IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Performance Of Copper Slag On Strength As Partial Replacement Of Fine Aggregate In Concrete

Ms. Varsha Balu Kamble[1], Prof. G. N. Shete[2]

[1]Student, M.Tech Structural Engineering, M. S. Bidve Engineering College, Latur, Maharashtra, India.

[2]Assistant Professor, M.Tech Structural Engineering, M. S. Bidve Engineering College, Latur, Maharashtra, India.

ABSTRACT

Concrete is extensively used in the civil engineering sector worldwide due to its superior strength and durability. Fine aggregate, typically derived from natural river sand, plays a vital role in concrete production. However, excessive sand mining has led to serious environmental issues, including the depletion of natural resources, increased scour depth, and a heightened risk of flooding. To address these concerns and promote sustainability, industrial by-products such as copper slag—generated in large quantities by the copper industry—can be utilized as alternative materials. This study explores the potential of copper slag as a partial replacement for fine aggregate in M30 grade concrete. The experimental program involved replacing river sand with copper slag at varying proportions of 0%, 4%, 8%, 12%, and 16%. The mechanical properties, including compressive strength, tensile strength, and flexural strength, were assessed at 7 and 28 days. Results were analyzed and compared with conventional concrete to evaluate the impact of copper slag on the performance of concrete mixtures. The findings support the feasibility of using copper slag in concrete production, contributing to waste utilization and environmental sustainability.

Keywords- Cement, Fine Aggregate, Coarse Aggregate, Copper Slag, Concrete, Compressive Strength, Tensile Strength, Flexural Strength.

I. INTRODUCTION

Concrete is the most widely used construction material in the world due to its strength, durability, and versatility. It is composed of cement, water, fine aggregate (typically sand), coarse aggregate, and sometimes admixtures. However, the rapid urbanization and infrastructure development have led to excessive mining of natural sand, causing severe environmental degradation such as riverbed erosion, habitat destruction, and ecological imbalance. Therefore, the search for sustainable alternatives to natural fine aggregates has become an urgent priority in modern construction practices.

Copper slag, a by-product generated during the smelting and refining of copper, has emerged as a potential replacement material. It is produced in large quantities globally and poses a significant disposal challenge. Copper slag is characterized by its angular shape, high specific gravity, and good pozzolanic properties, which make it suitable for use in concrete. Utilizing this industrial waste not only helps in reducing the burden on natural resources but also addresses the problem of waste management in an eco-friendly manner.

This study focuses on the experimental evaluation of the effects of partially replacing fine aggregate with copper slag in concrete. Different replacement levels—specifically 0%, 4%, 8%, 12%, and 16%—were tested to analyze the resulting changes in the fresh and hardened properties of concrete. Key parameters such as compressive strength, tensile strength and flexural strength were investigated to determine the optimum substitution level.

The overall aim of this research is to explore the feasibility of using copper slag as a sustainable construction material that can contribute to environmental conservation, cost reduction, and improved concrete performance. This study not only highlights the engineering potential of copper slag but also aligns with the principles of green building and circular economy in the construction industry.

II. LITERATURE REVIEW

1. Thomas et al. (2018) explored the use of both copper slag and ferrous slag as complete replacements for natural fine aggregates in concrete. Their findings revealed that concrete mixes incorporating 100% copper or ferrous slag exhibited compressive strength and slump values that were comparable to those of the conventional mix. Based on the performance observed, the study concluded that both types of slag can effectively substitute natural fine aggregates up to full replacement levels under mild environmental exposure conditions.

2. Sukhoon Pyo et al. (2016) they studied the straight tensile action of UHP-FRC at strain variation varies as of 90 to 146/s. The tests are conducted using a recently developed impact testing system that uses suddenly released strain energy to create an impact pulse. Three types of fiber were considered, a twisted fiber and two other types of straight fibers. Specimen impact reaction was estimated in terms of primary cracking strength, post-cracking strength, energy carrying capacity and strain power. The test outcome point to that specimen with twisted fibers usually exhibit somewhat better mechanical properties than specimens with straight fibers for the variety of strain variation calculated. All UHP-FRC sequence tested explained exceptional rate sensitivities in energy absorption power, usually becoming much more energy dissipative under increasing strain rates. This feature highlights the prospective of UHP-FRC as promising cement based substance for impact- and blast-resistant functions.

