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Mechanical Performance of Concrete with EOF Steel Slag as Partial Replacement for Coarse Aggregates

Rashmi Bhoumana
rbhoumana@gmail.com
Shri Shankaracharya Institute of Professional Management and Technology, Raipur, Chhattisgarh

Dr. Tarun Kumar Rajak
t.rajak@ssipmt.com
Shri Shankaracharya Institute of Professional Management and Technology, Raipur, Chhattisgarh

Toshan Singh Rathour
tsrathour@gmail.com
National Institute of Technology, Raipur, C.G., India

ABSTRACT

All Steel manufacturing industry generates by-products today, and one such by-product is Energy Optimized Furnace slag, i.e, EOF, steel slag. But EOF steel slag is less used in cement manufacturing. This study examines the feasibility of using EOF steel slag to replace natural aggregates in concrete, with the intention of minimizing waste disposal and conserving natural resources. Standardized tests were conducted to evaluate the physical, chemical, and mechanical characteristics of EOF steel slag. The results thus obtained were compared with those of natural aggregates. Concrete mix proportions were formulated in this research to obtain M30 grade concrete. The natural coarse aggregate in the designed mix was replaced with EOF steel slag aggregate at different percentages, from 0% to 100% in steps of 10%. Experimental studies were carried out to analyze the properties of fresh and hardened concrete, such as workability, compressive strength, splitting tensile strength, and flexural strength, for various replacement percentages of EOF steel slag aggregate. The best replacement ratio was found considering the outcomes of fresh and hardened concrete characteristics. Moreover, the correlation between flexural strength, splitting tensile strength, and compressive strength was investigated. The mechanical characteristics of EOF steel slag aggregates are similar to those of natural coarse aggregates. Nevertheless, the greater water absorption and surface roughness of EOF slag affect the workability of concrete. The mechanical characteristics of concrete made using a full replacement of natural aggregate with EOF steel slag are quite similar to those of normal concrete. From this study, one learns that concrete made from 100% replacement of EOF Steel slag as coarse aggregate has better strength characteristics. By utilizing EOF steel slag as a substitute for natural coarse aggregate in concrete, the issue of unsafe, environment-degrading practice of dumping steel slag can be avoided. In addition, an industrial byproduct like steel slag is utilized in an eco-friendly way. Use of EOF steel slag in concrete is an eco-friendly, useful, and cost-saving step. Use of EOF steel slag in concrete is an eco-friendly, useful, and cost-saving step.

Keywords: *Energy Optimised Furnace (EOF) steel slag, Conventional Concrete, Compressive Strength, Flexural Strength, Split Tensile Strength, and Workability.*

1. INTRODUCTION

An Energy Optimizing Furnace (EOF) is a technology used mostly in secondary steelmaking that produces slag as a byproduct of the steel production process. By combining oxygen blowing with electric arc melting, the EOF process aims to increase energy efficiency and decrease waste. Particularly in waste management and construction, the slag generated by this process offers a number of specific qualities and possible uses. Three separate but coupled reactors make up the Energy Optimising Furnace (EOF).

They are specifically a recuperator to repurpose waste heat for heating oxygen, a preheater to heat the scrap materials, and a furnace to make steel. By assessing the strength and durability characteristics, the researchers conduct a number of investigations to determine if iron and steel slag are suitable as aggregate in concrete. Ageing should keep the critical effect of free lime within acceptable bounds. The steel slag is stored for four to six months throughout this weathering or aging process, and free lime hydrates with ambient moisture. Long-term aging considerably reduces the amount of costly and hazardous components in steel slag.
The need to mine, transport, and process the natural material will be reduced if steel slag is utilized in place of natural aggregate. In addition, there will be less energy use, less disturbance of the land, less pollution of the air, land, and water, and fewer greenhouse gas emissions. Because steel slag eliminates the extraction and shipping stages of natural aggregate manufacturing, substituting steel slag for natural aggregate in concrete mixes can improve the sustainability of natural resources. Steel slag is produced as a by-product of the steelmaking process using a relatively small amount of energy. The steel industry would profit since their byproducts will be put to good use rather than being dumped in a dangerous manner, which would harm the environment.
The study's primary goals are to determine whether using EOF steel slag in place of natural coarse aggregate in concrete is feasible and to look into the characteristics of concrete that contains steel slag aggregate. By doing away with the need to remove natural aggregate, this study also improves sustainability.

