Steel Slag In Concrete: Sustainable Fine Aggregate Optimization

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Abstract- *This study investigates the optimization of concrete performance through the partial replacement of fine aggregate with steel slag, focusing on varying replacement levels of 15%, 20%, 25%, 30%, 35%, 40%, and 45%. The primary objective is to enhance the mechanical properties of concrete, specifically compressive strength, flexural strength, and split tensile strength. Experimental results indicate that the incorporation of steel slag significantly influences the performance of concrete mixtures. Among the various replacement levels tested, the 25% steel slag replacement exhibited the most favourable outcomes, achieving the highest compressive, flexural, and split tensile strengths. These findings highlight the potential of using steel slag as an effective alternative to conventional fine aggregates, promoting sustainable construction practices while improving concrete durability and strength. The study contributes valuable insights into the application of steel slag in concrete, paving the way for further research and development in eco-friendly building materials.*

Keywords- Steel Slag, fine aggregate, compressive strength, flexural strength, split tensile strength, Concrete.

I. INTRODUCTION

Steel slag, a by-product of the steel production process, serves as a viable aggregate for concrete applications. Its incorporation can enhance the material properties of concrete[1]. It offers several benefits, including improved compressive strength, increased durability, and greater stability [2]. Steel slag helps minimize the environmental impact of concrete production by recycling industrial waste and decreasing carbon emissions[3]. However, its application requires careful consideration of volume stability to prevent potential problems like cracking and spalling[1]. Incorporating steel slag into concrete offers a highly promising approach to creating construction materials that are not only more sustainable but also exceptionally durable [2, 3]. Many studies on concrete containing steel slag have consistently shown exceptional mechanical strength and durability properties. Industrial wastes like blast furnace slag, fly ash, and silica fume, steel scraps are increasingly being utilized as supplementary materials to replace cement in concrete.

Steel slag offers several benefits when used in concrete, enhancing its overall performance and sustainability. As a partial replacement for traditional aggregates, steel slag improves compressive strength, durability, and stability. Its unique properties help reduce the environmental impact of concrete production by recycling industrial waste and lowering carbon emissions. Additionally, steel slag contributes to increased resistance against cracking and spalling, making it an excellent choice for applications requiring robust and long-lasting construction materials.

R. Awasthi et al. (2021) investigated the mechanical properties of concrete using steel slag as a partial replacement for fine aggregates. The optimal replacement level was found to be 20%, which resulted in an 8% increase in compressive strength, a 7.5% increase in split tensile strength, and a 40.625% increase in flexural strength[4]. Similarly, Kunal K. Das et al. (2020) explored preplaced aggregate concrete (PAC) by partially replacing cement with ground granulated blast furnace slag (GGBS) and silica fume (SF). The study concluded that a mix with 30% GGBS and 10% SF showed improved strength and durability, though increased shrinkage was observed [5].

Arthi AJ et al. (2020) examined silica sand and copper slag as replacements for M-sand in concrete, focusing on compressive, flexural, and split tensile strengths. The results indicated significant strength improvements when these materials were used[6]. Maria et al. (2019) studied the use of different types of slag as cement substitutes, showing that blast furnace slag significantly improved mechanical properties, while ladle furnace slag was more suitable for non-structural applications [7].

Madhavi et al. (2018) investigated the effects of copper slag as a fine aggregate replacement in M40 grade concrete, specifically focusing on sulfate attack resistance [8]. Dhoble et al. (2018) reviewed the various applications of steel slag, such as its use in concrete, bituminous mixes, and even innovative uses like mechanomutable binders and green artificial reefs [9]. Mani et al. (2016) explored replacing coarse aggregates with steel slag, demonstrating improved compressive strength and density in concrete mixes [10].

Further studies, including those by Jalil et al. (2016) and San-Jose et al. (2014), explored the potential of using slags as pozzolanic materials and replacing natural aggregates with oxidizing slags. These studies found that slags can maintain or even enhance the mechanical properties of concrete [11, 12], Research by Kothai et al. (2014) and Pellegrino et al. (2013) emphasized the environmental and mechanical benefits of using steel slag and electric arc furnace slag as replacements for fine and coarse aggregates[13, 14] .different loading conditions.

