Enhancing Self-Compacting Concrete Performance Using Recycled Floor Steel Slag As Fine Aggregate

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ABSTRACT

The study explores the feasibility of utilizing floor steel slag as a partial replacement for sand in the production of self-compacting concrete (SCC). By incorporating varying replacement levels (0%, 5%, 10%, 15%, 20%, and 25%), the research evaluates the impact of steel slag on both fresh and hardened properties of SCC. Key performance indicators such as slump flow diameter and T50 time are analyzed to assess workability, while compressive and split tensile strengths are examined to determine mechanical performance. The results indicate that SCC mixes containing steel slag exhibit superior physical and mechanical characteristics compared to conventional SCC, demonstrating improved strength and durability. Furthermore, this approach offers a cost-effective and environmentally responsible alternative for waste management in the construction industry. The findings highlight the potential of floor steel slag as a valuable material in high-performance concrete applications, promoting resource efficiency and innovative material utilization.

Key words: self-compacting concrete (SSC), slump flow, T_{50}, compressive and split tensile strength.

1. INTRODUCTION

The increasing demands for high-performance concrete structures have led to innovations in material design, with self-compacting concrete (SCC) emerging as a game-changer in modern construction. SCC offers superior workability, high strength, and enhanced durability while eliminating the need for external vibration, ensuring seamless placement even in heavily reinforced sections. However, optimizing its composition remains a challenge, particularly in sustainable material utilization. This study explores the potential of recycling floor steel slag as a fine aggregate in SCC, aiming to enhance its mechanical properties while addressing environmental concerns. By systematically replacing sand with varying percentages of steel slag, the research evaluates its impact on flowability, stability, and strength characteristics. The findings not only highlight the structural advantages of incorporating steel slag but also promote resource-efficient concrete production, paving the way for cost-effective and eco-conscious construction practices.

