Experimental Investigation on Mechanical and Chemical Properties of Self-Compacting Concrete Containing Copper Slag and Metakaolin

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Abstract - *Cement is mainly utilized for construction in present time because of its need but simultaneously its drawbacks to environment due to emission of CO_2, so that to overcome this issue, I use industrial waste materials to replace with concrete materials such as waste Metakaolin and copper slag by means of cement and fine aggregate, respectively. The Self-compacting concrete is casted for M30 and M40 grade with the cement is replaced by MK as 0%, 5%, 10%, 15% and fine aggregate is replaced by CS as 0%, 20%, 40%, 60% by weight. The workability of fresh SCC was measured by Slump flow, L-box, and V-funnel Tests. Compressive strength test, flexural strength test, and split tensile strength test was carried out for the hardened properties. Acid attack, Sulphate attack and sorptivity was carried out for durability tests of SCC. The result shows that 10MK-40CS combination for M30 and M40 Grade SCC gives maximum strength of all mixes. For SCC M30 and M40 grade, it observed that concrete containing metakaolin and copper slag provide better performance against sulphate as well as acid resistivity aspect corresponding to control concrete at 28 Days.*

Key Words: **Metakaolin, Copper Slag, Self-Compacting Concrete, Viscosity Modifying Agent, Superplasticizer, etc.**

1. INTRODUCTION

Self-compacting concrete (SCC) is a highly viscous concrete that can spread into place under its own weight and accomplish good link in the absence of vibration without revealing defects due to segregation and bleeding. Self-compacting concrete is a creation of technological improvements in underwater concrete technology where the mix is proportioned to assure high fluidity as well as high resistance to water reduction and segregation. SCC was established in Japan in the late 1980s, and recently, this concrete has expanded wide use in many nations for different applications and structural formations.

Several changed approaches have been used to develop SCC. One technique to achieve self-compacting property is to increase suggestively the amount of fine materials (e.g., Copper Slag & Metakaolin) without changing the water content related with common concrete. One alternative method consists of incorporating a viscosity modifying admixture (VMA) to improve stability. The use of VMA along with suitable concentration of superplasticizer (SP) can ensure proper deformability and suitable workability, foremost to a good resistance to segregation.

In this study, starch ether and cellulose ether as VMA was tested in the creation of SCCs along with superplasticizer. The fresh concrete properties (slump flow, V-funnel, and L-box test) and hardened concrete properties (compressive strength, split tensile strength and flexural strength) of mixtures were estimated and compared with ordinary concrete mix.

2. EXPERIMENTAL WORK

2.1 Materials

Cement

Ordinary Portland Cement of 53 Grade manufactured by siddhi cement company was used in concrete mixes corresponding to IS-8112. The specific gravity of cement is 3.15.

Sand

Natural river sand is used as fine aggregate. As per IS: 2386 (Part III)-1963, the bulk specific gravity in oven dry condition and water absorption of the sand are 2.6 and 1% respectively.

Aggregate

Crushed stones of maximum size 20 mm are used as coarse aggregate. As per IS: 2386 (Part III)-1963, the bulk specific gravity in oven dry condition and water absorption of the coarse aggregate are 2.66 and 0.3% respectively.

Copper Slag

Copper slag is an industrial by-product obtained during the smelting and refining process of copper in industries. Copper Slag obtained from "Krishna Raj corporation", GIDC Gozaria, Mehsana. Chemical and Physical properties of Copper Slag are given in the Table 1 and 2, respectively.

