Smart Self-Compacting Concrete: Enhancing Sustainability with Steel Slag as an Eco-Friendly Alternative

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ABSTRACT

The study explores the feasibility of recycling floor steel slag as a sustainable fine aggregate in the production of Self-Compacting Concrete (SCC). By replacing sand with varying percentages of steel slag (0%, 5%, 10%, 15%, 20%, and 25%), the research evaluates the impact on workability, compressive strength, and split tensile strength of SCC mixes. Key tests such as slump flow diameter and T50 time were conducted to assess the flow properties, while mechanical properties were analyzed in the hardened state. The findings reveal that incorporating steel slag enhances certain physical and mechanical properties of SCC, outperforming conventional SCC in strength and durability. Additionally, this study highlights the economic and environmental benefits of utilizing industrial waste in concrete production, reducing raw material costs, and promoting eco-friendly construction practices.

Key words: Self-Compacting Concrete (SCC), Steel Slag, Slump Flow, T50 Time, Compressive Strength, Split Tensile Strength, Sustainable Construction

1. INTRODUCTION

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.

Self compacting concrete is a mix that can be compacted into every corner of formwork, by means of its own weight and without the need for vibrating compaction. Inspite of its high flowability, the coarse aggregate is not segregated. Thus, SCC eliminates the need of vibration either external or internal for compaction of concrete without compromising its engineering properties. Concrete is now no longer a material consisting of cement, aggregate, water and admixtures but it is an engineered material with several new constituents. The concrete today can take care of any specific requirements under most of different exposure conditions.

EFNARC has published specifications and guidelines for self compacting concrete (EFNARC 2002). Self compacting concrete can be defined as the concrete that is able to flow in the interior of the formwork, passing through the reinforcement, filling it in a natural manner, consolidating under the action of its own weight. The filling ability, passing ability and stability can be considered as the main properties of fresh SCC. To make durable concrete structures, sufficient compaction by skilled workers is required. However, gradual reduction in the number of skilled workers in Japan„s construction industry has led to similar reduction in the quality of construction work. One solution for achievement of durable concrete is the employment of self compacting concrete.

Self compacting concrete as the name signifies should be able to compact itself without any additional vibrations or compaction. Self compacting concrete should compact itself by its self weight and under gravity. Self compacting concrete should be able to assume any complicated formwork shapes without cavities and entrapment of air. The reinforcement should be effectively covered and aggregates should be fully soaked in concrete matrix. To meet performance requirements the following three types of self compacting concretes are available i.e., powder type, viscosity agent type and combination type.

Different test methods have been developed with a view to characterise the properties of SCC. So far, no single method or combination of methods has achieved universal approval. Similarly, no single method has been found to characterise all the relevant workability aspects. Thus, each mix design should be tested by more than one test method for the different workability parameters. For the initial mix design of SCC, all three workability parameters such as filling ability or flowability, passing ability and stability or segregation resistance need to be assessed to ensure that all aspects are fulfilled. For site quality control, two test methods are generally sufficient to monitor production quality.

One of the significant limitation in the ready adoption of self compacting concrete (SCC), also called self consolidating concrete, in India is the lack of availability of appropriate mixture proportioning methods. SCC mixes are likely to have high paste contents. For concrete with a maximum size aggregate of 16 to 20mm the paste content (cement + filler + water) is likely to range from 38 to 45 percent. The (absolute) volumes of coarse aggregates and fine aggregate are likely to be equal or that of fine aggregates may be more. Viscosity modifying agents are needed in all SCC mixes so that no bleeding or segregation occurs when there are variations in the moisture contents of the aggregates a phenomenon that is usually encountered at construction sites. Though, the V-funnel, L-box, U-box, and slump flow tests are yet to be incorporated into national standards, they have become now universally accepted by researchers and practitioners alike.

The stability of fresh concrete (cohesiveness) requires increased amount of fine materials in the mixers. Fine and coarse aggregates could be partially replaced with fly ash in producing high-strength self-compacting concrete with sufficient flow property and low segregation potential without affecting the early age strength. In addition, fly ash in self compacting concrete helps to improve later age strength beyond 28 days.

Self-compacting concrete is generally less tolerant to changes in the characteristics and dosages of its constituents. The most critical tests for evaluating self-compactability loss seem to be slump flow and J-ring tests; i.e., robustness is assured if the parameters of these tests are satisfied. The incorporation of VMA seems to increase the robustness of SCC significantly.

