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# To Investigate the Effects of Replacing Cement with Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBS) on Mechanical Properties

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**Abstract:** Concrete remains one of the most widely used construction materials due to its adaptability and suitability for various structural applications. However, its performance can deteriorate when subjected to aggressive environmental conditions, making enhanced durability a crucial requirement. In regions containing dense reinforcement, conventional concrete may experience segregation or obstruction while flowing through narrow spaces, resulting in weak internal bonding and compromised structural integrity. Self-compacting concrete (SCC) has emerged as a practical solution to these limitations, as it possesses the ability to flow and settle under its own weight without external vibration. Previous research has shown that the use of mineral admixtures such as fly ash (FA) and ground granulated blast furnace slag (GGBS) in low-fines self-compacting concrete (LFSCC) can effectively produce mixes with strengths ranging from 20 to 30 MPa. The addition of FA and GGBS improves the fresh-state flow behavior of SCC and contributes to enhanced mechanical performance after hardening. Furthermore, the partial replacement of cement with these supplementary cementitious materials significantly increases the durability of LFSCC by refining pore structure and reducing permeability.

**Keywords:** Self-Compacting Concrete, Fly Ash, Ground Granulated Blast Furnace Slag, Mineral Admixtures, Permeability.

## Introduction

In recent decades, improving work efficiency and ensuring better construction quality have been key priorities in concrete technology. Modern concrete is no longer a simple blend of cement, aggregates, and water; instead, it has evolved into a customized material designed to meet specific performance requirements. High-performance concrete has gained widespread acceptance because it provides improved strength, workability, and durability while also reducing project costs. Traditionally, the quality of hardened concrete depended heavily on proper compaction, making results inconsistent and reliant on skilled labor. To address this issue, self-compacting concrete (SCC) was developed in Japan during the 1980s. SCC flows freely under its own weight, filling formwork and encasing reinforcement without vibration, thus ensuring uniform consolidation and reducing human effort. To optimize SCC for practical and economical use, supplementary cementitious materials (SCMs) such as fly ash (FA), ground granulated blast furnace slag (GGBS), silica fume, and limestone powder have been widely adopted. These mineral admixtures enhance workability, reduce cement consumption, lower heat of hydration, and improve the durability of concrete by minimizing permeability and chemical attack. Additionally, their fine particle structure contributes to better packing density, improved cohesion, and reduced reliance on chemical admixtures. Overall, the incorporation of SCMs ensures longer-lasting, economical, and environmentally sustainable concrete.

1. Literature Review

Shi C. et al. (2015) investigated the effects of fly ash (FA) and ground granulated blast furnace slag (GGBS) on the compressive strength, gas permeability, and carbonation resistance of high-performance concrete (HPC). Their findings indicated that the influence of FA varies significantly with water–binder ratio, especially at higher replacement levels, whereas GGBS displayed consistent performance regardless of the water–binder ratio. Overall, HPC containing GGBS demonstrated better mechanical and durability characteristics than FA blends. Neelam Pathak and Rafat Siddique (2012) examined self-compacting concrete containing Class F fly ash under elevated temperatures. Concrete mixes with 30%–50% FA were tested at temperatures ranging from 20°C to 300°C. Their results showed slight improvements in compressive strength up to 300°C, although splitting tensile strength decreased gradually with increasing temperature and fly ash content. P. Dinakar (2013) evaluated the performance of SCC made with Portland pozzolana cement (PPC) and varying proportions of fly ash from 10% to 70%. The study revealed that replacing 30% of PPC with fly ash yielded high compressive strength (around 100 MPa at 56 days) and improved tensile and modulus properties. Water absorption levels remained low, and chloride permeability was significantly reduced at optimal replacement levels. Muhd Fadhil Nuruddin et al. (2014) focused on SCC incorporating lightweight aggregates produced from fly ash. Their work demonstrated that these mixes exhibited excellent deformability, passing ability, and resistance to segregation, while also achieving satisfactory compressive strength at both 28 and 90 days.

