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Strength Studies on Slag Sand Concrete Blended with Metakaolin and Glass Powder

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Abstract

The production of Portland cement is known to release a significant amount of greenhouse gases, making it imperative to explore eco-friendly alternatives. Slag sand is utilized as a complete substitute for natural sand, offering not only environmental benefits but also enhancing the structural strength and longevity of constructions. This is primarily due to the high tensile strength inherent in slag sand, which imparts superior compactness to the concrete mixture compared to river sand or natural sand. Glass powder which is typically produced from waste glass by crushing or milling glass materials into finely powdered form will be introduced into the concrete mix at three distinct levels: 0%, 10%, and 20%. Glass powder possesses the unique property of recyclability without altering its chemical composition. The inclusion of both glass powder and metakaolin serves to augment the concrete's strength and durability properties, while simultaneously conserving precious natural resources. Moreover, this approach presents economic advantages when applied in concrete production. Metakaolin will be employed as a substitute for cement at four varying levels: 0%, 10%, 20%, and 30%. To comprehensively evaluate the concrete properties, the study will encompass assessments of fresh concrete characteristics through slump cone tests, compaction factor tests, and Vee Bee tests. Additionally, the study will analyse hardened properties, including compressive strength, tensile strength, and flexural strength at the 28-day mark, as well as compressive strength at the 90-day mark. Ultimately, the findings from tests conducted at different percentage combinations will be compiled and presented in the paper.

Keywords: Slag Sand, Metakaolin, Glass Powder, Compressive Strength, Tensile Strength and Flexural strength.

1.0 Introduction:

1.1 General

Concrete is a fundamental construction material known for its versatility and structural integrity. However, the production of conventional concrete, primarily based on portland cement, is associated with significant greenhouse gas emissions and the depletion of natural resources. As a result, there has been a growing emphasis on developing sustainable alternatives that can reduce environmental impact while maintaining or even improving the performance of concrete structures. One such alternative involves the utilization of slag sand as a complete replacement for natural sand in concrete mixtures.

Slag sand, derived from the by-products of industrial processes, offers multiple advantages. Notably, it aids in mitigating environmental concerns related to sand mining and contributes to the conservation of natural resources. Additionally, slag sand exhibits high tensile strength and imparts exceptional compactness to concrete mixes, surpassing the qualities of traditional river sand. These properties make it an attractive choice for sustainable concrete production.

To further enhance the properties of slag sand concrete and reduce its environmental footprint, this study explores the incorporation of metakaolin and glass powder as partial replacements for cement.

Metakaolin is a valuable supplementary cementitious material in concrete due to its capacity to enhance the concrete's strength, durability, and workability. Its pozzolanic characteristics are pivotal in this regard. When metakaolin reacts with cement in the presence of water, it produces calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH). These chemical reactions significantly improve the pore structure of the concrete, leading to enhanced strength, workability, improved durability and reduced heat of hydration. These benefits not only improve the performance of concrete structures but also contribute to more sustainable and environmentally friendly construction practices.

Glass powder is a versatile material that can be recycled from waste glass, finding applications in various sectors, including construction. Its environmentally friendly nature, coupled with its ability to enhance the properties of concrete and other materials, makes it a valuable resource across multiple industries.

The combination of slag sand, metakaolin, and glass powder creates a concrete mix with improved workability, higher early and long-term strength, and enhanced durability.

1.2 Scope Of Study:

In this study, slag sand is employed as a complete replacement (100%) for natural sand, while metakaolin is introduced at varying levels 0%, 10%, 20%, and 30%. The utilization of slag sand is anticipated to enhance both the strength and workability of concrete, simultaneously conserving natural sand resources. Metakaolin, chosen as a cement substitute, is valued for its pozzolanic properties, which have the potential to enhance concrete strength.

Furthermore, glass powder is incorporated as an additional material relative to the cement content at different proportions 0%, 10%, and 20%. The research focuses on evaluating the strength properties of the hardened concrete for each mix proportion, including compressive strength, split tensile strength, and flexural strength. Compressive strength is assessed at two distinct curing periods 28 days and 90 days. Additionally, split tensile strength and flexural strength are determined at the 28-day mark, with the casting of three specimens for each mix proportion. These investigations are conducted within the framework of M30 grade concrete mix proportions.

