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Effect of Partial Replacement of Cement in Self-Compacting Concrete by Fly Ash and Metakaolin

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Abstract*— Self-compacting concrete (SCC) generally requires cement and chemical admixtures of high material cost. The use of mineral admixtures (such as fly ash, metakaolin etc.) as partial replacement of cement in SCC can bring down the cost. The use of industrial wastes such as fly ash, metakaolin etc in the binder of concrete reduces the storage, disposal and environmental problems. In the present study, the effects of partially replacing cement of self-compacting concrete by mineral admixtures (fly-ash and metakaolin) on (i) fresh state flow properties, (ii) 28 days compressive, splitting tensile and flexural strengths at room/standard temperature and (iii) 28 days compressive strengths at elevated temperatures. In the present study the mix design for M40 grade SCC was first carried out in accordance with EFNARC guidelines. The cement in SCC was partially replaced with (a) 5 % of flyash and 3% of metakaolin, (b) 5 % of flyash and 6% of metakaolin, (c) 5 % of flyash and 9% of metakaolin, (d) 15 % of flyash and 3% of metakaolin, (e) 15 % of flyash and 6% of metakaolin, (f) 15 % of flyash and 9% of metakaolin, (g) 25 % of flyash and 3% of metakaolin, (h) 25 % of flyash and 6% of metakaolin and (i) (a) 25 % of flyash and 9% of metakaolin. Tests such as slump flow, V-funnel, L-box, U-box, J-ring were carried out on fresh concrete. Conventional compressive strength test was carried out on hardened self-compacting concrete (SCC). The initial tangent modulus of SCC was also determined during the test. Compressive strength was also determined at 28 days after heating the specimens to 100ºC, 200ºC and 300ºC in a furnace for 6 hours. The splitting tensile test was conducted on SCC cylinders at 28 days at standard temperature to determine the splitting tensile strength. The flexural test was conducted on beam specimens at standard temperature in universal testing machine to determine the flexural strength as well as the load-deflection characteristics. It is observed that the replacement of cement by a combination of fly ash and metakolin in the range of 8 to 34 percent has no adverse effect on the workability properties of SCC. As the percentage of cement replacement increases, the 7 days and 28 days compressive strength, flexural strength, initial tangent modulus of SCC cubes increase up to 24 % and later decrease. The maximum splitting tensile strength of SCC cylinders at 28 days occurs for a percentage of cement replacement = 14 in the considered range. The minimum splitting tensile strength at 28 days occurs for a percentage of cement replacement = 28 in the considered range. The loss in compressive strength of SCC at elevated temperature is taken as a measure of durability against elevated temperature and it increases as the elevated temperature increases. The maximum loss of compressive strength at elevated temperature occurs at percentage of cement replacement = 8 in the considered range.

Keywords — Self-compacting concrete ; fly ash ; Metakaolin ; compressive strength ; splitting tensile strength ; flexural strength.

1. INTRODUCTION

1.1 GENERAL

Adequate compaction during casting of reinforced concrete members or structures is a primary requirement. Insufficient compaction of concrete results in creation of voids and reduces the strength and durability of structures. Self-compacting concrete (SCC) provides a solution to these problems. Self-compacting concrete (SCC) is a new concrete technology that has been developed during the last twenty years. This technology was first developed in 1986 in Japan. SCC is superior to conventionally vibrated concrete and is eminently suited for locations of high congestion of reinforcement in members or structures. Self- compacting concrete, in the plastic state, flows under its own weight through confined sections without segregation and bleeding, maintains uniformity while completely filling any formwork and flowing around congested reinforcement. In the hardened state, its strength and durability are either same or more than those of normal concrete. SCC can be adopted in situations where it is challenging or inaccessible to handle mechanical compaction for fresh-state concrete, such as submerged concreting, cast in-situ pile foundations, columns or walls and machine bases with reinforcement. The high flowing ability of SCC makes it possible to fill the formwork without mechanical vibration. Self-compacting concrete is composed of standard cement, supplementary materials (such as fly ash, GGBS etc.), fine and coarse aggregates, super plasticizer etc.