Metakaolin

In that project the collection of metakaolin from Gujarat Earth Minerals Pvt. Ltd. The specific gravity of Metakaolin is

2.63. Chemical and Physical properties of metakaolin are given in the Table 1 and 3, respectively.

Table -1: Chemical properties of Copper Slag and Metakaolin

Chemical properties		
Properties	**Copper Slag**	**Metakaolin**
SIO_2(%)	30.51	54
Al_2O_3(%)	2.80	41
Fe_2O_3(%)	57.82	0.35
Cao (%)	1.60	0.016
Na_2O (%)	0.34	0.13
SO_3(%)	1.59	-
K_2O (%)	0.71	1-2
MgO (%)	1.48	0.065

Table -2: Physical properties of Copper Slag

Physical Properties	Copper Slag
Particle Shape	Angular
Appearance	Black and glassy
Fineness Modulus	3.28
Specific Gravity	3.37
Bulk Density	1900 Kg/m3
Water absorption	0.36%

Table -3: Physical properties of Metakaolin

Physical Properties of Metakaolin	Results	As per IS: 3812-1981 Specifications
Physical Form	Amorphous powder	
Appearance(color)	Off-White	
Residual on 325 um sieves (%)	0.21	0-0.5
Specific Gravity	2.63	2.5-2.7
Bulk Density(gm/liter)	333	270-370
Specific surface area(m2/gm)	16.5	12-18
Average Particle Size(micron)	1.5	1.5-2.5
Moisture content (%)	0.18	0-0.5

Admixture

In this research the collection of super plasticizer and VMA from Contech Chemicals Pvt. Ltd. A polycarboxylate ether (Conflow pc2) based super plasticizer and Cellulose ether as VMA were used in concrete. The properties of admixtures are presented in tables 4.

Table -4: Typical properties of Cellulose Ether

Typical Properties	Cellulose Ether
Appearance	Off-white
Viscosity	850
Humidity	<6.0%
Ash Content	<5.0%
pH Value	5.5-7.0

2.2 Mix Design

A standard mix M30 and M40 grade was calculated as per Indian Standard (IS 10262-2009). The concretes were prepared at cementitious materials (Cement+CS+MK) dosages of 405.58 kg/m^3 for M30 and 470 kg/m^3 for M40. For each binder content, the W/C ratio and superplasticizer kept constant with different percentage of SCMs proportion were determined. The mix design is given in Table 5.

Table -5: Mix Design for M30 and M40 grade SCC

Grade	M30	M40
Mix Ratio	1:2.04:2.14	1:1.76:2.15
Water (Kg)	182.657	211.50
Cement (Kg)	405.58	470.00
Sand (Kg)	827.60	829.83
Aggregate (<10 mm) (Kg)	505.18	556.06
Aggregate (>20 mm) (Kg)	365.82	456.67
W/C ratio	0.45	0.45

2.3 Testing Procedure

For preparing SCCs, a batch mixer was used. First coarse aggregates, fine aggregates, cement, copper slag, metakaolin were mixed with ½ of the mixing water for 2 min. After addition of VMA and superplasticizer, mixing continued up to total 10 min. Slump flow, V-Funnel, L-box tests were performed on the SCC in fresh state to determine flow properties.

For Compressive strength, tests were conducted on 150x150x150 mm cube moulds, after 28 days of proper curing. 3 Cubes were casted and tested for each combination.

For split tensile strength, tests were conducted on cylindrical moulds with a diameter of 150 mm and a height of 300 mm, after 28 days of proper curing. 3 specimens were casted and tested for each combination.

For Flexural strength, tests were conducted on 150x150x700 mm beam moulds, after 28 days of proper curing. 3 specimens were casted and tested for each combination.

2.4 Concrete Mix Proportions

Table -6: Proportions of Concrete Mixes

Grade of Concrete	W/C Ratio(%)	Proportions (%)	Superplasticizer (%)	VMA (%)
M30	0.45	0CS-0MK	1	0.6
		20CS-10MK	1	0.6
		40CS-10MK	1	0.6
		60CS-10MK	1	0.6
M40	0.45	0CS-0MK	1.25	0.8
		20CS-10MK	1.25	0.8
		40CS-10MK	1.25	0.8
		60CS-10MK	1.25	0.8

3. TEST RESULTS AND DISCUSSION

3.1 Fresh Concrete Properties

A detailed study directed on various proportions included concrete (Mixing proportions are given in Table 6) for the binder content of 405.58 & 470.00 kg/m^3 and the fresh concrete testing results are exhibited in table 7 & 8 with respect to w/c ratio of 0.45.

