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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 significant advancements in concrete construction. Because it compacts itself, it can be compacted without the use of a mechanical vibrator.

The current study develops M50 grade self-compacting concrete (SCC) with metakaolin substitution. Plasticizers based on Poly-Carboxylic Ether were shown to be compatible with concrete-making materials. The goal of this research work is to look at the strength and durability of self-compacting concrete with and without Metakaolin in place of Portland slag cement at a constant water-cement ratio calculated using the efficiency principle.

The best percentage substitution of Portland Slag cement with Metakaolin has been determined to be 15%. The percentage increase in strength was found to be 7.85 percent higher than control concrete at 28 days (without replacement).

The ideal dosage of superplasticizer was found to improve the concrete's properties during the experimental examination. As a result, overall improvements in the self-compacting concrete's flow and filling ability have been noticed, and the specimens containing metakaolin have a higher strength value and are more durable when exposed to greater temperatures.

Keywords **—Metakaolin, M50, Self-Compacting Concrete.**

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I. INTRODUCTION

The problem of concrete construction durability has been a prominent topic of interest in Japan for several years, commencing in 1983. Sufficient compaction by competent workers is essential to create enduring concrete buildings. However, as the quantity of competent workers in Japan's construction industry declines, so does the quality of the job. The use of self-compacting concrete, which can be compacted into every corner of a formwork merely by its own weight and without the need for vibrating compaction, is one approach for achieving long-lasting concrete buildings regardless of the quality of construction work. Okamura recommended the requirement for this sort of concrete (1986).

II. OBJECTIVE

- Casting is done for various mixes by increasing the percentage of Portland Slag Cement replaced with metakaolin, and the optimum dosage of metakaolin is determined.
- A comparison of the M50 grade Self-Compacting Concrete with optimum percentage replacement of Portland slag cement with Metakaolin at constant W/C (using efficiency concept) ratio of 0.27 and 1% optimum dosage of superplasticizer

produces controlled self-compacting concrete.

- At 28 days, hardened qualities such as compressive strength, split tensile strength, and flexural strength are investigated, and concrete cubes exposed to a 100°C temperature increase for 24 hours are tested to determine the strength and durability of the concrete.

III. LITERATURE REVIEW

Dinakar and Manu (2014) proposed a new mix approach based on the efficiency idea for the formulation of high strength self-compacting metakaolin concretes. There are five steps in the proposed methodology. The overall powder content is established in the first phase. The proportion of metakaolin is then fixed depending on the strength required, and the efficiency factor (k) is calculated using the equation suggested for the same percentage. The required water content for SCC is estimated in the third phase, and the coarse and fine aggregate contents are determined in the fourth step using the combined grading curves of DIN standards. Finally, the slump flow and V-funnel tests for flow ability, as well as the L-box test for passing ability, are used to assess fresh self-compacting properties.

The strength qualities of metakaolin admixed concrete were investigated by **Nova John (2013)**. The results of an experimental examination into the applicability of metakaolin in the manufacturing of concrete are presented in this paper. The reference concrete M30 was manufactured using 53-grade OPC, while the other mixes were made by substituting Metakaolin for part of the OPC. The replacement levels for metakaolin were 5%, 10%, 15%, and 20% (by weight of cement). This paper presents a variety of studies that show the impact of replacing cement with metakaolin on concrete in order to derive meaningful conclusions. The outcomes were compared to a control mix. The results of the tests show that using metakaolin instead of cement in concrete improves compressive strength, split tensile strength, and flexural strength by up to 15%.

The compressive strength of metakaolin-based self-compacting concrete was investigated by **Anjali et al (2015)**. In compression, the strength of self-compacting concrete specimens was 12 percent greater than that of conventional concrete specimens, and in split tensile test, the strength of self-compacting concrete specimens was 30 percent higher than that of conventional concrete. As a result, it was discovered that replacing cement with metakaolin was possible in terms of strength.
The literature review provided insight into the benefits and qualities of SCC, as well as test methodologies and the spectrum of constituent materials and their relative proportions, all of which are necessary for its effective manufacturing. Because there isn't much study in this field, the current work is taken into consideration.

Srivastava et al. (2012) investigated the impact of metakaolin addition on concrete mechanical characteristics. The results revealed that using metakaolin as a partial replacement for cement improved concrete's compressive, tensile, flexural bond strength, and modulus of elasticity significantly; however, workability was marginally harmed. They discovered that the amount of gain in individual attributes is proportional to the replacement level.

IV. MATERIALS IN SELF COMPACTING CONCRETE

A. *Metakaolin*

MK is a pozzolanic substance. It's made by calcining kaolinite clay at temperatures ranging from 500 to 800 degrees Celsius. Kaolin clay is used to make metakaolin ($Al2Si2O7$). Kaolin is a fine, white clay mineral that has long been used to make porcelain.