A widespread research and development of SCC in the past two decades has resulted in vast literature on self-compacting concrete. A few of the available literature are mentioned here. Hajime Okamura and Masahiro Ouchi [1] carried out investigations for establishing a rational mix design method for SCC and self compactability testing methods. The work carried out by Dr. R. Sri Ravindrarajah, D. Siladyi and B. Adamopoulos [2] showed that fine and coarse aggregates could be partially replaced with fly ash for producing high-strength self-compacting concrete with adequate flow property and low segregation potential without affecting the early age strength. H.J.H. Brouwers and H.J. Radix [3] developed mixes consisting of slag blended cement, gravel (4–16 mm), three types of sand (0– 1, 0–2 and 0–4 mm) and a polycarboxylic ether type superplasticizer. Tests on both fresh and hardened states of these mixes were conducted. It was found that these mixes satisfied all practical and technical requirements such as medium strength and low cost. M. A. Ahmadi, O. Alidoust, I. Sadrinejad, and M. Nayeri [4] studied the properties of self-compacting and ordinary concretes with rice-husk ash procured from a rice paddy milling industry. Two different replacement percentages of cement by rice-husk ash, 10%, and 20%, and two different water/cementitious material ratios (0.40 and 0.35) were used for both the self-compacting and normal concrete specimens. SCC mixes exhibited higher compressive and flexural strength and lower modulus of elasticity when compared to conventional concrete. A. M. K. Abdelalim, G. E. Abdel-Aziz, M.A.K. El-Mohr and G. A. Salama [5] studied the effects of elevated fire temperature and cooling method on the fire resistance of self-compacting concrete and normal concrete. Both the concretes were subjected to elevated temperatures of 200, 400, 600 and 800 °C. In addition, the temperature was maintained at 800 °C while the exposure duration was increased to 15, 30, 60 and 120 minutes. Later the samples were cooled to room temperature using three different cooling methods, viz., air cooling, CO_2 powder cooling and water cooling. Reductions in compressive and tensile strengths occurred. It was observed that the elevated temperature is more damaging to the normal concrete compared with self-compacting concrete. S. Venkateswara Rao, M.V. Seshagiri Rao, and P. Rathish Kumar [6] attempted to develop standard and high strength self-compacting concrete with different sizes of aggregates using Nan Su's mix design procedure. The experimental results indicated that self-compacting concrete can be developed with all sizes of graded aggregate satisfying all the workability characteristics. Compressive, flexural and split tensile strengths were obtained at the end of 3, 7 and 28 days for standard and high strength SCC with different sizes of aggregates. The properties were superior in standard SCC with 10mm size aggregate and 52% flyash. 16 mm size aggregate and 31% fly ash enhanced the properties of high strength SCC. M Chandrasekhar, M V Seshagiri Rao and Maganti Janardhana [7] studied hybrid fiber reinforced self-compacting concrete (made with a combination of steel and glass fibers). The 28 days strength was observed to increase from 12.39% to 28.2% for different percentages of fibers. The peak stress and the corresponding strain were also observed to increase with an increase in fiber percentage. An empirical equation $E= 5700\sqrt{f_{ck}}$ was proposed. Prof. D. B. Kulkarni and Prof Mrs S N Patil [8] have assessed the effect of sustained temperatures on strength properties of self-compacting concrete and compared it with that of ordinary conventional concrete. It was observed that as temperature increased to 200ºC the compressive, splitting tensile, flexural and impact strengths of specimens decreased by 4.00%, 16.26%, 14.87% and 35.98% respectively of the room temperature strength for ordinary concrete. For self compacting concrete, the reduction in compressive, splitting tensile, flexural and impact strengths was 7.61%, 14.51%, 12.76%, 24.26% respectively. As temperature increased to 400ºC the compressive, splitting tensile, flexural and impact strengths of specimens decreased by 17.00%, 30.72%, 28.20% and 60.00% respectively of the room temperature strength for ordinary concrete. For self compacting concrete, the reduction in compressive, splitting tensile, flexural and impact strengths was 18.21%, 31.62%, 26.22%, 66.67% respectively. As temperature increased to 600^0C the compressive, splitting tensile, flexural and impact strengths of specimens decreased by 28.50%, 51.21%, 46.67% and 80.00% respectively of the room temperature strength for ordinary concrete. For self compacting concrete, the reduction in compressive, splitting tensile, flexural and impact strengths was 30.00%, 60.91%, 52.12%, 90.47% respectively. SCC was observed to have a higher strength loss than OCC in the temperature range 200^0C to 600^0C. SCC was observed to be more susceptible to explosive spalling when exposed to temperature above 300^0C upto 600^0C. N. Krishna Murthy, N. Aruna, A.V.Narasimha Rao, I.V.Ramana Reddy, B. Madhusudana Reddy, M.Vijaya Sekhar Reddy [9] studied the effects of using supplementary cementitious materials on the fresh and hardened properties of self-compacting concrete (SCC). For this purpose, four mixtures were designed with water/cement ratio as 0.36 with 0.9 % of super plasticizer cum retarder dosage by weight. The controlled designed mix had only ordinary Portland cement (SCC) as the binder while the remaining mixtures incorporated binary and ternary cementitious blends of OPC, metakaolin and fly ash. After mixing, the fresh properties of the SCC were tested for slump flow, V-funnel flow time and L-Box ratio. Compressive and splitting tensile strengths of the hardened concrete were determined at 7, 28, 90 and 180 days. In the work carried out by Kannan V and Ganesan K [10] the fresh state and strength properties of self compacting concrete (SCC) with metakaolin (MK) and Fly ash (FA) were determined. Different mixes were prepared with different amounts of MK and FA. Ordinary Portland cement (OPC) was replaced by 5% to 40% of MK and FA. The strength properties of SCC considerably improved when the percentages of MK, FA and MK+FA were increased. N.Anand and G.Prince Arulraj [11] developed a mix design procedure for the design of SCC mixes. The flow properties such as filling ability, passing ability and segregation resistance were found using the Slump Flow, J-Ring and V-Funnel test setups respectively. It was found that the requirements of SCC were satisfied. The effect of elevated temperature on SCC specimens heated from 27ºC to 900ºC under hot condition was studied. Mechanical properties such as compressive strength, tensile strength, flexural strength and modulus of elasticity of the reference and heated specimens were found. The reduction in the compressive, tensile and flexural strengths of SCC specimens were found to be 82.63%, 80.22%and 79.14% respectively for M40 concrete when compared with the reference specimen. Literature survey has revealed that few researchers have used the combination of fly ash and metakaolin to partially replace the cement in SCC. The optimum combination of fly ash and metakaolin in terms of percentages by weight of cement has not been determined yet.

