

Influence of Steel Slag as a Cementitious Material on the fresh and Mechanical Characteristics of Concrete

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ABSTRACT

Researchers have recently been pursuing the incorporation of eco-sustainable binding agents, such as industrial-wastes, in concrete to mitigate the carbon footprint associated with cement manufacture. The use of cementitious materials derived from industrial waste in concrete has recently been reported to enhance concrete performance. Steel slag is plentiful and often discarded as garbage in many places worldwide. The use of steel slag as a cementitious material mix offers synergistic advantages with Portland cement (PC) and could be an environmentally friendly employed in concrete. This research demonstrates the material performance of steel slag in concrete. The entire of 30 standard concrete specimens were created to assess the mechanical characteristics of concrete at a curing period age of 28 days. Following a 28-day curing period, the experimental findings indicate that the optimal compressive and tensile strengths achieved were 36.8 MPa and 3.62 MPa, correspondingly, with 10% steel slag used as a cement substitute. Furthermore, the workability of new concrete diminishes with an increase in steel slag concentration.

KEYWORDS: Steel Slag, Cementitious Material, Slump Test, Compressive Strength, Splitting Tensile Strength.

INTRODUCTION

The entire world's construction sector has a significant sustainability concern: the manufacturing of Portland cement is responsible for over 8% of global carbon dioxide emissions, making it one of the foremost industrial contributors to greenhouse gases [1-3]. With the escalating requirements for concrete due to fast urbanisation, the necessity for ecologically sustainable alternatives has become more pressing in terms of industrial/agricultural wastes like waste glass [4, 5], marble powder [6-8], metakaolin [9-13], silica fume [14, 15], corn cob ash [16, 17], fly ash [18-20], wheat straw ash [21-23], coconut shell ash [24, 25], millet husk ash [26-29], and steel slag. In this environment, industrial by-products like steel slag have emerged as viable supplementary cementitious materials (SCMs) capable of partly substituting cement whereas concurrently solving waste management issues [30].

Steel slag is a by-product produced from steel making, with worldwide output estimated at roughly 104–155 million tonnes per year in 2024 [30]. Historically, around 70% of this substance has been discarded by landfilling or stockpiling, depleting important land resources and presenting environmental hazards such as contaminants leaching and dust pollution [30]. The current research has shown that steel slag has considerable cementitious potential owing to its chemical constituents, which includes large quantities of SiO_2 , Al_2O_3 , Fe_2O_3 , and CaO , hence conferring both hydraulic and pozzolanic properties.

The use of steel slag as a partial substitute for cement has a dual environmental advantage: it lowers the carbon emissions linked to cement manufacturing and repurposes an industrial byproduct [31, 32]. Research has shown that steel slag may improve the mechanical properties of concrete via several processes. The tiny particles of steel slag have a micro-aggregate filling action that enhances pore structure and boosts matrix density [30, 33]. The pozzolanic reaction between steel slag and calcium hydroxide (portlandite) from hydration of cement generates more calcium silicate hydrate (C-S-H) gel, enhancing long-term strength and durability [34, 35].

The results of research on appropriate replacement amounts have provided encouraging outcomes. A 30% substitution of cement with steel slag has been recognised as notably beneficial, with research indicating compressive strength enhancements ranging from 3.24% to 5.79% relative to control samples after 28 days, contingent upon binder concentration. Correspondingly, enhancements in split tensile strength of up to 7.99% have been seen at elevated binder concentrations. These improvements are ascribed to the latent hydraulicity of steel slag and its capacity to facilitate a more thorough hydration of cementitious constituents.

This research seeks to thoroughly examine the impact of steel slag as a partial substitute for cement in concrete, specifically assessing its effects on compressive and tensile strength parameters. This study enhances the existing knowledge base on sustainable building methods and circular economy concepts in the cement and concrete industry by assessing different proportions of substitution and their associated mechanical performance.

MATERIALS AND METHODS

Materials

The Portland cement (PC) was obtained from a regional marketplace and used as a binding substance in the combination. The steel slag was obtained from a steel mill with prior permission, thereafter processed via a 75-micron sieve, and subsequently used as a cement substitute in this study. Additionally, the stones utilised for this investigation were crushed to serve as coarse aggregates (CA) with a size of 20 mm, whereas hill sand was employed as fine aggregates, passing through a #4 sieve. Furthermore, water suitable for consumption has been used for both mixing and curing concrete.

Mix Design

Five mixtures of concrete, created for this experimental study, are represented in Table 1, in accordance with the ASTM C192/C192M-19 coding process. Steel slag was used as a substitute for Portland cement at a maximum of 20%. One mixture of concrete incorporated 0% steel slag, while the other four comprised 5%, 10%, 15%, and 20% steel slag, respectively. All concrete mixtures in this investigation have water-binder ratios of 0.45. The entire 30 concrete specimens (cubes and cylinders) were cast, demoulded, and cured in water for 28 days.

