SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V11I7P103

Volume 11 Issue 7, 28-35, July 2024

Original Article

Strength and Durability Performance of Fibre Reinforced Pavement Quality Concrete with Copper Slag as Fine Aggregate

K. Athiappan[1], Sivaramakrishnan Subbaram[2]

[1]*Department of Civil Engineering, Thiagarajar College of Engineering, Tamil Nadu, India.*
[2]*Department of Civil Engineering, Sri Sairam Engineering College, Tamil Nadu, India.*

[1]*Corresponding Author : athiappan2010@gmail.com*

Received: 07 May 2024 Revised: 06 June 2024 Accepted: 06 July 2024 Published: 31 July 2024

***Abstract** - This research focuses on the use of copper slag as fine aggregate incorporated with steel fibre at a dosage of 0.4% to 1.6% with an increment of 0.4%. The mechanical properties, such as compressive strength, flexural strength and fatigue life, were investigated. The durability parameters such as acid, alkaline, sulphate, chloride resistance and resistance to abrasion and skid were investigated. The results obtained reveal that the concrete with copper slag and steel fibre possesses better mechanical properties, and concrete having copper slag as fine aggregate possesses high durability characteristics. The flexural strength has increased 2 times. A strong relationship between flexural strength and fatigue life was noted.*

***Keywords** - Sustainability, Durability, Concrete, Slag, Fibre, Fatigue.*

1. Introduction

Road construction is essential to the progress of humankind. Building roads encourages movement between locations and fosters tourism, cross-cultural dialogue, and mutual understanding. Road infrastructure connects people and places, promotes economic activity, and facilitates trade and commerce in local communities by making it easier to transport goods and services. In the end, enhanced connectivity makes it possible for people in remote areas to have better access to healthcare, education, and other necessities. On the other hand, there are also important environmental problems such as soil erosion, increasing pollution, biodiversity loss, and habitat fragmentation as well as climate change [1]. The construction of roads was essential to the economy's growth, but it also depletes natural resources, which include crushed stones extracted from rocks and fine aggregate made from river sand found in river beds. [2, 3]. To reduce pollution and clear landfill space, researchers should concentrate on the potential use of industrial waste in road construction. Stone and gravel, two common materials used for the construction of pavements, are naturally occurring resources that require a long time to create [4]. Instead, we may protect these natural resources for future applications by utilizing industrial residues. There are instances where employing industrial waste instead of conventional construction materials will result in lower costs. There is no need to harvest and transport fresh material because the industrial waste is already a result of another operation [5]. The capacity of copper slag to boost compressive and flexural strength up to a particular percentage makes it one of the several industrial wastes that may be used to make pavement-quality concrete [6]. The glassy, smooth texture of copper slag can help concrete mixtures become more workable, simpler to pour, and easier to mould. Copper slag can make concrete denser overall since it has a greater specific gravity than sand. By using copper slag as a substitute, natural sand resources are used less frequently, encouraging sustainable building methods [7].

The use of fibres in concrete has a number of benefits. Fibres reduce the size and propagation of concrete fractures. This is so that water and other chemicals cannot seep in, and the fractures are kept from getting worse. When it comes to tensile strength, FRC is superior to regular concrete. It can, therefore, bear higher pulling pressures without cracking [8]. Additionally, fibres increase the fatigue strength and impact resistance of the concrete. FRC reduces concrete's permeability, which increases its resistance to liquids like water seeping through the surface. This is crucial for buildings that are subjected to corrosive environments or severe weather. FRC may occasionally be a more affordable option than conventional steel reinforcing. This is because it eliminates the need for complex steel bar placement and reduces labor costs [9]. Hence, in this research, the conventional concrete, the fine aggregate, is fully replaced with copper slag and steel fire of dosage 0.4% to 1.6% with

0.4% increment, and the mechanical and durability properties are investigated.

2. Materials

The different concrete specimens required for the research are cast using the OPC 53 grade cement conforming to IS 12269-2013 standard. The conventional fine aggregate and copper slag obtained as residue from the copper industry satisfying the gradation requirement conform to standard IS:383-2016 shown in Figure 1. The coarse aggregate satisfying the physical and gradation requirements according to standard IS: 383-2016 was used. The crimped steel fibre of length 40mm, width 2.5mm and thickness 1mm, as shown in Figure 2 are used in this research.