2. MATERIALS AND METHODS

The study is conducted in two stages. Figure 3.1 displays the detailed characterization of EOF steel slag in Phase I. Analysing the properties of the ingredients used to make concrete is crucial. This information will be useful in selecting the right ingredients for high-quality concrete.

2.1 Characterization of EOF Steel Slag

The following tests were carried out in order to explain the characteristics of EOF steel slag. The characteristics of natural coarse aggregate are used to assess the experimental findings. Sieve analysis was used to evaluate the grading pattern of EOF steel slag, and the results were in accordance with IS383-1970, which specifies the coarse aggregate for concrete. Figure 1 displays the particle size distribution and compares it to the percentage passing limits for graded aggregate with a nominal size of 20 mm in accordance with IS 383-1970.

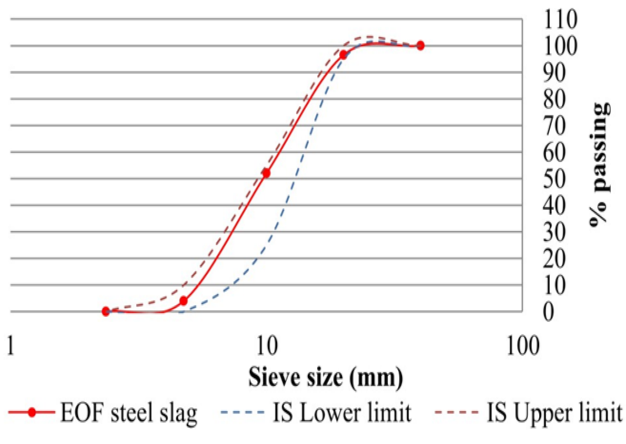

Fig -1: Particle size distribution curve of EOF steel slag aggregate

Since aggregate shape greatly affects the workability and consolidation of fresh concrete, it is an essential property. The EOF steel slag's shape characteristics, such as its elongation index, and flakiness index, are assessed. Table 1 displays the outcomes of steel slag and natural aggregate.

Table-1: Flakiness and Elongation Index of EOF steel slag and natural coarse aggregate

Test	Natural coarse aggregate	EOF steel slag
Flakiness index	18.30%	16.90%
Elongation index	15.00%	7.80%

EOF steel slag's flakiness index is slightly lower than that of natural aggregate, suggesting that its particles are thicker than those of the natural coarse aggregate. Slag particles are rounder and shorter than natural coarse aggregate, according to the EOF steel slag's lower elongation index.

EOF steel slag has a water absorption of about 3%, which is significantly higher than that of natural aggregate. Therefore, in order to decrease the EOF steel slag's capacity to absorb water, it must be saturated before being added to concrete. EOF steel slag has a bulk density that is 4.6% greater than that of natural coarse aggregate. Because of its high iron concentration, steel slag is found to be 4% denser than natural coarse aggregate.

In accordance with IS 2386 (Part IV)-1963, the mechanical characteristics of EOF steel slag and natural coarse aggregate were investigated experimentally. The findings are shown in Table 2.

Table 2: Mechanical properties of EOF steel slag and natural coarse aggregate

Test	**Natural aggregate**	**EOF steel slag**	**Limiting value as per IS: 2386**
Crushing value	6.55%	8%	Not more than 45%
Impact value	22.87%	29.57%	Less than 45%
Los Angeles abrasion	8.27%	1.16%	Not more than 50%

2.2 Mix Design:

M30 grade concrete was designed for the current study in order to profit from EOF steel slag compatibility under severe exposure conditions. Table 3 lists the mix ingredients and water-to-cement ratio for concrete of M30 grade.

