Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 42 Issue: 11-2023
DOI: 10.5281/zenodo.10153144

DEVELOPMENT OF SUSTAINABLE CONCRETE USING COPPER SLAG AS A SUBSTITUTE OF FINE AGGREGATE

AMRUTA A. YADAV*
Assistant Professor, Department of Civil Engineering, Yeshwantrao Chavan College of Engineering, Nagpur. *Corresponding Author Email: amruta1227@gmail.com

AJAY R. GAJBHIYE
Professor, Department of Civil Engineering, Yeshwantrao Chavan College of Engineering, Nagpur.
Email: argajbhiye@ycce.edu

ALPESH A. ADEKAR
Director, A.A. Engineers and Builders, Hingna, Nagpur. Email: aaaadekar@gmail.com

ROSHAN R. UMATE
Research Consultant, Directorate of Research, Jawaharlal Nehru Medical College, Datta Meghe Institute of Medical Sciences, Wardha. Email: roshanumate111@gmail.com

Abstract

The research aimed to investigate the mechanical and durability qualities of concrete mix designs by incorporating copper slag (CS) as a substitute for fine aggregate of natural sand (NS). Eleven concrete mixtures were casted, including the control mix, with varying concentrations of CS ranging from 0% to 100% at an increment of 10%. Tests were conducted to evaluate the mechanical properties of the concrete mixes, including flexural strength, compressive strength and split tensile strength. In addition, the durability of the concrete was assessed by conducting tests for water absorption and rapid chloride penetration test. (RCPT). The results indicated at 30% replacement of CS as NS, the maximum improvement in flexural, compressive, and split tensile strength of concrete is achieved. Addition upto 60% still resulted in concrete mixtures with comparable strength to the control mix. Beyond this replacement rate, the concentration of CS increases the amount of free water in the mixture, leading to a decrease in strength. Therefore, it is recommended that 30 wt% of CS can used as replacement of NS in order to obtain concrete with good strength and durability properties.

Keywords: Copper Slag, Density, Durability, RCPT, Strength, Water Absorption, Workability.

1. INTRODUCTION

Cement, sand, and aggregate are the essential necessary ingredients for the construction industry. Cement and natural sand are two essential ingredients in the preparation of concrete, and they have a significant impact on mix design. The primary objectives of the government and environmental protection organisations are to find solutions to the disposal issues and health risks associated with byproducts. Globally, natural resources are running out while industrial waste production is sharply rising at the same time [1]. Because of the increased demand for sand, there is a severe shortage of high-quality sand, particularly in India where natural sand reserves are getting depleted [2]. In the construction industry, some industrial waste items have been effectively used to produce concrete. Industrialization is essential for the development of our nation. However, numerous tonnes of industrial waste are released annually from industries. Utilizing industrial waste materials in concrete can assist in compensating for a shortage of natural

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 42 Issue: 11-2023
DOI: 10.5281/zenodo.10153144

resources, solve the waste disposal issue, and develop alternative methods of protecting the environment. CS a waste material, holds potential for the construction industry as a partial or full substitute for cement or aggregates [1]. It is created in vast amounts when copper is extracted. [7]. Approximately 2.2 to 3 million tonnes of CS are produced for every million tonnes of extracted copper ore [1]. Copper slag is considered a pozzolanic material due to the presence of three oxides: silicon dioxide (SiO2), iron(III) oxide (Fe_2O_3), and aluminum oxide (Al_2O_3). When the combined content of these three oxides exceeds 70%, the material is considered to have significant pozzolanic activity. This pozzolanic activity enables the copper slag to react with calcium hydroxide in the presence of moisture, forming additional cementitious compounds and contributing to the strength and durability of concrete. The high pozzolanic activity of copper slag makes it a valuable material for enhancing the performance of concrete in construction applications. The disposal of large amounts of waste from the mining industry is indeed an environmental challenge. However, recycling these materials or utilizing them as artificial aggregates can offer a viable solution[3].Due to its distinct mechanical and chemical characteristics, CS can be used in concrete as a partial replacement for Portland cement or as an aggregate. Copper slag possesses various beneficial mechanical properties that make it a suitable aggregate, like good stability, good abrasion resistance, and good soundness characteristics. [5]. Additionally, copper slag exhibits pozzolanic properties due to its low CaO content and the presence of other oxides such as Al2O3, SiO2, and Fe2O3 [5]. Copper slag is granular and shiny, and when incorporated into concrete, it improves the material's strength, durability, workability, and various other characteristics [7,8]. Concrete is made more affordable by using waste materials, and recycling material. An environmentally friendly solution to the problem of waste disposal is to utilize copper slag in various applications, such as concrete production, as it helps to reduce waste and minimize the environmental impact [2].As a result, the current study attempts to mitigate the potential environmental impact by substituting copper slag for natural sand.

