USE OF STEEL FIBER AND COPPER SLAG IN CONCRETE PAVEMENT

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Abstract : *This study explores the utilization of steel fiber as a reinforcement material in concrete pavement construction. The investigation delves into the mechanical and structural properties of steel fiber-reinforced concrete (SFRC) and its impact on the performance of pavement structures. Various proportions of steel fibers are incorporated into the concrete mix, and the resulting mixtures are subjected to comprehensive testing, including compressive strength, flexural strength, and fatigue resistance. The study aims to assess the potential enhancement in the durability and load-bearing capacity of concrete pavements through the incorporation of steel fibers.*

The findings indicate that the addition of steel fibers contributes to increased tensile strength and crack resistance, addressing common issues such as reflective cracking and fatigue failure in concrete pavements. Moreover, the study investigates the economic viability and sustainability aspects associated with the use of steel fiber in concrete pavements, considering its influence on lifecycle costs and environmental impact. The outcomes provide valuable insights for engineers and practitioners seeking optimized solutions for durable and resilient concrete pavement construction.

Keywords: *Steel fibers, Concrete pavement, Reinforcement, Mechanical Properties, Durability,Structural Performance, Compressive strength, Flexural Strength,Fatigue resistance, Reflective Cracking,Sustainability.*

I. INTRODUCTION

In the realm of modern civil engineering, the quest for innovative materials and techniques to enhance the performance and longevity of infrastructure is incessant. Concrete, being a fundamental construction material, often faces challenges related to cracking, spalling, and reduced durability, particularly in high-traffic and dynamic load environments. The utilization of steel fiber as a reinforcing component in concrete pavements emerges as a promising solution to mitigate these challenges and elevate the overall structural integrity. This study focuses on the integration of steel fiber into concrete pavement, a practice known as Steel Fiber-Reinforced Concrete (SFRC), with a primary objective to augment the mechanical properties and structural performance of traditional concrete pavements. Steel fibers, owing to their high tensile strength and ductility, exhibit the potential to act as an effective reinforcement material, addressing critical issues such as reflective cracking and fatigue failure commonly encountered in pavements. The introduction of steel fibers into the concrete mix alters the material's behavior, significantly enhancing its ability to withstand tensile stresses and resist crack propagation. This study systematically investigates varying proportions of steel fibers to comprehensively analyze their influence on key parameters, including compressive strength, flexural strength, and resistance to fatigue loading. Understanding these mechanical properties is crucial for determining the effectiveness of SFRC in real-world pavement applications. Beyond the mechanical aspects, this research extends its inquiry to consider economic and environmental dimensions associated with the implementation of steel fiber in concrete pavements. A detailed analysis of lifecycle costs and sustainability factors provides a holistic perspective, allowing for informed decision-making in the selection of construction materials and techniques. As the world grapples with the challenges of aging infrastructure and increasing demands on transportation networks, the findings of this study hold the promise of contributing not only to the optimization of concrete pavement design but also to the broader discourse on sustainable and resilient infrastructure development. The integration of steel fiber in concrete pavements stands poised as a transformative approach, reflecting the ongoing commitment to advancing the field of civil engineering for safer, more durable, and environmentally conscious infrastructure.

Objective:

This study, which is based on a thorough examination of existing literature, aims at addressing the following critical objectives. The primary goal of this research is to investigate the impact of integrating crimp steel fibres into pavement-quality concrete (PQC) that uses copper slag as a feasible substitute for fine aggregate. Furthermore, the overriding goal of this study is to assess the feasibility of using such mixed concrete in the building of stiff pavements. The key goals of this empirical inquiry can be summarized as follows:

1. Formulation of Optimal Mix Proportions: The primary goal is to meticulously determine the best mix ratio for pavement quality concrete, in which copper slag is seamlessly integrated as a fine aggregate substitute and strengthened with corrugated steel fibres. To achieve strength qualities similar to those of traditional concrete, this combination requires meticulous refining.

