Mechanical Property Investigation of M40 Concrete with Supplementary Cementitious Materials: GGBS and Silica Fume

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Abstract - Concrete is the most widely used construction material, but the production of cement generates a large amount of carbon dioxide, contributing to environmental concerns. To address this issue, supplementary cementitious materials such as ground granulated blast furnace slag (GGBS) and silica fume (SF) can be used as partial replacements for cement. This study investigates the mechanical properties of M40 grade concrete with different replacement levels of GGBS and silica fume. Seven mixes were prepared, including a control mix, binary mixes with GGBS or SF, and ternary mixes with both GGBS and SF. Standard tests for compressive strength, split tensile strength, and flexural strength were conducted at 7 and 28 days. The results showed that GGBS improved long-term compressive strength but reduced early-age strength, while silica fume significantly enhanced both early and later strength. The ternary blend of 20% GGBS and 10% silica fume achieved the highest strength values, with 57 MPa compressive strength, 4.9 MPa split tensile strength, and 6.8 MPa flexural strength at 28 days. The study concludes that the combination of GGBS and silica fume in M40 concrete not only improves strength properties but also promotes sustainability by reducing cement consumption and carbon emissions.

Keywords : M40 concrete, Ground granulated blast furnace slag, Silica fume, Compressive strength, Split tensile strength, Flexural strength, Sustainable concrete

1. INTRODUCTION

The construction industry is one of the most important parts of India's growth. It gives work to a large number of people and also adds a big share to the country's income. Concrete is the main material used in construction because it is strong and lasts long. But the main ingredient of concrete, cement, creates a big problem. When cement is made, a lot of carbon dioxide gas is released into the air. For every one ton of cement, about one ton of carbon dioxide is produced. This harms our environment.

To reduce this problem, other materials are used in place of some cement. These are called supplementary materials, and some examples are fly ash, rice husk ash, ground granulated blast furnace slag (GGBS), and silica fume (SF). They not only reduce pollution but also improve the quality of concrete.

Silica fume is a very fine powder that comes as a byproduct from the silicon and steel industry. Because of its small particle size, it makes the concrete stronger and more durable. In India, silica fume has been used in a few big projects like nuclear plants, flyovers, and bridges.

GGBS is another material that comes from the steel industry. It is made when the waste from molten iron is cooled quickly in water and then ground into a fine powder. GGBS helps concrete resist water, sulphates, and corrosion. It also makes concrete last longer and reduces the need for cement, which helps protect the environment.

This study is about using both GGBS and silica fume in M40 grade concrete. The aim is to check how the strength of concrete changes when part of the cement is replaced with these materials. The objectives of this study are:

1. To use GGBS and silica fume in M40 concrete as partial replacement of cement in different proportions.
2. To test the concrete for compressive strength, split tensile strength, and flexural strength.
3. To compare normal concrete with concrete made using GGBS and silica fume.
4. To see how the strength changes with different percentages of GGBS and silica fume.
5. To check if this method can be used in real construction work in India.

2. MATERIALS AND METHODOLOGY

2.1 Materials

The experimental investigation was carried out using the following materials:

- **Cement**: Ordinary Portland Cement (OPC) of 53 grade conforming to IS 12269-1987 was used throughout the study. It was fresh, free from lumps, and stored in dry conditions.
- **Fine Aggregate**: Natural river sand, conforming to Zone II of IS 383-2016, was used. The sand was clean, hard, and free from clay, silt, and organic impurities. It passed through a 4.75 mm IS sieve.

- **Coarse Aggregate**: Crushed angular coarse aggregates of two sizes, 20 mm and 10 mm, were used in suitable proportions to achieve good grading. The aggregates complied with IS 383-2016.
- **Water**: Potable water free from oils, acids, salts, and organic matter was used for both mixing and curing.
- **Ground Granulated Blast Furnace Slag (GGBS)**: GGBS was obtained as a byproduct of the iron and steel industry. It was off-white in color, finely ground, and had a specific surface area in the range of 400–600 m^2/kg.
- **Silica Fume (SF)**: Silica fume was procured from a ferro-silicon industry. It is a very fine pozzolanic powder with particles less than 1 micron in size, having more than 90% silicon dioxide content.

2.2 Mix Proportions

The control mix (Mix M0) was designed for M40 grade concrete as per IS 10262:2009, with a constant water–cement ratio of 0.40. In experimental mixes, cement was partially replaced with GGBS and silica fume in different percentages while keeping the total binder content constant.

A total of seven mixes were prepared: one control mix and six modified mixes with different replacement levels.