3. Binaya Patnaik et al. (2015) explored the mechanical strength and durability performance of concrete incorporating copper slag as a partial replacement for fine aggregate. The study involved two concrete grades—M20 and M30—with copper slag replacing sand in varying proportions from 0% to 50%. The evaluation covered multiple parameters, including compressive strength, split tensile strength, flexural strength, acid resistance, and sulphate resistance. The findings demonstrated that incorporating copper slag up to a 40% replacement level enhanced the mechanical strength properties of concrete. However, while the concrete exhibited improved resistance to sulphate exposure, it showed reduced durability against acid attack, indicating that copper slag improves strength but may compromise stability under acidic conditions.

4. Dr. T. Ch. Madhavi (2014) conducted a study to evaluate the impact of replacing fine aggregate with copper slag on the mechanical behavior of concrete. The research focused on assessing the potential of copper slag—an industrial by-product—as an alternative to natural sand. The findings demonstrated that incorporating copper slag as a partial replacement enhances several mechanical properties of concrete. The study indicated that copper slag can be effectively used up to a 30% replacement level. However, beyond 50% substitution, a reduction in strength was observed, suggesting that excessive replacement may negatively influence concrete performance.

5. R. R. Chavan et al. (2013) they investigate the result of by copper slag as a substitution of fine aggregate on the strength functions. Copper slag is the waste material of generating through copper production. Copper slag is an important material that is measured as a waste that might have a capable prospect in building Industry as fractional or full alternate of aggregates. For this investigate work, M25 grade concrete was used and experiments were performed for different fractions of copper slag substitution with sand of 0 to 100% in Concrete. The achieved outcomes were balanced with those of conventional concrete made with OPC and sand.

6. Arivalagan (2013) conducted an experimental investigation into the flexural performance of reinforced concrete beams incorporating copper slag as a partial replacement for fine aggregate. Concrete mixes were prepared by substituting natural sand with copper slag in varying proportions of 0%, 20%, 40%, 60%, 80%, and 100%. All samples underwent a 28-day curing period before being subjected to compressive strength, splitting tensile strength, and flexural strength tests. Among the different mix ratios, the highest compressive strength recorded was 35.11 MPa at a 40% replacement level, compared to 30 MPa for the control mix. The study highlighted that partial replacement with copper slag can enhance compressive strength, particularly around the 40% substitution mark, suggesting its effective potential in improving the structural performance of reinforced concrete elements.

7. Brindha and Nagan (2011) investigated the durability performance of concrete when copper slag was used as a partial replacement for fine aggregate. Their experimental work involved replacing sand with copper slag up to 50% and testing the concrete under various aggressive conditions such as sulphate, alkaline, acidic, and marine environments. The results showed that concrete with copper slag, particularly at a 40% replacement level, demonstrated improved compressive, tensile, and flexural strength. It also exhibited enhanced resistance to sulphate and seawater exposure. However, the durability of the concrete decreased under acidic conditions, where higher mass loss and surface degradation were observed. The study concluded that copper slag could effectively improve concrete durability in specific environments, promoting the sustainable use of industrial waste in construction.

8. Al-Jabri et al. (2009) carried out an experimental study to evaluate the performance of high-strength concrete (HSC) incorporating copper slag as a replacement for fine aggregate. The researchers examined both the fresh and hardened properties of concrete, focusing on how varying levels of copper slag influenced workability, strength, and durability. Two series of mixes were prepared—one adjusting water content to maintain a consistent slump, and another that included the use of a superplasticizer.

The findings showed that using copper slag reduced water demand significantly, with a full 100% replacement requiring approximately 22% less water than the control mix. The study also found that compressive strength increased with higher slag content, but only when proper workability was maintained. In mixes without a superplasticizer, workability issues such as segregation and poor paste bonding were observed, which negatively affected the final strength and consistency of the concrete. However, in mixes with a superplasticizer, copper slag enhanced both strength and durability without compromising workability.

