

## Strength Studies on Slag Sand Concrete Blended with GGBS and Glass Powder

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### Abstract

Use of concrete in present days is increasing enormously. It contributes to 7% of carbon dioxide in global warming. In order to reduce carbon emission in atmosphere, cement is partially replaced by fly ash, GGBS, glass powder etc.. In this work GGBS is used as partial replacement for cement with addition of glass powder in concrete to study strength properties. GGBS (Ground Granulated Blast Furnace Slag) is a cementitious material whose main use in the concrete and is a byproduct from the blast-furnace used to make iron. GGBS can be used as a partial replacement of OPC in concrete production at batching plants. It acts as a stabilising agent and improves the quality of concrete. It is highly cementitious and high in calcium silicate hydrates (CSH) which is a strength enhancing compound which improves the strength, durability and appearance of the concrete. Glass Waste available locally was collected and made into desired size glass powder. Glass waste is very hard material. Glass powder can be recycled and used in concrete which leads to cause a shield to the wastage of materials by recycling. Slag sand is considered as one of the waste materials which can have a promising future in the construction industry as a partial or full substitute of conventional sand. For each ton of steel production, about 2.2 tonnes of slag is generated. This project examines the effect of using GGBS and glass powder as a partial replacement for cement on the strength properties of concrete. For this purpose, we use M30 grade of concrete mixtures by partially replacing cement with GGBS is 0, 10, 20 and 30% by weight of cement and addition of glass powder 0, 10 and 20% by weight of cement and fine aggregate with slag sand respectively. The compressive strength test was carried out on specimen for 28 days and 90 days, split tensile strength test and flexural strength for 28 days.

**Keywords:** Glass powder, GGBS, Slag sand, compressive strength, split tensile strength and Flexural Strength.

### I. Introduction

#### 1.1. General

In the contemporary construction landscape, concrete stands as the undisputed champion, finding its application across a wide spectrum of structures, from soaring skyscrapers to robust industrial complexes, expansive highways to intricate road networks, and vital hydraulic projects. The appeal of concrete lies in its remarkable versatility, allowing it to assume diverse geometric configurations that shape our modern world. However, beneath its omnipresence, concrete's composition as a composite material, comprising cement, coarse and fine aggregates, and water, presents a complex set of challenges that extend beyond its structural utility. At the heart of this challenge is cement, a pivotal ingredient in concrete production.

Cement's global demand continues to escalate, given its indispensable role in construction, with annual production exceeding a staggering 5 billion kilograms. Yet, this widespread reliance on cement raises profound environmental concerns. Cement production depletes global lime reserves and engulfs substantial energy resources, contributing to its significant ecological footprint. In light of these challenges, it becomes increasingly imperative to explore sustainable alternatives and innovative strategies to address the environmental and resource-related issues associated with conventional concrete production.

Two compelling contenders in the quest for sustainable concrete construction are glass powder and Ground Granulated Blast Furnace Slag (GGBS). Glass powder, primarily sourced from

recycled glass, has emerged as a beacon of sustainability within the construction industry. When introduced into concrete mixtures, it acts as a supplementary cementitious material, reducing the reliance on traditional cement. This not only diminishes the environmental impact linked to cement production but also enhances the workability and durability of concrete structures. By repurposing post-consumer or post-industrial glass waste into a valuable construction material, glass powder embodies the principles of the circular economy, diverting glass from landfills and turning it into a resource.

Parallel to glass powder's promise, Ground Granulated Blast Furnace Slag (GGBS) enters the scene as a byproduct of the iron and steel industry. This pozzolanic material exhibits exceptional properties when blended with concrete, enhancing strength and long-term durability while curbing heat generation during curing. This unique attribute is particularly advantageous in large-scale construction projects, mitigating the risk of thermal cracking and bolstering concrete performance in demanding environmental conditions. What elevates the combination of glass powder and GGBS to greater heights is their synergistic effect when employed together in concrete formulations. By incorporating both materials, construction professionals can significantly reduce the carbon footprint associated with cement production, leading to concrete with superior mechanical properties, reduced permeability, and enhanced resistance to chemical deterioration. In essence, the incorporation of glass powder and GGBS in concrete represents a pioneering stride toward sustainable construction practices. By embracing these innovative materials, the construction industry can make substantial strides in reducing greenhouse gas emissions, conserving natural resources, and contributing to a more sustainable future. These materials not only optimize concrete performance but also exemplify the transformative power of environmentally conscious choices in shaping the infrastructure of tomorrow.

