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Title: **BEHAVIOUR OF M50 GRADE SELF- COMPACTING CONCRETE BY PARTIAL REPLACEMENT OF PORTLAND SLAG CEMENT WITH METAKAOLIN**

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BEHAVIOUR OF M50 GRADE SELF- COMPACTING CONCRETE BY PARTIAL REPLACEMENT OF PORTLAND SLAG CEMENT WITH METAKAOLIN

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ABSTRACT Self-compacting concrete is one of the most revolutionary developments in concrete construction. It does not require the use of any mechanical vibrator for compaction as it gets compacted under its own weight. In this present work M50 grade Self-compacting concrete with metalaolin replacement is developed. It is found that Poly-Carboxylic Ether based super plasticizer was compatible with the materials used for making concrete. The objective of the work is to study the strength and durability aspects of Self compacting concrete with and without replacement of Portland Slag cement with Metakaolin at constant water to cement ratio derived using efficiency concept. It is found that the optimum percentage replacement of Portland Slag cement with Metakaolin was found to be 15%. The percentage increase in strength at the age of 28 days was found to be 7.85% higher than controlled concrete (without replacement of met kaolin) From the experimental investigations it was observed that the optimum dosage of super plasticizer enhanced the flow property of the concrete. As a result, overall improvements in the flow and filling ability of the self-compacting concrete are observed and the specimen with metakaolin showed higher strength value and they are more durable when subjected to elevated temperatures.
Key Words: Metakoline, Compressive strength , Workability , Poly-Carboxylic Ether, Portland Slag cement

1. INTRODUCTION General In the world of construction 'concrete' is one of the most consumed material on earth's surface next to water (Mehta and Monteiro 2014). The concrete is absolutely indispensable in modern society's fascination with new roads, buildings and other constructions. This is attributed mainly to low cost of materials and construction for concrete structures as well as low cost of maintenance. Therefore, it is not surprising that much advancement in concrete technology have occurred as a result of two driving forces, namely the speed of construction and the durability of concrete. Earlier the availability of high early strength cements enabled the use of high water content in concrete mixtures that were easy to handle. This approach however, led to serious problems with durability of structures, especially those subjected to severe environmental exposures. One of the major developments in concrete technology in last three decades has been the introduction and usage of superplasticizers which reduces

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the usage of water for same workability. In addition, use of industrial by-products such as fly ash, GGBS and silica fume as supplementary cementitious materials (SCM) for the production of HPC is gaining importance. All these developments have extended the use of concrete and require appropriate expertise. SelfCompacting Concrete is one such latest innovation made in concrete technology where the concrete gets compacted due to its self-weight. Self-compacting Concrete is an innovative concrete that does not require any vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. Self-Compacting Concrete is a complex system that is usually proportioned with one or more additions and one or more chemical admixtures. A key factor for a successful formulation is a clear understanding of the role of the various constituents in the mix and their effects on the fresh and hardened properties. Successful Self-Compacting Concrete must have high fluidity (for flow under selfweight), high segregation resistance (to maintain uniformity during flow) and sufficient passing ability so that it can flow through and around reinforcement without blocking or segregating. 2. MATERIALS IN SELF-COMPACTING CONCRETE This chapter discusses the materials used for making Self-Compacting concrete. Mix proportions for SCC differ from those of ordinary concrete, in that the former has more powder content and less coarse aggregate. Moreover, SCC incorporates high range water reducers (HRWR, superplasticizers) in larger amounts and frequently a viscosity modifying agent (VMA) in small doses. i) Powder content The common practice to obtain self-compatibility in SCC is to limit the coarse aggregate content and the maximum size and to use lower water–powder ratios together with new generation super plasticizer. During the transportation and placement of SCC, the increased flow ability may cause segregation and bleeding which can be overcome by providing the necessary viscosity, which is usually supplied by either increasing the fine aggregate content, by limiting the maximum aggregate size, by increasing the powder content or by utilizing viscosity modifying admixtures. ii) Metakaolin Metakaolin (MK) is a pozzolanic material. It is obtained by calcination of kaolinite clay at a temperature between 500◌ C◌ and◌ 800◌ C. The raw material input in the manufacture of metakaolin (Al2Si2O7) is kaolin clay. Kaolin is a fine, white, clay mineral that has been traditionally used in the manufacture of porcelain. The behaviour of clay minerals on heating depends on their structure, crystal size and degree of crystalline.◌ At◌ just◌ above◌ 100◌ C,◌ clay◌ minerals◌ lose◌ most◌ of◌ their◌ adsorbed◌ water.◌ The◌ temperature◌at◌which◌kaolinite◌loses◌water◌by◌dehydroxylization◌is◌in◌the◌range◌of◌500◌ -◌800◌ C. This thermal activation of Mineral is also referred to as calcining. Beyond the temperature of dehydroxylization, kaolinite retains two-dimensional order in the crystal structure and the product is termed as metakaolin.