The authors concluded that copper slag can be a viable replacement for sand in high-strength concrete, especially when combined with chemical admixtures to maintain proper mix quality. The study supports the use of copper slag as a sustainable material in concrete production, particularly in high-performance applications.

III. MATERIALS USED

1. Cement

Cement is a hydraulic binding material that reacts chemically with water to form a hard matrix, which binds the fine and coarse aggregates together in concrete. In this study, Portland Pozzolana Cement (PPC) (Ultratech Cement) conforming to IS 1489 (Part 1)– 1991 was used throughout the experimental work. This cement is most widely used in the construction industry in India. The cement was stored in airtight conditions to prevent premature hydration due to moisture exposure. PPC was selected for its balanced properties, including adequate early strength development, long-term durability, widespread availability, and consistent quality, making it suitable for a wide range of structural concrete applications. The Table-1 shows the physical properties of cement.

Table-1: Physical Properties of Cement

Sr. No.	Physical Properties	Values
1.	Specific Gravity	3.15
2.	Initial Setting Time	35 minutes
3.	Final Setting Time	330 minutes
4.	Soundness (Le Chatelier)	10 mm

2. Fine Aggregate

Fine aggregate plays a crucial role in concrete by filling voids between coarse aggregates, thereby contributing to a dense, workable, and cohesive mix. In this study, natural river sand conforming to Zone II of IS 383:2016 was used as the fine aggregate. The sand passed through a 4.75 mm IS sieve and was retained on a 150 µm sieve, ensuring proper grading suitable for concrete applications. The sand was clean, well-graded and free from clay, silt, organic matter and salts, which can otherwise interfere with cement hydration and bond strength. Its selection was based on its ability to improve the workability, finishability and overall strength performance of the concrete mix. Natural river sand served as the control material for comparison in mixes containing copper slag as partial replacement. The Table-2 shows the physical properties of sand/ fine aggregate.

3. Coarse Aggregate

Coarse aggregate is a vital constituent of concrete, contributing to its mechanical strength, dimensional stability, and overall volume. In this study, crushed angular natural (such as gravel) or crushed stones aggregate was used as coarse aggregate. Coarse aggregate passed through a 20 mm IS sieve and was retained on a 4.75 mm sieve, conforming to the requirements of IS 383:2016. The aggregate was clean, hard and free from dust, clay, organic impurities and other deleterious materials that could affect bonding or durability. Angular aggregates were selected due to their superior interlocking properties, which enhance the compressive strength and reduce void content in the mix. The Table-2 shows the physical properties of coarse aggregate.

Table-2: Properties of Fine Aggregate and Coarse Aggregate

Sr. No.	Physical Properties	Natural Sand (Fine Aggregate)	Coarse Aggregate (Crushed Stone/Gravel)
1.	Specific Gravity	2.68	2.80
2.	Bulk Density	1450 kg/m³	1680 kg/m³
3.	Fineness Modulus	2.90	7.30

4.	Water Absorption	1.20%	1.25%
5.	Particle Size Range	150 µm – 4.75 mm	4.75 mm – 20 mm

4. Water

Water is a vital component in concrete, as it initiates the hydration reaction of cement, enables workability during mixing, and contributes to the development of strength and durability over time. In this study, clean potable water, free from suspended solids, organic matter, oils, acids, alkalies, and other harmful impurities, was used for both mixing and curing. The water quality conformed to the requirements of IS 456:2000, ensuring that it would not adversely affect the setting time, strength gain, or long-term performance of the concrete. The use of potable water ensured consistent hydration of cement and minimized the risk of delayed setting, low strength development, or corrosion of reinforcement in the long term.

5. Copper Slag

Copper slag is an industrial by-product generated during the smelting and refining of copper ore, where impurities are separated from molten copper in the form of a glassy, granular material. In this study, granulated copper slag was used as a partial replacement for natural fine aggregate (sand) in concrete. The copper slag used conformed to relevant physical property requirements and was free from contaminants, moisture, and deleterious substances. It passed through a 4.75 mm IS sieve, ensuring compatibility with the grading limits for fine aggregate as per IS 383:2016. The incorporation of copper slag not only provides an effective utilization route for industrial waste but also improves mechanical performance, reduces porosity, and contributes to the sustainability of concrete construction. Fig.-1 shows the picture of copper slag. The Table-3 shows the physical properties and Table-4 shows the chemical properties of copper slag.

