International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 02 Issue: 09 September 2024
Page No: 2355 - 2362
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2024.0323

Durability Analysis of Untreated Sugarcane Bagasse Ash for Sustainable Concrete Production

Ahmed Minhajuddin[1], *Dr. Arijit Saha*[2]
[1] *Research Scholar, Department of Civil Engineering, GITAM (Deemed to be University), Hyderabad-502329, Telangana, India.*
[2] *Assistant Professor, Department of Civil Engineering, GITAM (Deemed to be University), Hyderabad-502329, Telangana, India.*
Emails: *ahmedminhajuddin.civil@gmail.com*[1], *asaha@gitam.edu*[2]

Abstract

Around the world, vast amounts of waste are generated from various agricultural activities. Of this large quantity, only a small portion is recycled, while the rest is often discarded in open areas. This paper explores the potential use of solid waste in concrete, specifically focusing on untreated sugarcane bagasse ash (Ut-SCBA) from the sugarcane industry. The experimental study conducted in this research investigates the durability of concrete mixes incorporating Ut-SCBA as a partial cement substitute at levels of 5%, 10%, 15%, 20%, and 25%. The durability of these blended mixes is assessed through water absorption, water permeability, the rapid chloride penetration test (RCPT), and the half-cell potentiometer test (HCP). The results demonstrate that concrete containing 15% Ut-SCBA as a cement substitute significantly improved durability properties compared to the control mix, attributed to enhanced pozzolanic activity. The results show improved water permeability and water absorption in the blended concrete, with the RCPT and HCP responses of the blended mix outperforming those of the control mix. Thus, Ut-SCBA proves to be a feasible, eco-friendly pozzolanic material for developing sustainable concrete.

Keywords: *Sustainable Concrete, Untreated Sugarcane Bagasse Ash, Durability Properties, Rapid Chloride Penetration Test, Half-Cell Potentiometer.*

1. Introduction

The increasing accumulation of agricultural by-products and waste presents a growing global challenge, particularly regarding their disposal. The rising volume of waste and the associated disposal issues are driving researchers to explore sustainable utilization methods. Meanwhile, the concrete industry significantly impacts the environment by generating a substantial carbon footprint, primarily through the extensive use of conventional materials like cement and sand (Siddique et al., 2018). For cost-effective concrete production, durability and sustainability are key, particularly in resisting harsh environmental conditions. Using waste materials in concrete not only addresses solid waste management concerns but also offers societal benefits, such as reducing landfill burden, protecting riverbeds from excessive sand excavation, and mitigating environmental issues associated with cement production (Jain et al., 2020). Numerous studies (Abdurrahman et al., 2022; Alex et al., 2016; Assiamah et al., 2022; Bahurudeen & Santhanam, 2015; Her et al., 2021; Matos et al., 2015) have explored the use of agricultural waste materials like sugarcane bagasse ash (SCBA), groundnut shell, oyster shell, sawdust, rice husk ash, and cork wastes as cement substitutes. This study explores the use of untreated sugarcane bagasse ash (Ut-SCBA) as a supplementary cementitious material (SCM). The high pozzolanic activity of SCBA is primarily due to the formation of large quantities of amorphous silica, which typically occurs when SCBA is calcined at temperatures ranging from 600°C to 700°C (Bahurudeen & Santhanam, 2015; Praveenkumar et al., 2020; Quedou et al., 2021). Only one study has reported on the durability of mortars containing "practically as received" SCBA. In this study, SCBA is sieved using a 75-µm ASTM mesh for just four minutes, but workability issues arise when 20% SCBA is added to the mortar. The authors referred to this ash as untreated sugarcane bagasse ash (Ut-SCBA) due to its low-energy post-treatment process (Franco-Luján et al., 2019). Limited studies exist on the durability performance of Ut-SCBA against aggressive deteriorating agents such as chlorides, sulfates, oxygen, and carbon dioxide. The chemical composition of agricultural waste materials, such as sugarcane bagasse ash (SCBA), varies depending on factors like geographical location, crop type, soil characteristics, and underground water (Quedou et al., 2021; Yogitha et al., 2020). Chemical analyses of T-SCBA using X-ray diffraction (XRD) and thermogravimetric analysis (TGA) reveal the consumption of portlandite, confirming its pozzolanic potential. XRD analysis also shows the presence of quartz and cristobalite in bagasse ash, along with an amorphous silica peak around 20-25° 2θ, in line with previous research findings (Berenguer et al., 2020). (Chusilp et al., 2009), investigated the performance of concrete incorporating T-SCBA for water permeability characteristics and reported a reduction in water penetration depth compared to the control concrete. Incorporating T-SCBA in concrete enhances resistance to chloride and gas penetration, with recent studies showing that the addition of materials like fly ash, silica fume, metakaolin, and T-SCBA reduces pores and hinders chloride diffusion through the pozzolanic reaction and the presence of aluminates. [1-5]

