Performance Studies Of High Strength Self-Compacting Concrete Using Copper SlagAndFibers

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Abstract:

This research paper investigates the performance of high-strength self-compacting concrete (HSSCC) incorporating copper slag and fibers. The objective is to explore the effects of copper slag as a partial replacement for cement and the addition of fibers on the mechanical and durability properties of self-compacting concrete (SCC). The study aims to optimize the mix design parameters to achieve a sustainable and high-performance concrete with enhanced mechanical properties, improved workability, and reduced environmental impact. The experimental program includes comprehensive tests on fresh and hardened properties, such as slump flow, V-funnel flow time, compressive strength, flexural strength, drying shrinkage, and water absorption. The results demonstrate the potential of using copper slag and fibers to enhance the performance of self-compacting concrete, providing valuable insights for the construction industry.

Keywords:high-strength self-compacting concrete, copper slag, fibers, mechanical properties, durability properties, sustainable concrete.

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1.Introduction:

1.1 Background:

Concrete is a widely employed construction material globally, retaining its position as a favored and affordable option. This can be attributed to its numerous advantages, such as versatility, adaptability, formability, and cost-effectiveness. While concrete possesses high compressive strength, durability, and workability, its tensile capacity is rather limited. Conventional concrete may result in honeycombs, inadequate consolidation in thin sections, or congested reinforcements, compromising the strength and durability of the structural elements. To construct strong and durable structures, it is critical to improve the performance of concrete. Continuous research is being carried out throughout the world to improve the properties of concrete, leading to the invention of highperformance concrete (HPC) by Al-Jabri et al. (2009). HPC has the potential to possess superior properties compared to conventional concrete, including higher strength, greater durability, and desired workability levels. To produce HPC with these improved features, it may be necessary to enhance the following aspects: i) the ease of placement without segregation; ii) long-term strength properties; iii) early-age strength; iv) toughness; v) volume stability; and vii) resilience in harsh environmental conditions. In recent years, HPC has been widely used throughout the world, and to produce it, high-quality and relatively expensive materials are needed. Self-compacting concrete (SCC) is a type of HPC that is highly flowable and stable and that flows readily under its own weight into places around congested reinforcements, filling formwork without any consolidation or much segregation. The hardened SCC is strong and uniform, with better mechanical properties and durability when compared with vibrated concrete

With a population of over 1.3 billion people,

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India is the second-most populous nation globally, accounting for more than a sixth of the world's population. India currently holds 17.5% of the world's population, and it is estimated to surpass China and become the world's most populous country by 2022. It is projected that India's population will reach 1.6 billion by 2050. As a result, the demand for infrastructure is increasing at an alarming rate. Aggregates constitute a significant portion of concrete, occupying over 70% of the concrete matrix. In many parts of the world, as well as in India, there is a scarcity of natural aggregates suitable for construction. Moreover, the construction industry's rising demand has resulted in an upsurge in aggregate consumption. Hence this investigation aims at formulating a standard procedure for using copper slag in the manufacture of SCC.

1.3 Objectives:

The main objectives of this experimental investigation are

i) To formulate mix proportions for SCC from M30 to M100 and evaluate the properties of the above mixes at fresh and hardened.

ii) To investigate whether copper slag could be employed to replace fine aggregate, with and without glued steel fibers, and determine the properties of the mixes at a fresh and hardened state, including the durability.

iii) If copper slag could be effectively used in construction without affecting the strength and durability of SCC, the optimum proportion of copper slag that could be added to the SCC mix would be determined.

2.Literature Review

2.1 Self-compacting concrete (SCC)

Prof. Okamura of Kochi University of Technology in Japan was the first to invent self-compacting concrete back in 1986. Ozawa and Maekawa (1989) from the University of Tokyo conducted research on the feasibility and development of SCC. The requirement for admixtures in SCC has been reported by researchers all around the world.

The impact of superplasticizers on the equilibrium between the flowability and viscosity of mortar in SCC has been studied by Okamura &Ouchi (1997) (Nan Su et al.; 2001). 32

Mix design strategies for the SCC with various mineral admixtures have been provided by Okamura (2003) and EFNARC recommendations (2002 & 2005). The usage of fly ash, GGBS, etc., as filler materials in SCC has been documented by several researchers.

2.2 Copper slag as a supplementary cementitious material

Recycling, making goods with additional value, and dumping or stockpiling slag are the current options for slag management. Gorai et al. (2002), Ayano&Kuramoto (2000), and Tixier et al. (1997) have all employed copper slag in concrete as a replacement for cement based on the qualities of the material. Deja and Malolepszy state that slags with a copper content of less than 0.8% are either dumped as garbage or sold for pennies on the dollar (1989).

Ayano and Sakata explored how copper slag affected the drying time of cement (2002). The insoluble residue at 0.15 mm was found to be easily removed by simply washing the slag. This research demonstrated that the setting time of cement was affected by the particle size of copper slag, with smaller particles creating a longer delay. Several washes of the slag mitigated the impact on the setting time, nevertheless.

According to reports by Al-Jabri (2002) and Shoya et al. (2005), researchers from a variety of nations have studied the use of copper slag in cement concrete and mortar, and they have also studied high strength concrete and high performance concrete (HPC) (1997). Unfortunately, there is a lack of data on the use of copper slag in high strength concrete in India. 36

Akihiko and Toshiki (2008) have reported the use of copper slag as a replacement material for cement, fine aggregate and coarse aggregate in concrete, depending on the material's properties. Slags with less than 0.8% copper are either disposed of as waste or sold inexpensively, as reported by Al-Jabri et al. (2011). According to the findings of Persson et al., the field of cementitious matrix materials has been actively studying since 1930 to produce cementitious matrix materials that give excellent mechanical performance (2001).

