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 show that replacing 30% of M-Sand with GBFS yields the most favourable 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.*

Manuscript received on 21 August 2024 | Revised Manuscript received on 30 August 2024 | Manuscript Accepted on 15 October 2024 | Manuscript published on 30 October 2024.

*Correspondence Author(s)

Ms. Bandhavya G B*, Assistant Professor, Department of Civil Engineering, Navkis College of Engineering, Hassan (Karnataka), India. Email ID: bandhavyanavkis@gmail.com ORCID ID: 0000-0001-9920-5302

Ms. Lavanya H D, Assistant Professor, Department of Civil Engineering, Malnad College of Engineering, Hassan (Karnataka), India. Email ID: lavanya.gowda16@gmail.com

Mr. Mohana H S, Assistant Professor, Department of Civil Engineering, Navkis College of Engineering, Hassan (Karnataka), India. Email ID: mohan22hs@gmail.com

Mr. Theju R K, Assistant Professor, Department of Civil Engineering, Navkis College of Engineering, Hassan (Karnataka), India. Email ID: thejukumar95@gmail.com

Ms. Shilpa J, Assistant Professor, Department of Physics, Navkis College of Engineering, Hassan (Karnataka), India. Email ID: mithunankith28@gmail.com

Ms. Madhushree C, Assistant Professor, Department of Civil Engineering, Malnad College of Engineering Hassan (Karnataka), India. Email ID: ms@mcehassan.ac.in

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, particularly in the production of cement mortar and concrete. 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, such as 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 used in this investigation include Ordinary Portland Cement (Chettinad, 43-grade) 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 acceptable 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 in accordance with the procedures outlined in IS: 4031-1991. Table 1 presents the results of the physical tests performed 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) a) Initial setting time b) Final setting time	30 178	30 minimum 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 a 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, which falls within Zone 2 according to the standard grading requirements. Figure 2.1 illustrates the particle size distribution curve for 100% M-Sand.

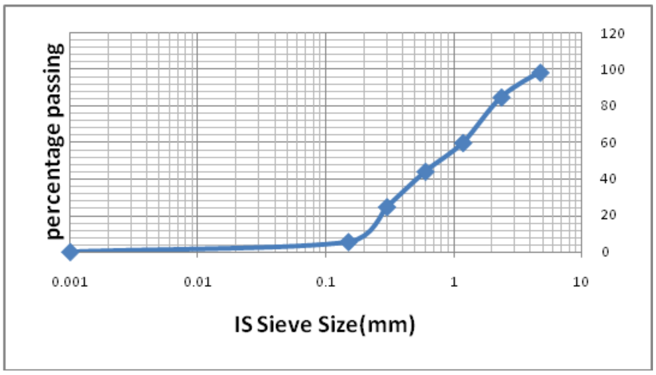

Figure 2. 1: Particle Size Distribution Curve for 20% M-Sand and 80% GBFS Mixture

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.

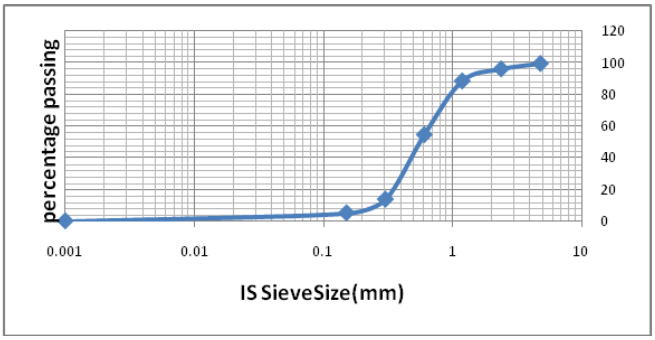

Fig 2. 2: Particle Size Distribution Curve for 40% M-Sand and 60% GBFS mixture

For the aggregate blend of 40% M-Sand and 60% GBFS, the fineness modulus was determined 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 to be 2.42, and it is categorised 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 of a blend comprising 40% M-Sand and 60% GBFS was analysed, and the results are presented 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%.

