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BEHAVIOR OF M 50 GRADE SELF-COMPACTING CONCRETE DEVELOPED USING PORTLAND SLAG CEMENT AND METAKAOLIN

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Self-compacting concrete (SCC) is a revolutionary development in concrete construction. The addition of mineral admixtures like metakaolin, which is a highly reactive pozzolana to the SCC mixes, gives it superior strength and durability. The present work is an effort to study the behavior of M50 grade SCC by partial replacement of Portland Slag Cement (PSC) with metakaolin. Its strength and durability aspects are comparable with a controlled concrete (without replacement of cement). In the present work, a new mix design methodology based on the efficiency of metakaolin is adopted. The optimum percentage replacement of cement with metakaolin is obtained based on compressive strength test results. The influence of metakaolin on the workability, compressive strength, splitting tensile strength and flexural strength of SCC and its behavior when subjected to elevated temperature was investigated through evaluation against controlled concrete and non-destructive testing. From the test results, it was observed that incorporation of metakaolin at an optimum dosage satisfied all the fresh properties of SCC and improved both the strength and durability performance of SCC compared to controlled concrete.

Keywords: Pozzolana, Optimum percentage replacement, Effective cementitious materials, Efficiency concept, Non-destructive testing.

1 INTRODUCTION

Self-Compacting Concrete (SCC) is a highly flowable, yet stable concrete that can spread readily into place and fill the formwork without compaction and without undergoing any significant separation of material constituents (Khayat and Schutter 2014). SCC is usually produced using supplementary cementitious materials (SCM) such as silica fume, fly ash or slag. Metakaolin, a highly reactive pozzolona was successfully used as a mineral admixture for the development of SCC. Unlike other mineral admixtures, metakaolin is not industrial waste. It is manufactured by calcination of kaolinitic clay under controlled conditions of 650 to 800^{o}C. Not only metakaolin is economical over silica fume but also due to higher silica and alumina content, the pozzolanic action of metakaolin is more significant as compared to silica fume and fly ash (Badogiannis *et al.* 2015). The particle size of metakaolin is not as fine as silica fume, hence the requirement of high range water reducing admixture (HRWRA) is less in case of metakaolin as compared to silica fume for the same slump flow (Balogh 1995, Ding and Li 2002).

In the present study, the effect of Indian metakaolin on the fresh concrete properties, strength, and durability of SCC has been investigated by adopting a specific mix design methodology proposed by Dinakar and Manu (2014). From the study, it was observed that as the percentage of metakaolin in SCC mixture increases, the 28-day compressive strength of SCC, the demand for high range water reducing admixture (HRWRA) and the rheological parameters (plastic viscosity and yield stress) increases (Hassan *et al.* 2010).

2 EXPERIMENTAL PROGRAM

2.1 Materials

Portland slag cement (PSC) of 53 grade conforming to IS 455 (1989) was used. Commercially available metakaolin was collected from a company in Gujarat, India, having a specific gravity of 2.5. Table 1 indicates the properties of the metakaolin used in this study. The Coarse aggregates of size 10 mm and down (granite rock) and well-graded river sand of maximum size 4.75 mm were used as fine aggregate. The specific gravity of coarse and fine aggregates was found to be 2.7 and 2.62 respectively. Polycarboxylic ether (PCE) based superplasticizer (SP) conforming to IS 9103 (1999) is used as a chemical admixture. The SP contains 0.01-0.02% of viscosity modifying agent (VMA) as reported by the manufacturer.

Table 1. Properties of Metakaolin (supplied by manufacturer).