II. EXPERIMENTAL SETUP

In our experimental study, we prepared eight different trial mix combinations to investigate the effects of various materials on concrete properties. One of these mixes served as the nominal mix, which was composed of the standard components: cement, sand, aggregate, water, and fly ash. The inclusion of fly ash in the nominal mix was essential due to the guidelines set by IS 10262:2019, which recommend that the cement content should not exceed 450 kg/m³ in concrete mixes. Without adding fly ash, the cement content for our target mix design would surpass this limit, so we incorporated fly ash as a partial cement replacement.

In addition to the nominal mix, we developed seven other trial mixes by replacing fine aggregate with steel slag in different percentages—15%, 20%, 25%, 30%, 35%, 40%, and 45%. These variations were designed to assess how increasing steel slag content affects the mechanical properties of the concrete. Consistent across all mixes, fly ash was kept at 20%, a percentage selected based on insights from previous literature that suggested it would optimize performance. The goal of these trials was to find the most effective combination of materials that would enhance the strength and durability of concrete while adhering to the standards set by the IS code.

Table 1Trial mixes with steel slag

Trial mix M65	**7 days**	**14 days**	**28 days**	**Total**
Mix 1 Normal mix	**3**	**3**	**3**	**9**
Mix 2 15% steel slag	**3**	**3**	**3**	**9**
Mix 3 20 % steel slag	**3**	**3**	**3**	**9**
Mix 4 25 % steel slag	**3**	**3**	**3**	**9**
Mix C5 30 % steel slag	**3**	**3**	**3**	**9**
Mix C6 35 % steel slag	**3**	**3**	**3**	**9**
Mix C7 40 % steel slag	**3**	**3**	**3**	**9**
Mix C8 45 % steel slag	**3**	**3**	**3**	**9**

Table 2 presents the mix designs for the various trial mixes included in the study. Each mix incorporates different proportions of materials, specifically varying the percentage of steel slag as a partial replacement for fine aggregate.

Table 2 Mix Designs of trial mixes

Notation	Cement (Kg/m^3)	Fine Aggregate (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Fly ash	water	Steel slag
Mix 1	391.78	653.23	1209.58	97.94	138.01	0
Mix 2	391.78	555.24	1209.58	97.94	138.01	97.98
Mix 3	391.78	522.58	1209.58	97.94	138.01	130.65
Mix 4	391.78	489.92	1209.58	97.94	138.01	163.31
Mix 5	391.78	457.26	1209.58	97.94	138.01	195.97
Mix 6	391.78	424.6	1209.58	97.94	138.01	228.63
Mix 7	391.78	391.94	1209.58	97.94	138.01	261.29
Mix 8	391.78	359.27	1209.58	97.94	138.01	293.95

III. DISCUSSION OF THE FINDINGS:

A total of 72 cubes were tested using a 3000 kN capacity compressive testing machine to evaluate the effects of steel slag replacement on concrete's compressive strength. The testing aimed to determine the optimal level of steel slag substitution that yields the highest compressive strength. The results of these experiments are presented in Table A, highlighting the performance variations across different replacement percentages. This data is crucial for identifying the most effective use of steel slag in concrete applications.

Table 3 Compressive strength of cube

Mix	7 days	14 days	28 days
Mix 1	51	63	72
Mix 2	52.1	64	72.2
Mix 3	56	67	78
Mix 4	60	70	80
Mix 5	55	66	73
Mix 6	54.3	64.3	72.8
Mix 7	53	63	72.6
Mix 8	53	62.9	71.6

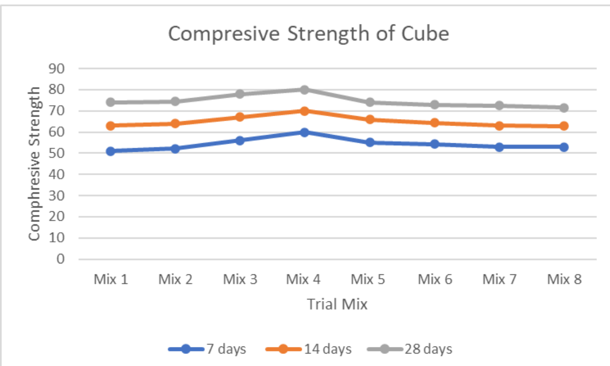

Figure 1Compressive strength of cubes

A total of 72 beams were tested to evaluate the flexural strength of concrete with varying percentages of steel slag as a partial replacement for fine aggregate. The goal was to determine the optimal level of steel slag substitution that enhances flexural strength. The results of these tests are detailed in Table C, showcasing the performance variations across different replacement percentages. This data is vital for optimizing steel slag's application in concrete structures.