Hardened mechanical properties of SCC are similar to that of normally vibrated concrete. There is wide range of materials and mixes for SCC. There is clear relationship between cylinder and cube compressive strength, tensile and compressive strength, and elastic modulus and compressive strength of SCC similar to that of normally vibrated concrete. Bond strength of SCC to reinforcing and prestressing steel is similar to or higher than that of normally vibrated concrete.

Self compacting concrete is placed or poured in the same way as ordinary concrete but without vibration. It is very fluid and can pass around obstructions and fill all the nooks and corners without the risk of either mortar or other ingredients of concrete separating out. At the same time there is no entrapped air or rock pockets. This type of concrete mixture does not require any compaction and it saves time, labour and energy. The surface finish produced by self-compacting concrete is exceptionally good and patching will not be necessary.

Self compacting concrete exposed to aggressive sulphuric acid environment is a key durability issue that affects the life cycle performance and maintenance costs of vital civil engineering structure. Sulphuric acid in ground water, chemical waste or generated from oxidation of sulphur bearing compounds in backfill can attack substructure concrete members. Moreover, concrete structures in industrial zones are susceptible to deterioration due to acid rain of which sulphuric acid is a chief

component. Considerable damage can occur to sewage systems by bioorganic sulphuric acid corrosion. Blended binders, hybrid fibers can improve the resistance of SCC to sulphuric acid attack.
The use of steel and synthetic fibres is known to alter flow properties of self compacting concrete. To maintain self consolidating ability, the fibre length and total volume must be controlled, which can restrict the gain in toughness imparted by fibres. Thus fibres intended for use in SCC need to be carefully optimized.
A database was created and evaluated regarding the relations between compressive strength, tensile strength, modulus of elasticity and bond properties which have shown compressive strength of SCC and normal concrete are similar under comparable conditions. Tensile strength, modulus of elasticity and shrinkage of SCC and normal concrete differ, but the differences vary within the usual scatter width known for normal concrete.

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.

Naveen Kumar C., Kiran V. John, Jagadish Vengala and Ranganath R. V. in their paper entitled “Self-Compacting Concrete with Fly Ash and Metakaolin”, have studied the properties of SCC containing fly ash and metakaolin. From their study they have concluded that mixes with different fillers like silica fume and metakaolin help in attaining a high early strength of around 50-70 MPa which is very useful in pre-cast applications. They also can provide high durability when used along with fly ash, The experimental study reported in this paper showed that fly ash can be used in large quantities in SCC and cement content can be reduced to as low as 200kg/cum without losing the requisite characteristics of SCC, blends of metakaolin and fly ash used as filler performed better than the use of fly ash or metakalin as individual filler in SCC. Good compressive and tensile strengths, good flowability and adequate self compactability were obtainable with only marginal increase in the 1superplasticizer dosage. The visual assessment of mixes containing metakaolin showed that VMAis not necessary for metakaolin incorporated SCC.

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.

3. PROPOSED SYSTEM

The proposed system focuses on developing Steel Slag-Based Self-Compacting Concrete (SCC) as an eco-friendly alternative to conventional SCC. This system aims to improve workability, strength, and durability while addressing environmental concerns by utilizing industrial waste (steel slag) as a partial replacement for fine aggregates.

1. Materials and Mix Design

- **Binders:** Ordinary Portland Cement (OPC) is used as the primary binder.
- **Fine Aggregate Replacement:** Sand is partially replaced with floor steel slag at different percentages (0%, 5%, 10%, 15%, 20%, and 25%) to analyze its effect on SCC properties.
- **Superplasticizer:** High-range water-reducing admixtures are added to enhance flowability and maintain SCC characteristics.
- **Water-to-Binder Ratio (w/b):** Maintained as per SCC mix design guidelines to balance workability and strength.
- **Curing Methods:** Water Curing for 7 & 28 Days at ambient temperature to achieve optimum hydration and strength development.

2. Workability Assessment

To assess the self-compacting ability of steel slag-based SCC, the following tests are performed:

- **Slump Flow Test:** Measures the free-flowing ability of SCC without external compaction.
- **T50 Time Test:** Evaluates the viscosity and filling ability of SCC mixes with different steel slag percentages.

Results indicate that while SCC remains workable, increasing steel slag content reduces flowability, requiring adjustments in water content and admixtures.