2. LITERATURE REVIEW

Hajime Okamura in his paper entitled “Self Compacting High-Performance Concrete” has discussed about self compacting concrete as a mix that can be compacted into every corner of a formwork, purely by means of its own weight and without the need for vibrating compaction. Inspite of its high flowability, the coarse aggregate in not segregated. A model formwork was used to observe how well self-compacting concrete can flow through obstacles. Concrete is placed into the right-hand tower, flows through the obstacles and rises in the left-hand tower. The obstacles were chosen to simulate the confined zones of an actual structure. The self-compacting concrete on the left can rise to almost the same level as on the right. It is realized that the development of self compacting concrete would be necessary to guarantee durable concrete structures in the future. When concrete flow between reinforcing bars, the relative location of the coarse aggregate is changed. The relative displacement causes shear stress in the paste between the coarse aggregate, in addition to compressive stress. Shear force required for relative displacement largely depends upon water cement ratio. Increasing water cement ratio leads to improved flowability of cement paste and decreases viscosity. Therefore, superplaticizer is indispensible. Coarse aggregate is limited to 50 percent of solid volume and fine aggregate content is 40 percent of mortar volume. U type test is most appropriate for evaluating self compactability. Bharathi V Subramania, Ramasamy J.V., Ragupathy R. and Seenivasan C. in their paper entitled “Workability and Strength Study of High Volume Flyash Self-Compacting Concrete” have focused investigation on the workability characteristics and strength parameters of SCC containing fly ash. Nowadays, performance expectations from concrete structures are more demanding. As a result, concrete is required to have properties like high fluidity, self compactability, high strength, high durability, better serviceability and long service life. In order to address these requirements, self-compacting concrete (SCC) was developed in 1980s in Japan. The cement used for the study was 43 grade ordinary Portland cement and was partially replaced by 0 %, 25%, 50% and 75% of fly ash. Based on the guidelines of European Federation of producers And contractors of specialist products for structures (EFNARC), the mix proportion were chosen and the cement content alone was varied without varying the aggregate content. The water- powder ratio was kept at 0.4 throughout the study. Water reducing admixture (WRA) and viscosity modifying admixture (VMA) were used to improve the workability characteristics. Akinbinu (2010) reported that compressive strength of concrete mix containing steel slag have higher value when compared with laterite. Shih et al. (2004) studied that the characteristics of brick made from steel slag and revealed that it reduced the required firing temperature. Alizadeh et al. (2003) concluded that steel slag can be used as aggregate in concrete, however it has more advantages in high strength concrete than normal strength concrete. Wu et al. (2007) reported that the high temperature property of Stone Mastic Asphalt (SMA) mixture with steel slag is improved when compared with SMA mixture with basalt. The better physical properties of steel slag enhances the ability of resisting permanent deformation at high temperature. Adegoloye et al. (2013) investigated the effects of EAF and stabilized argon oxygen decarburization (AOD) stainless steel slags as coarse aggregate replacements in concrete. Partial (50%) and full (100%) replacements of virgin coarse aggregate with the EAF and AOD slag aggregates increased the compressive strength and dynamic modulus relative to the control concrete. However, the concrete porosity and gas permeability were higher for concrete with stainless steel slags, although the permeability was still lower than the maximum recommended value for building construction. The concrete expansion was measured on prismatic samplesstored in water, and it was found that concrete with EAF slag had similar expansions to the control, but the AOD slag concrete expanded more, which was likely due to a higher MgO content. The expansion amounts for all concretes were still below the maximum allowable limit. Ali (2003) investigated the effect of aggregates on the corrosion potential of steel reinforcement in concrete and compared the results from concrete made with 100% limestone and 100% steel slag as coarse aggregate. The split tensile strength of concrete increased with the use of steel slag aggregates. The chloride diffusion coefficient was not very different between the concretes with different coarse aggregates. After thermal cycling, the concrete with steel slag aggregates still had the highest split tensile strength, and the reduction in strength with increasing thermal cycles was greater for the concretes with limestone aggregates. Ali et al. (2011) examined the use of EAF slag aggregate as 0, 10, 50 and 100% replacements of coarse aggregate in concrete. After 28 days of curing, the concrete specimens were exposed to a sulfate solution for 20 weeks. There was minimal volumetric change for all concrete mixes, demonstrating that concrete with EAF slag aggregates is as resistant to sulfate attack as concrete with granite aggregate. Ameri et al. (2012) analysed different replacements (0, 25, 50, 75, and 100%) of virgin aggregate with BOF slag aggregate. The authors found that 25% BOF slag increased the compressive strength relative to the control (100% virgin aggregate) while the other replacement ratios decreased the strength. Not all replacement levels were tested for flexural strength, but in general, the inclusion of BOF slag aggregate increased the flexural strength of concrete. Anastasiou et al. (2014) tested mortar and concrete with combined coarse EAF slag aggregates, fine construction and demolition waste (CDW), and high calcium fly ash. With 100% coarse EAF aggregate, the compressive, split tensile, and flexural strengths and the modulus of