IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Annales de Chimie - Science des Matériaux
Vol. 48, No. 5, October, 2024, pp. 685-690
Journal homepage: http://iieta.org/journals/acsm

Experimental Investigation of Micronized Biomass Silica-Based Concrete as a Sustainable Construction Material

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https://doi.org/10.18280/acsm.480509

Received: 22 July 2024
Revised: 31 August 2024
Accepted: 14 October 2024
Available online: 29 October 2024

Keywords:
micronized biomass silica (MBS), SEM, compressive strength, split tensile strength

ABSTRACT

This study explores the potential of Micronized Biomass Silica (MBS), a high-silica agricultural byproduct, as a partial substitute for cement in concrete mixtures. MBS can lead to a reduction in CO_2 emissions associated with cement production, contributing to more sustainable concrete practices. The study explores the effects of replacing cement with MBS in varying percentages, ranging from 3% to 12% at intervals of 3%, to identify the optimal mix combination. Concrete samples, both with and without the addition of Micronized Biomass Silica (MBS), were subjected to compressive strength and split tensile strength tests. The results indicate that incorporating up to 6% MBS enhances the strength of concrete, while higher percentages lead to a decrease in strength. Additionally, a detailed microstructural analysis of the concrete with MBS was performed using Scanning Electron Microscopy (SEM), which provided insights into the mechanisms underlying the observed strength development. The optimal percentage of MBS for enhanced strength development is 6%, as it improves compressive and split tensile strength while enhancing the interfacial transition zone. The findings suggest that MBS can be effectively utilized to improve concrete performance at optimal replacement levels.