Table -7: Fresh properties of M30 grade SCC

Grade of Concrete	Proportion (%)	Flow Test(mm)	V-Funnel Test(sec)	L-Box Test
M30	0CS-0MK	740	11.2	1.00
	20CS-10MK	715	9.2	0.94
	40CS-10MK	680	8.5	0.88
	60CS-10MK	672	8.1	0.85

Table -8: Fresh properties of M40 grade SCC

Grade of Concrete	Proportion (%)	Flow Test(mm)	V-Funnel Test(sec)	L-Box Test
M40	0CS-0MK	700	11.6	0.98
	20CS-10MK	680	9.8	0.92
	40CS-10MK	675	8.7	0.87
	60CS-10MK	660	8.2	0.82

3.2 Hardened Concrete Properties

The 7 days and 28 days compressive strengths for both M30 and M40 grade SCC, in Table 9 and Chart 1 & 2. The 28 days flexural strengths for both M30 and M40 grade SCC, in Table 10 and Chart 3 & 4. The 28 days split tensile strengths of SCCs are given in Table 11 and Chart 5 & 6 are shown.

Table -9: Compressive strengths of M30 and M40 grade SCC

Grade of Concrete	Proportions (%)	Compressive strength at 7 days (N/mm²)	Compressive strength at 28 days (N/mm²)
M30	0CS-0MK	25.02	38.103
	20CS-10MK	27.68	40.22
	40CS-10MK	29.43	42.78
	60CS-10MK	27.77	40.82
M40	0CS-0MK	33.04	49.32
	20CS-10MK	35.27	51.65
	40CS-10MK	37.18	53.56
	60CS-10MK	34.86	51.82

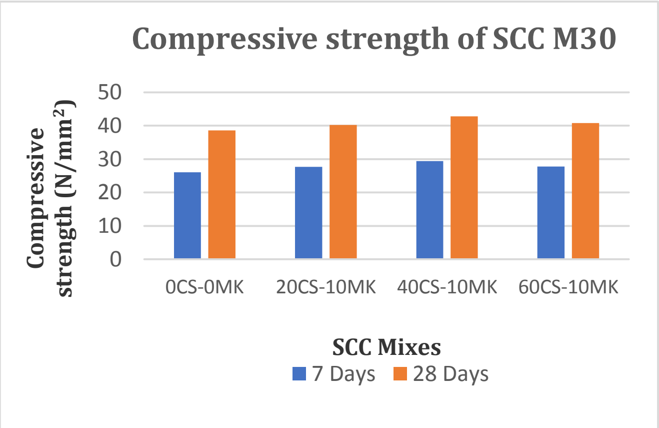

Chart -1: Compressive strengths of M30 grade SCC

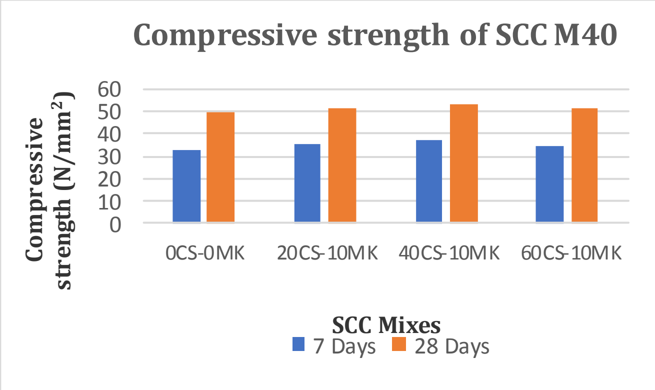

Chart -2: Compressive strengths of M40 grade SCC

Table -10: Flexural strengths of M30 and M40 grade SCC

Grade of Concrete	Proportions (%)	Flexure strength at 28 days (N/mm^2)
M30	0CS-0MK	3.93
	20CS-10MK	4.59
	40CS-10MK	5.28
	60CS-10MK	4.06
M40	0CS-0MK	4.5
	20CS-10MK	5.38
	40CS-10MK	5.86
	60CS-10MK	4.63