This study seeks to comprehensively assess the impact of replacing natural sand with slag sand, varying levels of metakaolin substitution, and the introduction of glass powder on concrete performance, specifically concerning its strength, workability and durability characteristics.

2.0 Literature Review

1. **A. Sivakumar, B. Arunachalam, and K. Arulshri. (2020)** investigated the effects of incorporating metakaolin and glass powder admixture on the strength and workability of slag sand concrete. Different mix proportions were examined, and various tests were conducted to evaluate the mechanical properties and workability characteristics. The results indicate that the combined addition of metakaolin and glass powder enhances the compressive strength, flexural strength, and workability of slag sand concrete.
2. **Bhowmik and Hossain in 2018** investigated the enhancement of strength properties in concrete through the incorporation of various supplementary cementitious materials such as slag, fly ash, metakaolin, and glass powder. These materials are commonly used to improve the performance of concrete and reduce its environmental impact. The research published in the "Construction and Building Materials" journal delves into the effects of these additives on the compressive strength, flexural strength, and durability of concrete. The findings presented in this study contribute to the growing body of knowledge concerning sustainable construction practices and the optimization of concrete properties through the utilization of alternative materials.
3. **M.S. Ramesh, S. S Rajesh, and K.S Jagadish**, investigated the effect of replacing cement with metakaolin and incorporating slag sand on the strength and durability properties of concrete. The results show that the addition of metakaolin and slag sand improves the compressive strength, split tensile strength and durability of concrete.
4. **Pradeep Kumar D, Venkataramana R, and Madhavi G. (2018)** investigated the individual and combined effects of metakaolin and glass powder on the strength and workability of slag sand concrete. Different mix proportions were tested, and various tests were conducted to assess the fresh and hardened properties. The findings reveal that the combination of metakaolin and glass powder produces superior strength and workability compared to individual additions in slag sand concrete.
5. **S. Ambily and R. Sreevalsa Kumar**, focused on the performance evaluation of concrete blended with slag sand and glass powder as partial replacements

for cement. The study examines the compressive strength, flexural strength and workability of the concrete mixtures. The results indicate that the combination of slag sand and glass powder enhances the mechanical properties and workability of concrete.

6. **S. Nanda, P. Dash, and S. R. Dash. (2019)** focused on optimizing the mix proportions of slag sand concrete blended with metakaolin and glass powder to improve its strength and workability. A Taguchi experimental design approach was employed, and the properties of the concrete, including compressive strength, split tensile strength, and workability, were evaluated. The study reveals that the optimal combination of metakaolin and glass powder enhances the strength and workability of slag sand concrete significantly.

3.0 Objectives

To examine the influence of incorporating glass powder and metakaolin into concrete mixtures and to access the resulting strength properties for each mix proportion.

The primary aim of this study is to identify the optimal percentage of metakaolin and glass powder that yield superior strength in the concrete with slag sand.

4.0 Methodology

In this study, the research encompasses a comprehensive discussion of the materials employed, their respective mix proportions, and the concrete preparation process.

4.1 Materials Used

1. Cement

The primary ingredient extensively employed in construction is cement, serving as a crucial binder that solidifies upon mixing with water and various additives. In this investigation, I utilized OPC 53-grade cement, specifically sourced from the Sri Chakra brand, which is produced through a meticulous process involving the amalgamation of clinker, gypsum, and other supplementary materials. OPC cement is distinguished by its noteworthy attributes, including exceptional compressive strength, fast setting capabilities, and its capacity to effectively adhere diverse materials together. The specific gravity of cement used is 3.14.

2. Slag Sand

The demand for natural sand in construction is steadily increasing with each passing day, while the availability of this resource is on the decline. To address this challenge, I have opted for slag sand, a by-product of the steel-making industry. This material is widely employed in concrete production owing to its advantageous properties, including high strength, durability, and environmental benefits. In this research, the slag sand utilized is manufactured by JSW, ensuring that it complies with all the stipulated requirements outlined in IS: 383-2015.The specific gravity of slag sand is 2.62

3. Coarse Aggregate

In this study, Crushed granite serves as the source material for the coarse aggregate utilized. In accordance with IS 383-1970, the selected size for the coarse aggregate is 20mm. It's worth noting that the characteristics of concrete can be influenced by the size and shape of the aggregates employed. For this research, I have deliberately incorporated angular coarse aggregates of various shapes to explore their impact on concrete properties. The specific gravity of coarse aggregates used is 2.65

4. Glass Powder

Glass powder, derived from recycled waste glass, serves as an additional supplementary cementitious material in this concrete blend. The utilization of glass powder in concrete contributes to environmental sustainability, particularly when produced from recycled glass, thereby reducing the volume of glass waste in landfills. In this study, glass powder manufactured by SGS India Private Ltd is employed, boasting a fineness level of 98%. Incorporated as an additive to the cement, the introduction of glass powder enhances the concrete's strength, durability, and workability properties.

