Experimental Analysis of M-25 Grade Concrete Incorporating Manufactured Sand and Bamboo Fiber: A Study on Mechanical Properties and Sustainability

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Abstract: *This study involved the experimental analysis of M-25 grade concrete, with a focus on examining its various properties such as compressive strength, tensile strength, workability, and flexural strength. In these experiments, manufactured sand (M-sand) was utilized to replace natural sand in proportions of 20%, 40%, 60%, 80%, and 100% by weight, along with a consistent inclusion of 1% bamboo fiber as an admixture. The properties of both fresh and hardened concrete were tested and analyzed at different ages: 7, 14, 28, and 50 days.*

Keywords: *Manufactured Sand, Bamboo Fiber, Concrete Mixtures, Sustainability, Mechanical Properties, Environmental Impact, Construction Industry,*

I. INTRODUCTION

In present day unexpectedly advancing world, the sector of construction is constantly adapting and innovating to fulfill the needs of modern society. Concrete, a cornerstone material in this area, is significantly used across diverse construction initiatives because of its flexible nature and robust characteristics. Its massive utility isn't solely attributed to the various variety of uses it offers but additionally stems from its intrinsic characteristics including strength, cost-effectiveness, sturdiness, and flexibility. These attributes make concrete a dependable and critical material within the construction industry.

Concrete serves as a fundamental element in a myriad of construction ventures. Its utility spans from the erection of residential houses to the construction of towering workplace buildings, playing a critical position in shaping the urban panorama. Moreover, concrete's importance extends to the development of critical infrastructure, which includes roads and bridges, underlining its necessary role in helping modern civilization.

Concrete's adventure from historical times saw considerable improvements within the current technology. Whilst its initial applications have been mainly useful, that specialize in foundations and retaining walls, the 20th century marked a rapid evolution in concrete technology, increasing its use to a variety of structures.

A pivotal development in current concrete era changed into the introduction of bolstered concrete, regarding rebar to beautify power and persistence. This innovation has led to reinforced concrete becoming a ubiquitous constructing material globally.

The introduction of latest admixtures has also revolutionized concrete generation. Those substances, introduced to modify concrete's properties, have had a profound effect, with superplasticizers considerably improving workability without compromising strength.

Advances in construction techniques, such as slip forming and precast concrete, have furthered concrete's versatility. Slip forming enables the continuous pouring and shaping of concrete for tall structures, even as precast concrete, molded off-website and transported to construction sites, has streamlined constructing strategies. Those improvements have now not most effective yielded stronger, more resilient systems but have additionally optimized construction efficiency.

II. LITERATURE REVIEW

The field of concrete technology has witnessed significant progress in recent years, focusing on sustainable and eco-friendly alternatives to traditional construction materials. Research across the globe has investigated the use of supplementary cementitious materials, waste products, and alternative aggregates to enhance concrete properties and mitigate environmental impact. These studies have shown promising results, improving mechanical properties, workability, and durability of concrete, thus highlighting the potential of these innovative methods in the construction industry.

Tahwia et al. (2022) explored the effects of silica fume (SF), rice husk ash (RHA), and blast furnace slag powder (BFSP) on sustainable high strength concrete (SHSC) properties. Using materials from Egypt, they prepared 13 SHSC mixtures with strengths ranging from 69.7 to 102.1 MPa. The study found that SF had higher pozzolanic activity than RHA and BFSP, and the best results for partial cement replacement were at 15% for SF and 10% for RHA.

Abdulfattah et al. (2022) addressed environmental concerns from waste tires by examining the pyrolysis process and proposing the use of pyrolyzed carbon black (PCB) as a concrete additive. They found significant increases in compressive strength and improvements in abrasion resistance and water absorption in concrete mixes with PCB, identifying the optimal PCB to cement ratio between 3% and 5%.

El-Sayed et al. (2022) aimed to create sustainable lightweight concrete using cement kiln dust (CKD) and liquified polystyrene waste. They discovered that a mix with 30% liquified polystyrene and CKD significantly improved mechanical properties. Adding Portland cement, waste glass, or iron slag to this mix further increased the compressive strength.

Tripathi et al. (2022) assessed self-compacting concrete (SCC) with dual admixtures, finding that the optimal level for cement substitution was 25% (FA 15% + MK 10%). The study showed the efficacy of these material combinations for sustainable concrete development.

