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ENHANCING WORKABILITY AND STRENGTH OF SELF-COMPACTING CONCRETE THROUGH COPPER SLAG AND SUPPLEMENTARY CEMENTITIOUS MATERIALS

Ajmal M Sajeev[1]
Research Scholar, Department of Civil Engg.,
Sri Satya Sai University of Technology and Medical Sciences, Sehore, Madhya Pradesh.

Dr. Ajay Swarup[2]
Research Guide, Department of Civil Engg.,
Sri Satya Sai University of Technology and Medical Sciences, Sehore, Madhya Pradesh

Abstract
Copper slag has become a practical and economical substitute for natural aggregates in concrete applications, especially in self-compacting concrete (SCC) blends. The goal of this study is to find out if self-compacting concrete (SCC) mixtures are possible and how strong they are by changing the amount of copper slag in them in a controlled way, from 0% to 50%. The inquiry also includes the use of Portland slag cement and examines how supplemental cementitious ingredients affect the performance of the concrete. The study highlights the environmental advantages of using copper slag, such as the preservation of resources and the mitigation of greenhouse gas emissions. The material qualities of several components, such as cement, coarse aggregate, copper slag, ground granulated blast furnace slag (GGBS), fly ash, water and fine aggregate are specified to offer a full knowledge of the mix composition. The study's findings, which encompass rheological properties, workability, and compressive strength, emphasise the beneficial impact of copper slag on the long-term structural performance of SCC mixes. This influence is particularly notable when copper slag is used as a substitute at a 20% level.

Introduction

Concrete has been a fundamental component in the building industry for a significant period, serving a crucial function in the creation of structures around the globe. Nevertheless, the extensive use of cement has detrimental effects on the environment, mostly due to the energy-intensive and carbon-emission-heavy nature of the cement manufacturing process. The environmental consequences have led to a transition towards more sustainable practices in recent years.

Two notable methods in the pursuit of environmentally friendly buildings are green self-compacting mixes (GSCM) and the integration of slag replacements in concrete. These approaches provide novel options to reduce the environmental impact linked to conventional concrete manufacturing while still guaranteeing that the performance and longevity of structures are not impaired.

Green self-compacting mixes are an innovative advancement in concrete technology. These blends are designed to possess both self-compacting properties and eco-friendly characteristics. They mitigate the requirement for excessive mechanical compaction, a procedure that conventionally uses a substantial quantity of energy during building. GSCM formulations frequently use alternative and sustainable components, reducing dependence on traditional resources that contribute to environmental damage.

Another potential approach is using slag substitutes in concrete. Slag, a residual material produced during different industrial operations, can be used as a replacement for a certain amount of conventional cement in concrete mixes. This method not only decreases the need for cement, which is a significant source of carbon emissions, but also utilises a substance that would otherwise be considered refuse. The use of slag improves the overall sustainability of concrete manufacturing while preserving the structural integrity and durability of the resulting construction.

Both the use of Green Sustainable Concrete Mixtures (GSCM) and Ground Granulated Blast Furnace Slag (GGBFS) highlight the construction sector's dedication to tackling environmental issues while maintaining the essential characteristics of concrete. These advancements correspond to the increasing recognition of the building industry's influence on the environment and the necessity for more conscientious methods. Given the ongoing development of the building sector, these eco-friendly options are positioned to have a significant impact on creating a more sustainable and durable built environment.

Green Self-Compacting Mixes (GSCM)

Concrete that can self-consolidate without vibration is known as self-compacting concrete (SCC), and it has great flowability. Complex and densely packed structural components benefit greatly from this. Green Self-Compacting Mixes enhance this concept by including eco-friendly components into the mix design. These blends are designed to mitigate the ecological consequences of concrete manufacturing by minimising the use of conventional cement and integrating SCMs such as GSCM (Green Supplementary Cementitious Materials), fly ash, silica fume, ground granulated blast furnace slag (GGBFS), achieves a high level of performance and reduces the carbon footprint of concrete buildings through the optimisation of mix proportions, particle packing, and rheological qualities.

