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Source-Based Variability in the Properties of Sugarcane Bagasse Ash: A Comparative Study

N.S.Ajeeshkumar[1*], K.L. Radhika[2]

[1,2]Department of Civil Engineering, University College of Engineering, Osmania University, Hyderabad, Telangana, INDIA

ABSTRACT: Sugarcane bagasse ash (SCBA) is produced when sugarcane bagasse is burnt in sugar mills. Its properties can differ depending on the source, which may affect its use as a supplementary cementitious material. In this study, raw SCBA collected from three sugar mills in Telangana, India, was characterized using X-ray fluorescence (XRF), X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), and field-emission scanning electron microscopy (FESEM). The XRF results showed that silica (SiO_2) was the major oxide in all three samples, with contents of 62.57%, 66.72%, and 56.36% in Samples A, B, and C, respectively. The combined content of SiO_2, Al_2O_3, and Fe_2O_3 ranged from 59.73% to 70.02%. Loss on ignition (LOI) also varied between the samples, from 11.68% to 25.90%. The XRD patterns showed quartz, cristobalite, and tridymite, along with a noncrystalline fraction. FTIR was used to examine the bonding characteristics of the ash. The FESEM images showed differences in particle morphology, with irregular, fibrous, and porous features. Among the three samples, Sample B had the highest silica content and the lowest LOI. The results show that the characteristics of raw SCBA vary between sources. Therefore, its potential use in cementitious materials needs to be assessed by considering its chemical composition, mineralogical characteristics, and particle morphology. Further testing is required to determine its pozzolanic reactivity.

1. INTRODUCTION

The production of Portland cement releases a considerable amount of carbon dioxide, mainly during clinker production and the energy-intensive manufacturing process[1]. With the growing demand for cement, researchers have been investigating materials that can partially replace Portland cement in construction. Industrial and agricultural wastes are among the materials considered for this purpose. Their use can reduce the amount of cement required and provide an alternative to conventional waste disposal [2,3]. However, their suitability for cement-based materials depends on their composition and other material characteristics.

India produced about 454.8 million tonnes of sugarcane in 2024–25, generating nearly 136 million tonnes of bagasse[4]. Sugarcane bagasse ash (SCBA) is generated when sugarcane bagasse is burnt as a fuel in sugar mills. Bagasse supplies part of the energy required for sugar production, leaving ash as a residue. This ash contains silica, which may contribute to pozzolanic reactions when it is present in a reactive form[5]. For this reason, SCBA has been investigated as a supplementary cementitious material (SCM). Its properties are not the same in all cases.

Combustion conditions, residual carbon content, and the nature of the silica present can influence the quality of the ash and its potential use in cementitious materials [6].

The properties of SCBA vary with the source of bagasse and the operating conditions of the sugar mill. Incomplete combustion can leave unburnt fibrous particles and residual carbon in the ash. The temperature during combustion can also affect the formation of crystalline silica phases. These differences may influence the potential reactivity of SCBA. A high total silica content, therefore, does not necessarily indicate that the ash will perform well as an SCM. Its chemical composition needs to be considered along with its mineralogical characteristics and particle morphology[7].

Previous studies have examined SCBA for use in cement and concrete, including its chemical composition, silica content, and pozzolanic performance [8-11]. Quartz and cristobalite have been reported as crystalline phases in SCBA, along with a non-crystalline fraction. The proportions of these phases can vary with the combustion conditions and any subsequent processing[12]. Different characterization techniques provide information on different aspects of the ash. X-ray fluorescence (XRF) is used to determine its chemical composition, while X-ray diffraction (XRD) identifies the crystalline phases. Fourier transform infrared

spectroscopy (FTIR) provides information on characteristic vibrational bands, and field-emission scanning electron microscopy (FESEM) allows the particle morphology and surface features to be examined.

Although SCBA has been investigated in several studies, the properties of raw ash can differ between sugar mills[13-15]. These differences need to be understood before considering further processing or its use in cementitious materials. Examining the ash in its as-received condition provides a basis for comparing the materials without the effects of additional treatment. A comparison of samples from different sources can show how their chemical composition, mineralogical phases, infrared spectra, and particle morphology differ.

In the present study, raw SCBA collected from three sugar mills in Telangana, India, was characterized and compared. The samples were examined in their as-received condition using XRF, XRD, FTIR, and FESEM. XRF was used to determine the chemical composition, with the results compared against those of the cement. XRD was used to identify the principal crystalline phases, while FTIR was used to examine the characteristic vibrational bands. FESEM observations were used to compare particle shape, surface texture, and other morphological features. The aim was to assess the differences among the three raw SCBA samples and discuss their potential for use as supplementary cementitious materials based on the characterization results.