elasticity increased relative to the control concrte. When CDW fine aggregates were used, the addition of coarse EAF slag aggregates did not significantly improve the properties. The high calcium fly ash further improved the hardened properties of the concrete with 100% coarse EAF slag aggregates, but only at later ages (>1 year). The use of coarse EAF slag aggregates did not appear to increase the water absorption, but the concrete porosity was slightly increased; the use of CDW with and without EAF slag aggregates increased the porosity and water absorption. Under pressure, the water penetration increased when EAF slag and/or CDW aggregates were used. The chloride penetration resistance slightly improved with EAF slag aggregates and decreased with CDW. Coppola et al. (2010) studied partial replacements (0, 10, 15, 20, and 25%) of the total (coarse, intermediate, and fine) aggregates in concrete with EAF slag aggregate. As the percentage of EAF slag aggregate increased, the slump loss rate increased, the modulus of elasticity increased, and the compressive, split tensile, and flexural strengths increased. Increasing contents of EAF slag aggregates drastically increased the drying shrinkage strain in the concrete with 25% EAF slag aggregate increasing the shrinkage strain by 30% at later ages. Ducman & Mladenovic (2011) studied the use of fine EAF slag aggregate (0-4 mm size) as partial and full replacements of a cement mortar with bauxite aggregates (0-6 mm size) for refractory applications. It was found that EAF steel slag was not suitable for high-temperature applications because of a phase transformation around 700-800°C which led to expansion, cracking, and reduced mechanical properties. However, the transformation is irreversible, so if the EAF slag aggregate is heated to 1000°C and then added to the concrete, then the concrete remains stable in high-temperature applications. Liu et al. (2011) tested the use of EAF slag aggregates as replacements of both fine and coarse aggregates in concrete. By replacing 100% coarse and fine aggregate with EAF slag aggregate, the compressive strength increased while the flexural strength slightly decreased relative to the control concrete. The drying shrinkage decreased with the use of EAF slag aggregates. Lun et al. (2008) investigated various methods to reduce the free CaO content in BOF steel slag fine aggregate for use in concrete. The treatment methods were by steam for 8 and 12 hours and by autoclaving for 3 hours, all of which reduced the free CaO content. By soaking mortar bars in hot water, the steam-treated steel slag aggregates delayed the onset of, but did not prevent, deleterious expansion while the autoclave-treated steel slag did not undergo deleterious expansion. Initial results, without deleterious expansion, showed that the treated slag aggregate mortars had higher compressive and flexural strengths than the control with untreated slag aggregate. After the mortar was hot water cured and the aggregates expanded, the compressive and flexural strengths decreased, although the strengths were relatively consistent for the autoclaved slag aggregate mortar. Mathew et al. (2013) replaced crushed granite coarse aggregate with 0, 20, 40, 60, 80, and 100% steel slag aggregate. The concrete slump increased with increasing steel slag aggregate content. As the slag aggregate content increased, the compressive, split tensile, and flexural strengths decreased. However, the target flexural strength for concrete pavements was achieved by all steel slag aggregate concretes. Papayianni & Anastasiou (2011) studied concrete with full replacements of coarse aggregate and partial replacements of fine aggregate with EAF slag aggregate in addition to 60% replacement of cement with high calcium fly ash. The EAF slag aggregates increased the unit weight of the concrete. Replacing only the coarse aggregate with EAF slag aggregates resulted in higher compression, split tension, and flexural strengths versus the virgin aggregate control mixes, both with and without fly ash. With coarse and fine EAF slag aggregates, the concrete resulted in slightly higher compression, split tension, and flexural strengths than the virgin aggregate control mix with fly ash. The elastic modulus was higher for the concrete with EAF slag aggregates compared with the virgin mixes with and without fly ash. The concrete with coarse EAF slag aggregate and fly ash showed improved abrasion resistance compared with the control concrete with limestone aggregate and no fly ash. A leaching test revealed that the leachate from the concrete with coarse EAF slag aggregate and fly ash was minimal and was categorized as ”inactive waste”. San-Jose et al. (2014) tested concrete with two different sources of EAF slag aggregates. The total aggregate consisted of mainly EAF slag coarse and fine aggregates (92-93% by weight) with some limestone filler added. The water-to-cement ratio was not constant between all mixtures, which may have skewed the interpretation of the results. Relative to a control concrete with limestone aggregates, the concretes with EAF slag aggregates resulted in similar split tensile strengths and moduli of elasticity but higher compressive strengths. The concrete porosity increased slightly for the concretes with EAF slag aggregates relative to the control. The depth of water penetration was below the allowable limit for all mixtures, although the concretes with EAF slag aggregates exhibited slightly lower depths of penetration than the control. Tarawneh et al. (2014) investigated by weight replacements of fine, intermediate, and coarse limestone in concrete with 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% SFS aggregates. The general trend indicated an increase in compressive strength with increasing SFS content. Brand & Roesler (2014) tested concrete mixtures with 100% coarse virgin SFS, evaluating the effects of the SFS with high (3.4%) and low (<0.1%) free CaO contents. The compressive and split tensile strengths were lower than dolomite concrete, with the exception of the low free CaO SFS concrete compressive strength.