Environmental Benefits

The incorporation of Green Supply Chain Management (GSCM) and the utilisation of slag replacements in concrete are in accordance with the overarching objectives of sustainable development. Through the reduction of dependence on conventional cement and the integration of recycled materials, these methods effectively contribute to a substantial decline in carbon dioxide emissions linked to the manufacture of concrete. The use of industrial byproducts such as slag not only minimises the environmental effect but also tackles the problem of waste disposal.

Challenges and Future Perspectives

In order to achieve broad adoption, it is necessary to overcome issues such as mix design optimisation, standardisation, and market acceptability, despite the promising solutions offered by GSCM and slag substitutes. Ongoing research is being conducted to improve the performance of these materials, investigate new environmentally friendly binders, and provide recommendations for their practical implementation in different building projects.

Methodology

Copper slag has become a cost-efficient and firmly established substitute for natural aggregates such as sand and crushed rocks. The use of this replacement has been widely embraced, especially by makers of ready-mix concrete and in government road projects where strict compliance with the criteria given in BIS IS 383:2016 is essential. In recent years, copper slag has become crucial in concrete applications, making a substantial contribution to sustainable construction methods.

An important benefit of using copper slag is its favourable influence on environmental preservation. By replacing natural aggregates with copper slag, there is a significant decrease in the use of resources like sand, hence aiding in the conservation of fragile ecosystems found in hills and river bottoms. This sustainable method is in line with the worldwide endeavour to reduce greenhouse gas emissions and address global warming, since it contributes to the preservation of vegetation in ecologically vulnerable regions.

The purpose of this research is to evaluate self-compacting concrete (SCC) mixes for both their compressive strength and workability. In this experiment, systematically adjust the percentage of copper slag in the mixture, ranging from 0% to 40% in 9% increments. The primary objective of this comprehensive study is to ascertain the effects of different concentrations of copper slag on the properties of SCC mixes.

In addition, the study contains Portland slag cement in the mix, demonstrating a dedication to using supplemental cementitious materials that offer environmental advantages. This decision is in line with sustainable building practices and emphasises the need to evaluate both alternate aggregates and cementitious materials when seeking environmentally friendly and efficient concrete solutions.

Material Properties

Cement

Portland Slag Cement (PSC), a blended cement, distinguishes itself with a composition primarily derived from slag, a glassy by product of steel manufacturing comprising over 90% silicates and alumino-silicates of lime. Manufactured by JSW Cement with adherence to IS: 12089 standards, this PSC blend incorporates up to 4-6% gypsum, 45-50% clinker and 45-50% slag. Notably, PSC's low heat of hydration makes it particularly suitable for mass construction projects, mitigating the risk of thermal cracking and ensuring structural durability. In essence, PSC represents a sustainable and quality-driven solution, showcasing innovation in the cement industry to meet evolving construction needs.

Coarse Aggregate

In Self-Compacting Concrete (SCC), the choice of coarse aggregate is critical for ensuring optimal flowability and deformability while preventing segregation. Typically, round-shaped aggregates, well-graded and smaller than those in conventional concrete (not exceeding 40 mm), are preferred. This configuration, with a maximum size ranging from 10 mm to 20 mm, enhances SCC's fluidity and deformability, minimizing the risk of segregation. The selection also considers aggregate types—crushed aggregates, with angular particles, enhance strength through particle interlocking, while rounded aggregates facilitate SCC's smooth flow. This strategic aggregate choice underscores the careful balance needed to achieve structural integrity and optimal performance in SCC.