Another explored avenue for sustainable concrete production lies in the realm of slag, an often-overlooked waste product generated across various industries. One particular form of slag,

Granulated Blast Furnace (BF) slag, is commonly used in Portland slag cement. However, its resourceful potential extends further, as it can serve as a substitute for river sand in fine aggregate, presenting an ingenious solution for recycling slag. Frequently, slag materials contain a mix of coarse and very fine particles, and they are too often discarded as waste, contributing to resource depletion, environmental pollution, and ecological harm. In light of these challenges, the imperative to recycle industrial waste slag emerges as a cornerstone of sustainable development and environmental stewardship, carrying profound social implications. The adoption of slag as an alternative material in concrete not only conserves precious natural resources but also stands as a vigilant guardian of the environment, aligning with overarching sustainability goals and responsible resource management.

## II. Literature Review

1. Wang Ling et al. (2009) analyzed the performance and the effect of GGBS on fresh concrete and hardened concrete. The strength of GGBS concrete is high and heat of hydration is low and it is resistance to chemical corrosion.
2. Shariq et al.(2010) studied the effect of curing procedure on the cement mortar and concrete incorporating ground granulated blast furnace slag compressive strength development. The compressive strength development of cement mortar is calculated by the 20, 40 and 60 percent replacement of GGBFS for different types of sand. Similarly the strength development of concrete is investigated with 20, 40 and 60 percent replacement of GGBFS on two grades of concrete. Tests results show that the incorporating 20% and 40% GGBFS is highly significant to increase the compressive strength of mortar after 28 days and 150 days, respectively.
3. Md. Moinul Islam et. al. discussed the results of partial replacement of cement using slag in various percentages (10% – 70%). He tested various properties of concrete and found that the compressive strength and tensile strength of mortar mixes with slag when determined at the ages of 3, 7, 14, 28, 60, 90 and 180 days decreases at early ages of curing (3 and 7 days). However, the rate of decrease diminishes with the increasing age

of curing. 40% of cement replacement is the optimum use of slag in the mortar because it has 19% compressive strength and 25% tensile strength when compared to OPC mortar. He concluded that the use of slag reduces the amount of cement content in a mortar mix as well as heat of hydration which results in lower risk of thermal cracking. Thus the use of slag concrete in construction becomes economical and also environmentally safe.

