Strength Studies on Slag Sand Concrete Blended with Silica Fume and Glass Powder

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Abstract
Concrete is the backbone of modern construction, and its properties can be significantly enhanced by incorporating innovative materials like silica fume, fly ash, glass powder, slag sand, etc. This project explores the effects of incorporating slag sand, silica fume, and glass powder into concrete mixtures with Grade M30 specifications using a water-cement ratio of 0.5. The primary objective is to investigate how these innovative materials impact both fresh and hardened concrete properties. By fully replacing fine aggregate with slag sand, varying the percentages of silica fume (0, 10, 20, and 30), and adding glass powder (0, 10, and 20) by weight of cement, a total of 12 different concrete mixtures were prepared to achieve optimum strengths. The fresh properties of the concrete are evaluated by a slump test and a compaction factor test. The hardened properties are assessed by a compressive strength test at 28 days and 90 days, a split tensile strength test, and a flexural strength test after 28 days of curing.

Keywords: Glass powder, Silica fume, Slag sand, Compressive strength, Split tensile strength, and Flexural strength.

1. Introduction

1.1 General

Concrete is one of the most widely used construction materials globally due to its versatility, durability, and structural strength. However, as the construction industry seeks to become more sustainable and environmentally friendly, there is a growing interest in enhancing the properties of concrete while reducing its environmental impact. One promising avenue for achieving this balance is through the incorporation of supplementary cementitious materials and innovative additives into concrete mixes.

This study explores into the interesting new form of concrete technology, specifically focusing on the strength and workability characteristics of concrete blends that incorporate a trifecta of materials: slag sand, silica fume, and glass powder. Slag sand, a byproduct of the steel manufacturing process, offers potential as a sustainable replacement for conventional sand in concrete mixes. Silica fume, an ultrafine pozzolanic material, is known for its ability to enhance concrete strength and durability. Glass powder, sourced from recycled glass, not only contributes to sustainability but also introduces unique properties to the concrete mix.

By combining these three components, concrete may be produced that not only satisfies the demanding standards of construction but also conforms to the values of sustainability and environmental responsibility. This study intends to investigate how these elements affect the strength and workability of concrete, as well as other concrete qualities.

1.2 Need for Replacement

In this study, replacing a portion of cement with silica fume, the resulting concrete gains higher early and ultimate strength, making it suitable for applications that require high strength, such as in high-rise buildings and infrastructure projects. And also, silica fume can help mitigate the heat generated during the hydration process of cement, the carbon footprint of concrete production can be reduced, contributing to more sustainable construction practices. Structures built with silica fume-blended concrete have demonstrated improved long-term performance. Silica fume can enhance the workability and rheological properties of concrete.

1.3 Need For Addition

Here we have taken glass powder as addition by weight of cement. As the glass powder reacts with cement hydrates, it forms additional binding compounds, contributing to increased compressive strength, resistance to chemical attacks, and mitigation of potential alkali-silica reactions. Furthermore, the integration of glass powder aligns with environmentally- conscious practices, reducing the carbon footprint of concrete production and exemplifying the industry's commitment to innovation and responsible material usage.