5. Water

Water is a critical component in concrete mixtures and plays several roles in concrete making process. Water which is used in this study are free from oils, acids, slats biological matter and other pollutants.

6. Metakaolin

Metakaolin, derived from the anhydrous calcination of the clay mineral kaolinite, is a vital component. It is produced by heating kaolin clay at high temperatures which cause it to undergo a chemical transformation. The particle size of metakaolin is smaller than that of cement particles, although it does not reach the fineness level of silica fume. Metakaolin is highly reactive and when added to concrete, it chemically reacts with calcium hydroxide (a byproduct of cement hydration) to form additional calcium silicate hydrates (CSH) and reduce calcium hydroxide crystals. This leads to increased strength, denser microstructure and improved durability of concrete. In this research, metakaolin is employed as a partial substitute for cement at varying percentages, specifically 0%, 10%, 20%, and 30%.

4.2 Mix Proportions

In accordance with IS: 10262-2009 standards, we have developed mix proportions tailored for concrete of M30 grade. A water-cement ratio of 0.5 has been applied as the baseline. Our study encompasses the design of 12 distinct concrete mixes, each featuring different combinations of metakaolin replacement (0%, 10%, 20%, and 30% in lieu of cement) and glass powder addition (0%, 10%, and 20% in addition to cement).

The Table 1 shows designed properties of basic ingredients in concrete:

Table No: 1 Mix Proportions

S. No	MATERIALS	QUANTITY(Kg/m^3)
1.	Cement	425
2.	Salg Sand	560
3.	Coarse Aggregate	1150
4.	Glass Powder	0%, 10% and 20%
5.	W/C Ratio	0.5
6.	Metakaolin	0%, 10%, 20% and 30%

4.3 Casting

The process begins with the precise measurement and weighing of the necessary materials for a specific mix, all of which are introduced into the concrete mixer, excluding the water. These materials are thoroughly mixed until a uniform consistency is achieved. Subsequently, water is gradually added and mixed until the concrete attains a uniform texture.

The prepared concrete mixture is then carefully placed into moulds, layer by layer, and compacted using a compaction rod. Following this compaction step, the moulds are positioned on a vibrating machine and subjected to vibration.

After the compaction and vibration stages, the moulds, containing the concrete specimens, are placed in a controlled environment with a temperature maintained at approximately 24°C for a duration of 24 hours.

Here 3 cubes, 3 cylinders and 3 beams are prepared for each mix.

4.4 Curing

The moulds are demoulded, and the resulting specimens are marked based on their respective mixes. Subsequently, these marked specimens are carefully immersed in a curing tank for a curing period of 28 days. On the final day, the specimens are taken out from the curing tank and allowed to air-dry, ensuring the surfaces are thoroughly dried. Following this drying phase, the specimens undergo testing.

5.0 Results & Discussion

Strength Properties of Concrete

The various strength properties of slag sand concrete are discussed below:

A. Compressive Strength

The table 2 presents the average compressive strength values achieved at 28 days

Table No: 2 Compressive Strength at 28 days

Glass Powder (Addition)	**Average Compressive Strength** (N/mm²)			
	Metakaolin (Replacement)			
	0%	**10%**	**20%**	**30%**
0%	38.6	42.7	41.6	38.3
10%	41.8	45.4	42.7	39.6
20%	39.9	43.8	41.2	38.6

The ability of a material to endure forces until it reaches a point of failure can be termed as compressive strength. Compressive strength test was conducted on 150mm*150mm-sized cubes following a 28-day curing period.

