CHARACTERISTICS OF HIGH PERFORMANCE SELF COMPACTING CONCRETE INCORPORATING FLY-ASH AND METAKAOLIN

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Abstract

This paper presents the experimental studies on strength & Durability properties of High Performance Self Compacting Concrete (HPSCC) made with manufactured sand and as partial replacement of cement by Mineral Admixture (Flyash, Metakaolin). The mix design for HPSCC was arrived as per the guidelines of European Federation of National Association representing for Concrete (EFNARC). The Rheology properties was determined by tests as filling ability, passing ability and segregation resistance including pH and Temperature. Strength properties was determined by Compressive, split tensile, Flexural strength and Young's Modulus were examined. And durability properties were determined by Rapid Chloride Penetration Test (RCPT) are carried out.

Keywords: *High performance self-compacting Concrete, Metakaolin, Flyash, Manufactured sand.*

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1. INTRODUCTION

Concrete is currently the most widely used building material. Although many structures are built of concrete there some relations related to use of conventional concrete such as passing in congested rebar, compaction, Homogeneity, compressive, tensile strength and reduction in Noise pollution and cost effectiveness. One of the main challenges now in concrete industry in India is to meet the demand posed by enormous infrastructure, rapid industrialization and urbanization needs early stripping formwork. High performance self-compacting concrete to overcome these limitation with using the industrial by products such as Flyash (FA) and Metakaolin(MK) as a replacement of cement.

The use of Mineral Admixture to decrease the content of Portland cement results not only in an environmentally friendly product but also gives numerous profits to the properties of fresh and hardened concrete such as enhanced workability, better homogeneity, low heat of hydration, lower permeability etc. This is moreover important approach to reduce the environmental impact of the concrete and cement industry. This sort of cementations system has good mechanical properties and better durability characteristics when compared to conventional concrete. The study of this paper is to produce High performance self-compacting concrete. And to study a set of test method and performance based specifications for the workability of structural HPSCC that can be used for casting highly restricted or congested sections. Proven combinations of test methods to assess filling capacity and stability are proposed and should be of interest to engineers and contractors using SCC.

This paper discusses the properties of HPSCC with mineral admixtures. Ordinary Portland cement (OPC), Metakaolin (MK), and Flyash (FA) were used in ternary cementitious blends. SCC were tested by using Abrams Slump Cone Test, V-funnel, L-Box ratio. Moreover, development in the compressive strength and Split Tensile Strength of the hardened SCC were determined at 7, 28 and 56 days.

2. MATERIALS AND METHODOLOGY

Cement: Ordinary Portland cement (53 grade) confirming IS 12269: 2013 was used. Its Physical Properties are as given in Table 1

Table -1 Physical properties of cement

Parameters	**Results**
Specific Gravity	2.95
Standard Consistency	28%
Initial setting Time	62 min
Final Setting Time	537min

Admixtures: Commercially available MK was used for this study whereas Class F Flyash from Bellary Thermal Power Plant (BTPP), Bellary, Karnataka, India is used as additives according to IS: 3812-2003.

Table -2 Physical Properties of Admixtures

Physical Properties	**Test Results**	
	Flyash	**Metakaolin**
Colour	Grey Blackish	White
Specific Gravity	2.1	2.42
Bulk density	1.11gm/cc	0.39gm/cc

Table -3 Chemical Properties of Admixtures

Parameters	Percentage by weight	
	FA	MK
Silicon Dioxide(SiO2)	62.63	52.0
Alumina(Al_2O_3)	23.35	42.2
Iron oxide(Fe_2O_3)	3.93	0.7
Calcium oxide (CaO)	2.04	0.08
Magnesium oxide (MgO)	0.46	1.76
Sodium oxide(Na_2O)	0.32	0.07
Loss on ignition	0.39	0.3

Aggregates: Manufactured sand confirming Zone II and The crushed coarse aggregate obtained from the local crushing plant are used in the present study. The properties of Coarse Agg. and Fine Agg. are given in the Table 4.

