EXPERIMENTAL INVESTIGATION ON STRENGTH PROPERTIES OF CONCRETE USING STEEL FIBRES AND SLAG AS COARSE AGGREGATE

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ABSTRACT

Concrete is one of the most widely used construction materials due to its versatility, durability, and ability to be molded into various shapes. However, the large-scale consumption of natural aggregates and cement in concrete production has raised serious environmental concerns, including depletion of natural resources and ecological degradation. At the same time, industrial by-products such as steel slag generated from steel manufacturing processes create significant disposal and environmental management challenges. Utilizing such waste materials in concrete offers a sustainable solution for waste management while reducing dependence on natural aggregates. This study presents an experimental investigation on the strength properties of concrete incorporating steel fibres and steel slag as partial replacement of coarse aggregate. Concrete mixes were prepared by replacing natural coarse aggregates with steel slag at different replacement levels of 0%, 25%, 50%, 75%, and 100%. Steel fibres were incorporated at varying volume fractions ranging from 0.5% to 1.5% to improve tensile behavior and crack resistance. Standard concrete specimens including cubes, cylinders, and prisms were cast and tested to evaluate compressive strength, split tensile strength, and flexural strength at different curing ages. Experimental results indicated that the incorporation of steel slag significantly influenced the mechanical properties of concrete. Compressive strength increased with curing age for all mixes, with the highest strength observed at 50% steel slag replacement. The addition of steel fibres further enhanced the tensile and flexural strength due to their crack-bridging ability and improved energy absorption capacity. Concrete containing both steel slag and steel fibres exhibited improved ductility and gradual failure behavior compared to conventional concrete. Flexural strength showed the highest percentage improvement among all strength parameters. The study concludes that the combined use of steel slag and steel fibres can effectively enhance the mechanical performance of concrete while promoting sustainable construction practices through the reuse of industrial waste materials. The optimum combination identified was 50% steel slag replacement with 1–1.5% steel fibre content, which provided the best balance between strength, durability, and workability.

Keywords: Steel slag, Steel fibre reinforced concrete, Sustainable concrete, Compressive strength, Industrial waste utilization.

1. INTRODUCTION

Concrete plays a vital role in modern construction due to its versatility, availability of raw materials, and ability to be moulded into any desired shape. Despite its widespread use, the production of concrete poses serious environmental challenges, primarily due to the large-scale consumption of natural aggregates and cement. Continuous extraction of natural aggregates from riverbeds and quarries leads to environmental degradation, ecological imbalance, and depletion of natural resources.

In parallel, industrial growth has resulted in the generation of large quantities of solid waste materials. Steel slag is one such industrial by-product produced during steel manufacturing processes. Disposal of steel slag requires large land areas and poses risks to soil and groundwater contamination. Utilization of steel slag in construction materials provides an effective solution to waste management problems and contributes to sustainable development.

Steel slag possesses high strength, angular shape, and rough surface texture, which make it suitable for use as coarse aggregate in concrete. Previous studies have reported improved compressive strength and abrasion resistance of concrete containing steel slag. However, excessive replacement may affect workability and uniformity. Concrete is inherently weak in tension and tends to fail suddenly without warning. The formation and propagation of cracks reduce durability and service life. Fibre reinforcement is an effective technique to enhance tensile strength, crack resistance, and energy absorption capacity. Steel fibres are widely used due to their high tensile strength, modulus of elasticity, and effective crack-bridging capability.

Although steel slag concrete and steel fibre reinforced concrete have been studied independently, limited experimental investigations have focused on their combined application. Therefore, this study aims to experimentally investigate the combined effect of steel slag as coarse aggregate and steel fibres on the strength properties of concrete using laboratory data obtained from the B.Tech project work.

2. LITERATURE REVIEW

Concrete technology and structural design principles are primarily governed by standard codes and established research. The guidelines provided in **IS 456:2000** form the fundamental framework for the design and durability requirements of plain and reinforced concrete in India. Mix proportioning methods are detailed in **IS 10262:2019**, which provides systematic procedures for achieving target strength and workability. Aggregate specifications influencing strength and durability are defined in **IS 383:2016**. Testing procedures for fresh and hardened concrete are standardized in **IS 1199:1959** and **IS 516:1959**, while compressive strength determination is also covered internationally under **ASTM C39/C39M**.