Table 3: Proportion of Concrete Mix of M30 Grade

Details	**Cement**	**Fine Aggregate**	**Coarse Aggregate**	**Water**
Quantity for 1 m^3 concrete	438	638	1148	197
Mix Proportion	1	1.457	2.621	W/C = 0.45

3. RESULTS AND DISCUSSIONS

This chapter will present all of the compressive strength results for conventional and dolomite concrete. Through these results, analysis and comparison of compressive strength between conventional and dolomite concrete could done easily. At the age of 28 days of curing will show the overall results.

3.1 Workability of Concrete

The workability reduces as the replacement levels of EOF steel slag increases, according to the above figure. Because of their rough surface and irregular shape, EOF steel slag aggregates require more cement volume to cover the surface than natural aggregates do. Another aspect is that EOF steel slag has more ability to absorb water.

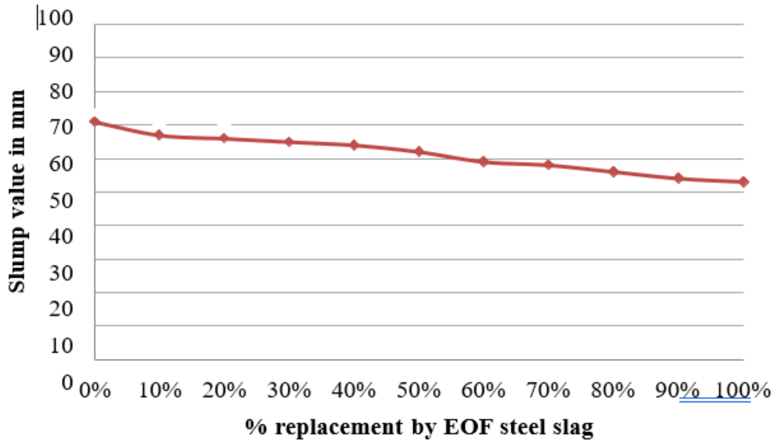

Figure 2: Slump of M-30 grade concrete with various levels of replacement by EOF steel slag

3.2 Compressive Strength Test

Concrete's compressive strength gradually rises as the amount of EOF steel slag replacement increases. This is explained by the EOF steel slag aggregate's rough surface texture. In addition to its physical contribution, EOF steel slag hydration makes it easier for cement paste to consolidate around the slag. It is calculated that using EOF slag in place of coarse aggregate increases the compressive strength of concrete of M30 grade by 21%.

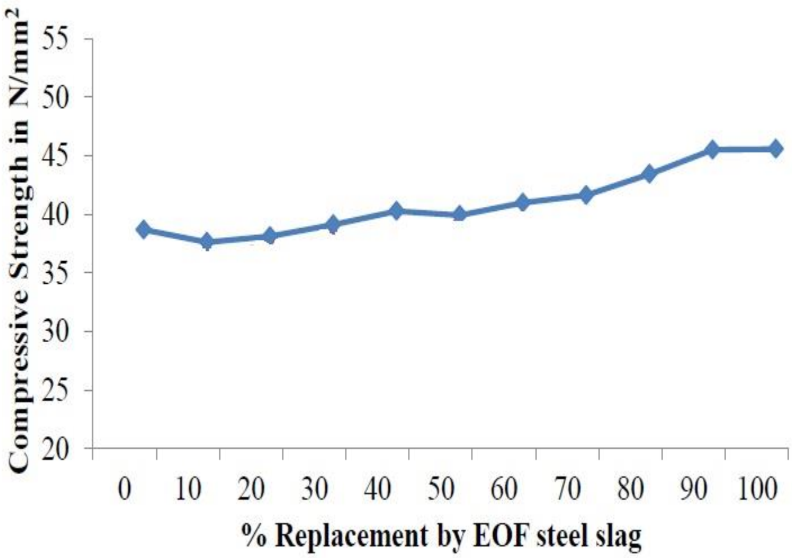

Figure 3: Compressive strength of concrete of M30 grade with different proportions of EOF steel slag material substituted for coarse aggregate

3.3 Flexural Strength Test

The flexural strength of concrete tends to rise as the replacement amount of EOF steel slag aggregate increases because these aggregates are more angular than natural aggregates. The concrete constructed with 100% EOF steel slag aggregate in place of coarse aggregate has the best flexural strength value for all concrete grades, as shown in Figure 4.