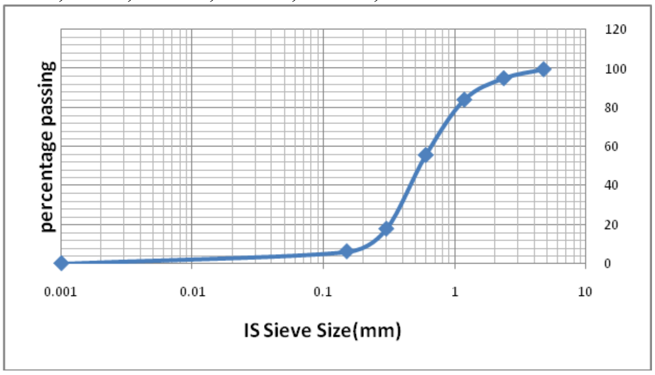

Fig. 2. 3: Particle Size Distribution Curve for 20% M-Sand+80% GBFS

Retrieval Number: 100.1/ijitee.K997113111024
DOI: 10.35940/ijitee.K9971.13111024
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-13 Issue-11, October 2024

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, resulting in a fineness modulus of 2.47, categorises this blend into Zone 2. Figure 2.3 illustrates the particle size distribution curve for this blend.

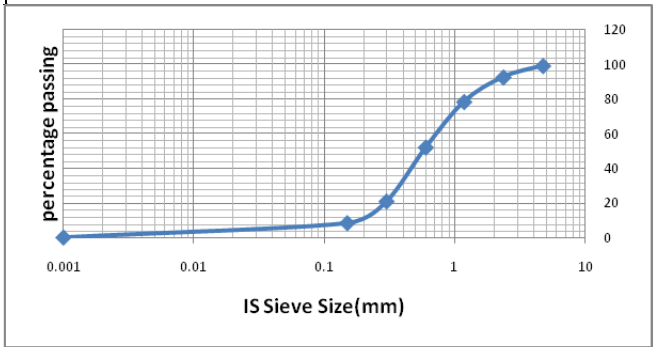

Fig 2. 4: Particle Size Distribution Curve for 60% M-Sand+40% GBFS

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.

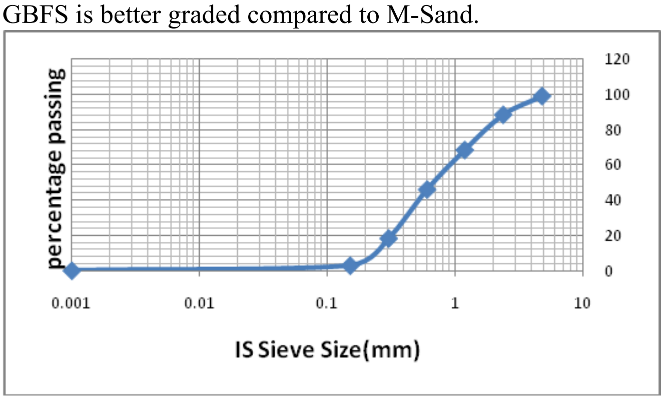

Fig 2. 5: Particle Size Distribution Curve for 80% M-Sand+20% GBFS

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

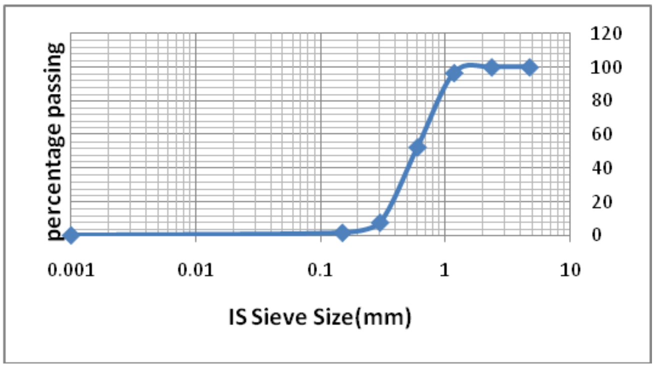

Figure 2. 6: Particle Size Distribution Curve for 100% GBFS

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 Figs 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.

