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Enhancing Concrete Performance Through Ternary Mixtures: Utilizing SCBA and Silica Fume for Sustainable Construction

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Abstract

This study investigates the effects of incorporating Sugarcane Bagasse Ash (SCBA) and Silica Fume (SF) as supplementary cementitious materials on the properties of concrete. Compressive strength, split tensile strength, and water absorption characteristics of ternary blended concrete mixes containing varying proportions of SCBA and SF were examined at curing periods of 7, 28, and 56 days. The results reveal that up to 15% SCBA replacement and 10% SF addition led to increased concrete strength, with TBSSF15 mix demonstrating the highest compressive and split tensile strengths. Moreover, water absorption values were significantly lower in TBSSF concrete compared to conventional concrete, indicating enhanced durability. TBSSF15 emerged as the optimal mix proportion, offering superior performance. This research underscores the potential of using SCBA in concrete formulation to not only enhance concrete properties but also address waste management challenges in the sugar industry. Overall, ternary mix concrete exhibited promising performance compared to Ordinary Portland Cement (OPC) concrete, emphasizing its potential as a sustainable alternative.

Keywords: Sugarcane bagasse ash, silica fume, ternary blended concrete, compressive strength, split tensile strength, water absorption, sustainable construction.

INTRODUCTION

The versatile nature of concrete allows for the incorporation of various waste materials as substitutes for both cement and aggregate during its production. The effective utilization of fly ash as a pozzolanic material in concrete, coupled with its improved economic and technological feasibility, has spurred researchers to explore the utilization of additional waste materials and ashes in concrete manufacturing. Consequently, materials such as rice husk ash, silica fume, granite fines, quarry dust, rock dust, siliceous stone powder, slag, eggshell powder, sludge, and SCBA have found application in concrete production [1–8].

Each of these materials possesses distinct properties and interacts with water in unique ways, with some exhibiting contrasting effects on concrete characteristics. To enhance concrete properties, it has been determined that combining two or more types of mineral admixtures yields superior results compared to using a single type. The efficacy of ternary blends (incorporating two types of pozzolans) and binary blends (comprising one type of pozzolan) is currently under investigation The sugar industry in India, a longstanding cornerstone

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of the agricultural landscape, boasts 538 operational sugarcane factories according to current figures from the Indian Sugar Mill Association. Over the past century, many of these enterprises have achieved self-sufficiency through various means, including electricity generation, with surplus power being supplied to the national grid [9–12].

Sugarcane holds a prominent position as a Kharif crop in India, ranking second globally in production. With an average annual output ranging from 300 to 350 million tonnes over the past five years, sugarcane farming is widespread in the country. Bagasse, the fibrous residue left after sugarcane processing, possesses a high gross calorific value of approximately 2,250 kcal/kg in its wet state, making it a promising resource for power generation.

However, SCBA holds promise as a Supplementary Cementitious Material (SCM) due to its high proportion of amorphous silica. Its characteristics, including chemical composition and pozzolanic activity, vary depending on factors such as calcining conditions and raw material source. Although research on SCBA as a cement replacement material has commenced in India, its large-scale utilization as a value-added product will require significant time and effort.

SCBA's pozzolanic activity, assessed by its Strength Activity Index (SAI) compared to control mortars, indicates its potential to enhance cement performance when incorporated. Despite its high silica content, the presence of carbon and unburnt components may influence its reactivity and impact concrete characteristics. The interaction of silica with free lime during cement hydration results in the formation of new calcium silicate hydrate products, thereby improving concrete's mechanical and durable properties. Decreasing the particle size of SCBA further enhances its pozzolanic activity [13–19].

Silica fume, a byproduct of the bag house filter utilized in the production of silicon and ferrosilicon metals, serves as a highly effective pozzolana due to its ultra-fine texture, filler properties, and high content of amorphous silica. According to ASTM C 642-13 (2013), silica fume enhances concrete's strength, durability, abrasion resistance, corrosion resistance, and reduces permeability, making it a valuable addition to concrete mixtures. It finds application both as a pozzolan and an additive in concrete [20–27].