This study has resulted in the creation of a new type of extremely long-lasting concrete called reactive powder concrete in recent years (RPC). This type of concrete has compressive capabilities equivalent to some forms of steel and has been categorized as ultra-high-performance fibre reinforced concrete (UHPFRC) (UHPFRC). Witte and Backstrom emphasize that these materials successfully deal with the durability problems that are typical of both NSC and HPC (1951).

There are several uses for copper slag, including in the production of a variety of tools and implements, as well as in the production of glass, tiles, road foundation, train ballast, cement, asphalt pavements, and concrete. The effect of copper slag as a pozzolanic material on hydration processes and as a partial replacement for regular Portland cement have both been described in studies. Copper slag has been studied to see how its incorporation as both fine and coarse particles into conventional concrete would affect the material's mechanical and long-term properties. Certain drawbacks, including a longer setting time, have been found when just copper slag has been used as a fine aggregate, despite the advantages of utilising it in both forms.

3 Experimental Methodology

3.1 Materials

Cement: The cement utilised in this investigation was a 53-grade Ordinary Portland cement because it was readily accessible in the local market. Even 2 when high-quality materials are utilised, the quality of the cement paste has a huge impact on how strong and permeable the resulting concrete will be. As this is the case, the cement's mineralogical composition and physical features are essential. Cement with a finer grind is preferable when making SCC. The mineral makeup and physical characteristics of the cements tested in this investigation are detailed in Tables 5.1 and 5.2. Cement used in this investigation has been tested for various proportions as per IS: 4031 (Part IV)- 1988 and found to be confirming to various specifications of IS:12269-1987, ASTM C150 / C150M – 12 (2012)

Table3.1.1Mineralogicalcompositionofcement

Compound	PercentageComposition(%)	RequirementsasperIS:12269-1987
C3S	50±5	Minimum45% bymass
C2S	30±5	-
C3A	9±1	Maximum10%bymass
C4AF	12±3	Minimum8% bymass
Freelime	1±0.5	-

FineAggregate

Among many other aspects, the grading of fine aggregates plays asignificant role in SCC. The fine aggregate used in SCC must be properlygraded and free of hazardous components including clay, silt content, andchloride contamination in order to reach the minimal voids ratio. Coarser sandispreferablesinceSCCispredominantlycementandfineparticleslikemicrosilica.

Table3.1.2Sieveanalysisoffineaggregate

ISSievedesignation	CumulativePercentage		SpecificationasperIS383:1970forzoneII
	Retained	Passing	
4.75mm	-	100	90–100
2.36mm	9.14	90.86	75–100
1.18mm	32.48	67.52	55–90
600 µm	48.72	51.28	35–59
300 µm	82.22	17.78	8–30
150 µm	99.47	0.53	0–10

CoarseAggregate

Crushedbluegraniteaggregatesfrom

regionalsourcesmeetingASTMC33/C33M-13(2013)specificationswereusedforthestudies, witha mean size distribution of 8-12.5 mm. An angular form, specific gravity of2.70, fineness modulus of 6.013, dry rodded bulk density of 1526 kg/m^3, loosebulkdensityof1437kg/m^3,andwaterabsorptionof0.4%areallcharacteristicsofthecoarseaggregates.ThecoarseaggregatemeetstheguidelinessetforthbyMehta*etal.*(1990)formaximumgrainsizeandfineness modulus, with a value of 6.4. Coarse aggregates made from granite'sequidimensionalparticlesfrequentlymeetorexceedexpectations.Thefindings of the coarse aggregate sieve analysis are shown in Table 5.4, and thecharacteristics of the coarse aggregates employed in this experiment are listedin Table3.1.3

Table3.1.3Sieveanalysisofcoarseaggregate

ISSievedesignation	CumulativePercentage		SpecificationasperIS383:1970
	Retained	Passing	
20 mm	-	100	100
12.5mm	16.24	83.76	85–100
10 mm	82.22	17.78	0–45
4.75mm	98.46	4.54	0–10

FlyAsh

Insteadof beingdisposedof as garbage,flyash maybe used asapozzolanicmaterial,which has financial benefits.Itsbenefits include lessbleeding, lessheat evolution, and a reduced needfor water toachievethesame level of workability. In order to control the heat of hydration-inducedexpansion and reduce the likelihood of early-age cracking, fly ash has found ahome inmass concreteapplicationsandbig volume placement.

Table3.1.4Propertiesofflyash

Property	Detail	ASTMrequirementC618(%) / IS:3812(Part 1) :2003
Physicalproperties		
Specificgravity	2.23	-
Fineness(m^2/kg)*	294.35	Minimum200
Colour	Light grey	-
Chemicalproperties		
Silicondioxide SiO2	70.35	Minimum35%
Aluminumoxide Al2O3	21.61	-
Ferricoxide Fe2O3	3.78	-
Calciumoxide CaO	0.92	-
Magnesiumoxide MgO	3.88	Maximum5%
Sulfurtrioxide SO3	0.08	Maximum5%
Potassiumoxide K2O	0.19	-
Sodiumoxide Na2O	0.37	Maximum1.5%
Titaniumoxide TiO2	1.29	-
Lossonignition	0.97	Maximum5%
SiO2+Al2O3+Fe2O3	95.55	Minimum70%

CopperSlag

Copper slag used in this investigation has been collected from M/sSterlite Industries India Limited (SIIL), Tuticorin, Tamil Nadu. The test sieveanalysis ofcopper slagisshowninFigure5.1.