2.1. Mix Designation

The mix designation used in this research is shown in Table 1. If the Mix ID is C-0.4, C-represents the copper slag as fine aggregate and 0.4 represents the percentage of steel fibre included in the concrete.

Table 1. Mix designations and specifications

S. No.	Mix	Fibre	% of Fibre	Remarks
1	R	Nil	Nil	Conventional Fine Aggregate Used (River Sand)
2	C	Nil	Nil	Copper Slag is Used as Fine Aggregate
3	C-0.4	40mm Length Steel Fibre	0.4	
4	C-0.8		0.8	
5	C-1.2		1.2	
6	C-1.6		1.6	

3. Tests and Methods

3.1. Strength Tests

The compressive strength and flexural strength of the hardened pavement quality concrete were determined according to IS: 516-2021 (Part-1). The concrete cube of size 150mm and prism of size 150mm x 150 mm x 700mm were used to determine compressive and flexural strength, respectively. The fatigue life of the specimen was determined by maintaining a 0.5 stress ratio of haiver sine loading pattern, and the stress-strain and deflection behaviour are shown in Figure 3, maintaining a frequency of 4Htz with centre point loading on the concrete specimen of dimension 10mm x 100mm x 500mm as shown in Figure 4.

3.2. Durability and Skid Resistance Test

The resistance to the acidic and alkaline conditions of copper slag contained concrete was determined by immersing the concrete cube specimen of size 150mm in solution, maintaining a pH value of 1.54 (using HCL for acidic medium) and 12.20 (using $NaHCO_3$ for alkaline medium) respectively for 30 days, the percentage weight and strength loss was determined according to IS: 516-2021 (Part-5). Similarly, sulphate resistance and chloride resistance are determined by immersing the concrete cube specimen in a solution having 5% sodium sulphate and 3 % sodium chloride respectively. The Rapid Chloride-ion Penetration Test (RCPT) using concrete specimens of dimension 10mm diameter and 200m height is shown in Figure 5. In this experiment, the electric current that passes through the concrete specimen after six hours was determined; the higher the charge passes, the higher the permeable and the lower the charge passes, the lower the permeable. This was interpreted according to the ASTM C1202 standard. The charge passed was estimated using Equation (1).

$$q = 900\ (i0+2i30+2i60+2i90+2i120+...+2i300+2i330+I360) \quad (1)$$

Where,

q - Electric charge passed through a single specimen

i0 - Initial electric charge passed after the current supply (coulombs)

It - Electric charge passed after the current applied (voltage)

The resistance to the abrasive action of the copper slag and fibre contained concrete was determined according to BIS 1237-2012. The test set-up is shown in Figure 6(a), and abraded concrete specimens are shown in the figure. The test was performed by casting a concrete cube of size 7.06cm.

The concrete specimen was placed on the abrasive disc, rotated at a speed of 30 rpm, and subjected to 220 revolutions. The 20 grams of abrasive powder was replaced after every 22 revolutions. The reduction in thickness was determined by Equation (2).

$$t = \frac{(w1-w2)}{w1} X \frac{v1}{a} \quad (2)$$

Where,

t- loss in thickness (mm)

w1,w2 - where the w1 and w2 are initial and final weights of the concrete where the w1 and w2 are initial and final weights of the concrete specimen before and after being subjected to abrasive action, respectively, in grams specimen before and after being subjected to abrasive action respectively in grams.

V1- The volume of the concrete specimen before abrasive action (cm^3)

a - Cross-sectional area of the concrete specimen (cm^2)

4. Result and Discussion

4.1. Mechanical Properties

The variations in the compressive strength, flexural strength and fatigue life of pavement quality concrete with various dosages of steel fibre are shown in Figures 7, 8 and 9, respectively. The compressive strength and flexural strength were found to be lower for the concrete mix (Mix C) with copper slag as fine aggregate than the concrete mix (Mix R) with conventional fine aggregate (river sand) due to less water absorption of the cooper slag contributing to excessive water content in the concrete mix which leads to bleeding and segregation. It was noted that with the inclusion of steel fibre upto the dosage of 0.8%, the compressive strength, flexural strength and fatigue life were found to increase; it was due to the copper slag and steel fibre combined together exhibiting a synergistic effect [10, 11]. In addition the pozzolonic reaction of copper slag tends to improve the performance by having better bonding with the steel fibre.