2.Analysis of Workability and Mechanical Properties: The secondary goal is to conduct a thorough analysis of the effect of crimped steel fibre dose and length on the workability and mechanical properties of PQC containing copper slag and steel fibres.

3. Thorough Durability Assessment: The third goal is a comprehensive examination of the effects of crimped steel fibre dose and length on the durability of PQC, with a comparison of these results to ordinary concrete.

4. Performance Evaluation: The fourth goal is to compare the performance of PQC slab panels under static and cyclic loadings to determine their structural integrity and resilience.

5. Determination of appropriate Fiber Dosage and Length: The ultimate goal is determining the appropriate dosage and length of crimped steel fibres, improving PQC characteristics and performance. This project is intended to support the progress of strong pavement-building techniques.

Schroeder (1994) emphasized the significant potential inherent in the use of large quantities of industrial waste and by-products in highway construction. The author painstakingly compiled a thorough inventory of fifteen waste materials that have been used in the development of highways and embankments, both historically and more recently.

Dawson et al. (1995) undertook a thorough assessment of the acceptability of industrial by-products created expressly for pavement building in the United Kingdom. This evaluation included the use of crushed rock and aggregate materials such as sand and gravel.

In a study conducted by Swamy and Das (2012), a significant emphasis was made on the use of diverse waste materials in highway construction. These resources included building debris, waste glass, fly ash, slag, colliery spoil, kiln dust, and foundry sand, indicating that they may be used in highway construction procedures.

II. MATERIALS USED

2.1 Cement

Cement assumes an important function as the main binding agent in concrete, putting significant control over its ability to hold together. In this inquiry, it was decided to use nearby regular Portland cement that met the stringent standards specified in IS 12269-1987. The tests included essential characteristics such as standard consistency, specific gravity, start and final setting times, fineness, soundness, and compressive strength, which were all methodically carried out in compliance with IS 4031-1988.

The physical and chemical properties of the cement used in this study were meticulously assessed, and the results were rigorously compared to the tough specifications given in IS 12269-1987. The results of these comparative investigations are summarized in Tables 2.11 and 2.12. These tables are used to determine the extent to which the cement adheres to the established criteria, providing information on its compliance with the requirements specified.

Sl.No.	Typesof Tests	Value	IS12269-1987 Requirements
1	Fineness(m^2/kg)	265	>225
2	SpecificGravity	3.12	-
3	StandardConsistency(%)	31	-
4	Soundness(mm)	4	<10
5	InitialSettingTime (min)	48	>30
6	FinalSettingTime(min)	386	<600
7	CompressiveStrengthat 3days(MPa)	39.3	>37
8	CompressiveStrengthat 7days(MPa)	46	<37
9	CompressiveStrengthat 28days(MPa)	59.4	>53

Table2.11PhysicalPropertiesofCement

Sl.No.	Compound	Composition (%)	IS12269-1987 Requirements
1	CalciumOxide(CaO)	61.60	-
2	SiliconDioxide (SiO_2)	22.40	-
3	AluminiumOxide (Al_2O_3)	5.20	-
4	FerricOxide (Fe_2O_3)	3.80	-
5	SulphurTrioxide (SO_3)	2.36	-
6	MagnesiumOxide(MgO)	1.70	<6
7	PottasiumOxide(K_2O)	0.66	-
8	SodiumOxide(Na_2O)	0.48	-
9	Losson Ignition	1.44	<4
10	InsolubleResidue	0.4	<3

Table2.12 ChemicalPropertiesofCement

2.2 Conventional Fine Aggregates:

Within the scope of this inquiry, conventional fine aggregate was procured from locally accessible river sand while adhering to the specifications outlined in IS 383-1970. To confirm the fine aggregate's appropriateness for the study, a rigorous cleaning process involving rigorous cleaning and filtering of the river sand was carried out. This procedure is intended to remove any harmful chemicals found within

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the recovered aggregates.