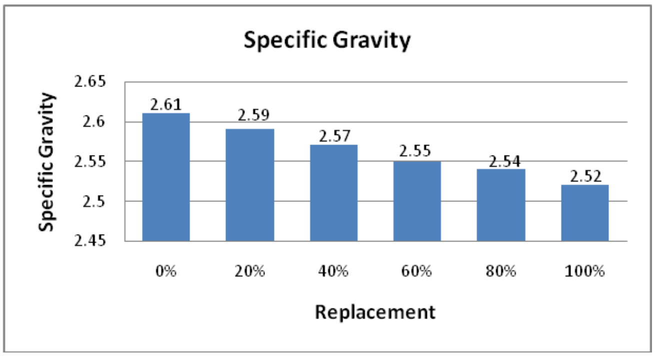

Figure 2. 7: Bulk Density of Fine Aggregate (Uncompacted)

Various tests, including absorption, compressive strength, shape and size, and soundness tests, were conducted to evaluate the quality of bricks for construction purposes. The absorption test results show that good-quality bricks should have a water absorption by weight of no more than 20%.

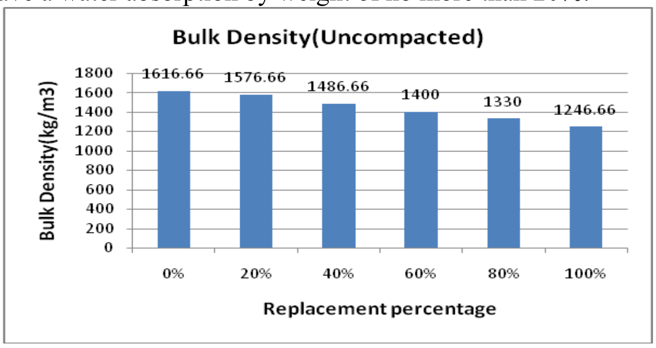

Figure 2. 8: Bulk Density of Fine Aggregate (Uncompacted)

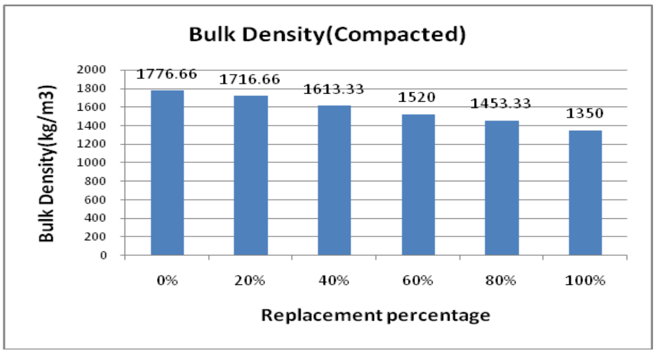

Figure 2. 9: Bulk Density of Fine Aggregate (Compacted)

The compressive strength test revealed that bricks should have a minimum strength of 3.50 N/mm². The shape and size test confirmed the uniformity of the bricks, while the soundness test indicated that a clear, bell-like ringing sound with no breakage is a sign of good-quality bricks.