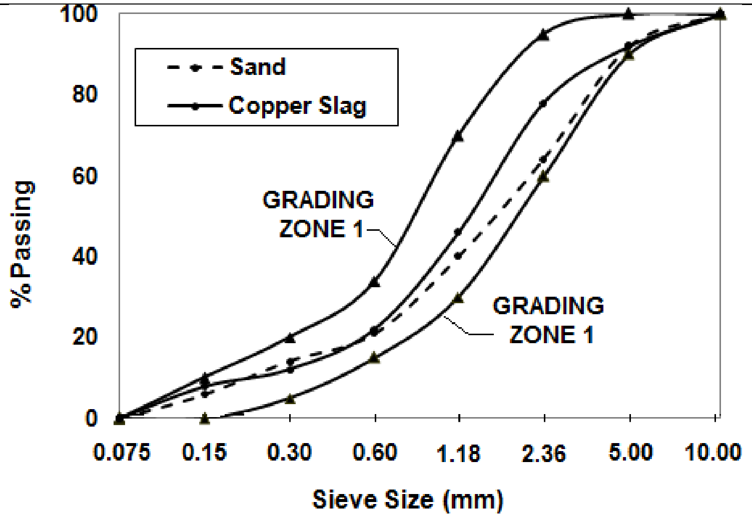

Figure3.1.1 Sieve analysis of copper slag and sand

Water

AkeycomponentofSCC,waterplaysacriticalroleinthechemicalinteractionswithcement.Concrete'sstrengthoriginatesinthebinding action of the cement hydrates gel. Pure drinking water meeting thestandardsofASTMC1602/ C1602M-12 wasutilised.

SteelFibers

Flexural capacity and toughness is improved by adding steel fibers.Steel fibers are added to substitute secondary reinforcements or for crackcontrolinlesscriticalconstructionpartsand toenhancethemechanicalproperties and were optimized by carrying out flow studies. Steel fibers arewidely used as the main and unique reinforcement for tunnelling applications,industrial floor slabs and prefabricated concrete products. Steel fibersareconsidered for structural purposes to guarantee the construction‘s ability anddurabilityincombinationwithtraditionalreinforcementsforcrackcontrol.

Chemicals-Acids,H_2SO_4,HCl

Acids like 0.1% sulphuric acid and hydrochloric acid have beenused in this experimental work.To test the durability ofSCC mixes, theaboveacidsarenecessary.

Superplasticizer

Tofacilitatetheflowofthematerial,areasonabledosageofsuperplasticizerhasbeenadded.Anewgenerationbasedmodifiedpolycarboxylicether(PCE),namedGLENIUMB233isusedassuperplasticizerandthepropertiesaregiveninTable3.1.5

Table3.1.5Propertiesofsuperplasticizer

Property	Testresult*
Colour	Lightbrownincolour,freeflowingliquid
Specificgravity	1.20
Relative densityat 25ºC	1.09 ±0.01
Chlorideironcontent	<0.2%
pH	> 6.0

*testresultsgivenbythemanufacturer

3.2 Mix Proportioning :

Self-compactability can be largely affected by the characteristics ofmaterials and the mix proportion. A rational mix design method for self-compacting concrete using a variety of materials is necessary. Okamura &Ozawa (1995) proposed a simple mix proportioning system. The coarse andfine aggregate contents are fixed so that self-compactability can be achievedeasily by adjusting the water-powder ratioand superplasticizer dosage only.In the current investigation, the mix proportioning has been done as per theRational Mix Design Method proposed by Okamura & Ozawa (1995).

Mixproportioninghasbeenarrivedataperthe

followingsequence.

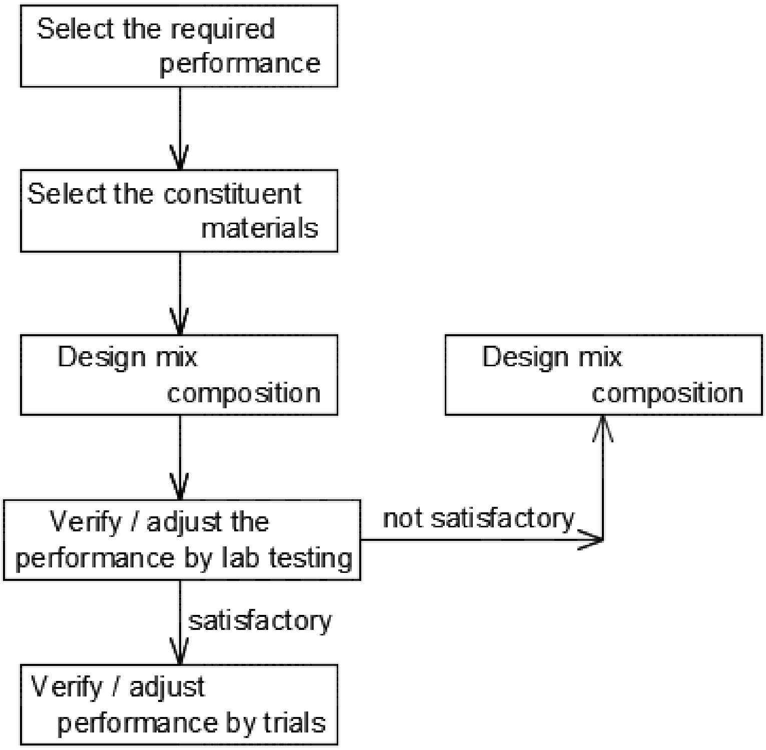

Figure3.2Mixdesignprocedure

SccMixProportions

The mix proportion of SCC mixes M1 to M8 used in the currentinvestigationislistedinTable3.2