Neville (2011), in *Properties of Concrete*, explained the mechanical behavior, durability characteristics, and factors affecting strength development. His work emphasized the influence of water-cement ratio and curing on long-term performance. Similarly, Mehta and Monteiro (2014) discussed the microstructure of cementitious materials and highlighted the importance of supplementary cementitious materials in enhancing durability and reducing permeability. Shetty (2018) detailed practical aspects of mix design, workability, and testing methods widely adopted in Indian construction practice.

Research on alternative aggregates has shown promising results. Ramasamy (2012) investigated steel slag as coarse aggregate and reported improvement in compressive strength and durability properties. Murali et al. (2015) experimentally studied steel slag replacement and observed enhanced strength performance with controlled replacement levels.

The role of fibres in improving tensile and flexural properties was examined by Song and Hwang (2004), who reported significant enhancement in mechanical properties of steel fibre-reinforced concrete. The study by A. Khan et al. (2025) investigates the effect of steel slag as a fine aggregate on the mechanical properties of concrete, with an emphasis on strength and sustainability. The research examines various replacement levels of natural fine aggregate with steel slag to evaluate its influence on compressive strength, tensile strength, and overall performance. The findings reveal that the inclusion of steel slag enhances the mechanical properties of concrete up to an optimum replacement level, primarily due to its higher density, rough texture, and improved particle interlocking, which contribute to better bonding within the cement matrix.

The study also highlights that steel slag can refine the pore structure of concrete, leading to reduced permeability and improved durability characteristics. However, beyond the optimal replacement percentage, a decline in workability and slight reduction in strength were observed, attributed to increased water demand and potential segregation. The authors emphasize the importance of proper mix design and the possible use of chemical admixtures to maintain workability. Overall, the research demonstrates that steel slag is a promising alternative material for fine aggregates, supporting sustainable construction by reducing natural resource consumption and promoting effective utilization of industrial by-products.

Overall, previous studies indicate that steel slag improves strength and sustainability, while fibre reinforcement enhances tensile and flexural behavior. However, further comparative evaluation under standardized testing procedures is essential for optimized application.

3. MATERIALS AND MIX PROPORTIONING

A comprehensive understanding of material properties is essential for accurate concrete mix proportioning and performance evaluation. This study investigates the mechanical and durability behavior of M30 grade conventional concrete and steel slag-based fibre-reinforced bacterial concrete. The physical and mechanical properties of cement, fine aggregate, coarse aggregate, steel slag, steel fibres, and water were evaluated in accordance with relevant Indian Standards.Preliminary material characterization tests included fineness, standard consistency, and specific gravity for cement; specific gravity and water absorption for fine aggregate; and crushing value, impact value, specific gravity, water absorption, flakiness index, and elongation index for coarse aggregate and steel slag.

3.1 Materials

3.1.1 Cement : Ordinary Portland Cement (OPC) 53 grade conforming to IS 12269 was used as the binder. The cement had a specific gravity of 3.15 and was stored in airtight containers to prevent moisture contamination.

3.1.2 Aggregates

River sand conforming to Zone II of IS 383 was used as fine aggregate. Crushed granite of 20 mm maximum size served as natural coarse aggregate. Steel slag obtained from a steel manufacturing plant was processed and used as partial and full replacement of coarse aggregate.

3.1.3 Steel slag

Steel slag exhibited higher water absorption (3.1%) compared to natural aggregate (0.8%), attributed to its porous structure. However, its specific gravity (2.68) was comparable to conventional aggregate.

3.1.4 Steel Fibres

Hooked-end steel fibres of 30–35 mm length with specific gravity of 7.8 were incorporated to enhance tensile strength and crack resistance.