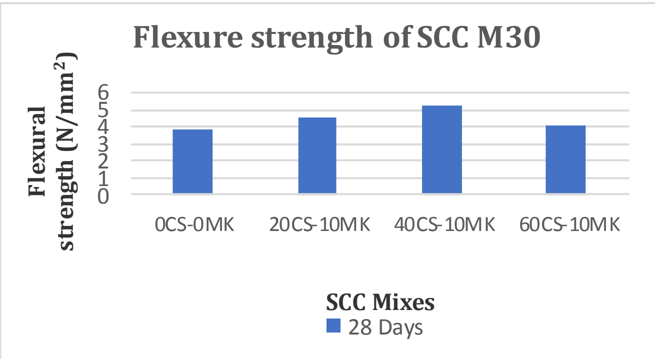

Chart -3: Flexural strengths of M30 grade SCC

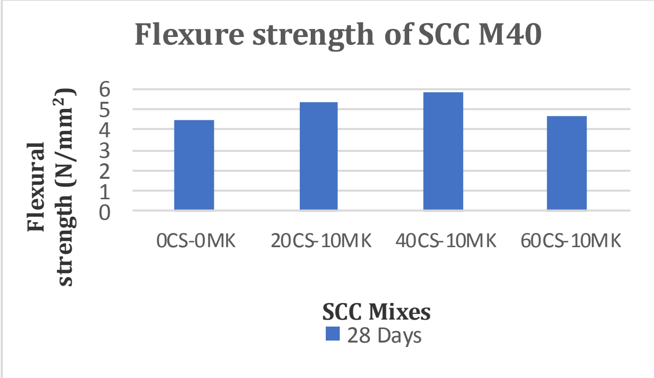

Chart -4: Flexural strengths of M40 grade SCC

Table -11: Split tensile strengths of M30 and M40 grade SCC

Grade of Concrete	Proportions (%)	Flexure strength at 28 days (N/mm^2)
M30	0CS-0MK	3.18
	20CS-10MK	3.32
	40CS-10MK	3.74
	60CS-10MK	3.26
M40	0CS-0MK	3.33
	20CS-10MK	3.69
	40CS-10MK	4.06
	60CS-10MK	3.41

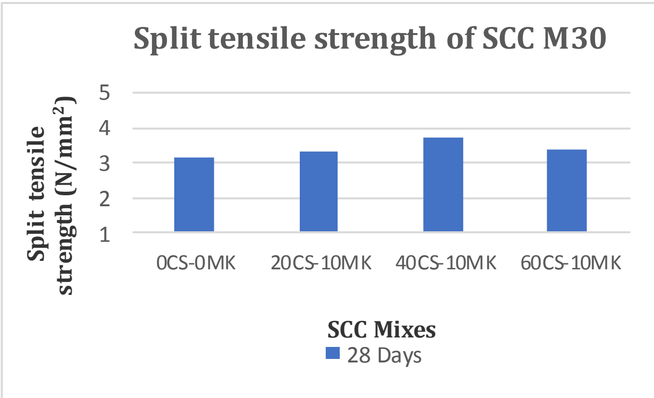

Chart -5: Split tensile strengths of M30 grade SCC

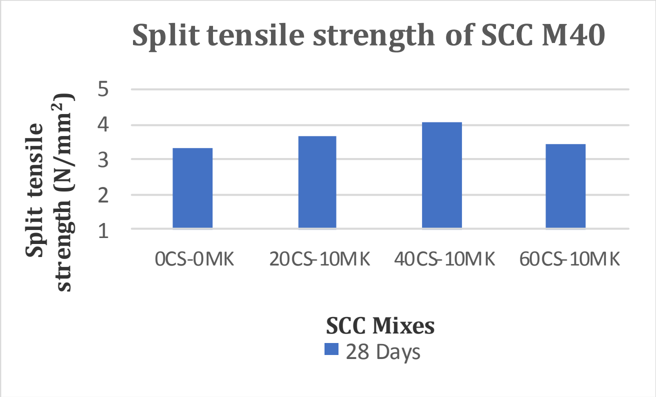

Chart -6: Split tensile strengths of M40 grade SCC

3.2 Durability Properties of Concrete

The 28 days durability test results were given in charts and tables as shown below.