2. PRESENT WORK

2.1 General

The scope of the present work is limited to workability and strength studies on M40 grade self-compacting concrete in which cement is partially replaced by fly ash and metakaolin. In the present work the cement in SCC is partially replaced with (a) 5 % of flyash and 3% of metakaolin, (b) 5 % of flyash and 6% of metakaolin, (c) 5 % of flyash and 9% of metakaolin, (d) 15 % of flyash and 3% of metakaolin, (e) 15 % of flyash and 6% of metakaolin, (f) 15 % of flyash and 9% of metakaolin, (g) 25 % of flyash and 3% of metakaolin, (h) 25 % of flyash and 6% of metakaolin and (i) (a) 25 % of flyash and 9% of metakaolin.

2.2 Materials Used

In this work normal Portland cement of 53 grade conforming to IS: 12269-1987 has been utilized. The physical properties of the cement obtained by conducting appropriate tests as per IS: 269/4831 and the requirements as per IS: 12269-1987 are given in Table 1.

Table 1: Physical properties of cement

Sl.	Property	Value	As per IS:12269-1987
1	Standard	28%	………………………..
2	Fineness	2.9%	Not more than 10%
3	Soundness	2mm	Not more than 10mm
4	Initial setting time	62 min	Not less than 30 min
5	Final setting time	537min	Not more than 600 min
6	Specific gravity	2.98	…………………………
7	Temperature	27.0℃	Should be 27.0℃

Fine aggregate used in this work is manufactured sand (M-sand) obtained from nearby crusher. It conforms to zone II as per IS: 383-l997. The physical properties of fine aggregate like specific gravity, gradation and fineness modulus are tested as per IS: 2386 and are given below in the Table 2.