Fig.-1: Copper Slag

Table-3: Physical Properties of Copper Slag

Sr. No.	Physical Properties	Values/ Description
1.	Appearance	Dark, granular, glassy, angular
2.	Specific Gravity	3.3 – 3.6
3.	Bulk Density	1800 – 2000 kg/m³
4.	Fineness Modulus	2.4 – 3.2 (comparable to natural sand)
5.	Water Absorption	< 0.5% (very low)
6.	Hardness	6 – 7 on Mohs scale
7.	Particle Size	< 4.75 mm (for fine aggregate replacement)
8.	Shape	Mostly angular with rough texture
9.	Color	Black or dark brown

Table-4: Chemical Properties of Copper Slag

Sr. No.	Chemical Component	Percentage Range
1.	Silicon Dioxide (SiO_2)	25% – 40%
2.	Iron Oxide (Fe_2O_3)	40% – 50% (gives it high density and color)
3.	Aluminum Oxide (Al_2O_3)	1% – 3%
4.	Calcium Oxide (CaO)	1% – 2%
5.	Magnesium Oxide (MgO)	0.5% – 1.5%
6.	Copper Content (Cu)	< 0.5% (trace amounts only)
7.	Titanium Dioxide (TiO_2)	1% – 2%
8.	Sulphur Trioxide (SO_3)	< 1%
9.	Chloride Content	Negligible – < 0.01%
10.	Loss on Ignition (LOI)	< 1%

IV. MIX DESIGN

Concrete mix was designed for M30 grade as per IS 10262:2019 standards by trail mix for 1 m3 of concrete. Copper slag was used to replace fine aggregate by weight in the following proportions: 0% (control), 4%, 8%, 12% and 16%. The Table-5 shows the mix proportion and mix ratio for M30 grade of concrete.

Table-5: Mix Proportion (Kg/m3) and Mix Ratio for M30

Cement (Kg/m^3)	Sand / Fine Aggregate (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Water (Kg/m^3)
469.43	628.23	1146.83	197.16
1	1.33	2.44	0.42

V. RESULTS AND DISCUSSIONS

1. Compressive strength

Compressive strength is defined as the ability of a material or structural component to resist axial compressive forces that tend to reduce its dimensions. Test is done according to IS code specification IS 516:1959. To determine the compressive strength, cube mould of size 150x150x150 mm were casted. Cubes were prepared and tested at 7 and 28 days of curing in water. A gradual load is applied on the surface of the cube to obtain maximum compressive load. The cubes are tested under universal testing machine (UTM). Readings are noted and graphs are drawn. The results of compressive strength at the age of 7 and 28 days are shown in Table-6.

The compressive strength is calculated using the formula,

Compressive strength (N/mm²) = P/A

Where,

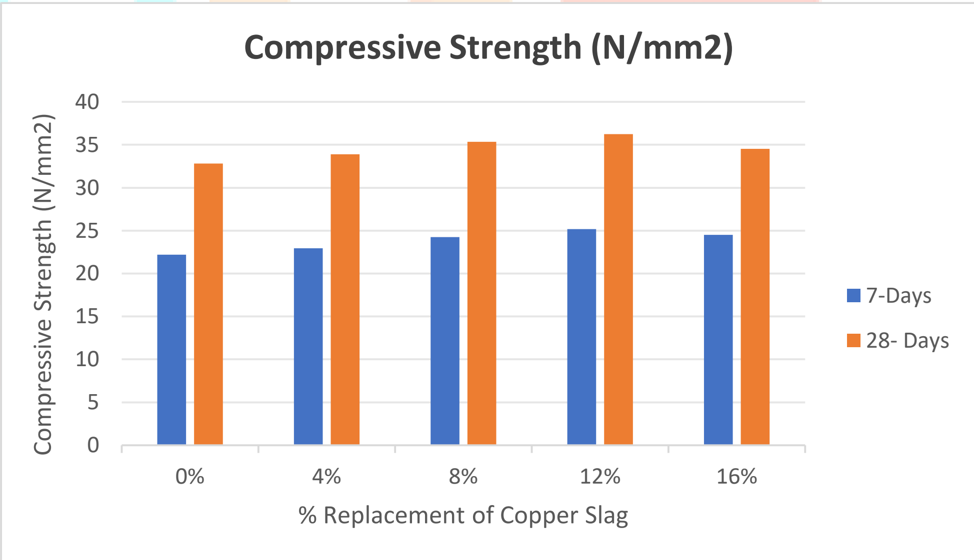
P – Ultimate load (N)