2. MATERIALS AND METHODOLOGY

2.1 Materials

In this investigation, Ordinary Portland Cement of Ultra tech 53 grade is used. The construction industry in India uses this cement the most. The Table 1 shows cement's various characteristics. The specific gravity of OPC is 3.15 and following IS 269 was used as binder material to produce copper slag concrete.The NS were procured from the supplier near Nagpur (India), it is hard, durable and free of clay or inorganic materials. The NS specific gravity is 2.64 and graded under Zone II. The fineness modulus of NS is 2.84 using sieve analysis method as per per IS 2386 part1 1963. According to IS 2386 part I, the grading of the fine aggregate was determined. It is observed that the natural sand lies in Zone II, as per the grading limit provide in IS 383-2016. The perfect grading or perfect particle size distribution is observed for CS(30%), since particle size distribution curve of zone II nearly matches with particle size distribution combination of 30% Copper slag + 70% Natural sand.

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 42 Issue: 11-2023
DOI: 10.5281/zenodo.10153144

Table 1: Physical Properties of Cement

Property	Experimental value	Standard value for OPC
Fineness of cement ((%))	1.5	--
Consistency (%)	30	--
Initial Setting time (min)	40	>60
Final Setting time (min)	225	<600

The angular crushed coarse aggregate with specific gravity 2.89 and water absorption as 0.8% having size of 10mm and 20mm are used in this research. Viscofluz 5507 is a high performance superplasticizer designed for applications that necessitate significant water reduction and prolonged workability retention is used weighing 1.0 percent of the cement.

The CS used in this investigation is from Birla copper industry. The specific gravity of CS is 3.31 and percentage of water absorption is 0.87. Due to its high specific gravity, the material is heavier. The fineness modulus of CS is found to be 2.86. The chemical properties of Copper slag and Natural sand is presented in Table 2.

Table 2: Chemical Properties of Natural and Copper Slag

Component	Natural Sand	Copper slag
SiO_2	73.79	27.94
K_2O	3.46	0.98
CaO	1.79	3.55
MgO	0.47	0.99
P_2O_5	0.13	0.1
Fe_2O_3	2.69	56.75
Al_2O_3	15.39	3.75
Na_2O	0.59	0.52
TiO_2	0.34	0.5

2.2 Experimental Procedure

In the fresh state, the workability parameters of the concrete mix were examined by conducting a slump test. The slump test is a commonly used method to evaluate the consistency and flowability of fresh concrete, and it involves measuring the slump value. In the hardened stage, strength tests were conducted to assess the performance of the concrete. The tests included examining flexural strength, split tensile strength, and compressive strength. Cube specimens measuring 150mm x 150mm x 150mm were prepared in moulds and cured for 7 days and 28 days. After the curing period, the compressive strength of the cubes was determined using a CTM (Compression Testing Machine). To determine the flexural strength of the concrete, a beam specimen measuring 100mm x 100mm x 500mm was cast and cured for 28 days. Similarly, cylindrical specimens with a diameter of 150mm and a height of 300mm were cast and cured for 28 days to measure the split tensile strength of the concrete.