2. Literature Review

1. **Ramakrishnan et al. (2014)** investigated the effect of glass powder on the workability of slag sand concrete. It was found that the addition of glass powder decreased the workability of concrete due to its finer particle size. However, the use of superplasticizer mitigated the decrease in workability, resulting in concrete with acceptable workability.
2. **Ramakrishna and Venkateshwara Rao (2015)** evaluated the partial replacement of cement with silica fume and glass powder in concrete can increase its strength and durability. The study found that using a mixture of glass powder and silica fume as a partial replacement of cement can increase the compressive strength of concrete by up to 8.64%, tensile strength by up to 15%, and flexural strength by up to 7.08% at the age of 28days.
3. **Sharma and Chandel (2016)** investigated the effects of incorporating silica fume and glass powder in slag sand concrete on its mechanical and durability properties. The results indicated that the addition of glass powder increased the compressive strength, split tensile strength, and durability of the concrete. The inclusion of silica fume further improved these properties, demonstrating the potential synergy between the two pozzolanic materials.
4. **Zou et al. (2017)** conducted a noteworthy study on the enhancement of concrete properties through the incorporation of glass powder and silica fume. Their research, published in Applied Sciences, delves into the effects of these supplementary materials on both the strength and workability of concrete. The results showed that the compressive strength of slag sand concrete increased with the addition of silica fume and glass powder.
5. **Khan and khan (2017)** conducted a study on the effect of partial replacement of cement by a mixture of glass powder and silica fume on concrete strength. The author discovered that the usage of a mixture of glass powder and silica fume in concrete as a partial replacement of cement increases the concrete strength.
6. **Kumar et al. (2018)** investigated the effect of silica fume and glass powder on the workability of slag sand concrete. They found that the inclusion of glass powder improved the workability of the concrete, compensating for the decrease caused by silica fume. They suggested that the combination of these materials in an appropriate proportion can achieve a workable mixture without compromising other properties.
7. **Kothari et al. (2018)** focused on the influence of glass powder and silica fume on the workability and strength properties of slag sand concrete. The researchers observed that the addition of glass powder improved the workability of the concrete by improving the packing density and reducing the internal friction. Additionally, the presence of silica fume enhanced the strength properties, such as compressive strength and split tensile strength, due to the pozzolanic reaction and formation of calcium silicate hydrate (C-S-H) gel.
8. **Kumar, Chopra, and Sood (2020)** evaluated the impact of incorporating slag and silica fume into glass powder concrete was investigated. The research delves into the enhancement of concrete properties through these supplementary materials. Their findings shed light on the potential for improved strength and durability, offering valuable insights for the construction industry. This study contributes to the ongoing efforts to develop sustainable and high-performance construction materials, thus paving the way for more eco-friendly and resilient infrastructure.

3. Objectives of The Study

The following are the main objectives of the study:

1. To investigate how the inclusion of slag sand, silica fume, and glass powders affect the compressive, split tensile, and flexural strengths of M30 grade concrete.

2. To Examine the characteristics of the concrete mixture’s workability and how the modified concrete influences the concrete's setting time and early development of strength.
3. To study the strength characteristics of concrete blended with slag sand, silica fume and glass powder.

4. Methodology

4.1 Materials Used:

In this experiment, cement, slag sand, glass powder, silica fume, coarse aggregate, and water are employed as the components.

A. Cement:

The building industry uses cement as a binding agent because it hardens and adheres to other materials. It possesses adhesive and cohesive qualities. Throughout the trial, 53- grade Ordinary Portland Cement (OPC) from Sri Chakra Supertech, a widely available brand, was used. It was brand-new and lump-free. Cement has a specific gravity of 3.14.

B. Fine Aggregate (Slag Sand):

Slag sand is a type of artificial sand that is easily obtainable locally and is a by-product of the steel industry. Here, slag sand has totally taken the place of natural sand.

In this project, we have used slag sand manufactured by JSW confining zone II and Referring to IS:383-2016. The specific gravity of slag sand, which we measured in a lab, is 2.62.

C. Coarse Aggregates:

The main functions of coarse aggregate are to provide resistance to deformation and breaking and to equally distribute the applied loads throughout the concrete. The angular- shaped aggregates used for this project have a maximum size of 20 mm. These aggregates are formed of crushed granite stone and were obtained from a local quarry. Laboratory tests indicated that these aggregates have a specific gravity of 2.72.

D. Silica Fume:

Silica fume, also known as micro silica, is a by-product of silicon metal or ferrosilicon alloy production. It consists of very fine particles, making it highly reactive with the cement matrix. When used in concrete, silica fume can significantly enhance the strength, durability, and overall performance of the material. Silica Fume was bought from K Mohan and Company, Chennai.