2. MATERIALS AND METHODS

2.1 Materials

Raw sugarcane bagasse ash (SCBA) samples were collected from three sugar mills in Telangana, India. The samples were designated A-RS, B-RS, and C-RS, corresponding to Sources A, B, and C, respectively. They were tested in their raw condition, without additional sieving, grinding, or thermal treatment. The appearance of the three samples is shown in Fig. 1.

Ordinary Portland cement (OPC) was used as a reference material for comparison of the chemical composition [16]. The compositions of the cement and SCBA samples are given in Table 1. The ash samples were characterised using X-ray fluorescence (XRF), X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), and field-emission scanning electron microscopy (FESEM).

2.2 Chemical Composition

The chemical composition of the cement and SCBA samples was determined using X-ray fluorescence (XRF). A Rigaku NEX DE spectrometer was used for the analysis under FP_Powder application conditions. Measurements were carried out in a helium atmosphere using the Low-Z and Mid-Z modes. The oxide contents were compared to identify differences in the chemical composition of the three SCBA samples and the reference cement. The results are presented in Table 1.

2.3 Mineralogical Analysis

X-ray diffraction (XRD) was used to identify the crystalline phases present in the raw SCBA samples. The analysis was performed using a Bruker D2-Phaser diffractometer with monochromatic Cu-Kα_1 radiation at 30 kV and 10 mA. The samples were scanned over a 2θ range of 10–80° at a rate of 1.5°/min. The diffraction peaks were compared with standard patterns from the Joint Committee on Powder Diffraction Standards–International Centre for Diffraction Data (JCPDS–ICDD) database to identify the crystalline phases. Rietveld refinement was used for phase identification and quantification. The XRD patterns of Samples A-RS, B-RS, and C-RS are presented in Fig. 2.



Figure 1. Visual Appearance of Raw Sugarcane Bagasse Ash (SCBA)

2.4 Fourier Transform Infrared Spectroscopy(FTIR)

FTIR was used to examine the characteristic absorption bands of the SCBA samples. The measurements were carried out using a Vertex 70 spectrometer (Bruker Optik GmbH, Germany). The spectra were examined for bands associated with silica-containing phases and other functional groups. The results were considered along with the XRD patterns to compare the characteristics of the three samples. The FTIR spectra are shown in Fig. 3.

2.5 Microstructural Analysis

Field-emission scanning electron microscopy (FESEM) was used to examine the surface features and morphology of the raw SCBA particles. The images were compared to identify differences in particle shape, surface texture, and the presence of fibrous, irregular, or porous structures. These observations were used alongside the chemical and mineralogical results to compare the characteristics of the three raw ashes. The FESEM micrographs are presented in Fig. 4.

3. RESULTS AND DISCUSSION

3.1 Chemical Composition

The chemical compositions of the cement and raw SCBA samples are given in Table 1. SiO_2 was the major oxide in all three ashes, with contents of 62.57%, 66.72%, and 56.36% in Samples A, B, and C, respectively. Sample B had the highest silica content, while Sample C had the lowest. This difference shows that the chemical composition of the ash varied among the three sugar mills.

The Al_2O_3 and Fe_2O_3 contents were much lower than the SiO_2 content. The combined content of SiO_2, Al_2O_3, and Fe_2O_3 was 67.43% for Sample A, 70.02% for Sample B, and 59.73% for Sample C. Among the three samples, only Sample B reached the 70% combined oxide requirement specified for Class N pozzolans in ASTM C618. Samples A and C were below this value. This comparison is based on chemical composition alone; it does not establish whether the ashes meet all the requirements for use as supplementary cementitious materials.

The CaO content ranged from 3.83% to 4.82%, while K_2O ranged from 3.72% to 5.20%. Sample B contained 5.20% K_2O, the highest value among the three samples. These results show that, although silica was the major oxide, the ashes also contained appreciable amounts of other oxides. The differences in their proportions may reflect variations in the source material and combustion conditions.

The loss on ignition (LOI) also varied considerably. Samples A, B, and C had LOI values of 16.71%, 11.68%, and 25.90%, respectively. Sample C had the highest value, whereas Sample B had the lowest. A higher LOI may indicate a greater amount of residual unburnt carbon and other volatile constituents, although LOI alone cannot identify their individual contributions. Sample B therefore had the more favourable combination of silica content and LOI among the three raw ashes. Further assessment is still needed to determine whether this difference translates into better pozzolanic performance.