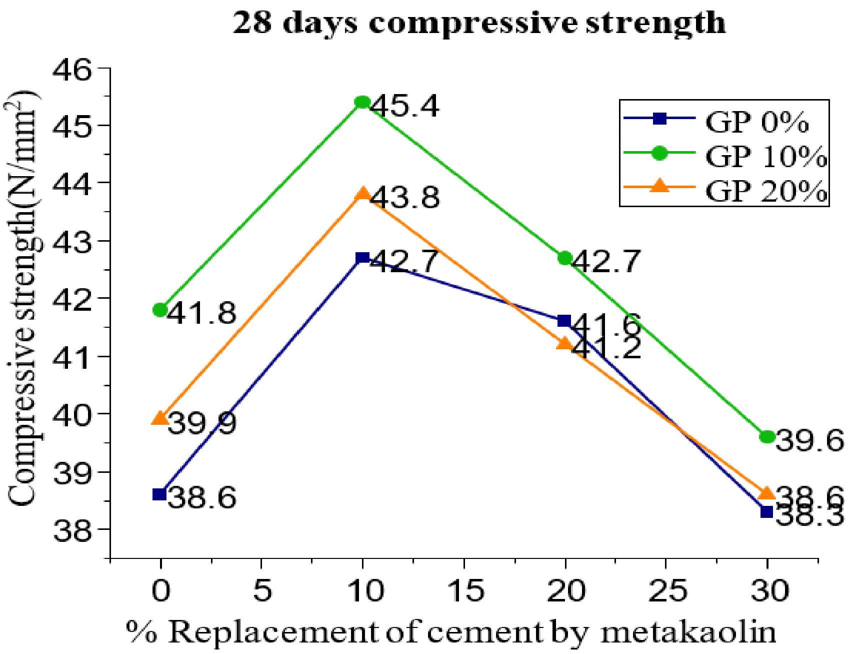

Fig.1 Compressive Strength at 28 Days

The fig.1 represents the average compressive strength at 28 days. On the x axis, percentage of metakaolin replacement with cement and addition of glass powder and on y axis, the compressive strength is taken. Metakaolin replacement ranges from 0% to 30% with 10% increments, while glass powder is added with increments of 10% up to a maximum of 20%. Initially, maintaining a constant percentage of glass powder and varying the levels of metakaolin replacement with cement reveals a gradual increase in compressive strength till 10% level of glass powder. The maximum strength is attained when 10% of the cement is replaced with metakaolin and 10% with glass powder due to pozzolanic characteristics of metakaolin and glass powder. However, further increments in metakaolin or glass powder percentages result in a gradual decline in compressive strength. Therefore, optimal strength is achieved by replacing cement with metakaolin up to 10%-15% and adding glass powder in the range of 10% -15%.

The table 3 presents the average compressive strength values achieved at 90 days

Table No: 3 Compressive Strength at 90 days

Glass Powder (Addition)	**Average Compressive Strength** (N/mm^2)			
	Metakaolin (Replacement)			
	0%	**10%**	**20%**	**30%**
0%	44.6	50.12	47.8	43.95
10%	47.45	51.68	48.73	45.83
20%	45.6	49.5	46.26	43.09