1.1.Research Significance

Untreated sugarcane bagasse ash (Ut-SCBA) offers a more cost-effective and environmentally friendly alternative to treated sugarcane bagasse ash (T-SCBA), as the treatment process requires energy-intensive steps like burning, fine sieving (<90µm) and grinding. This study evaluates the durability properties of Ut-SCBA, sourced from a high-efficiency co-generation boiler, as a partial cement replacement in concrete. The research focuses on the effects of Ut-SCBA on water absorption, water penetration, rapid chloride permeability test (RCPT), and half-cell potentiometer test, comparing the results with control samples to determine the optimal cement replacement percentage for achieving the target strength of M25-grade concrete. [6-10]

1.2.Raw Materials

This paper examines the partial replacement of cement with untreated sugarcane bagasse ash (Ut-SCBA) in various proportions. It describes the raw materials used and the specimen preparation process. Ordinary Portland cement (OPC-53 grade), adhering to Indian standards (BIS: 12269 (2013)), is utilized, with its physical properties evaluated per IS guidelines (BIS: 4031 (Part 11) (1988)) as shown in Table 1. Sugarcane bagasse is sourced from the Ganpati sugarcane industry in Sangareddy, where it is burned to generate steam during sugar processing. The resulting ash, containing both fine and coarse particles, is collected, dried, screened to a particle size of less than 150 µm, and then oven-dried at 110°C for 24 hours to eliminate moisture. This processed ash is used in producing blended concrete, with its physical properties listed in Table 1 per IS specifications (BIS 1727 (1967)). River sand, obtained locally, conforms to IS 4.75 mm sieve standards, and crushed stones are graded into 20mm and 10mm sizes, with their physical properties listed in Table 2, per Indian Standard specification (BIS: 383 (1970)). ECMAPLAST 104 HS, a superplasticizer based on sulphonated naphthalene formaldehyde (SNF), with a specific gravity of 1.26 ± 0.02 @ 27°C, is used to maintain the desired slump with a dosage of 1% by the weight of cementitious content in each mix. The study designs M25 grade concrete according to BIS: 10262 (2019) guidelines, with and without Ut-SCBA as a partial cement replacement. Six different mixtures are prepared, maintaining a constant water-cement ratio of 0.5. The chemical composition of raw materials used in the study is illustrated in Table 3. The mix without Ut-SCBA is designated as MIX0, while cement is substituted with Ut-SCBA at 5%, 10%, 15%, 20%, and 25%, corresponding to mixes MIX05, MIX10, MIX15, MIX20, and MIX25, respectively. The mix proportions for these concrete mixtures are provided in Table 4. [11-15]

Table 1 Physical Characteristics of Cement & Ut-SCBA

Experiments	Test Results	Specification as per IS 12269:2013
Cement 53 G		
Standard Consistency (%)	29	-
Initial Setting Time	134 Min	30 Min
Final Setting Time	178 Min	600 Max
Soundness (mm)	1.02	10 Max.
Specific Gravity	3.15	-
Fineness Modulus	309	370 Max.
Colour	Grey	-
Ut-SCBA		
Specific Gravity	2.05	IS: 1727
Fineness Modulus	30	IS: 1727
Density (kg/m^3)	256	-
Colour	Light Grey	-
Mean particle size	< 0.15 mm	-

Table 2 Physical Properties of Aggregates

Experiments	Test Results			
	Fine aggregate		Coarse aggregate	
	IS 4.75 mm sieve retained		20mm	10mm
Specific Gravity	2.538		2.658	2.634
Free Moisture Content (%)	5.93		Nil	Nil
Water Absorption (%)	0.903		0.235	0.294
Bulk Density (kg/m^3)	Loose	1422	1469	1427
	Compact	1585	1549	1508
Fineness Modulus	3.04		-	-