The physical parameters of the fine aggregates produced as a result of this intensive preparation regimen are detailed in Table 2.21. This tabular data provides an in-depth depiction of the characteristics of these fine aggregates, providing vital insights regarding their suitability for use in the study.

Sl.No.	Properties	Value
1	SpecificGravity	2.60
2	FinenessModulus	2.71
3	WaterAbsorption(%)	0.64
4	BulkDensity(g/cc)	1.47
5	ParticleShape	Smooth

Table2.21 Propertiesof FineAggregates

2.3 CopperSlag(asFineAggregate):

Copper slag, a byproduct of the complex smelting and refining processes required for copper production, was obtained for this study from Sterlite Industries, a significant copper manufacturing firm in Tamil Nadu. This source supplied a consistent and substantial stock of copper slag material.

The careful presentation of the physical and chemical features of the copper slag used in this study provides a comprehensive clarification of its qualities. Tables 2.31 and 2.32 carefully outline the complexities of these properties, providing a comprehensive grasp of the features as well as the composition of the copper slag under consideration.

Sl.No.	Properties	Description/Value
1	ParticleShape	Irregular
2	Appearance	Black&Glassy
3	Type	AirCooled
4	SpecificGravity	3.91
5	PercentageofVoids	43.20 %
6	Bulk Density	2.08g/cc
7	FinenessModulus	3.47
8	AngleofInternalFriction	51°20‘
9	Hardness	6-7mhos

10	WaterAbsorption	0.3 – 0.4 %
11	MoistureContent	0.10 %
12	Fineness	125 m^2/kg

Table2.31 PhysicalPropertiesofCopperSlag

Sl.No.	ChemicalCompound	Composition
1	SiO_2	25.84 %
2	Fe_2O_3	68.29 %
3	Al_2O_3	0.22 %
4	CaO	0.15 %
5	Na_2O	0.58 %
6	K_2O	0.23 %
7	LoI	6.59 %
8	Mn_2O_3	0.22 %
9	TiO_2	0.41 %
10	SO_3	0.11 %
11	CuO	1.2 %
12	SulphideSulphur	0.25 %
13	InsolubleResidue	14.88 %
14	Chloride	0.018 %

Table2.32 ChemicalPropertiesofCopperSlag

2.4 CoarseAggregates:

The coarse aggregates used in this experiment were obtained from local vendors and were 20 mm in size, complying with the rigorous criteria given in IS 383-1970. A set of stringent test procedures were carried out in strict accordance with the techniques outlined in IS 383-1970 and IS 2386-1936 (Part 3), to determine the acceptability of these aggregates for the study. Table 2.41 describes in detail the resulting physical features of these coarse aggregates. This tabular dataset provides a detailed exposition of the features inherent in these coarse aggregates, allowing for a thorough understanding of their characteristics and suitability for inclusion in the study.

S.No.	Property	TestResult	Requirement*
1	SpecificGravity	2.76	-
2	WaterAbsorption(%)	0.7	<2%
3	Deleteriousmaterial(%byvolume)	Nil	<5%
4	BulkDensity(kg/m^3)	1890	-
5	AggregateCrushingValue(%)	22.6	-
6	AggregateImpactValue(%)	14.9	-
7	LosAngelesAbrasionValue(%)	18.3	<35%
8	FlakinessIndex (%)	9	Combined<35 %
9	ElongationIndex(%)	12	

*asperMORTH(India)specifications

Table2.41 PhysicalpropertiesofCoarseAggregate

2.5 Water

Water is essential in concrete because it contributes to the development of hydration products when coupled with cement. It is commonly known that too much water in a concrete mix reduces its overall strength. A water-to-binder ratio of 0.4 was used in our study, and the required workability was accomplished with the help of a superplasticizer. For this experiment, potable drinking water was used.

IS 3025 (Part 17)-1984, IS 3025 (Part 24)-1986, IS 3025 (Part 32)-1988, and IS 4506-2000 were used to examine the fundamental qualities of the water used. The results, shown in Table 2.51, provide critical insights into the water's quality, confirming its appropriateness for inclusion in the study.