Produced during the manufacture of silicon or various silicon alloys, silica fume contains an amorphous SiO2 content exceeding 80% to 85%, making it suitable for use in the cement and concrete industries. With a nitrogen BET surface area of 20,000 m3/kg and particle sizes typically ranging from 0.1 to 0.5 μm, silica fume is increasingly employed globally as a mineral admixture for high-performance concrete. Originally introduced as an additive in Norwegian concrete, silica fume weighs between 200 and 300 kg/m3 and is characterized by its light weight [28].

In concrete, silica fume acts both physiochemically and chemically. Physiochemically, its minute particle size focuses on refining the void system of cement paste, particularly in the transition zone. This results in a denser, more homogeneous, and consistent paste. For instance, replacing 15% of the cement mass with silica fume means that each cement grain is surrounded by approximately 2,000,000 particles, leading to matrix densification and enhanced bonding with aggregates and reinforcing elements such as glass fibers. Chemically, silica fume contributes to the pozzolanic reaction, converting weak calcium hydroxide crystals into a robust C-S-H gel, thereby influencing concrete properties through various mechanisms [29].

OBJECTIVES

The study aims to analyze the impact of Sugarcane Bagasse Ash (SCBA) and Silica Fume (SF) on concrete's mechanical properties, specifically compressive strength and split tensile strength.. The research aims to identify the optimal mix proportions of SCBA and SF to achieve superior concrete performance, emphasizing strength and durability. Furthermore, it aims to assess the potential of SCBA utilization in concrete production for effective waste management, addressing disposal challenges related to sugarcane processing residues. Finally, the study intends to compare the performance of ternary mix concrete with conventional Ordinary Portland Cement (OPC) concrete, determining its feasibility as a sustainable alternative in construction applications.

MATERIAL AND MIX DESIGN

Material

The constituent materials used in this study included Grade 53 ordinary Portland cement, locally sourced river sand, machine-crushed angular granite metal as coarse aggregate, Sugarcane Bagasse Ash (SCBA), and Silica Fume. The cement underwent evaluation based on IS 4031-1988 standards and was stored in airtight containers. The river sand met IS 2386-1963 guidelines and complied with IS 383-1970 specifications for grading zone II. Coarse aggregate was obtained from machine-crushed angular granite metal in line with IS 383-1970 standards. SCBA, sourced from a reputable sugar industry in Madhya Pradesh, underwent high-temperature calcination. Silica Fume was procured from a supplier in Mandideep Industrial area, Bhopal, India. Potable water from the laboratory was used for mixing and curing, adhering to IS: 3025 – 1964 standards to ensure absence of harmful substances. The pH level of the water was maintained at a minimum of 6, and no solids were present as per IS: 456–2000 guidelines.

Mix Design

In this Work, Grade M30 concrete was employed, and the mix designs were formulated following the guidelines provided in IS 10262-2009. The mix proportions for Grade M30 concrete are detailed in Table 1, outlining the ratios of the respective quantities obtained.

For the experimental study, an M30 concrete mix with a water-to-cement ratio of 0.45 was selected. Cubes were fabricated by substituting cement with SCBA at levels of 0%, 5%, 10%, 15%, 20%, and 25%, along with the addition of 10% silica fume across all replacement percentages. The materials were proportioned based on weight. Cube molds measuring 150x150x150mm and the cylindrical molds with dimensions of 200 mm in length and 100 mm in diameter were utilized for casting.

RESULT AND DISCUSSION

Compressive Strength Analysis

The compressive strength of concrete with untreated SCBA and silica fume was assessed over 7, 28, and 56 days by replacing varying cement percentages with SCBA (0%, 5%, 10%, 15%, 20%, and 25%) alongside a constant 10% silica fume addition, as depicted in Table 2 and Figure 1. Results show that up to 15% SCBA replacement, combined with silica fume, there's a notable improvement in compressive strength across all ages of ternary concrete. However, with higher SCBA content alongside silica fume, compressive strength declines for all ages of ternary concrete. Percentage increases in compressive strength for 5%, 10%, and 15% SCBA replacements with 10% silica fume were 3.3%, 8.3%, and 13.3%, respectively. Conversely, further SCBA replacements at 20% and 25% with 10% silica fume resulted in strength decreases by 3.4% and 6.6%, respectively, over a 7-day curing period compared to standard concrete. For a 28-day curing period, percentage increases in compressive strength for 5%, 10%, and 15% SCBA replacements with 10% silica fume were 1.15%, 4.59%, and 9.19%, respectively, while further SCBA replacements at 20% and 25% with 10% silica fume led to strength decreases by 3.49% and 6.79%, respectively. Finally, over a 56-day curing period, percentage increases in compressive strength for 5%, 10%, and 15% SCBA replacements with 10% silica fume were 3.29%, 5.49%, and 9.95%, respectively, while further SCBA replacements at 20% and 25% with 10% silica fume resulted in strength decreases by 2.19% and 4.43%, respectively.