2. Methodology

The LFSCC was prepared by initially mixing 10 mm coarse aggregates and less than 10 mm aggregates for a few seconds in a tilting drum mixer. The fine aggregates were sieved, weighed and mixed with the coarse aggregates in the mixer machine. Then, cement, fly ash was included in the mix as it was used as a cementitious replacement of different percentages and were mixed for a few seconds Later the chemical admixtures like superplasticizer were dispersed in water and then added to the materials in the mixer machine. Based on the trial and error methods, these mix proportions have arrived and this procedure was followed for concrete preparation. The fresh SCC was prepared and checked for the workability tests like slump flow, L-box, V-funnel and J-ring tests. The fresh concrete properties were measured and checked for the suitability standards of SCC. The LFSCC ingredients namely cement, fine aggregate (sand) and coarse aggregate were weighed proportionately and they were dry mixed on pan mixer. At this stage required quantity of superplastcizer was added and mixed thoroughly in a mixture. Different flowability tests like slump test, V funnel, L Box test, J-Ring test these flow properties are assess fresh flow properties. The fresh concrete was placed into the mould with the help of scoop. Without any compaction all specimens are casted for different tests like compressive test, flexural test and tensile test. After 24 hours, the specimens were demoulded and transferred to curing tank wherein they were allowed to cure for 28 days.

Testing Of Concrete Specimens

Compressive strength test

The compressive strength test was conducted after the concrete specimens were cured for 28 days. The test procedure was carried out in accordance with IS: 516-1959 specification.

Split Tensile Strength Test

The concrete specimens for indirect tensile test were 150mm diameter and 300mm height. The specimens were placed with its axis horizontal, between the platens of a compression-testing machine. Load was applied until the specimen failed in its vertical diameter. The test procedure was carried as per IS: 5816-1999.

3. Results And Discussions

### 3.1 Effect of combination of FA+GGBS on mechanical strength characteristics of LFSCC

### 3.1.1 Compressive Strength

The table summarizes the compressive strength development of Low-Fines Self-Compacting Concrete (LFSCC) mixes with and without the addition of combined mineral admixtures, namely Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBS). The study includes three strength grades: **S20, S25, and S30**, each tested at **7, 28, 56, and 90 days**. The results highlight the influence of FA and GGBS on both early-age and long-term strength development. For **S20 grade concrete**, the reference mix exhibited a steady strength gain from 19.06 N/mm² at 7 days to 28.66 N/mm² at 90 days. When FA and GGBS were introduced, all modified mixes showed improvements in long-term strength. Among them, the **S20F15G15** mix recorded the highest 90-day strength of 37.11 N/mm², indicating a significant enhancement compared to the reference. The **S20F15G25** mix also showed excellent performance with a 90-day strength of 37.25 N/mm². In the **S25 grade concrete**, the reference mix reached 35.38 N/mm² at 90 days. The incorporation of FA and GGBS led to noticeable improvement, particularly for **S25F10G20**, which achieved the highest strength of 39.74 N/mm² at 90 days. This demonstrates that replacing cement with balanced proportions of FA and GGBS improves pozzolanic reaction and densifies the matrix. For **S30 grade concrete**, the reference mix attained 36.63 N/mm² at 90 days. The combination blends yielded better performance, with **S30F5G15** achieving the highest strength of 39.66 N/mm². This confirms that even at higher grade concrete, moderate FA and GGBS replacement contributes to improved strength development. Overall, the results demonstrate that the **synergistic use of FA and GGBS enhances the long-term compressive strength of LFSCC**, with optimal performance depending on the grade and replacement ratio.