1. INTRODUCTION

Rapid development and industrialization have started in recent decades, coinciding with an increase in the population rate. In order to satisfy resident demand, the rate of development has significantly increased, with concrete potentially playing an integral part [1]. Increased cement consumption results in higher atmospheric emissions of carbon dioxide, which has detrimental effects on the environment [2]. To make concrete production more environmentally and financially viable, alternative additives should be used in place of Ordinary Portland cement (OPC) during the preparation process [3]. It is possible to reduce the yearly global use of cement by about 121 million tonnes while preserving the desirable features of cement concrete by partially substituting cement content with agricultural waste materials [4]. With the right processing, agricultural waste material can be utilised to partially vary the cement component by weight in cement concrete due to its pozzolanic qualities, such as rice husk ash (RHA), micronized biomass silica (MBS), sugarcane bagasse ash (SCBA), groundnut shell ash (GSA), oyster shell powder (OSP), and palm oil fuel ash (POFA) [5]. The requirement for agricultural products is rising due to the growing global population, which presents a number of disposal difficulties for the resulting residue from agriculture. Incineration is a common technique for handling agricultural waste; this produces biomass ash, which is then landfilled and pollutes the environment. Research studies are looking into the possibility of substituting waste materials for energy- and carbon-intensive materials like cement in order to reduce reliance on them [6, 7]. Innovative research on substitute cementitious materials that might decrease the adverse environmental effects of concrete production has been stimulated by a desire for sustainable building materials. Many mineral admixtures which have been used in making concrete have shown good performance both in normal concrete and special concrete [8-12]. Integrating various agricultural wastes has a beneficial effect on the microstructure's pore size distribution, which decreases as the amount of ashes increases and leads to the formation of ultra-lightweight foamed concretes with strong matrices [13]. Improvements were obtained in compressive, tensile, and flexural strength when olive waste ash, sugarcane leaf ash, and rice husk were substituted for 50% of the OPC weight [14]. The characteristics of ultra-high-strength concrete (UHSC) were significantly improved by the use of corn stalk ash (CSA) and SCBA [15]. When up to 15% of cement was replaced by SCBA, the strength improved and then decreased, and a rise in strength in concrete was observed through SEM examination [16]. An agricultural residue produced by burning rice husk and grinding in a jar mill is MBS. It represents twenty percent of the global rice paddy production, which totals 500 million tonnes [17]. The inclusion of MBS as an innovative cement alternative in concrete mixtures has demonstrated promising performance [18]. Due to the high amorphous silica concentration in MBS, more calcium silicate hydrates (CSH) gel is formed when it interacts with hydration products. This enhances the strength and durability characteristics of concrete [19]. Flexural, compressive and split tensile strength improved at 25% blending for all ages when combined with nano biomass silica, polycarboxylate ether (PCE) chemical admixture, and bio-admixture [20]. Based on the results, there are three benefits to utilizing agricultural wastes in geopolymer concrete: it establishes energy from waste, reduces environmental impact, and increases compressive strength [21]. The maximum strength and durability were seen in a geopolymer concrete mixture that contained 90% Ground Granulated Blast-furnace Slag (GGBS) and 10% MBS as a binder. The outcome of this work indicate that micronized biomass silica can be utilised as a material which enhance binding in geopolymer concrete production [22]. According to the experimental studies, the best resistance and durability were attained by geopolymer concrete that used GGBS as the significant binder with 20% MBS manufactured from rice husk instead of Portland cement in place of slag powder [23]. Similarly, the result showed that 10% MBS with 0.2% fiber addition gave optimum split-tensile ,compressive, and flexural strength [24]. Compressive strength and split tensile strength were found to be most effective in specimens containing 20 ml of bacteria and 8% MBS. Thus, the bacteria and MBS combination would strengthen the concrete while also assisting it in resisting moisture and other damaging particles [25, 26]. The strengths increased up to a specific point and then decreased, according to the data. When 10% of the MBS in the concrete was replaced with recycled aggregates, the best strength values were achieved [27]. In comparison to the control mix, replacing 10% of the MBS with GGBS results in a more strength value as well as replacing up to 20% of MBS without sacrificing strength or workability is feasible [28]. It is possible to increase compressive strength by up to 17.20% and decrease the water penetration and water permeability coefficient by using concrete that contains 12% MBS and 100% recycled aggregate (RA). The results indicate that RA with MBS performs more effectively [29]. Concrete can perform better when the MBS material is used because it reduces water permeability and increases the development of compressive strength. To mitigate the workability issues associated with the use of MBS in fresh concrete, superplasticizers can be employed [30]. MBS's pozzolanic interaction with cement hydrates produced improved properties that can reduce the concentration of Calcium hydroxide $Ca(OH)_2$, also produced secondary CSH. Based on the experimental results, it was determined that 8% of MBS was the ideal percentage to replace cement in the materials [31]. While several studies have investigated at the performance of ordinary concrete including RHA. There has been limited research on the effectiveness of concrete incorporating MBS. From previous studies, it was concluded that up to 12% MBS replacement with cement was optimal, while higher percentages of MBS replacement resulted in strength loss. This work investigates the impacts of replacing cement with MBS at varied percentages, ranging from 3% to 12% at 3% intervals, to determine the Fresh and Mechanical properties of concrete containing MBS and to identify the optimal mix combination. The lower limit (3%) ensures noticeable influence on concrete properties, while the upper limit (12%) prevents excessive reductions in strength Microstructural features were examined by doing SEM analysis on the optimum concrete mix. The primary aim of this paper is to enhance the use of agricultural waste-based concrete as an alternative binder.

2.MATERIALS

In accordance with IS 12269-2013 [32], an OPC of 53 grade and a specific gravity of 3.14, was used as the binder. MBS made from rice husk with high silica content, with a specific gravity of 2.2 was also utilized. The chemical attributes of MBS are tabulated in Table 1. Crushed stone sand with a size less than 4.75 mm, conforming to IS 383-2016 [33], was utilized as the fine aggregate which has a specific gravity of 2.62. In this study, coarse aggregates with a specific gravity of 2.7 and a nominal size of 20 mm were utilized.

Table 1. Chemical constitution of MBS

Chemical Composition	(%)
SiO_2	87.62
Al_2O_3	0.27
Fe_2O_3	0.577
CaO	0.806
MgO	0.728
K_2O	5.078
SO_3	0.593

3. MIX DESIGN AND METHODOLOGY

The quality of concrete is primarily influenced by the proportions of its constituent materials. The mix design for M30 grade concrete was performed in compliance with IS 10262-2019 standards [34]. MBS was incorporated as a partial cement replacement at levels of 3%, 6%, 9%, and 12%. A uniform water-to-cement ratio of 0.43 was maintained for all concrete mixes. The results were compared with control mix (concrete without MBS). Table 2 details the concrete mix proportions, and Figure 1 outlines the methodology of the study. Three identical specimens, each measuring 15 cm × 15 cm × 15 cm, were prepared for compressive strength testing, which was conducted according to IS 516-1959 [35], with results recorded at 7 and 28 days. The split tensile test was performed on cylindrical specimens (150 mm diameter and 300 mm height) in accordance with IS 5816:1999 [36]. Figure 2 and 3 shows the test set up of compressive strength test and split tensile strength test.