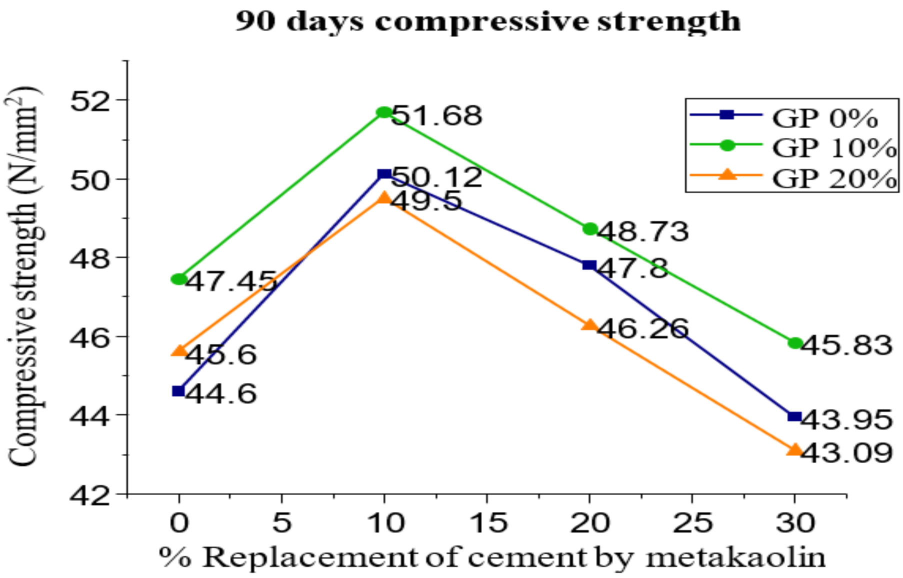

Fig.2 Compressive Strength at 90 Days

The 90-days compressive strength of concrete is an important indicator of its long-term durability and structural performance. When slag sand is blended with replacements such as metakaolin and glass powder, it can result in a modified concrete mix with potentially enhanced properties. Slag sand improves the workability, durability, and long-term strength of concrete. From the graph, it is noted that metakaolin results in increased compressive strength especially at later ages like 90 days. Metakaolin and glass powder can improve the pozzolanic activity of the concrete mix, leading to increased compressive strength over time. This effect may become more pronounced at 90 days compared to earlier ages. The peak compressive strength is obtained at 10% metakaolin replacement level and 10% glass powder addition to the concrete mix.

B. Split Tensile Strength

The table 4 shows the average split tensile strength values from this study:

Table No: 4 Split Tensile Strength at 28 days

Glass Powder (Addition)	**Average Split Tensile Strength** (N/mm^2)			
	Metakaolin (Replacement)			
	0%	**10%**	**20%**	**30%**
0%	3.12	3.76	3.40	3.50
10%	3.76	4.30	3.80	3.60
20%	3.37	3.96	3.52	3.27

The term "Split Tensile Strength" refers to the material's capacity to withstand tensile forces. To measure split tensile strength, a cylinder of 300mm long and 150mm diameter specimen is typically subjected to diametral compression using a compression testing machine until it fractures along its diameter. Split tensile strength is determined by applying a compressive force perpendicular to the axis of a cylinder.

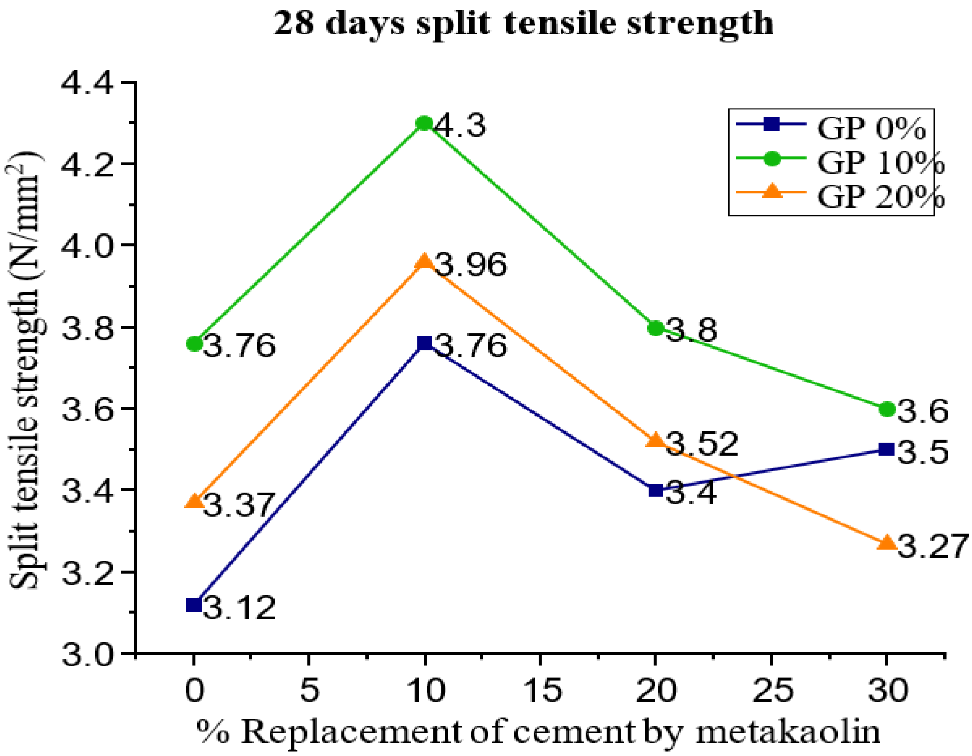

Fig.3 Split Tensile Strength at 28 Days

The fig.3 above provides an explanation that the split tensile strength subsequently increases up to the 10% replacement of metakaolin with cement at different levels of glass powder addition. Further increase in levels of metakaolin and glass powder, the split tensile strength was getting reduced. The peak split tensile strength was achieved at 10% replacement of metakaolin and at 10% addition of glass powder with cement. It is recommended to adopt 10% of replacement of metakaolin and 10% glass powder addition with cement to achieve best strength and workability.