2. Methodology

Various experimental investigations have been conducted to evaluate the durability properties of concrete incorporating untreated sugarcane bagasse ash (Ut-SCBA) as a cementitious material. The durability properties such as water absorption test, performed on 150 mm x 150 mm x 150 mm cube samples after 28 days of water curing, follows BIS 1124 (1974) standards. Samples are dried, weighed (W1), then oven-dried at 100–110°C for 24 hours, cooled to room temperature, and weighed again (W2). Water absorption is calculated from three readings taken at different intervals for each mixture. Water penetration tests, per BIS: 516 (Part 2/Sec 1) (2018), involve applying 500 ± 50 kPa of water pressure to concrete cubes cured for 28 days, for 72 ± 2 hours. Afterward, the cubes are split, and the water penetration depth is measured. The average depth from three specimens is recorded. The RCPT is crucial for assessing concrete durability. According to ASTM C 1202-12, a 50 mm thick, 100 mm diameter disc is extracted from the center of cylindrical concrete specimens cured for 28, 56, and 90 days. Six discs are tested at a time by placing them between a positive cell containing 0.3 N NaOH and a negative cell with 3.0% NaCl. A charge of 60 ± 0.1 V is applied, and observations are recorded every 30 minutes for 6 hours. The total charge passed is calculated, and the average of three values for each sample is documented. To assess corrosion resistance per BIS 516 (Part 5/Sec 2) (2021), a 150 mm diameter, 300 mm height cylindrical specimen with a 10 mm steel bar centered and covered with 40 mm concrete is used. After 28 days of curing, half-cell potentials are measured using a voltmeter connected to the reinforcement and a copper-copper sulfate reference electrode on the concrete surface. The recorded potential difference helps determine the corrosion rate, following BIS guidelines. [16-20]

3. Results and Discussion

3.1. Durability Properties

3.1.1. Water Absorption Test

Compared to conventional concrete, all Ut-SCBA mix samples show a marked decrease in water absorption, as illustrated in Fig. 1. The reduction in water absorption is 10.08%, 13.25%, 19.02%, 25.93%, and 28.53% for MIX05 to MIX25, respectively, relative to the control mix (MIX0). This reduction is attributed to the formation of C-S-H gel, which increases concrete density and reduces porosity. The lowest water absorption at 25%

replacement may result from improved pore connectivity, limiting water permeability. This result aligns with findings by (Bayapureddy et al., 2020) on the hygroscopic nature and fineness of T-SCBA. [21-25]

Table 3 **Chemical Composition of Raw Materials**

S.No.	Oxides	Cement	Ut-SCBA	Fine Aggregate
1	CaO	72.488 %	6.139 %	4.406 %
2	SiO_2	14.291 %	75.844 %	75.999 %
3	Fe_2O_3	6.148 %	4.822 %	2.039 %
4	SO_3	2.547 %	1.562 %	0.209 %
5	Al_2O_3	2.450 %	3.104 %	10.145 %
6	BaO	0.811 %	-	0.117 %
7	TiO_2	0.639 %	0.775 %	0.339 %
8	K_2O	0.418 %	6.411 %	6.591 %
9	MnO	0.106 %	0.199 %	0.034 %
10	SrO	0.073 %	0.024 %	0.031 %
11	ZrO_2	0.016 %	-	0.029 %
12	CuO	0.013 %	0.034 %	0.012 %
13	P_2O_5	-	0.975 %	-
14	ZnO	-	0.054 %	-
15	V_2O_5	-	0.040 %	-
16	Rb_2O	-	0.011 %	0.037%
17	Br	-	0.006 %	-
18	ThO_2	-	-	0.010 %
19	Y_2O_3	-	-	0.002 %

Table 4 **Mix Proportion of Materials**

Mix ID	Ut-SCBA (%)	OPC (kg)	Ut-SCBA (kg)	F.A (kg)	C.A (kg)		Water (kg)	Admixtures (kg)
					20mm	10mm		
MIX0	00	330	-	780	660	450	165	3.3
MIX05	05	313.5	16.5	780	660	450	165	3.3
MIX10	10	297	33	780	660	450	165	3.3
MIX15	15	280.5	49.5	780	660	450	165	3.3
MIX20	20	264	66	780	660	450	165	3.3
MIX25	25	247.5	82.5	780	660	450	165	3.3