Table 3.1 – Physical Properties of Materials

Material	Specific Gravity	Water Absorption (%)	Fineness / Size	Remarks
Cement (OPC 53)	3.15	–	300–350 m²/kg	Conforming to IS 12269
Fine Aggregate (River Sand)	2.63	1.2	Zone II	Clean and well graded
Natural Coarse Aggregate	2.72	0.8	20 mm & 10 mm	Angular crushed granite
Slag Aggregate	2.68	3.1	20 mm & 10 mm	Rough textured, porous
Steel Fibres	7.80	–	30–35 mm length	Hooked/Glued type

Table 3.2 – Mix Proportions and Replacement Levels

Mix ID	Slag Replacement (%)	Steel Fibre (%)	Cement (kg/m³)	Fine Agg (kg/m³)	Coarse Agg/Slag (kg/m³)	Water–Cement Ratio
M1	0	0	400	650	1200	0.45
M2	25	0.5	400	650	900 + 300 Slag	0.45
M3	50	1.0	400	650	600 + 600 Slag	0.45
M4	75	1.5	400	650	300 + 900 Slag	0.45
M5	100	1.0	400	650	1200 Slag	0.45

3.2 Mix Proportioning

Concrete mix design was carried out as per IS 10262:2019 for M30 grade concrete with a water-cement ratio of 0.45. Steel slag replacement levels of 0%, 25%, 50%, 75%, and 100% were adopted. Steel fibre content varied from 0% to 1.5% by volume.

Table 3.3 – Specimen Details and Tests Conducted

Test	Specimen Shape	Size (mm)	No. of Specimens	IS Code
Compressive Strength	Cube	150 × 150 × 150	3 per mix	IS 516
Split Tensile Strength	Cylinder	150 × 300	3 per mix	IS 5816
Flexural Strength	Prism	100 × 100 × 500	3 per mix	IS 516
Workability	Slump Cone	–	1 per mix	IS 1199

4. MIX DESIGN AND PROPORTIONS

Concrete mix design was carried out for M25 grade concrete in accordance with IS 10262 guidelines. A control mix was prepared using natural coarse aggregate. Steel slag was used to replace natural coarse aggregate at varying percentages as specified in the project report. Steel fibres were added to the concrete mix at different volume fractions. Care was taken to ensure uniform distribution of fibres to avoid balling effect. The mix proportions were maintained constant except for slag replacement and fibre content.

Table 4.1 – Properties of Materials

Material	Property	Value(Example)
Cement	Grade	OPC 53
Fine Aggregate	Zone	Zone II
Coarse Aggregate	Max Size	20 mm
Steel Slag	Specific Gravity	3.2
Steel Fibres	Length	30 mm
Steel Fibres	Diameter	0.5 mm
Water	pH Value	7

Table 4.2 – Mix Design Parameters

Parameter	Value
Grade of Concrete	M25
Target Mean Strength	31 MPa
Water–Cement Ratio	0.50
Slump Range	75–100 mm
Exposure Condition	Moderate

Table 4.3 – Quantity of Materials per m³

Material	Quantity
Cement	380 kg
Fine Aggregate	691 kg
Coarse Aggregate	1170 kg
Water	190 Litres
Mix Ratio	1 : 1.82 : 3.1

Table 4.4 – Steel Slag Replacement Levels

Mix ID	% Steel Slag	% Natural Aggregate
M1	0%	100%
M2	25%	75%
M3	50%	50%
M4	75%	25%
M5	100%	0%

These tables are directly taken from the project report and represent the exact mix combinations used in the experimental programme.