Properties	Metakaolin
Physical Form	Off white powder
Specific Gravity	2.5
Bulk Density	300 ± 30 gm/ltr
Average Particle Size	1.5 µ
Residue 325 #	0.5 % max
Pozzolan Reactivity - mg $Ca(OH)_2$	>1000
Loss of ignition (LOI)	0.68
Fineness {Blaine} (m^2 /kg)	15,000

2.2 Mix Proportions

The mix design was carried out according to the mix design methodology proposed by Dinakar and Manu (2014) based upon the efficiency concept. It was also taken care that all mixes satisfied the regulations given in EFNARC (2002) guidelines. Trial mixes were prepared to arrive at optimum percentage replacement of PSC with metakaolin based on compressive strength test results. The optimum ‘water to effective cementitious materials content’ (ratio) was arrived at like 0.27 and the SP dosage was kept constant to satisfy fresh properties of SCC. The final mix proportions of SCC containing different percentages of metakaolin are shown in Table 2.

3 RESULTS AND DISCUSSIONS

Based on the tests carried out, properties of fresh and hardened concrete are reported in the following section.

3.1 Fresh Properties

The fresh properties of SCC were determined using slump flow, U-box, and L-box tests as per EFNARC (2002) guidelines and the results are shown in Table 3.

From the above results, it is evident that with the increase in metakaolin content, the slump flow decreased and the T_{50cm} time increased. This may be due to the higher surface area of metakaolin which increases the water demand and thereby SCC loses fluidity. All the fresh properties of SCC satisfied the regulations given in EFNARC guidelines.

Table 2. Details of the mix proportions.

$w/(c + k_{28}\times m)$	P (%)	k_{28}	C (kg/m^3)	m (kg/m^3)	W (kg/m^3)	F.A (kg/m^3)	C.A (kg/m^3)	SP (kg/m^3)	SP (%)
0.27	0	0	550	0	148.5	783.89	873.478	5.5	1
0.27	8	4.8346	506	44	194.057	725.42	808.323	5.5	1
0.27	10	4.4059	495	55	221.2	713.302	794.825	5.5	1
0.27	15	3.5375	467.5	82.5	205.022	710.663	791.851	5.5	1
0.27	20	2.9596	440	110	206.701	707.868	788.76	5.5	1
0.27	25	2.6729	412.5	137.5	210.606	702.266	782.54	5.5	1

$w/(c + k_{28}\times m)$ - water to effective cementitious materials content ratio, *c* - Cement content, k_{28}- Efficiency of metakaolin, *m* – Metakaolin, *p* - Percentage replacement of cement with metakaolin, *F.A* - Fine aggregate, *C.A* - Coarse aggregate, *SP* – Superplasticizer. SCC without metakaolin is referred to as control concrete.

Table 3. Fresh Properties of SCC.

Replacement of cement with metakaolin (%)	Flow time T_{50cm} (sec)	Slump flow (mm)	L-Box	U-Box (mm)
0	2.06	780	0.98	1
8	2.21	765	0.94	5
10	2.36	745	0.89	9
15	3.08	720	0.873	15
20	3.9	690	0.832	21
25	5.01	646	0.813	27

3.2 Strength Studies

3.2.1 *Compressive strength*

The unconfined compressive strength of 100 mm cubes was obtained, by subjecting to a compressive loading at the rate of 2.5 kN/s, at the age of 7 and 28 days on 3,000 kN machine and the test was performed as per IS 516 (1959). The strength variation with varying percentage of metakaolin is illustrated in Figure.1.

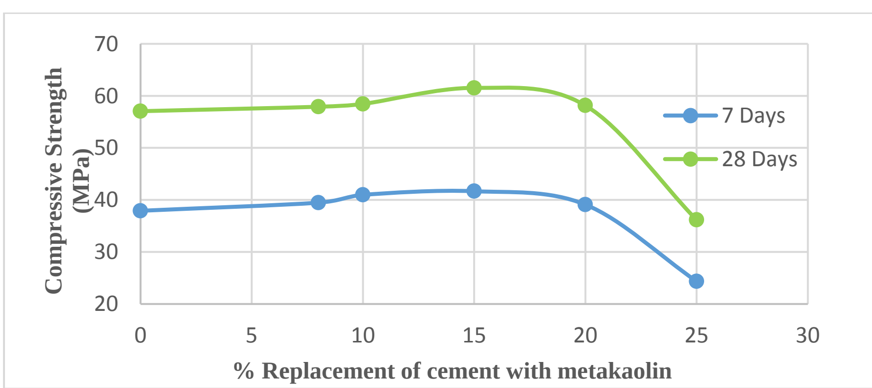

Figure 1. Variation of compressive strength with respect to metakaolin percentage.