4. Chao-Lung Hwang and Chao-Yin Lin replaced cement with BFS in various percentages (0 – 80%) with three different w/c ratios (0.35, 0.47 and 0.59) in his research and found that the use of slag reduces the strength of mortar at early age (3 days) but it enhance after 7 days. It was also found out that when the specimens demoulded at the age of one day had significantly less strength as compared with those demoulded at one and half days. Three different temperatures were used during curing and specimens cured under 50°C have the best results. He also concluded that the bleeding of the mortar will also reduced when the mortar is mixed with slag. The pores tend to become smaller when slag is used in the mix. This may increase the durability of the cement mortar when it is exposed to adverse environment.
5. Peter et al. (2010) studied the BS 15167-1 which requires that the minimum specific surface area of GGBS shall be 2750 cm<sup>2</sup>/g (BS 15167-1:2006). GGBS is classified into three grades in China; S75, S95 and S105. Minimum 3000 cm<sup>2</sup>/g surface area is required for the GB/T18046 for grade S75 GGBS, 4000 cm<sup>2</sup>/g for grade S95 and 5000 cm<sup>2</sup>/g for grade S105, which are higher than the BS EN's requirements (GB/T18046-2008). Slag with a specific surface area between 4000 cm<sup>2</sup>/g and 6000 cm<sup>2</sup>/g would significantly improve the performance of GGBS concretes.
6. Shilpa Raju and Dr. P. R. Kumar discussed global warming, attributing it to greenhouse gas emissions like CO<sub>2</sub>. In this paper, an attempt has been made to find out the strength of concrete containing waste glass powder as a partial replacement of cement for concrete. Cement replacement by glass powder in the range 5% to 40% increment of 5% has been studied. It was tested for compressive strength and flexural strength at the age of 7, 28 and 90 days and compared with those of conventional concrete. Results showed that replacement of 20% cement by glass powder was found to have higher strength. Also alkalinity test was done to find out resistance to corrosion.
7. J.M. Khatib, E.M. Negim, H.S. Sohl and N. Chileshe examined concrete with glass powder as a partial cement substitute. They found that the maximum strength occurred at 10% glass powder replacement but noted reduced strength beyond that level. Beyond 10% glass powder the strength of concrete reduces and is lower than that of the control. Using ground glass powder can reduce the use of cement and the associated energy demand and impact on air pollution and CO<sub>2</sub> emission. They also observed increased workability but lower compressive strength with higher glass powder content. At 10% glass powder content the compressive strength of concrete is higher than that of substantially decreases.
8. Gunalaan Vasudevan, Seri Ganis Kanapathy pillay were presented in this study was conducted to investigate the effect of using waste glass powder in concrete. Laboratory work was conducted to determine the performance of control sample and concrete with used waste glass powder. The workability of concrete is determined using slump test and compacting factor test. Meanwhile, compressive strength test is done to determine the strength of concrete. For each type of concrete, a total of six cubes were cast. The cubes were tested at the ages of 7, 14 and 28 days to study the development of compressive strength. The results indicate that the concrete with using waste glass powder were able to increase the workability of concrete and also the compressive strength. However, the density is reduced compare to standard mixture of concrete.
9. Dhanaraj mohan patil , Dr. Keshav , K.Sangle explored the use of waste glass powder as a partial replacement for cement in concrete. They studied different replacement levels (10%, 20%, and 30%) and two glass powder grades. Their findings showed initial strength gains were modest on the 7th day but improved by the 28th day, with 20% glass powder replacement resulting in higher strength, especially with glass powder sizes below 90 microns.

10. Li Yun-feng, Yao Yan, and Wang Liang (2009), investigated into the impact of steel slag powder on the workability and mechanical properties of concrete. Their experiments demonstrated that mechanical properties could be further enhanced through the synergistic effects and mutual activation when composite mineral admixtures containing steel slag powder and blast furnace slag powder were incorporated into concrete.
11. Lun Yunxia, Zhou Mingkai, Cai Xiao, and Xu Fang (2008), harnessed steel slag as a fine aggregate to enhance the volume stability of mortar. Their experimental findings indicated that variations in powder ratio, free lime content, and linear expansion rates could effectively express improvements in volume stability achieved through different treatment methods. Autoclave treatment was identified as a more efficacious process for enhancing the volume stability of steel slag.
12. Sean Monkman, Yixin Shao, and Caijun Shi (2010), explored the feasibility of using carbonated Ladle Furnace (LF) slag as a fine aggregate in concrete. Their approach involved CO<sub>2</sub> treatment to reduce free lime content while converting gaseous CO<sub>2</sub> into solid carbonates. The resulting carbonated LF slag was employed as a fine aggregate in zero-slump press-formed compact mortar samples and compared to similar samples containing standard river sand. The 28-day strength of mortars incorporating carbonated slag sand proved comparable to that using regular river sand. This carbonation process rendered LF slag suitable as a

fine aggregate, offering significant potential for carbon sequestration in a valuable form derived from waste slag material. Mortars incorporating carbonated LF slag sand exhibited the most substantial reductions in CO<sub>2</sub> emissions.

### III. Objectives of Research

1. To study the effect of GGBS and GP on hardened properties of M30 grade concrete.
2. To investigate the impact of using Slag-sand as fine aggregate, GGBS and GP as partial replacement for cement in M30 concrete in respect of compressive, splitting tensile and flexural strength.
3. To determine the best proportion for GGBS and GP that may be added as partial cement replacement in producing M30 grade sustainable concrete.