E. Glass Powder:

Glass powder, derived from waste glass, is another alternative material that can be used in concrete production. Glass Powder which is manufactured by SGS India Private Ltd was used in this project. It has pozzolanic properties, meaning it reacts with calcium hydroxide in the presence of moisture to form cementitious compounds. The addition of glass powder to concrete can improve its mechanical properties and reduce its environmental impact by utilizing recycled material.

F. Water:

The presence of chemicals, sulphates and chlorides, organic matter, and other substances in the water should have a harmful effect on the concrete when water binds to it. It has an effect on concrete strength. For this investigation, we used potable (drinking) water for concrete mixing.

4.2 Mix Proportions

To obtain M30-grade strength, the concrete was designed in accordance with IS 10262-2019, and a water-to-cement ratio of 0.5 was employed. Twelve distinct mixes of concrete with varying proportions containing silica fume (0%, 10%, 20%, 30%) and glass powder (0%, 10%, 20%) by weight of cement. The strength characteristics are analysed in terms of compressive

Strength, Flexural Strength, and Split Tensile Strength. Six cubes, three cylinders, and three beams were caste for each mix and tested for hardened properties. The table shows the designed proportions of the basic ingredients in concrete.

Table No.1 Mix Proportions of Different Mixes

S. No	MATERIALS	QUANTITIES (kg/m^3)
1	Cement	425
2	Fine Aggregate	560
3	Coarse Aggregate	1150
4	W/C Ratio	0.5
5	Glass Powder	0%, 10%, 20%
6	Silica Fume	0%, 10%,20%, 30%

5. Results & Discussion

Below is an overview of the examination of characteristics assessed during its hardened state of concrete, along with the experimental observations that were made.

1. Compressive Strength Test:

The average compressive strength values taken into consideration and the findings are displayed in Table 2.

Table No 2. Compressive Strength Test Results After 28 Days

% Addition Of Glass Powder	% Replacement Of Silica Fume			
	0	**10**	**20**	**30**
0	38.9	43.8	41.6	38.5
10	41.4	45.3	42.7	39.9
20	40.1	42.5	40.3	37.6

To determine the concrete's maximum load-bearing capacity, compression strength tests are conducted. In order to perform a compressive test, we prepared cubes that were 150mm*150mm*150mm in size. Each mix contains three samples of cubes for 28 days compressive strength.