Table 4 Results of flexural strength test

Mix	7 days	14 days	28 days
Mix 1	4.2	5.6	7.3
Mix 2	4.3	5.66	7.39
Mix 3	4.9	6	8
Mix 4	5	6.2	8.2
Mix 5	4.6	5.83	7.43
Mix 6	4.39	5.75	7.40
Mix 7	4.33	5.65	7.3
Mix 8	4.3	5.6	7.22

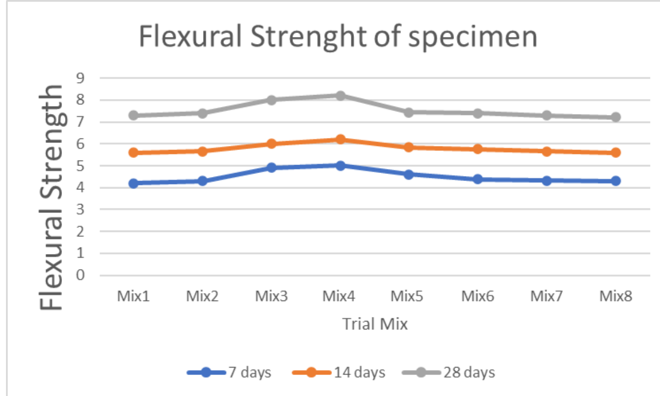

Figure 2Flexural strength of beam specimen

Seventy-two cylinders were subjected to testing using a 3000 kN capacity testing machine to assess the split tensile strength of concrete incorporating steel slag as a partial replacement for fine aggregate. The objective was to identify the optimal percentage of steel slag substitution that maximizes split tensile strength. The results of these tests are summarized in Table B, illustrating the performance differences across various replacement levels. This information is essential for optimizing the use of steel slag in concrete applications.

.Table5 Results of split tensile test

Mix	7 days	14 days	28 days
Mix 1	4.0	5.2	7.00
Mix 2	4.05	5.25	7.03
Mix 3	4.56	5.9	7.6
Mix 4	5	6.2	8
Mix 5	4.3	5.35	7.19
Mix 6	4.22	5.35	7.0
Mix 7	4.15	5.25	6.98
Mix 8	4.2	5.3	6.92

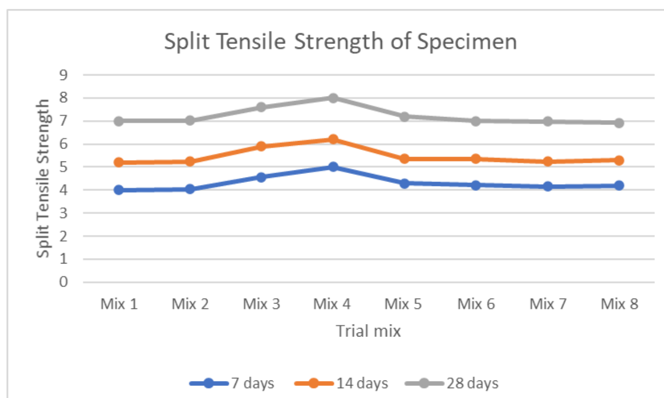

Figure 3 Split tensile strength of cylinder specimen

IV. CONCLUSIONS

Within the constraints of the current study, the following conclusions are drawn.

1. A 25% replacement of fine aggregate with steel slag consistently achieves optimal strength and stability in various trials, highlighting its effectiveness as a sustainable concrete alternative.
2. The modified concrete exhibits over a 10% increase in tensile strength compared to conventional mixes, demonstrating improved performance and durability under tensile loads.
3. Early-age compressive strength of High-Performance Fiber-Reinforced Concrete (HPFRC) increases by about 17.65% over standard mixes, showcasing the benefits of fiber inclusion for enhanced performance during initial curing.
4. Based on the analysis, it can be concluded thatthe production cost of M65 grade High-Performance Concrete is approximately on par with that of the nominal mix. However, significant improvements in strength parameters have been observed, highlighting the added value of using High-Performance Concrete despite similar production costs.

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