The combined effect of the steel fibre and copper slag tends to produce denser and more durable concrete, thus increasing the compressive strength, flexural strength and fatigue life [12, 13, 14]. It was also noted that, beyond 0.8% dosage of steel fibre, the compressive strength, flexural strength and fatigue life were found to be decreasing; the impedance of hydration processes, agglomeration causing localized stress, increased porosity and non-uniform distribution of fibre at the higher dosage of steel fibre were noticed [15, 16, 17].

The flexural strength and fatigue life of concrete were found to increase to a greater extent upto 0.8% dosage of steel fibre due to the fibre acting as a crack resistant by reducing the crack formation and delaying the crack initiation and propagation of the crack, especially during fatigue loading, improved ductility as the concrete specimen tends to deform before failure, improved toughness, reduced crack width and high resistance to the micro crack formation were noticed [18]. It was noted from Figures 10 and 11 that the compressive strength and fatigue life have a strong relationship with flexural strength due to the uniform distribution of steel fibre in concrete reducing the localized stress concentration, which reduces the fatigue failure initiation sites and the flexural strength of fibre reinforced concrete tends to remain consistent under fatigue loading leads to have a linear relationship with fatigue life and compressive strength of fibre reinforced concrete. This sentence is too long and the meaning is not clear. Break it up into smaller sentences [19, 20]. It was also noted that the flexural strength and compressive strength fall below the minimum requirement of 4.5N/mm2 and 40 N/mm2, respectively, beyond 1.2% dosage of steel fibre.

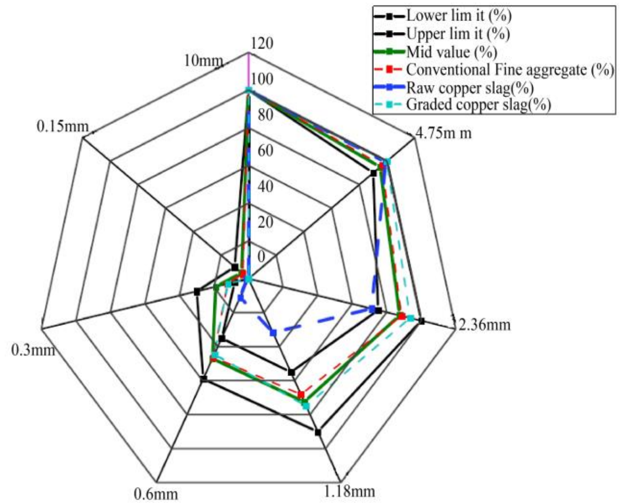


Fig. 1 Gradation of conventional fine aggregate and copper slag according to IS 383; 2016

Fig. 2 Steel fibre

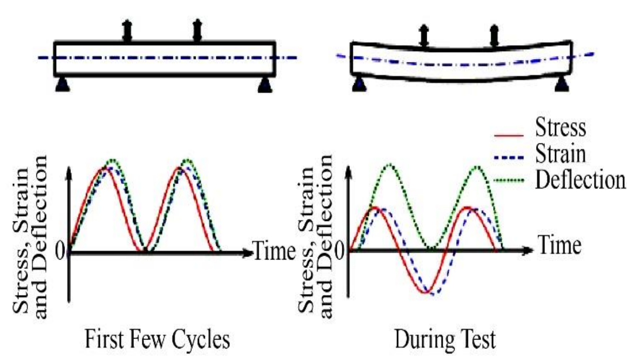


Fig. 3 Stress-strain and deflection behavior of Haver sine controlled fatigue test

(Source; Pronk, 2010)