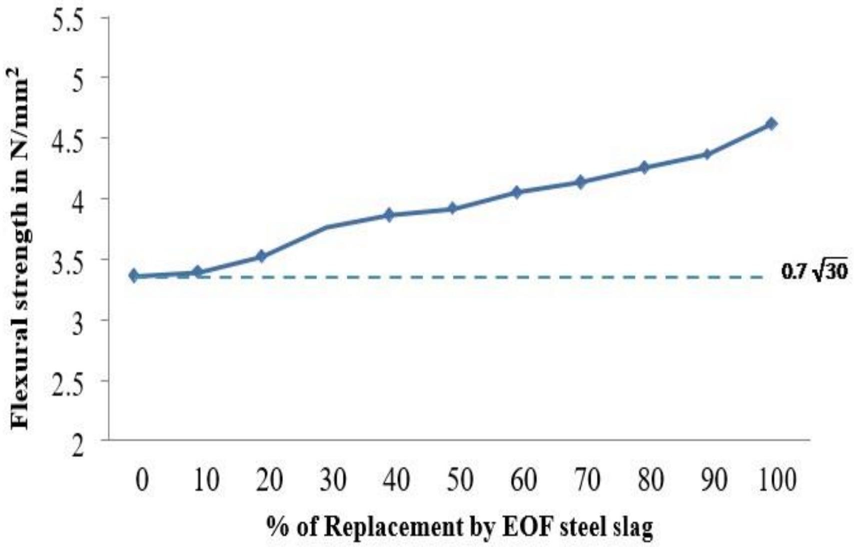

Figure 4: Flexural Strength of M30 grades of concrete with various levels of replacement by EOF steel slag aggregate

3.4 Split Tensile Test

According to Figure 5, the split tensile strength of concrete progressively rises as the amount of EOF steel slag replacement increases. For concrete mixes made using 100% EOF steel slag aggregate in place of natural aggregate, the increase in split tensile strength varies from 11% to 15%. The amount of cement paste in the concrete has a significant impact on split tensile strength. In the current study, the same quantity of cement paste was used for all replacement levels for any given grade of concrete. Improved bonding between aggregate and cement paste is thought to be the cause of the increase in split tensile strength of EOF steel slag aggregate concrete.

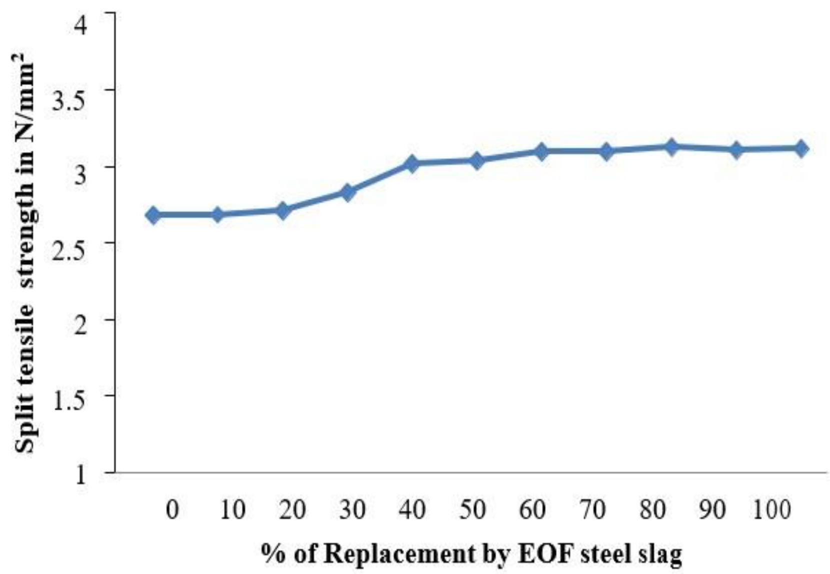

Figure 5: Split Tensile Strength of M30 grades of concrete with various levels of replacement by EOF steel slag aggregate