In acid resistance test, cubes of different combinations were compared with normal cube by bulk diffusion, compressive strength and visually inspection.

In sulphate resistance test, cubes are immersed in 5% concentrated sodium sulphate solution and bulk diffusion should be checked.

Table -12: Bulk diffusion and Compressive strength in Acid at 28 days

Grade of Concrete	Proportions (%)	Wt. of cubes after 28 days of water curing (Kg)	Wt. of cubes after 28 days of acid curing (Kg)	Bulk Diffusion (kg)	Compressive strength after 28 days in acid (N/mm²)
M30	0CS-0MK	8.67	7.51	1.16	26.09
	20CS-10MK	8.11	7.39	0.75	28.52
	40CS-10MK	7.98	7.47	0.51	34.55
	60CS-10MK	7.74	7.08	0.66	27.43
M40	0CS-0MK	8.97	7.85	1.12	37.38
	20CS-10MK	8.42	7.69	0.73	41.58
	40CS-10MK	8.12	7.58	0.54	40.94
	60CS-10MK	7.89	7.27	0.62	38.33

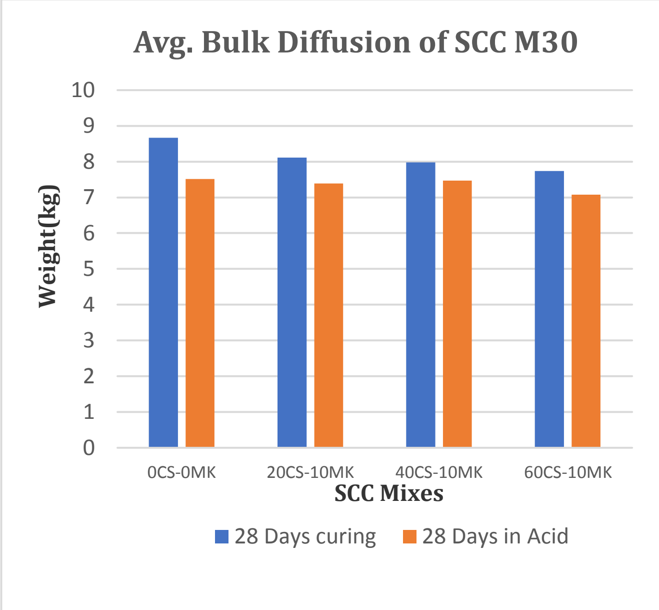

Chart -7: Average bulk diffusion in acid resistance test of M30 grade SCC

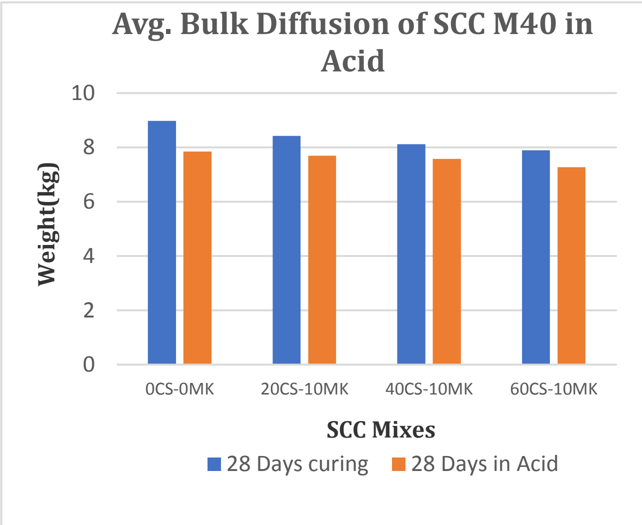

Chart -8: Average bulk diffusion in acid resistance test of M40 grade SCC

Table -13: Bulk diffusion and Compressive strength in Sulphate solution at 28 days