C. Flexural Strength

The table 5 displays the mean values for flexural strength obtained from this investigation:

Table No: 5 Flexural Strength at 28 days

Glass Powder (Addition)	**Average Flexural Strength** (N/mm^2)			
	Metakaolin (Replacement)			
	0%	**10%**	**20%**	**30%**
0%	6.43	6.76	6.61	6.21
10%	7.97	8.31	7.80	6.97
20%	7.41	7.45	6.91	6.7

The material's capacity to withstand bending deflection under applied loads is defined as flexural strength. A beam of 500mmx100mmx100mm size was used to determine the flexural strength.

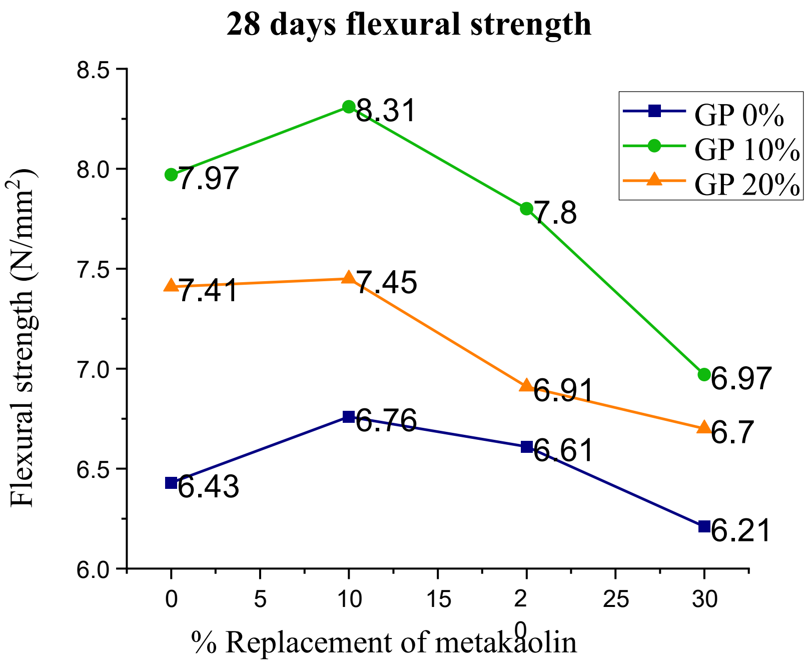

Fig.4 Flexural Strength at 28 Days

The fig.4 provides an illustration about the flexural strength.at the earlier stages the flexural strength increases later on decreases after getting highest strength. It is showing that peak strength is achieved at the replacement of metakaolin with 10% and addition glass powder with 10%. Metakaolin always increases the strength of the concrete due to its pozzolanic properties.

6. Conclusion

In conclusion, the incorporation of slag sand, metakaolin, and glass powder in concrete presents a promising avenue for enhancing both the strength and workability of the material. This blended approach capitalizes on the unique properties of each component, resulting in several key benefits:

1. The utilization of slag sand in concrete, combined with the inclusion of metakaolin and glass powder, presents a favourable strategy for augmenting both the strength and workability of concrete mixtures.
2. Based on the results mentioned earlier, it is important to highlight that optimal metakaolin replacement levels for achieving good compressive strength range from 10%
3. to 15%. However, it's noteworthy that exceeding these replacement percentages with metakaolin can lead to degradation in the concrete's strength.
4. Similarly, it is observed that the strength of concrete remains unaffected up to the addition of 10% glass powder. Thus, we can draw the conclusion that concrete mixes incorporating 10% glass powder achieve superior strength and workability.
5. In summary, we can conclude that the combination of slag sand, metakaolin and glass powder can improve the strength, workability when compared to conventional concrete.

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