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Material properties and chemical compositions supplied by the manufacturers are given in table below.

Table Properties of Metakaolin

Properties	MetaCem 85 C
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
Blaine (m^2/kg)	15,000

Chemical Composition of Metakaolin

Chemical composition	Metakaolin (%)
Silica (SiO_2)	54.3
Alumina (Al_2O_3)	38.3
Ferric oxide (Fe_2O_3)	4.28
Calcium oxide (CaO)	0.39
Magnesium oxide (MgO)	0.08
Sodium oxide (Na_2O)	0.12
Potassium oxide (K_2O)	0.5
Sulphuric anhydride (SO_3)	0.22

iii) Cement

Portland slag cement (PSC) of 53 grades. The cement used has been tested for various properties as per IS: 4031-1988 and found to be confirming to various specifications of IS: 455-1989 having specific gravity of 2.627.

Properties of Cement

Properties		Results	Limits (IS 455- 1989)	Codes
Standard Consistency (%)		33	-	IS: 4031 (part4)-1988
Specific Gravity		2.627	-	
Le-Chatelier Expansion (mm)		1	Max.10 mm	IS: 4031 (part3)-1988
Fineness (%)		1	Max. 10%	IS: 4031 (part1)-1996
Setting Time (min)	Initial Setting Time	146	Min.30 min	IS: 4031 (part5)-1998
	Final Setting Time	207	Max.600min	
Compressive Strength Of Mortar Cubes (MPa)	7 Days	36.5374	-	IS:4031 (part 6)-1988
	28 Days	54.806	-	

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iv) Aggregates To ensure its high filling ability, flow without blockage and to maintain homogeneity, SCC requires a reduction in coarse aggregate content, high cement content, superplasticizer (SP) and viscosity modifying agent (VMA). Blocking depends on the size, shape and content of coarse aggregate. A reduction in the coarse aggregate content and lowering the size are both effective in inhibiting blocking. Most SCC applications have used coarse aggregate with a maximum size in the range of 16-20 mm depending on local availability and practice. v) Fine aggregates Fine aggregates can be natural or manufactured and obtained from local market. The grading must be uniform throughout the work. The moisture content or absorption characteristics must be closely monitored as quality of SCC is sensitive towards moisture variation .The physical Properties like specific gravity, bulk density, gradation, fineness modulus are tested in accordance with IS 2386.

