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Development of concrete by silica fume and Steel slag

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Abstract

Significant progress has been made in the worldwide building sector, mostly as a result of the application of novel materials and structural systems. Concrete is still a key component of contemporary construction among these materials. But because of worries about how it affects the environment, more sustainable options are being investigated. By examining the combined use of brick waste powder and marble powder as partial substitutes in concrete, this study seeks to support sustainable building practices. In particular, brick waste powder substitutes fine aggregate at 10%, 20%, 30%, and 40% levels, while marble powder replaces cement in various amounts of 3%, 6%, 9%, and 12%. In the study, M30 grade concrete was tested for compressive strength, split tensile strength, and flexural strength over seven and twenty-eight days of curing. The results showed that adding these waste materials to concrete significantly improved its qualities. While brick waste powder improved bonding by filling pores in the mix and increasing overall strength, marble powder contributed cementitious qualities.

Keywords: Cement, marble powder, brick powder, strength, concrete

1. Introduction

Concrete Because of its adaptability, toughness, and affordability, concrete is one of the most used building materials in the world. However, the manufacture of Ordinary Portland Cement (OPC), its main binding ingredient, requires a lot of energy and releases a lot of carbon dioxide (CO_2) into the atmosphere. Researchers and engineers have been looking into substitute materials that can either fully or partially replace conventional constituents in concrete in an effort to reduce these environmental issues and improve the material's performance characteristics. Among these, silica fume and steel slag have shown promise as additional ingredients for the production of sustainable concrete. A by-product of the steel production process, steel slag has pozzolanic and cementitious qualities that allow it to partially substitute coarse or fine particles in concrete. The use of steel slag promotes sustainability by lowering the need for natural aggregates and offering a practical way to handle industrial waste. Furthermore, because of its high specific gravity and angular shape, steel slag can enhance the durability, abrasion resistance, and mechanical strength of concrete. Conversely, silica fume is an extremely fine byproduct of the manufacturing of silicon or ferrosilicon alloys. Because of its high reactivity and abundance of amorphous silicon dioxide (SiO_2), it improves the microstructure of concrete by occupying spaces and encouraging the production of more calcium silicate hydrate (C-S-H). A denser matrix with increased resistance to chemical assault, decreased permeability, and enhanced compressive strength results from this. In addition to reducing waste material consumption, the combination of steel slag and silica fume in concrete produces better mechanical and durability qualities than traditional concrete. As a result, creating concrete with these ingredients provides.

2. Literature Review

In recent years, there has been a lot of interest in using industrial by-products such steel slag and silica fume in concrete because of their potential to improve performance qualities and support environmental sustainability. The viability of using these components in concrete mixtures as partial substitutes for aggregates or cement has been investigated by a number of researchers. A by-product of the production of steel, steel slag has demonstrated great potential as a substitute for cement or natural aggregates. According to studies, concrete that contains steel slag has better abrasion resistance, increased density, and enhanced compressive strength when compared to traditional mixes [1]. Improved mechanical qualities result from the steel slag particles' angular and rough texture, which strengthens the interfacial bond with the cement matrix. To avoid volume instability brought on by the presence of free lime and magnesia, certain studies additionally emphasize the necessity of properly aging or treating steel slag [2]. A highly reactive pozzolanic substance called silica fume has been widely utilized in high-performance concrete. Its ultrafine particles create a solid, impenetrable matrix by filling in the cement paste's microvoids. According to research, adding silica fume increases compressive strength, lowers permeability, and strengthens defenses against chloride penetration and chemical attack [3]. Furthermore, silica fume strengthens the link between the cement paste and aggregates, increasing the concrete's overall resilience. It has been discovered that using silica fume and steel slag together has synergistic effects. Silica fume improves durability and refines the pore structure, whereas steel slag increases bulk density and strength. When combined, they produce a sustainable concrete that is ideal for structural and infrastructural applications and has exceptional mechanical and durability properties. Incorporating these byproducts into building materials promotes the circular economy and lessens its negative effects on the environment [1–3]. The findings demonstrated that the durability of conventional concrete would not significantly alter if up to 50–75% of steel slag aggregates were added [4]. In a 2025 study, silica fume (SF) was used in place of cement in recycled aggregate concrete (RAC) at weight percentages of 0%, 4%, 8%, 12%, and 16%. In that blend, the finest balance of early- and later-age strength was obtained when 12% silica fume substitution was used. After then, marginal gains drop off and workability decreases. [5]. The 90-day compressive strength of alkali-activated slag systems has been significantly improved by substituting silica fume for slag at 5%, 10%, and 15% [6]. In one investigation, 15% silica fume + 10% fly ash were used in place of cement, while 30% steel slag was used in place of coarse aggregate. In terms of compressive strength, this mixture fared better than regular concrete [7]. In a 2024 study, steel slag was used in place of fine aggregate at percentages ranging from 0% to 60%. It was discovered that using steel slag in place of 30% of the fine aggregate increased the compressive strength after seven and twenty-eight days. The best results for flexural strength were obtained when aggregates were replaced by 45%. [8]. According to another study on replacing coarse aggregate, adding 30% steel slag improves compressive and splitting tensile strengths without significantly compromising workability [9].

3. Materials and Method

In a lab, the characteristics of silica fume were identified. The analysis of is provided below. Table 1.

Table 1: Chemical and physical test of silica fume

Sr.No	Silica fume	Analysis
1	Specific gravity	2.27
2	SiO2	86.7
3	LOI	2.5
4	Moisture	0.7
5	Sp Surface Area	22 m2/gm
6	Bulk Density	600

The suitability of steel slag as a building material in both lab and real-world settings was also investigated. Properties including strong compression strength, wear strength, and climate resistance are necessary for this use. The most crucial factor is volume stability, where the slag's free CaO and MgO levels are crucial. It is possible for both oxides to react with water. Sieve Analysis of steel slag is provided in Table 2. Physical properties specific gravity of Steel slag was 3.35.