Table 2. Mix Proportion

MIX DESIGNATION	0% MBS	3% MBS	6% MBS	9% MBS	12% MBS
Cement (Kg/ m^3)	356.51	345.82	335.12	324.43	313.72
MBS (Kg/m^3)	0	10.69	21.39	32.08	42.78
Crushed Stone Sand (Kg/m^3)	767.91	767.91	767.91	767.91	767.91
Coarse Aggregate (Kg/m^3)	1124.65	1124.49	1122.93	1122.30	1120.12
Water (Kg/m^3)	153.28	153.28	153.28	153.28	153.28

Figure 1. Methodology

Figure 2. Compressive strength test

Figure 3. Split tensile strength test

4. RESULT AND DISCUSSION

4.1 Fresh properties

The fresh properties of concrete were assessed using the slump test, as detailed in IS 1199:2018 [37]. The slump cone test was performed on all concrete mixes. The results indicated that MBS absorbs more water, leading to a progressive decrease in slump values with increasing MBS content. For 3% MBS, the slump value was observed to be 80 mm, suggesting minimal impact on workability. At 6% MBS, the slump value reduced to 75 mm, indicating medium workability. Further increases to 9% and 12% MBS resulted in slump values of 72 mm and 70 mm, respectively, demonstrating a significant reduction in workability. This may be due to the high surface area and fine particle size of the silica. Slump value decreased when the proportion of MBS increased. Similar observations were made by Hani et al. [38], indicating that higher MBS may result in a harsh and less cohesive mix, thus affecting the compaction process.

4.2 Compressive strength

Figure 4 displays the compressive strength test results of all the mixes at 7 and 28 days. Each compressive strength result represents the average of three specimens tested at various ages for the same percentages. Every comparison is made with control concrete (0% MBS). Notably, at 28 days, the mix with 6% MBS partial substitution had a higher compressive strength (38.8 MPa) than the other mixes, showing an increase of more than 10% over the control concrete. The improvement in strength up to 6% MBS is primarily attributed to the pozzolanic reaction between MBS and calcium hydroxide, producing additional calcium silicate hydrate, which improves the binding and density of the concrete composition, thereby reducing porosity and creating a denser, more cohesive structure. However, a decrease in strength was observed with higher MBS percentages; for instance, the 12% MBS mix showed a lower strength of 35.3 MPa, although it was comparable to the control concrete. Higher MBS content may disrupt the hydration process, whereas MBS based concrete up to 6% has shown the optimum performance. This phenomenon underscores the complex interplay of MBS content and its impact on concrete strength. When silicon dioxide (SiO2) from MBS undergoes secondary hydration, it combines with calcium hydroxide produced during the primary cement hydration process, leading to an enhancement in the compressive strength of MBS concrete. The formation of CSH gel occupies larger pores, transforming them into finer pores within the interfacial transition zone (ITZ) and micropores of concrete. This reaction significantly enhances the concrete's strength development. Moreover, the finer particle sizes of MBS compared to cement improve the densifying the cement matrix, filler mechanism, enhancing bonding with aggregates and filling voids with hydration products [39]. The physical activity of pozzolanic materials results in a denser, more uniform, and homogeneous paste [30]. Thus, it is evident that the filler effect of pozzolan materials contributes to densifying the cement matrix alongside the pozzolanic reaction. Many researchers have investigated the strength properties of MBS for various types of concrete and has observed that addition of MBS improved the strength properties [23, 40]. Similar to MBS, many agricultural waste has been used as a replacement of cement and their results were promising [41].

In comparison to control concrete, MBS concrete has a better compressive strength and less water permeability due to the pozzolanic interaction between silicon dioxide from MBS and calcium hydroxide from cement hydration. This reaction produces C-S-H gel, which fills gaps between the aggregates and cement paste, as well as pores within the concrete. These mechanisms collectively decrease the concrete's permeability.