Fig. 4 Concrete specimen subjected to fatigue loading

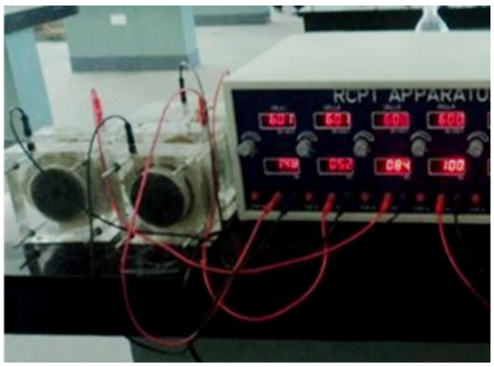


Fig. 5 RCPT test-up

Fig. 6(a) Abrasive resistance test set-up

Fig. 6(b) Concrete specimen subjected to abrasive test

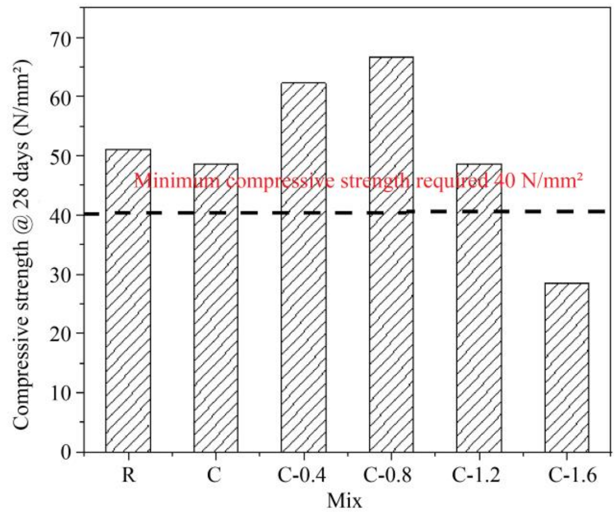


Fig. 7 Variation of compressive strength with 40mm steel fibre for various dosages