3.1.2. Water Penetration Test

The water penetration depth of both the control mix and Ut-SCBA mix specimens after 28 days of curing is shown in Fig. 2. The control mix (MIX0) has a penetration depth of 23.5 mm, while Ut-SCBA mixes (MIX05 to MIX25) show a progressive reduction in penetration by 19.15%, 31.91%, 27.66%, 23.40%, and 14.89%, respectively, compared to MIX0. The lowest penetration depth is observed at 10% Ut-

SCBA. This reduction is attributed to the filler effect of Ut-SCBA particles, which fill voids and limit water penetration, as well as the pozzolanic reaction and pore refinement that convert calcium hydroxide into additional C-S-H gel (Deepika et al., 2017; Praveenkumar et al., 2020). Overall, Ut-SCBA significantly reduces penetration and enhances mix density. [26-30]

3.1.3. Rapid Chloride Permeability Test (RCPT)

The rapid chloride permeability test results for Ut-SCBA blended concrete specimens are presented in Fig. 3. The Ut-SCBA specimens showed significantly higher resistance to chloride ion penetration compared to the control specimens at 28, 56, and 90 days. At 28 days, the total charge passed decreased by 14.95%, 24.13%, 34.40%, 61.01%, and 71.08% for MIX05 to MIX25, respectively, compared to the control mix (MIX0). According to ASTM C1202-12, this reduction categorizes the Ut-SCBA blended concrete as "very low" in chloride ion permeability. The significant reduction in charge passed is attributed to the pozzolanic reaction between Ut-SCBA elements like SiO2, Al2O3, and Fe2O3, which lowers pore conductivity and enhances pore structure (Ahmad et al., 2021; Bahurudeen & Santhanam, 2015; Chindaprasirt et al., 2020; Praveenkumar & Sankarasubramanian, 2021). Ut-SCBA concrete has more hydration products and a larger surface area for reaction products, leading to greater chloride adsorption (Chindaprasirt et al., 2020; Kroehong et al., 2016; Thomas et al., 2012).

3.1.4. Half-Cell Potentiometer Test (HCP)

Fig. 4 shows the results of the HCP test for corrosion rate at 28 days, comparing the control mix and Ut-SCBA blended mixes. The results reveal that samples MIX05, MIX10, and MIX15 with Ut-SCBA exhibit corrosion potentials 7.3%, 4.89%, and 3.25% lower, respectively, than the control mix (MIX0). The high SiO2 content in Ut-SCBA promotes additional C-S-H gel formation during hydration, creating a denser, more compact cement matrix that enhances protection around the steel reinforcement. This increased density and reduced permeability limit water ingress, improving steel passivation and corrosion resistance. The lower corrosion potential at early ages is due to effective hydration and pozzolanic reactions (Garrett, 2019). However, when Ut-SCBA substitution exceeds 15%, changes in hydration and matrix characteristics, such as increased porosity or reduced essential compounds, can reduce steel passivation effectiveness, leading to a higher corrosion potential compared to the control mix (MIX0).