Sebastin et al. (2022) investigated the use of red soil as an alternative to M-Sand in concrete. They found that certain combinations of red soil with river sand or M-Sand improved compressive, flexural, and split tensile strength, showing potential for red soil as a sustainable alternative in concrete production.

Patil and Naik (2022) focused on reducing greenhouse gas emissions through the use of geo-polymer concrete as an alternative to Portland cement concrete. Their research highlighted early strength gain in ambient curing conditions and detailed the material's mechanical properties, promoting the use of geo-polymer concrete with M-sand for sustainable construction.

Kumar and Kumar (2022) explored the structural behavior of deep beams using hybrid fiber reinforced concrete (HFRC) with M-sand. Their research indicated that hybrid fiber reinforced deep beams significantly outperform standard reinforced concrete deep beams in terms of strength and structural behavior.

Jagad et al. (2022) examined the development of high-strength geopolymer concrete incorporating M-sand, demonstrating the feasibility of producing sustainable and eco-friendly concrete in the construction industry.

Janani et al. (2022) explored the potential of construction and demolition waste as a substitute for M-sand in concrete. Their findings indicated that recycled fine aggregate can be a viable and environmentally friendly material in modern construction.

Tripathi et al. (2022) conducted a study on self-compacting concrete incorporating M-sand and Fly ash, which revealed improved performance in sulphate environments, enhancing both environmental sustainability and durability.

Xia et al. (2022) examined the shear fatigue behavior of reinforced concrete beams using M-Sand, finding that different types of sand influenced the fatigue life of concrete beams, with the methylene blue value being a critical factor.

Bhavanishankar et al. (2022) assessed self-compacting concrete's characteristics by using industrial by-products as partial substitutes for cement and M-sand. The study showed that the best fresh and hardened properties of SCC were obtained with a combination of M-sand, GGBS, fly ash, and silica fume.

Overall, these contributions underscore the evolving nature of concrete technology, focusing on sustainability and the responsible use of materials, thus paving the way for more eco-friendly construction practices in the future.

IV. METHODOLOGY

To create quality concrete, we used a combination of essential substances. Those materials include cement, fine aggregate (comprising both natural sand and manufactured sand), coarse aggregate, and an admixture, especially Bamboo fiber. Every of these additives plays a critical position inside the normal composition and overall performance of the concrete aggregate.

Ingredient of Mix Concrete

Cement – The Binding Agent: Cement is the primary binding agent in concrete, responsible for holding the entire mixture together. It is typically composed of calcium, silicon, aluminum, and iron. When water is added to cement, a chemical reaction known as hydration occurs. This process results in the formation of a strong, adhesive paste that coats the surfaces of the aggregates (coarse and fine) and eventually hardens. The hardened paste binds the aggregates together, creating a solid and durable structure. The type and quality of cement used significantly impact the strength and durability of the concrete.

Chemical Component	Ordinary Portland Cement (OPC)
Calcium Oxide (CaO)	60-67%
Silicon Dioxide (SiO_2)	17-25%
Aluminum Oxide (Al_2O_3)	3-8%
Iron Oxide (Fe_2O_3)	0.5-6%
Sulfur Trioxide (SO_3)	1-3%
Magnesium Oxide (MgO)	1-5%
Alkalis (Na_2O + K_2O)	0.5-1.5%
Pozzolanic Materials	-

Property	Value/Range
Compressive Strength (1 day)	15-25 MPa

Compressive Strength (7 days)	35-50 MPa
Compressive Strength (28 days)	50-70 MPa
Tensile Strength	Approximately 10% of compressive strength
Flexural Strength	Approximately 10-20% of compressive strength
Workability (Slump)	50-100 mm
Abrasion Resistance	Loss in weight after abrasion: < 3%
Blaine Fineness	Typically 300-400 m²/kg

Coarse Aggregate (e.g., Gravel, Stone, Brick Chips) – The Filler Material: Coarse aggregates are larger, bulkier materials that provide stability and strength to the concrete mixture. These materials, such as gravel, crushed stone, or brick chips, make up a significant portion of the concrete's volume. They act as a structural filler, imparting robustness to the concrete. The size, shape, and quality of coarse aggregates influence the concrete's strength and workability.