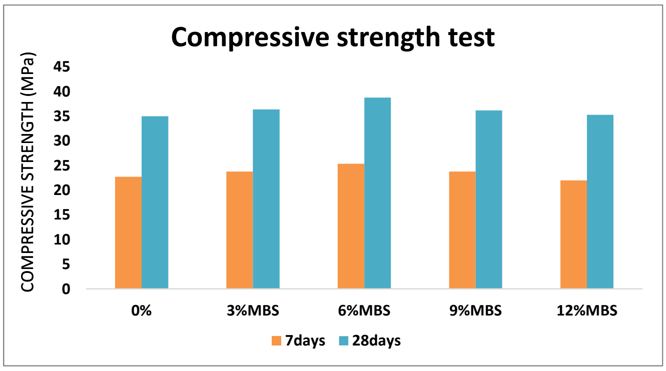

Figure 4. Compressive strength of concrete with and without MBS

4.3 Split tensile strength

Figure 5 depicts the split tensile strength of the cylinder specimens for all combinations after 7 and 28 days of curing. Mix 6% MBS exhibited the highest split tensile strength compared to all other mixes. From the figure, it is evident that all mixes up to 6% MBS exhibited greater split tensile strength compared to the control concrete. However, increasing the MBS percentage beyond 6% resulted in a reduced split tensile strength. The improvement in split tensile strength is attributed to MBS enhancing the ITZ between the aggregates and the cement paste, thereby reducing the likelihood of crack initiation and propagation under tensile stress. The denser matrix, improved bonding, and stronger ITZ collectively contribute to the observed increase in split tensile strength in MBS-based concrete. Conversely, it was observed that replacing more than 9% of MBS resulted in lower strength compared to the control concrete, possibly due to excessive water demand and reduced workability, leading to increased porosity. The high surface area of MBS at these levels requires more water for proper hydration, potentially resulting in a stiffer mix that is challenging to consolidate and may introduce voids and weak zones within the concrete matrix.

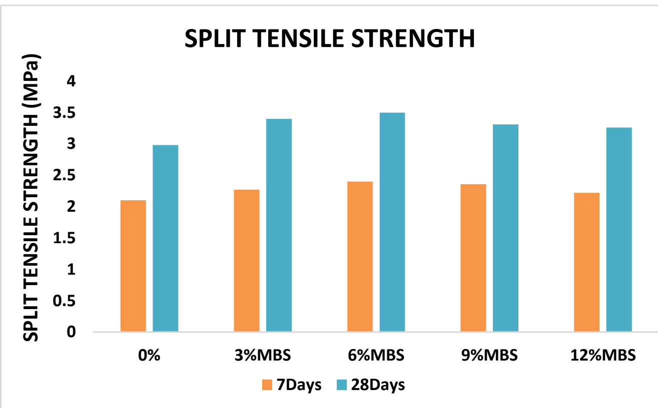

Figure 5. Split tensile strength of concrete with and without MBS

4.4 Microstructural studies

In this study, Scanning Electron Microscopy (SEM) was used to analyze concrete samples incorporating 6% micronized biomass silica (MBS). The SEM image of 6% MBS-based concrete is depicted in Figure 6. The distinctive properties of MBS, particularly its fine particle size and high surface area, enhance its pozzolanic activity when integrated into concrete. This leads to improved strength through dense particle packing and reduced pore space. Similar observation was made by Priya et al. [26] for concrete made with Bacteria-Bacillus sphaericus. During the hydration process, MBS particles interact with the $Ca(OH)_2$ produced during cement hydration, facilitating the generation of additional calcium-silicate-hydrate gel. This gel effectively fills the pores and voids in the concrete matrix, enhancing densification and improving the ITZ between aggregates and cement paste. The surface area and pozzolanic reactivity of MBS facilitates the development of C-S-H and nucleation processes. The inclusion of MBS in concrete thus refines the microstructure and enhances bonding. SEM images corroborate these findings, illustrating a homogeneous distribution of hydration products and confirming the effective use of MBS as an adjunct cementitious material in concrete.

