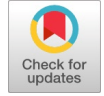


# Utilization of Granulated Blast Furnace Slag in Cement Mortar: Performance Analysis Against M-Sand

Bandhavya G B, Lavanya H D, Mohana H S, Theju R K, Madhushree C, Shilpa J



**Abstract:** This study aims to explore the feasibility of incorporating Granulated Blast Furnace Slag (GBFS) as a sustainable alternative to manufactured sand (M-Sand) in cement mortar, to enhance both environmental sustainability and mechanical performance. The research involves a systematic investigation where M-Sand is progressively replaced by GBFS at varying levels of 10%, 20%, 30%, 40%, and 50%. The effects of these replacements are evaluated through a series of tests that focus on the mortar's physical properties, as well as its compressive and tensile strengths. Experimental results reveal that replacing 30% of M-Sand with GBFS produces the most favorable outcomes, with the compressive strength of the mortar exceeding that of the control mix by 12% after 28 days. The tensile strength also showed marked improvements at this replacement level. However, when the replacement level exceeds 30%, both compressive and tensile strengths begin to diminish, indicating that excessive substitution may adversely affect the mortar's structural integrity. The findings of this study provide valuable insights into the optimal use of GBFS in cement mortar, demonstrating that a 30% substitution not only enhances strength characteristics but also contributes to more sustainable construction practices by reducing reliance on natural sand resources. This research supports the potential of GBFS as a viable material for improving the environmental profile and durability of cement-based materials.

**Keywords:** Granulated Blast Furnace Slag (GBFS), Manufactured Sand (M-Sand), Cement Mortar, Compressive Strength, Tensile Strength, Sustainable Construction, Replacement Ratio, Eco-friendly Materials, Building Durability, Construction Material.

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## I. INTRODUCTION

The demand for sustainable construction materials has intensified as the building industry grapples with the challenges of environmental sustainability and resource scarcity. Manufactured sand (M-Sand) has emerged as a popular alternative to natural river sand, especially in cement mortar and concrete production. Despite its widespread use, concerns over the depletion of natural sand reserves and the ecological damage caused by sand mining have driven the search for even more sustainable material solutions. Granulated Blast Furnace Slag (GBFS), an industrial by-product from steel manufacturing, holds potential as an eco-friendly substitute [1]. While GBFS has traditionally been used as a supplementary material in cement production, its application as a partial replacement for fine aggregates like M-Sand in cement mortar is less explored. Utilizing GBFS in this way could not only reduce the environmental impact of sand extraction [2] but also offer a viable recycling pathway for industrial waste, contributing to sustainable construction practices. This research focuses on evaluating the feasibility of substituting M-Sand with GBFS in cement mortar [3]. The study systematically examines how varying proportions of GBFS affect the mortar's physical and mechanical properties, particularly its compressive and tensile strengths. The goal is to identify the optimal GBFS replacement level that enhances the mortar's performance while promoting environmental sustainability. The findings aim to advance sustainable construction methodologies and expand the use of GBFS in the building materials sector.

## II. MATERIALS AND METHODOLOGY

The materials utilized in this investigation include Ordinary Portland Cement (Chettinad, 43 grades) as the binder. The fine aggregates employed were M-sand and Granulated Blast Furnace Slag (GBFS). Additionally, bricks and water were used in the study. Initially, basic tests were conducted on the materials to establish their properties [3]. Subsequently, the effect of replacing M-sand with GBFS in increments of 20% was assessed to determine how GBFS impacts the properties of the fine aggregate. This evaluation was extended to specimens where GBFS was used as the sole fine aggregate.

Mortar cubes and cylinders were cast with various levels of M-sand replacement by GBFS. The compressive strength of these cubes and the split tensile strength of the hardened mortar were tested on the 7th and 28th days.