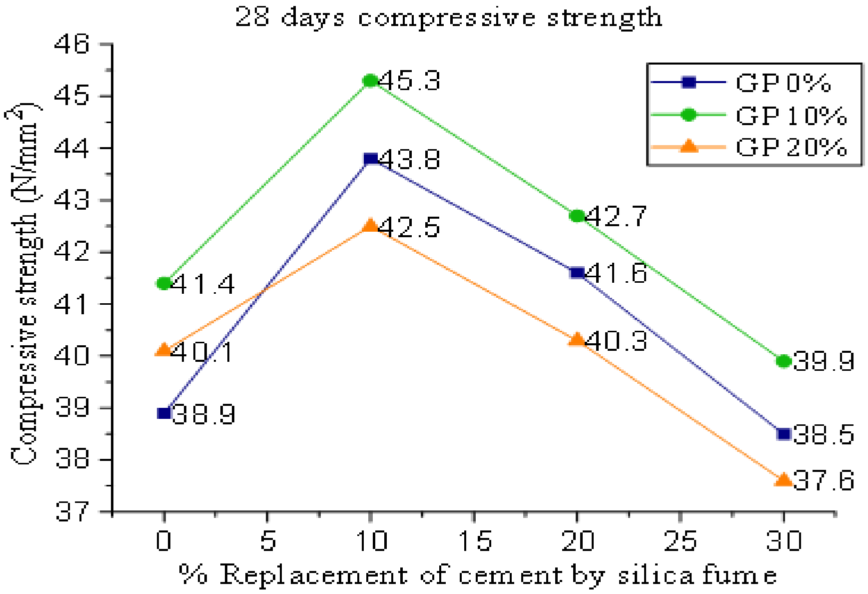

Fig No.1 Variation of Compressive Strength

Figure 1 shows that compressive strength varies for slag sand concrete at different percentages of silica fume replacement and glass powder addition. Due to silica fume's highly reactive pozzolanic reactions and glass powder fineness properties, its strength increases up to 20% replacement levels of silica fume and 20% glass powder addition. Beyond that limit, the compressive strength starts to decrease. The highest compressive strength observed is 45.3 N/mm^2, which was attained by replacing 10% of the silica fume and 10% glass powder addition.

The following table shows the compressive strength test values at 90 days:

Table No 3. Compressive Test Results After 90 Days

% Addition Of Glass Powder	% Replacement Of Silica Fume			
	0	**10**	**20**	**30**
0	44.72	50.18	47.8	44.01
10	47.83	51.88	48.92	45.83
20	45.76	49.4	46.23	43.14

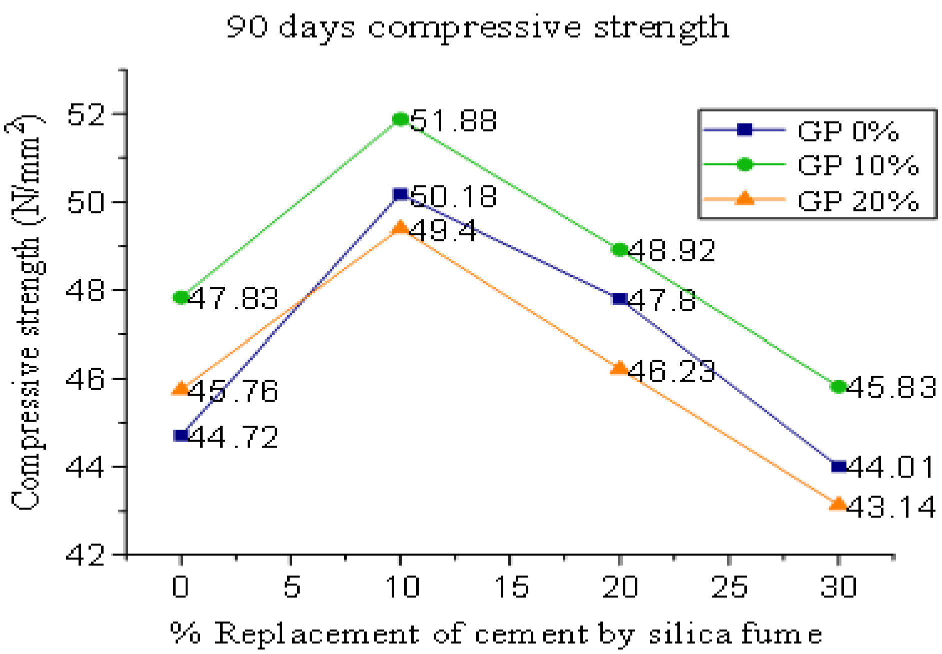

Fig No.2 Variation of Compressive strength

Concrete attains its maximum strength after 28 days of curing. if it is further cured for more days to observe if there are any changes in strength. Figure 2 shows that the experiment's sample extension period of curing increases its strength. 90-day-old samples give around 15% more strength when compared to the 28-day-old samples, due to the lengthy curing process and ongoing microstructural development of the concrete. The obtained compressive strength is 51.88 N/mm2 at 10% silica fume replacement and 10% glass powder addition to the slag sand concrete after 90 days of curing.

2. Split Tensile Strength:

Tensile strength tests are carried out to determine how a material will react to specific circumstances or stresses. Here, for finding splitting tensile strength, 300mm height, 150mm diameter sized three cylinders are prepared for each mix. After the completion of the 28-day curing period, perform a test with the help of a compression testing machine.

The average split tensile strength values are represented in Table no.4.