Table 1. Chemical Composition of Cement and Raw SCBA Samples

Chemical Composition (%)	Cement	A-RS	B-RS	C-RS
SiO_2	19.65	62.57	66.72	56.36
Al_2O_3	5	3.19	3.2	2.7
Fe_2O_3	4.82	1.57	1.2	1.27
CaO	63.45	4.82	4.8	3.83
K_2O	0.28	4.57	5.2	3.72
MgO	1.25	1.67	1.2	0.76
Na_2O	0.26	0.44	0.6	0.72
P2O5	–	1.85	2.12	1.91
SO_3	2.9	2.37	2.91	2.62
TiO_2		0.24	0.37	0.21
LOI	2.29	16.71	11.68	25.9
$SiO_2 + Al_2O_3 + Fe_2O_3$	29.47	67.43	70.02	59.73

The XRD patterns of the raw SCBA samples are presented in Fig. 2. The patterns show the presence of crystalline silica phases, including quartz, cristobalite, and tridymite. These phases indicate that a portion of the silica in the ashes exists in crystalline form. Their relative occurrence and intensity provide information about differences in the mineralogical characteristics of the samples.

In addition to the distinct diffraction peaks, a broad hump extending approximately from 20° to 40° (2θ) was observed in the XRD patterns. This feature indicates the presence of a noncrystalline fraction in the ashes. The combined content of amorphous and unidentified phases, determined using the external standard method, ranged from 53% to 66%. This fraction should not be interpreted entirely as amorphous silica because it may also include other non-crystalline constituents, including residual carbonaceous material.

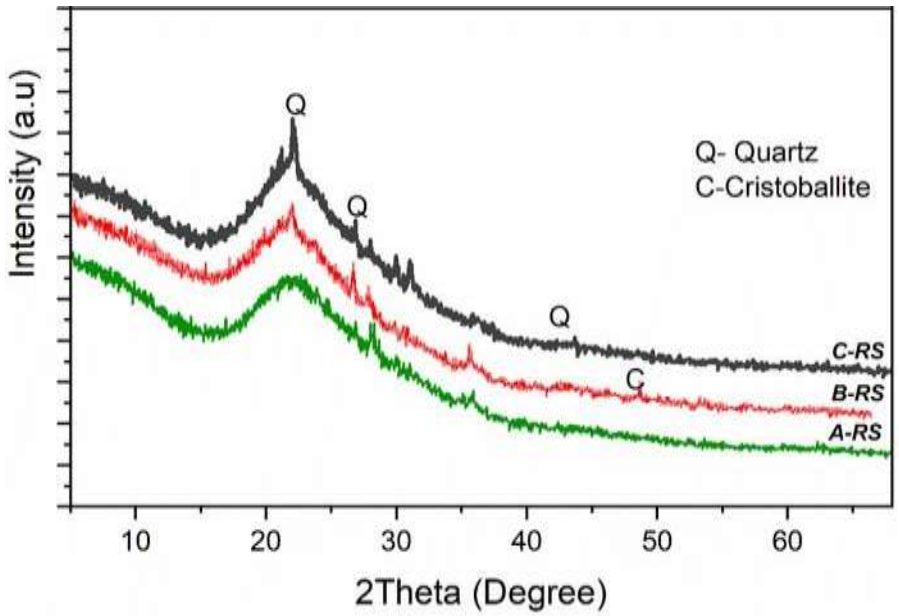


Figure 2. XRD Image of SCBA Samples

The coexistence of crystalline silica phases and a non-crystalline fraction is important when assessing the potential use of SCBA as a supplementary cementitious material. Crystalline quartz and other ordered silica phases generally contribute less readily to pozzolanic reactions than reactive amorphous silica. However, the presence of a broad XRD hump alone does not establish the amount or reactivity of amorphous silica. The mineralogical results therefore need to be considered together with the chemical composition and FTIR observations.