3. Hardened Properties Evaluation

- **Compressive Strength Test:**
  - Concrete cubes (15 cm × 15 cm × 15 cm) are cast and tested at 7 and 28 days to evaluate strength development.
  - Compressive strength improves up to 15% steel slag replacement, after which a slight decline is observed.
- **Split Tensile Strength Test:**
  - Cylindrical specimens are tested to determine tensile strength and crack resistance.
  - SCC containing up to 15% steel slag shows enhanced tensile properties, indicating improved bonding and durability.

4. Key Findings

- **Optimal Performance:** 15% steel slag replacement achieves the highest compressive and tensile strength, enhancing SCC durability.
- **Workability Variation:** Increasing steel slag content affects slump flow and viscosity, requiring mix design adjustments.
- **Sustainability Benefits:** Utilizing steel slag reduces sand dependency, minimizes industrial waste, and contributes to greener construction practices.

This study highlights Steel Slag-Based SCC as a cost-effective, high-performance, and environmentally sustainable alternative for modern construction applications.

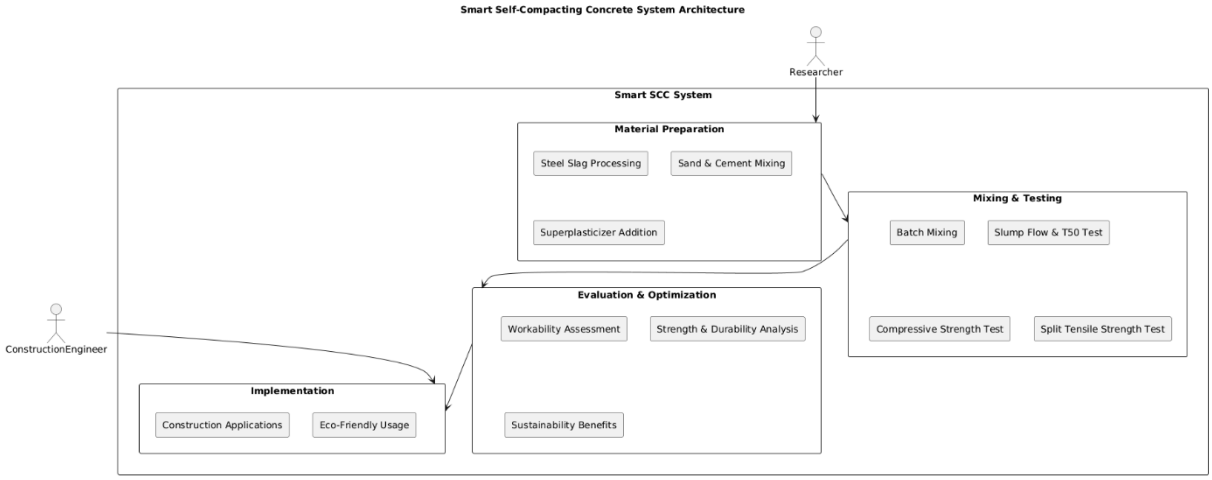

Figure 1 Presents the Block Diagram of Proposed System.