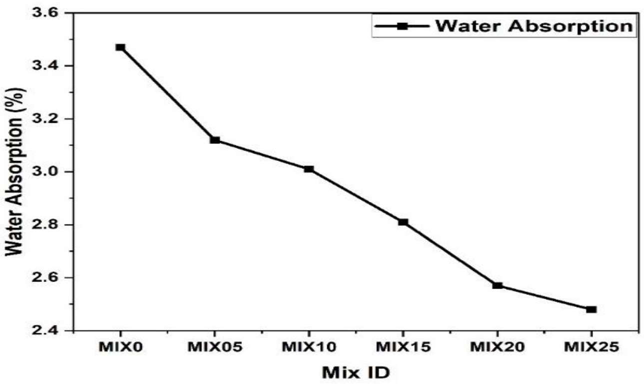

Figure 1 **Water Absorption at 28 Days of Curing**

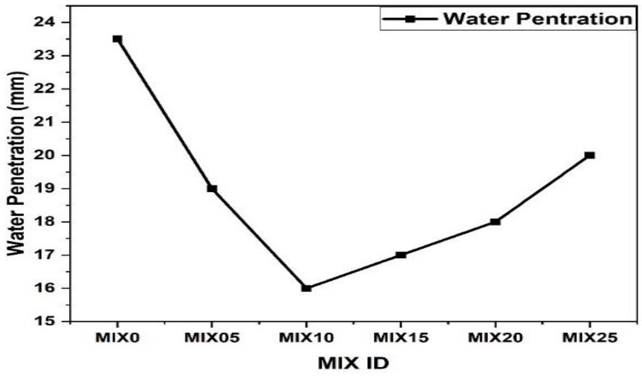

Figure 2 **Water Penetration at 28 Days of Curing**

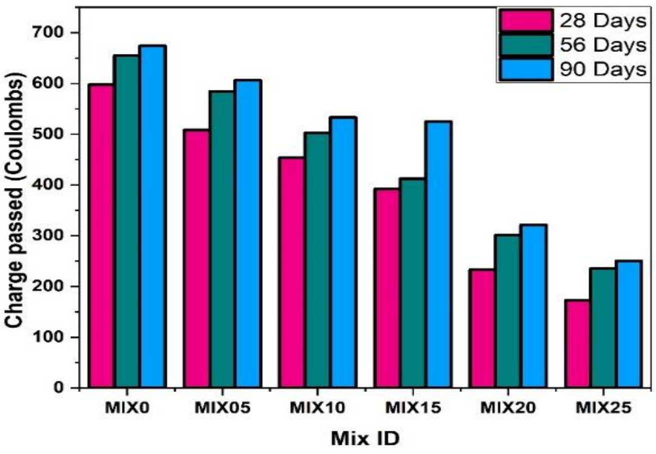

Figure 3. **RCPT at 28, 56 and 90 Days of Curing**

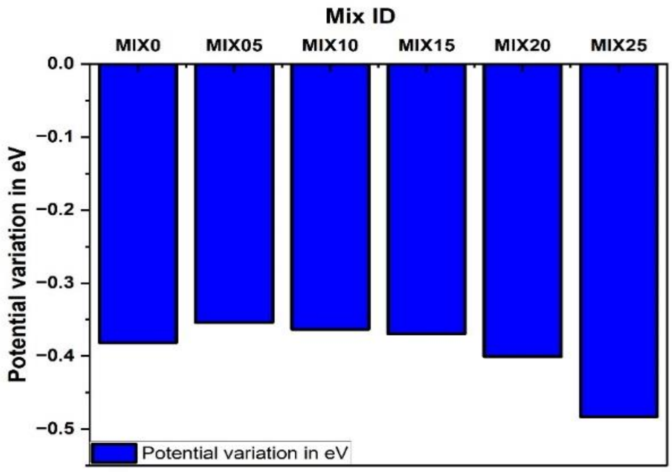

Figure 4 **Half-Cell Potentiometer Test at 28 Days of Curing**

Conclusion

The study shows that using Ut-SCBA as a supplementary cementitious material (SCM) can effectively contribute to sustainable concrete practices. It evaluates the potential of replacing cement with Ut-SCBA in amounts ranging from 5% to 25% on concrete's durability properties.

- The durability of Ut-SCBA blend concrete is assessed using water absorption tests. A notable decrease in water absorption is observed at 25% substitution, attributed to the formation of additional C-S-H gel, which enhances concrete densification.
- The fine nature of Ut-SCBA leads to reduced water penetration values compared to the control mix, particularly at up to 10% substitution.
- RCPT results show that concrete blends with up to 25% Ut-SCBA are classified as ‘very low chloride ion penetrability’ according to ASTM C1202-12.
- The HCP test results show better corrosion resistance with up to 15% Ut-SCBA replacement compared to the control mix. This is due to reduced permeability from pozzolanic reactions and additional C-S-H gel formation, which strengthens the concrete.
- The experiments show that substituting up to 15% of cement with untreated sugarcane bagasse ash (Ut-SCBA) is optimal. This substitution improves both the sustainability and economic efficiency of the concrete.

Acknowledgements

The authors thank Ganapati Sugar Limited, Sangareddy, India, for supplying the sugarcane bagasse ash and UltraTech Cement for providing the OPC 53 grade cement used in this study.