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 42 Issue: 11-2023
DOI: 10.5281/zenodo.10153144

2.3 Mix Proportions

For this study, a mix proportion of M-30 grade was utilized, and Table 3 presents the different combination of mix proportions used. In order to conduct a comparative study, ten different mixes were prepared, each incorporating varying amounts of CS as a partial replacement for NS. These mixes ranged from 0% to 100% CS content control concrete mix (CC) with increments of 10%. As per IS 10262, the required quantity of materials for the mix was determined through the concrete mix design process is shown in Table 4

Table 3: Various Mix Replacements (%)

S.N	Mix	Proportion			
		Cement	*Fine Aggregate*		*Coarse Aggregate*
			CS	*NS*	
1	CC	100 %	0 %	100 %	100%
2	CS(10%)	100 %	10 %	90 %	100%
3	CS(20%)	100 %	20 %	80 %	100%
4	CS(30%)	100 %	30 %	70 %	100%
5	CS(40%)	100 %	40 %	60 %	100%
6	CS(50%)	100 %	50 %	40 %	100%
7	CS(60%)	100 %	60 %	40 %	100%
8	CS(70%)	100 %	70 %	30 %	100%
9	CS(80%)	100 %	80 %	20 %	100%
10	CS(90%)	100 %	90 %	10 %	100%
11	CS(100%)	100 %	100 %	0 %	100%

Table 4: Mix Proportions (kg/m^3)

S.N	Mix	Cement	Fine aggregate		Coarse Aggregate	Water/Cement Ratio
			Natural sand	*Copper slag*		
1	CC	350	701.18	--	1368.17	0.45
2	CS(10%)	350	631.06	88.08	1368.17	0.45
3	CS(20%)	350	560.94	176.16	1368.17	0.45
4	CS(30%)	350	490.83	264.25	1368.17	0.45
5	CS(40%)	350	420.71	352.33	1368.17	0.45
6	CS(50%)	350	350.59	440.41	1368.17	0.45
7	CS(60%)	350	280.47	528.49	1368.17	0.45
8	CS(70%)	350	210.35	616.57	1368.17	0.45
9	CS(80%)	350	140.24	704.66	1368.17	0.45
10	CS(90%)	350	70.12	792.74	1368.17	0.45
11	CS(100%)	350	--	880.82	1368.17	0.45

3. RESULTS AND DISCUSSION

3.1 Workability

The workability of concrete was measured according to IS 1199 and the results indicated that the workability increases as the percentage of copper slag (CS) increases, as depicted in Figure 1. The higher value of slump was found to be 130mm for the CS(100%) mix while the control mix had a slump value of 90mm as presented in Table 5.This significant increase in slump value can be attributed to the excess free water that remains

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 42 Issue: 11-2023
DOI: 10.5281/zenodo.10153144

after the absorption and hydration processes, primarily due to CS's low water absorption properties and its glassy (crystalline) or smooth texture in comparison to NS [8].Mixes with high levels of CS exhibited segregation as well as bleeding which is worth noting as it can have a detrimental impact on the performance of the concrete. These problems can compromise the overall quality and durability of the concrete.

Table 5: Test Results of Various Mix

S.N	Mix	Slump Value in mm	Compressive Strength		Flexural Strength	Split Tensile Strength	Density (kg/m^3)
			7 Days (MPa)	28 Days (MPa)	28 Days (MPa)	28 Days (MPa)	
1	CC	90	36.69	38.23	7.87	2.87	2595.56
2	CS(10%)	100	39.80	45.67	8.82	3.04	2637.04
3	CS(20%)	105	41.78	47.87	9.24	3.20	2666.67
4	CS(30%)	108	43.56	51.20	9.45	3.36	2728.89
5	CS(40%)	110	37.78	49.80	9.10	3.22	2737.78
6	CS(50%)	114	37.20	45.40	8.40	3.18	2761.48
7	CS(60%)	115	36.89	41.12	8.10	3.04	2800.00
8	CS(70%)	118	33.30	36.20	7.20	2.56	2817.78
9	CS(80%)	120	30.44	34.56	6.27	2.33	2832.59
10	CS(90%)	126	28.78	31.12	5.12	2.22	2897.78
11	CS(100%)	130	27.45	29.23	4.80	2.10	2900.74