Table -4 Properties of Aggregates

Properties	Coarse Aggregate	Fine Aggregate
Specific Gravity	2.7	2.62
Water Absorption	0.8%	3.8%
Fineness Modulus	6.86	2.68

Water: Fresh and potable water free from organic waste is used for mixing and curing of the HPSCC. The analysis of water are given in Table 5

Table -5 Analysis of Water

Properties	Results
pH	7.72
Acidity	Nil
Alkalinity	260 mg/lit
Specific Conductance	835 mΩ
Total Hardness	274 mg/lit
Chloride	105 mg/lit
Sulphate	63 mg/lit
Na+	10 mg/lit
K+	2 mg/lit

Chemical admixture: Super plasticizer (SP) poly carboxylic ether base Glenium Sky B233 was used as percentage of cementations material.

Table-6 Properties of Glenium sky B233

Aspect	Light brown liquid
Relative Density	1.08 $\pm$0.01 at 25°C
pH	>6
Chloride ion content	< 0.2%

Test Method: Self-compacting concrete is characterized by filling ability, passing ability and resistance to segregation. The rheological characteristics have been found out using the following tests as per EFNARC Guide lines. Slump flow test, V-Funnel test, L-Box blocking ratio test

Table- 7 Recommended Limits for Different Properties

Test	Range
Slump flow Diameter	650 – 800 mm
$T_{50\,cm}$ Slump flow	2 – 5 sec
V-funnel	6 – 12 sec
L-Box (H2 /H1)	0.8 – 1.0
J-Ring	0 – 10 mm

Strength of 150mmx150mmx150mm size cubes is found at 7days, 28days, and 56days age. Split Tensile Strength, flexural strength at 28 days and 56 days is calculated.

NDT (Ultra-sonic Pulse Velocity Test): This test is done to assess the quality of concrete by ultrasonic pulse velocity method as per IS: 13311 (Part 1) – 1992. The guidelines given below in the Table 8.

Table 8. Guidelines for UPV Test

Pulse Velocity (km/s)	Concrete Quality (Grading)
Above 4.5	Excellent
3.5 – 4.5	Good
3.0 – 3.5	Medium
Below 3.0	Doubtful

Rapid Chloride Penetration Test: Table 9 shows the rating of chloride permeability according to ASTM C 1202-97.

Table 9 Rating of chloride permeability

Charge passing in coulombs	Chloride permeability rating
Greater than 4000	High
2001 to 4000	Moderate
1001 to 2000	Low
100 to 1000	Very low
Less than 100	Negligible

3. RESULTS AND DISCUSSION

3.1 Proportions of Concrete Mixtures

The mixture design is made according to the EFNARC guidelines. Nine mixture compositions for each cubic metre of concrete are calculated. HPSCC trail mix proportions is made with manufactured sand and partial replacement of cement with Flyash and Metakaolin were made. The results of the SCC mixes prepared are summarized in Table-10.

Table 10 Mix proportion of High Performance Self Compacting Concrete (Kg/m^3)

Mix No	FA+MK in %	OPC	Flyash	MK	Water	M sand	CA	W/B	SP
FA5MK3	8	514.5	19.91	13.76	189.6	880.94	714.42	0.346	4.39
FA5MK6	11	497.7	19.91	27.53	189.6	880.94	714.42	0.348	4.36
FA5MK9	14	480.9	19.91	41.29	189.6	880.94	714.42	0.350	4.34
FA15MK3	18	458.6	59.72	13.76	189.6	880.94	714.42	0.356	4.26
FA15MK6	21	441.8	59.72	27.53	189.6	880.94	714.42	0.358	4.23
FA15MK9	24	425.0	59.72	41.29	189.6	880.94	714.42	0.360	4.21
FA25MK3	28	402.6	99.53	13.76	189.6	880.94	714.42	0.367	4.13
FA25MK6	31	385.8	99.53	27.53	189.6	880.94	714.42	0.369	4.11
FA25MK9	34	369.0	99.53	41.29	189.6	880.94	714.42	0.371	4.09