3. PROPOSED SYSTEM

The proposed system investigates the feasibility of incorporating floor steel slag as a partial replacement for fine aggregates in self-compacting concrete (SCC) to enhance its mechanical and durability properties while promoting resource efficiency. The system follows a structured methodology involving material selection, mix design, testing, and analysis.

1. Material Selection:

- **Cement:** Ordinary Portland Cement (OPC) as the primary binder.
- **Fine Aggregate:** Natural river sand (control) and floor steel slag as a partial replacement (0%, 5%, 10%, 15%, 20%, and 25%).
- **Coarse Aggregate:** Crushed stones with a nominal size of 12-20mm.
- **Admixtures:** Superplasticizers to improve workability and viscosity-modifying agents (VMA) to prevent segregation.
- **Water:** Potable water to maintain the required water-cement ratio.

2. Mix Design & Optimization:

- SCC mix is designed following EFNARC guidelines, considering filling ability, passing ability, and segregation resistance.
- Floor steel slag is introduced in incremental percentages to assess its impact on fresh and hardened SCC properties.

3. Experimental Evaluation:

Fresh Properties Testing:

- **Slump Flow Test:** To assess the flowability of SCC.
- **T50 Test:** To determine the viscosity and workability.
- **V-Funnel Test:** To evaluate segregation resistance.
- **L-Box & U-Box Tests:** To measure passing ability and stability.

Hardened Properties Testing:

- **Compressive Strength Test:** Evaluates the load-bearing capacity.
- **Split Tensile Strength Test:** Determines the tensile performance.
- **Durability Assessment:** Investigates resistance to environmental effects such as sulphuric acid exposure.

4. Comparative Analysis & Optimization:

- The results of SCC with floor steel slag are compared against conventional SCC to determine the optimum replacement percentage.
- A cost-benefit and environmental impact assessment is conducted to validate the feasibility of large-scale implementation.

5. Practical Implementation & Recommendations:

- The study concludes with recommendations for the industrial application of steel slag-based SCC, considering economic and environmental benefits.

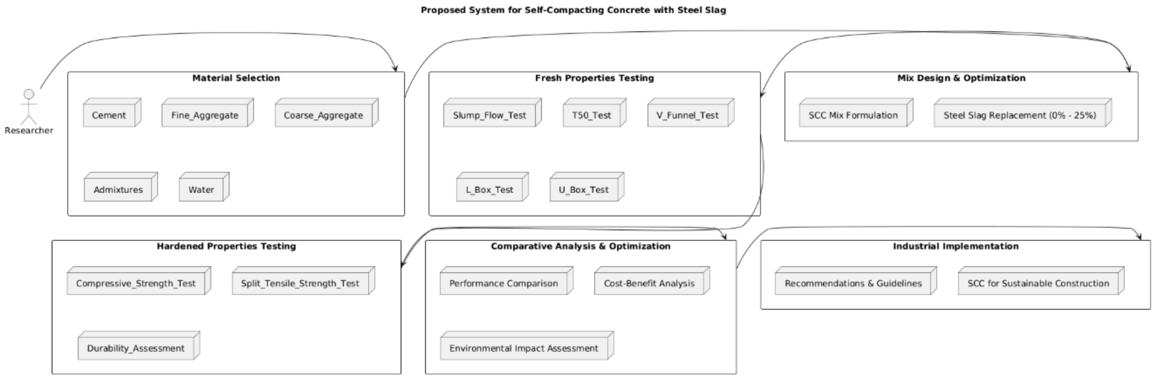

Figure 1 Presents the Block Diagram of Proposed System.