Property	**Description/Value**
Physical Properties	
Particle Size	Usually 5 mm to 20 mm in diameter
Shape and Texture	Irregular, angular, rough-surfaced
Specific Gravity	Typically around 2.5 to 3.0
Bulk Density	Varies, roughly 1,200-1,800 kg/m³
Water Absorption	Around 0.5 to 2%
Soundness	Resistance to weathering and chemical attack

Fine Aggregate (Sand) – The Micro Filler Material: Fine aggregates consist of smaller particles, primarily sand. While they may not directly contribute to the structural strength of the concrete, they play a crucial role in enhancing workability. Fine aggregates fill the spaces between coarse aggregates, resulting in a more cohesive mixture. The smooth texture of sand allows for better distribution of the cement paste, improving bonding and reducing the risk of voids in the concrete.

Property	**Description/Value**
Physical Properties	
Particle Size	Typically finer than 4.75 mm (passing through a No. 4 sieve)
Shape and Texture	Can be rounded, angular, or a mixture; surface texture varies from smooth to rough
Specific Gravity	Usually around 2.6 to 2.7
Bulk Density	Ranges from about 1,500 to 1,700 kg/m³
Fineness Modulus	A measure of the average size of particles; typically between 2.3 and 3.1
Silt Content	Should be limited (usually less than 3%) to avoid strength reduction
Moisture Content	Varies; crucial for concrete mix calculations

Water – The Essential Component: Water is an indispensable ingredient in concrete. It serves multiple functions, the most critical of which is enabling the hydration of cement. When water is added to dry cement, a chemical reaction begins, causing the cement particles to form bonds with each other and with the aggregates. This process transforms the initially fluid mixture into a solid structure. The amount of water used determines the concrete's workability – too much water can weaken the mixture, while too little can make it too stiff. Achieving the right water-cement ratio is crucial for optimal concrete performance.

Admixtures – The Enhancing Agents: Admixtures are additives introduced to the concrete mixture to modify its properties. These agents are used to achieve specific characteristics or overcome challenges. For example, plasticizers can enhance workability and flowability, making it easier to place and compact the concrete. Retarders and accelerators can adjust the setting time of the concrete to suit construction needs. Additionally, waterproofing admixtures can provide resistance to moisture penetration, increasing the concrete's durability.

Bamboo Fibre - The use of bamboo fiber as an admixture in concrete is an innovative and sustainable approach in the field of construction and material engineering. Bamboo fibers, derived from the bamboo plant, are being explored for their potential to enhance the properties of concrete. Here's an overview of how bamboo fiber is used in concrete and its effects:

Integration into Concrete

- Admixture Form: Bamboo fibers are incorporated into concrete mixtures as an admixture. They are usually added in small quantities to the concrete mix.
- Preparation: The fibers are often treated chemically or mechanically before mixing to ensure better bonding with the concrete and to enhance durability.

Properties and Benefits

- Increased Tensile Strength: Bamboo fibers can improve the tensile strength of concrete. The fibers distribute throughout the concrete, providing resistance to cracking and improving overall structural integrity.
- Enhanced Ductility: The addition of bamboo fibers can increase the ductility of concrete, making it more flexible and less prone to brittle failure.
- Crack Resistance: Bamboo fibers help in controlling the formation of micro-cracks in the concrete, leading to an improved resistance to crack propagation.
- Sustainability: Bamboo is a renewable resource with a fast growth rate, making it an eco-friendly choice compared to synthetic fibers.

M-Sand - Manufactured Sand (M-sand) is an artificial sand produced by crushing hard granite stones into fine particles. It has emerged as a viable alternative to river sand, which has been rapidly depleting due to extensive mining activities. M-sand is created through a precise and controlled process that involves multiple stages of crushing and screening, ensuring a consistent particle size and shape. The material is then thoroughly washed to remove any impurities, such as silt or clay, resulting in a high-quality product.

One of the key properties of M-sand is its uniform particle size and angular, cubical shape. This distinct morphology contributes to better interlocking and a stronger bond in concrete and mortar, enhancing the structural integrity of buildings. Moreover, M-sand maintains a consistent quality, devoid of the variations typically found in natural river sand, thus ensuring predictability and reliability in construction.

Environmentally, M-sand is a more sustainable option. Its production helps in preserving natural river ecosystems by reducing the dependence on river sand. Furthermore, it is often more cost-effective than river sand, making it an attractive choice for large-scale construction projects.