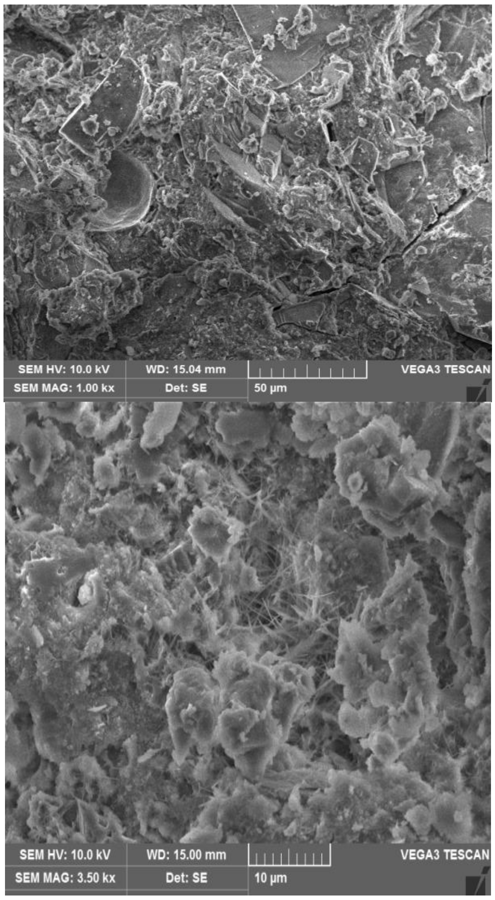

Figure 6. SEM image of 6% MBS based concrete

5. CONCLUSION

The following observations were established after investigating concrete made with and without MBS:

1. Concrete with 6% MBS showed the highest compressive strength of 38.8 MPa compared to other mixes.

2. The split tensile strength of concrete with 6% MBS showed better results of 2.4 MPa and 3.5 MPa at 7 and 28-day curing ages.
3. MBS exhibited a good pozzolanic reaction, enhancing particle packing density, indicating its suitability as a pozzolanic material.
4. SEM images confirmed the clustering and improved bonding of materials, which enhanced the interfacial transition zone (ITZ).
5. All mixes demonstrated superior strength compared to the control concrete.
6. The use of MBS is more environmentally friendly and cost-effective. It can be partially substituted for cement, thereby reducing carbon dioxide emissions.
7. Scope of this study were limited to strength performance, Future studies on long term performance of MBS based concrete can be studied by conducting chemical resistance test, life cycle assessment, etc.

REFERENCES

[1] Singh, R., Patel, M. (2023). Strength and durability performance of rice straw ash-based concrete: An approach for the valorization of agriculture waste. International Journal of Environmental Science and Technology, 20(9): 9995-10012. https://doi.org/10.1007/s13762-022-04554-5

[2] Waliitagi, A., Dasarathy, A.K., Kavitha, S. (2024). Brief review on agricultural waste based self compacting concrete. In Advancements in Science and Technology for Healthcare, Agriculture, and Environmental Sustainability. CRC Press, pp. 95-98.

[3] Hakeem, I.Y., Amin, M., Agwa, I.S., Abd-Elrahman, M.H., Abdelmagied, M.F. (2023). Using a combination of industrial and agricultural wastes to manufacture sustainable ultra-high-performance concrete. Case Studies in Construction Materials, 19: e02323. https://doi.org/10.1016/j.cscm.2023.e02323

[4] Gudainiyan, J., Kishore, K. (2023). A review on cement concrete strength incorporated with agricultural waste. Materials Today: Proceedings, 78: 396-402. https://doi.org/10.1016/j.matpr.2022.10.179

[5] Razeman, N.A., Itam, Z., Beddu, S., Izam, N.S.M.N., Ramli, M.Z., Syamsir, A., Asyraf, M.R.M. (2023). A review on the compressive strength and workability of concrete with agricultural waste ash as cement replacement material. In International Conference on Civil and Environmental Engineering, Penang, Malaysia, 1135: 012058. https://doi.org/10.1088/1755-1315/1135/1/012058

[6] Danish, A., Karadag, O., Bilir, T., Ozbakkaloglu, T. (2023). Valorization of biomass ashes in the production of cementitious composites: A comprehensive review of properties and performance. Construction and Building Materials, 405: 133244. https://doi.org/10.1016/j.conbuildmat.2023.133244

[7] Khalife, E., Sabouri, M., Kaveh, M., Szymanek, M. (2024). Recent advances in the application of agricultural waste in construction. Applied Sciences, 14(6): 2355. https://doi.org/10.3390/app14062355

[8] Waliitagi, A., Rathanasalam, V., Chinnadurai, M., Pitchaimuthu, E. (2024). Strength and microstructural behavior of sustainable concrete with varied proportions of recycled fine aggregate from construction and demolition waste. Annales de Chimie - Science des Matériaux, 48(1): 109-113. https://doi.org/10.18280/acsm.480113

[9] Gill, P., Rathanasalam, V.S., Jangra, P., Pham, T.M., Ashish, D.K. (2024). Mechanical and microstructural properties of fly ash-based engineered geopolymer mortar incorporating waste marble powder. Energy, Ecology and Environment, 9(2): 159-174. https://doi.org/10.1007/s40974-023-00296-3

[10] Jude, A.B., Ramar, V., Vigneshkannan, S., Sarathy, R.V. (2022). Influence of rice husk ash and silica fumes in flexural behavior of self-compacting concrete. Journal of Environmental Protection and Ecology, 23(6): 2401-2409.