A –Cross-sectional area of specimen (mm^2)

Table-6: Compressive strength results in N/mm^2

Sr. No.	Percentage Replacement of Copper Slag	Compressive Strength (N/mm^2)	
		7 Days	28 Days
1.	0%	22.18	32.81
2.	4%	22.95	33.90
3.	8%	24.24	35.34
4.	12%	25.18	36.26
5.	16%	24.52	34.52

From the test result, it can be seen that optimum percentage attained at 12% of replacement using copper slag. Finally, the compressive strength increases with increase in its duration. The maximum percentage of increase in strength is found to be 36.26 N/mm^2 at 12% replacement of fine aggregate by copper slag, while comparing to 32.81 N/mm^2 for a normal mix. Bar Chart-1 shows the compressive strength of concrete at 7 and 28 days.



Bar Chart-1: Compressive strength of concrete at 7 and 28 days

2. Tensile Strength Test

The tensile strength test is a critical mechanical evaluation technique used to analyze how materials respond when subjected to uniaxial tensile loads. It plays a significant role in determining a material's capacity to resist stretching forces without experiencing irreversible deformation or failure. Commonly expressed as the ultimate tensile strength (UTS), this parameter indicates the maximum stress a material can withstand before it fractures. This test is essential for material selection, quality assurance, and optimizing manufacturing techniques. During testing, a standardized specimen is exposed to a progressively increasing tensile force while monitoring its elongation. The results provide valuable information regarding the strength, ductility, and overall mechanical reliability of the material, supporting its suitability for structural and industrial applications. The results of tensile strength at the age of 7 and 28 days are shown in Table-7.

The tensile strength is calculated using the formula,

Tensile strength (N/mm^2) = 0.642P/A

Where,

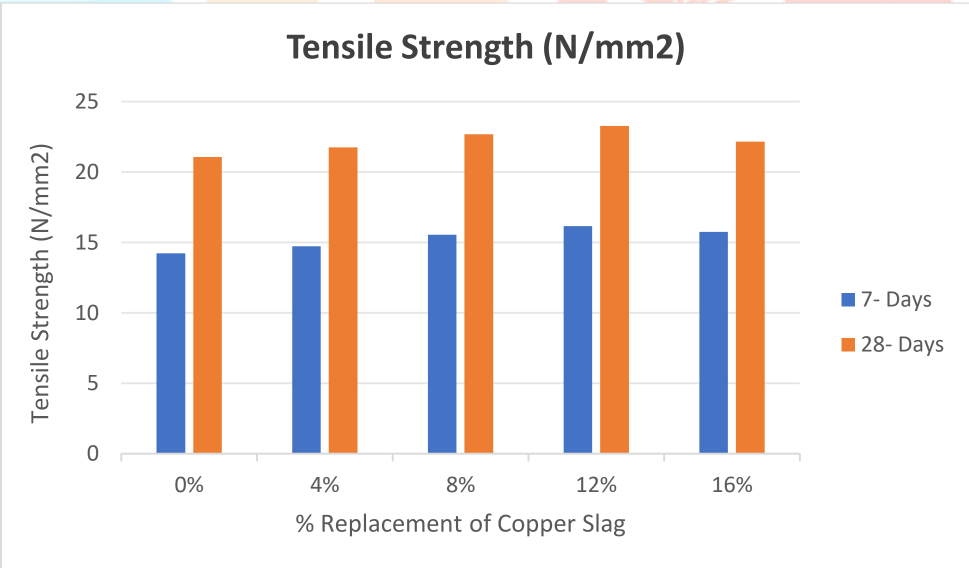
P – Ultimate load (N)