4. RESULTS AND DISCUSSIONS

4.1 Test Results and Graphs

4.1.1 Fresh concrete properties of SCC

Table 4.1 Fresh properties of SCC test results

Steel slag (%)	**Slump value (mm)**	**T_{50} (sec)**	**J-ring value (mm)**
0	603	4.1	550
5	607	3.9	555
10	610	3.5	558
15	612	3.4	560
20	617	3.1	563

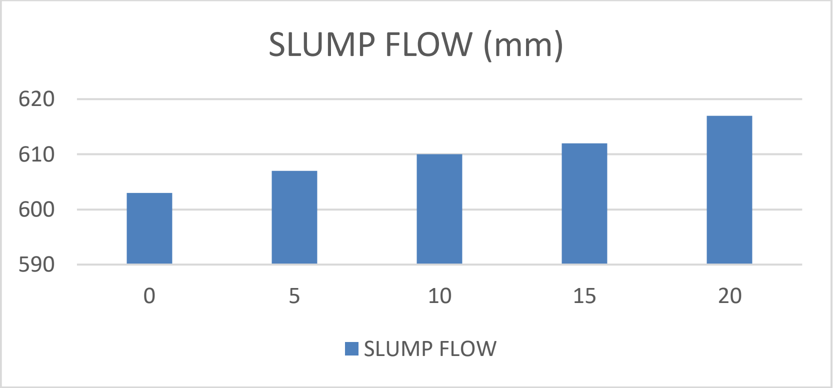

Figure 4.1 : Slump values graphs

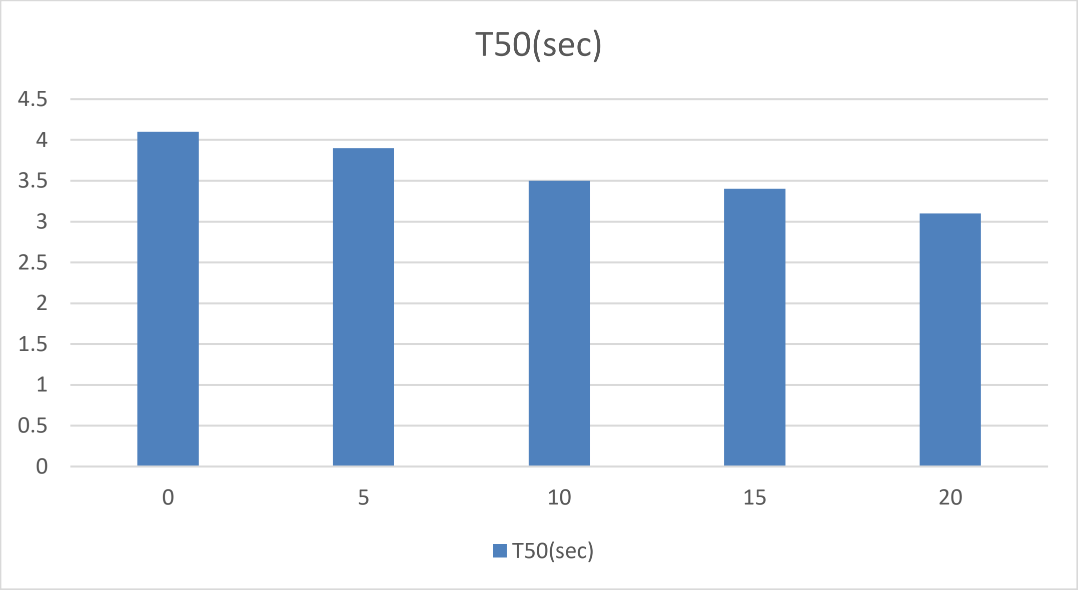