### IV. Materials and Methodology

The blends were created with the goal of giving concrete its maximum strength. The mix proportions of the different materials used in the concrete mixes are provided based on the IS 10262-2019 Code approach.

#### 4.1. Materials Used

##### 4.1.1. Cement

Ordinary Portland Cement (OPC) of 53 grade from Sri Chakra cements Pvt. Ltd. of India from a single batch has been used in the present investigation. The chemical and physical properties of OPC are presented in Table 1(a) and Table 1(b) respectively.

**Table 1(a). Chemical composition of OPC used.**

S.NO	Constituent	Percentage
1.	CaO	64.00
2.	SiO <sub>2</sub>	22.00
3.	Al <sub>2</sub> O <sub>3</sub>	4.10
4.	Fe <sub>2</sub> O <sub>3</sub>	3.60
5.	MgO	1.53
6.	SO <sub>3</sub>	1.90

**Table 1(b). Physical Characteristics of OPC**

S.No	Property	Test result
1	Normal consistency	29%
2	Specific gravity	3.14
3	Initial setting time	65min
4	Final setting time	550min
5	Soundness	3mm
6	Fineness (sieve)	5%

#### 4.1.2 Coarse aggregate

The coarse aggregates originate from a combination of naturally existing rock fragments and crushed granite. Concrete's strength qualities may also be affected by the coarse aggregate's form. These can be found in a variety of shapes, with angular aggregates potentially providing the

best density of mix and minimizing void holes. As per IS: 383-1970, we are now using angular coarse aggregates with a nominal maximum size of 20mm in this project. The nearby quarry provides this crushed stone with a specific gravity is 2.89, See Fig 1.



**Fig 1. Natural Granite Coarse aggregate for the reference mix**

#### 4.1.3 Ground Granulated Blast Furnace Slag (GGBS)

Ground Granulated Blast Furnace Slag (GGBS) is a byproduct of the iron and steel industry and is widely used as a supplementary cementitious material in concrete. GGBS is produced by quenching molten iron slag from a blast furnace with water or steam to rapidly cool and solidify it. After that, the slag is finely ground into a powder form. GGBS primarily consists of amorphous silica, calcium, and alumina compounds. It contains a significant amount of glassy, amorphous material due to its rapid cooling process. The composition of GGBS can vary, but it

typically contains around 30-40% calcium oxide (CaO), 35-50% silicon dioxide (SiO<sub>2</sub>), and smaller amounts of aluminum oxide (Al<sub>2</sub>O<sub>3</sub>), magnesium oxide (MgO), and other minor constituents. The GGBS imparts the properties in concrete like pozzolanic activity, improved workability, reduced heat of hydration, and increased durability. GGBS is commonly a grayish powder, similar in color to cement. Its color can vary slightly depending on its source and processing, but it is generally in the gray to light gray range. The specific gravity of GGBS is 2.85 as tested in laboratory. The physical appearance of GGBS is depicted in Fig 2.



**Fig 2. Ground Granulated Blast Furnace Slag (GGBS)**

#### **4.1.4 Glass powder**

Glass powder is a finely ground material made by processing waste glass, often from post-consumer or post-industrial sources, into a fine powder form. It is used as a supplementary cementitious material (SCM) in concrete to enhance its properties and sustainability. Glass powder primarily consists of amorphous silica ( $\text{SiO}_2$ ), which is the main component of glass. It may also contain small amounts of other elements and compounds found in glass, such as alumina ( $\text{Al}_2\text{O}_3$ ), calcium oxide ( $\text{CaO}$ ), magnesium oxide

( $\text{MgO}$ ), and traces of various metal oxides. Glass powder may impart the properties in concrete like Supplementary cementations material, improved workability, and reduced alkali-silica reactivity. The color of glass powder can vary depending on the source of the glass it is derived from. It can range from white to light gray or even green or brown, depending on the type of glass used. The color of the glass powder is often retained in the concrete mix to some extent. The specific gravity of glass powder is 2.85 as tested in laboratory. The physical appearance of glass powder is depicted in Fig 3.