Table3.2MixproportionforSCCmixesM1toM8(perm^3)

MixID	Cement	Flyash	FineAggregate	Coarse Aggregate	Water	Superplasticizer	VMA	Remarks
	kg	kg	kg	kg	lit	lit	lit	
M1	228.37	226.85	905.38	873.20	182.7	1.37	0.41	Fineaggregateisreplacedbycopperslag byweightfrom 0%to 100% in allmixes
M2	275.87	236.49	900.31	875.94	180.67	1.67	0.50	
M3	320.43	243.6	864.07	881.83	179.05	1.92	0.57	
M4	357.28	253.75	831.99	888.13	178.64	2.03	0.64	
M5	389.76	258.11	833.01	893.2	177.73	2.50	0.75	
M6	413.6	264.9	792.31	889.3	177.73	2.51	0.75	
M7	444.29	273.03	775.66	907.41	177.73	2.68	0.79	
M8	469.84	280.14	761.25	908.42	177.73	2.79	0.90	

Thetotalweightofcopperslagconsumedforcastingthetestspecimenwasapproximately5500kg.

3.3 Specimen Preparation

Topreparetheconcretemix,coarseaggregatewas placedinsidethe concrete mixer followed by fine aggregate. Then 20% of the total quantityof water was added. The concrete mixer was allowed to rotate a few timesafterwhichflyashandcementwereadded.Approximately40%ofthetotal quantity of water was poured into the concrete mixer and the materials weremixed for 1 minute. Superplasticizer and VMA were added to the remainingquantity of water and added to the mixer. Mixing was continued for another 2minutes.

3.4 Testing Program:

After mixing, the mix must be tested to determine the properties offresh concrete as per EFNARC guidelines. The details of the tests are given inTable3.4Slumpflow,L–box,U–box,andV–funneltestwereusedtoevaluatethefreshconcrete propertiesofSSC.A concretemixcanonlybeclassifiedasSCCiftherequirements for all the following three workability properties are fulfilled(EFNARC,2002)

i) Fillingability
ii) Passingabilityand
iii) Segregationresistance

Table3.4ListoftestmethodsforworkabilitypropertiesofSCCandacceptanceCriteriaforSCC

S.No	PropertyofSCC	Test Method	Unit	Typicalrangeofvalues	
				Minimum	Maximum
1	Fillingability	SlumpFlow Test	Mm	650	800
		T50cm Slump FlowTest	Sec	2	5
		V-Funnel Test	Sec	6	12
		OrimetTest	Sec	0	5
2	PassingAbility	L-BoxTest	h2/h1	0.8	1.0
		U-BoxTest	(h2-h1)mm	0	30
		FillBoxTest	%	90	100
		J-RingTest	Mm	0	10
3	SegregationResistance	V-FunnelTestat5minutes	Sec	0	+3
		GTM ScreenStabilityTest	%	0	15

4. Results and Discussion:

Test methods used to study the characteristics of fresh concrete include slump test, U – box V – funnel and L – Box. These tests had been conducted to determine the filling ability, passing ability and resistance to segregation of the SCC mix. The results of workability tests on fresh SCC mixes M1 to M8 are listed. Without steel fibers, for mix M4 with 100 % sand + 0 % copperslag, the slump flow was 665 mm and for mix M4 with 0 % sand + 100 %copper slag, the slump flow was 700mm.With the addition of steel fibers,for mix M4 with 100 % sand + 0 % copper slag, the slump flow was 665 mmandformixM4with0%sand+100%copperslag,theslumpflowreducedto 681 mm. The workability of SCC increases with the increase in copper slagpercentage.Moderatebleedingwithoutsegregationwasnoticedfor SCCmixes with 80 % to 100 % copper slag. Addition of steel fibers, reduced theflowabilityand passingabilitybutsatisfyingthe suggestedlimitsfor SCC.Copper slag has water absorption 0.28% and fine aggregate haswater absorption 1.05%. Hence when the percentage of copper slag increases,the free water content in SCC mix also increases, resulting an increase in theworkability of the concrete. The increase in free water content in the SCC mixcouldbethereasonforthemoderatebleedingnoticedforSCCmixeswith80% to 100 % of copper slag. The variation of workability for SCC mixes M1 toM8 with copper slag proportions without steel fibers is shown in Figure 4.1.The variation of workability forSCCmixesM1 to M8 with copper slagproportionsandwithsteelfibersisshowninFigure4.2