### 3.2 Test results of mechanical strength characteristics of LFSCC

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Table 1- Test Results of Compressive Strength Of LFSCC with and Without Addition of Combination of FA+GGBS for S20, S25 and S30 Mix

| Mix | Mix Id | Average Compressive Strength N/mm² 7 Days | Average Compressive Strength N/mm² 28 Days | Average Compressive Strength N/mm² 56 Days | Average Compressive Strength N/mm² 90 Days |
|---|---|---|---|---|---|
| S20 | Reference Mix | 19.06 | 26.12 | 27.56 | 28.66 |
| | S20F15G15 | 19.55 | 31.18 | 34.39 | 37.11 |
| | S20F15G20 | 21.76 | 29.87 | 31.76 | 35.88 |
| | S20F15G25 | 18.54 | 30.56 | 32.54 | 37.25 |
| S25 | Reference Mix | 24.50 | 32.16 | 33.45 | 35.38 |
| | S25F10G10 | 22.47 | 33.44 | 35.45 | 38.29 |
| | S25F10G15 | 22.91 | 34.18 | 35.68 | 39.58 |
| | S25F10G20 | 24.73 | 36.55 | 37.90 | 39.74 |
| S30 | Reference Mix | 24.56 | 34.11 | 35.55 | 36.63 |
| | S30F5G5 | 21.82 | 34.64 | 36.13 | 37.34 |
| | S30F5G10 | 20.87 | 35.38 | 37.29 | 38.58 |
| | S30F5G15 | 21.82 | 37.12 | 38.65 | 39.66 |

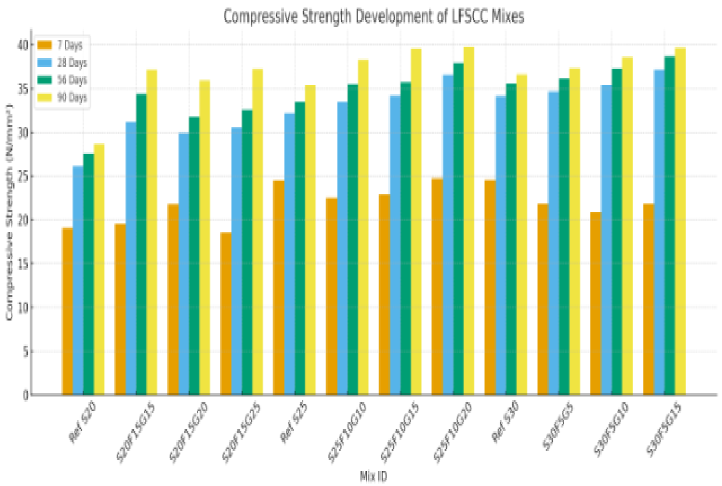


Fig. 1 - Variations of Compressive Strength Values of LFSCC with and Without Combination of FA+GGBS For Mix of S20 Mix (A), S25 Mix (B), S30 Mix (C)

Tensile Strength

The table presents the split tensile strength results of Low Fines Self-Compacting Concrete (LFSCC) mixes at 28 and 90 days, with and without the combined incorporation of Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBS). For the S20 grade, the reference mix recorded tensile strengths of 2.76 N/mm² at 28 days and 2.98 N/mm² at 90 days. The modified mixes showed slightly improved performance, with S20F15G20 achieving the highest 28-day value of 2.90 N/mm², while S20F15G25 reached the highest 90-day strength of 3.15 N/mm², indicating long-term strength gain due to mineral admixtures. For the S25 grade, the reference mix exhibited strengths of 2.89 N/mm² at 28 days and 3.22 N/mm² at 90 days. The addition of FA and GGBS significantly enhanced performance, with S25F10G20 displaying the maximum values of 3.18 N/mm² at 28 days and 3.80 N/mm² at 90 days. In the S30 grade, the reference mix showed strengths of 3.41 N/mm² and 3.72 N/mm² at 28 and 90 days, respectively. The modified mixes demonstrated further improvement, with S30F5G10 reaching the highest values of 3.89 N/mm² at 28 days and 4.09 N/mm² at 90 days. Overall, the results confirm that FA + GGBS combinations enhance tensile strength, particularly at longer curing ages.