From the above figure, it can be observed that compressive strength of concrete is maximum for 15% replacement of cement with metakaolin and hence, it is chosen as optimum dosage. Further, when the dosage of metakaolin was increased, it was observed that the compressive strength was decreased, and this might be due to clinker-dilution effect.

3.2.2 *Flexural strength and splitting tensile strength*

The split tensile strength test was conducted on 150×300 mm cylindrical specimens at the age of 28 days, and the test was performed as per IS 5816 (1999) and the flexural strength test was conducted on a beam of size 100×100×500 mm subjected to pure bending and the test was performed as per IS 516 (1959). Table 4 indicates the flexural and splitting tensile strength test results for control concrete and SCC having an optimum replacement of PSC with metakaolin.

Table 4. Flexural and Splitting Tensile Strength Test Results.

Replacement of cement with metakaolin (%)	**Flexural strength at 28 Days (MPa)**	**Splitting tensile strength at 28 Days (MPa)**
0	8.042	4.576
15	8.209	4.844

From the test results, it was observed that the flexural and split tensile strengths for SCC having an optimum replacement of PSC with metakaolin was slightly higher than the values obtained for control concrete.

3.3 Durability Studies

3.3.1 *Elevated temperature test*

For elevated temperature testing, the cube specimens are subjected to 100°C temperature for 24 hours at the age of 28 days and tested for compressive strength. The average compressive strength of specimens subjected to 100°C is compared with average compressive strength of specimens before heating, for both control concrete and SCC having optimum replacement of PSC with metakaolin and the results are shown in Table 5.

Table 5. Elevated Temperature Test.

Replacement of Portland slag cement with metakaolin (%)	**Compressive Strength (MPa) at 28 Days**	
	At Room Temperature	**After subjected to 100^0C for 24 hour and cooled to room temperature**
0	57.05	66.81
15	61.53	72.29

From the test results, it was observed that the compressive strength was increased for both the concretes after subjected to 100^0C for 24 hours and cooled to room temperature. The increase in compressive strength is slightly higher in case of SCC having an optimum replacement of PSC with metakaolin when compared to control concrete. This might be due to further densification of pore structure, due to the addition of metakaolin to concrete (Mehta and Monteiro 2006). Increase in temperature beyond a certain value can result in explosive spalling due to the build-up of pore pressure by steam, so the rate of increase in compressive strength decreases for concrete with metakaolin due to densified pore structure. Thermal cracks develop due to the evaporation of physically absorbed water which starts at 80^{o}C and such concretes may show inferior performance as compared to concretes without metakaolin at elevated temperatures (Phan 1996).

3.4 Non-Destructive Tests

3.4.1 *Rebound hammer and ultrasonic pulse velocity tests*

The non-destructive tests on 100 mm cube specimens were performed as per IS 13311 (1992). A summary of the results of non-destructive tests of control concrete and SCC with optimum dosage is presented in Table 6 respectively.

Table 6. Non-Destructive Test Results of Control Concrete and SCC with optimum dosage.

Sample at 28 Days (Average)	**Rebound number**	**Ultrasonic pulse velocity (m/s)**	**Compressive Strength from combined UPV and Rebound hammer test (MPa)**
0	38	4326.67	53.83
15	49.4	4370	57.5

From the results, it was observed that both the rebound number and ultrasonic pulse velocity values are increased for SCC having an optimum replacement of PSC with metakaolin as compared to control concrete and this increase is due to the pozzolanic properties of metakaolin i.e., densified pore structure. The compressive strength of concrete is predicted from combined ultrasonic pulse velocity and rebound number to have better accuracy in estimating the compressive strength of concrete (Malhotra 1976). The compressive strength obtained from NDT was found to be lesser than the actual compressive strength for both the control concrete and SCC having an optimum replacement of PSC with metakaolin, but the percentage variation is within the range (± 20 %) as specified in IS 13311 (1992).