TABLE I
PROPERTIES OF METAKAOLIN

Properties	**MetaCem85 C**
PhysicalForm	Offwhitepowder
SpecificGravity	2.5
BulkDensity	300±30 gm/ltr
AverageParticleSize	1.5µ

Residue325 #	0.5%max
PozzolanReactivity- mg Ca(OH)2	>1000
Lossofignition(LOI)	0.68
Blaine(m^2/kg)	15,000

TABLE II
CHEMICAL COMPOSITION OF METAKAOLIN

Chemicalcomposition	**Metakaolin(%)**
Silica(SiO_2)	54.3
Alumina(Al_2O_3)	38.3
Ferricoxide (Fe_2O_3)	4.28
Calciumoxide(CaO)	0.39
Magnesiumoxide(MgO)	0.08
Sodiumoxide(Na_2O)	0.12
Potassiumoxide(K_2O)	0.5
Sulphuricanhydride(SO_3)	0.22

B. Cement

Portland slag cement (PSC) of 53 grade. 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.

TABLE III
PROPERTIES OF CEMENT

Properties		**Results**	**Limits (IS455-1989)**	**Codes**
StandardConsistency (%)		33	-	IS:4031(part4)-1988
SpecificGravity		0.627	-	
Le-Chatelier Expansion(mm)		1	Max.10 mm	IS:4031 (part3)-1988
Fineness(%)		1	Max.10 %	IS:4031 (part1)-1996
SettingTime(min)	InitialSettingTime	146	Min.30 min	IS:4031 (part5)-1998
	FinalSetting Time	207	Max.600 min	
Compressive Strength OfMortar Cubes (MPa)	7Days	36.5374	-	IS:4031 (part6)-1988
	28Days	54.806	-	

C. Fine Aggregates

IS 2386 is used to assess physical properties such as specific gravity, bulk density, gradation, and fineness modulus.

TABLE IV
PHYSICAL PROPERTIES OF FINE AGGREGATES

Properties		**Results**	**Codes**
SiltContent		Nil	IS:2386 (part 2)–1963
SpecificGravity		2.625	IS:2386 (part 3)-1963
BulkingOfSand (%)		4.6	IS:2386 (part 3)-1963
MoistureContent(%)		0.3	IS:2386 (part 3)-1963
FinenessModulus		2.854	-
Grading		IV	IS: 383 –1970
BulkDensity(g/cc)	Loosecondition	1.462	IS:2386 (part 3)-1963
	Compactedcondition	1.626	

D. Coarse Aggregates

A local crusher facility was used to obtain crushed coarse aggregate with a maximum size of 10 mm for this study. Specific gravity, bulk density, gradation, and fineness modulus of coarse aggregates are all assessed in accordance with IS 2386.

TABLE IV
PHYSICAL PROPERTIES OF COARSE AGGREGATES

Properties		**Results**	**Codes**
ImpactValue		25.2	IS: 2386 (part 4) –1963
CrushingValue		32.8	IS:2386 (part 4) –1963
SpecificGravity		2.7	IS:2386(part3)-1963
MoistureContent(%)		0.1	IS:2386(part3)-1963
FinenessModulus		6.53	-
BulkDensity(g/cc)	Loosecondition	1.664	IS:2386(part3)-1963
	Compacted condition	1.631	

E. Chemical Admixtures

In the present investigation "Auramix 400" a poly-carboxylic ether based superplasticizer is used. This superplasticiser contains 0.01% -0.02% of VMA incorporated in it.

TABLE V
PHYSICAL PROPERTIES OF SUPERPLASTICIZER

Appearance	Lightyellowcolouredliquid
Ph	Minimum6
Volumetricmass @20°C	1.105±0.02kg/litre
Chloridecontent	Nilto IS:456
Alkalicontent	Typically less than 1.5 g Na_2Oequivalent/litreofadmixture

F. 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.

V. MIX DESIGN

Step 1: Fix the total cementitious or powder content for SCC
Step 2: Fix the percentage of metakaolin and calculate the efficiency of metakaolin
Step 3: Calculation of water content in SCC
Step 4: Determination of coarse and fine aggregate contents
Step 5: Calculation of admixture dosage
Step 6: Trial mixtures and fresh tests on SCC
Step 7: Adjustment of mixture proportion

TABLE VI
LIST OF TEST METHODS FOR WORKABILITY PROPERTIES

Methods	Property
SlumpflowbyAbrams cone	Fillingability
T_{50cm}slumpflow	Fillingability
J-ring	Passingability
V-funnel	Fillingability
V-funnelat$T_{5minutes}$	Segregationresistance
L-box	Passingability
U-box	Passingability
Fill-box	Passingability
GTMscreenstabilitytest	Segregationresistance
Orimet	Fillingability

VI. RESULTS AND DISCUSSIONS

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:

TABLE VII
COMPRESSIVE STRENGTH FOR DIFFERENT TRIAL MIX

Trail no	W_s (C_s+k28×m)ratio	% Replacementof cement byMetakaolin	% SP	7 Dayscompressivestrength(MPa)	28 Dayscompressivestrength(MPa)
1	0.31	7.5	1	25.3	23.45(act)
2	0.28	7	1	23.713	25(act)
3	0.25	8	1	45.4933	43.2667
4	0.24	8	1	39.7633	61.21667
5	0.24	8	1.1	37.5533	57.613
6	0.27	0	1	37.91	57.0533
7	0.27	8	1	39.47	57.91
8	0.27	10	1	40.976	58.45
9	0.27	15	1	41.67	61.53
10	0.27	20	1	39.1	58.15
11	0.27	25	1	24.35	36.16

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 theoptimumreplacementpercentage is 15 at a$W_s/(C_s+k_{28}\times m)$ratioof0.27.