Table 2- Test Results of Splitting Tensile Strength of LFSCC with and Without Addition of Combination of FA+GGBS for S20, S25 and S30 Mix

| MIX ID | Tensile Strength N/mm² 28 days | Tensile Strength N/mm² 90 days |
|---|---|---|
| Reference Mix | 2.76 | 2.98 |
| S20F15G15 | 2.81 | 3.12 |
| S20F15G20 | 2.90 | 3.11 |
| S20F15G25 | 2.72 | 3.15 |
| Reference Mix | 2.89 | 3.22 |
| S25F10G10 | 2.91 | 3.54 |
| S25F10G15 | 3.04 | 3.52 |
| S25F10G20 | 3.18 | 3.80 |
| Reference Mix | 3.41 | 3.72 |
| S30F5G5 | 3.76 | 3.98 |
| S30F5G10 | 3.89 | 4.09 |
| S30F5G15 | 3.65 | 4.08 |

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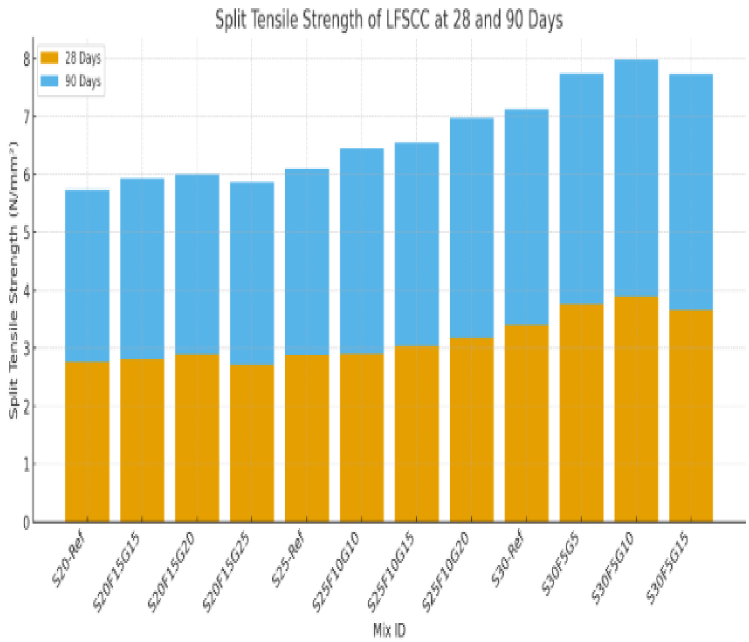


Fig. 2 - Variations of Tensile Strength Values of LFSCC With and Without Combination of FA+GGBS for Mix Of S20 Mix (A), S25 Mix (B), S30 Mix (C)

## *4.* Conclusions

The experimental study clearly demonstrates that the combined use of Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBS) significantly enhances both the compressive and tensile strength characteristics of Low-Fines Self-Compacting Concrete (LFSCC). Across all mix grades (S20, S25, and S30), concrete containing FA and GGBS exhibited superior long-term strength development compared to the corresponding reference mixes. The improvement is attributed to the pozzolanic reaction and refined microstructure, which enhance matrix densification and reduce voids over time. For compressive strength, the S20 grade showed the most notable enhancement, particularly in the S20F15G15 and S20F15G25 mixes, confirming that optimal FA and GGBS proportions contribute to improved binder efficiency. In the S25 mixes, moderate but consistent strength improvements were observed, with S25F10G20 achieving the highest 90-day strength. In the S30 mixes, S30F5G15 resulted in the highest compressive strength, although the enhancement was comparatively lower than in S20 and S25 mixes. Similarly, tensile strength results demonstrated progressive strength gain with curing age. The mixes with combined FA and GGBS yielded higher tensile strength at 90 days, particularly in S25F10G20 and S30F5G10, indicating better crack resistance and improved durability. Overall, the study confirms that FA + GGBS blends are effective in producing high-performance, durable LFSCC.

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