Table 11: Rheology properties of fresh concrete

Mix	FA+MK in %	Slum Flow Dia.	T_{50cm} (sec)	V Funnel	L-Box (H_2/H_1)	Temperature
FA5MK3	8	693	3.9	7.6	0.90	24
FA5MK6	11	684	4.1	8.2	0.88	25
FA5MK9	14	670	4.4	8.7	0.87	24
FA15MK3	18	708	3.6	7.0	0.91	23
FA15MK6	21	701	3.8	7.4	0.90	26
FA15MK9	24	688	4.1	7.7	0.88	23
FA25MK3	28	722	3.5	6.7	0.93	25
FA25MK6	31	712	3.6	7.0	0.92	24
FA25MK9	34	704	3.8	7.4	0.90	24

T_{50cm}: time taken for concrete to reach the 500 mm spread circle ; V-funnel flow time after keeping the concrete in funnel for 10 sec ; H1/ H2: Heights of the concrete at both ends of horizontal section of L-box after allowing the concrete to flow.

3.2 Properties of Fresh Concrete

The rheological characteristics results are given in Table-11.

The slump flow characteristics of the mixtures are between 690 and 725 mm, which satisfy the EFNARC requirement. Slump flow improves with the increase in cement replacement by Flyash and decreases as increase in Metakaolin. As far as filling ability of the mixes was concerned, the results of V-funnel test satisfied the standard requirements-Funnel time between from 12 to 6 sec indicating increase in flow ability of concrete. The blocking ratios in the L - box test were as per the requirement laid down by EFNARC guidelines.

3.3 Properties of Hardened Concrete

Mechanical properties such as compressive strength, split tensile strength, flexural strength are evaluated for all the mix designs specimens and pH test are also conducted on the specimens at 28 day. The densities of the mixes are also calculated. Properties of Hardened concrete are given below in Table-12.

Compressive Strength: HPSCC achieves higher compressive strength at 7, 28 and 56 days for FA15MK9 composition of concrete. i.e., till 24% of partial replacement of cement, strength increases and there after increase in admixture decreases the compressive strength. The mineral admixture reduce the pore structure of concrete results improve the strength of concrete

Table 12. Hardned HPSCC Properties

Mix No	FA+MK in %	Compressive strength (Mpa)			Split tensile strength (Mpa)		Flexural Strength (Mpa)		pH	Density of concrete (Kg/m^3)
		7 days	28 days	56 days	28 days	56 days	28 days	56 days		
FA5MK3	8	40.8	60.4	66.9	4.30	4.72	4.67	4.88	11.56	2499.7
FA5MK6	11	41.9	61.8	68.0	4.72	5.13	4.85	5.12	11.62	2487.4

FA5MK9	14	43.4	63.4	70.8	5.17	5.83	5.41	5.68	11.65	2482.5
FA15MK3	18	47.1	67.5	75.5	4.16	4.44	5.62	5.89	11.83	2469.1
FA15MK6	21	50.4	70.8	80.3	4.51	4.82	5.95	6.25	11.92	2467.5
FA15MK9	24	58.2	78.7	85.2	4.99	5.27	6.59	6.78	12.00	2459.4
FA25MK3	28	49.3	65.7	78.7	3.75	4.12	6.32	6.54	12.30	2442.3
FA25MK6	31	47.5	63.2	76.4	4.20	4.54	6.21	6.38	12.35	2436.1
FA25MK9	34	46.3	60.8	75.3	4.51	4.79	5.98	6.08	12.41	2430.6