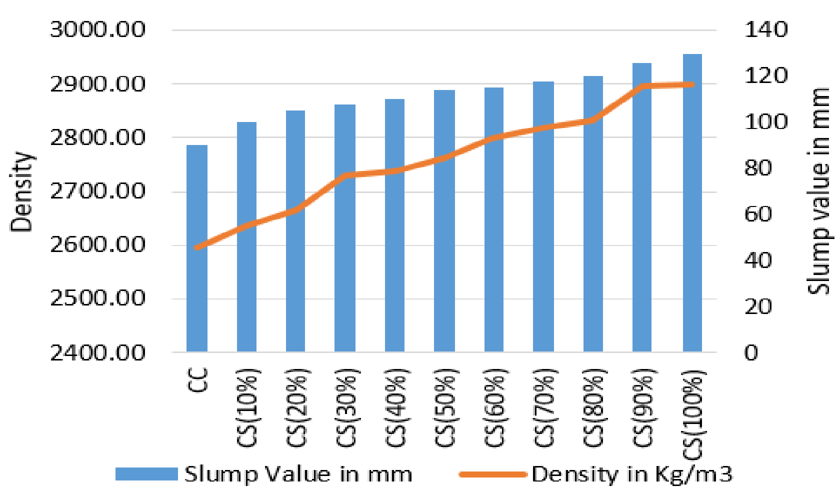

Fig 1: Workability and Density

3.2 Compressive Strength

CS(30%) demonstrated superior performance in terms of compressive strength, as indicated by Figure 2. This can be attributed to two main factors: the higher iron oxide (Fe_2O_3) content of copper slag (CS) and the material's toughness. The increased iron oxide content in CS likely played a role in boosting the compressive strength of the CS(30%) mix. This finding suggests that the presence of CS, specifically at a 30% substitution level, positively influenced the compressive strength of the concrete. The control mix exhibited a compressive strength of 38.23 N/mm2, while the CS(30%) mix

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 42 Issue: 11-2023
DOI: 10.5281/zenodo.10153144

achieved a significantly higher compressive strength of 51.2 N/mm2 as presented in Table 5. The CS (10%), CS (20%), and CS (40%) mixes also showed notable increases in compressive strength, at 19.46%, 25.22%, and 30.26% respectively. However, the CS (50%) and CS (60%) mixes showed slightly lower increases in compressive strength, at 18.75% and 7.56% respectively, compared to the control mix.