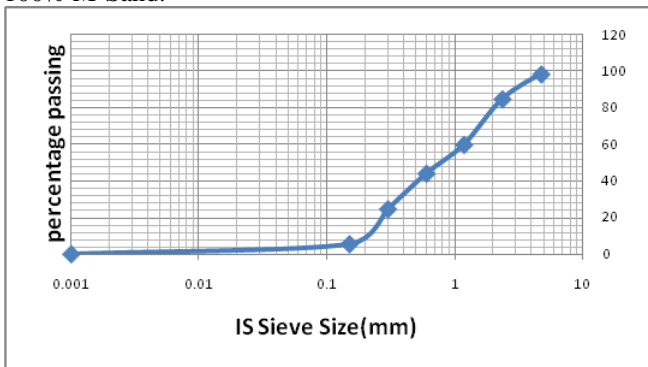
Eighteen triplet specimens were prepared with different GBFS replacement levels, maintaining a mortar joint thickness of 12 mm. These specimens were cured for 28 days. Finally, based on the results, an optimum percentage of fine aggregate replacement was recommended.

For the present study, Chettinad-43 grade Ordinary Portland Cement was utilized, which adheres to the Indian Standard Specification IS: 8112-1989 [5]. Cement testing was conducted following the procedures outlined in IS: 4031-1991. Table 1 presents the results of the physical tests conducted on the cement. The fineness, determined by the percentage retained on a 90µm sieve, was 3.09%, which is below the maximum limit of 10% specified by IS: 8112-1989. The normal consistency was found to be 31%, and the specific gravity of the cement was 3.12. The Vicat time of setting was measured as 30 minutes for the initial setting time and 178 minutes for the final setting time, meeting the minimum requirement of 30 minutes and well within the maximum limit of 600 minutes [6].

**Table 1: The Results of the Physical Tests Conducted on the Cement**

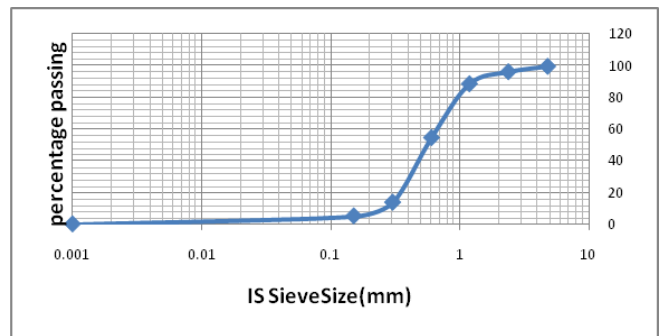
Sl. No.	Physical test	Result obtained	Requirement IS:8112-1989
1	Fineness	3.09	10 maximum
3	Normal consistency (%)	31	-
4	Specific gravity of cement	3.12	-
5	Vicat time of setting(minutes)	30	30 minimum
	a) Initial setting time b) Final setting time	178	600 maximum

The fineness modulus of the fine aggregate was determined following the procedure outlined in IS: 2386, Part I-1963. This numerical index indicates the mean particle size of the aggregate. For this study, 1 kg of fine aggregate was sieved through a series of IS sieves with sizes 4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.3 mm, 0.15 mm, and pan. The cumulative percentage of mass retained on each sieve was calculated and divided by 100 to obtain the fineness modulus. Two trials were conducted, and the average of these trials is reported. For the fine aggregate consisting of 100% M-Sand and 0% GBFS, the particle size distribution is summarized in Table 1. The sieve analysis results show the mass retained and passing through each sieve, the percentage retained and passing, and the cumulative percentage retained. The calculated fineness modulus for this sample is 2.82, and it falls within Zone 2 as per the standard grading requirements. Figure 2.1 illustrates the particle size distribution curve for 100% M-Sand.



**Fig 2. 1: Particle Size Distribution Curve for 20% M-Sand and 80% GBFS Mixture**

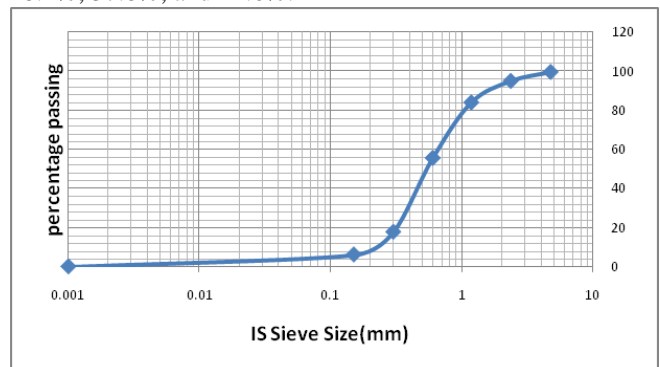
For the aggregate blend consisting of 20% M-Sand and 80% GBFS, the fineness modulus was determined according to the procedures specified in IS: 2386, Part I-1963. The analysis involved sieving 1 kg of the aggregate mixture through IS sieves of sizes 4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.3 mm, 0.15 mm, and pan. The table presents the mass retained and passing through each sieve, the percentage retained and passing, and the cumulative percentage retained. The computed fineness modulus for this blend is 2.42, and it is classified under Zone 2 according to standard grading criteria [4]. Figure 2.1 illustrates the particle size distribution curve for the 20% M-Sand and 80% GBFS mixture.