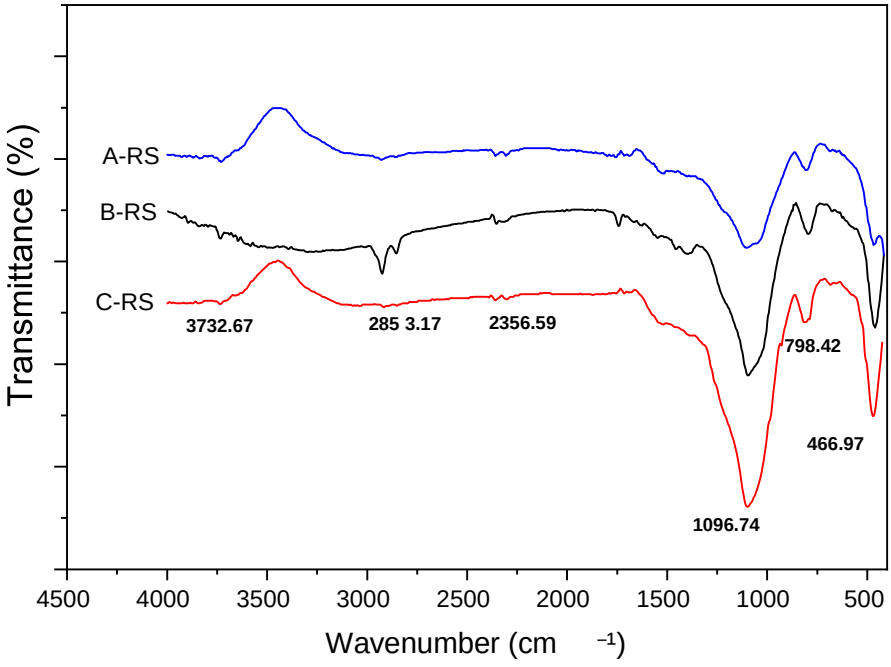


Figure 3. FTIR Images of SCBA sample

The differences in silica content identified by XRF do not necessarily correspond to differences in pozzolanic potential. The form in which silica occurs is also important. Therefore, the XRD results provide complementary information to the chemical analysis and help explain why ashes from different sources may show different behaviour in cementitious systems.

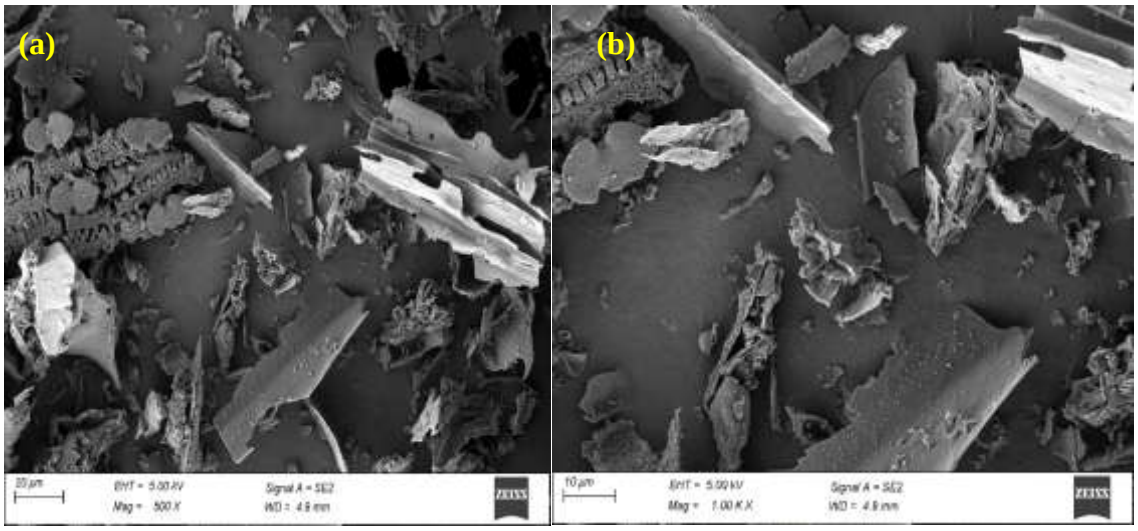


Figure 4. SEM Micrographs of SCBA sample

The FTIR spectra of the three raw SCBA samples are presented in Fig. 3. FTIR analysis was used to examine the characteristic vibrational bands associated with silica-containing phases and other functional groups present in the ashes. The positions, widths, and relative intensities of the absorption bands can provide information about the bonding environment of the constituent materials.

The interpretation of the silica-related bands should be considered alongside the XRD results. XRD identifies crystalline phases through their diffraction patterns, whereas FTIR provides information on the vibrational behaviour of chemical bonds. The two techniques therefore provide complementary information about the mineralogical and bonding characteristics of SCBA.