Table No. 4. Split Tensile Strength Results After 28 Days

% Addition Of Glass Powder	% Replacement Of Silica Fume			
	0	10	20	30
0	3.42	3.82	3.72	3.41
10	3.88	4.2	3.86	3.63
20	3.29	3.96	3.52	3.28

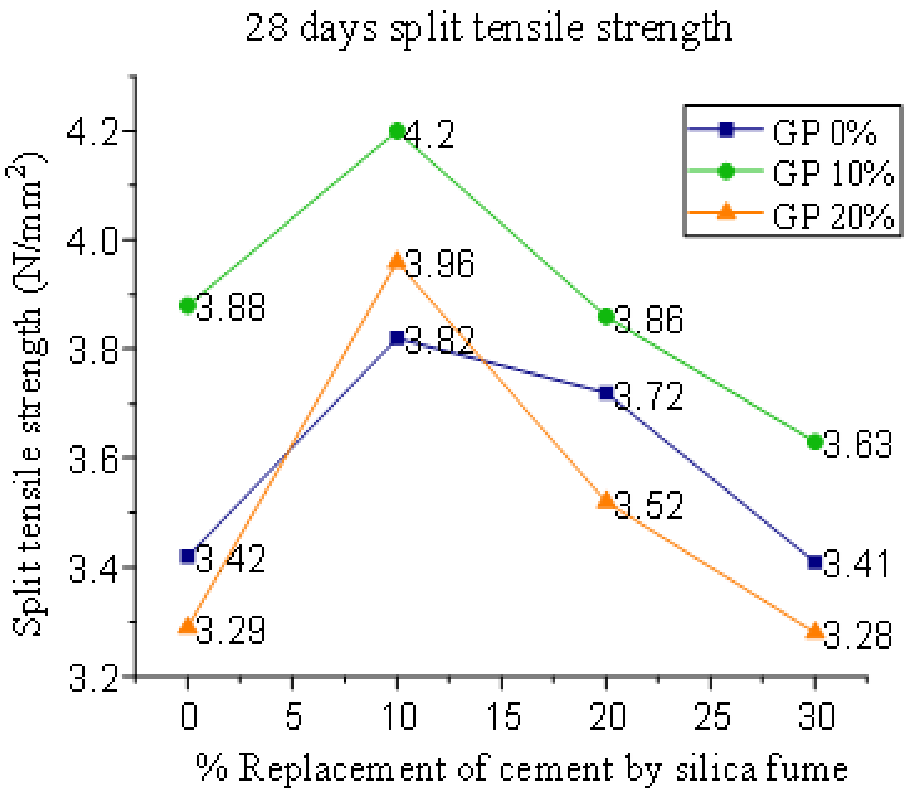

Fig No.3 Variation of split tensile strength

Figure 3 demonstrates the effect of several combinations, including silica fume, glass powder, and slag sand concrete, on the split tensile strength. The observable cause is that because silica fume particles are so small, they can fill in the spaces left by missing cement particles, increasing cement's strength. When water is present, the glass powder combines with calcium hydroxide to create calcium silicate hydrates, which increase the concrete's strength. The maximal value, 4.25 N/mm^2, was achieved with 10% silica fume and 10% glass powder, as shown by the results of the 28-day test.

3. Flexural Strength Test:

Flexural strength tests are performed to assess a material's capacity to resist bending or flexural loads. In order to establish the flexural strength of the concrete in this experiment, we made 500mm*100mm*100mm beams and examined them after the samples had been curing for 28 days.

The outcomes of the average flexural strength test values are displayed in Table 5.