Figure 4.2 : T50 values graphs

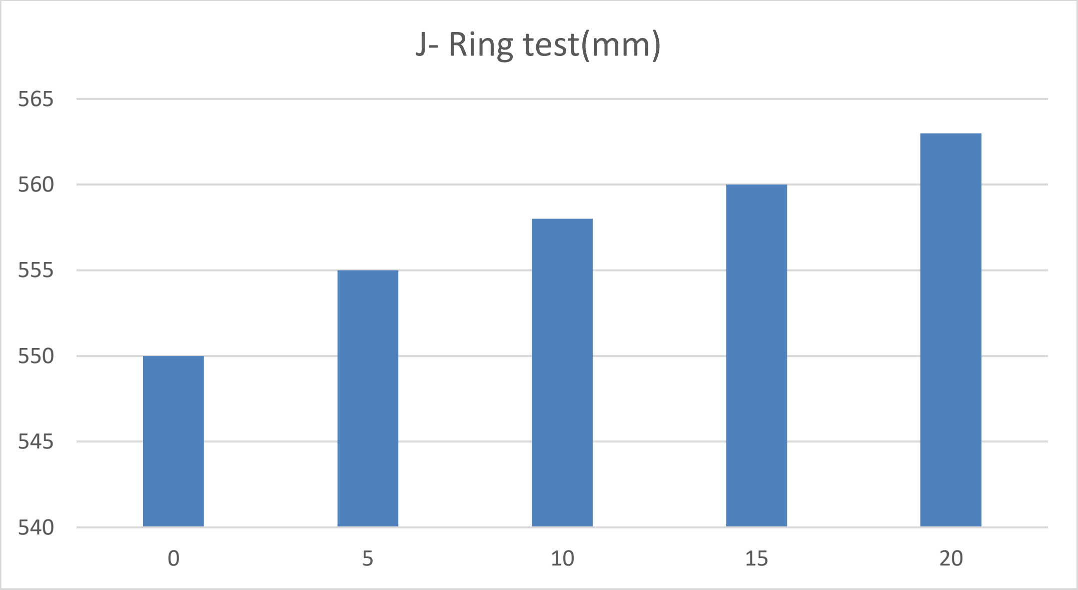

Figure 4.3 : j-ring test values graphs

4.1.2 Harden concrete properties of SCC

4.1.2.1 Compressive strength

Table-4.2 Compressive Strength at 7, 14 and 28 days for SCC

Steel slag (%)	Compressive strength in (Mpa)		
	7 DAYS	14 DAYS	28 DAYS
0	33.9	39.9	47.43
5	34.4	41.2	48.92
10	36.2	43.2	50.4
15	37.6	44.6	52.6
20	29.41	35.43	41.52