A –Cross-sectional area of specimen (mm^2)

Table-7: Tensile strength results in N/mm^2

Sr. No.	Percentage Replacement of Copper Slag	Tensile Strength (N/mm^2)	
		7 Days	28 Days
1.	0%	14.23	21.06
2.	4%	14.73	21.76
3.	8%	15.55	22.68
4.	12%	16.16	23.27
5.	16%	15.74	22.16

From the test result, it can be seen that optimum percentage attained at 12% of replacement using copper slag. Finally, the tensile strength increases with increase in its duration. The maximum percentage of increase in strength is found to be 23.27 N/mm^2 at 12% replacement of fine aggregate by copper slag, while comparing to 21.06 N/mm^2 for a normal mix. Bar Chart-2 shows the tensile strength of concrete at 7 and 28 days.



Bar Chart-2: Tensile strength of concrete at 7 and 28 days

3. Flexural Strength

Flexural strength tests were conducted on concrete beams of size 150 mm × 150 mm × 700 mm were cast with varying fine aggregate replacement levels from 0% to 16%. After 24 hours in saturated conditions, specimens were water-cured for 28 days, then air-dried before testing. A total of 30 beam samples were prepared as per IS 516:1959. The beam placed under loading type of two-point loading testing setup. The strength of a material in bending is measured as the stress on the outermost fibres of a testing specimen, at the direct to failure. The results of flexural strength at the age of 7 and 28 days are shown in Table-8.

The flexural strength was calculated using the formula:

Flexural Strength (N/mm^2) = PL/bd2

Where,

F –Flexural strength (N/mm^2)

P –Ultimate load (N)

L –Length of the beam (mm)

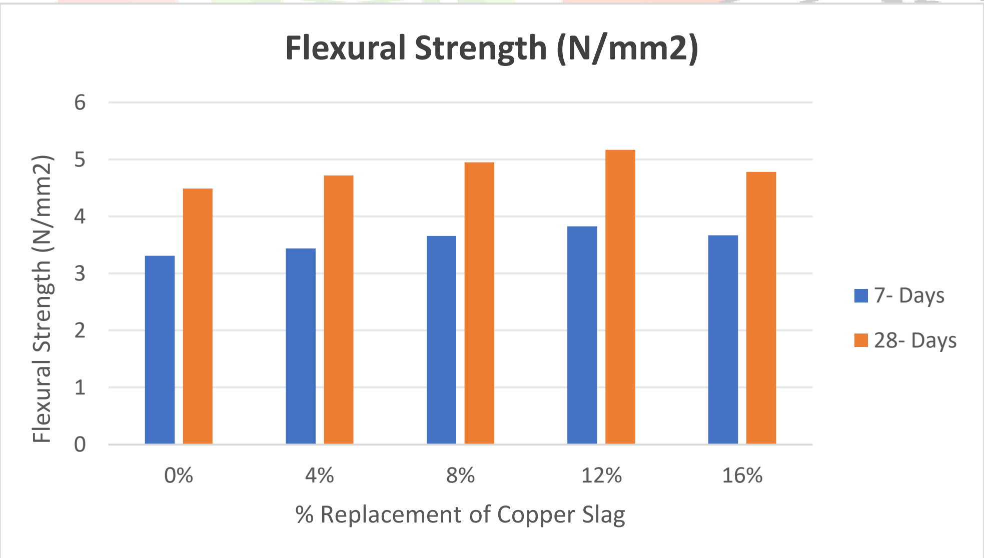
b –Average width (mm)

d –Average depth (mm)

Table-8: Flexural strength results in N/mm^2

Sr. No.	Percentage Replacement of Copper Slag	Flexural Strength (N/mm^2)	
		7 Days	28 Days
1.	0%	3.31	4.49
2.	4%	3.44	4.72
3.	8%	3.66	4.95
4.	12%	3.83	5.17
5.	16%	3.67	4.78

From the test result, it can be seen that optimum percentage attained at 12% of replacement using copper slag. Finally, the flexural strength increases with increase in its duration. The maximum percentage of increase in strength is found to be 5.17 N/mm^2 at 12% replacement of fine aggregate by copper slag, while comparing to 4.49 N/mm^2 for a normal mix. Bar Chart-3 shows the flexural strength of concrete at 7 and 28 days.