Grade of Concrete	Proportions (%)	Wt. of cubes after 28 days of water curing (Kg)	Wt. of cubes after 28 days of sulphate curing (Kg)	Bulk Diffusion (kg)	Compressive strength after 28 days in sulphate solution (N/mm²)
M30	0CS-0MK	8.12	8.28	0.16	33.36
	20CS-10MK	7.94	8.14	0.20	36.20

	40CS-10MK	7.72	7.94	0.22	36.95
	60CS-10MK	7.56	7.86	0.30	33.13
M40	0CS-0MK	9.18	9.33	0.15	44.40
	20CS-10MK	8.83	9.01	0.18	45.92
	40CS-10MK	8.56	8.74	0.20	47.38
	60CS-10MK	8.11	8.36	0.25	44.33

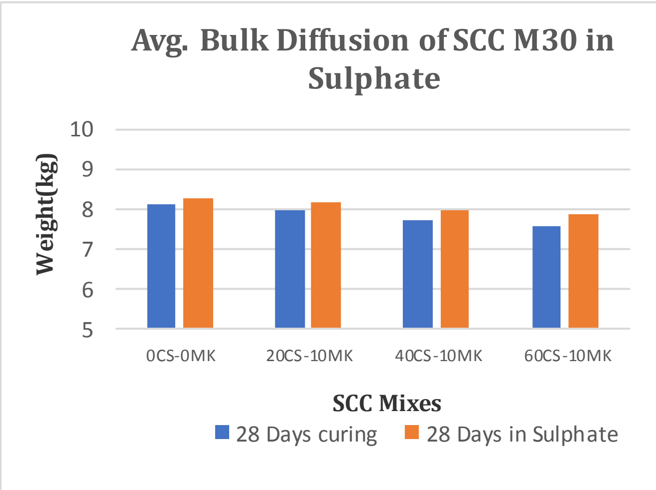

Chart -9: Average bulk diffusion in sulphate resistance test of M30 grade SCC

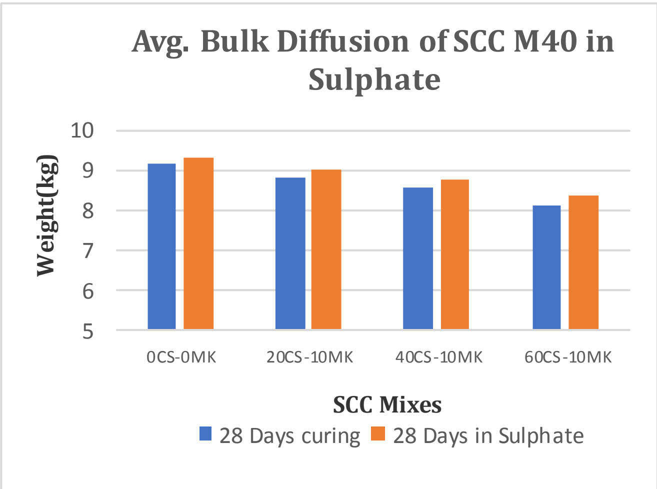

Chart -10: Average bulk diffusion in sulphate resistance test of M40 grade SCC

4. CONCLUSIONS

1) Workability results shows that, Slump flow test values decreases, L-box test values decreases, and V-Funnel time increases by increasing the percentage of replacement of sand by copper slag.
2) Replacement of metakaolin more than 10% reducing strength of SCC at 28 days.
3) The compressive strength was maximum for 10MK- 40CS among all mixes at each curing period.
4) For M30 grade SCC, at 28 days compressive strength, flexure strength and split tensile strength was increased by 10.86% ,38.58% and 17.61% with 10% cement replaced by metakaolin and 40% sand replaced by copper slag.
5) For M40 grade SCC, at 28 days compressive strength, flexure strength and split tensile strength was increased by 8.60% ,30.92% and 21.93% with 10% cement replaced by metakaolin and 40% sand replaced by copper slag.
6) By adding more than 40% of copper slag, it decreases the compressive strength, flexure strength and split tensile strength.
7) For M30 and M40 grade SCC, it observed that concrete containing metakaolin and copper slag provide better performance against sulphate as well as acid resistivity aspect corresponding to control concrete at 28 Days.

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