S.No.	Properties	Values	PermissibleValues
1	pHvalue	7.61	6-8
2	Chloride	125 ppm	0to 2000 ppm forPCC 0to 500 ppm forRCC
3	Sulphates	110 ppm	0 to 400 ppm
4	TDS	890 ppm	0 to 2000 ppm

Table2.51 PropertiesofWater

2.6 Superplasticizer

Superplasticizers are critical in managing increased water demand in concrete mixtures. They achieve this by increasing fluidity and minimizing the need for extra water. As a result, it is easier to create a homogeneous mix with the appropriate workability.

To achieve the required workability in the concrete, we used a naphthalene-based superplasticizer that complied with IS 9103-1999. The superplasticizer volume was set at 0.6% by weight of the cement content.

Table 2.61 summarizes the key aspects of the superplasticizer used in our work, providing useful insights into its properties and applicability for research objectives.

S.No	Properties	Specifications
1	Type	Sulphonatednaphthaleneformaldehyde (Conplast SP430)
2	Colour	Brown
3	SpecificGravity	1.22at 30°
4	RecommendedDosage	0.6to1.5 %ofweight of cement
5	CompressiveStrength	EarlyStrength up to 40-50 %
6	ChlorideContent	NilasperIS456-2000
7	SolidContent	40 %

Table2.61 PropertiesofSuper-plasticizers

2.7 Fibers

Corrugated steel fibres with varied aspect ratios were used in this investigation, which was obtained from Jeetmul Jaichandl Pvt. Ltd. in India. These steel fibres have a tensile strength of 1100 MPa, according to the manufacturer. Steel fibres with lengths of 30mm and 50mm, widths of 2.5mm, and thicknesses of 1mm were used specifically. The study also looked at different fibre doses to see how they affected the fresh and hardened qualities of concrete. Fibre proportions of 0.5%, 1.0%, 1.5%, and 2.0% of the concrete's volume were chosen. These fibres were evenly dispersed after being homogeneously mixed into the concrete.

Table 2.71 provides a succinct review of the steel fibres' properties, providing critical information regarding their properties. Figure 2.72 shows a graphic representation of these steel filaments.

FibreProperties	**Value**
Material	100%steel
Type	Crimped
Fibrelengths(mm)	30, 50
FilamentDiameter(mm)	1
Aspectratio	30, 50
TensileStrength (MPa)	1100
SpecificGravity	7.85

Table2.71 PropertiesofSteelFibre

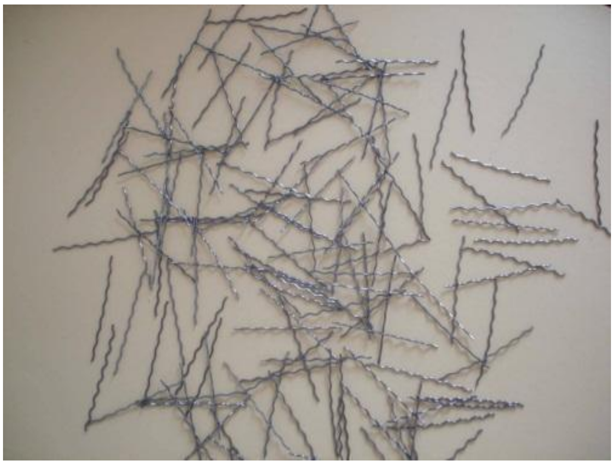

Figure2.72 SteelFibers

III. RESULTSANDDISCUSSIONS

A battery of tests was used to thoroughly examine the mechanical properties of concrete specimens reinforced with steel fibres and integrating copper slag as fine aggregate. The results of these trials revealed a clear pattern: concrete examples with 1.0% steel fibres demonstrated higher strength when compared to other fibre proportions. This observation was held after 7 days and 28 days of healing.