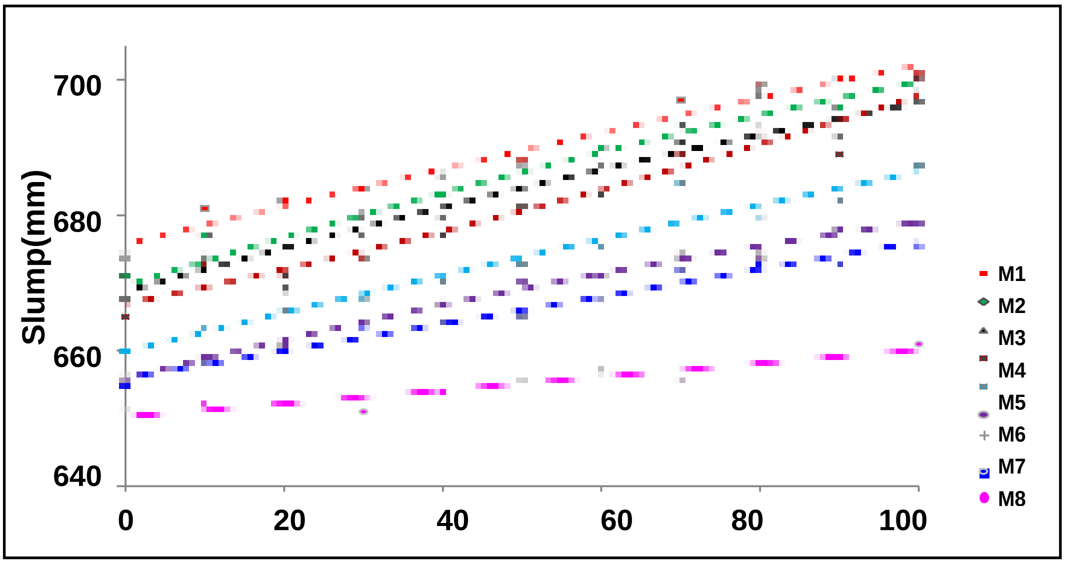

Figure4.1VariationofworkabilitywithcopperslagproportionsforSCCmixesM1toM8(withoutsteelfibers)

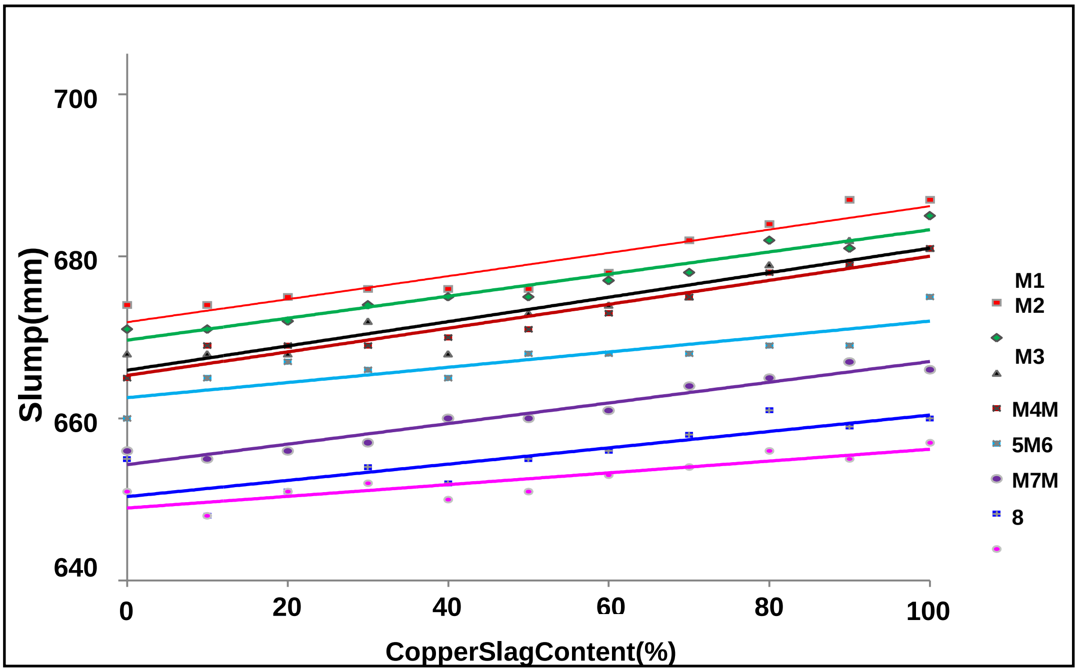

Figure 4.2 Variation of workability with copper slag proportions for SCCmixesM1toM8(withsteelfibers)

Density

Figure 4.3 shows the variation of density of SCC mixes M1 to M8.Without steel fibers, for mix M4 with 100 % sand + 0 % copper slag, thedensitywas24.83kN/m^{3}andformixM4with0%sand+100%copperslag,thedensityincreasedto25.57kN/m^3.