In terms of applications, M-sand is widely used in the construction industry. It is a key ingredient in concrete and mortar and is employed in various construction activities, including brickwork, plastering, and masonry. Its growing popularity is a testament to its effectiveness as a building material and its role in promoting environmentally responsible construction practices.

Lab Testing

Laboratory tests were conducted on aggregates following the relevant IS standards and a mix design for M-25 grade concrete. The laboratory testing protocol included the following:

Physical Properties of Coarse Aggregate:

- Sieve analysis and determination of fineness modulus.
- Measurement of Specific Gravity.
- Assessment of Water Absorption.

The study also evaluated the compressive strength, flexural strength, and split tensile strength of concrete cubes, beams, and cylinders after curing periods of 7, 14, 28, and 50 days. Five experimental concrete mixtures were prepared, as outlined below:

- Normal Mix (Trial-1 control): Comprising Cement, Sand, Coarse Aggregate, and Water.
- Special Mix (Trial-2): Consisting of Cement, Sand, Coarse Aggregate, 20% M-sand (with 1% Bamboo fiber), and Water.
- Special Mix (Trial-3): Formulated with Cement, Sand, Coarse Aggregate, 40% M-sand (with 1% Bamboo fiber), and Water.
- Special Mix (Trial-4): Made of Cement, Sand, Coarse Aggregate, 60% M-sand (with 1% Bamboo fiber), and Water.
- Special Mix (Trial-5): Composed of Cement, Sand, Coarse Aggregate, 80% M-sand (with 1% Bamboo fiber), and Water.

These trials were designed to assess the impact of varying M-sand and bamboo fiber proportions on concrete's structural properties.

V. RESULTS AND DISCUSSION

Consistency of Cement Test

The concept of standard consistency is fundamental in the preparation of cement paste, and it is critically defined in terms of the behavior of the paste under specific testing conditions. Standard consistency is achieved when a Vicat plunger, used in the Vicat apparatus test, penetrates the cement paste to a depth that leaves a distance of 5 to 7 mm from the bottom of the Vicat mould. This measurement is crucial as it indicates the optimal water content required to make the cement paste plastic and workable, without being overly fluid or rigid.

In the context of pastes that contain fibers, as mentioned in Table 4.7, the normal consistency is a key parameter. The control paste, which is a reference paste without any fiber addition, has a recorded normal consistency of 34.7%. This percentage reflects the ratio of water to cement by weight needed to reach the standard consistency for the control paste.

When fibers are introduced into the paste, there is a noticeable impact on the consistency. The observations indicate that all fiber-containing pastes have a normal consistency that is either equal to or higher than that of the control paste. This means that the addition of fibers to the paste increases or at least does not decrease the amount of water required to achieve standard consistency. This increase can be attributed to the fibers' tendency to absorb water or affect the mix's overall workability.

The consistency of the paste is a crucial aspect as it influences the ease of mixing, placing, and compacting the cement in construction applications. A higher water content in fiber-reinforced pastes may necessitate adjustments in mix design to ensure that the final concrete product maintains its desired properties, such as strength and durability. The study of normal consistency, especially in modified pastes like those containing fibers, is vital for understanding how different additives influence the fundamental properties of cement mixes.