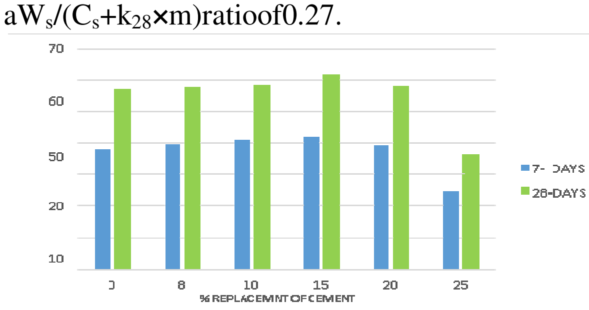

Fig. 1 Compressive Strength for Different percentage replacement of Portland slag cement with Metakaolin

TABLE VIII
COMPRESSIVE STRENGTH OF CONTROLLED CONCRETE CUBE BASED ON UPV AND REBOUND NUMBER

Sample @ 28Controlle dconcrete	Reboundn umber	Ultrasonic pulsevelocity		Compressivestren gth ofconcretecombin ed UPVandRebound hammer test(MPa)
		Timeoftr avelof pulse(s)	Velocity(m/s)	
Sample1	39.7	22.6	4430	59
Sample2	36.7	23.2	4310	52.5
Sample3	37.6	23.6	4240	50
Average	38	23.133	4326.67	53.83

TABLE IX
COMPRESSIVE STRENGTH OF CONCRETE CUBES BY 1% REPLACEMENT OF PORTLAND SLAG CEMENT WITH METAKAOLIN BASED UPV AND REBOUND NUMBER

Sample@28 Days(SCC15 %)	Reboundnum ber	Ultrasonic pulsevelocity		Compressivestr ength ofconcretecombi ned UPVand Reboundhamme rtest (MPa)
		Time oftravel of pulse(s)	Velocity (m/s)	
Sample1	49.8	24.2	4430	60
Sample2	47.9	24.5	4380	54
Sample3	50.5	23.8	4300	585
Average	49.4	24.1667	4370	57.5

TABLE X
SPLIT TENSILE AND FLEXURAL STRENGTH VALUES

Hardened properties@28da ys	M50 SCC (0% replacemen t)	M50 SCC (15% repl acement)
Split tensile strength(MPa)	4.576	4.844
Flexuralstrength(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.

TABLE XI
COMPRESSIVE STRENGTH OF SCC CUBE SUBJECTED 100C RAISE IN TEMPERATURE

Sample @ 28days	Compressivestrengt hSCC(0%)		Compressivestrength SCC(15%)		%Increase in strength	
	Room temper ature(MPa)	@100̊C for 24hr(MPa)	Room temper ature(MPa)	@100̊C 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 100̊ C their strength increased by 17.1% and 17.5% for 0% and 15% replacement of cement with Metakaolin.

TABLE XII
WEIGHT OF SCC CUBE SUBJECTED 100C RAISE TEMPERATURE

Samp le@2 8days	Weight of SCC(0%)		WeightofSCC(15 %)		%Decreasewei ght	
	Room tempera ture(kg)	@100̊C for 24hr(kg)	Roomtemp erature(kg)	@100̊C 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

When the cubes are subjected to elevated temperature of 100̊ C their weights decreased by 1.1832% and 1.023% for 0% and 15% replacement of cement with Metakaolin.

VII. CONCLUSIONS

The experimental results of Self-Compacting Concrete mixes evaluated for compressive strength, split tensile strength, flexural strength, Non-Destructive Test (NDT), modulus of elasticity, and strength at super high temperature at W/C 0.27 are addressed in this paper.

1. All trail mix properties, such as slump values, flow values, L-box, and U-box, were in compliance with EFNARC rules.
2. The best percentage substitution of Portland Slag Cement with Metakaolin was found to be 15%.
3. At the age of 28 days, the percentage increase in compressive strength for SCC with 15% Portland Slag Cement substitution with metakaolin was determined to be 7.846 higher than controlled concrete.
4. When compared to controlled concrete, split tensile and flexural strength for SCC with 15% Portland Slag Cement replacement demonstrated improved results.

5. The modulus of elasticity of concrete with replacement is found to be higher than that of controlled concrete at 40% of ultimate strength.

6. A non-destructive test provides approximate strength values. For controlled concrete and concrete with 15% replacement, the compressive strength obtained using NDT was 5.65 percent and 6.55 percent lower than that obtained using conventional testing.

7. When cubes are heated to 100 degrees Celsius, their compressive strength increases by 17.1 percent and 17.5 percent, respectively, for cubes with and without Metakaolin.

8. The weight loss for cubes exposed to a temperature increase of 100 C with and without Metakaolin was determined to be 1.023 percent and 1.183 percent, respectively.

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