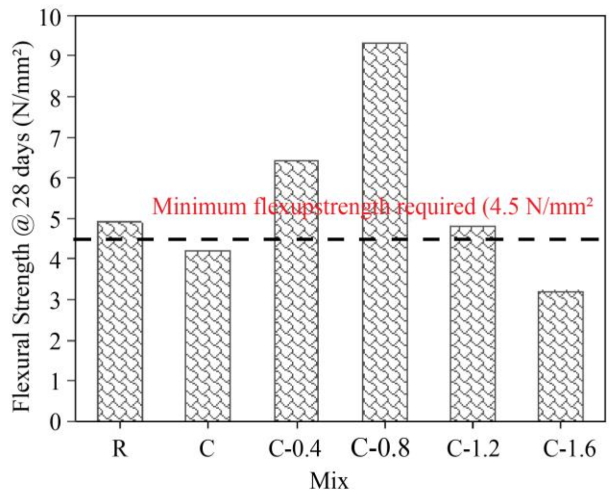


Fig. 8 Variation of flexural strength with 40mm steel fibre for various dosages

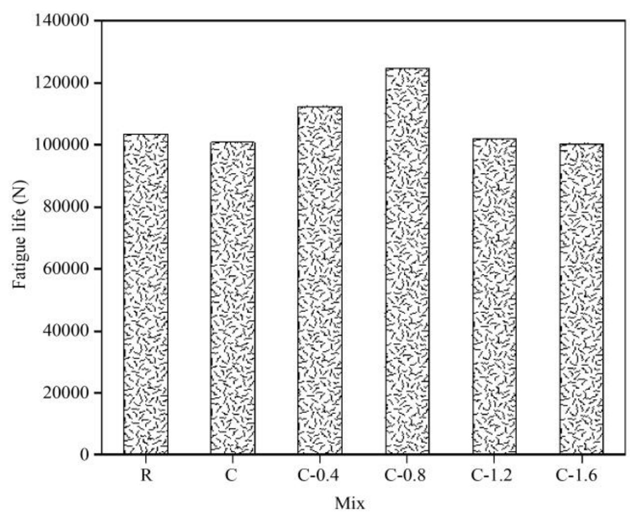


Fig. 9 Variation of fatigue life with 40mm steel fibre for various dosages

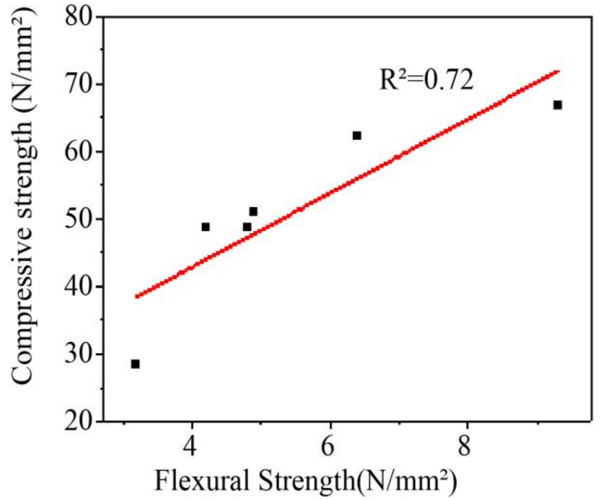


Fig. 10 Relation between flexural strength and compressive strength

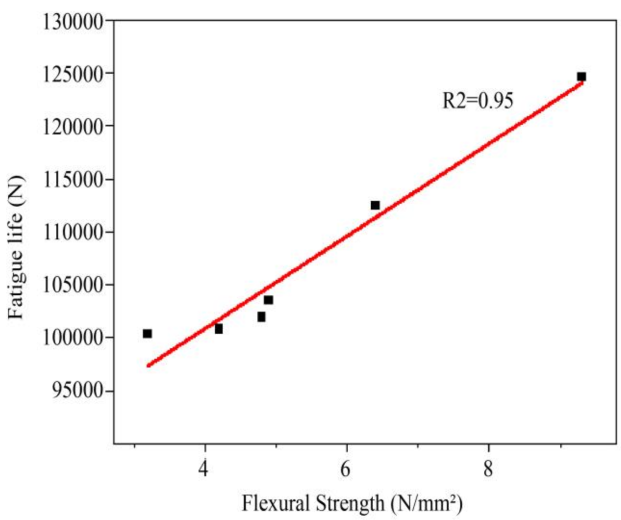


Fig. 11 Relation between flexural strength and fatigue life

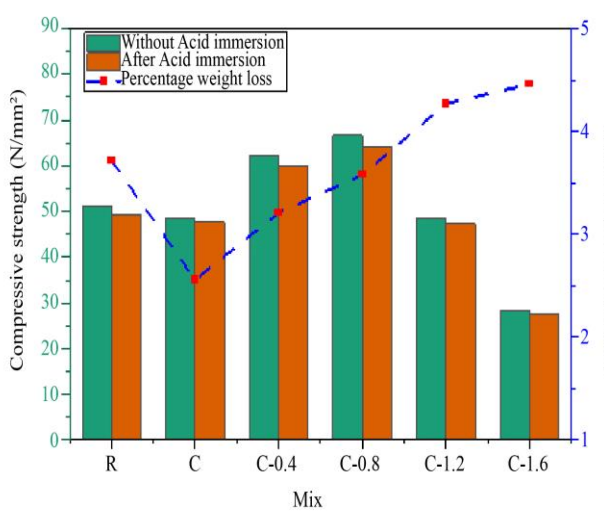


Fig. 12 Percentage of weight loss and reduction in compressive strength of specimen subjected to acid environment

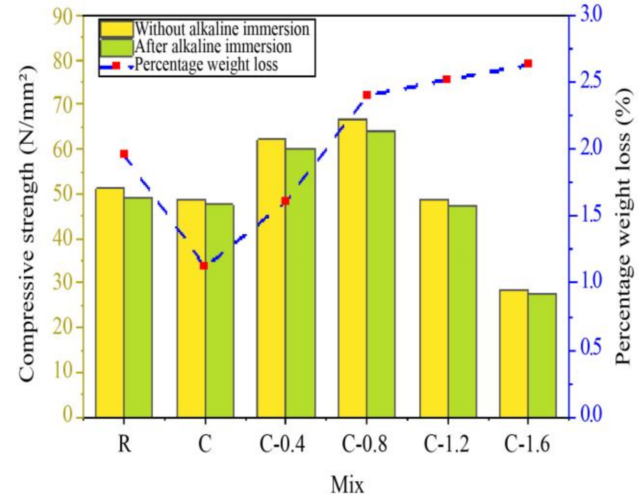


Fig. 13 Percentage of weight loss and reduction in compressive strength of specimen subjected to the alkaline environment

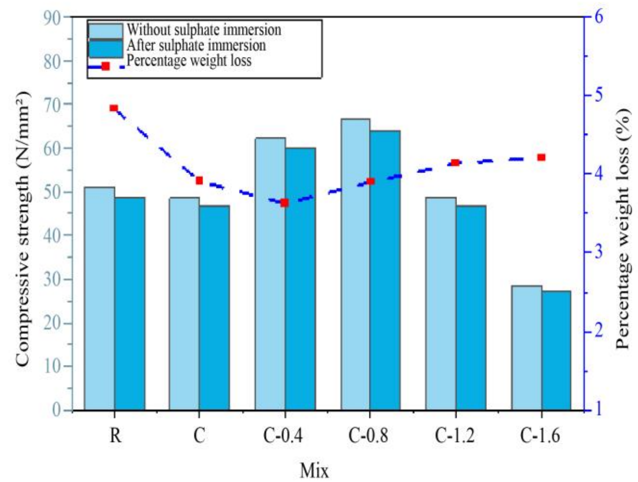


Fig. 14 Percentage of weight loss and reduction in compressive strength of specimen subjected to sulphate environment