Table 2: Physical Properties of Fine Aggregate

Sl. No.	Property	Value
1	Type	Manufactured
2	Surface Texture	Crystalline
3	Specify gravity	2.62
4	Water absorption	3.8%
5	Moisture content	0.8%
6	Fineness modules	2.68
7	Grading zone	Zone II

Crushed granite stone of 12.5 mm and down has been used as coarse aggregate. The sieve analysis of coarse aggregates conforms to the specifications of IS 383:1997 for graded aggregate. The physical properties of coarse aggregate are given in Table 3.

Table 3: Physical Properties of Coarse Aggregate

Sl. No.	Property	Value
1	Surface Texture	Crystalline
2	Particle Shape	Angular
3	Specific gravity	2.69
4	Water absorption	0.24%
5	Bulk density	1.62

Fly-ash is finely divided powder resembling Portland cement. In the present investigation work the fly ash used was obtained from Bellary thermal power station in Karnataka. The bulk density of fly-ash is l.l gm/cc and its specific gravity is 2.4. The chemical composition of fly-ash is given in Table 4.

Table 4: Chemical Coposition of Fly-Ash

Sl.	Constituent	Percent by wt.
1	Silica (SiO_2)	62.63
2	Iron oxide (Fe_2O_3)	3.93
3	Alumina (Al_2O_3)	32.35
4	Calcium oxide (CaO)	2.04
5	Magnesium oxide (MgO)	0.46
6	Total sulphur (SO_3)	0.53
7	Loss of ignition	0.39
8	Sodium oxide(Na_2O)	1.35
9	Total chlorides	0.06

Metakaolin used in this present investigation is bought from Gujarat. The color of the Metakaolin is off white. The bulk density is 0.39 gm/cc. The specific gravity is 2.42. The chemical composition of Metakaolin are given in Table 5.

Table 5: Chemical Composition of Metakaolin

Sl.	Constituent	Percentage by Wt.
1	Silicon Dioxide (SiO_2)	52.0
2	Alumina (Al_2O_3)	42.2
3	Iron oxide (Fe_2O_3)	0.7
4	Calcium oxide (CaO)	0.08
5	Magnesium oxide (MgO)	1.76
6	Sodium oxide (Na_2O)	0.07
7	Loss on ignition	0.3

AUROMIX 400, a super plasticizer manufactured by FOSROC constructive solutions, was used in the present work. Its properties are listed in Table 6. Its use enhances the workability of the mix and strength; helps in producing better compaction and finishing. It also permits reduction in water content.

Table 6: Typical Properties of Auro-mix 400 Super Plasticizer

Property	Value
Appearance	Light yellow colored liquid
pH	Min 6
Volumetric mass @ 20°C	1.09 kg per liter
Chloride content	Nil
Alkali content	< 1.5 g Na_2O proportionate liter of admixture

Water which is fit for drinking was used for making concrete and curing.

2.3 Trial Mix Proportions for M40 Grade SCC

The mix design calculations were carried out in accordance with EFNARC guidelines. The proportions of the various mixes considered in the present study are given in Table 7 along with their designations.

Table 7: Mix Proportions for SCC

Mix Designation	FA (%)	MK (%)	OPC (kg/m^3)	Fly-ash (kg/m^3)	MK (kg/m^3)	Water (kg/m^3)	M Sand (kg/m^3)	CA (kg/m^3)	W/P ratio	SP (kg/m^3)	Density (kg/m^3)
F5M3	5	3	514.5	19.91	13.76	189.6	880.94	714.42	0.346	4.39	4385.53
F5M6	5	6	497.7	19.91	27.53	189.6	880.94	714.42	0.348	4.36	4361.42
F5M9	5	9	480.9	19.91	41.29	189.6	880.94	714.42	0.350	4.34	4337.31
F15M3	15	3	458.6	59.72	13.76	189.6	880.94	714.42	0.356	4.26	4256.62
F15M6	15	6	441.8	59.72	27.53	189.6	880.94	714.42	0.358	4.23	4232.51
F15M9	15	9	425.0	59.72	41.29	189.6	880.94	714.42	0.360	4.21	4208.39
F25M3	25	3	402.6	99.53	13.76	189.6	880.94	714.42	0.367	4.13	4127.70
F25M6	25	6	385.8	99.53	27.53	189.6	880.94	714.42	0.369	4.11	4103.59
F25M9	25	9	369.0	99.53	41.29	189.6	880.94	714.42	0.371	4.09	4079.48

2.4 Tests on Fresh Concrete

The tests mentioned in Table 8 were conducted to assess whether the mixes meet the workability requirements of SCC.