Please use Table 3.1 for a more detailed breakdown of specimen specifications relevant to concrete specimen testing.

Sl. No.	Specimen ID	Length of steel fibres(mm)	Volumeof steel fibres(%)	Remarks
1	MR-0	Nofibres	-	Controlspecimenwithconventionalsandasfineaggregates
2	MC-0	Nofibres	-	
3	MC30-0.5		0.5	
4	MC30-1.0		1.0	
5	MC30-1.5		1.5	
6	MC30-2.0	30	2.0	
7	MC50-0.5		0.5	
8	MC50-1.0		1.0	Concrete specimens withcrimped steel fibres andgraded copper slag as fineaggregates
9	MC50-1.5		1.5	
10	MC50-2.0	50	2.0	

Table3.1Specimendescriptionsfortestonconcretespecimens

The test procedures were precisely to the specifications given in IS 516 - 1959 (reaffirmed in 1999). This scientific inquiry used standard concrete cubes of 150 x 150 x 150 mm. Each test batch had three cubes, for a total of 60 cubes. The average of these measures served as the foundation for further investigation.

Table 3.2 provides a complete review of the compressive strength values for steel fiber-reinforced concrete. Furthermore, Figures 4.5 and 4.6 show the compressive strength of 30mm and 50mm steel fibre-reinforced concrete cubes after 7 days and 28 days of water curing, respectively.

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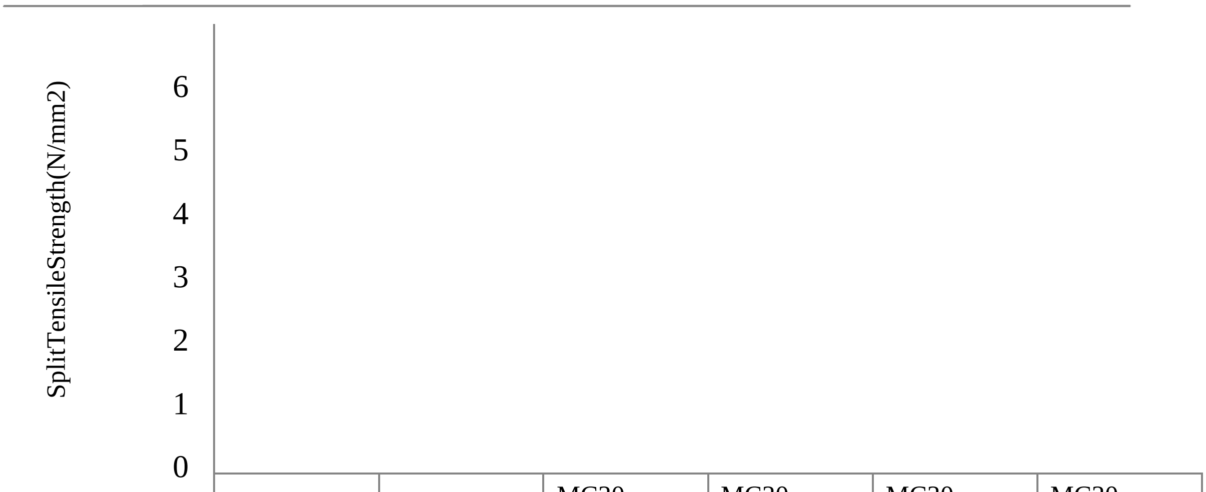
Sl.No.	ID	Compressivestrength(N/mm^2)			
		7days		28days	
	Fibrelength(mm)	30	50	30	50
1	MR	34.1		51.1	
2	MC	33.0		48.6	
3	MC30-0.5andMC50-0.5	41.8	35.6	62.2	53.8
4	MC30-1.0andMC50-1.0	44.2	37.3	66.7	55.9
5	MC30-1.5andMC50-1.5	32.1	33.6	48.6	50.1
6	MC30-2.0andMC50-2.0	19.1	19.5	28.4	29.2

Table 3.2 Compressive Strength of steel fiber reinforced concrete cubes after 7 days and 28 days water curing

Pavements are subjected to tensile forces that include both tension and compression as a result of temperature-induced expansion and contraction. Pavements must therefore be able to withstand these tensile forces adequately.