[11] Rathanasalam, V., Perumalsami, J., Jayakumar, K. (2020). Characteristics of blended geopolymer concrete using ultrafine ground granulated blast furnace slag and copper slag. Annales de Chimie - Science des Matériaux, 44(6): 433-439. https://doi.org/10.18280/acsm.440610

[12] Rathanasalam, V., Perumalsami, J., Jayakumar, K. (2020). Mechanical properties of a geopolymer concrete/ultrafine material based composite. Materiali in Tehnologije, 54(6): 867-871. https://doi.org/10.17222/mit.2020.072

[13] Alharthai, M., Mydin, M.A.O., Kaze, R.C., Majeed, S.S., Tayeh, B.A. (2024). Properties of ultra lightweight foamed concrete utilizing agro waste ashes as an alkaline activated material. Journal of Building Engineering, 90: 109347. https://doi.org/10.1016/j.jobe.2024.109347

[14] Alyami, M., Hakeem, I.Y., Amin, M., Zeyad, A.M., Tayeh, B.A., Agwa, I.S. (2023). Effect of agricultural olive, rice husk and sugarcane leaf waste ashes on sustainable ultra-high-performance concrete. Journal of Building Engineering, 72: 106689. https://doi.org/10.1016/j.jobe.2023.106689

[15] Maglad, A.M., Amin, M., Zeyad, A.M., Tayeh, B.A., Agwa, I.S. (2023). Engineering properties of ultra-high strength concrete containing sugarcane bagasse and corn stalk ashes. Journal of Materials Research and Technology, 23: 3196-3218. https://doi.org/10.1016/j.jmrt.2023.01.197

[16] Gupta, C.K., Sachan, A.K., Kumar, R. (2023). Experimental study on microstructural and mechanical behaviour of self compacting concrete using agricultural waste. Iranian Journal of Science and Technology, Transactions of Civil Engineering, 47(2): 925-942. https://doi.org/10.1007/s40996-022-00980-0

[17] Nageswari, N., Divahar, R., Paiyanoor, C. (2023). Temperature impact on the hydration and setting mechanism of C-SH bonding on nano-biomass silica with poly-carboxylate ether. Global Nest Journal, 25(9): 11-19. https://doi.org/10.30955/gnj.005227

[18] Hanita, A.R. (2023). Unlocking sustainability: Micronised biomass silica as a novel cement replacement in concrete. The American Journal of Engineering and Technology, 5(9): 5-9. https://doi.org/10.37547/tajet/Volume05Issue09-02

[19] Jayanthi, V., Avudaiappan, S., Amran, M., Arunachalam, K.P., Qader, D.N., Delgado, M.C., Rashid, R.S. (2023). Innovative use of micronized biomass silica-GGBS as agro-industrial by-products for the production of a sustainable high-strength geopolymer concrete. Case Studies in Construction Materials, 18: e01782.