The results of the tests conducted on fresh concrete are given in Table 9.

Table 8: Test Methods for Workability Properties of SCC

l.	Test	Property measured
1	Slump-flow	Filling ability
2	T_{50} cm slump flow	Filling ability
3	V-funnel	Filling ability
4	J-ring	Passing ability
5	L-box	Passing ability
6	U-box	Passing ability

Table 9: Workability Test Results for Different Mix Proportions of SCC

Mix	Fly-ash In (%)	Metakaolin In (%)	Slump Flow Dia.(mm)	V-Funnel (s)	L-Box (H_2/H_1)	U-Box (H_2-H_1) mm
F5M3	5	3	694	7.7	0.91	5
F5M6	5	6	685	9.6	0.87	6
F5M9	5	9	672	11.2	0.85	5
F15M3	15	3	710	7.1	0.89	7
F15M6	15	6	703	9.5	0.89	8
F15M9	15	9	689	10.3	0.90	9
F25M3	25	3	724	5.7	0.92	6
F25M6	25	6	713	8.3	0.91	7
F25M9	25	9	705	9.2	0.89	6

- F denotes flyash; M denotes metakaolin
- H_2/H_1= blocking ratio (L-box)
- H_1 = height of concrete in the chimney
- H_2 = height of concrete in the trough

- $H_2 - H_1$ = filling height (U-box) = height of the concrete in the compartment that has been filled.

Table 10: Acceptance criteria for SCC (as per EFNARC)

Sl.No	Method	Unit	Range of values	
			Min	Max
1	Slump flow	mm	650	800
2	J-Ring	mm	0	10
3	V-Funnel	Sec	6	12
4	L-Box	H_2/H_1	0.8	1.0
5	U-Box	mm	0	30

From Tables 9 and 10, it is observed that all the trial mix proportions satisfy the workability requirements of self-compacting concrete.

2.5 Compressive Strength Tests

Compressive strength tests were conducted on 150 mm size cubes of SCC in a compression testing machine at 7 and 28 days. The results are given in Table 11 and plotted in Fig.1.

Table11: Compressive Strength Test Results at Room Temperature

Mix Designation	Percentage of cement replacement	7 days Strength (N/mm^2)	28 days strength (N/mm^2)
F5M3	8	24.46	40.05
F5M6	11	29.68	40.16
F5M9	14	32.30	42.16
F15M3	18	36.32	42.68
F15M6	21	39.92	46.12
F15M9	24	38.0	48.76
F25M3	28	37.24	47.02
F25M6	31	32.08	44.22
F25M9	34	30.80	41.52

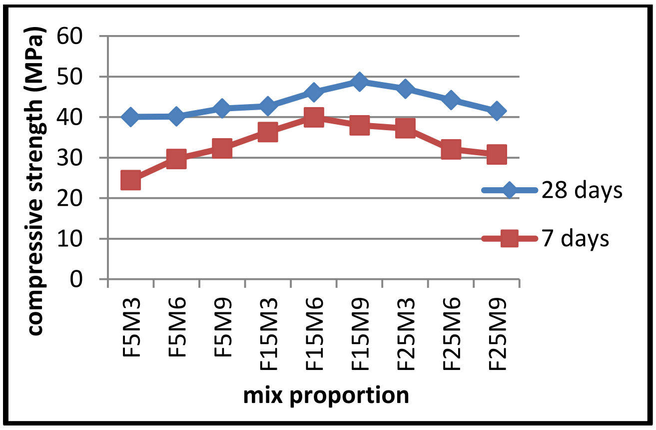

Fig. 1: Compressive Strengths of Various Mixes

From Table 11 and Fig.1, it is observed that as the percentage of cement replacement increases, the 28 days compressive strength increases up to 24 % and later decreases. All the mixes have achieved a 28 days compressive strength of more than 40 MPa. From Table 11 and Fig. 1, it is also observed that as the percentage of cement replacement increases, the 7 days compressive strength increases up to 21 % and later decreases.