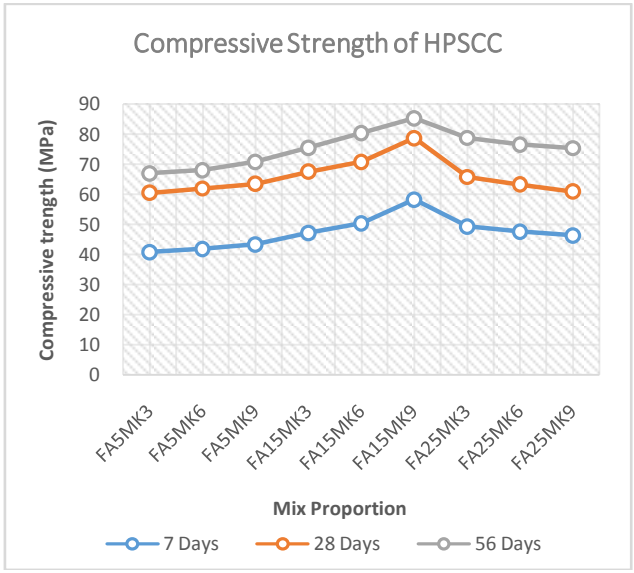

Fig 1. Compressive Strength of HPSCC mixes for 7, 28 and 56 days curing

Split Tensile Strength: It is evident from the above fig that the split tensile strength increases as the percentage of metakaolin increases and decreases as the Flyash content increases. At 5% of Flyash and 9% of Metakaolin the maximum Split tensile strength of 5.17 and 5.83 N/mm2 achieved at 28 and 56 days respectively.

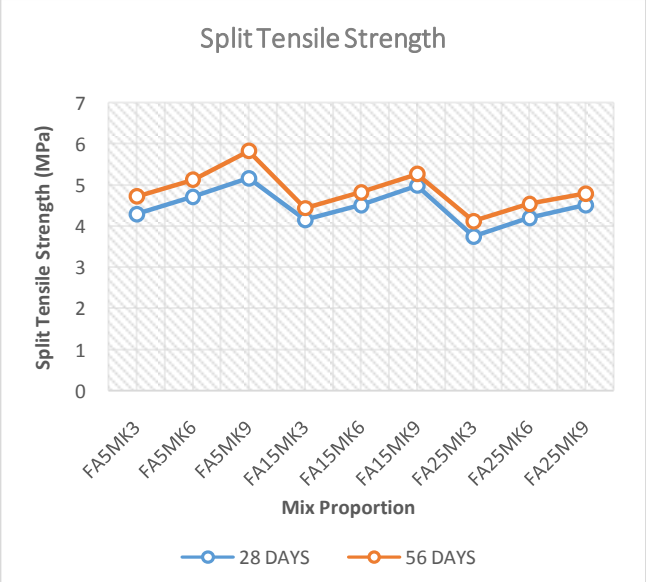

Fig 2. Split Tensile Strength of HPSCC mixes for 28 and 56 days curing

Flexural Strength: The test datas show that increase in partial replacement of cement with FA and Mk increases the flexural strength till 24%, there after the flexural strength will decrease. The flexural strength of HPSCC mixes for 28 days and 56 days are plotted in the Fig. 3. The mix FA15MK9 gives the maximum strength at 28 and 56 days.

NDT (Ultra Sonic Pulse Velocity Test): The UPV values calculated for ternary blends of MK and FA specimens after 28 days of curing is presented in Table 13. It can be seen that the UPV increased with increasing percentage of combination of MK and FA up to 24% after that there is a decrease in UPV.

