahabad from last two years. He is member of American Society of Civil Engineers (ASCE) since 2018. He has two National and three International conference papers and two papers are considered for scopus publication.

Dr. Rakesh Kumar is currently serving as a Professor of Civil Engineering at MNNIT Allahabad, Prayagraj, India. He was completed his B. Tech. in Civil Engineering from IET Lucknow in 1991, M. Tech. in Structural Engineering from Faculty of Engineering and Technology, Baroda in 1993 and Ph. D. from IT, BHU, Varanasi in 2001. He has organised more than 10 short term courses/workshop till now. He has life membership of Indian Concrete Institute, Chennai. He has more than 92 research papers in the National and International reputed journals. His research interests include concrete technology, composite materials and waste material utilization in construction industry.

Dr. P.K. Mehta is currently serving as a Professor of Civil Engineering at MNNIT Allahabad, Prayagraj, India. He was completed his B.E. from MNREC, Allahabad in 1986, M. Tech. in 1991 and Ph.D. from IT, BHU, Varanasi in 1996. He has organised more than 15 short term courses/workshop till now. He has life membership of Indian Society for Construction Material and Structures (ISCMS), IIT-Roorkee and Swadeshi Science Movement of India, New Delhi. He has more than 70 research papers in the National and International reputed journals. His areas of interests include concrete technology, bridges and buildings.

Amrendra Singh is a Research scholar in Civil Engineering Department, MNNIT Allahabad, Prayagraj, India. He was completed his B. Tech. in Civil Engineering from Ideal Institute of Technology, Ghaziabad, U. P. India and M. Tech. in Structural Engineering from MNNIT Allahabad, Prayagraj with thesis topic “Effect of Nitric Acid on Rice Husk Ash Stone Dust Concrete”. He has attended more than 3 short term courses and worked as a volunteer in summer training programme organized by Department of Civil Engineering, MNNIT Allahabad, Prayagraj. He has two National and two International conference papers.