Fine Aggregate

In Self-Compacting Concrete (SCC), various sands, including crushed and rounded varieties, as well as siliceous or calcareous sands, are considered suitable. The presence of fines, particles less than 0.125 mm, is crucial for SCC's rheology, with a delicate balance needed to prevent segregation. These fines often result from the decomposition of sandstones due to weathering effects. The shape and surface structure of fine aggregate significantly influence water demand in concrete, with smooth and rounded particles proving superior for workability compared to sharp and rough ones. This nuanced consideration highlights the importance of fines and fine aggregate characteristics in achieving optimal rheological properties and workability in SCC.

Copper Slag

Copper slag, a by-product of copper smelting in India, is produced in significant quantities by major copper producers like Hindustan Copper, Birla Copper, Sterlite. With approximately 2.2-3.0 tons generated for every ton of copper, its versatile use as a substitute for Portland cement and aggregates presents a triple benefit. This includes eliminating dumping costs, reducing concrete production expenses, and mitigating air pollution issues. By repurposing copper slag in construction, not only is an economic advantage realized, but it also transforms an industrial by-product into a valuable resource, aligning with sustainability goals.

Ground Granulated Blast-Furnace Slag

GGBS is a non-metallic powder with silicates and aluminates of calcium, created by rapidly cooling molten slag with water. This glassy, sand-like material, when ground to particles under 45 microns, exhibits a specific surface area of 400 to 600 m2/kg. Similar to cement clinker in chemical composition, GGBS performance hinges on this aspect. Quality adherence is maintained through compliance with IS 12089 of 1987 standards, ensuring consistency and reliability in its application.

FLYASH

Pulverized fly ash is a by product of coal combustion in thermal plants, obtained through mechanical separators. Its composition varies based on factors like fuel type, boiler load, and separation method. The fly ash comprises spherical glassy particles ranging from 1 to 150 microns in diameter, capable of passing through a 45-micron sieve. This fine and diverse particle structure makes pulverized fly ash valuable for applications in construction and as a supplementary material in cement production.

Water

The water in concrete is very important because it reacts chemically with the cement and helps the cement gel form, which gives the concrete its power. The amount and type of water used are very important when making concrete. To fully understand how much water quality affects the strength of concrete, it is necessary to look closely at water standards and cleanliness. Potable water is used for both the mixing and hardening steps in this study, which shows how important it is to use water that meets certain standards. This makes sure that the concrete is as strong and long-lasting as it can be, which shows how important it is to be very careful when choosing water for a building.

Result and Discussion

The initial trial mix is formulated with a water-to-cement ratio (W/C) of 0.49 using the Nan Su method for 0% Copper Slag replacement. A 7-liter mix is prepared with Coarse Aggregate, Fine Aggregate, Copper Slag, Cement, Flyash, GGBS, and SP-mixed water, following a specific order in the mixing machine for the slump flow test. The obtained slump flow value is 700mm, aligning with EFNARC guidelines. In the second trial mix designed for a W/C of 0.45, also per Nan Su method for 0% Copper Slag replacement, a 7-liter mix is prepared similarly. However, improper mixing in the machine leads to rejection of this trial. Moving on to the third trial mix designed for W/C of 0.47, following the Nan Su method for 0% silica fume replacement, a 7-liter mix is prepared in the specified order. The slump flow test results in a value of 650mm, meeting EFNARC guidelines. These trials illustrate the meticulous process of mix design, emphasizing the importance of proper ingredient mixing for successful concrete formulation in line with industry standards.

Table 1. Nan-Su Method: Producing Mix Proportions for 1 Cubic Meter Concrete on a Weight Basis

Mix trails	Fine Aggregate		SP Content (kg/m^3)	SP Dosage (%)
	Percentage of copper slag	Percentage of fine aggregate		
M1	0	100	4.010	1.25
M2	10	90	3.818	1.19
M3	20	80	3.625	1.13
M4	30	70	3.433	1.07
M5	40	60	3.240	1.01
M6	50	50	3.048	0.95

Table 1 summaries the formulation of various mix proportions labelled M1 to M6. In these mixes, the Copper Slag content varies from 0% to 50%, while the dosage of Super plasticizer (SP) ranges from 1.25% to 0.95% across the different formulations. This variation in Copper Slag and SP dosage allows for a comprehensive exploration of their impact on the concrete mixes, offering insights into the range of possibilities and their effects on the final properties of the concrete.