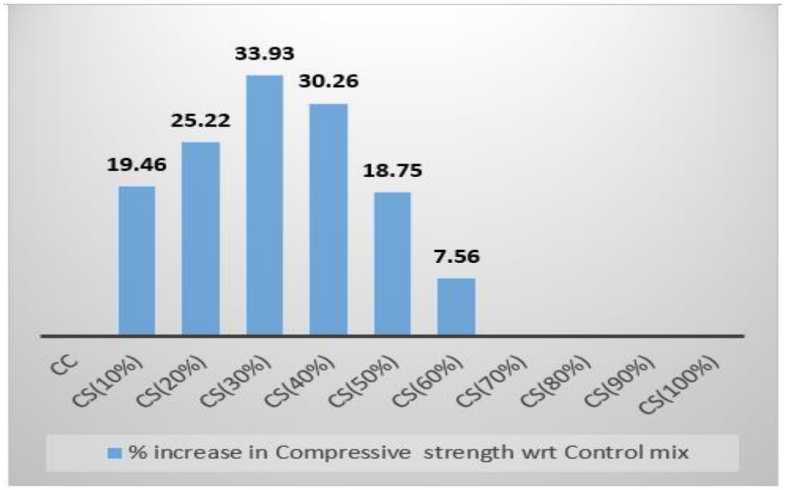

Fig 2: Increase in compressive strength

3.3 Flexural strength

The beam specimen casted (500mm x 100mm x 100mm) and allowed to cure for 28 days before being put through the flexural strength test and the results are presented in Table 5. For 30% replacement level of CS as NS the maximum flexural strength was achieved i.e. for CS (30%) mix, as shown in Figure 3. After that, the mix's strength decreased as the copper slag content increased. CS (30%) mix produced the highest flexural strength of 9.45 N/mm^2. Flexural strength increased by 12.12%, 17.46%, 20.13%, 13.55%, 6.78%% and 2.97% for the CS10%), CS (20%), CS (30%), CS (40%), CS (50%) and CS (60%) mixes respectively.

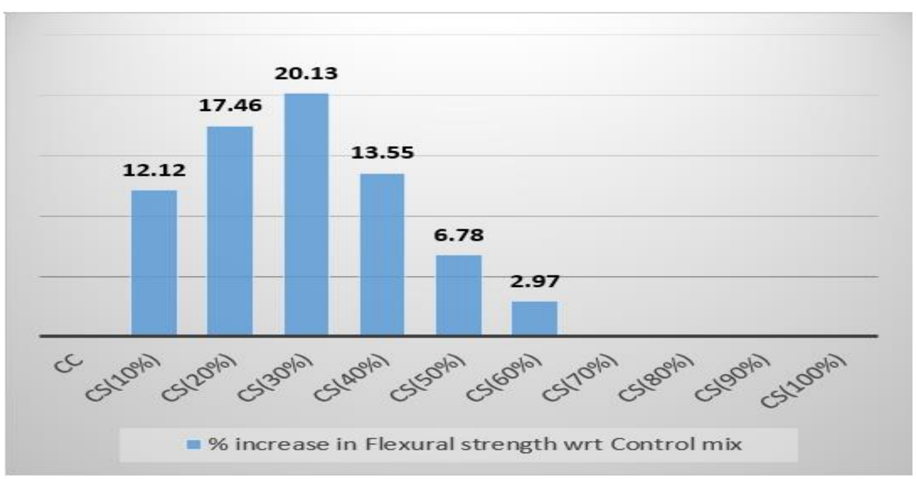

Fig 3: % increase in Flexural Strength

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 42 Issue: 11-2023
DOI: 10.5281/zenodo.10153144

3.4 Spilt tensile strength

A cylindrical specimen with dimensions of 300mm in height and 150mm in diameter was cast for a 28-day curing time in order to assess the split tensile strength. Figure 4 depicts that the maximum split tensile strength was achieved for CS (30%). This information suggests that the optimal proportion of CS as a replacement for NS in terms of split tensile strength is 30%. Beyond this level, the strength of the mix tends to decrease. The mix with 30% copper slag (CS) substitution produced the highest split tensile strength of 3.36 N/mm2 as presented in Table 5. Figure 4 provides a comparison of the split tensile strength for various mixes, including CS (10%), CS (20%), CS (30%), CS (40%), CS (50%), and CS (60%), in relation to the control mix (CC). According to the data in Figure 7, the CS (10%) mix exhibited a 6.06% increase in split tensile strength compared to the CC mix. Similarly, the CS (20%) mix exhibited an 11.64% increase in split tensile strength, while the CS (30%) mix showcased a significant 17.23% increase. When compared to the CC mix, the CS (40%) mix showed the increase in split tensile strength at 12.34%, followed by the CS (50%) mix with a 10.95% increase. The CS (60%) mix exhibited a 6.17% increase in split tensile strength.