Table 3.4 Physical Properties of Fine Aggregates

Properties		Results	Codes
Silt Content		Nil	IS: 2386 (part 2) – 1963
Specific Gravity		2.625	IS: 2386 (part 3) - 1963
Bulking Of Sand (%)		4.6	IS: 2386 (part 3) - 1963
Moisture Content (%)		0.3	IS: 2386 (part 3) - 1963
Fineness Modulus		2.854	-
Grading		IV	IS: 383 – 1970
Bulk Density(g/cc)	Loose condition	1.462	IS: 2386 (part 3) - 1963
	Compacted condition	1.626	

Vi) Coarse aggregates The crushed coarse aggregate of 10 mm maximum size obtained from the local crushing plant, is used in the present study. The physical properties of the coarse aggregate like specific gravity, bulk density, gradation, fineness modulus are tested in accordance with IS 2386. Physical Properties of Coarse Aggregates

Properties		Results	Codes
Impact Value		25.2	IS: 2386 (part 4) – 1963
Crushing Value		32.8	IS: 2386 (part 4) – 1963
Specific Gravity		2.7	IS: 2386 (part 3) -1963
Moisture Content (%)		0.1	IS: 2386 (part 3) -1963
Fineness Modulus		6.53	-
Bulk Density (g/cc)	Loose condition	1.664	IS: 2386 (part 3) -1963
	Compacted condition	1.631	

Vii) Chemical admixturesSuper plasticisers are an essential component of SCC to provide necessary workability. The new generation superplasticizer termed poly-carboxylic ether (PCE) is particularly useful for SCC.Other types may be incorporated as necessary, such as Viscosity Modifying Agents (VMA) for stability, air entraining agents (AEA) to improve freeze-thaw resistance, and retarders for control of setting.In the present investigation "Auramix 400" a poly-carboxylic ether based superplasticizer is used. This super plasticiser contains 0.01% -0.02% of VMA incorporated in it.

viii) Water Normal water conforming to "European Federation of National Associations Representing for Concrete (EFNARC)" guidelines is used as mixing water for making concrete. A proper control has to be kept over the water to cement ratio as SCC is very sensitive to moisture variation.

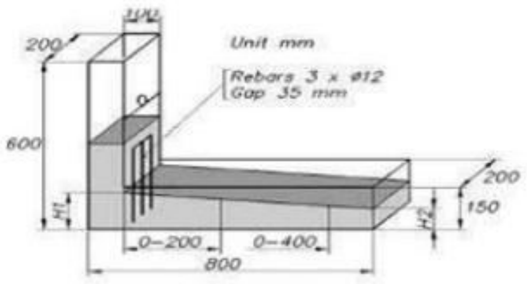
Material proportions required for making one cubic meter of concrete is fixed based on themix design mentioned in next chapter.

3.TESTS CONDUCTED

i) Slump flow and t50cm test The higher the slump flow (SF) value, the greater its ability to fill formwork under its own weight. A value of at least 650mm is required for SCC. There is no generally accepted advice on what are reasonable tolerances about a specified value, though ±50mm, as with the related flow table test, might be appropriate. The T50 time is a secondary indication of flow. A lower time indicates greater flow ability. The Brite EuRam research suggested that a time of 3-7 seconds is acceptable for civil engineering applications, and 2-5 seconds for housing applications.

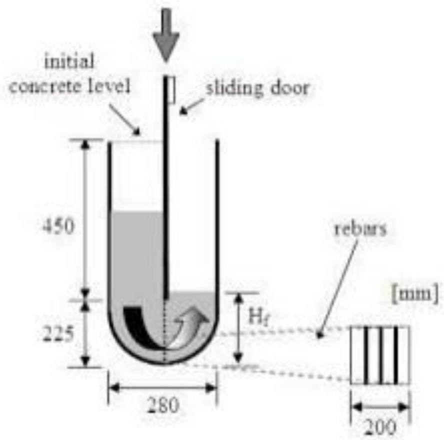
ii) L-box test method

If the concrete flows as freely as water, at rest it will be horizontal, so H2/H1 = 1. Therefore the nearer this test value, the 'blocking ratio', is to unity, the better the flow of the concrete. The EU research team suggested a minimum acceptable value of 0.8. T20 and T40 times can give some indication of ease of flow, but no suitable values have been generally agreed. Obvious blocking of coarse aggregate behind the reinforcing bars can be detected visually.



iii) U box test method

If the concrete flows as freely as water, at rest it will be horizontal, so H1 - H2 = 0. Therefore the nearer this test value, the 'filling height', is to zero, the better the flowand passing ability of the concrete.