**Fig 2. 2: Particle Size Distribution Curve for 40% M-Sand and 60% GBFS mixture**

For the aggregate blend of 40% M-Sand and 60% GBFS, the fineness modulus was evaluated using the method outlined in IS: 2386, Part I-1963. The analysis involved sieving 1 kg of the aggregate through IS sieves of sizes 4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.3 mm, 0.15 mm, and pan. The fineness modulus for this blend is calculated as 2.42, and it is categorized under Zone 2 based on standard grading criteria. Figure 2.2 provides the particle size distribution curve for the 40% M-Sand and 60% GBFS mixture.

The particle size distribution for a blend of 40% M-Sand and 60% GBFS was analyzed, and the results are detailed in Table 1. The analysis involved passing the blend through a series of sieves with decreasing sizes, specifically 4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.3 mm, and 0.15 mm. The mass retained on each sieve was recorded as 4 g, 46 g, 110 g, 284 g, 378 g, and 116 g, respectively. The corresponding percentage retained values were calculated as 0.4%, 4.6%, 11.0%, 28.4%, 37.8%, and 11.6%.



**Fig. 2. 3: Particle Size Distribution Curve for 20% M-Sand+80% GBFS**

The cumulative percentages retained were determined, leading to a fineness modulus of 2.42. This blend falls into Zone 2 as per the classification. The particle size distribution curve for this blend is depicted in Figure 2.2.

The mass retained on sieves of different sizes was recorded as follows: 4.75 mm (6 g), 2.36 mm (66 g), 1.18 mm (142 g), 0.6 mm (264 g), 0.3 mm (312 g), and 0.15 mm (126 g). The corresponding percentage retained values were 0.6%, 6.6%, 14.2%, 26.4%, 31.2%, and 12.6%. The cumulative percentage retained, leading to a fineness modulus of 2.47, categorizes this blend into Zone 2. Figure 2.3 illustrates the particle size distribution curve for this blend.

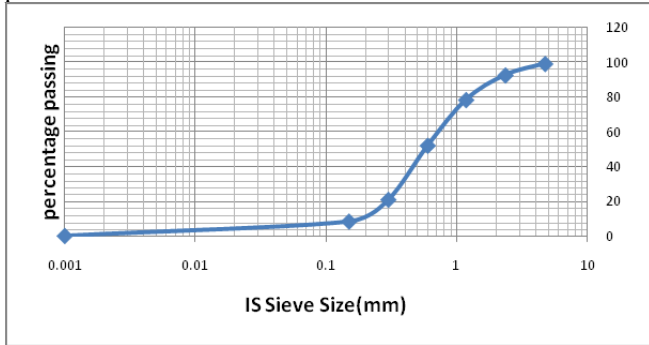


Fig 2. 4: Particle Size Distribution Curve for 60% M-Sand+40% GBFS

Similarly, the particle size distribution for an 80% M-Sand and 20% GBFS blend showed mass retained on sieves as follows: 4.75 mm (8 g), 2.36 mm (106 g), 1.18 mm (200 g), 0.6 mm (224 g), 0.3 mm (278 g), and 0.15 mm (154 g). The percentage retained values were 0.8%, 10.6%, 20.0%, 22.4%, 27.8%, and 15.4%, resulting in a cumulative percentage retained and a fineness modulus of 2.76, placing it in Zone 2. The particle size distribution curve for this blend is depicted in Figure 2.4. For the 100% GBFS blend the mass retained on the sieves was as follows: 4.75 mm (0 g), 2.36 mm (0 g), 1.18 mm (34 g), 0.6 mm (442 g), 0.3 mm (448 g), and 0.15 mm (60 g). The corresponding percentage retained values were 0%, 0%, 3.4%, 44.2%, 44.8%, and 6.0%. The cumulative percentage retained led to a fineness modulus of 2.42, again placing it in Zone 2. Figure 2.5 displays the particle size distribution curve for this blend. Fineness modulus across varying replacement percentages, demonstrating that as the percentage of GBFS in fine aggregate increases, the fineness modulus decreases. This indicates that GBFS has finer particles compared to M-Sand [5]. The particle size distribution curves further suggest that GBFS is better graded compared to M-Sand.