Differences in the positions or intensities of the absorption bands among Samples A, B, and C may reflect variations in their silica-related bonding environments and other constituents. However, the presence of a particular absorption band alone is not sufficient to quantify amorphous silica or establish pozzolanic reactivity. The FTIR results should therefore be interpreted together with the XRF and XRD findings.

The FESEM images of the raw SCBA samples are presented in Fig. 4. The micrographs show that the raw ashes contain particles with different shapes and surface characteristics. Irregular particles, fibrous structures, and porous features are present, indicating that the ashes are heterogeneous materials rather than uniform collections of mineral particles.

The observed morphology is consistent with the origin of SCBA as a residue from the combustion of sugarcane bagasse. Some particles retain features associated with the original fibrous material, while other particles appear more fragmented and irregular. Differences in particle morphology among the three samples may be related to variations in combustion conditions, boiler operation, and ash collection practices.

The porous and irregular structures observed in the raw ash may influence its interaction with water and cement particles. Such features can contribute to water absorption and affect particle packing when SCBA is incorporated into cementitious mixtures. The presence of fibrous particles also indicates that combustion did not completely remove all the original bagasse structure.

The FESEM observations complement the chemical and mineralogical results. Although XRF indicates that silica is the major oxide, the micrographs show that the raw ash contains particles with different morphologies. Consequently, the bulk chemical composition does not fully describe the physical characteristics of the material. The combined assessment of composition, mineralogical phases, bonding characteristics, and morphology provides a more complete description of the raw SCBA samples.

3.2 Comparative Assessment of the Raw SCBA Samples

The results from XRF, XRD, FTIR, and FESEM show that the characteristics of raw SCBA vary between the three sugar mills. Sample B had the highest SiO_2 content and the lowest LOI, while Sample C had the lowest SiO_2 content and the highest LOI. The combined SiO_2, Al_2O_3, and Fe_2O_3 content also differed, with Sample B reaching 70.02%.

The XRD results identified crystalline silica phases together with a non-crystalline fraction in the raw ashes. These findings show that total silica content alone cannot be used to assess the potential contribution of SCBA to cementitious reactions. The FTIR spectra provide additional information on the bonding characteristics, while FESEM reveals variations in particle morphology and the presence of fibrous and porous structures.

Taken together, the results demonstrate the importance of characterising SCBA before its use as a supplementary cementitious material. Sample B showed the most favourable combination of silica content and LOI among the three samples, based on the available chemical data. However, confirming its overall suitability requires consideration of the mineralogical and microstructural characteristics as well. The present characterisation provides a basis for comparing the raw ashes, but their actual pozzolanic performance cannot be established from these analyses alone.

4. CONCLUSION

This study compared the chemical composition, mineralogical phases, bonding characteristics, and microstructure of raw sugarcane bagasse ash (SCBA) collected from three sugar mills in Telangana, India. The main conclusions are as follows:

1. The chemical composition of SCBA varied between the three sources. SiO_2 was the major oxide, with contents ranging from 56.36% to 66.72%. The combined SiO_2, Al_2O_3, and Fe_2O_3 content varied from 59.73% to 70.02%, while LOI ranged from 11.68% to 25.90%.
2. XRD analysis identified quartz, cristobalite, and tridymite as crystalline silica phases in the raw ashes. A broad diffraction hump also indicated the presence of a non-crystalline fraction. However, the combined amorphous and unidentified phase content cannot be considered entirely as amorphous silica.
3. FTIR analysis provided complementary information on the bonding characteristics of the SCBA samples. The interpretation of the absorption bands alongside XRD helps to understand the silica-related features of the ashes.
4. FESEM observations showed variations in particle morphology, including irregular, fibrous, and porous structures. These features reflect the heterogeneous nature of raw SCBA and may influence its water demand and behaviour in cementitious mixtures.
5. Among the three samples, Sample B had the highest silica content (66.72%) and the lowest LOI (11.68%). Based on these chemical characteristics, it showed the most favourable composition among the samples examined. Nevertheless, the overall suitability of raw SCBA as a supplementary cementitious material requires further assessment of its pozzolanic reactivity and performance in cement-based systems.