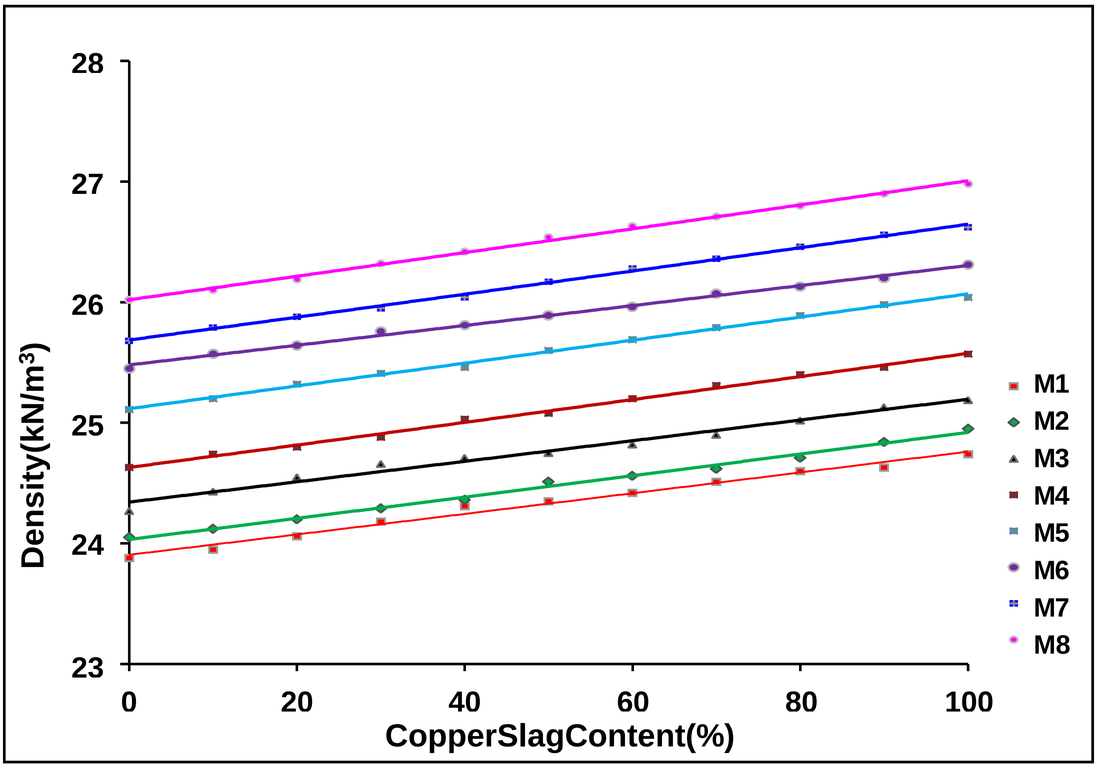

Figure4.3VariationofdensitywithcopperslagproportionsforSCCmixes M1 toM8 on28thdayinMPa(withoutsteelfibers)

With the addition of steel fibers, for mix M4 with100 % sand + 0 % copper slag, the density was 25.33 kN/m³ and for mix M4with 0 % sand + 100 % copper slag, the density increased to 26.41kN/m³.The variation of density with copper slag proportions for SCC mixes M1 toM8withsteelfibersisshowninFigure4.4Duetotheadditionofsteelfibers,thedensityofSCCmixesincrease approximately 2% to 3.5%. Copper slag has aspecific gravity of3.68, higher than that of OPC (3.09) and fine aggregate (2.78), replacement ofFAwithcopperslagleads to theincreaseindensityof concretecubes.

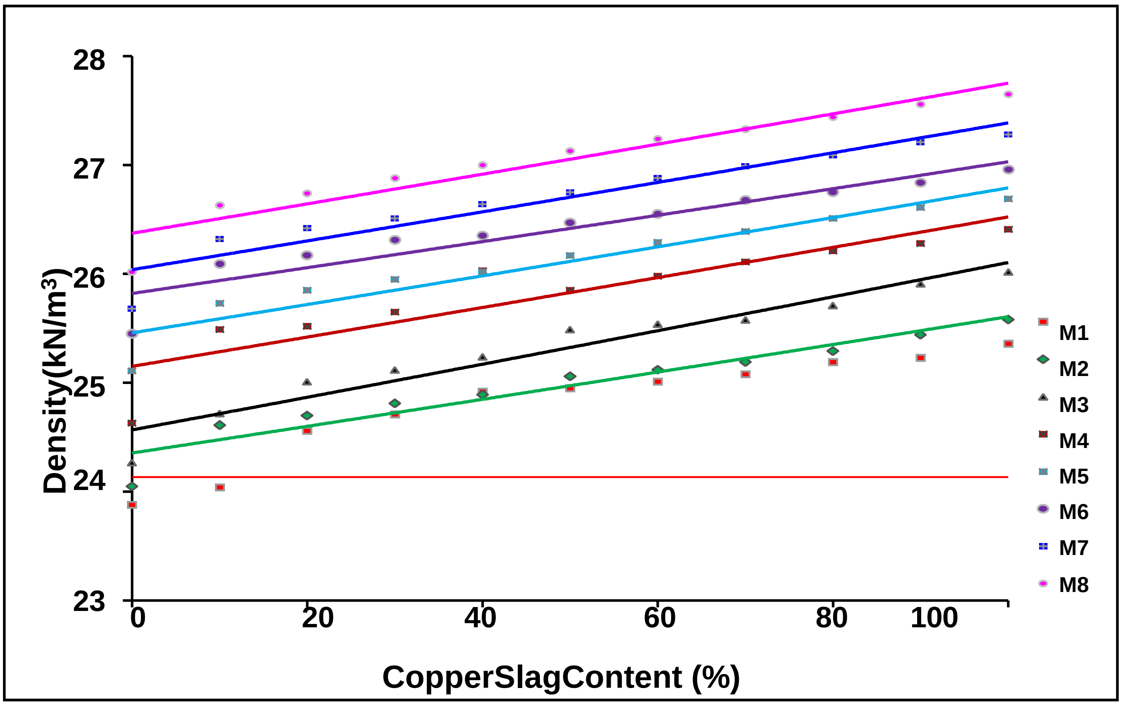

Figure4.4VariationofdensitywithcopperslagproportionsforSCCmixesM1 toM8 on28thday inMPa (withsteel fibers

CompressiveStrength

Three cubes, each measuring 150 x 150 x 150 mm had been testedfor each of the SCC mixes M1 to M8 to determine the compressivestrengthon 1, 3, 7, 14, 28, 56 and 90 days.Test results aregiven in TableA1.9 toTableA1.16intheappendix.