**Fig 3. Glass powder**

#### **4.1.5 Slag sand**

Slag sand derived at JSW Company in India, is used. Fifty percent of finer variety & Fifty percent of coarser variety is utilized in

combination. For sustainability, in the present work Natural River sand is not used. Slag sand is tried as total fine aggregate. Slag sand belonging to Zone II are used. The specific gravity of slag sand is 2.6



**Fig 4. Slag sand as Fine aggregate**

#### **4.1.6 Water**

The primary ingredient in making concrete is water. Concrete was mixed and cured using drinkable water. Oils, acids, alkalis, salts, biological matter, and other pollutants that might

harm concrete should not be present in the water used to mix concrete, including the free water on the aggregates.

#### 4.2 Mix Proportions

Water/cement ratio is the primary important factor defining strength characteristics of concrete. The properties of the aggregate, in addition to water/cement ratio, influence the properties of the concrete. Because low w/c ratio is required to achieve desirable strength, the mix's workability suffers as a result. With today's technology, it's possible to use standard techniques for compacting mixes to create concrete with a compressive strength of at least 30 MPa after 28 days.

To obtain M30 grade strength concrete, the mix proportion was prepared in accordance with IS 10262- 2019, with a water/cement ratio of 0.5 is used. The final mix proportion arrived for M30 grade concrete is 1:1.31:2.70. Fifteen distinct mixes of Concrete with different proportions comprising GGBS (0, 10, 20 and 30%) as cement, glass powder (0, 10 and 20%) as cement, fine aggregate as slag sand are tested to examine the

strength properties in terms of Compressive, Split Tensile and flexure Strengths. Three cubes, three cylinders, & three prisms are molded for each combination and evaluated for strength characteristics.

#### 4.3 Casting of Specimen

The necessary components were weighed for these mixed proportions. Separate dry blends of cement as GGBS and coarse aggregates and fine aggregates as slag sand were made. All components were blended into a homogenous mix after being added to the water. Before being added to the water in the mixer, GGBS is mixed as coarse aggregate. The final casting of the mixtures was carried out right away after the testing for fresh characteristics. Test samples were cast, then those were withdrawn from the moulds after 24 hours then kept in water-curing chamber at a temperature of roughly 20°C until testing or as required by the test.

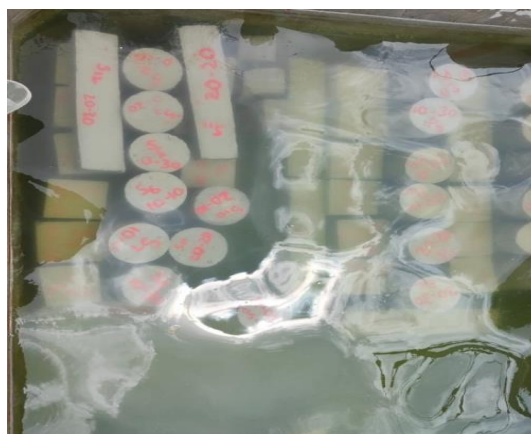


**Fig 5. Casting of Specimens**

#### 4.4 Curing

The test samples were maintained in moisture for 24 hours, after which those are marked, taken from the moulds, and submerged in

water throughout the period of test. Then curing should be at 27±2°C temperature and ought to be inspected for every seven days. Curing of concrete is depicted in fig 6.