Table 1. Mixing ratios for M30 grade concrete.

Mix	Cement	Fine aggregate	Coarse aggregates	Water	Superplasticizer	Water/binder ratio	Target strength
M30	375 kg/m^3	804 kg/m^3	1380 kg/m^3	170 kg/m^3	1.80 kg	0.45	38.19 N/mm^2

Table 2. Compressive strength results of ternary blended concrete.

S.N.	Mix proportion	SCBA	Silica fume	Compressive strength (in N/mm^2)		
				7 days	*28 days*	*56 days*
1.	TBSSF0	0.00%	0.00%	26.65	38.64	40.00
2.	TBSSF5	5.00%	10.00%	27.54	39.09	41.31
3.	TBSSF10	10.00%	10.00%	28.85	40.42	42.19
4.	TBSSF15	15.00%	10.00%	30.19	42.19	43.97
5.	TBSSF20	20.00%	10.00%	25.74	37.31	39.09
6.	TBSSF25	25.00%	10.00%	24.84	35.98	38.18

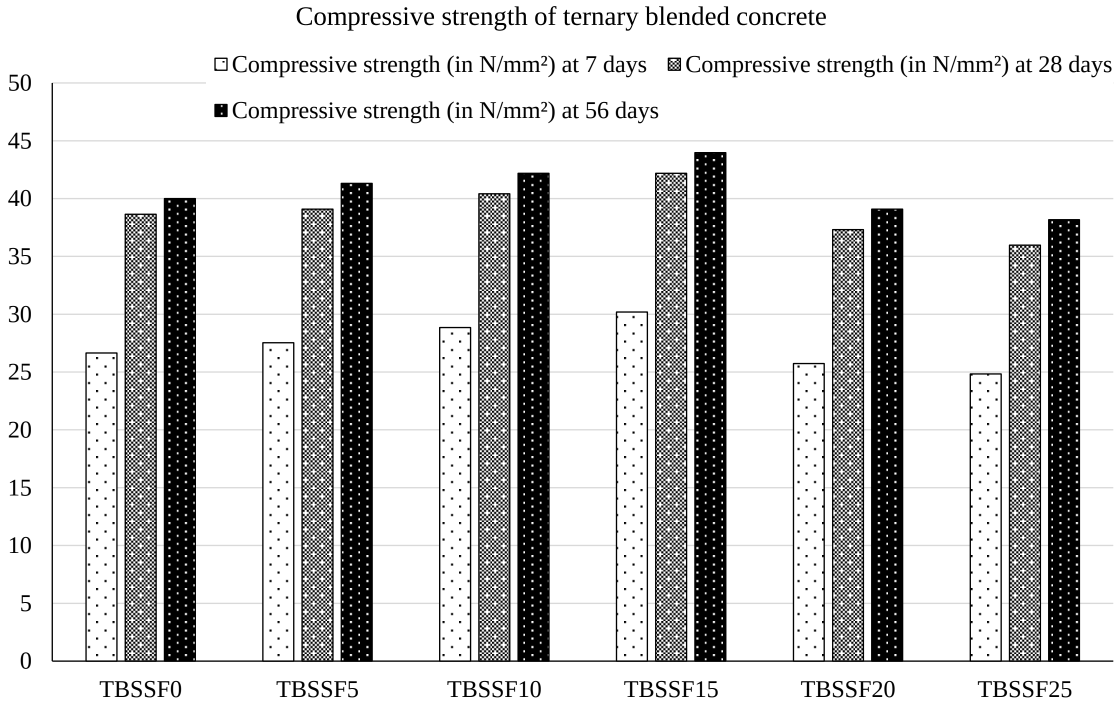

Figure 1. Represent compressive strength analysis of ternary blended concrete.