Without steel fibers, for mix M4 with 100 % sand + 0 % copperslag, compressive strength on 28th day was 60.8 MPa. Replacing FA withcopper slag, the compressive strength increased up to 65.73 MPa for Mix M4with70%sandand30%copperslag.Compressivestrengthincreasedapproximately by 8%. Further replacement of FA with copper slag resulted inreduction of compressive strength. For Mix M4 with 0% sand and 100%copperslag,thecompressivestrengthwas49.72MPa.Thereductionincompressive strength was 18% when compared with the compressive strengthof mix M4 with 100 % sand + 0 % copper slag. Figure9.4 shows the variationofcompressivestrengthofSCCmixM4withdifferentcopperslagproportions

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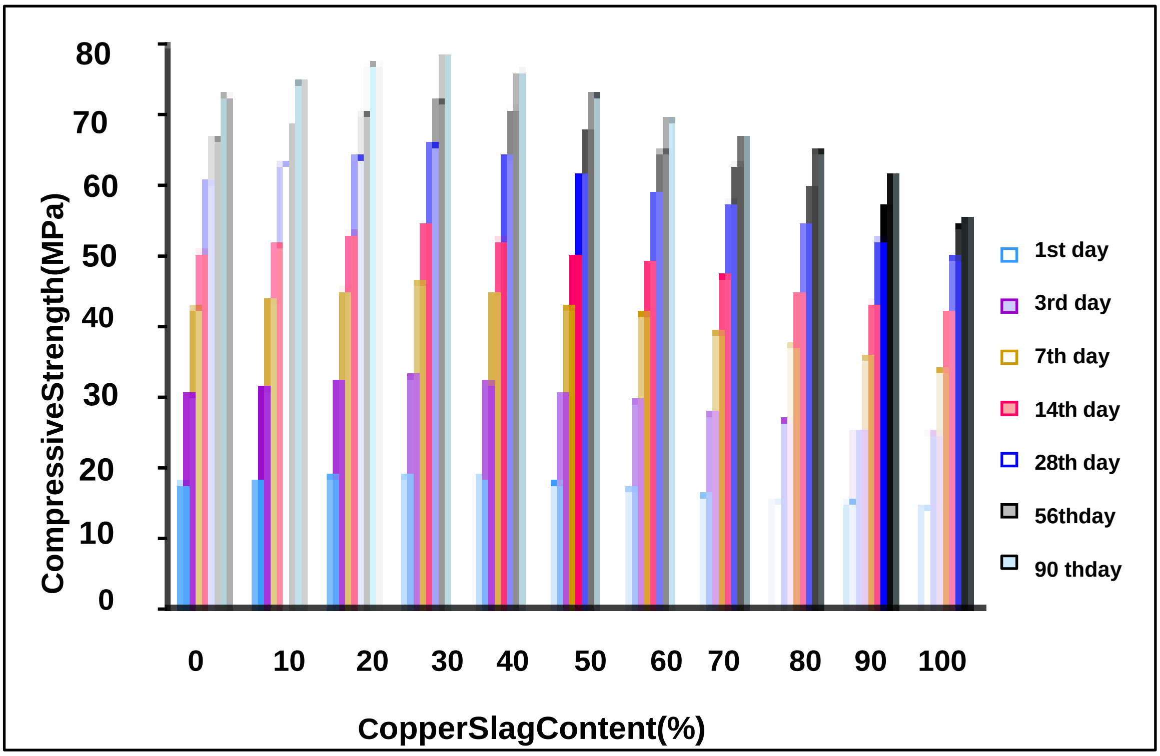

Figure 4.5 Variation of compressivestrength withcopperslag Proportions for SCC Mix M4 (without steel fibers)

Withtheadditionofsteelfibers,formixM4with100%sand+0% copper slag, compressive strength on 28th day was 61.88 MPa. ReplacingFA with copper slag, the compressive strength increased upto 64.81 MPa forMix M4 with 70% sand and 30% copper slag. Compressive strength increasedapproximately by 5%. Further replacement of FA with copper slag resulted inreduction of compressive strength. For Mix M4 with 0% sand and 100%copperslag,thecompressivestrengthwas53.92MPa.Thereductionincompressive strength was 13% when compared with the compressive strengthof mix M4 with 100 % sand + 0 % copper slag. Figure 9.6 shows the variationofcompressivestrengthofSCCmixM4withdifferentcopperslagproportions.M1toM8with differentcopperslagproportions(withsteelfibers).