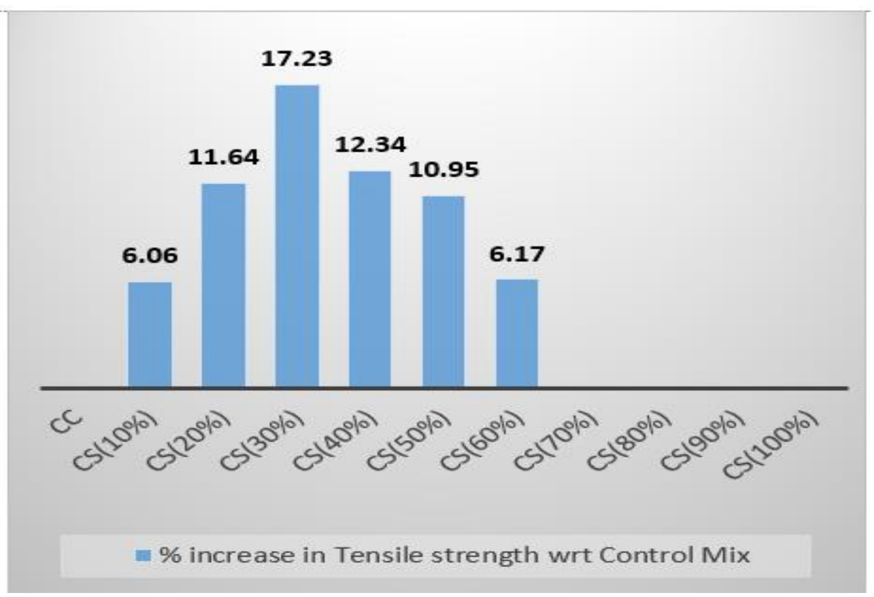

Fig 4: % increase in Split Tensile Strength

3.5 Density

As the CS content increases the density of hardened concrete also increases, as shown in the results presented in Table 5. The higher specific gravity of CS compared to NS, with CS having a specific gravity of 3.31 and NS having a specific gravity of 2.64, can be attributed to the increase in density of hardened concrete, as observed in the results presented in Figure 1. The higher specific gravity of CS leads to an overall increase in the density of the concrete as the percentage of CS in the mix increases. This observation highlights the influence of CS on the physical properties of the concrete and suggests that using CS as a replacement for NS can result in denser concrete.

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 42 Issue: 11-2023
DOI: 10.5281/zenodo.10153144

3.6 Water Absorption

The durability of concrete was assessed using the water absorption test, and the results are presented in Table 6. From the Figure 5, it can be observed that the water absorption reduces as the percentage of CS in the mixes increases, up to a 60% substitution of CS. Specifically, for CS (10%), CS (20%), CS (30%), CS (40%), CS (50%), and CS (60%), the water absorption reduces by 1.35%, 2.25%, 6.76%, 10.81%, 13.51%, and 13.96% respectively. The density of concrete improves by substituting CS which reduces the water absorption by concrete [12]. It is important to note that higher content of CS particles, such as CS (70%), CS (80%), CS (90%), and CS (100%), lead to an increase in water absorption in the concrete as shown in Figure. CS (100%) containing 100% copper slag exhibited the highest water absorption among all the mixes.