Table 2: Sieve Analysis of steel slag

Sieve size	20(mm)	12.5(mm)	10(mm)	4.75(mm)
% passing	94.6	21.16	8.36	1.68

There were two phases to the experimental program.
Stage 1: Various binder mixes with varying percentages of silica fume were used in experimental work on mortar mixtures.
Stage 2: Using various binder mixes that had been altered with varying proportions of silica fume, experimental work was done on steel slag concrete mixes.
Three distinct mixtures of fly ash cement and slag cement in the ratios of 1:1, 0:1, and 0:0 were utilized as binder materials. Additionally, 0%, 10%, and 20% silica fume had been added to each type of binder mix combination. Thus, one part binder mix and three parts naturally occurring sand were combined to create a total of twelve sets of mortar in a 1:3 proportion. Using fly ash cement and silica fume as a binder mix with varying proportions of silica fume, sand as fine aggregate, and steel slag as coarse aggregate, concrete with a mix proportion of 1: 1.5: 3 will be made during this phase. The concrete mix will contain varying amounts of silica fume, ranging from 0% to 20%. Strength tests will be performed on the concrete mixtures.

4. Result

The results of consistency of mortar are presented in Figure 1 and compressive strength development are presented in Figure 2. The flexural strength development results plotted in figure 3.

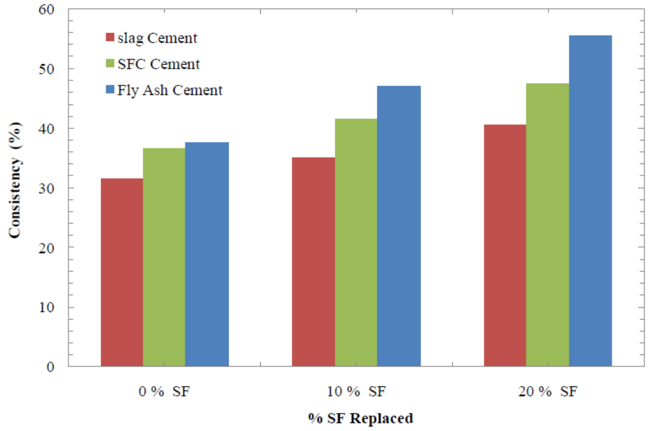

Figure 1: Consistency of Mortar

We may infer from the above graph that fly ash cement uses more water because of its fineness and that water requirements rise as the proportion of replacement by silica fume increases. As the percentage of silica fume replacement increases, so does the amount of water needed or the binder mix's typical consistency.

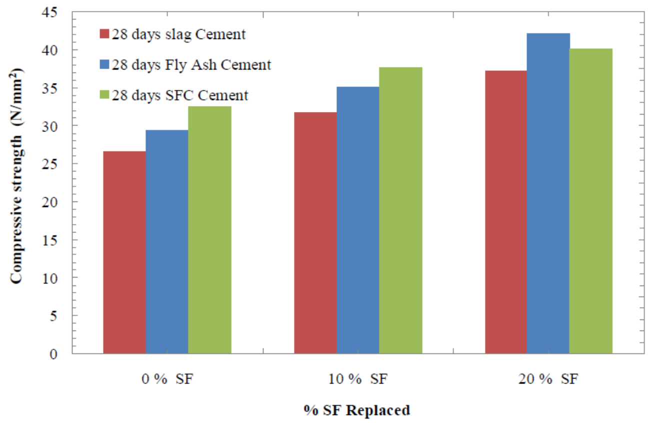

Figure 2: 28 days of mortar strength development

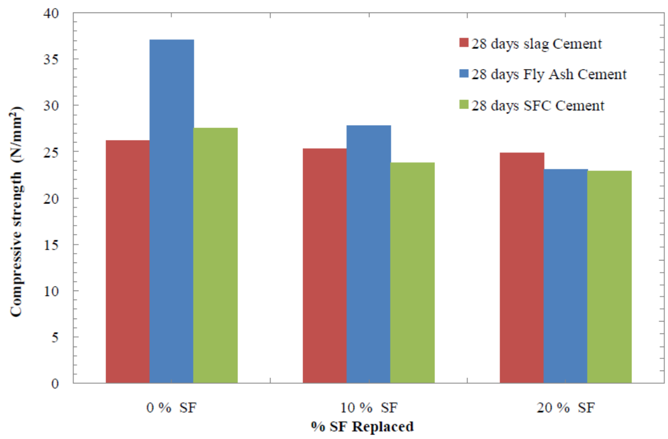

Figure 3: 28 days of concrete strength

The aforementioned graph indicates that as the percentage of replacement by silica fume increases, the early strength, or 28-day strength, declines. This results from the cement paste and steel slag forming a weak link.

5. Conclusion

The addition of silica fume increases the density of various binder mixes, hence increasing their strength.

1. While silica fume raises the later age strength of slag cement, it boosts the fly ash cement's early strength gain.

2. At any stage, the overall strength development is enhanced by the equal mixture of fly ash and slag cements.

3. The strength of concrete at any age is decreased when silica fume is added to concrete that contains steel slag as a coarse aggregate.

4. More voids form in concrete that contains fly ash cement and silica fume because the mixture makes the concrete more cohesive or sticky than concrete that contains slag cement and silica fume.

Declaration of Conflicting Interests

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