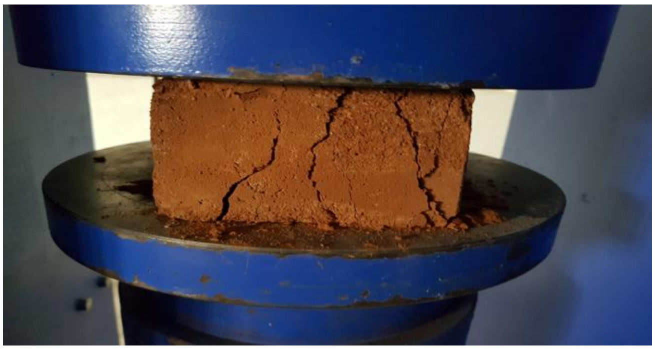

Figure 2. 9: Crushing Strength or Compressive Strength Test on Bricks

Tests on mortar included the flow table test and tests on hardened mortar. The flow table test assessed the workability of fresh mortar. In contrast, the compressive strength test, split tensile strength test, and triple shear bond strength test evaluated the properties of hardened mortar. 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.

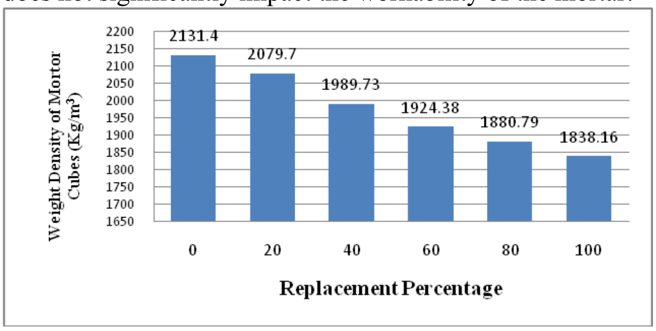

Figure 3. 1: Variation of Weight Density of Hardened Mortar Cubes

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/m³ at 0% GBFS to 1838.16 kg/m³ at 100% GBFS, while the density of mortar cylinders decreases from 2319.58 kg/m³ to 1987.26 kg/m³ 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.

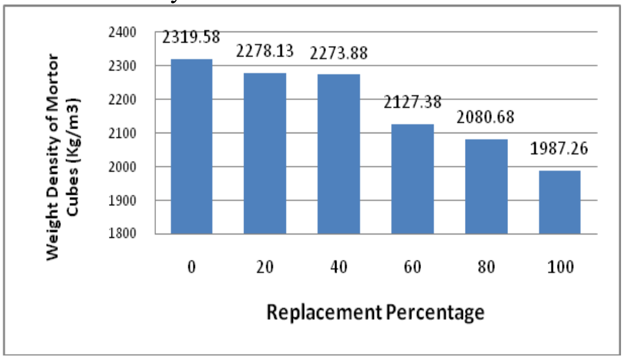

Figure 3. 2: Variation of Weight Density of Hardened Mortar Cylinder

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/mm² at 0% GBFS to 0.11 N/mm² at 100% GBFS. Similarly, at 28 days, the strength decreases from 9.42 N/mm² to 2.92 N/mm².

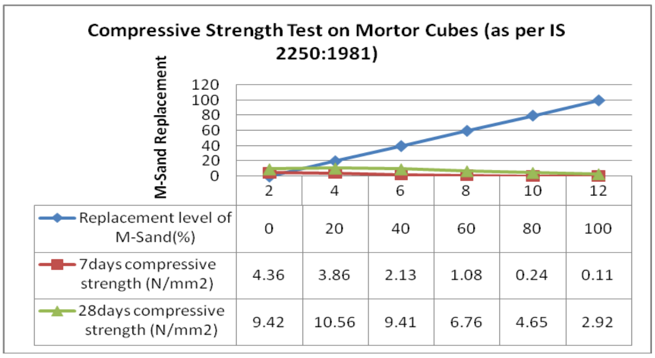

Fig 3. 3: Compressive Strength Test on Mortor Cubes

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%.