2.6 Splitting Tensile Strength Tests

Splitting tensile strength tests were conducted on cylindrical specimens of 150mm diameter and 300mm height at 28 days in accordance with BIS specifications and procedures. The results are given in Table 12.

Table 12: Splitting tensile strengths of mixes at 28 days

Mix Designation	Percentage of cement replacement	Splitting tensile strength (N/mm^2) 28days
F5M3	8	4.31
F5M6	11	4.73
F5M9	14	5.19
F15M3	18	4.15
F15M6	21	4.52
F15M9	24	4.98
F25M3	28	3.74
F25M6	31	4.21
F25M9	34	4.52

From Table 12, it is seen that maximum splitting tensile strength at 28 days occurs for a percentage of cement replacement = 14 in the considered range. The minimum splitting tensile strength at 28 days occurs for a percentage of cement replacement = 28 in the considered range.

2.7 Flexural Strength Tests

Flexure tests were conducted on beams of size 100 mm x 100 mm x 500 mm subjected to two point loading at 28 days in UTM and the results are given in Table 13. These results are plotted in Fig. 2.

Table 13: Flexural Strength Test Results

Mix Designation	Percentage of cement replacement	Flexural strength results (N/mm^2) 28days
F5M3	8	4.68
F5M6	11	4.84
F5M9	14	5.42
F15M3	18	5.63
F15M6	21	5.96
F15M9	24	6.60
F25M3	28	6.34
F25M6	31	6.22
F25M9	34	5.99

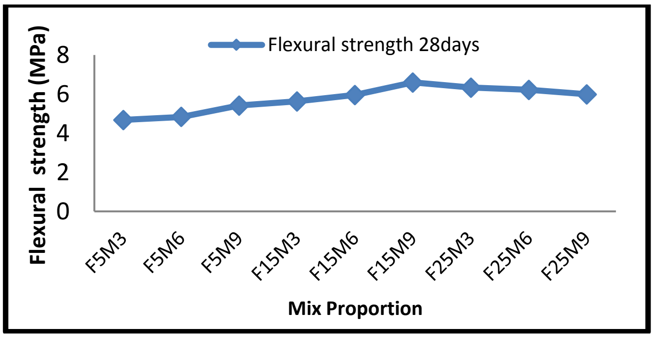

Fig 2: Flexural Strength of Mix Proportions

From Table 13 and Fig.2, it is observed that the flexural strength increases as the percentage of cement replacement increases up to 24% and later decreases. The maximum flexural strength occurs at percentage of cement replacement

= 24 in the considered range. During the flexure test, the midspan deflection was measured at various load levels. The load v/s deflection curve for all the prism specimens are plotted in Fig. 3. The load and midspan deflection at failure are given in Table 14 for various prism specimens.

Table 14: Load and Midspan Deflection at Failure of SCC beams

Mix Designation	Percentage of cement replacement	Load at failure in kN	Midspan deflection in mm
F5M3	8	9.34	0.161
F5M6	11	9.7	0.165
F5M9	14	10.82	0.176
F15M3	18	11.24	0.181
F15M6	21	11.9	0.184
F15M9	24	13.18	0.199
F25M3	28	12.64	0.194
F25M6	31	12.42	0.192
F25M9	34	11.96	0.186