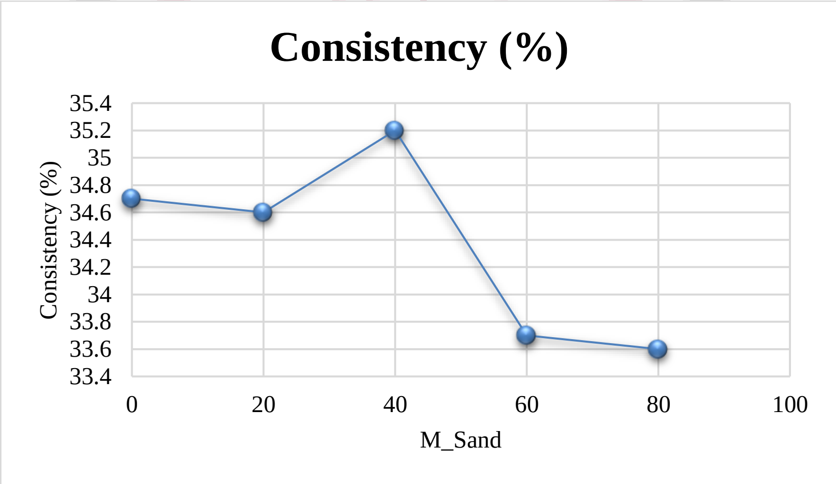

Figure 1 Cement Consistency having Different Composition of M-sand

The Indian standard sets specific recommendations for the setting times of concrete, stipulating that the initial placing time need to not be less than half-hour, and the final setting time should no longer exceed 10 hours. According to the statistics provided in table 4.8, the addition of fibers and M-sand (manufactured sand) to the concrete mix appears to delay the setting process. However, this delay stays within the acceptable limits defined by the Indian standards. Significantly, because the fiber content within the concrete mix increases, there is a corresponding trend toward longer setting times. This indicates that fibers, when added to the concrete, can impact the rate at which the concrete transitions from a workable to a hardened state. It's important to notice that while this trend is typically consistent, there are exceptions in which the setting time does now not growth as predicted with higher fiber content material.

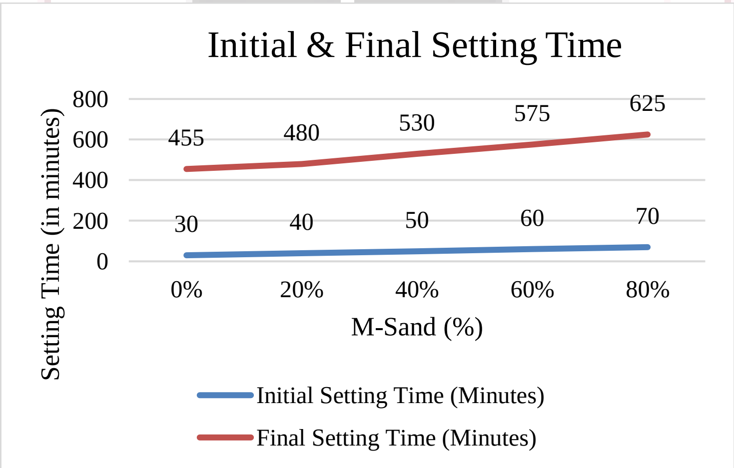

Figure 2 Initial and Final Setting time of Cement having Different Composition of M-sand

Compressive Strength of Concrete Cube Sample

The compressive strength test on concrete is easy to do the test outcome is trying to derive as far as actual quality which is impact by various components. A significant number of the imperative properties of concrete like the modulus of flexibility, imperviousness to shrinkage, and web blanket and solidness enhance with the increment in compressive quality. The compressive strength of mortar for OPC were tested and analyzed.

Compressive Strength of Concrete M-25 Grad.

The compression assessments carried out the usage of a Compression testing machine (CTM) found out a tremendous upward trajectory in the compressive strength as the concrete specimens aged. in particular, the outcomes of the compressive strength assessments were obtained for various combinations of M-sand, ranging from 20% to 80%, replacing natural sand. Those mixtures had been complemented with a fixed 1% admixture, Bamboo fiber. The data collected spans distinctive curing periods, inclusive of 7, 14, 28, and 56 days. The complete findings for M-25 grade concrete are offered in table 1. This table serves as a valuable reference for understanding how the usage of M-sand and bamboo fiber admixture affects the concrete's compressive strength over the years.

Table-1 Compressive Strength Reading for M-25 Grade having Normal Composition with M-sand Different Composition

Day's	0	20	40	60	80
7	17.0	19.5	21.0	| 11.0	10.0
14	24.0	24.5	25.0	17.0	14.0
28	26.5	30.0	31.0	18.0	14.5
50	37.0	41.5	42.0	32.0	28.5

It could be observed that Compressive strength reading (for the ordinary estimation of three cube test) at 7, 14, 28 and 50 days are better than with the usage as 40 % m-sand and 20% M-sand replacing natural sand.

Flexural Strength of Concrete Beam Sample

Flexural potency also called as modulus of crack. In concrete flexure is the bending moment caused by the applied load, in which a concrete beam has compression at top and tensile stress at the bottom side. Beams on testing will fail in tension due to its property and shear will appear on concrete. In this experimental works totally 45- beams of size 700 x 100 x 100 are casted of M-25 grade of concrete with utilized as 0%, 20%, 40%, 60% and 80% of M-sand. Then compare the values of both design mixes.