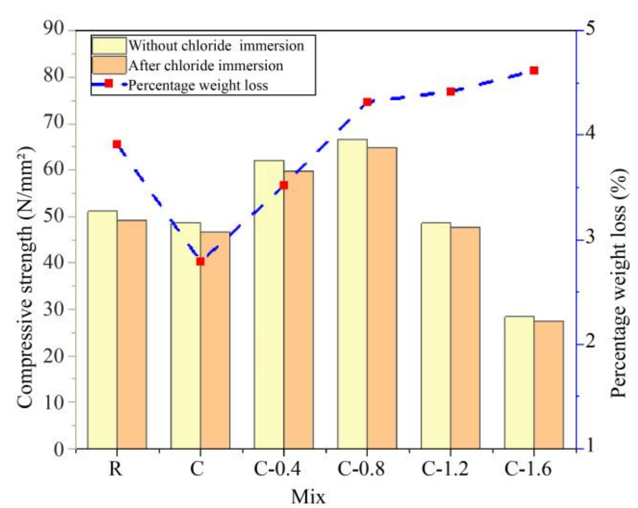
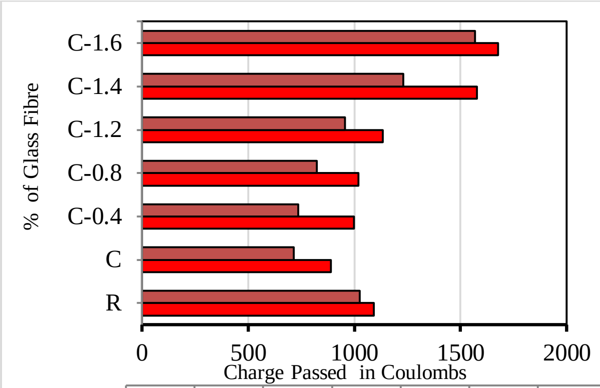


Fig. 15 Percentage weight loss and reduction in compressive strength of specimen subjected to sulphate environment



	R	C	C-0.4	C-0.8	C-1.2	C-1.4	C-1.6
56th days	1026	715	737	823	956	1231	1567
28th day	1090	889	998	1020	1134	1578	1678

Fig. 16 Variation of charge passed through different concrete mixes (columbs)

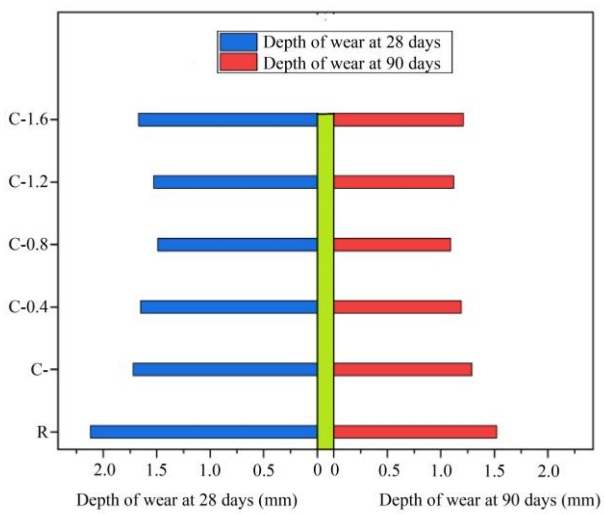


Fig. 17 Variation of wear depth of different concrete mixes

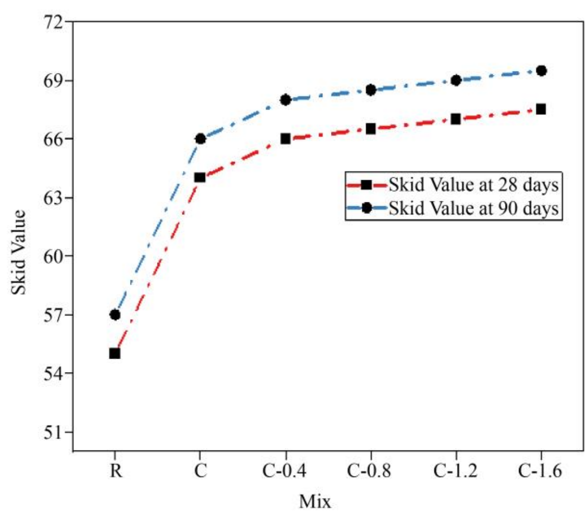


Fig. 18 Variation of skid value for different concrete mixes

4.2. Durability on Different Exposure Conditions

The variation in compressive strength and corresponding weight loss of the concrete specimen subjected to the acid and alkaline environments is shown in Figures 12 and 13. The results obtained show that the maximum reduction in compressive strength and weight loss for the acid condition of copper slag contained specimen was found to be 3.75% and 0.34%, respectively. Similarly, under alkaline conditions, the maximum reduction in compressive strength and weight loss was found to be 2.39% and 0.23%, respectively.