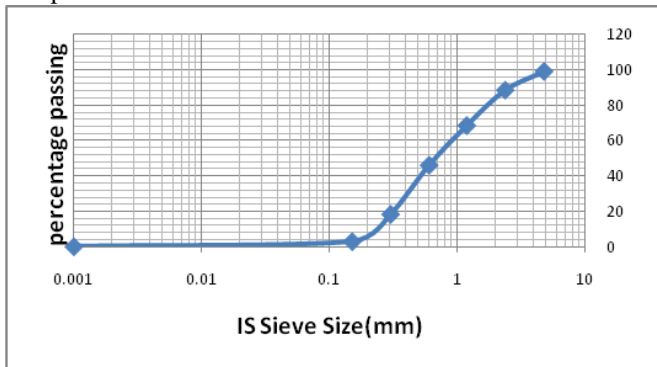


Fig 2. 5: Particle Size Distribution Curve for 80% M-Sand+20% GBFS

The bulking of fine aggregates show that the bulking percentage varies with the water added and the M-Sand to GBFS ratio.

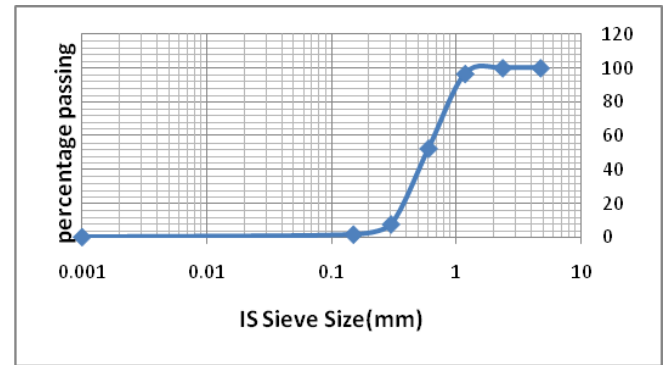


Fig 2. 6: Particle Size Distribution Curve for 100% GBFS

The results indicate that granulated slag bulked more compared to mortar, with the optimum moisture content increasing as the GBFS content increased in the fine aggregate.

The specific gravity and bulk density tests, as presented in Fig 2.7 and 2.8, reveal a decrease in specific gravity and bulk density with an increase in GBFS content. This suggests that GBFS has a lower mass density compared to M-Sand.

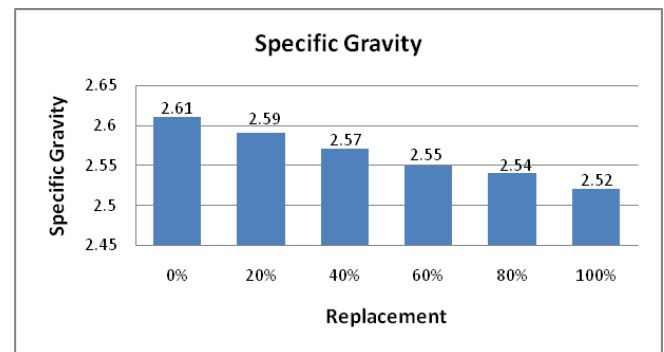


Fig 2. 7: Bulk Density of Fine Aggregate (Uncompacted)

Various tests such as absorption, compressive strength, shape and size, and soundness tests were conducted to test the quality of bricks for construction. The absorption test results show that good-quality bricks should be at most 20% water absorption by weight.