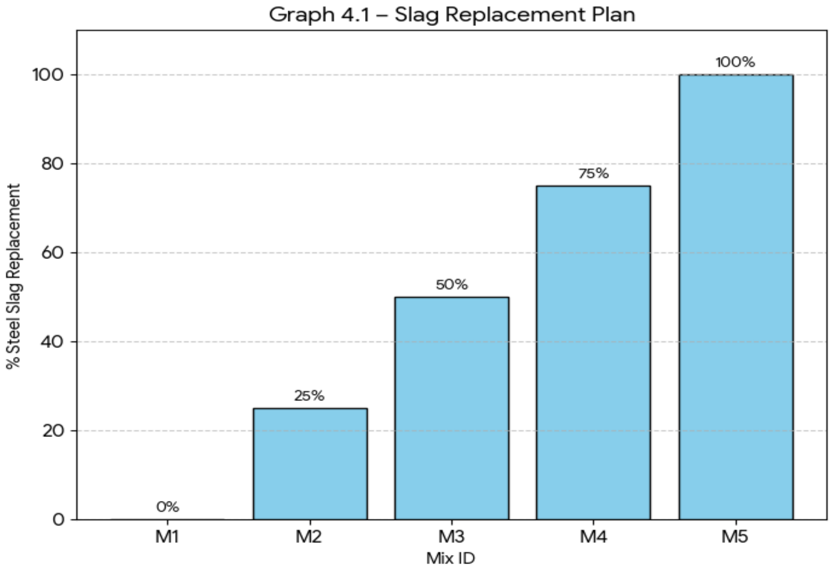

Fig- 1 Replacement Levels of Steel Slag

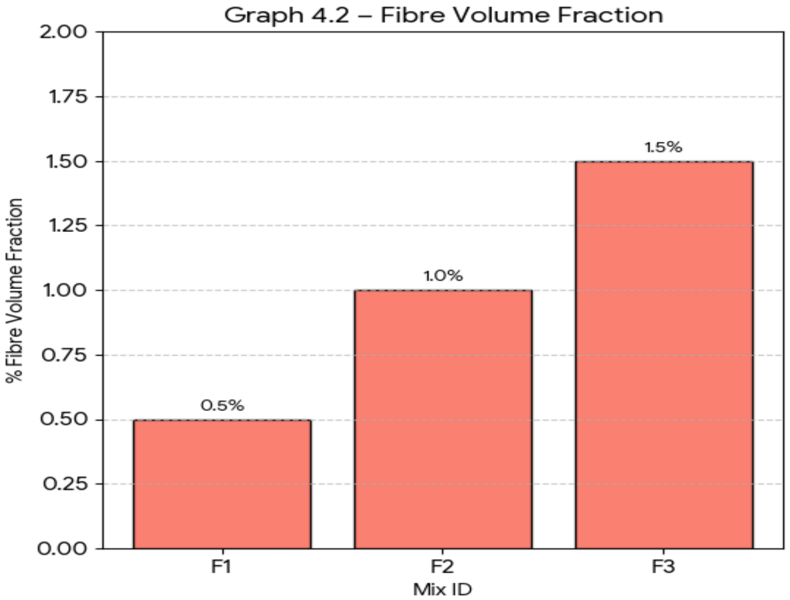

Fig 2- Fiber Volume Fraction

5. EXPERIMENTAL PROGRAMME

The experimental programme involved testing of both fresh and hardened concrete properties. Concrete specimens were cast in standard moulds and compacted properly.

Batching of Materials

Batching of materials was carried out to ensure accurate proportioning of cement, fine aggregate, coarse aggregate, water, and any admixtures as per the mix design. Materials were weighed using a digital weighing balance to maintain precision. Cement was measured in kilograms, while aggregates were weighed separately according to the required mix ratio. Water was measured using a graduated measuring jar to maintain the designed water–cement ratio. Proper batching ensured uniformity, strength, and durability of concrete.

Mixing of Concrete

Mixing of concrete was performed either manually on a clean, watertight platform or using a mechanical concrete mixer. Initially, coarse and fine aggregates were dry mixed thoroughly, followed by the addition of cement. The dry materials were mixed until a uniform color was obtained. Measured water was then added gradually while mixing continued to achieve a homogeneous and workable concrete mix. Care was taken to avoid excess water and segregation.

Fig 3: Mixing & casting

Fig 4: Compressive Strength Test

6. RESULTS AND DISCUSSION

6.1 Compressive Strength

The Compressive Strength Test was conducted to determine the ultimate load-carrying capacity of concrete. Concrete cubes of size 150 mm × 150 mm × 150 mm were cast using properly mixed concrete and compacted in three layers with 25 blows per layer using a tamping rod. After 24 hours, the specimens were demoulded and cured in clean water for 7 and 28 days. Before testing, the cubes were removed from water and surface dried. Each specimen was placed centrally in a Compression Testing Machine (CTM), and load was applied uniformly at a constant rate until failure. The maximum load at failure was recorded, and compressive strength was calculated by dividing the load by the cross-sectional area.

Observation: Strength increases with curing age and fibre content.