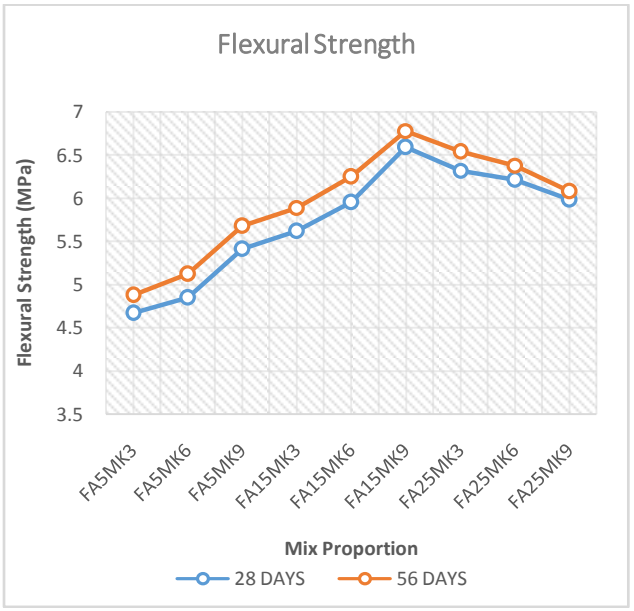

Fig 3. Flexural Strength of HPSCC mixes for 28 and 56 days curing

Young's Modulus of Elasticity: The Young's modulus of elasticity (MOE) values calculated for ternary blends of MK and FA specimens after 28 days curing is presented in Table 13. It can be seen that the MOE increased with increasing percentage of combination of MK and FA up to 24%. The relationship between MOE and compressive strength of combination of MK and FA blended HPSCC is shown in Fig. 4From Fig. 4, it is evident that the MOE increases linearly with compressive strength values and the value of correlation coefficients indicating fairly good linear correlation between MOE and compressive strength of combination of MK and FA blended HPSCC

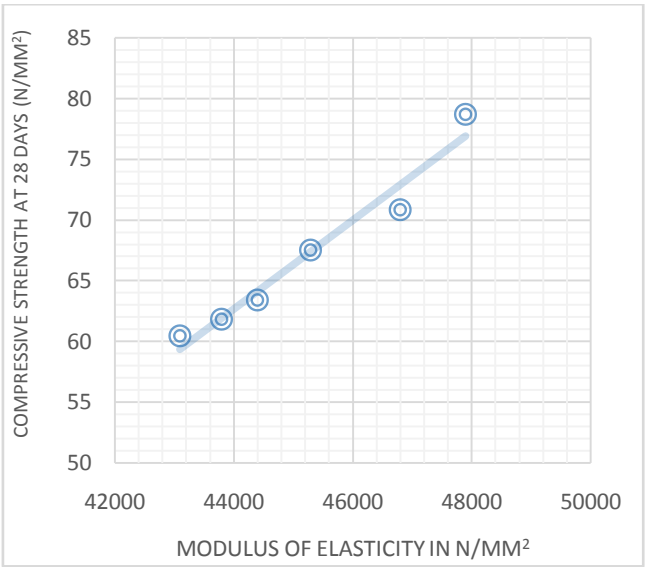

Fig. 4 Correlation between MOE and compressive strength of HPSCC

Table 13 UPV and Young's Modulus of Elasticity of HPSCC

Mix	FA+MK in %	UPV (km/s)	Category of UPV values	Young's Modulus of Elasticity (N/mm^2)
FA5MK3	8	4.47	Good	43100
FA5MK6	11	4.56	Excellent	43800
FA5MK9	14	4.66	Excellent	44400
FA15MK3	18	4.71	Excellent	45300
FA15MK6	21	4.77	Excellent	46800
FA15MK9	24	4.85	Excellent	47900
FA25MK3	28	4.71	Excellent	46900
FA25MK6	31	4.68	Excellent	46400
FA25MK9	34	4.63	Excellent	45800

Rapid chloride penetration test: It can be concluded that all the SCC mixes have performed extremely well in an aggressive chloride-rich environment. Comparatively speaking, it is observed that FA25MK9 mix has the lowest RCPT values compared to the other HPSCC mixes. This could be due to the fact that the chloride ion penetration depends on the chloride binding capacity of the constituent materials. Usually chlorides penetrate into concrete by diffusion along water-conveyance paths or open pores. The resistance to such diffusion can be increased by refining the pore-structure of the concrete. Again from the point of view of chemical reactions, some of these chlorides can react with the cement compounds, mainly tricalcium-aluminates (C_3A), forming stable chloro-complexes while the excess of chloride ions are free and may lead to the initiation of the corrosion process. The increased % of Flyash along with Metakaolin may lead to an increase in the amount of alumina present in the mix and to an increase in the content of calcium silicate hydrate that is formed in the pozzolanic reactions. Thus, the chloride-binding capacity of concrete tends to increase with Flyash addition and consequently less free-chloride is available to initiate the corrosion process.