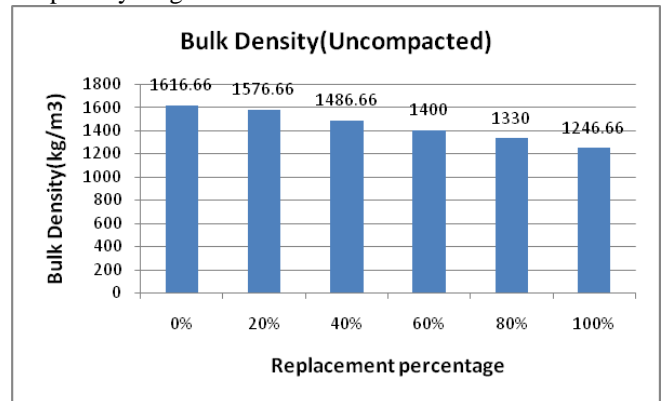


Fig 2. 8: Bulk Density of Fine Aggregate (Uncompacted)

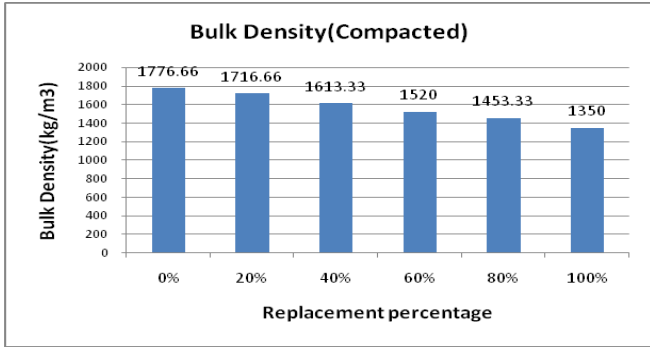


Fig 2. 9: Bulk Density of Fine Aggregate (Compacted)

The compressive strength test revealed that bricks should have a minimum strength of 3.50 N/mm<sup>2</sup>. The shape and size test confirmed the uniformity of bricks, while the soundness test indicated that a clear bell ringing sound with no breakage is a sign of good-quality bricks.



Fig 2. 9: Crushing Strength or Compressive Strength Test on Bricks

Tests on mortar included the flow table test and tests on hardened mortar. The flow table test assessed the workability of fresh mortar, while the compressive strength test, split tensile strength test, and triplet shear bond strength test evaluated the hardened mortar's properties. These tests provided essential data on the performance and quality of the mortar mixes used in construction.

III. RESULT AND DISCUSSION

The flow table test results, as shown in the corresponding graph, indicate that the workability of cement mortar remains relatively consistent across different levels of M-Sand replacement with GBFS. Although the percentage of water added slightly increases as the GBFS content rises, the flow values remain nearly constant, with only minor fluctuations observed. This suggests that replacing M-Sand with GBFS does not significantly impact the workability of the mortar

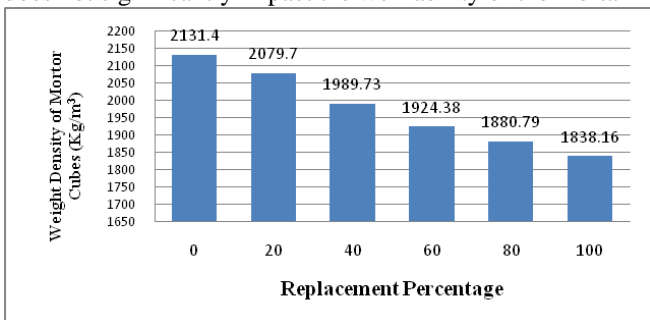


Fig 3. 1: Variation of Weight Density of Hardened Mortar Cubes

The density of hardened mortar, both in cubes and cylinders, decreases as the GBFS content increases, as illustrated in the graphs. The density of mortar cubes drops from 2131.4 kg/m<sup>3</sup> at 0% GBFS to 1838.16 kg/m<sup>3</sup> at 100% GBFS, while the density of mortar cylinders decreases from 2319.58 kg/m<sup>3</sup> to 1987.26 kg/m<sup>3</sup> over the same range. These trends, clearly visible in the plotted graphs, suggest that GBFS, being less dense than M-Sand, leads to a reduction in the overall density of the hardened mortar.