Split Tensile Strength Analysis

The split tensile strength of untreated SCBA silica fume concrete was examined over 7, 28, and 56 days by substituting cement with SCBA at varying percentages (0%, 5%, 10%, 15%, 20%, and 25%) alongside a constant 10% silica fume addition for all concrete proportions. Results indicate that up to a 15% SCBA replacement, combined with silica fume, there's an increase in tensile strength across all durations of ternary concrete, while further SCBA increments alongside silica fume lead to a decline in tensile strength for all periods of ternary concrete. The percentage increases in tensile strength for replacements of 5%, 10%, and 15% SCBA with 10% silica fume were 8.79%, 17.09%, and 29.45%, respectively. Conversely, further SCBA replacement at 20% and 25% with 10% silica fume resulted in a decrease in tensile strength by 4.08% and 8.19%, respectively, over a 7-day curing period compared to standard concrete. For a 28-day curing period, percentage increases in tensile strength for replacements of 5%, 10%, and 15% SCBA with 10% silica fume were 5.45%, 8.15%, and 13.38%, respectively, while further SCBA replacement at 20% and 25% with 10% silica fume led to decreases in tensile strength by 3.05% and 2.58%, respectively. Lastly, for a 56-day curing period, percentage increases in tensile strength for replacements of 5%, 10%, and 15% SCBA with 10% silica fume were 4.88%, 7.36%, and 12.27%, respectively, whereas additional SCBA replacement at 20% and 25% with 10% silica fume resulted in decreases in tensile strength by 0.69% and 2.38%, respectively, compared to standard concrete.

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Table 3. Split tensile strength values of ternary concrete with SCBA and silica fume.

S.N.	Mix proportion	SCBA	Silica fume	Split tensile strength (in N/mm^2)		
				7 days	***28 days***	***56 days***
1.	TBSSF0	0.00%	0.00%	1.67	2.66	2.81
2.	TBSSF5	5.00%	10.00%	1.82	2.81	2.94
3.	TBSSF10	10.00%	10.00%	1.95	2.89	3.02
4.	TBSSF15	15.00%	10.00%	2.17	3.02	3.15
5.	TBSSF20	20.00%	10.00%	1.59	2.73	2.79
6.	TBSSF25	25.00%	10.00%	1.52	2.59	2.72