Table 2. Examining the Workability and Rheological Traits of Self-Compacting Concrete

Mix trails	Percentage of copper slag	Slump Flow	L-Box	V-Funnel	J-Ring
M1	0	650	0.89	8	2.5
M2	10	720	0.95	6	8.5
M3	20	740	0.91	7	7.5
M4	30	720	0.96	5	8.5
M5	40	695	0.89	6	9.5
M6	50	700	0.82	7	9.5

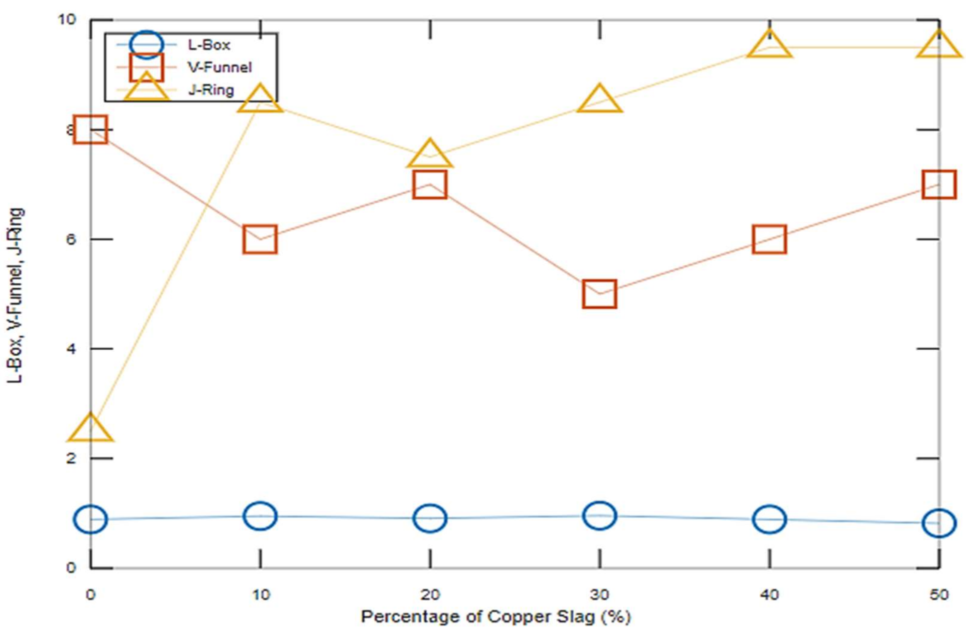

Figure 1. Workability of Self-Compacting Concrete (SCC)

Test Result of Compressive strength

With great care, the concrete cubes were made according to the mix pattern shown in Table 3. The mix design uses different amounts of copper slag replacements, from 0% to 50%. It is important to note that the cubes were made without any compression. After being prepared, these cubes are water-cured at room temperature for three, seven, and 28 days, and then their compressive strength is tested.

Table 3. Concrete Cubes Compressive strength

Mix trails	Percentage of copper slag	Compressive strength (N/mm^2) 3 Days	Compressive strength (N/mm^2) 7 Days	Compressive strength (N/mm^2) 28 Days
M1	0	10.57	19.55	24.52
M2	10	12.55	17.73	23.66
M3	20	13.29	19.67	27.09
M4	30	12.68	18.84	24.37
M5	40	13.52	20.05	26.44
M6	50	12.71	19.24	26.5