The testing technique followed the IS: 5816 - 1999 standard and the split tensile strength was assessed using standard test cylinders of 300 mm in length and 150 mm in diameter. Figures 3.3 and 3.4 show a graphical representation of the split tensile strength of 30mm and 50mm steel fibre-reinforced concrete cylinders after 7 and 28 days of water curing, respectively.



	MR	MC	MC30-0.5andMC50-0.5	MC30-1.0andMC50-1.0	MC30-1.5andMC50-1.5	MC30-2.0andMC50-2.0
7days	3.5	3.4	3.6	3.7	3.5	2.6
28days	4.2	3.9	5.4	6.3	5.1	3.2

Figure3.3 SplitTensileStrengthof30mmsteelfiberreinforcedconcretecylindersafter7daysand28dayswatercuring

Figure3.4 SplitTensileStrengthof50 mmsteelFibrereinforcedconcretecylinders after7 days and28dayswatercuring

Table 3.5 displays data on the flexural strength of steel fiber-reinforced concrete prisms after 7 and 28 days of water cure. The experimental approach corresponded completely to the IS: 516 - 1959 requirements, as updated in 1999. The evaluation made use of conventional plain concrete prisms measuring 150 x 150 x 700 mm. A total of 60 prisms were tested in this study, with three prisms tested under each circumstance. The resulting average values were used for further analysis.

Sl.No.	ID	Flexuralstrength(N/mm^2)			
		7days		28days	
	Fibrelength(mm)	30	50	30	50
1	MR	3.9		4.9	
2	MC	3.7		4.2	
3	MC30-0.5andMC50-0.5	4.3	4.0	6.4	5.6
4	MC30-1.0andMC50-1.0	4.4	4.1	9.3	6.6
5	MC30-1.5andMC50-1.5	3.7	3.9	4.8	5.2
6	MC30-2.0andMC50-2.0	2.9	3.0	3.2	3.4

Figure3.5 FlexuralStrengthofsteelfiberreinforcedconcreteprismsafter7daysand28dayswatercuring

The binding strength of steel fiber-reinforced concrete cubes was evaluated after 7 and 28 days of water cure. Table 3.6 provides a full summary of these findings.

Sl.No.	ID	Bondstrength(N/mm^2)			
		7days		28days	
	Fibrelength(mm)	30	50	30	50
1	MR	5.0		7.0	
2	MC	4.9		5.6	
3	MC30-0.5andMC50-0.5	5.5	5.1	7.8	6.6
4	MC30-1.0andMC50-1.0	5.7	5.2	8.1	7.3
5	MC30-1.5andMC50-1.5	4.8	4.9	6.3	6.5
6	MC30-2.0andMC50-2.0	3.7	3.6	3.6	3.7

Table3.6 BondStrengthofsteelfiberreinforcedconcretecubesafter 7 daysand28 dayswater curing

Fatigue failure was observed uniformly across all specimens. As can be seen in Table 4.8, all specimens failed after 1 x 105 cycle counts. Control specimens failed after 103,526 cycles, while 100% copper slag specimens failed after 100,818 cycles. Surprisingly, specimens with and without fibres but containing copper slag displayed fatigue strength comparable to the control specimens.

Sl.No.	ID	No.of Cycles	
	Fibrelength(mm)	30	50
1	MR	103526	
2	MC	100818	
3	MC30-0.5andMC50-0.5	112465	108714
4	MC30-1.0andMC50-1.0	124612	113465
5	MC30-1.5andMC50-1.5	101912	102464
6	MC30-2.0andMC50-2.0	100374	100956

Table3.7 FatigueStrength

IV. Conclusion

The project began with a detailed feasibility study to investigate the possibility of substituting or enhancing traditional building components in concrete pavements using industrial waste materials, including copper slag incorporated as a fine aggregate. To explore the behaviour of concrete pavement slabs under static and cyclic vertical stresses, a total of twenty pavement slabs were cast.