Table 2. 1: Mix Proportions with Replacement Percentages

Mix ID	Cement (%)	GGBS (%)	Silica Fume (%)	Remarks
M0	100	0	0	Control mix (OPC only)
M1	80	20	0	Partial replacement with GGBS
M2	60	40	0	Higher GGBS content
M3	90	0	10	Partial replacement with SF
M4	80	0	20	Higher SF content
M5	70	20	10	Ternary blend (GGBS + SF)
M6	60	30	10	Ternary blend with higher GGBS

2.3 Preparation of Specimens

As described earlier, specimens were cast for compressive, split tensile, and flexural strength tests using the sizes shown in Table 2.

Table 2.2: Specimen Details

Test Type	Specimen Size	Standard Code	No. of Specimens per Mix
Compressive Strength	150 × 150 × 150 mm cubes	IS 516-2018	3 (for 7 days) + 3 (for 28 days) = 6
Split Tensile Strength	150 mm dia × 300 mm height cyl.	IS 5816-1999	3 (for 28 days)
Flexural Strength	150 × 150 × 700 mm beams	IS 516-2018	3 (for 28 days)

For each mix, a total of 12 specimens were cast (6 cubes, 3 cylinders, 3 beams). With 7 mixes, the total number of specimens prepared was 84.

3. RESULTS AND DISCUSSION

The experimental program was conducted to study the influence of partial replacement of cement with ground granulated blast furnace slag (GGBS) and silica fume (SF) on the mechanical properties of M40 grade concrete. The properties studied include compressive strength, split tensile strength, and flexural strength.

3.1 Compressive Strength

Fig. 3.1 : Compressive Strength Testing

The compressive strength results for all mixes at 7 and 28 days are presented in Table 3.1.

Table 3.1: Compressive Strength Results (MPa)

Mix ID	7 Days	28 Days
M0 (Control)	33.5	47.0
M1 (20% GGBS)	31.0	49.5
M2 (40% GGBS)	28.0	46.5
M3 (10% SF)	37.5	53.5
M4 (20% SF)	39.0	55.0
M5 (20% GGBS + 10% SF)	38.5	57.0
M6 (30% GGBS + 10% SF)	36.5	55.5

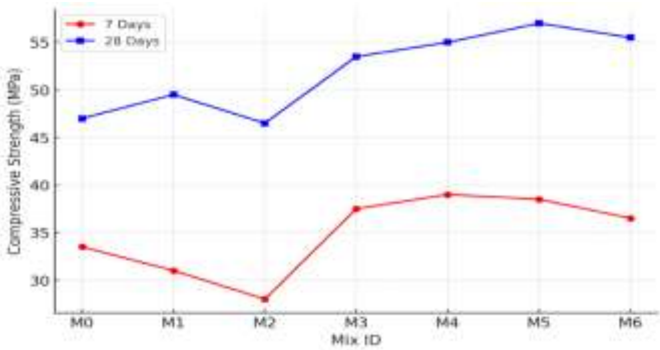

Fig 3.2 : Compressive Strength Results

The control mix (M0) achieved the target strength of M40 concrete. Mixes with GGBS (M1 and M2) recorded lower early-age strength compared to control concrete due to the slower hydration process of GGBS. However, at 28 days, Mix M1 (20% GGBS) surpassed the control, while M2 (40% GGBS) showed slightly lower strength. Mixes with silica fume (M3 and M4) exhibited a significant increase in both 7-day and 28-day strength, which can be attributed to the high pozzolanic reactivity and filler effect of silica fume. The ternary blends (M5 and M6) outperformed all other mixes, with M5 (20% GGBS + 10% SF) achieving the highest 28-day compressive strength of 57 MPa.

3.2 Split Tensile Strength

Fig. 3.3 : Split Tensile Strength Testing

The split tensile strength results at 28 days are given in Table 3.2.

Table 3.2: Split Tensile Strength Results (MPa)

Mix ID	28 Days
M0 (Control)	3.9
M1 (20% GGBS)	4.1
M2 (40% GGBS)	3.8
M3 (10% SF)	4.5
M4 (20% SF)	4.7
M5 (20% GGBS + 10% SF)	4.9
M6 (30% GGBS + 10% SF)	4.8