This study examined the fundamental mechanical properties of concrete incorporating different replacement levels of EOF steel slag. Experimental findings indicate a significant enhancement in strength characteristics, including compressive strength, flexural strength, and split tensile strength, as the proportion of EOF steel slag increases. The highest strength values were achieved when natural aggregate was fully replaced (100%) with EOF steel slag, demonstrating its effectiveness in improving concrete performance.

4. CONCLUSION

In concrete made using EOF steel slag, EOF steel slag was used in place of natural coarse aggregate at replacement levels ranging from 10% to 100% in 10% increments. Experimental research on the characteristics of EOF steel slag and the fresh and hardened properties of concrete with natural aggregate and EOF steel slag aggregate has led to the following conclusions.

i. The particle size distribution of EOF steel slag aggregate is found to be within the limits of percent proportion passing through sieve of nominal size 20 mm for graded aggregate as per IS: 383-1970.

ii. The combined flakiness and elongation index of EOF steel slag is measured at 8.60, which is lower than that of natural coarse aggregate. This indicates that EOF steel slag aggregates possess a more compact shape, being thicker and shorter compared to natural coarse aggregates.

iii. EOF steel slag has an angular shape and exhibits a water absorption capacity that is 2.2% higher than that of natural coarse aggregate. To minimize its water absorption and ensure proper mix proportions, it is essential to pre-saturate the EOF steel slag before using it in concrete.

iv. Mechanical characteristics, specifically impact and crushing values, are 6.7% and 1.45% greater, respectively, than those of natural coarse aggregate.

v. Compared to natural coarse aggregate, EOF steel slag has resistance values against wear and abrasion that are 14.88% and 7.11% greater, respectively.

vi. The workability of concrete is impacted by the rough surface texture and higher water absorption capacity of EOF steel slag. Concrete becomes less workable when EOF steel slag is added as a coarse aggregate. Accordingly, it is discovered that the workability of EOF steel slag concrete is reduced by roughly 18% when compared to that of natural aggregate concrete.

vii. The strong interfacial bond surrounding the EOF steel slag helps to increase the concrete's compressive strength. In comparison to natural aggregate concrete, concrete made with EOF steel slag in place of all natural coarse aggregate has a compressive strength that is 9% to 15% greater for various concrete classes.

viii. EOF steel slag's rough surface and angular shape are thought to be the cause of the concrete's increased flexural and split tensile strengths. Between 11% and 15% more tensile strength is achieved with EOF steel slag concrete.

ix. The study reveals that concrete with 100% replacement of natural coarse aggregate by EOF steel slag exhibits significant enhancement in mechanical properties. Overall, the performance of EOF steel slag concrete at this replacement level is highly comparable to that of conventional concrete made with natural coarse aggregates. Therefore, it can be concluded that fully replacing natural coarse aggregate with EOF steel slag is the optimal choice for achieving high-performance concrete.

x. The findings of this research indicate that EOF steel slag can be effectively used as a partial or complete replacement for natural coarse aggregate in concrete. Concrete incorporating EOF steel slag is well-suited for various applications, including mass concreting, foundation works, retaining walls, roads, dams, and breakwater blocks. As a sustainable alternative to natural coarse aggregates, EOF steel slag helps in reducing waste disposal and minimizing the depletion of natural resources. Additionally, integrating EOF steel slag into concrete production can contribute to meeting the increasing demand for coarse aggregates in the rapidly expanding construction industry.

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