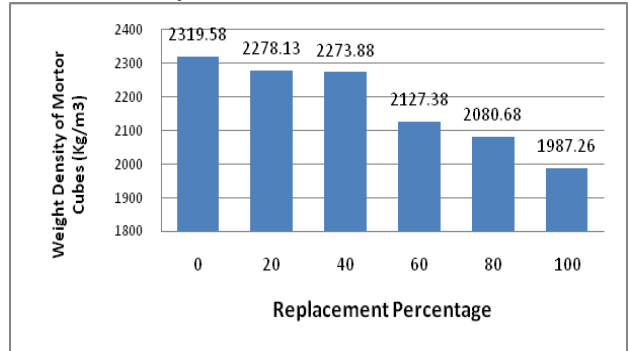


Fig 3. 2: Variation of Weight Density of Hardened Mortar Cylinder

The compressive strength results, depicted in the graphs, reveal a significant decline with increasing GBFS content. At 7 days, the compressive strength falls from 4.36 N/mm<sup>2</sup> at 0% GBFS to 0.11 N/mm<sup>2</sup> at 100% GBFS. Similarly, at 28 days, the strength decreases from 9.42 N/mm<sup>2</sup> to 2.92 N/mm<sup>2</sup>.

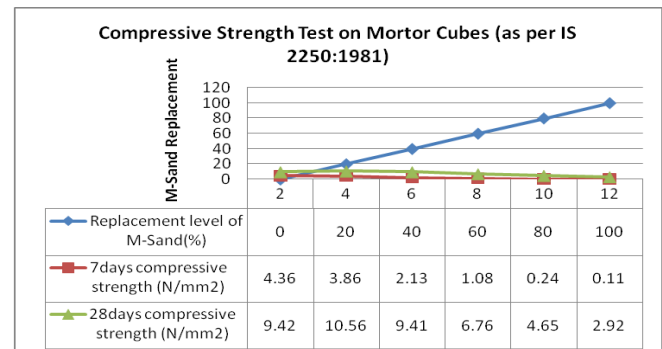


Fig 3. 3: Compressive Strength Test on Mortar Cubes

The graphs highlight that while the mortar maintains its characteristic compressive strength at lower GBFS replacement levels, the strength diminishes substantially when the replacement exceeds 60%.

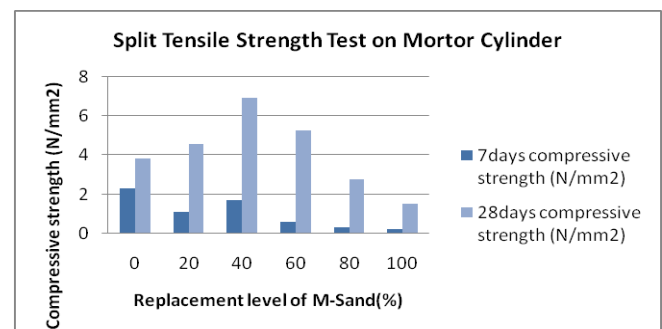


Fig 3. 4: Split Tensile Strength Test on Mortar Cubes



These graphical analyses emphasize that while GBFS can partially replace M-Sand, the resulting mortar exhibits lower density and compressive strength, particularly at higher levels of GBFS replacement. The Triplet Shear Test on mortar cylinders, conducted by IS 2250:1981, reveals a significant reduction in compressive strength at 28 days with increasing replacement levels of M-Sand by Ground Granulated Blast Furnace Slag (GBFS) [7] [8] [9] [10] [11]. The compressive strength decreases consistently as the GBFS content increases, as illustrated by the results and corresponding graphical analysis.



Fig 3. 5: Mortor Cubes

At 0% GBFS (100% M-Sand), the mortar exhibits the highest compressive strength, serving as the control benchmark. With a 20% replacement of M-Sand by GBFS, the compressive strength drops to 0.357 N/mm<sup>2</sup>. This reduction continues, with the strength decreasing to 0.258 N/mm<sup>2</sup> at 40% GBFS, 0.224 N/mm<sup>2</sup> at 60% GBFS, 0.183 N/mm<sup>2</sup> at 80% GBFS, and reaching the lowest value of 0.144 N/mm<sup>2</sup> at 100% GBFS. The trend, as depicted in the graph, shows a nearly linear decline in compressive strength as the proportion of GBFS increases. This indicates that while GBFS can be employed as a partial substitute for M-Sand in mortar, its use significantly reduces the material's ability to resist shear forces, particularly as the replacement level exceeds 40%.