Bar Chart-3: Flexural strength of concrete at 7 and 28 days

VI. CONCLUSION

Based on this experimental study, the following conclusions were made:

1. The replacement of fine aggregate using copper slag in concrete increases the density of concrete thereby increases the self-weight of the concrete.
2. The workability of concrete increased with the increase in copper slag content of fine aggregate replacements at same water-cement ratio.
3. As per the IS code recommendations the material properties are within the limit and we will be using for our research.
4. The maximum compressive strength is found to be 36.26/N/mm^2 at 12% replacement of fine aggregate by copper slag, while comparing to 32.81 N/mm^2 for a normal mix.
5. The maximum tensile strength is found to be 23.27 N/mm^2 at 12% replacement of of fine aggregate by copper slag, while comparing to 21.06 N/mm^2 for a normal mix.
6. The maximum flexural strength is found to be 5.17 N/mm^2 at 12% replacement of of fine aggregate by copper slag, while comparing to 4.49 N/mm^2 for a normal mix.
7. The strength has been increased by 12% replacement of copper slag. Hence to reduce the use of fine aggregate in future this can affect the environment and avoid digging of lands
8. The construction industry is the only area for safe use of waste materials, which reduces the environmental problems, space problems and cost of construction.

VII. REFERENCES

1. J. Thomas, N. N. Thaickavil and M. P. Abraham (2018), "Copper or ferrous slag as substitutes for fine aggregates in concrete", Advances in Concrete Construction, Vol. 6, No. 5, pp. 545-560. DOI: https://doi.org/10.12989/acc.2018.6.5.545
2. Sukhoon Pyo, Sherif El-Tawil, Antoine E. Naaman, “Direct tensile behavior of ultra-high performance fiber reinforced concrete (UHP-FRC) at high strain rates”, Elsevier 2016. Cement and Concrete Research. 88. 144-156. DOI:10.1016/j.cemconres.2016.07.003
3. Binaya Patnaik, Seshadri Sekhar T., Srinivasa Rao, “Strength and Durability Properties Of Copper Slag Admixed Concrete”, International Journal of Research in Engineering and Technology, e-ISSN: 2319-1163, p-ISSN: 2321-7308, Volume 4, Issue 1, 158-166, Feb 2015. DOI:10.15623/ijret.2015.0413027
4. Dr. T.Ch. Madhavi, “Copper Slag in Concrete as Replacement Material”, International Journal of Civil Engineering and Technology (IJCIET), ISSN 0976 – 6316, Volume 5, Issue 3, March (2014), pp. 327-332.
5. R. R. Chavan, D. B. Kulkarni, “Performance of copper slag on strength Properties as partial replace of fine aggregate in concrete mix design” International Journal of Advanced Engineering Research and Studies, E-ISSN2249–8974, Volume 2, Issue 4, Sep (2013), pp. 95-98.
6. Arivalagan S. (2013), “Experimental Study on the Flexural Behavior of Reinforced Concrete Beams as Replacement of Copper Slag as Fine Aggregate”, Journal of Civil Engineering and Urbanism, 3(4), 176-182. http://www.ojceu.ir/main/
7. Brindha D, Nagan S (2011) Durability Studies on Copper Slag Admixed Concrete. Asian Journal of Civil Engineering (Building and Housing) 12: 563- 578.

https://www.researchgate.net/publication/268438151_Durability_studies_on_copper_slag_admixed_concrete

8. Al-Jabri KS, Hisada M, Al-Saidy AH, Al-Oraimi SK (2009) Performance of High Strength Concrete made with Copper Slag as a Fine Aggregate. Construction and Building Materials 23: 2132-2140. https://doi.org/10.1016/j.conbuildmat.2008.12.013