4 CONCLUSIONS

Based on the experimental investigation of M 50 grade SCC developed by partially replacing Portland slag cement with metakaolin (having an optimum replacement of PSC with metakaolin), following conclusions are drawn:

- With the increase in the percentage of metakaolin, the slump value decreased and T_{50cm} time was found to increase.
- The ‘water to effective cementitious materials content’ ratio was fixed as 0.27 as it satisfied all the fresh concrete properties. By keeping this constant, optimum percentage replacement of cement (PSC) with metakaolin was found to be 15% for SCC.
- The increase in compressive strength of self-compacting concrete mix with optimum percentage replacement of cement with metakaolin is 9.918% for 7-days and 7.846% for 28-days age of the sample.
- There is an increase in flexural strength and splitting tensile strength by 2.07% and 5.86% respectively by replacing cement (PSC) with optimum content of metakaolin (15%).
- The compressive strength was found to increase after 24 hours of exposure to an elevated temperature of 100^{0}C, and this increase in compressive strength is relatively higher for SCC with optimum percentage replacement of metakaolin content when compared to controlled concrete.

- The results obtained from the correlation of in-situ compressive strength with rebound number and ultrasonic pulse velocity showed lower values of concrete compressive strength, compared to results obtained from actual compressive strength test for the same mixes, for both controlled concrete and SCC with optimum percentage replacement of metakaolin content.

References

Badogiannis, E., Sfikas, I. P., Voukia, D. V., and Trezos, K., Durability of Metakaolin Self-Compacting Concrete, *Construction and Building Materials*, 82, 133-141, 2015.

Balogh, A., *High-Reactivity Metakaolin*, The Aberdeen Group, Publication #C950604, 1995.

Ding, J. T., and Li, Z., Effects of Metakaolin and Silica Fume on Properties of Concrete, *Materials Journal*, 99(4), 393-398, 2002.

Dinakar, P., and Manu, S. N., Concrete Mix Design for High Strength Self-Compacting Concrete using Metakaolin, *Materials and Design*, 60, 661–668, March 2014.

EFNARC, *Specification, and Guidelines for Self-Compacting Concrete,* Surrey, UK, 2002.

Hassan, A. A. A., Lachemi, 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.* Rilem Bookseries, 1(3), 103–112, July 2010.

IS 455, *Portland Slag Cement Specification*, Bureau of Indian Standards, New Delhi, India, 1989.

IS 516, *Method of Tests for Strength of Concrete*, Bureau of Indian Standards, New Delhi, India, 1959.

IS 5816, *Splitting Tensile Strength of Concrete-Method of Test,* Bureau of Indian Standards, New Delhi, India, 1999.

IS 9103, Concrete Admixtures Specification, Bureau of Indian Standards, New Delhi, India, 1999.

IS 13311, *Non-Destructive Testing of Concrete-Methods of The Test*, Bureau of Indian Standards, New Delhi, India, 1992.

Khayat, K. H., and Geert, De, Schutter., *Mechanical Properties of Self-Compacting Concrete State-of-the-Art Report of the RILEM Technical Committee 228-MPS on Mechanical Properties of Self-Compacting Concrete,* RILEM, 14, Springer, 2014.

Malhotra, V. M., Testing of Hardened Concrete: Non-destructive Methods, Monograph No. 9, *American Concrete Institute*, Detroit, MI, 52, 1976.

Mehta, K., and Monteiro, P. P. J. M., *Concrete-Microstructure, Properties and Materials,* Third Edition, *McGraw-Hill*, United States of America, 2006.

Phan, L.T., Fire Performance of High-Strength Concrete: A Report of The State-of-The-Art. *National Institute of Standards and Technology*, Gaithersburg, MD, 105, 1996.