Flexural Strength Test with M-25 Grade

The statistics obtained from the flexural assessments performed the usage of a universal testing device (UTM) reveals an interesting sample within the flexural strength of concrete specimens over time. as the concrete specimens age, there is a steady and noticeable increase of their flexural strength. this implies that concrete becomes stronger and extra resistant to bending forces as it matures.

The study particularly focuses on M-25 grade concrete, wherein M-sand is used as a substitute for herbal sand at specific percentages (20%, 40%, 60%, and 80%). moreover, 1% bamboo fiber is integrated into the concrete blend. The cause of this research is to evaluate the impact of those variations at the flexural strength of the concrete.

The consequences of the flexural strength tests are provided in table 2, and the assessments were performed after a curing period of 28 days. This table presents valuable insights into how the inclusion of M-sand and bamboo fiber affects the flexural electricity of the concrete, permitting us to make informed choices about concrete mix layout and composition for precise applications..

Table-2 Flexural Strength for M-25 Grade

Flexural Strength M-25 Grade					
Day's	0	20	40	60	80
28	3.80	4.20	4.00	2.25	1.90

We can watched that flexural strength has expanded with the 20 and 40% contain M sand and diminish with 60 and 80%.

Split Tensile Strength of Concrete Cylinder

The Split tensile strength of concrete material is tested by creating cylinders of size 150mm x 300mm and is continuously cured for 28 days testing. Totally 15 cylinders were casted for normal M-25 grade and for 0, 20, 40, 60 and 80% replacing natural sand by m-sand and utilize as admixture 1% bamboo fiber. Three samples are tested and the average values are taken as tensile strength of concrete. The values of split tensile strengths are shown in table.

Split Tensile Strength of Concrete Cylinder with M-25 Grade

The Split tensile test by CTM (Compression Testing machine) indicates an increasing trend of Split tensile strength with age of the concrete specimens. The result of the Split tensile strength with utilization of m sand (0, 20, 40, 60 and 80%) and admixture for 28 days are shown in the Table 3 for M-25 concrete.

Table- 3 Split Tensile Strength for M-25 Grade

Spit Tensile Strength M-25 Grade					
Day's	0	20	40	60	80
28	4.80	5.35	4.98	3.55	3.25

We can watched that Spit Tensile Strength has expanded with the 20% and 40% contain m-sand and diminish with 60% of contain m-sand, contrast with ordinary concrete and other msand composition with the age of 28 days.

V. CONCLUSION

The experimentation highlights the importance of achieving standard consistency in cement pastes, particularly when fibers are introduced. The normal consistency of the control paste without fibers was 34.7%. With the addition of fibers, the consistency values varied, with 20% M-sand showing a consistency of 34.6%, and 40% M-sand increasing it to 35.2%. These changes in consistency underscore the fibers' influence on water requirements and overall workability.

The study also delved into the initial and final setting times of the cement pastes. The addition of M-sand and fibers lengthened these times, suggesting a delayed setting process. For instance, with 0% M-sand, the initial setting time was 30 minutes, extending to 70 minutes with 80% M-sand. Similarly, the final setting time increased from 455 minutes (0% M-sand) to 625 minutes (80% M-sand), illustrating the gradual transition from a plastic to a solid state in the concrete.

Workability of Concrete: Workability, evaluated through the slump test, showed a direct correlation with the proportion of M-sand. For example, with 0% M-sand, the slump was 75 mm, which increased to 100 mm with 80% M-sand. These results indicate that higher M-sand content enhances the concrete's workability.

Compressive and Flexural Strength Analysis: The compressive strength of M-25 grade concrete varied significantly with different M-sand contents. Notably, at 28 days, the strength was 26.5 N/mm² for 0% M-sand and increased to 31.0 N/mm² for 40% M-sand. The flexural strength also showed a similar trend; with 20% M-sand, the strength was 4.20 kN compared to 3.80 kN for 0% M-sand at 28 days.

Split Tensile Strength of Concrete Cylinders: The split tensile strength tests demonstrated a noteworthy increase with the inclusion of M-sand and bamboo fiber. For instance, at 28 days, the split tensile strength for 0% M-sand was 4.80 N/mm², which increased to 5.35 N/mm² with 20% M-sand. However, it decreased to 3.25 N/mm² with 80% M-sand, indicating an optimal range for M-sand content.