Table 6: Durability Results

S.N	Mix	Water Absorption (%)	RCPT (Charge passes in Coulombs)	
			28 Days	56 Days
1	CC	2.22	1960.45	1910.78
2	CS(10%)	2.19	1880.56	1820.96
3	CS(20%)	2.17	1760.54	1700.23
4	CS(30%)	2.07	1600.12	1520.45
5	CS(40%)	1.98	1550.34	1480.23
6	CS(50%)	1.92	1454.17	1390.56
7	CS(60%)	1.91	1449.87	1360.45
8	CS(70%)	2.23	1980.98	1920.98
9	CS(80%)	2.38	2078.79	2000.56
10	CS(90%)	2.43	2254.23	2190.23
11	CS(100%)	2.5	2365.33	2290.67

3.7 Rapid Chloride Ion Penetration Test (RCPT)

The test results of chloride ion penetration are presented in Table 6. It can be observed that for all samples up to 60% CS substitution, the charge passed falls under the low category as per ASTM C 1202-12. This indicates that the concrete with CS substitution has a good resistance to chloride ion penetration, which is beneficial for the durability of the concrete structure. The Coulombs charge passed for concrete mixes CS (10%), CS (20%), CS (30%), CS (40%), CS (50%), and CS (60%) reduces by 4.7%, 11.02%, 20.43%, 22.53%, 27.23%, and 28.80% respectively, compared to the CC mix, as shown in the Figure 5. This indicates that the substitution of CS in concrete leads to a significant reduction in the penetration of chloride ions, further enhancing the durability of the concrete. The lower absorption characteristics and higher angularity of CS particles can be attributed to the decrease in Coulombs charge passes, resulting in the formation of a concrete microstructure with less pore volume [11]. Consequently, this reduction in pore volume leads to lower RCPT values. However, it is important to note that for higher CS content, i.e., beyond 60% CS, the RCPT (rapid chloride penetration test) values increase compared to the CC (control) mix thought it is in Moderate category as per ASTM C 1202-12.

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 42 Issue: 11-2023
DOI: 10.5281/zenodo.10153144

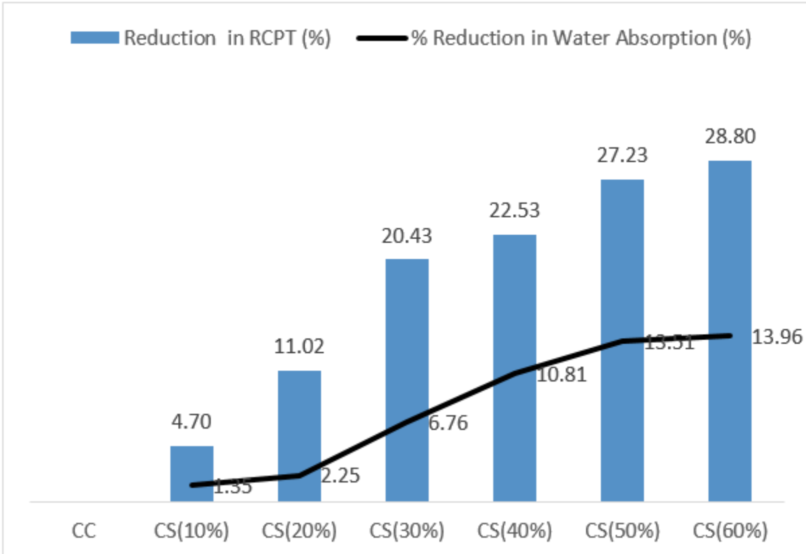

Fig 5: Durability results

4. CONCLUSION

1) The workability of the concrete also increases as the percentage of copper slag in the concrete mix rises.
2) The concrete mix CS (30%) produces the maximum compressive strength with an increase of 33.93% compared to the CC (control) mix.
3) For CS (30%) the maximum flexural strength of concrete increases by 20.13% compared to the CC (control) mix.
4) The split tensile strength of concrete mix CS (30%) increases by 17.23% with respect to CC mix.
5) Strength of specimen tested was found to be higher upto 60% CS but further addition reduces the strength.
6) Concrete's density increases as the amount of CS in it increased.
7) The water absorption of the concrete decreased as the percentage of CS replacement increased. Specifically, the lower water absorption was observed up to a 60% replacement of CS.
8) The chloride ion penetration in concrete decreased as the percentage of CS increased. Specifically, the lower value of chloride ion penetration was observed up to a 60% replacement of CS. Lower chloride ion penetration is desirable as it can help reduce the risk of corrosion in reinforcement bars and increase the durability of concrete structures in chloride-rich environments.