References

[1]. S. Siddique, S. Shrivastava, and S. Chaudhary, “Durability properties of bone china ceramic fine aggregate concrete,” Construction and Building Materials, vol. 173, pp. 323–331, Jun. 2018, doi: 10.1016/j.conbuildmat.2018.03.262.
[2]. K. L. Jain, G. Sancheti, and L. K. Gupta, “Durability performance of waste granite and glass powder added concrete,” Construction and Building Materials, vol. 252, p. 119075, Aug. 2020, doi: 10.1016/j.conbuildmat.2020.119075.
[3]. S. Abdurrahman, B. Olawumi, Y. Idris, A. Mode, and M. Nda, “Compressive Strength and Optimization of Concrete Produced by Replacing Cement with Coconut Shell Ash (CSA) and Groundnut Shell Ash (GSA),” Saudi Journal of Civil Engineering, vol. 6, pp. 207–214, Aug. 2022, doi: 10.36348/sjce.2022.v06i08.002.
[4]. J. Alex, J. Dhanalakshmi, and B. Ambedkar, “Experimental investigation on rice husk ash as cement replacement on concrete production,” Construction and Building Materials, vol. 127, pp. 353–362, Nov. 2016, doi: 10.1016/j.conbuildmat.2016.09.150.
[5]. S. Assiamah, S. Agyeman, K. Adinkrah-Appiah, and H. Danso, “Utilization of sawdust ash as cement replacement for landcrete interlocking blocks production and mortarless construction,” Case Studies in Construction Materials, vol. 16, p. e00945, Jun. 2022, doi: 10.1016/j.cscm.2022.e00945.
[6]. A. Bahurudeen and M. Santhanam, “Influence of different processing methods on the pozzolanic performance of sugarcane bagasse ash,” Cement and Concrete Composites, vol. 56, pp. 32–45, Feb. 2015, doi: 10.1016/j.cemconcomp.2014.11.002.
[7]. S. Her, T. Park, E. Zalnezhad, and S. Bae, “Synthesis and characterization of cement

clinker using recycled pulverized oyster and scallop shell as limestone substitutes," Journal of Cleaner Production, vol. 278, p. 123987, Jan. 2021, doi: 10.1016/j.jclepro.2020.123987.

[8]. A. M. Matos, S. Nunes, and J. Sousa-Coutinho, "Cork waste in cement based materials," Materials & Design, vol. 85, pp. 230–239, Nov. 2015, doi: 10.1016/j.matdes.2015.06.082.

[9]. S. Praveenkumar, G. Sankarasubramanian, and S. Sindhu, "Strength, permeability and microstructure characterization of pulverized bagasse ash in cement mortars," Construction and Building Materials, vol. 238, p. 117691, Mar. 2020, doi: 10.1016/j.conbuildmat.2019.117691.

[10]. P. G. Quedou, E. Wirquin, and C. Bokhoree, "Sustainable concrete: Potency of sugarcane bagasse ash as a cementitious material in the construction industry," Case Studies in Construction Materials, vol. 14, p. e00545, Jun. 2021, doi: 10.1016/j.cscm.2021.e00545.

[11]. V. A. Franco-Luján, M. A. Maldonado-García, J. M. Mendoza-Rangel, and P. Montes-García, "Chloride-induced reinforcing steel corrosion in ternary concretes containing fly ash and untreated sugarcane bagasse ash," Construction and Building Materials, vol. 198, pp. 608–618, Feb. 2019, doi: 10.1016/j.conbuildmat.2018.12.004.

[12]. B. Yogitha, M. Karthikeyan, and M. G. Muni Reddy, "Progress of sugarcane bagasse ash applications in production of Eco-Friendly concrete - Review," Materials Today: Proceedings, vol. 33, pp. 695–699, 2020, doi: 10.1016/j.matpr.2020.05.814.

[13]. R. A. Berenguer, A. P. B. Capraro, M. H. F. De Medeiros, A. M. P. Carneiro, and R. A. De Oliveira, "Sugar cane bagasse ash as a partial substitute of Portland cement: Effect on mechanical properties and emission of carbon dioxide," Journal of Environmental Chemical Engineering, vol. 8, no. 2, p. 103655, Apr. 2020, doi: 10.1016/j.jece.2020.103655.

