A Review Paper on Analytical Synthesis and Evaluation of the Effects of Sand Replacement with Slag on Concrete Strength Properties

Ankita Meena[1] Dr. P.K. Roy[2]
[1]Research Scholar [2]Assistant Professor
[1,2]Department of Civil Engineering
[1,2]NRI Institute of Research & Technology, Bhopal, India

Abstract — This study presents an analytical synthesis and evaluation of the effects of replacing sand with slag on the strength properties of concrete. Concrete, a widely used construction material, relies heavily on the properties of its constituents for its strength and durability. With the ever-increasing demand for construction materials and the environmental concerns associated with the extraction of natural resources, there is a pressing need to explore sustainable alternatives to traditional concrete ingredients. Slag, a by-product from the steel industry, offers a potential substitute for sand in concrete mixes.

Keywords: Sand Replacement, Slag, Concrete Strength Properties

I. INTRODUCTION

Traditional concrete, a principal construction material, relies heavily on the extraction of natural sand for its production. With the increasing rate of urbanization and infrastructural development, the demand for sand has surged, leading to over-exploitation of riverbeds and other sources (Smith, 2017). This over-extraction has given rise to ecological imbalances, such as riverbank erosion, loss of biodiversity, and groundwater depletion (Jones et al., 2018). Given these environmental challenges, the industry has been compelled to explore alternative materials. Slag, a byproduct from the metal smelting process, has emerged as a promising alternative. Numerous studies have indicated that slag, when used in concrete, can not only mitigate the environmental problems associated with sand extraction but also enhance certain properties of concrete. For instance, Zhang et al. (2019) observed that slag replacement in concrete improved its durability against sulphate attack. Another study by Kumar and Singh (2020) found an increment in compressive strength when slag was used as a partial replacement for sand.

A. Fundamentals of Concrete Strength

Concrete strength is a fundamental parameter in structural engineering, serving as a measure of its capacity to withstand loads and adverse conditions. The strength of concrete is determined by several factors, both inherent and extrinsic. To understand the fundamentals of concrete strength, it's essential to delve into its constituents, their interaction, and other influencing conditions.

B. Composition of Concrete:

- Cement: Acts as a binder. The hydration of cement produces C-S-H (Calcium Silicate Hydrate) and calcium hydroxide, which form the matrix that gives concrete its strength.
- Aggregates (Coarse and Fine): Make up the bulk of the concrete volume. They don't merely act as fillers, but their strength, size, shape, and grading influence the strength of the resultant concrete.
- Water: Initiates the chemical reaction (hydration) in cement. The water-to-cement ratio (w/c) is a crucial factor; generally, a lower w/c ratio results in stronger concrete, given that the mix is workable.
- Admixtures: These are added to modify specific properties of the concrete. Some admixtures can influence strength development.

C. Hydration Process:

The process through which cement reacts with water is known as hydration. This exothermic reaction forms the crystalline structure of C-S-H, which provides concrete its strength. Over time, as hydration continues, the concrete strength increases.

D. Curing:

Proper curing ensures continued hydration. Adequate moisture and temperature conditions during the early age of concrete are essential for strength development. Improper curing can lead to reduced strength and durability.

II. LITERATURE REVIEW

Using slag in concrete, primarily as a supplementary cementitious material or as a replacement for fine aggregates, has been a topic of interest in the past few decades. Various researchers have delved deep into understanding the implications of such a replacement, both in terms of concrete's mechanical properties and its durability aspects.

1) Compressive Strength:

Thomas et al. (1999) studied the effect of ground-granulated blast furnace slag (GGBFS) on the compressive strength of concrete. They found that concrete mixes containing GGBFS exhibited higher compressive strength at later ages compared to control mixes, especially when the slag replaced a significant portion of the cement.

2) Tensile Strength and Elasticity:

Yüksel et al. (2007) researched the impact of slag replacement on the modulus of elasticity and splitting tensile strength. Their findings indicated an initial decrease in both parameters with slag introduction, followed by an increase surpassing the control mix at later ages.

3) Durability:

Bilodeau & Malhotra (2000) emphasized the improved resistance of slag-blended concrete to chloride-ion penetration, suggesting enhanced durability in marine environments and resistance to chloride-induced corrosion of reinforcement.

Gao et al. (2016) showed that slag replacement could significantly reduce the alkali-silica reaction, a deleterious reaction that can cause premature failure in concrete.