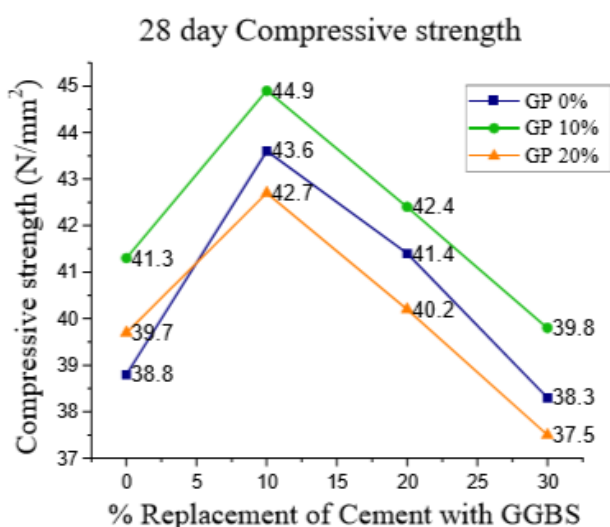
**Fig 6. Curing of Specimens**

**V. Results & Discussions**

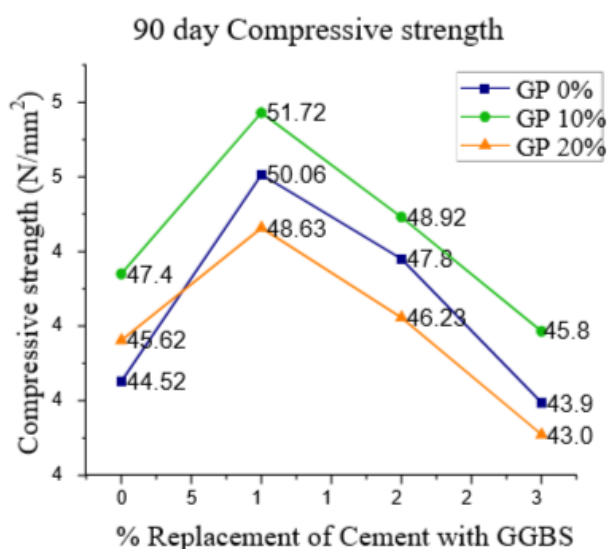
From the explanation above, it is clear that adding GGBS and Glass powder as a replacement to cement and slag sand as fine aggregate will show reasonable influence on the different properties of concrete when it is still fresh. Therefore, it is crucial to consider whether these effects will lead to changes in the varying characteristics of concrete during its hardened condition. The experimental program was carried out as a consequence.

**5.1. compressive Strength**

A material's ability to support loads that tend to compress it is measured by its compressive strength. Incorporating different percentages of GGBS as cement replacement by weight into OPC concrete resulted in an increment in steep manner up to 10% of GGBS with 10% of glass powder as 44.90MPa and then after that reduction in the 28-day compressive strength has occurred, as seen in Fig. 7., and as well as the same phenomenon occurred for 90 days in various percentages of GGBS and glass powder strength achieving as 51.72MPa as shown in Fig 8.



**Fig 7. Variation of 28-day Compressive strength**



**Fig 8. Variation of 90 day Compressive strength**

Comparatively to conventional concrete, the findings show that the compressive strength of concrete increased sharply between 0% and 10% at the age of 28 days, and after that from 10% to

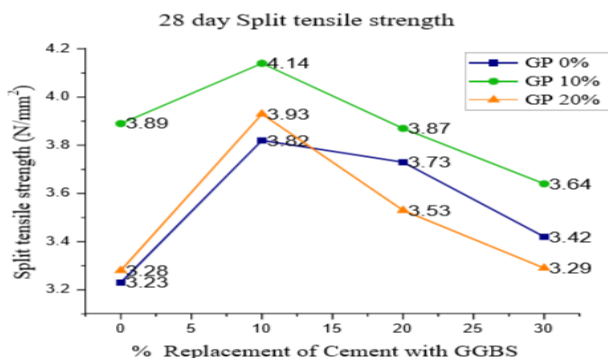
30% the compressive strength is subsequently decreased at the steep rate in the mixes containing GGBS and glass powder. With the addition of GGBS and glass powder, we can observe a slight rise in

the graph which represents a rise in the strength of concrete. At 10% replacement the concrete attains its maximum compressive strength when compared with the conventional mix. Therefore, it can be extrapolated that utilizing GGBS and glass powder with slag sand results in an increase in compressive strength.