https://doi.org/10.1016/j.cscm.2022.e01782
[20] Nageswari, N., Divahar, R., Sangeetha, S.P., Raj, P.A., Kesavan, G. (2024). Empirical predictions for the mechanical properties of nano-biomass silica with chemical and bio-admixture concrete. Silicon, 16(5): 2081-2101. https://doi.org/10.1007/s12633-023-02817-5
[21] Raju, G.K., Nagaraju, T.V., Jagadeep, K., Rao, M.V., Varma, V.C. (2023). Waste-to-energy agricultural wastes in development of sustainable geopolymer concrete. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2023.05.481
[22] Sankaranarayanan, R., Vivekanandan, G. (2023). Study on mechanical and durability characteristics of sustainable geopolymer concrete. International Journal for Research in Applied Science & Engineering Technology, 11(3): 717-725. https://doi.org/10.22214/ijraset.2023.49473
[23] Vediyappan, S., Chinnaraj, P.K., Hanumantraya, B.B., Subramanian, S.K. (2021). An experimental investigation on geopolymer concrete utilising micronized biomass silica and GGBS. KSCE Journal of Civil Engineering, 25: 2134-2142. https://doi.org/10.1007/s12205-021-1477-8
[24] Suda, V.R., Sutradhar, R. (2021). Strength characteristics of micronized silica concrete with polyester fibres. Materials Today: Proceedings, 38: 3392-3396. https://doi.org/10.1016/j.matpr.2020.10.569
[25] Agarwal, A., Bhusnur, S., Chaudhary, K., Priya, T.S. (2020). Experimental investigation on bacterial concrete with micronized biomass silica. Materials Today: Proceedings, 22: 2475-2481. https://doi.org/10.1016/j.matpr.2020.03.375
[26] Priya, T.S., Ramesh, N., Agarwal, A., Bhusnur, S., Chaudhary, K. (2019). Strength and durability characteristics of concrete made by micronized biomass silica and Bacteria-Bacillus sphaericus. Construction and Building Materials, 226: 827-838. https://doi.org/10.1016/j.conbuildmat.2019.07.172
[27] Sutradhar, R., Suda, V.R. (2020). Experimental investigation on optimization of micronized biomass silica for the strength characteristics of recycled aggregate concrete. Materials Today: Proceedings, 27: 1331-1336. https://doi.org/10.1016/j.matpr.2020.02.609
[28] Ambily, P.S., Ravisankar, K., Umarani, C., Kumar, S.S. (2015). Influence of micronised biomass silica on the workability and strength of alkali activated slag concrete. Journal of Scientific & Industrial Research, 74(2): 98-101.
[29] Suraya Hani, A., Rahman, I.A., Saman, H.M. (2015). Enhancing the performance of recycled aggregate concrete using micronized biomass silica. In Proceedings of the International Civil and Infrastructure Engineering Conference 2014 (InCIEC 2014), pp. 65-77. https://doi.org/10.1007/978-981-287-290-6_6
[30] Adnan, S.H., Rahman, I.A., Lee, Y.L., Yusof, H. (2009). Compressive strength and water permeability performance of micronised biomass silica concrete. International Journal of Integrated Engineering, 1(2): 103-109.
[31] Prameetthaa, J., Bharatkumar, B.H., Iyer, N.R. (2015). Investigation on micronized biomass silica as a sustainable material. Cement and Concrete Composites, 60: 25-33. https://doi.org/10.1016/j.cemconcomp.2015.04.004
[32] IS 12269-2013. (2013). Ordinary Portland Cement, 53 Grade-Specifications. Bureau of Indian Standards, New Delhi, India.
[33] IS 383-2016. (2016). Specification for Coarse and Fine Aggregate from Natural Sources for Concrete. Bureau of Indian Standards, New Delhi, India.
[34] IS 10262-2009. (2016). Recommended Guidelines for Concrete Mix Design. Bureau of Indian Standards, New Delhi, India.
[35] IS 516-1959. (1959). Methods of Tests for Strength of Concrete. Bureau of Indian Standards, New Delhi, India.
[36] IS 5816-1999. (1999). Method of Test for Splitting Tensile Strength of Concrete. Bureau of Indian Standards, New Delhi, India.
[37] IS 1199-2018. (2018). Methods of sampling and analysis of concrete. Bureau of Indian Standards, New Delhi, India.
[38] Hani, A.S., Lee, Y.L., Ismail, A.R., Hamidah, M.S., Hanita, Y. (2010). Micronised biomass silica as cement replacement material in concrete. Journal of Engineering and Technology (JET), 1: 15-22.
[39] Adnan, S.H., Rahman, I.A., Saman, H.M., Riza, F.V. (2012). Pozzolanic properties of micronized biomass silica in enhancing compressive strength and water permeability of concrete. Modern Applied Science, 6(11): 1-8. https://doi.org/10.5539/mas.v6n11p1
[40] Adnan, S.H., Rahman, I.A., Loon, L.Y. (2010). Performance of recycled aggregate concrete containing micronized biomass silica. International Journal of Sustainable Construction Engineering & Technology, 1(2): 1-10.
[41] Concrete, A.B., Rathanasalam, V.S., Hithani, B., Rajendra, M.B., Raikhola, A.S., Bisalahalli, A. (2024). Brief review on cotton plant stalk ash-based concrete. In Recent Advances in Building Materials and Technologies, pp. 271-281. https://doi.org/10.1007/978-981-99-9458-8_25