Table No.5 Flexural Test Values After 28 Days

% Addition Of Glass Powder	% Replacement Of Silica Fume			
	0	10	20	30
0	6.44	6.98	6.72	6.44
10	7.92	8.66	7.82	7.2
20	7.41	7.87	6.98	6.53

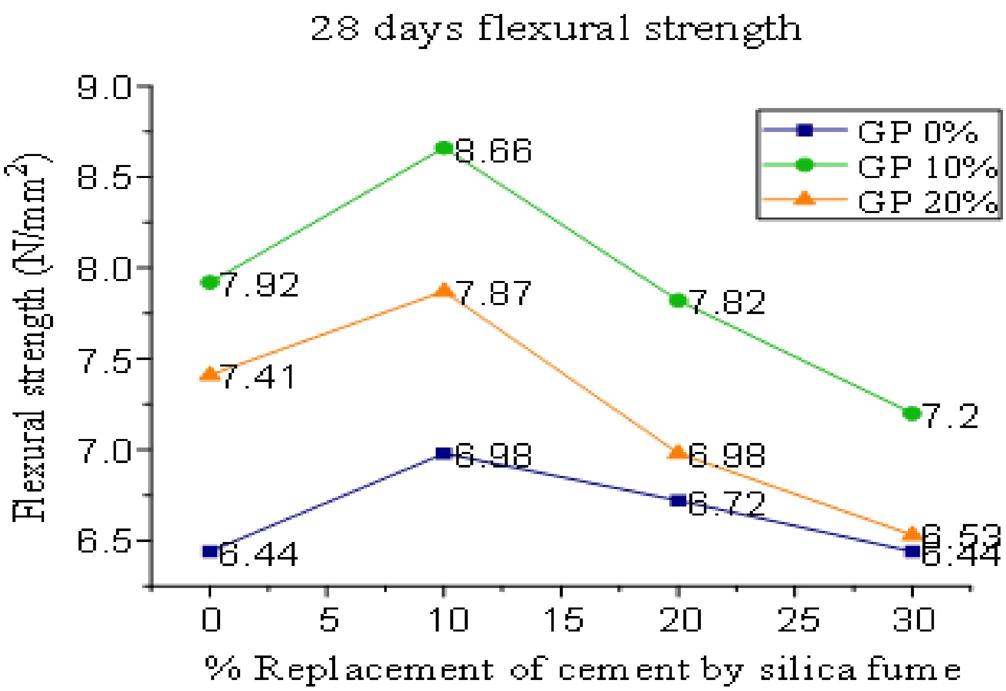

Fig no.4 variation of flexural strength

The flexural values shown in Fig. 4 vary depending on the concrete mix. From 0% to 20% of glass powder addition and 0% to 20% of silica fume replacement indicate a strength increase index. At the 20% glass powder addition and 30% silica fume replacement, the strength decreased. The reason behind this is that supplementary cementitious materials contribute to the formation of additional hydration products, and glass powder reduces the alkali-silica reaction, making it stronger than conventional concrete. The highest strength achieved is 8.66 N/mm^2 at the combination of 90% cement, 10% silica fume, and 10% glass powder.

6. Conclusions

The following conclusions may be drawn based studies on the strength and workability of concrete made of slag sand, silica fume, and glass powder:

1. The slag sand concrete blended with silica fume and glass powder gives more strength compared to conventional concrete.
2. The observed increase in strength in slag sand concrete mixed with silica fume and glass powder is the result of a combination of highly reactive pozzolanic reactions, increased particle packing, enhanced bonding, reduced cracking tendencies, chemical attack, workability and durability.

3. According to this study, strength increases from 0 to 20% of both silica fume and glass powder; over that point, strength starts decline. For compressive strength, split tensile strength and flexural strength tests, the maximum strength observed at 10% replacement of cement by silica fume and 10% addition of glass powder.
4. Hence it proves the usage of slag sand, glass powder and silica fume in concrete reduces waste and environmental footprint of concrete production, increases cost efficiency, and also contributes to eco-friendly construction.

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[10] IS CODES

i. Specification for 53 grade ordinary Portland cement: IS:10262-2019

ii. Methods of test for aggregate of concrete: IS: 383-1970

iii. Compressive strength: IS:516-1959

iv. Split tensile strength: IS: 5816-1999

v. Flexural strength:IS:516-1956.