Finally, the use of copper slag as a fine aggregate in concrete mix design shows tremendous promise as a sustainable alternative to standard construction materials. This extensive research looked into numerous elements of concrete performance, including workability, mechanical characteristics, durability, and load-bearing capability. The findings shed light on the enormous potential of copper slag-incorporated concrete in tackling critical building industry difficulties.

Concrete Mix Design and Workability

To ensure uniform fine aggregate size across samples, the concrete mix design procedure, which has been deliberately customized to use copper slag as a fine aggregate, relies on the specific gravities of copper slag and river sand. This thorough mix design method, which included a water-cement ratio of 0.4, cleared the door for a notable improvement in workability. The substitution of copper slag for natural sand resulted in a significant increase in workability, from 60 mm to 75 mm. This improvement is related to copper slag's low water absorption qualities, emphasizing its potential for enhancing concrete workability.

Mechanical Properties:

The investigation focused on the mechanical properties of copper slag concrete, namely compressive strength, split tensile strength, flexural strength, Young's modulus, and bond strength. The results revealed differences amongst concrete compositions. The 28-day compressive strength of the reference concrete with conventional fine aggregate was commendable, but the copper slag concrete showed a modest loss of 4.89%. However, the addition of 1.0% steel fibres of 30 mm or 50 mm length resulted in increased compressive strength, particularly after 7 and 28 days of curing.

Significant increases, notably with 30 mm steel fibres, were noted, with a surprising 26.67% rise after 7 days and a continuing improvement of 21.72% at 28 days. The trend persisted for 50 mm steel fibres, with significant percentage increases in compressive strength. Notably, samples with 1.0% fibre content, particularly with fibres of 30 mm length, demonstrated the greatest durability, sustaining 124,612 cycles before failure during fatigue testing.

Durability Tests:

The durability evaluation revealed several critical characteristics of concrete performance. The resistance of copper slag to acid attacks was established, with much lesser weight loss when compared to standard concrete. Furthermore, the impermeable characteristic of copper slag-containing concrete resulted in limited surface scaling and insignificant permeability, protecting it from environmental difficulties like chloride ion reactions.

Load-Bearing Capacity:

Steel fibres had a surprising impact on concrete slabs subjected to static and cyclic vertical loads. The addition of 1.0% steel fibres, regardless of length, considerably increased load-carrying capability, with percentage increases ranging from 30.16% to 73.72%. This highlights the critical function of 1.0% steel fibre content in increasing the load-bearing capacity of concrete slabs, especially under cyclic loading circumstances.

In conclusion, the findings of this lengthy investigation provide a comprehensive view of the possibilities of copper slag-incorporated concrete in a variety of construction applications. The material's promise is evidenced by the accurate mix design process, better workability, and improved mechanical and durability features. Furthermore, the ecologically benign component of recycling industrial waste materials for construction is consistent with the expanding global emphasis on environmentally responsible practices.

The study also emphasizes the value of steel fibres, particularly those with a length of 30 mm, in improving the mechanical characteristics, ductility, and load-bearing capacity of concrete. This knowledge is useful for engineers and researchers looking for novel solutions for construction projects that require durability and better performance.

The successful transformation of copper slag into a suitable fine aggregate for concrete, conforming to IS 383 standards, is a significant step toward more sustainable construction practices. The material's ability to withstand acid attacks, mitigate surface scaling, and exhibit low permeability contributes to its attractiveness as a construction component.

As the construction industry continues to evolve in response to environmental concerns and resource scarcity, the integration of industrial waste materials like copper slag into concrete mix designs becomes increasingly relevant. The results of this study reinforce the feasibility and benefits of adopting copper slag in concrete production, offering a compelling case for its widespread implementation.

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