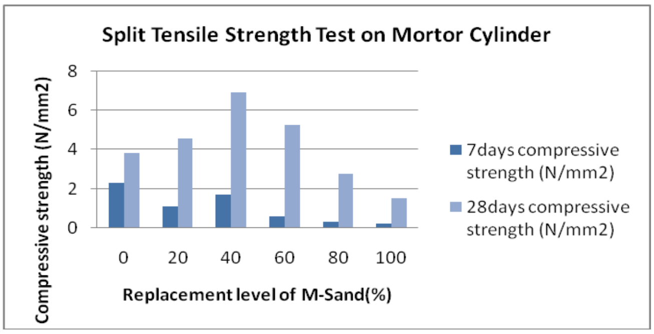

Fig 3. 4: Split Tensile Strength Test on Mortor Cubes

Retrieval Number: 100.1/ijitee.K997113111024
DOI: 10.35940/ijitee.K9971.13111024
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

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). 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/mm². This reduction continues, with the strength decreasing to 0.258 N/mm² at 40% GBFS, 0.224 N/mm² at 60% GBFS, 0.183 N/mm² at 80% GBFS, and reaching the lowest value of 0.144 N/mm² 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%.

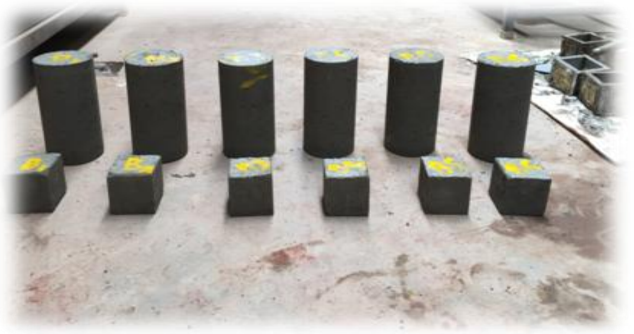

Fig 3. 6: Mortor Cubes After Curing

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.

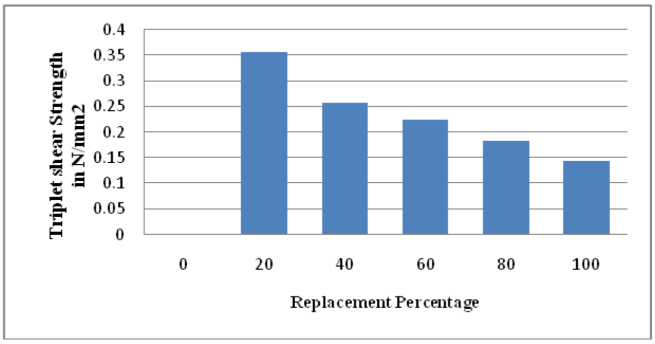

Fig 3. 7: Triplet Shear Strength Test on Mortor Cubes

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 offer valuable insights for optimising the use of GBFS in sustainable construction practices, thereby balancing environmental benefits with performance requirements.

IV. CONCLUSION

This study investigated the mechanical properties of Engineered Cementitious Composites (ECC) using two types of fibres: polyethene and glass fibres. ECC mixtures were prepared with varying fibre 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 fibre provided the optimum balance of strength and ductility. Specifically, ECC mixtures with glass fibres exhibited higher compressive and flexural strengths compared to those with polyethene fibres, particularly at the 1.5% fibre content. These findings suggest that glass fibres are more effective than polyethene fibres in enhancing the mechanical properties of ECC, making them a preferable choice for applications that require high strength and durability. The use of ECC with optimised fibre content has the potential to enhance the longevity and performance of concrete structures, particularly in environments where cracking and durability are significant 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 does not have any 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 was conducted without any external influence.
- **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.
- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.