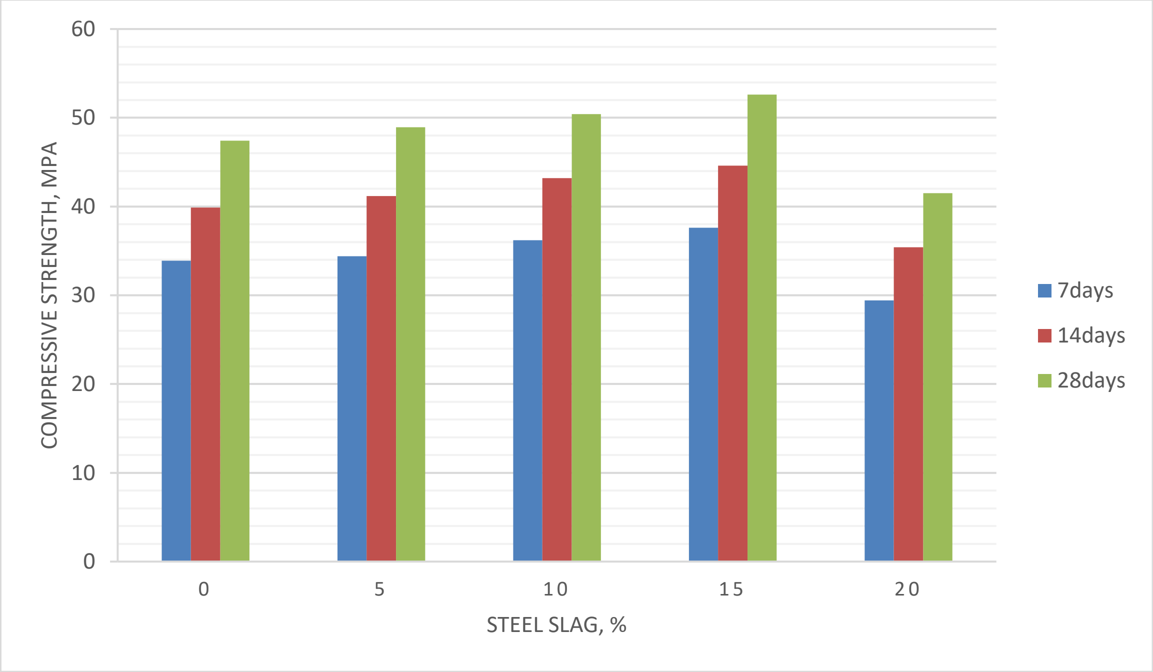

Figure 4.4: Compressive strength test result graph for SCC

4.1.2.2 Tensile strength

Table-4.3 Tensile Strength at 28 days for SCC

Steel slag (%)	28 Days Tensile strength (Mpa)
0	6.98
5	7.21
10	7.35

15	7.4
20	7.28

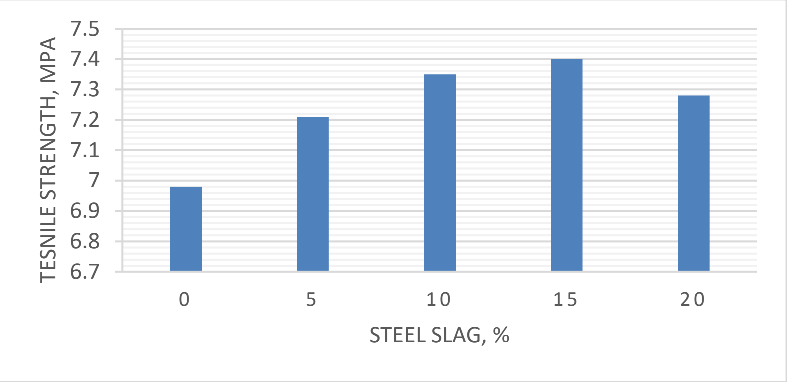

Fig -4.5: Compressive strength test result graph for SCC

4.2 DISCUSSION

4.2.1 Strength Characteristics

The compressive strength values obtained by testing standard cubes for SCC (with partial replacement of fine aggregate with steel slag) samples. The average value is taken as final output. The SCC mix has strength above 40 MPa in compression. The compressive strength of Steel slag-based SSC, replacement of 15% gains higher strength compare to conventional SSC. The strength for Steel slag-based SSC gains 10.9% more than Conventional SSC.

The Split tensile strength values obtained by testing standard cylinders for SCC (with partial replacement of fine aggregate with steel slag) samples. The average value is taken as final output. The tensile strength of Steel slag-based SSC, replacement of 15% gains higher strength compare to conventional SSC. The strength for GGBS based SSC gains 6% more than Conventional SSC.

5. CONCLUSIONS

The study demonstrates the potential of utilizing steel slag as a partial replacement for fine aggregates in self-compacting concrete (SCC), offering both structural and economic benefits. Experimental results confirm that incorporating steel slag enhances the compressive and tensile strength of SCC, with an optimal replacement level of 15%, yielding a 10.9% increase in compressive strength and a 6% improvement in tensile strength compared to conventional SCC. Additionally, the use of steel slag aggregates proves to be a cost-effective alternative, reducing overall material expenses by approximately 10%. By integrating waste construction materials into concrete production, this approach not only enhances performance but also promotes sustainable construction practices, addressing environmental concerns associated with material waste and resource depletion.

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