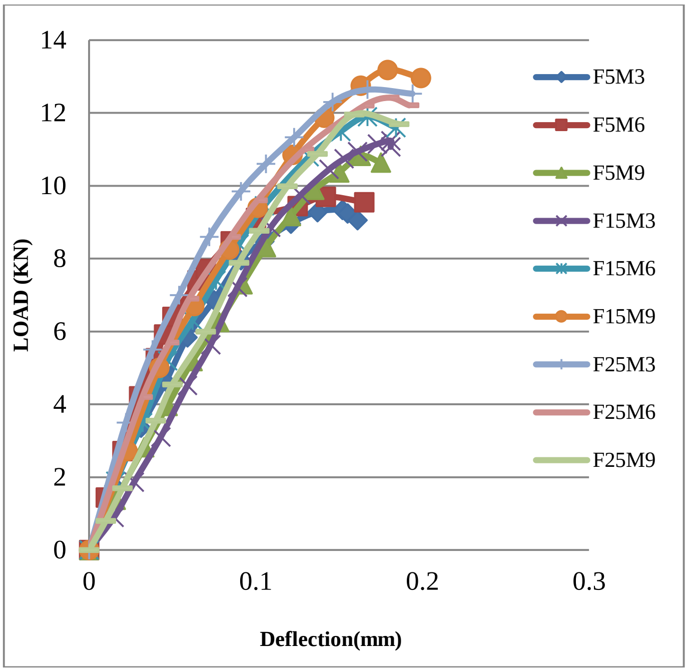

Fig.3: Load-Deflection Behavior of SCC beam specimens

From Table 14 and Fig. 3, it is observed that both failure load and midspan deflection increase as the percentage of cement replacement increases up to 24% and later decrease. The failure load and midspan deflection are maximum at percentage of cement replacement = 24.

2.8 Initial Tangent Modulus of SCC

Compression test was conducted on 150 mm diameter x 300 mm height cylinders for determining the initial tangent modulus of SCC mixes. It is conducted in stress controlled UTM of 1000kN capacity at 500 N/s stress rate. Strains were measured at various load levels and stress-strain plots were made. The initial tangent modulus was obtained from the stress versus strain plot. These values are given in Table 15. From Table 15, it is seen that the initial tangent modulus increases as the percentage of cement replacement increases up to 24% and later decreases.

Table 15: Initial Tangent Modulus of SCC

Mix	Percentage of cement replacement	Initial tangent modulus (N/mm^2)
F5M3	8	30124
F5M6	11	32004
F5M9	14	32794
F15M3	18	32994
F15M6	21	34334
F15M9	24	35240
F25M3	28	34646
F25M6	31	33539
F25M9	34	32534

A plot of 28 days compressive strength versus initial tangent modulus of SCC is shown in Fig. 4. It is observed the initial tangent modulus of SCC is a function of the 28 days compressive strength. As the strength increases the modulus also increases.

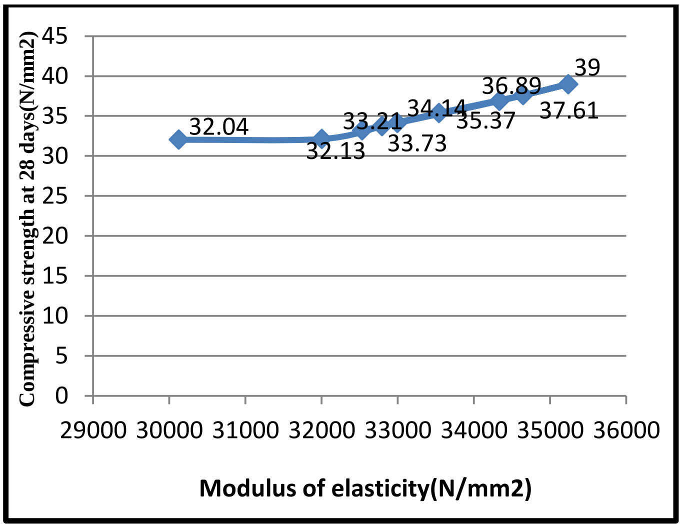

Fig.4: Compressive Strength Versus Initial Tangent Modulus of SCC

2.9 Compressive Strength Test at Elevated Temperatures

SCC cubes of 100 mm size were heated after 28 days of curing to 100˚C, 200˚C and 300˚C for 6 hours and tested for compressive strength in compression testing machine. The test results are given in Table 16.