REFERENCES

[1] Tahwia, A.M., El-Far, O. & Amin, M. Characteristics of sustainable high strength concrete incorporating eco-friendly materials. Innov. Infrastruct. Solut. 7, 8 (2022). https://doi.org/10.1007/s41062-021-00609-7

[2] Abdulfattah, O., Alsurakji, I. H., El-Qanni, A., Samaaneh, M., Najjar, M., Abdallah, R., & Assaf, I. (2022). Experimental evaluation of using pyrolyzed carbon black derived from waste tires as additive towards sustainable concrete. Case Studies in Construction Materials, 16, e00938 https://doi.org/10.1016/j.cscm.2022.e00938

[3] El-Sayed, A. M., Faheim, A. A., Salman, A. A., & Saleh, H. M. (2022). Sustainable Lightweight Concrete Made of Cement Kiln Dust and Liquefied Polystyrene Foam Improved with Other Waste Additives. Sustainability, 14(22), 15313. https://doi.org/10.3390/su142215313

[4] Tripathi, D., Kumar, R., Mehta, P.K., Singh, A. (2022). Use of Mineral Admixtures and M-sand for Sustainable Concrete. In: Kondraivendhan, B., Modhera, C.D., Matsagar, V. (eds) Sustainable Building Materials and Construction. Lecture Notes in Civil Engineering, vol 222. Springer, Singapore. https://doi.org/10.1007/978-981-16-8496-8_7

[5] S. Sebastin, M. Franchis David, Alagar Karthick, Ashita Singh, J. Vanjinathan, Sanjeev Kumar, Mahseena Akter Meem, "Investigation on Mechanical and Durability Performance of Reinforced Concrete Containing Red Soil as Alternate for M-Sand", Journal of Nanomaterials, vol. 2022, Article ID 5404416, 15 pages, 2022. https://doi.org/10.1155/2022/5404416

[6] Patil, M. B., & Naik, M. (2022). Comparative study on geo-polymer concrete using natural sand & M-sand. Materials Today: Proceedings, 62, 1879-1882. https://doi.org/10.1016/j.matpr.2022.01.013

[7] Kumar, K. R., & Kumar, R. Y. (2022). Structural behaviour of deep beam using hybrid fiber reinforced concrete with M− sand. Materials Today: Proceedings, 68, 1481-1485. https://doi.org/10.1016/j.matpr.2022.07.097

[8] Jagad, G., Modhera, C. D., & Patel, D. (2022). Experimental investigation on development of compressive strength of high-strength geopolymer concrete containing M-sand. In Sustainable Building Materials and

Construction: Select Proceedings of ICSBMC 2021 (pp. 21-29). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-16-8496-8_3

[9] Janani, S., Kulanthaivel, P., Nidharshana, S., Kumar, S. N., & Narendhiran, J. (2022). Performance evaluation of mechanical behaviour of concrete with recycled aggregate and M-sand. Materials Today: Proceedings, 65, 1867-1872. https://doi.org/10.1016/j.matpr.2022.05.047

[10] Tripathi, D., Kumar, R. & Mehta, P.K. Development of an environmental-friendly durable self-compacting concrete. Environ Sci Pollut Res 29, 54167–54180 (2022). https://doi.org/10.1007/s11356-022-19638-5

[11] Xia, J., Chen, K., Wu, Y., Xiao, W., Jin, W., & Zhang, J. (2022). Shear fatigue behavior of reinforced concrete beams produced with manufactured sand as alternatives for natural sand. Journal of Building Engineering, 62, 105412. https://doi.org/10.1016/j.jobe.2022.105412

[12] Bhavanishankar, S., Jayaramappa, N., Sai Nagendra, C.V., Venkata Siva Rama Prasad, C. (2022). Influence of Mineral Admixtures and M-Sand on Fresh and Hardened Properties of Self-Compacting Concrete. In: Kumar, P.G., Subramaniam, K.V.L., Santhakumar, S.M., Satyam D., N. (eds) Recent Advances in Civil Engineering. Lecture Notes in Civil Engineering, vol 233. Springer, Singapore. https://doi.org/10.1007/978-981-19-0189-8_7