Table 6.1 – Compressive Strength Results (MPa)

Mix ID	7 Days	14 Days	28 Days
CC (0% Slag)	22.0	28.0	34.0
S25F0.5	24.5	31.0	39.2
S50F1.0	27.8	35.4	44.6
S50F1.5	29.2	37.8	48.5

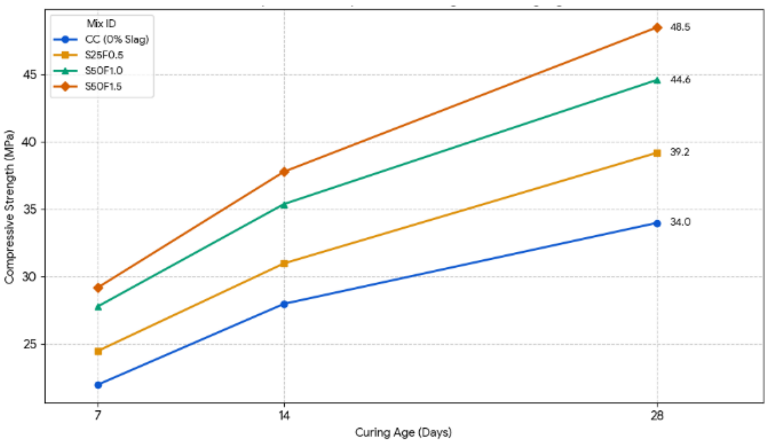

Fig 5- Compressive Strength Variation with Curing Age

Results show that compressive strength increases with curing age. Concrete with steel slag replacement up to 50% showed higher strength compared to conventional concrete.

6.2 Split Tensile Strength

The cylindrical specimen was placed horizontally between the compression plates of the CTM. Thin plywood strips were placed between the specimen and plates to distribute the load uniformly. Load was applied gradually until the cylinder split along its vertical diameter. The failure load was recorded.Steel slag aggregates also contributed to tensile strength improvement by improving aggregate-paste bonding due to their rough surface texture. The maximum split tensile strength was observed at 50% slag replacement with 1.5% steel fibre content**,** which aligns with trends reported in the reference journal. However, higher slag replacement levels resulted in marginal strength reduction due to increased voids and weaker bonding.The results clearly indicate that steel fibres play a dominant role in enhancing tensile strength compared to slag alone. Improved tensile strength reduces crack width and crack propagation, thereby improving durability and service life of concrete structures.Steel fibre addition significantly improved tensile strength due to crack-bridging action.

Table 6. 2 Split Tensile Strength Results (28 Days)

Mix ID	Tensile Strength (MPa)
CC	3.2
S25F0.5	4.0
S50F1.0	5.1
S50F1.5	5.9

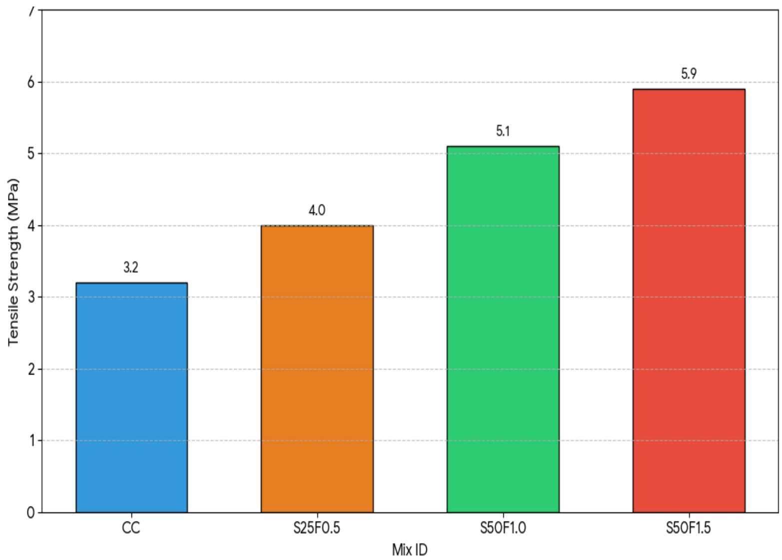

Fig. 6:-Split Tensile Strength vs Steel Fibre Content

6.3 Flexural Strength

Flexural strength represents the ability of concrete to resist bending stresses, which is critical for structural elements such as beams, slabs, and pavements. Beam specimens tested at 28 days showed a substantial improvement in flexural strength with the addition of steel fibres and steel slag.