Table16: Compressive Strength Results at Different Temperatures for SCC

Mix Designation	Compressive strength (N/mm^2) at			
	Room Temp	100˚C	200˚C	300˚C
F5M3	41.08	40.17	38.63	35.58
F5M6	41.19	40.28	38.74	35.69
F5M9	43.18	42.27	40.73	37.68
F15M3	43.71	42.80	41.26	38.21
F15M6	47.15	46.24	44.70	41.65
F15M9	49.79	48.88	47.34	44.29
F25M3	48.05	47.14	45.60	42.55
F25M6	45.25	44.34	42.80	39.75
F25M9	42.55	41.64	40.10	37.05

The percentage losses of compressive strength at 100˚C, 200˚C and 300˚C are computed for various SCC specimens and presented in Table 17 and Fig.5. These are measures of the durability of SCC against elevated temperature.

Table 17: Percentage Reduction in Compressive Strength at Elevated Tempertures

Mix	% Reduction in compressive strength (N/mm²)		
	100˚C	200˚C	300˚C
F5M3	2.21	5.96	13.38
F5M6	2.20	5.94	13.35
F5M9	2.10	5.67	12.73
F15M3	2.08	5.60	12.58
F15M6	1.93	5.19	11.66
F15M9	1.82	4.92	11.04
F25M3	1.89	5.09	11.44
F25M6	2.01	5.41	12.15
F25M9	2.13	5.75	12.92

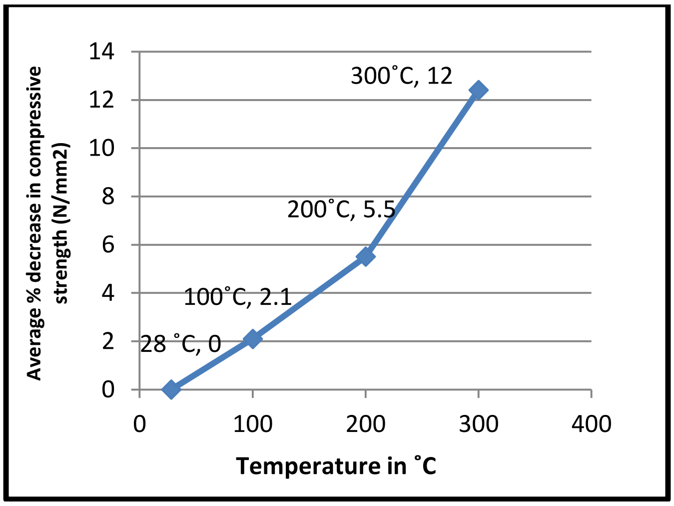

Fig. 5: Loss in Compressive Strength of SCC at Various Temperatures

From Table 17 and Fig.5, it is observed that:

- The loss in compressive strength of SCC increases as the temperature increases.
- The maximum loss of compressive strength occurs at percentage of cement replacement = 8 in the considered range.

3. CONCLUSIONS

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

- Replacement of cement by a combination of fly ash and metakaolin in the range of 8 to 34 percent has no adverse effect on the workability properties of SCC.
- As the percentage of cement replacement increases, the 7 days and 28 days compressive strength of SCC cubes increase up to 24 % and later decrease.
- The maximum splitting tensile strength of SCC cylinders at 28 days occurs for a percentage of cement replacement = 14 in the considered range. The minimum splitting tensile strength at 28 days occurs for a percentage of cement replacement = 28 in the considered range.
- The flexural strength of SCC beams increases as the percentage of cement replacement increases up to 24% and later decreases. The maximum flexural strength occurs at a percentage of cement replacement = 24 in the considered range.
- Both failure load and midspan deflection of simply supported SCC beams under two point loading increase as the percentage of cement replacement increases up to 24% and later decrease. The failure load and midspan deflection are maximum at a percentage of cement replacement = 24.
- The initial tangent modulus of elasticity of SCC increases as the percentage of cement replacement increases up to 24% and later decreases.
- The initial tangent modulus of SCC is a function of the 28 days compressive strength. As the strength increases the modulus also increases.
- The loss in compressive strength of SCC at elevated temperature is taken as a measure of durability at elevated temperature and it increases as the elevated temperature increases.
- The maximum loss of compressive strength at elevated temperature occurs at percentage of cement replacement = 8 in the considered range.

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