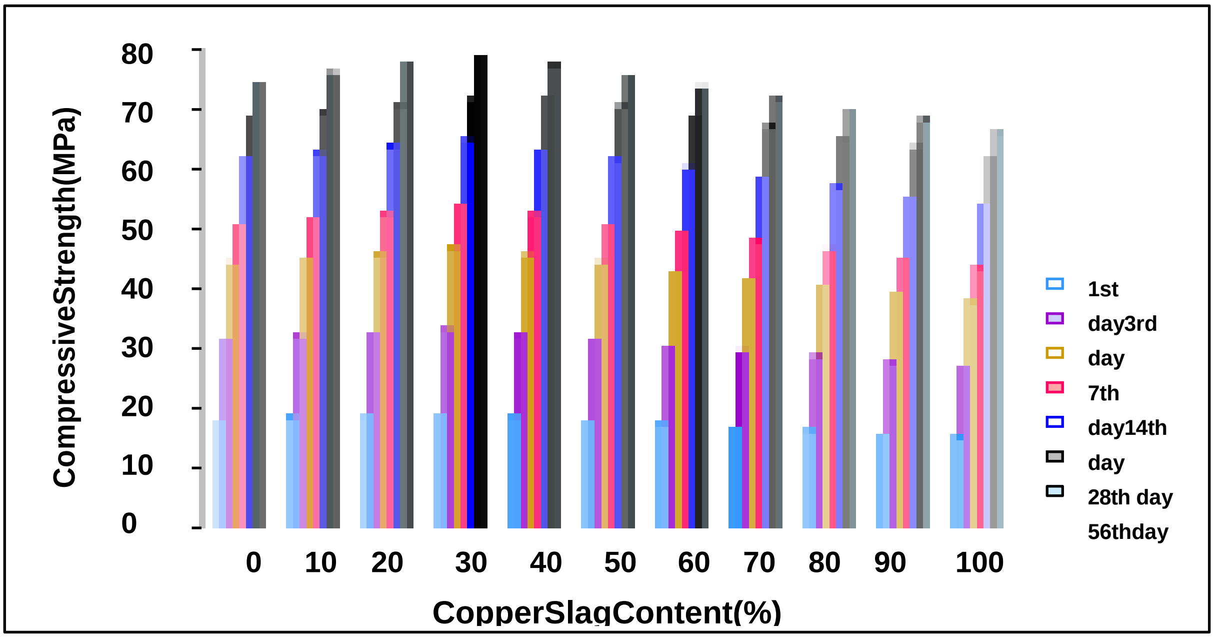

Figure4.6VariationofcompressivestrengthwithcopperslagproportionsforSCCMixM4(withsteelfibers)

4Conclusions:

Theconclusionsthatfollowarebasedontheresults oftheexperimental investigations.

Workability:

The fresh concrete's test results indicate that it meets the requirementsforSCC(Self-CompactingConcrete),whichincludeflowability, passing ability, and segregation resistance. SCC mixes with 80% to100% copper slag exhibited moderate bleeding without segregation.However, the inclusion of steel fiber decreased the flowability andpassing ability of SCC mixes while still satisfying the recommendedlimits.

The addition of copper slag content led to a significant improvementin the workability of SCC mixes. This is likely due to the low waterabsorptionandglassysurfaceofcopperslag, whichhasawaterabsorption rate of 0.28%, compared to 1.05% for fine aggregate. Asthe percentage of copper slag in the mix increased, the amount of freewater content in the SCC mix increased, resulting in a more workableconcrete.However,thisincreaseinfree watercontentmayhave caused the moderate bleeding observed in SCC mixes containing 80%to 100%copperslag.

HardenedProperties:

Withtheincreaseincopperslagpercentage,thedensityofSCCincreases. Copper slag has a specific gravity of 3.68, higher than thatof OPC (3.09), fine aggregate (2.78) and the replacement of FA withcopper slagleadsto the production ofSCCwith higherdensity.

Whensteelfiberswerenotadded,replacingfineaggregatewithcopper slag up to 30% in SCC mixes resulted in an improvement incompressivestrengthofroughly6-10%,flexuralstrengthofapproximately5-8%,andsplittingtensile strengthof3-5%.

When steel fibers were incorporated into the SCC mixes mentionedearlier, the substitution of fine aggregate with copper slag led to a risein compressive strength of around 5-8% after 28 days. Additionally,flexural strength increased by roughly 4-6%, while splitting tensilestrength increasedbyabout3-5%.

Additionalamountsofcopperslagresultedinadeclineinthestrengths mentioned above. As the percentage of copper slag in themix increased, the quantity of free water content in the SCC mix alsoincreased,which ultimately ledto a decreasein strength.

Based on the current study, for SCC mixes consisting of 100% sandand0%copperslag,thecorrelationbetweencompressivestrengthandflexuralstrengthcanbeexpressedas$fb=0.897(fck)^{0.4522}$.However, with the inclusion of steel fibers, the correlation betweencompressive strength and flexural strength is represented as$fb= 0.868(fck)^{0.4554}$

Basedonthecurrentstudy,itwasfoundthatforSCC mixesconsisting of 100% sand and 0% copper slag, the correlation betweencompressive strength and split tensile strength can be represented as$fct = 0.751\ (fck)^{0.455}$. With the incorporation of steel fibers into themix, the correlation between compressive strength and split tensilestrength wasexpressedas$fct=0.790(fck)^{0.4371}$.

In the current investigation, it was found that for SCC mixes withoutcopper slag and steel fibers, the correlation between static modulus ofelasticityandcompressivestrengthcanberepresentedas$E=3594.6fck^{0.5743}$. However, with the inclusion of steel fibers in the mix,the correlation between static modulus of elasticity and compressivestrength wasexpressedas$E=4275.7fck^{0.4781}$.

Durability:

In the current study, it was observed that when subjected to sulphuricacid, the compressive strength of SCC mixes without steel fibers andcontaining 100% sand and 0% copper slag decreased by 18% to 19%.On the other hand, for mixes containing 0% sand and 100% copperslag, the compressive strength decreased by 22% to 24%. However,when steel fibers were added to the mix, the compressive strength ofSCC mixes with 100% sand and 0% copper slag decreased by 19% to21%, while for mixes containing 0% sand and 100% copper slag, thecompressivestrengthdecreasedby22%to25%.

Whensubjectedtohydrochloricacid,the compressivestrengthofSCC mixes without steel fibers and containing 100% sand and 0%copper slag decreased by 20-22%, and for mixes containing 0% sandand 100% copper slag, it decreased by 24-26%. When steel fiberswere added, the compressive strength of SCC mixes containing 100%sandand0%copperslagdecreasedby21-23%,andformixescontaining0%sandand100%copperslag,itdecreasedby28-30%.

Thus,basedonthefindingsofthisinvestigation,itcanbeinferredthat incorporating copper slag as a replacement for fine aggregate inSCC isafeasibleandbeneficialoption.

The compressive, flexural, and split tensile strengths of SCC increaseupto30%whencopperslagisaddedasareplacementforfineaggregate, compared to the control mix. However, further additions ofcopper slag lead to a reduction in these strengths. Therefore, replacing30% of fine aggregate with copper slag can be considered the optimalproportion for replacement. Hence, it can be concluded that usingcopper slag as a replacement for fine aggregate in SCC is technicallyfeasible andbeneficial.

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