**5.2. Split Tensile Strength**

Testing for splitting tensile strength was done, on cylindrical specimens of Standard 300mm-

height, and 150 mm diameter positioned horizontally on the compression testing machine, by application of the load till failure. Incorporating different percentages of GGBS and glass powder with slag sand into OPC concrete resulted in an increment in steep manner up to 10% of GGBS with 10% of glass powder as 4.14MPa. Then after, reduction in the 28-day split tensile strength has occurred, as seen in Fig. 9.



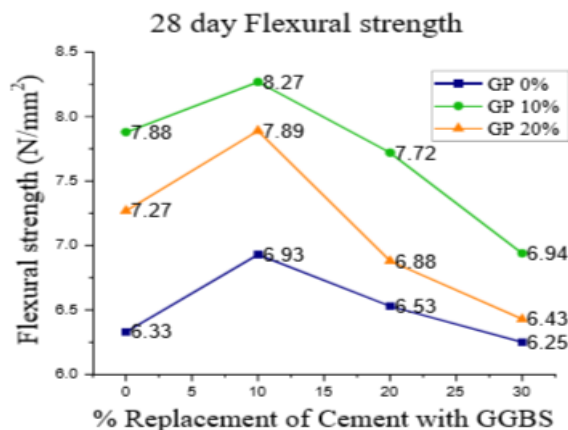
**Fig 9. Variation of 28 day Split tensile strength**

Comparatively to conventional concrete, the findings show that the split tensile strength of concrete increased sharply between 0% and 10% at the age of 28 days, and after that from 10% to 30% the split tensile strength is subsequently decreased at the steep rate in the mixes containing GGBS and glass powder with slag sand. With the addition of GGBS and glass powder with slag sand, we can observe a slight rise in the graph which represents a rise in the strength of concrete. At 10% replacement the Concrete attains its maximum tensile strength when compared with the conventional mix. Therefore, it can be extrapolated that utilizing GGBS and glass powder

with slag sand itself results in an increase of split tensile strength.

**5.3. Flexural Strength:**

Testing for flexural strength was done, on beam specimens of Standard 500x100x100mm positioned horizontally on the flexure testing machine. Application of the load till failure crack appears is done. Incorporating different percentages of GGBS and glass powder with slag sand by weight into OPC concrete resulted in an increment in steep manner up to 10% of GGBS, 10 % of glass powder with slag sand as 8.27MPa. Then after reduction in the 28-day flexural strength has occurred, as seen in Fig. 10.



**Fig 10. Variation of 28 day Flexure strength**

Comparatively to conventional concrete, the findings show that the flexure strength of concrete increased sharply between 0% and 10% at the age of 28 days, and after that from 10% to 30% the flexure strength is subsequently decreased at the steep rate in the mixes containing GGBS and glass powder with slag sand. With the addition of GGBS and glass powder with slag sand, we can observe a slight rise in the graph which represents a rise in the strength of concrete. Maximum flexural strength is noted at 10% replacement of cement by GGBS and glass powder with slag sand when compared with the conventional mix. Therefore, it can be extrapolated that utilizing GGBS and glass powder with slag sand itself results in an increase of flexural strength.

#### VI. Conclusions

Following are the study's key findings and conclusions.

1. The 28-day testing of concrete mixes using GGBS, glass powder, and slag sand showed a maximum 20.38% increase in compressive strength. The addition of GGBS improves the bond between aggregate and C-S-H gel, resulting in slightly higher compressive strength compared to control mixes.
2. The results indicate that the maximum compressive, tensile and flexural strengths of concrete are attained when the cement is replaced by 10% of GGBS and 10% of glass powder addition with slag sand.
3. The maximum split tensile strength was found at 10% of GGBS and 10% of glass powder with slag sand, the split tensile strength has increased by 21.42% when compared to the normal concrete mix after 28 days.
4. The highest flexure strength was found at 10% of GGBS and 10% of glass powder with slag sand, increasing the flexure strength by 13.75% when compared to the standard concrete mix after 28 days.
5. From this experimental study it is concluded that for M30 grade sustainable concrete, optimum dosage of GGBS and glass powder with slag sand as partial replacement to cement is 10% of GGBS and 10% of glass powder with hundred percent slag sand as fine aggregate.

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