4. RESULTS AND DISCUSSIONS

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

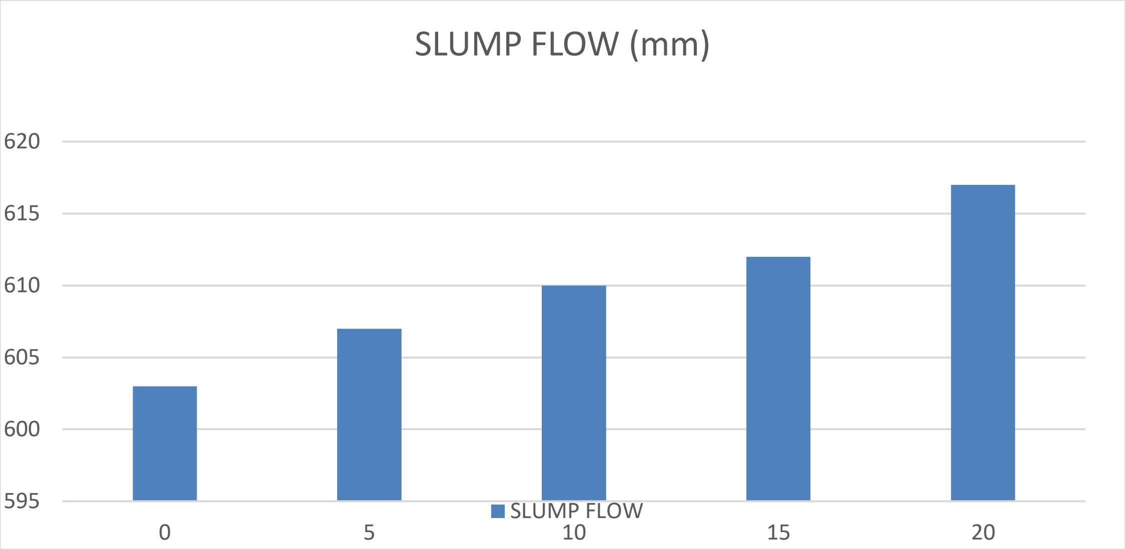

Figure 4.1: Slump values graphs

4.2 Harden concrete properties of SCC

4.2.1 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

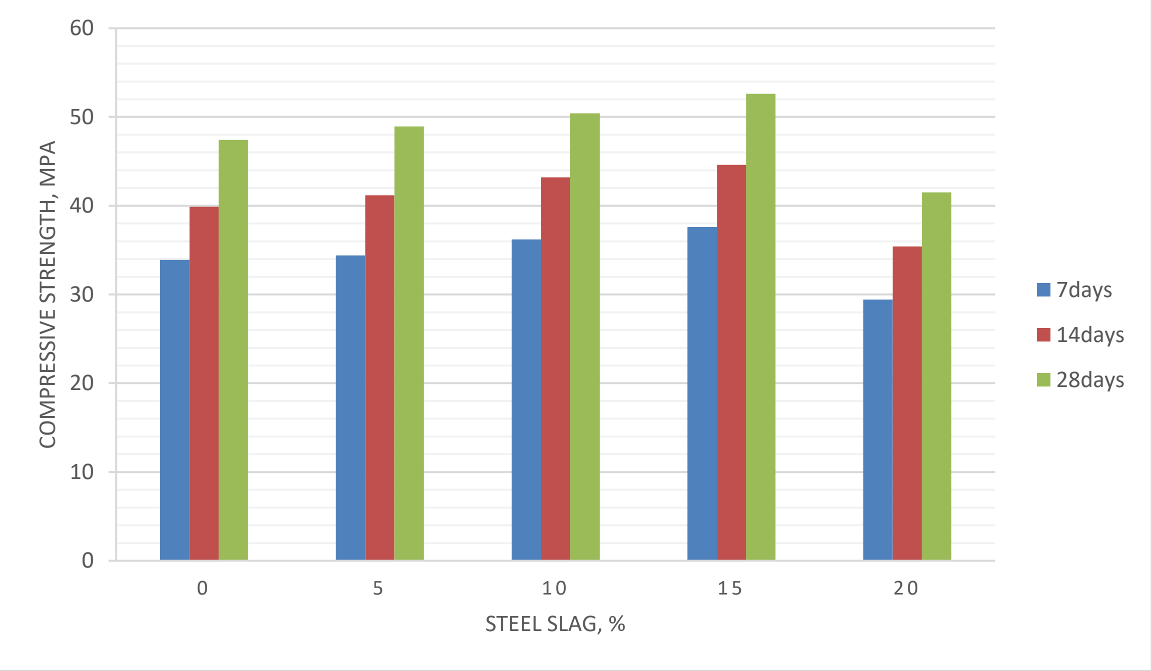

Figure 4.2: Compressive strength test result graph for SCC

5. CONCLUSIONS

The study demonstrates the feasibility and effectiveness of utilizing steel slag as a partial fine aggregate replacement in Self-Compacting Concrete (SCC). The results indicate that incorporating steel slag in SCC improves mechanical properties such as compressive and tensile strength while maintaining adequate workability. The optimal replacement level was found to be 15%, where SCC exhibited the highest strength without compromising its self-compacting ability.

Additionally, the use of steel slag contributes to sustainable construction by reducing the dependence on natural sand, minimizing industrial waste disposal issues, and lowering environmental impact. However, higher percentages of steel slag lead to reduced workability, requiring modifications in mix design through adjustments in water content and admixtures.

Overall, Steel Slag-Based SCC presents a cost-effective, high-performance, and eco-friendly alternative to conventional SCC, aligning with modern sustainable construction practices. Future research can explore long-term durability aspects, microstructural analysis, and real-world applications to further optimize its performance in diverse construction environments.

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