Acceptance Criteria for SCC

Methods	Units	Typical range of value	
		Minimum	Maximum
Slump flow by Abrams cone	mm	650	800
T_{50cm} slump flow	sec	2	5
J-ring	mm	0	10
V-funnel	sec	6	12
V-funnel at $T_{5minutes}$	sec	0	+3
L-box	h_2/h_1	0.8	1
U-box	h_2-h_1	0	30
Fill-box	%	90	100
GTM screen stability test	%	0	15
Orimet	sec	0	5

iv) Compressive strength test (IS 516-1959): Specimens stored in water is tested immediately on removal from the water and while they are still in the wet condition. Surface water and grit is be wiped off the specimens and any projecting fins removed. Specimens when received dry shall be kept in water for 24 hours before they are taken for testing. The dimensions of the specimens to the nearest 0.2 mm and their weight are being noted before testing

v) Flexure strength test (IS 516- 1959):
Test◌ specimens◌ stored◌ in◌ water◌ at◌ a◌temperature◌ of◌ 24◌ C◌ to◌ 30˚◌ C◌ for◌ 48◌ hours◌before testing, shall be tested immediately on removal from the water whilst they are still in a wet condition. The dimensions of each specimen are being noted before testing. No preparation of the surfaces is required

Vi) Split tensile strength (IS: 5816- 1999)
Specimens when received dry is kept in water for 24 h before they are taken for testing. Unless other conditions are required for specific laboratory investigation specimen is tested immediately on removal from the water whilst they are still wet. Surface water and grit is wiped off the specimens and any projecting fins removed from the surfaces which are to be in contact with the packing strips.

Vii) Rebound Hammer Test (IS: 13311 Part (II) -1992) The rebound hammer method provides a convenient and rapid indication of the compressive strength of concrete by means of establishing a suitable correlation between the rebound index and the compressive strength of concrete. It is also pointed out that rebound indices are indicative of compressive strength of Concrete to a limited depth from the surface. If the concrete in a particular member has internal micro cracking, flaws or heterogeneity across the cross-section, rebound hammer indices will not indicate the same

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Viii) Ultra-Sonic Pulse Velocity Test (IS: 13311 Part (I) -1992)

The ultrasonic pulse velocity of concrete is mainly related to its density and modulus of elasticity. This in turn, depends upon the materials and mix proportions in making concrete as well as the method of placing, compaction and curing of concrete. For example, if the concrete is not compacted as thoroughly as possible, or if there is segregation of concrete during placing or there are internal cracks or flaws, the pulse velocity will be lower, although the same materials and mix proportions are used. The quality of concrete in terms of uniformity, incidence or absence of internal flaws, cracks and segregation are indicative of the level of workmanship employed; can thus be assessed using the guidelines given in table given below , which have been evolved for characterising the quality of concrete in structures in terms of the ultrasonic pulse velocity. The assessment of compressive strength of concrete from ultrasonic pulse velocity values is not adequate because the statistical confidence of the correlation between ultrasonic pulse velocity and the compressive strength of concrete is not very high. The reason is that a large number of parameters are involved, which influence the pulse velocity and compressive strength of concrete to different extents.