Table 1: Mix Design of the Research

Mixture ID	PC	Slag	Water	Fine aggregate	Coarse aggregate
0% Slag	345	0	155	520	980
5% Slag	327.75	17.25	155	520	980
10% Slag	310.50	34.50	155	520	980
15% Slag	293.25	51.75	155	520	980
20% Slag	276.00	69.00	155	520	980

Testing Methods

The slump test was conducted to assess the workability of freshly produced concrete. It was assessed instantly upon mixing in accordance with BS EN 12350-2:2009. The compressive strength assessment was conducted to investigate the breakdown stress of samples that were subjected to uniaxial compressive load. This test adheres to BS EN 12350-3:2009. Cube-shaped samples (100x100x100 mm) were fabricated, and a split tensile test was conducted on cylindrical specimens (100x200 mm) in accordance with BS EN 12390-6:2009.

RESULTS AND DISCUSSION

Slump Test

A typical slump cone was used to assess the workability of concrete by measuring slump decrease. The higher flow of fresh concrete was measured at 54 mm with no slag, while the lower workability of fresh concrete was measured at 25 mm with 20% slag as a cement substitute. The workability of new concrete diminished with the incorporation of slag. The diminished workability may be attributed to the fineness of the slag, which has enhanced the surface area of the slag particulates. Consequently, slag grains acquired moisture, resulting in a reduction in concrete flow. A reduction in

workability may result from a deficiency of available water in the concrete. The outcomes are shown in Figure 1.

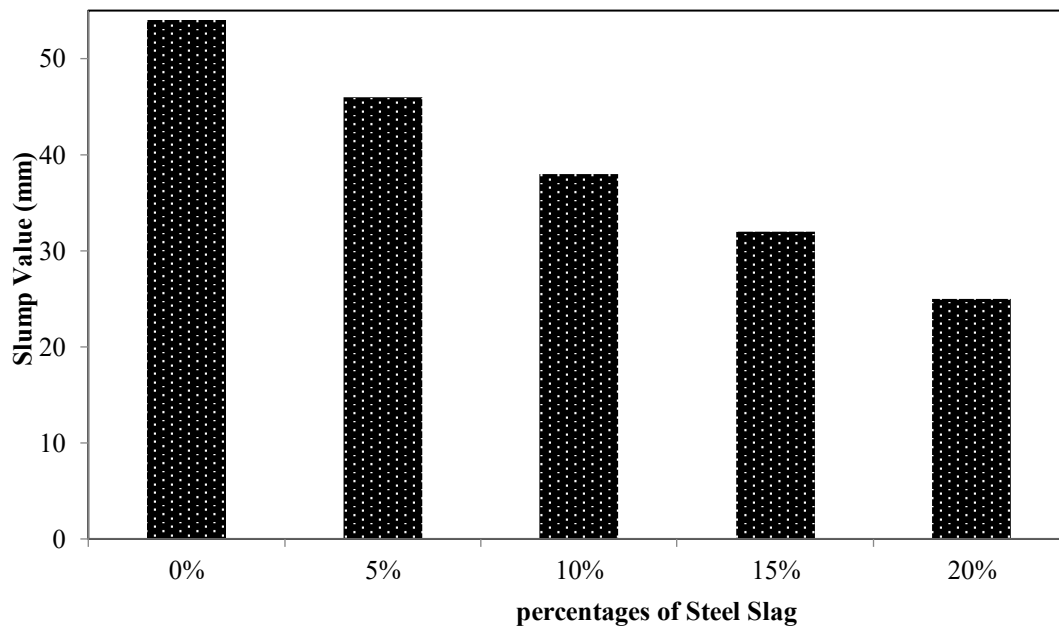


Figure 1: Slump Test of Steel Slag Concrete

Compressive Strength

The test conducted on a cubic sample composed of concrete containing slag as a partial replacement for Portland cement, together with the compressive strength results, is shown in Figure 2. The maximum compressive strength of 36.80 MPa is achieved with 10% steel slag, while the minimum strength of 23.58 MPa is observed with 20% steel slag as a replacement for Portland cement in concrete at 28 days of curing. The findings from the experiment indicated an increase in the strength of hardened concrete with the incorporation of up to 10% steel slag, attributed to the fineness of the steel slag particulates that filled the micropores left by the remaining concrete components. However, further additions of slag led to a decline in strength due to the dilution effect of steel slag on cement, which minimises the pozzolanic interactions among the concrete constituents.