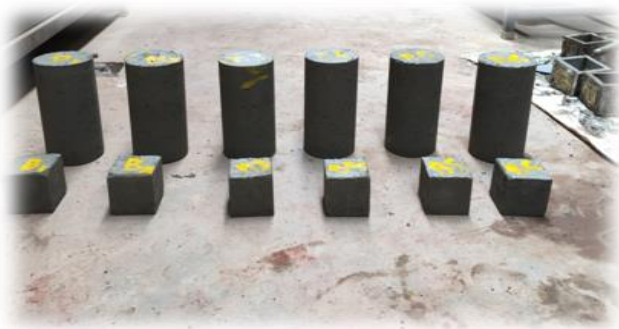


Fig 3. 6: Mortor Cubes After Curing

The reduction in compressive strength with increasing GBFS content can be attributed to the distinct physical and chemical properties of GBFS compared to M-Sand. GBFS has a lower density and different particle size distribution, which likely impacts the overall bond strength within the cement matrix. Furthermore, the lower calcium oxide content in GBFS may result in fewer hydration products, which are crucial for achieving the desired compressive strength.

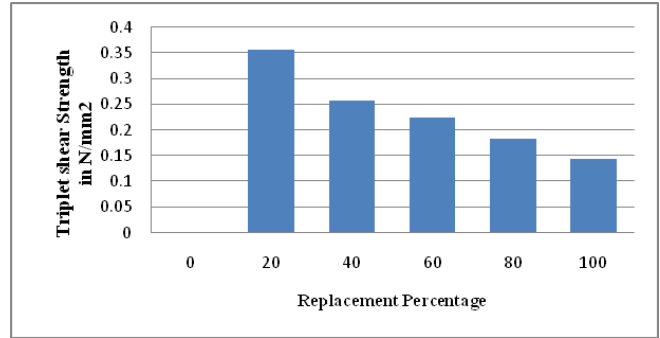


Fig 3. 7: Triplet Shear Strength Test on Mortor Cubes

GBFS offers potential as a supplementary material in mortar production, its impact on the mechanical properties, particularly compressive strength under shear, must be carefully evaluated. The findings suggest that the replacement level of M-Sand by GBFS should be limited to avoid compromising the structural integrity of mortar in applications where high shear strength is essential. These results provide valuable insights for optimizing the use of GBFS in sustainable construction practices, balancing environmental benefits with performance requirements.

#### IV. CONCLUSION

This study investigated the mechanical properties of Engineered Cementitious Composites (ECC) using two types of fibers: polyethylene and glass. ECC mixtures were prepared with varying fiber content, and the resulting compressive and flexural strengths were measured at different curing ages (7, 28, and 56 days). The experimental results indicated that the addition of 1.5% glass fiber provided the optimum balance of strength and ductility. Specifically, ECC mixtures with glass fibers exhibited higher compressive and flexural strengths compared to those with polyethylene fibers, particularly at the 1.5% fiber content. These findings suggest that glass fibers are more effective than polyethylene fibers in enhancing the mechanical properties of ECC, making them a preferable choice for applications requiring high strength and durability. The use of ECC with optimized fiber content has the potential to improve the longevity and performance of concrete structures, particularly in environments where cracking and durability are critical concerns.

#### DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
- **Funding Support:** This article has not been sponsored or funded by any organization or agency. The independence of this research is a crucial factor in affirming its impartiality, as it has been conducted without any external sway.
- **Ethical Approval and Consent to Participate:** The data provided in this article is exempt from the requirement for ethical approval or participant consent.

- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Authors Contributions:** The authorship of this article is contributed equally to all participating individuals.

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**Madhushree C** has nine years of teaching experience with a primary focus on Water Resources Engineering and Hydraulics. She has published over eight papers in reputed journals and has actively presented her research at various international and national conferences. Dedicated to continuous learning and professional development, she has attended more than 20 faculty development programs and over five short-term training programs. Additionally, Madhushree has guided various multidisciplinary projects, demonstrating her commitment to advancing knowledge and fostering innovation in her areas of expertise

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