4. RESULTS AND DISCUSSIONS

This chapter includes the test results on both fresh and hardened properties of concrete. The results of compressive strength for different water/cement ratio and different percentage replacements of Metakaolin each for 7 and 28 days are given in the table below:

Compressive Strength for Different Trail Mix

S. no	W/C	% Replacement of cement by Metakaolin	% SP	7 Days compressive strength (MPa)	28 Days compressive strength (MPa)
1	0.33	5	1	37.91	57.053
2	0.38	10	1	40.97	58.45
3	0.43	15	1	41.67	61.53
4	0.48	20	1	39.1	58.15
5	0.53	25	1	24.35	36.16

Initially for two trail mix compressive strength for 28 days samples were determined by using Accelerated Curing Test method (ACT). The test results obtained were not accurate as the result of compressive strength at 7 days is more than 28 days strength. This may be probably due to in-compatibility of chemical admixture when subjected to higher temperature. In the present study the grade of concrete was fixed to M50. In trail mix 4 and 9 strength criteria was in accordance with M50 grade concrete but, for the trail mix 4 the fresh concrete properties are not satisfied. Therefore from the above values for compressive strength we can conclude that the optimum replacement percentage is 15 at a W/c ratio of 0.43..

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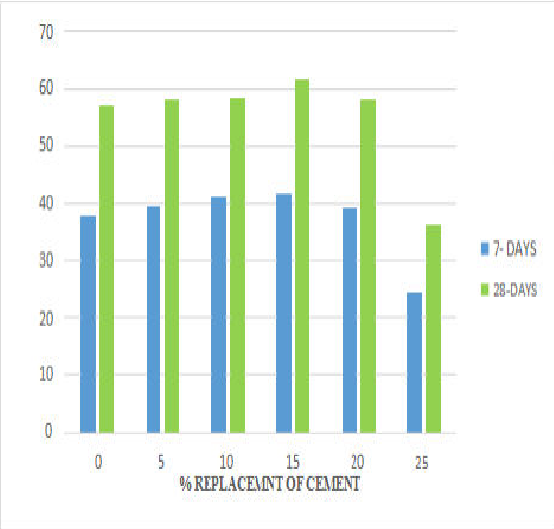

Compressive strength for different percentage replacement of Portland Sl Cement with Metakaolin

From the above graph it can be inferred that the optimum percentage replacement of Portland Slag Cement with Metakaolin is found to be 15%. Material Quantities per Cubic Meter of Concrete

Material	Quantity (kg/m^3)	
	0% replacement	15 % replacement
Cement	550	467.5
Metakaolin	0	82.5
Water	148.5	205.022
Fine aggregate	783.89	710.663
Coarse aggregate	873.478	791.851
Superplasticizer and VMA	5.5	5.5

Both mixes are designed at constant water to cement ratio (W/C) of 0.27 and at 1% superplasticizer dosage.

Fresh concrete properties

% Replacement of cement with Metakaolin	Flow time (sec)	Slump flow (mm)	L-Box	U-Box (mm)
0	2.06	780	0.98	1
5	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

From the above mentioned table it can be observed that the slump values, flow Values, L-box, U-box for all trail mix were in accordance with EFNARC guidelines.

Compressive strength of controlled concrete cube based on UPV and Rebound number

Sample @ 28 Controlled concrete	Rebound number	Ultrasonic pulse velocity		Compressive strength of concrete combined UPV and Rebound hammer test (MPa)
		Time of travel of pulse (s)	Velocity (m/s)	
Sample 1	39.7	22.6	4430	59
Sample 2	36.7	23.2	4310	52.5
Sample 3	37.6	23.6	4240	50
Average	38	23.133	4326.67	53.83

Compressive strength of concrete cubes by 15% replacement of Portland Slag cementwith Metakaolin based UPV and Rebound number

Sample @ 28 Days (SCC 15%)	Rebound number	Ultrasonic pulse velocity		Compressive strength of concrete combined UPV and Rebound hammer test (MPa)
		Time of travel of pulse (s)	Velocity (m/s)	
Sample 1	49.8	24.2	4430	60
Sample 2	47.9	24.5	4380	54
Sample 3	50.5	23.8	4300	58.5
Average	49.4	24.1667	4370	57.5

Compressive strength given in above table are obtained from Graph B5 (Appendix).