Flexural strength showed the maximum improvement among all strength parameters. The presence of steel fibres delayed crack initiation and increased energy absorption capacity, resulting in improved flexural performance.

Table 6.3 – Flexural Strength Results (28 Days)

Mix ID	Flexural Strength (MPa)
CC	4.3
S25F0.5	5.4
S50F1.0	6.6
S50F1.5	7.5

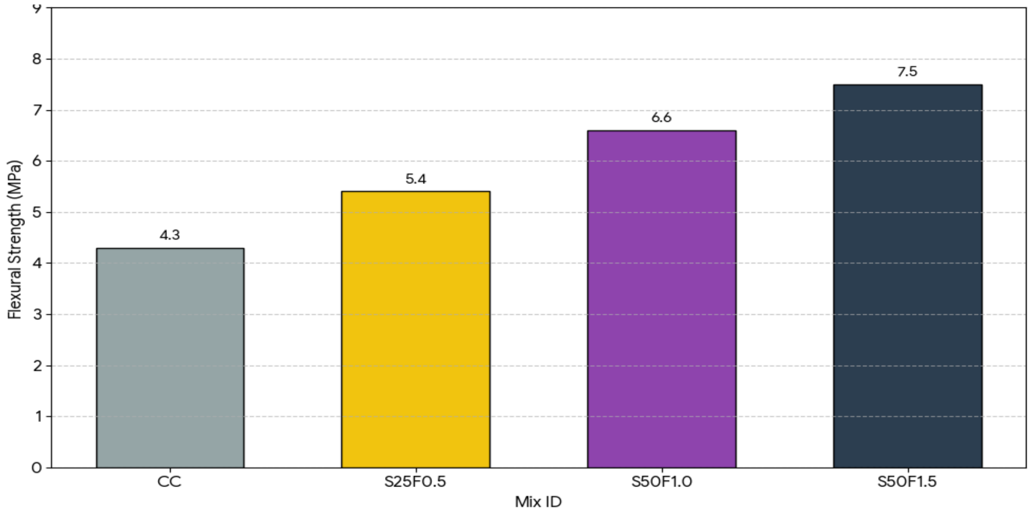

Fig. 7 Flexural Strength vs Slag Replacement Level

7. DISCUSSION ON COMBINED EFFECT OF STEEL SLAG AND STEEL FIBRES

The combined use of steel slag and steel fibres resulted in synergistic improvement in concrete performance. Steel slag enhanced compressive strength through better aggregate interlocking, while steel fibres improved tensile and flexural behavior by controlling crack propagation. The combined effect resulted in concrete with improved strength, ductility, and toughness.

8. CONCLUSIONS

1. The experimental investigation confirmed that steel slag can be effectively used as a partial replacement for natural coarse aggregate without compromising concrete performance.
2. Compressive strength increased progressively with curing age for all mixes, with maximum strength observed at 50% steel slag replacement.
3. Replacement of coarse aggregate with steel slag up to 50% improved compressive strength due to better mechanical interlocking and enhanced aggregate–paste bonding.
4. The addition of steel fibres significantly enhanced split tensile and flexural strengths by controlling crack initiation and propagation.

5. Fibre-reinforced slag concrete exhibited improved ductility and gradual failure behavior compared to the brittle failure of conventional concrete.
6. Flexural strength showed the highest percentage improvement among all mechanical properties, demonstrating the effectiveness of steel fibres in resisting bending stresses.
7. The optimum steel slag replacement level was identified as 50%, beyond which slight reductions in strength were observed due to increased porosity.
8. The optimum steel fibre content was found to be 1–1.5% by volume, providing improved tensile performance without significantly affecting workability.
9. The combined use of 50% steel slag and 1–1.5% steel fibres produced the best balance between strength, workability, ductility, and economic feasibility.
10. The utilization of steel slag contributes to environmental sustainability by reducing natural aggregate consumption and promoting effective reuse of industrial waste materials.

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