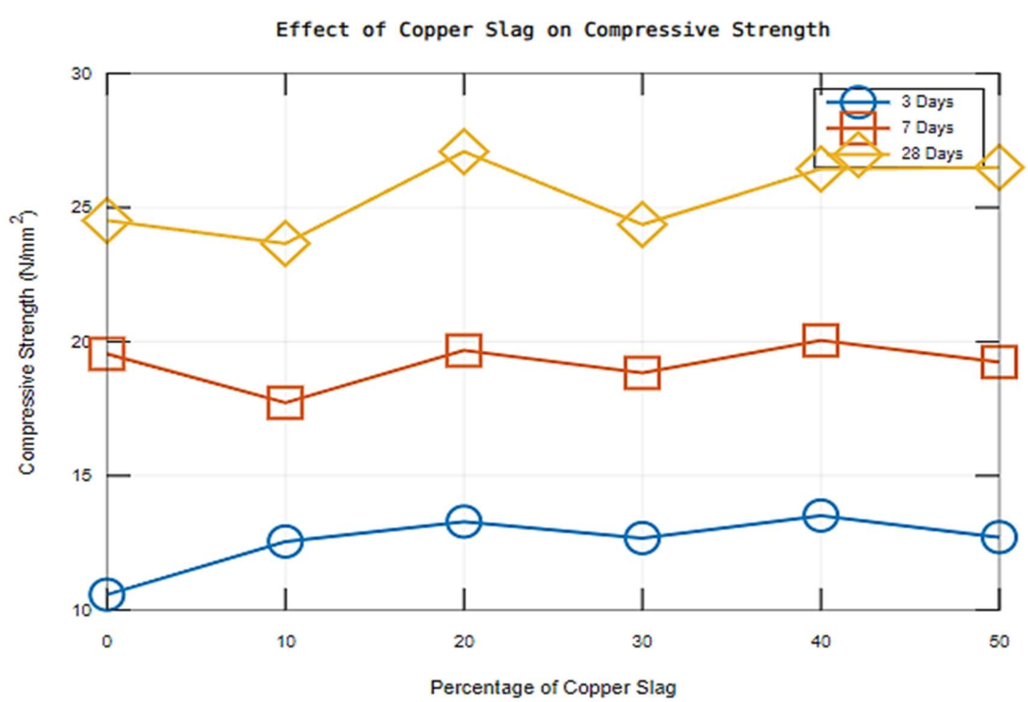

Figure 2. Concrete Cubes Compressive strength

Based on the results presented in Figure 3, an important remark is made about the compressive strength of concrete mixes including different amounts of copper slag over a period of 28 days. The mix with a 20% substitution of copper slag has superior compressive strength in comparison to all other mix variants. This particular composition exhibits a significant enhancement, with a 10.48% increase in compressive strength compared to the mixture without any replacement of copper slag (0% copper slag replacement).

The results indicate that including 20% copper slag as a substitute in the concrete mixture has a beneficial effect on its compressive strength over the 28-day curing period. These insights are essential for optimising the composition of concrete, offering useful information for applications in building and engineering. The noticeable increase in compressive strength underscores the potential advantages of using copper slag in concrete mixes, emphasising its influence on the material's long-term structural performance. These findings provide a significant contribution to the continuous investigation of sustainable and efficient techniques for producing concrete, providing useful information for the building sector.

Conclusion

The detailed examination of SCC mixes with varied amounts of copper slag indicates good workability and compressive strength findings. The addition of 20% copper slag to the mix improves compressive strength substantially, demonstrating a remarkable increase of 10.48% throughout the 28-day curing period when compared to the mix without any copper slag replacement. This discovery highlights the potential benefits of adding copper slag into concrete compositions, which might contribute to more sustainable and efficient construction processes. In the search of eco-friendly concrete solutions, the study further emphasises the necessity of examining not just alternate aggregates but also extra cementitious materials such as Portland Slag Cement, GGBS, and fly ash. Overall, these findings give useful information to the construction sector, encouraging further research into new and ecologically sensitive ways to concrete manufacturing.