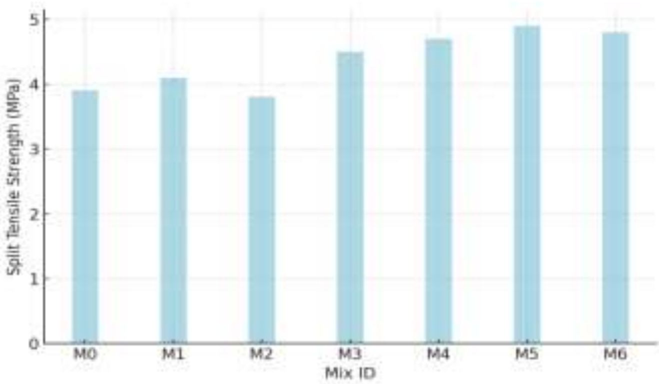

Fig 3.4 : Split Tensile Strength Results

The results indicate that the addition of silica fume significantly enhanced tensile capacity. GGBS alone produced only a moderate improvement compared to the control, whereas the ternary blends (M5 and M6) showed the highest tensile strength, with M5 recording 4.9 MPa at 28 days. This improvement can be explained by the densification of the matrix and improved bond between aggregates and the cementitious paste.

3.3 Flexural Strength

Fig 3.5 : Flexural Strength Testing

The flexural strength results at 28 days are presented in Table 3.3.

Table 3.3: Flexural Strength Results (MPa)

Mix ID	28 Days
M0 (Control)	5.4
M1 (20% GGBS)	5.6
M2 (40% GGBS)	5.3
M3 (10% SF)	6.2
M4 (20% SF)	6.5
M5 (20% GGBS + 10% SF)	6.8
M6 (30% GGBS + 10% SF)	6.6

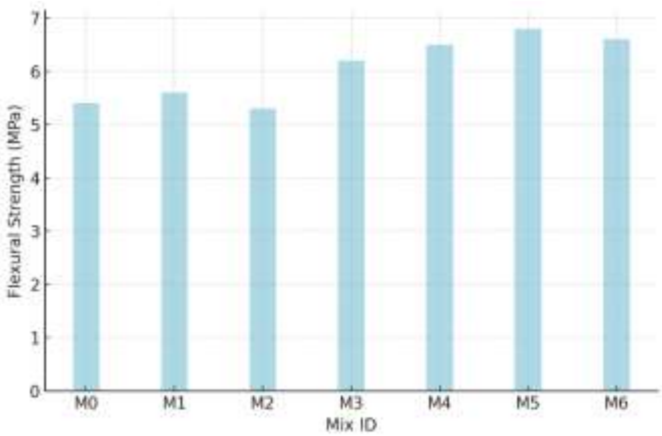

Fig 3.6 : Flexural Strength Results

It is observed that concrete mixes containing silica fume exhibited better flexural strength compared to the control and

GGBS mixes. The ternary blends showed the highest values, with Mix M5 achieving 6.8 MPa, which is about 26% higher than the control mix. The very fine particle size of silica fume improved the bond and reduced microcracks, while GGBS contributed to long-term strength gain.

3.4 Overall Discussion

From the test results, the following observations can be made:

- GGBS reduced early-age strength but enhanced long-term compressive performance.
- Silica fume improved both compressive and tensile strength due to its high pozzolanic activity.
- The ternary blends (GGBS + SF) combined the advantages of both materials, giving the best results in all mechanical tests.
- Mix M5 (20% GGBS + 10% SF) was found to be the optimum mix, showing the highest compressive (57 MPa), split tensile (4.9 MPa), and flexural strength (6.8 MPa) at 28 days.

Thus, the combination of GGBS and silica fume in M40 grade concrete proved to be a sustainable and effective approach for improving mechanical properties while reducing cement consumption.

4. CONCLUSION

The present investigation was carried out to study the effect of partial replacement of cement with ground granulated blast furnace slag (GGBS) and silica fume (SF) on the mechanical properties of M40 grade concrete. Based on the experimental results, the following conclusions are drawn:

1. The control mix (M0) achieved the target strength of M40 concrete, while mixes with GGBS alone showed slightly lower early-age strength. However, at 28 days, the mix with 20% GGBS (M1) exceeded the strength of the control, confirming that GGBS improves long-term performance.
2. Silica fume significantly enhanced both early and 28-day strength due to its very fine particle size and high pozzolanic reactivity. Mixes with 10–20% SF (M3 and M4) showed higher compressive, tensile, and flexural strength compared to the control.
3. The combined use of GGBS and silica fume (ternary blends) gave the best overall performance. In particular, the mix with 20% GGBS and 10% SF (M5) achieved the highest values of compressive strength (57 MPa), split tensile strength (4.9 MPa), and flexural strength (6.8 MPa).
4. The study demonstrates that replacing cement with GGBS and silica fume not only improves the mechanical properties of concrete but also reduces cement consumption, thereby lowering carbon dioxide emissions and promoting sustainable construction.

It can be concluded that the optimum replacement level for M40 grade concrete is 20% GGBS and 10% silica fume, which provides superior strength performance and contributes to eco-friendly concrete technology.

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