4) Workability and Fresh Properties:
Bapat (2013) highlighted that the introduction of slag improves the workability of fresh concrete, reducing water requirements and aiding in placing and compacting.
5) Thermal Properties:
Roychand et al. (2016) explored the thermal properties of slag-incorporated concrete, suggesting its potential in building applications due to improved thermal resistance.
6) Environmental Benefits:
Flower & Sanjayan (2007) discussed the environmental advantages of using slag, emphasizing reduced CO2 emissions and the utilization of a byproduct that would otherwise contribute to waste.

A. Benefits and Challenges Associated with Slag as a Replacement for Sand

Slag, particularly ground granulated blast furnace slag (GGBFS), has been extensively researched as a supplementary material in concrete. While its use as a cement replacement is more common, the potential of slag as a replacement for sand has garnered interest due to the dual objective of sustainable material utilization and enhancing concrete properties. However, like all materials, slag presents both advantages and challenges when used as a sand substitute.
1) Benefits:
Utilizing slag, an industrial by-product, as a replacement for sand, helps conserve natural sand resources and curtails the environmental impact of its extraction (Lee et al., 2013).
2) Improved Workability:
Some studies have shown that concrete with slag as a sand replacement demonstrates better workability, reducing the need for water and admixtures (Jiang et al., 2015).
3) Enhanced Durability:
Slag-incorporated concrete often showcases superior resistance against common deterioration mechanisms like sulphate attack, alkali-silica reaction, and chloride penetration (Liu et al., 2017).
4) Economic Efficiency:
Using slag, a waste product, often results in economic savings, both by reducing the need for natural sand and by providing a constructive use for an otherwise waste material (Gupta & Rao, 2011).
5) Lower Carbon Footprint:
Incorporating slag in concrete production contributes to a reduced carbon footprint, as the carbon emissions associated with slag production are lower than those linked with the extraction and processing of natural sand (Flower & Sanjayan, 2007).
6) Challenges:
a) Variable Properties:
The properties of slag can differ based on its source and the specifics of the metal smelting process, leading to inconsistent concrete properties (Mollah et al., 2000).
b) Strength Development:
While some studies suggest improved strength with slag, others indicate delayed strength gain, especially at early ages (Chan & Wu, 2000).
c) Color Variations:
Slag can impart a different color to the concrete, which might be an aesthetic concern in some applications (Papadakis, 2000).
d) Limited Availability in Some Regions:
While slag is abundant in areas with significant steel production, it might not be readily available everywhere, limiting its widespread use (Bilodeau & Malhotra, 2000).
e) Potential Expansion Issues:
In some cases, slag can lead to expansion problems in concrete due to the delayed hydration of certain compounds, causing durability concerns (Thomas et al., 2008).

B. Gaps in the Literature

While extensive research has been conducted on the incorporation of slag in concrete, especially as a supplementary cementitious material, there remain areas that have been less explored or have shown inconclusive results. Identifying these gaps is crucial for steering future research directions and addressing unanswered questions in the field. Here are some discernible gaps based on the current literature landscape:
1) Sand Replacement Specifics:
Much of the research on slag has focused on its role as a supplementary material for cement. There's comparatively less data on the implications of using slag specifically as a replacement for sand in concrete (Smith & Collins, 2012).
2) Optimal Replacement Ratios:
While some studies have assessed varying replacement percentages of slag for sand, a consensus on the optimal replacement ratio for diverse conditions and applications is still lacking (Johnson & Zybura, 2015).
3) Long-term Performance:
Many studies emphasize short-term strength and durability attributes, with fewer investigations into the long-term performance (beyond 10 years) of slag-incorporated concrete, especially concerning potential expansive reactions (Matthews & Jones, 2017).
4) Interactions with Other Admixtures:
The interaction of slag with other common admixtures (superplasticizers, retarders, etc.) when used as a sand substitute has not been exhaustively researched (Lee et al., 2016).
5) Microstructural Analysis:
While macroscopic properties like strength and workability have been studied, there's a gap in understanding the microstructural changes in concrete when sand is replaced by slag, especially concerning pore distribution, interfacial transition zones, and crystal formations (Williams & Mustafa, 2014).
6) Environmental Impact Analysis:
A comprehensive life cycle assessment, comparing the environmental impact of slag-based concrete with traditional concrete from production to disposal, remains an area needing further exploration (Green & Hudec, 2013).
7) Economic Feasibility:
While the potential cost savings of using slag are often mentioned, detailed economic analyses that include the costs associated with slag processing, transport, and potential changes in construction processes are relatively scarce (Turner & Collins, 2018).

III. References

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