The reduction in compressive strength and corresponding weight loss of the concrete specimen subjected to sulphate and chloride environments is shown in Figures 14 and 15. It was noted that the maximum compressive strength reduction and weight loss in the sulphate environment for the copper slag contained concrete specimen were 4.21% and 0.40%, respectively.

Similarly, in the chloride condition, the maximum reduction in compressive strength and weight loss was found to be 3.76 % and 1.26 %, respectively. The reduction in compressive strength and weight loss for all the above conditions was found to be very low and negligible, and it was due to the inert property of copper slag, which used as a fine aggregate will not react with alkaline, acid, sulphate and chloride ions present in the environment, thus maintaining stability and integrity of the concrete [21].

Further, the density of the copper slag concrete increased due to the formation of additional Calcium Silicate Hydrates (C-S-H) due to the chemical reaction between the calcium hydroxide and copper slag [22]. The results of the RCPT test are shown in Figure 16.

The result obtained shows that, the concrete contained copper slag is highly impermeable when compared to the conventional concrete having river sand as fine aggregate. However, with the inclusion of fibre, the impermeable characteristics are slightly reduced after both the 28 days and 56 days curing. However, the 56 days cured concrete samples are highly impermeable due to the increase in the density of concrete.

4.3. Abrasive and Skid Resistance

The interaction between the tyre of the vehicle and the road surface induces abrasive action and causes high wear and tear on the concrete road surface. Hence, the concrete used for the construction of a rigid pavement should have enough resistance to the abrasive action. Similarly, the surface of the concrete pavement should have enough skid resistance to avoid accidents due to skidding of the vehicle, which is most common on the road. The test results of the abrasion and skid resistance are shown in Figures 17 and 18. It was noted that the concretes having copper slag as fine aggregate are found to be sand) after both 28 days and 90 days of curing. Similarly, the copper slag contained concrete has a high skid resistance value.

5. Limitations of the Study

In this research, the laboratory investigation alone is done for steel fibre of a single length. The stress-strain behavior on fatigue loading, rutting resistance, performance under different axle loadings and field validation were not investigated.

6. Scope of the Research

The above research can be extended to different dynamic axle loads and impact loading. The use of different types of fibres, such as glass, polypropylene, carbon fibre, etc., and other industrial waste, such as steel slag, ground granulated blast furnace slag, tile waste, marble waste, etc., could also be investigated.

7. Conclusion

The following conclusion was drawn from the experimental research:

- The flexural strength fatigue and fatigue life of concrete was found to increase to a greater extent upto 0.8% dosage of steel fibre due to the fibre's crack resistance.
- The maximum reduction in compressive strength and weight loss for the acid, alkaline, sulphate and chloride environments of copper slag contained specimen was found to be negligible.
- The concrete having copper slag as fine aggregate is found to have high resistance to abrasive action when compared to the concrete with conventional fine aggregate (river sand) after both 28 days and 90 days of curing. Similarly, the copper slag contained concrete has a high skid resistance value.