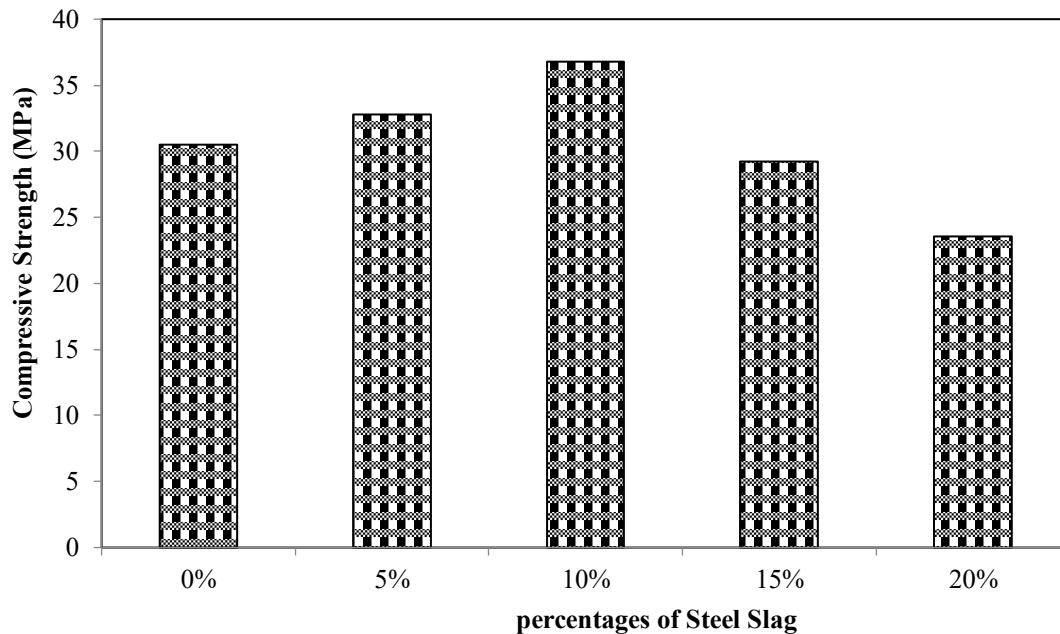


Figure 2: Compressive Strength of Steel Slag Concrete

Splitting Tensile Strength

A test conducted on a concrete cylinder sample including slag as a partial replacement for Portland cement, together with the study results, is shown in Figure 3. The maximum split tensile strength is measured at 3.62 MPa with 10% slag, whereas the minimum strength is noted at 2.86 MPa with 20% slag as a replacement for Portland cement in concrete after 28 days. The test results indicated an increase in the strength of concrete with the incorporation of up to 10% slag, attributed to its greater specific surface area relative to cement. However, further additions of slag resulted in a decline in strength, potentially due to the reduced calcium hydroxide content in the combination, a consequence of the dilution effect of slag.

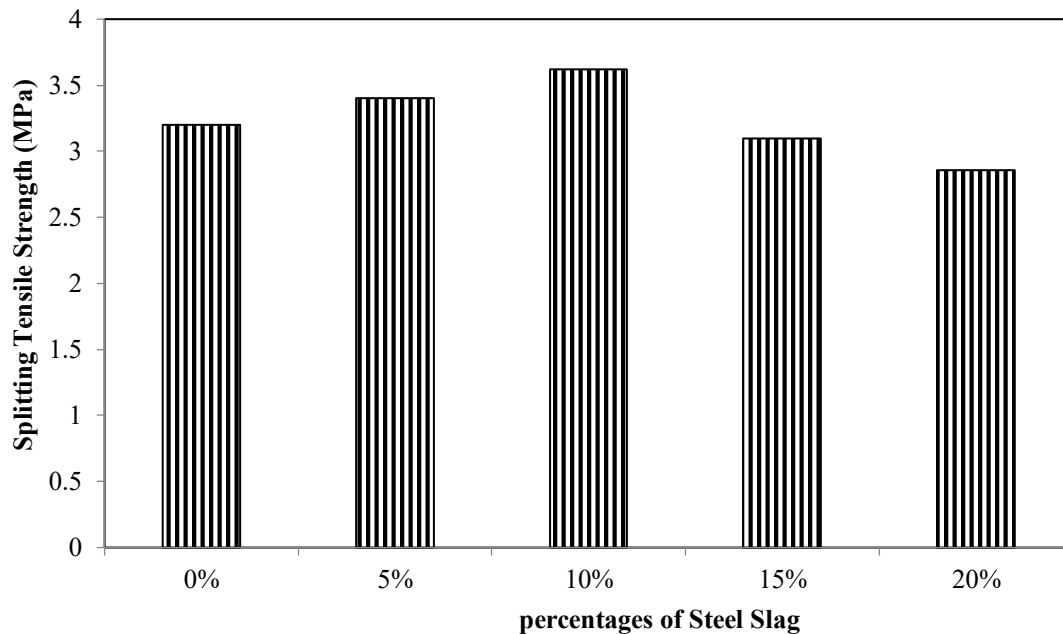


Figure 3: Splitting Tensile Strength of Steel Slag Concrete

CONCLUSIONS

This research assessed the fresh and mechanical characteristics of concrete including steel slag as a cementitious component. The examined property categories included workability and hardened concrete characteristics. The following findings were derived from the investigation:

- The value of slump for all mixtures decreased with a growing proportion of additional cementitious ingredients; for instance, the control mixture exhibited a slump of 54 mm, while the smallest slump recorded was 25 mm for 20% slag content.
- Overall, for all mixtures, the compressive strength and split-tensile strength properties improved with the addition of steel slag up to 10%. The research demonstrated that the strength progression in the modified concrete exceeds that of the control mixture. A blend with 10% an additional cementitious material produced the greatest strength. Nevertheless, strength reduces somewhat when SCM content exceeds 10%.
- From the experimental findings, it is observed that the utilization of 10% steel slag offers highest strength therefore it is recommended for practical applications in the construction industry.

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