[14]. N. Chusilp, C. Jaturapitakkul, and K. Kiattikomol, "Utilization of bagasse ash as a pozzolanic material in concrete," Construction and Building Materials, vol. 23, no. 11, pp. 3352–3358, Nov. 2009, doi: 10.1016/j.conbuildmat.2009.06.030.

[15]. Y. Bayapureddy, K. Muniraj, and M. R. G. Mutukuru, "Sugarcane bagasse ash as supplementary cementitious material in cement composites: strength, durability, and microstructural analysis," J. Korean Ceram. Soc., vol. 57, no. 5, pp. 513–519, Sep. 2020, doi: 10.1007/s43207-020-00055-8.

[16]. S. Deepika, G. Anand, A. Bahurudeen, and M. Santhanam, "Construction Products with Sugarcane Bagasse Ash Binder," J. Mater. Civ. Eng., vol. 29, no. 10, p. 04017189, Oct. 2017, doi: 10.1061/(ASCE)MT.1943-5533.0001999.

[17]. W. Ahmad, A. Ahmad, K. A. Ostrowski, F. Aslam, P. Joyklad, and P. Zajdel, "Sustainable approach of using sugarcane bagasse ash in cement-based composites: A systematic review," Case Studies in Construction Materials, vol. 15, p. e00698, Dec. 2021, doi: 10.1016/j.cscm.2021.e00698.

[18]. P. Chindaprasirt, W. Kroehong, N. Damrongwiriyanupap, W. Suriyo, and C. Jaturapitakkul, "Mechanical properties, chloride resistance and microstructure of Portland fly ash cement concrete containing high volume bagasse ash," Journal of Building Engineering, vol. 31, p. 101415, Sep. 2020, doi: 10.1016/j.jobe.2020.101415.

[19]. S. Praveenkumar and G. Sankarasubramanian, "Synergic Effect of Sugarcane Bagasse Ash Based Cement on High Performance Concrete Properties," Silicon, vol. 13, no. 7, pp. 2357–2367, Jul. 2021, doi: 10.1007/s12633-020-00832-4.

[20]. W. Kroehong, N. Damrongwiriyanupap, T. Sinsiri, and C. Jaturapitakkul, "The Effect of Palm Oil Fuel Ash as a Supplementary Cementitious Material on Chloride Penetration and Microstructure of Blended Cement Paste," Arab J Sci Eng, vol. 41, no. 12, pp. 4799–4808, Dec. 2016, doi: 10.1007/s13369-016-2143-1.

[21]. M. D. A. Thomas, R. D. Hooton, A. Scott, and H. Zibara, "The effect of supplementary cementitious materials on chloride binding in hardened cement paste," Cement and Concrete Research, pp. 1–7, 2012, doi: https://doi.org/10.1016/j.cemconres.2011.01.001.

[22]. T. D. Garrett, "Effects on Strength and Corrosive Characteristics of Hardened Cement Paste Using Rice Husk and Sugarcane Bagasse," 2019.

[23]. BIS:12269 (2013) Indian Standard 53 Grade ordinary Portland cement—Specification. New Delhi: Bureau of Indian Standards.

[24]. BIS: 4031 (Part 11) (1988) Methods of Physical Tests for Hydraulic Cement Part 11 Determination of Density (First Revision). New Delhi: Bureau of Indian Standards.

[25]. BIS 1727 (1967): Methods of test for pozzolanic materials. New Delhi: Bureau of Indian Standards.

[26]. BIS: 383 (1970) Specification for Coarse and Fine Aggregates from Natural Sources for Concrete. New Delhi: Bureau of Indian Standards. www.standardsbis.in.

[27]. BIS: 10262 (2019). Concrete Mix Proportioning-Guidelines (Second Revision). New Delhi: Bureau of Indian Standards. www.standardsbis.in.

[28]. BIS 1124 (1974): Method of test for determination of water absorption, apparent specific gravity and porosity of natural building stones. New Delhi: Bureau of Indian Standards."

[29]. "BIS: 516 (Part 2/Sec 1) (2018) Properties of Hardened Concrete Section - 1 Water Penetration under pressure. New Delhi: Bureau of Indian Standards."

[30]. "ASTM (C618 − 12a). (2012). Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete 1. https://doi.org/10.1520/C0618-12a.