REFERENCES

1) India Brand Equity Foundation, "Cement Industry in India." [Online]. Available: https://www.ibef.org/industry/cement-india. [Accessed: Jun. 30, 2026].
2) Global Cement and Concrete Association,Net CO2 emissions-Weighted average, 2024. https://gccassociation.org/sustainability-innovation/gnr-gcca-in-numbers/ [Accessed: Jun. 30, 2026].
3) International Energy Agency (IEA) and World Business Council for Sustainable Development (WBCSD), Technology Roadmap: Low-Carbon Transition in the Cement Industry. [Online]. Available: https://www.iea.org/reports/technology-roadmap-low-carbon-transition-in-the-cement-industry. [Accessed: Jun. 30, 2026].
4) "ISMA, Indian Sugar Mills Association," 2025.
5) G. C. Cordeiro, T. R. Barroso, and R. D. Toledo Filho, "Enhancement the Properties of Sugar Cane Bagasse Ash with High Carbon Content by a Controlled Re-calcination Process," KSCE Journal of Civil Engineering, vol. 22, no. 4, pp. 1250–1257, Apr. 2018, doi: 10.1007/s12205-017-0881-6.
6) N. Chusilp, C. Jaturapitakkul, and K. Kiattikomol, "Utilization of bagasse ash as a pozzolanic material in concrete," Constr Build Mater, vol. 23, no. 11, pp. 3352–3358, Nov. 2009, doi: 10.1016/j.conbuildmat.2009.06.030.
7) J. Paya , J. Monzo , M. V. Borrachero, L. Dí az-Pinzo n, and L. M. Ordo nez, "Sugar-cane bagasse ash (SBA): Studies on its properties for reusing in concrete production," in Journal of Chemical Technology and Biotechnology, 2002, pp. 321–325. doi: 10.1002/jctb.549.
8) V. Rí os-Parada, V. G. Jime nez-Quero, P. L. Valdez-Tamez, and P. Montes-Garcí a, "Characterization and use of an untreated Mexican sugarcane bagasse ash as supplementary material for the preparation of ternary concretes," Constr Build Mater, vol. 157, pp. 83–95, Dec. 2017, doi: 10.1016/j.conbuildmat.2017.09.060.
9) G. C. Cordeiro, P. V. Andrea o, and L. M. Tavares, "Pozzolanic properties of ultrafine sugar cane bagasse ash produced by controlled burning," Heliyon, vol. 5, no. 10, Oct. 2019, doi: 10.1016/j.heliyon.2019.e02566.

10) G. C. Cordeiro, R. D. Toledo Filho, L. M. Tavares, and E. M. R. Fairbairn, “Pozzolanic activity and filler effect of sugar cane bagasse ash in Portland cement and lime mortars,” CemConcr Compos, vol. 30, no. 5, pp. 410– 418, May 2008, doi: 10.1016/j.cemconcomp.2008.01.001.
11) N. Chusilp, C. Jaturapitakkul, and K. Kiattikomol, “Effects of LOI of ground bagasse ash on the compressive strength and sulfate resistance of mortars,” Constr Build Mater, vol. 23, no. 12, pp. 3523–3531, Dec. 2009, doi: 10.1016/j.conbuildmat.2009.06.046.
12) G. Chagas, R. Dias, T. Filho, L. M. E. de Moraes, R. Fairbairn, and S. Hempel, "Influence of particle size and specific surface area on the pozzolanic activity of residual rice husk ash," Cement and Concrete Composites, vol. 33, no. 5, pp. 529–534, 2011, doi: 10.1016/j.cemconcomp.2011.02.005.
13) K. Kiattikomol, C. Jaturapitakkul, S. Songpiriyakij, and S. Chutubtim, "A study of ground coarse fly ashes with different finenesses from various sources as pozzolanic materials," Cement and Concrete Composites, vol. 23, no. 4–5, pp. 335–343, 2001.
14) R. Mohan, G. Athira, A. K. Mali, A. Bahurudeen, and P. Nanthagopalan, "Systematic pretreatment process and optimization of sugarcane bagasse ash dosage for use in cement-based products," Journal of Materials in Civil Engineering, vol. 33, no. 8, pp. 1–10, 2021, doi: 10.1061/(ASCE)MT.1943-5533.0003650.
15) Y. Bayapureddy, K. Muniraj, and M. Reddy G. Mutukuru, "Enhancing material properties of agro-industrial waste sugarcane bagasse ash—Way towards sustainable development," Sustainable Futures, vol. 7, Art. no. 100154, 2024, doi: 10.1016/j.sftr.2024.100154.
16) Bureau of Indian Standards, IS 269:2015 — Ordinary Portland Cement — Specification, New Delhi, India, 2015.

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