Sample	28 days Chloride Permeability	
	Coulombs	Remark
FA5MK3	2850	Moderate
FA5MK6	2673	Moderate
FA5MK9	2439	Moderate
FA15MK3	1954	Low
FA15MK6	1716	Low
FA15MK9	1564	Low
FA25MK3	1298	Low
FA25MK6	1126	Low
FA25MK9	984	Very Low

4. CONCLUSION

Series of tests were performed on the self-compacting concrete developed using commercially available Metakaolin and Flyash produced from Bellary thermal power plant, Bellary of Karnataka, India. The rheological and strength characteristics have been assessed. The test was performed on number of specimens for all the Nine mix compositions. The ternary mix composition is prepared replacing cement with Flyash (5%, 15%, and 25%) and Metakaolin (3%, 6%, and 9%). The fresh state properties were assessed as per EFNARC guidelines such as slump flow test, L-Box test, V-funnel test. The hardened state compressive strength at 7, 28 and 56 days, Split tensile Strength and flexural Strength at 28 and 56 days were also evaluated. Also Young's Modulus of Elasticity, NDT (Ultrasonic pulse velocity) and RCPT test are also conducted.

Based on the above investigations the following conclusions have been drawn.

1. Establishment of standard mix design procedure and appropriate testing methods is essential for widespread use of HPSCC.
2. Based on the test results as indicated by the EFNARC 2002 and 2005 guidelines and its specifications can be taken up for the further investigations of long term strength and durability studies.
3. The combination of MK and FA can be fixed based on the synergic effect of mineral additives such as MK content increases and FA content is decreasing manner due to as per IS specifications should not exceed 35 % of powder.
4. Incorporation of MK and FA as partial replacement of cement in to OPC pastes causes substantiates changes in the chemical composition of the pore solution phase of the hydrated material.
5. The increase in workability is primarily due to the high surface area of the Flyash. Fresh concrete containing Flyash is more cohesive and less prone to segregation. As the Flyash content increased, the concrete may appear to become sticky.

6. The results of the mechanical properties (compressive, split and flexure strength) have shown significant performance differences, and the higher compressive strength has been obtained for FA15MK9 mix. Also, the increase in replacement level has resulted in a decrease in strength for the increase in Flyash. So, FA15MK 9 mix i.e., 24% of partial replacement of cement could be of optimum consideration for flowability, mechanical properties and durability study.
7. As the percentage of MK in SCC mixture increases, the 28-day compressive strength increases.
8. The increase of FA and MK in SCC increases the resistance to chloride penetration of SCC.

REFERENCES

[1] N. Bouzoubaa and M. Lachemi, "Self-compacting concrete incorporating high volumes of class F fly ash Preliminary results", *Cement and Concrete Research*, 31, 2001, pp 413-420. DOI:10.1016/S0008-8846(00)00504-4

[2] Nan Su, Kung-Chung Hsu and His-Wen Chai, "A simple mix design method for self-compacting concrete", *Cement and Concrete Research*, 31 ,2001, pp 1799–1807. DOI:10.1016/S0008-8846(01)00566-X

[3] Mustafa Sahmaran, Heru Ari Christianto and Ismail Ozgur Yaman, "The effect of chemical admixtures and mineral additives on the properties of self-compacting mortars", *Cement & Concrete Composites*, 28,2006,pp 432–440. DOI: 10.1016/j.cemconcomp.2005.12.003

[4] Paratibha Aggarwal, Rafat Siddique, Yogesh Aggarwal and Surinder M Gupta, "Self-Compacting Concrete - Procedure for Mix Design", *Leonardo Electronic Journal of Practices and Technologies*, Issue 12, 2008, pp 15-24. ISSN 1583-1078

[5] J. M. Khatib, "Performance of self-compacting concrete containing fly ash", *Construction and Building Materials*, 22, 2008, pp 1963–1971. ISSN 0950-0618