References

[1] Jawad Ahmad et al., "Performance of Concrete Reinforced with Jute Fibers (Natural Fibers): A Review," *Journal of Engineered Fibers and Fabrics*, vol. 17, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[2] Jawad Ahmad, Zhiguang Zhou, and Ahmed Farouk Deifalla, "Steel Fiber Reinforced Self-Compacting Concrete: A Comprehensive Review," *International Journal of Concrete Structures and Materials*, vol. 17, no. 1, pp. 1-22, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[3] Muhammad Anas et al., "Fiber Reinforced Concrete: A Review," *Engineering Proceedings*, vol. 22, no. 1, pp. 1-7, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[4] Le Hung Anh et al., "Life Cycle Assessment of River Sand and Aggregates Alternatives in Concrete," *Materials*, vol. 16, no. 5, pp. 1-19, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[5] Hadi Bolooki Poorsaheli, Amir Behravan, and Seyed Taha Tabatabaei Aghda, "Durability Performance of Hybrid Reinforced Concretes (Steel Fiber + Polyolefin Fiber) in a Harsh Marine Tidal Zone of Persian Gulf," *Construction and Building Materials*, vol. 266, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[6] Brajesh Mishra, and Ravi Shanker Mishra, "A Study on Use of Industrial Wastes in Rural Road Construction," *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 4, no. 11, pp. 10387-10398, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[7] Bypaneni Krishna Chaitanya, and Ilango Siva Kumar, "Effect of Waste Copper Slag as a Substitute in Cement and Concrete-A Review," *IOP Conference Series: Earth and Environmental Science*, vol. 982, no. 1, pp. 1-11, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[8] Primož Jeluši˘c et al., "Potential of Using Waste Materials in Flexible Pavement Structures Identified by Optimization Design Approach," *Sustainability*, vol. 15, no. 17, pp. 1-19, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[9] Ashfaque Ahmed Jhatial et al., "Effect of Steel Fibres on the Compressive and Flexural Strength of Concrete," *International Journal of Advanced and Applied Sciences*, vol. 5, no. 10, pp. 16-21, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[10] Linwei Li et al., "Fatigue Behaviors of Graphene Reinforcing Concrete Composites under Compression," *International Journal of Fatigue*, vol. 151, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[11] X.M Li et al., "Preparation and Mechanical Properties of Steel Fiber Reinforced High Performance Concrete with Copper Slag as Fine Aggregate," *IOP Conference Series: Materials Science and Engineering*, vol. 531, no. 1, pp. 1-9, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[12] Gulnara Mamirkulova et al., "New Silk Road Infrastructure Opportunities in Developing Tourism Environment for Residents Better Quality of Life," *Global Ecology and Conservation*, vol. 24, pp. 1-19, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[13] Sounthararajan Vallarasu Manoharan, and Sivakumar Anandan, "Steel Fibre Reinforcing Characteristics on the Size Reduction of Fly Ash Based Concrete," *Advances in Civil Engineering*, pp. 1-11, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[14] Maria Mavroulidou, "Mechanical Properties and Durability of Concrete with Water Cooled Copper Slag Aggregate," *Waste and Biomass Valorization*, vol. 8, no. 5, pp. 1841-1854, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[15] M.I. Abdul Aleem, and P.D. Arumairaj, "Geopolymer and Conventional Concrete : A Review," *International Journal of Engineering Sciences & Emerging Technologies*, vol. 1, no. 2, pp. 118-122, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[16] Ravindranatha, Ashwin Shenoy, and Sidharth, "Exploring Flexural Strength in High-Performance Concrete with Iron Slag and Copper Slag as Sand Substitutes," *Engineering Proceedings*, vol. 59, no. 1, pp. 1-9, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[17] Nacira Saoudi, and Boudjema Bezzazi, "Flexural Fatigue Failure of Concrete Reinforced with Smooth and Mixing Hooked-End Steel Fibers," *Cogent Engineering*, vol. 6, no. 1, pp. 1-17, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[18] S. Sebastin, "Combined Effect of Copper Slag and Hybrid Fiber on Compressive Strength in High Strength Concrete," *International Journal of Advance Civil Engineering and Technology*, vol. 6, no. 1, pp. 27-64, 2021. [Google Scholar]

[19] Yasser Sharifi et al., "Effect of Copper Slag on the Resistance Characteristics of SCC Exposed to the Acidic Environment," *Asian Journal of Civil Engineering*, vol. 21, pp. 597-609, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[20] K. Shyam Prakash, and Ch. Hanumantha Rao, "Study on Compressive Strength of Quarry Dust as Fine Aggregate in Concrete," *Advances in Civil Engineering*, pp. 1-5, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[21] Jun Zhang, Henrik Stang, and Victor C. Li, "Fatigue Life Prediction of Fiber Reinforced Concrete under Flexural Load," *International Journal of Fatigue*, vol. 21, no. 10, pp. 1033-1049, 1999. [CrossRef] [Google Scholar] [Publisher Link]

[22] Lu Zhang et al., "Mechanical Properties and Chloride Penetration Resistance of Copper Slag Aggregate Concrete," *Fractal and Fractional*, vol. 6, no. 8, pp. 1-19, 2022. [CrossRef] [Google Scholar] [Publisher Link]