References

1. Okamura, H.; Ouchi, M. Self-compacting concrete. J. Adv. Concr. Technol. 2003, 1, 5–15.

2. Concrete, S.-C. The European Guidelines for Self-Compacting Concrete. BIBM 2005, 22, 563.

3. Esfandiari, J.; Loghmani, P. Effect of perlite powder and silica fume on the compressive strength and microstructural characterization of self-compacting concrete with lime-cement binder. Measurement 2019, 147, 106846.

4. Shi, C.; Wu, Z.; Lv, K.; Wu, L. A review on mixture design methods for self-compacting concrete. Constr. Build. Mater. 2015, 84, 387–398.

5. Mohamed, H.A. Effect of fly ash and silica fume on compressive strength of self-compacting concrete under different curing conditions. Ain Shams Eng. J. 2011, 2, 79–86.

6. ACI Concrete Terminology; American Concrete Institute. In Ferrocement. 2013.

7. Khayat, K.H.; De Schutter, G. Mechanical Properties of Self-Compacting Concrete: State-of-the-Art Report of the RILEM TechnicalCommittee 228-MPS on Mechanical Properties of Self-Compacting Concrete; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2014; Volume 14.

8. BS EN 206:2013; Concrete-Specification, Performance, Production and Conformity. The British Standards Institution, BSI Standards Limited: London, UK, 2014.
9. Shi, C.; Wu, Y. Mixture proportioning and properties of self-consolidating lightweight concrete containing glass powder. ACI Mater. J. 2005, 102, 355.
10. Wang, X.; Wang, K.; Taylor, P.; Morcous, G. Assessing particle packing based self-consolidating concrete mix design method. Constr. Build. Mater. 2014, 70, 439–452.
11. Siddique, R.; Aggarwal, P.; Aggarwal, Y. Mechanical and durability properties of self-compacting concrete containing fly ash and bottom ash. J. Sustain. Cem.-Based Mater. 2012, 1, 67–82.
12. Esmaeilkhanian, B.; Khayat, K.H.; Yahia, A.; Feys, D. Effects of mix design parameters and rheological properties on dynamic stability of self-consolidating concrete. Cem. Concr. Compos. 2014, 54, 21–28.
13. Owsiak, Z.; Grzmil, W. The evaluation of the influence of mineral additives on the durability of self-compacting concretes. KSCE J. Civ. Eng. 2015, 19, 1002–1008.
14. Ashish, D.K. Feasibility of waste marble powder in concrete as partial substitution of cement and sand amalgam for sustainable growth. J. Build. Eng. 2018, 15, 236–242.
15. Technical Report No. 74, Cementitious Materials, The Effect of Ggbs, Fly Ash, Silica Fume and Limestone Fines on the Properties of Concrete. 2011. Available online: www.concrete.org.uk (accessed on 11 May 2019).
16. Cement Association of Canada. Sustainable Cement Manufacturing.
17. Rajhans, P.; Panda, S.K.; Nayak, S. Sustainable self compacting concrete from C&D waste by improving the microstructures of concrete ITZ. Constr. Build. Mater. 2018, 163, 557–570.
18. Revilla-Cuesta, V.; Skaf, M.; Faleschini, F.; Manso, J.M.; Ortega-L ó pez, V. Self-compacting concrete manufactured with recycled concrete aggregate: An overview. J. Clean. Prod. 2020, 262, 121362.
19. Rojo-L ó pez, G.; Nunes, S.; Gonz á lez-Fonteboa, B.; Mart í nez-Abella, F. Quaternary blend so Portland cement, metakaolin, biomass ash and granite powder for production of self-compacting concrete. J. Clean. Prod. 2020, 266, 121666.
20. Salih, M.A. Strength and Durability of High Performance Concrete Containing Fly Ash and Micro Silica. Intern. J. Civ. Eng. Technol. (IJCIET) 2018, 9, 104–114.