REFERENCES

1. Garg, M., & Jain, M. (2021). Evaluation of strength characteristics of engineered cementitious composites using locally available materials in India. Indian Journal of Engineering & Materials Sciences, 28(6), 732-738
2. Sharma, R., & Bansal, P. P. (2020). Utilization of waste foundry sand and recycled coarse aggregates in the production of concrete. Journal of Environmental Management, 262, 110522.
3. Patel, S., & Shah, D. (2019). Impact of industrial by-products on the properties of high-performance concrete: An Indian perspective. Construction and Building Materials, 221, 116-125.
4. Chopra, P., & Siddique, R. (2019). Strength, Permeability, and Microstructure of Self-Compacting Concrete Incorporating Rice Husk Ash. Construction and Building Materials, 207, 596-605.
5. Verma, A. K., & Gupta, A. (2020). Sustainable utilization of quarry dust in cement-based materials: An Indian overview. Materials Today: Proceedings, 34, 216-220.
6. Rana, A., & Singh, P. (2022). Experimental study on the durability of concrete incorporating recycled aggregates and industrial by-products. Journal of Building Engineering, 45, 103662.

AUTHORS PROFILE

Ms. Bandhavya G. B. is an Assistant Professor at Navkis College of Engineering, with over 12 years of experience in Environmental Engineering. She holds a Master's degree in Environmental Engineering, with a focus on wastewater management, and is pursuing a PhD in Environmental Engineering. Prof. GB specialises in Water Supply Engineering, Wastewater Engineering, Solid Waste Management, Municipal Wastewater Engineering, Air Pollution Control, and Concrete Technology. She is actively involved in research, having participated in over 20 workshops and published extensively in peer-reviewed journals. Additionally, she serves as a reviewer for several civil engineering journals, reflecting her ongoing engagement with the latest developments in the field. Her mentorship has led to several successful student projects. Notably, her student's 2018 project, "Treatment of Low Strength Wastewater Characteristics by Floating Technique," was recognised as VTU's Best Project and funded by the Karnataka State Council for Science and Technology (KSCST). Another project, "Extraction of Crude Oil from Plastic Waste Using Pyrolysis Treatment," earned the VTU Best Project Award in 2021. In 2022, her student's project received the 45th Series KSCST Project Award. In 2024, she was recognised for selecting her student's project, "Green Brick Constructions," for the 47th KSCST. Prof. G B's commitment to advancing sustainable engineering practices and her continuous involvement in research underscore her significant contributions to the field of environmental engineering.

Lavanya H D is an Assistant Professor at Malnad College of Engineering, Hassan, where she has been working since December 2020. She has a rich academic background, completing her B.E. with a project on "Defluoridation of Groundwater Using Tamarind Seeds," and her M. Tech with a thesis on "Eutrophication Status and Water Quality Index of Lakes at South Belgaum." Lavanya is currently pursuing a PhD with a focus on "Biochar Mediated Nutrient Recovery from Wastewaters and Responsible Reutilization." She has published numerous papers and has actively participated in several conferences, where she has presented her research. Her work reflects a deep commitment to environmental sustainability and innovative water management solutions.

Mohana H.S. is an Assistant Professor at Navkis College of Engineering with a decade of experience in Structural Engineering. Throughout his 10-year career, he has made significant contributions to the field through the publication of several papers and active participation in numerous conferences. His expertise in Structural Engineering, coupled with his ongoing involvement in research and academic discourse, highlights his dedication to advancing the field and sharing knowledge with the broader engineering community.

Theju R.K is an Assistant Professor at Navkis College of Engineering, specializing in Structural Engineering. With 2.5 years of academic and professional experience, he has actively participated in numerous workshops and conferences, continually enhancing his expertise in the field. His dedication to research in Structural Engineering highlights his commitment to advancing knowledge and contributing innovative solutions within the industry. Theju's passion for structural analysis and design, coupled with his research interests, positions him as a promising scholar in the field.

Ms. Shilpa J is an Assistant Professor at Navkis College of Engineering, bringing over 14 years of experience in the field of Physics. She holds a Master's degree in Physics and is currently pursuing a PhD in Nanomaterials and Polymers. Prof. Shilpa J specialises in Solid-State Physics and is deeply involved in research activities. Her commitment to advancing scientific knowledge is reflected in her participation in over five workshops, where she has engaged with the latest developments in her areas of expertise.

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 over 20 faculty development programs and more than 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.