References

1) Khalifa S. Al-Jabri, Makoto Hisada, Salem K. Al-Oraimi, Abdullah H. Al-Saidy "Copper Slag As Sand Replacement For High Performance Concrete" Elseveir Volume 31, Issue 7, August 2009, doi:10.1016/j.cemconcomp.2009.04.007

2) Manoj Kumar Dash, Sanjaya Kumar Patro, Ashoke Kumar Rath "Sustainable Use of Industrial-Waste as Partial Replacementof Fine Aggregate For Preparation Of Concrete – A Review" Elsevier International Journal of Sustainable Built Environment Science Direct. https://doi.org/10.1016/j.ijsbe.2016.04.006

3) Romy SuryaningratEdwin[a]ElkeGruyaert[b]NeleDe Belie[c], "Valorization Of Secondary Copper Slag As Aggregate And Cement Replacement In Ultra-High Performance Concrete", Journal of Building Engineering, Volume 54, 15 August 2022, 104567, https://doi.org/10.1016/j.jobe.2022.104567

4) AliZalnezhad[a]Seyed AzimHosseini[a]RezaShirinabadi[b]Mohammad EmamiKorandeh[a], "Feasibility Of Using Copper Slag As Natural Aggregate Replacement In Microsurfacing For Quality Enhancement: Microscopic And Mechanical Analysis" Construction and Building Materials, Volume 354, 7 November 2022, 129175, https://doi.org/10.1016/j.conbuildmat.2022.129175

5) Khalifa S. Al-Jabri, Abdullah H. Al-Saidy, Ramzi Taha "Effect Of Copper Slag As A Fine Aggregate On The Properties Of Cement Mortars And Concrete" Elsevier Construction and Building Materials 25 (2011) 933–938, doi:10.1016/j.conbuildmat.2010.06.090

6) Navdeep Singh Akshit Gupta Md Marghoobul Haque "A Review On The Influence Of Copper Slag As A Natural Fine Aggregate Replacement On The Mechanical Properties Of Concrete, Volume 62, Part 6, 2022 Pages 3624-3637. https://doi.org/10.1016/j.matpr.2022.04.414

7) FarshadAmeri[a]ParhamShoaei[b]HamidReza Musaeei[c]SeyedAlireza Zareei[c]CheahChee Ban[a], "Partial Replacement Of Copper Slag With Treated Crumb Rubber Aggregates In Alkali-Activated Slag Mortar" Construction and Building Materials, Volume 256, 30 September 2020, 119468, https://doi.org/10.1016/j.conbuildmat.2020.119468.

8) Mahesh V. Patil ⇑, Yogesh D. Patil" Effect of Copper Slag and Granite Dust as Sand Replacement On the Properties of Concrete", Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2020.10.029

9) M. V. PATIL "Properties and Effects of Copper Slag in Concrete" International Journal of Advances in Mechanical and Civil Engineering, ISSN: 2394-2827 Volume-2, Issue-2, April-2015

10) R. Elamaran, K. Srinivasan, S. Vimala "Use of Copper Slag for Partial Replacement to Fine Aggregate in Concrete" International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-7, Issue-5S3, February 2019

11) Jagan Sivamani "Influence of Copper Slag On The Mechanical And Durability Properties of High Strength Concrete" https://doi.org/10.21203/rs.3.rs-1187203/v1

12) Abhishek Mahaishi,S.P.Singh,Lalit kumar Gupta,Shehnazdeep "Strength And Durability Studies On Slag Cement Concrete Made With Copper Slag As Fine Aggregate" Materials Today Proceeding Volume 38, Part 5, 2021, Pages 2639-2648 https://doi.org/10.1016/j.matpr.2020.08.232.