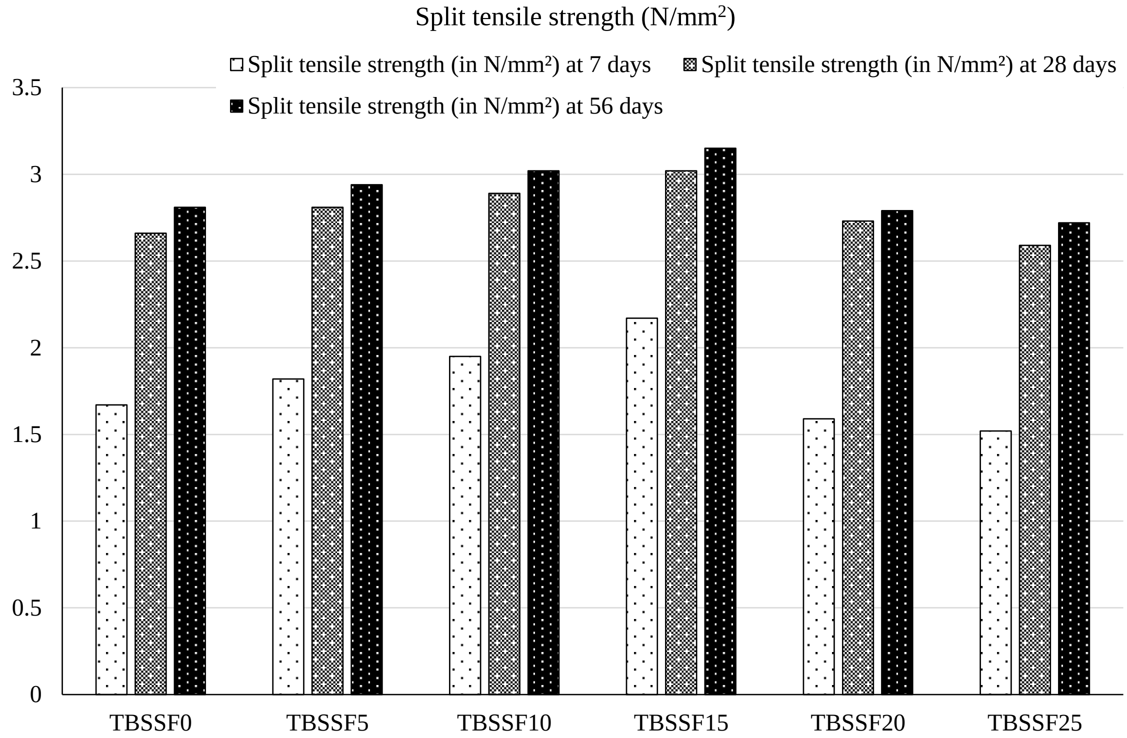

Figure 2. Represent split tensile strength of ternary blended concrete.

CONCLUSIONS

1. Concrete strength exhibited an upward trend with increasing SCBA and SF content, reaching a peak at 15% SCBA replacement and 10% SF addition across all curing periods (7d, 28d, and 56d).
2. Ternary mix concretes (TBSSF) comprising a blend of 10% SF and SCBA replacement up to 15% demonstrated superior compressive strength compared to conventional concrete (TBASF0) across all age stages (7d, 28d, and 56d).
3. Notably, TBSSF15 concrete mix showcased the highest compressive and split tensile strengths, surpassing conventional concrete (TBASF0) by 11.83%, 14.4%, and 18.8%, respectively.
4. The TBSSF15 concrete mix, incorporating 15% BA and 10% Silica Fume as Supplementary Cementitious Materials (SCM), emerged as the optimal mix proportion

Overall, it can be concluded that ternary mix normal strength concrete outperforms OPC concrete, as demonstrated by the experimental results. Additionally, the utilization of SCBA in concrete formulation not only reduces cement consumption but also presents a viable solution for managing bagasse ash waste disposal issues in the sugar manufacturing industry.