Split tensile and flexural strength values

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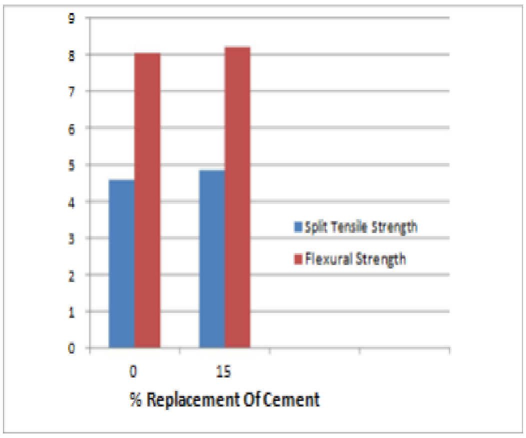
Hardened properties @ 28 days	M50 SCC (0% replacement)	M50 SCC (15% replacement)
Split tensile strength (MPa)	4.576	4.844
Flexural strength (MPa)	8.04173	8.2093

It is found that the spilt tensile strength and flexural strength of M50 grade concrete with partial replacement of Cement with Metakaolin was found to be more than concrete without replacement.



DURABILTY STUDIES

Compressive strength of SCC cube subjected 100◌̊ C raise in temperature

Sample @ 28 days	Compressive strength SCC (0%)		Compressive strength SCC (15%)		% Increase in strength	
	Room temperature (MPa)	@ 100◌̊C for 24hr (MPa)	Room temperature (MPa)	@ 100◌̊C for 24hr (MPa)	SCC (0%)	SCC (15%)
1	57.0533	66.49	61.53	72.21	16.54	17.36
2	57.0533	68.5	61.53	70.39	20.063	14.41
3	57.0533	65.44	61.53	74.28	14.7	20.72

When◌the◌cubes◌are◌subjected◌to◌elevated◌temperature◌of◌100◌ C their strengthincreased by 17.1% and 17.5% for 0% and 15% replacement of cement with Metakaolin Weight of SCC cube subjected 100◌̊ C raise in temperature

Sample @ 28 days	Weight of SCC (0%)		Weight of SCC (15%)		% Decrease weight	
	Room temperature (kg)	@ 100◌̊C for 24hr (kg)	Room temperature (kg)	@ 100◌̊C for 24hr (kg)	SCC (0%)	SCC (15%)
1	2.698	2.67	2.71	2.691	1.0486	0.706
2	2.639	2.613	2.692	2.641	0.995	1.165
3	2.629	2.59	2.687	2.655	1.506	1.197

5. CONCLUSIONS

In the present work, the experimental results of Self-Compacting Concrete mixes tested for compressive strength, split tensile strength, flexural strength, Non-Destructive Test (NDT), modulus of elasticity, Strength at super elevated temperature are discussed at W/C 0.27.

1. The fresh concrete properties like slump values, flow values, L-box, U-box for all trail mix were in accordance with EFNARC guidelines.
2. It was found that optimum percentage replacement of Portland Slag Cement with Metakaolin was 15%.
3. The Percentage increase in compressive strength for SCC with 15% replacement of Portland Slag Cement with metakaolin is found to be 7.846 higher than controlled concrete at the age of 28 days.
4. Split tensile and flexural strength for SCC with 15% replacement of Portland Slag Cement with Metakaolin showed improved results as compared with controlled concrete.
5. Modulus of elasticity at 40% of ultimate strength is found to higher for concrete with replacement than controlled concrete.
6. Non-destructive test gives approximate values for strength. Compressive strength obtained in accordance with NDT showed 5.65% and 6.55% lesser value of strength obtained then from normal testing for controlled concrete and concrete with 15%

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replacement.

7.Compressive strength of cubes subjected to 100˚ C raise of temperature is found to increase by 17.1% and 17.5% for cubes with and without Metakaolin.

8.Weight loss for cubes subjected to 100˚ C raise of temperature with and without Metakaolin was found to be 1.023% and 1.183%.

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