REFERENCES

1. Wassmann, R. et al. (2022). Carbon Footprint Calculator Customized for Rice Products: Concept and Characterization of Rice Value Chains in Southeast Asia. Sustainability (Switzerland), 14 (1). https://doi.org/10.3390/su14010315
2. Montiel-Bohórquez, N.D., Agudelo, A.F. and Pérez, J.F. (2021). Effect of origin and production rate of MSW on the exergoeconomic performance of an integrated plasma gasification combined cycle power plant. Energy Conversion and Management, 238. Available from https://doi.org/10.1016/J.ENCONMAN.2021.114138
3. Doukari, O. and Greenwood, D. (2020). Automatic generation of building information models from digitized plans. Automation in Construction, 113. https://doi.org/10.1016/J.AUTCON.2020.103129
4. Castillo, A.B., Al-Maslamani, I. and Obbard, J.P. (2016). Prevalence of microplastics in the marine waters of Qatar. Marine Pollution Bulletin, 111 (1–2), 260–267. https://doi.org/10.1016/J.MARPOLBUL.2016.06.108.
5. Beaudoin, J. and Odler, I. (2019). Hydration, setting and hardening of Portland cement. Lea's chemistry of cement and concrete, 5, 157–250.
6. Bahurudeen, A. and Santhanam, M. (2014). Performance evaluation of sugarcane bagasse ash-based cement for durable concrete.
7. Arenas, C. et al. (2015). Technical specifications for highway noise barriers made of coal bottom ash-based sound absorbing concrete. Construction and Building Materials, 95, 585–591.
8. Akram, T., Memon, S.A. and Obaid, H. (2009). Production of low cost self compacting concrete using bagasse ash. Construction and Building Materials, 23 (2), 703–712.
9. Amudhavalli, N.K. and Mathew, J. (2012). Effect of Silica Fume on Strength and Durability Parameters of Concrete. International Journal of Engineering Sciences & Emerging Technologies, 3 (1), 2231–6604.
10. Leiva, C. et al. (2016). Characteristics of fired bricks with co-combustion fly ashes. Journal of Building Engineering, 5, 114–118. https://doi.org/10.1016/j.jobe.2015.12.001
11. Kowsik, R. and Jayanthi, S. (2015). Durability study of bagasse ash and silicafume based hollow concrete block for lean mix. Int J Appl Environ Sci, 10 (1), 395– 407.
12. Worathanakul, P., Payubnop, W. and Muangpet, A. (2009). Characterization for post- treatment effect of bagasse ash for silica extraction. World Academy of Science, Engineering and Technology, 56 (8), 360–362.
13. Suvimol, S. and Daungruedee, C. (2008). Bagasse ash: effect of pozzolanic activity and application in cement use aspect. The 3rd ACF international conference- ACF/VCA. 2008. 165–173.
14. Tanoursaz, H. and Labibzadeh, M. (2011). Comparison of Uniaxial Compressive Strength of Light Weight Concrete Prepared with Bagassese between Cubic and Cylindrical Specimens. Journal of American Science, 7 (2).
15. Oke, A., Aigbavboa, C. and Khangale, T. (2018). Effect of skills shortage on sustainable construction. Advances in Intelligent Systems and Computing, 600, 303–309. https://doi.org/10.1007/978-3-319-60450-3_29
16. Muangtong, P. et al. (2013). Effects of fine bagasse ash on the workability and compressive strength of mortars. Chiang Mai Journal of Science, 40 (1), 126– 134.
17. Leiva, C. et al. (2016). Characteristics of fired bricks with co-combustion fly ashes. Journal of Building Engineering, 5, 114–118. https://doi.org/10.1016/j.jobe.2015.12.001
18. Khanzadi, M. et al. (2016). An integrated fuzzy multi-criteria group decision making approach for project delivery system selection. Scientia Iranica, 23 (3), 802–814. https://doi.org/10.24200/SCI.2016.2160
19. Hannan, N.I.R.R. et al. (2017). Sound absorption coefficient of coal bottom ash concrete for railway application. IOP Conference Series: Materials Science and Engineering. 2017. IOP Publishing, 12077.
20. Habeeb, G.A. and Fayyadh, M.M. (2009). Rice husk ash concrete: the effect of RHA average particle size on mechanical properties and drying shrinkage. Australian Journal of Basic and Applied Sciences, 3 (3), 1616–1622.

21. Gupta, T., Sharma, R.K. and Chaudhary, S. (2015). Impact resistance of concrete containing waste rubber fiber and silica fume. International Journal of Impact Engineering, 83, 76–87.
22. Ghizdăveț, Z. et al. (2016). Sound absorbing materials made by embedding crumb rubber waste in a concrete matrix. Construction and Building Materials, 124, 755–763.
23. Franus, W., Panek, R. and Wdowin, M. (2015). SEM investigation of microstructures in hydration products of portland cement. 2nd International Multidisciplinary Microscopy and Microanalysis Congress. 2015. Springer, 105–112.
24. Frías, M., Villar, E. and Savastano, H. (2011). Brazilian sugar cane bagasse ashes from the cogeneration industry as active pozzolans for cement manufacture. Cement and concrete composites, 33 (4), 490–496.
25. Siddique, R. and Khan, M.I. (2011). Supplementary cementing materials. Springer Science & Business Media.
26. Singh, M. and Garg, M. (1999). Cementitious binder from fly ash and other industrial wastes. Cement and Concrete Research, 29 (3), 309–314.
27. Singh, S.K.L. and All Jawald, S. (2013). Utilization of sugarcane bagasse ash (SCBA) as pozzolanic material in concrete. A review, IJBSTR.
28. Sivakumar, G., Hariharan, V. and Barathan, S. (2013). Preparation of Bio-cement using sugarcane bagasse ash and its Hydration behavior. International Journal of Science, Engineering and Technology Research (IJSETR), 2 (10), 1887–1889.
29. Srinivasan, R. and Sathiya, K. (2010). Experimental study on bagasse ash in concrete. International Journal for Service Learning in Engineering, Humanitarian Engineering and Social Entrepreneurship, 5 (2), 60–66.

