Optimization of Bagasse Ash and Recycled Aggregates in M40 Concrete for Sustainable Pavement Construction: A Fuzzy Logic-Based Approach

Fatima Uz Zehra Ansari
Bharati Vidyapeeth (Deemed to be University) College of Engineering, Pune, Maharashtra, India
fatima.ansari19@gmail.com (corresponding author)

Vidula S. Sohoni
Bharati Vidyapeeth (Deemed to be University) College of Engineering, Pune, Maharashtra, India
vssohoni@gmail.com

Received: 22 April 2025 | Revised: 7 May 2025 | Accepted: 13 May 2025

 DOI: https://doi.org/10.48084/etasr.11669

ABSTRACT

The growing concern for sustainability in the construction industry has led to the exploration of alternative materials to reduce the negative environmental impacts of the demanding use of concrete production. This study investigates the potential use of bagasse ash as a partial replacement for cement and the complete replacement of natural aggregates with recycled aggregates in M40-grade concrete to develop a sustainable and cost-effective pavement material. The percentage replacement with bagasse ash ranged from 10% to 40%, with experimental evaluations focusing on compressive, split tensile, and flexural strengths at 7 and 28 days. Previous results indicated a loss of strength with a replacement of more than 25%, which requires further investigation with intermediate replacement rates of 21%, 22%, 23%, and 24%. The optimal replacement percentage was 22%, offering a positive trade-off between mechanical performance and sustainability. Furthermore, a fuzzy logic-based predictive model was used to validate the experimental results, which confirmed the optimal replacement percentage. The findings demonstrate the feasibility of using bagasse ash and recycled aggregates in pavement construction, ensuring waste valorization and reduction of carbon footprint. This research offers an integrated framework for designing sustainable concrete and ensuring structural performance and economic viability in road infrastructure projects.

Keywords-bagasse ash; recycled aggregates; sustainable pavement; fuzzy logic; M40 concrete; cost-effective design; strength analysis

I. INTRODUCTION

A. *The Role of Bagasse Ash and Recycled Aggregates in Sustainable Construction*

The construction industry employs vast amounts of natural resources, raising concerns about resource depletion and environmental degradation [1-4]. Cement production is one of the leading contributors to carbon emissions, which calls for the need to explore alternative sustainable methods to reduce its environmental impact [5-8]. Among the most effective measures is the substitution of natural materials in concrete with pozzolanic industrial and agricultural by-products, such as bagasse ash, and the complete replacement of natural aggregates with recycled aggregates from demolished concrete structures. Bagasse ash, a by-product of sugarcane processing, has high levels of silica (SiO_2) content that enable it to exhibit pozzolanic characteristics that enhance strength and durability when used in the right mix [9-14]. The utilization of recycled aggregates reduces the demand for primary materials and supports waste management, promoting the agenda of sustainable development. The joint use of bagasse ash and recycled aggregates in concrete is an sustainable solution with economic and environmental benefits while maintaining the necessary structural strength of modern infrastructure projects.

B. *Research Significance in Road Pavement Applications*

Long-lasting, economically feasible, and environmentally friendly materials for road pavement construction are extremely desirable for contemporary infrastructure [15, 16]. Since road pavements are subjected to intense traffic stresses, climatic conditions, and degradation, they require materials to withstand mechanical stress while having low maintenance over long periods. Conventional concrete use in pavements is largely dependent on cement and natural aggregates, both being responsible for resource depletion and CO_2 emissions [17, 18].

This study investigates the partial replacement of cement with bagasse ash and the complete replacement of natural aggregate with recycled aggregate in M40-grade concrete, which is commonly used in pavement construction. Through the use of these green materials, this study aims to mitigate the environmental effects of pavement construction while providing sufficient compressive, tensile, and flexural strength. The primary purpose of this study is to examine the compressive, flexural, and splitting tensile strength of M40 concrete with various proportions of bagasse ash and the complete replacement of recycled aggregates. This study seeks to identify the optimal replacement with bagasse ash that ensures structural integrity and sustainability on road pavements. To increase reliability, fuzzy logic-based modeling was employed to validate the experimental work, providing a predictive tool for mix design optimization. By optimizing the ratio of bagasse ash and recycled aggregate, this work facilitates waste valorization, enables the efficient use of industrial by-products, and aids in the construction of green infrastructure for sustainable road construction.

Experiments on the use of bagasse ash as a partial cement replacement have established its pozzolanic properties [9-14]. Previous studies have established that an optimal replacement level of 20% leads to improved compressive strength, resistance against chloride ion penetration, and concrete durability [9, 19]. Investigations of recycled aggregates have also confirmed their viability as a complete replacement for natural aggregates, with key findings showing that high packing density improves mechanical performance and appropriate pretreatment improves bond strength in concrete [7, 20]. The strength properties of sustainable concrete that incorporates bagasse ash and recycled aggregates have been extensively analyzed, with studies highlighting the influence of mix proportions, cure regimes [21], and water absorption on long-term durability against weathering actions and mechanical properties [22, 23].

The progress in soft computing methods has led to the development of fuzzy logic-based predictive models that facilitate the optimization of concrete mix designs. This approach allows an accurate assessment of the strength parameters and material behavior at various levels of replacement [24]. These models have shown significant precision in predicting compressive, tensile, and flexural strengths, thus establishing a reliable framework for the enhancement of sustainable concrete mixtures [25, 26]. However, there are notable research deficiencies on the utilization of bagasse ash and recycled aggregates in high-strength pavement concrete (M40 grade). Previous studies focused primarily on lower-grade concrete mixes, with inadequate examination of their structural performance in pavement contexts [27, 28]. This study addresses these gaps by conducting a comprehensive experimental analysis of M40 concrete, identifying optimal replacement levels with bagasse ash (22%) and validating the results through a fuzzy logic-based approach. By integrating experimental and computational methods, this study provides a systematic framework for cost-effective and sustainable pavement construction, contributing to the advancement of green infrastructure solutions [29, 30].

II. MATERIALS AND TESTING

A. *Materials Used*

The materials used in this study are Ordinary Portland Cement (OPC) 53 Grade, bagasse ash, recycled coarse aggregates, fine aggregates (sand), and superplasticizers. Various physical and chemical tests were conducted to ensure the suitability of the M40 concrete mix.

B. *Cement Properties*

OPC Grade 53 (Birla Shakti / Birla A-1 Cement) was used, and Tables I and II show its chemical and physical properties.

TABLE I. CHEMICAL PROPERTIES OF CEMENT

Property	Obtained value	IS 12269:2013 limit
Loss on Ignition (LOI)	1.09%	≤ 4%
Insoluble Residue (IR)	0.73%	≤ 2%
Sulfuric Anhydride (SO_3)	1.82%	≤ 3%
Magnesia (MgO)	1.16%	≤ 6%
Chloride Content	0.04%	≤ 0.05%

TABLE II. PHYSICAL PROPERTIES OF CEMENT

Property	Obtained value	IS 12269:2013 limit
Fineness (m^2/kg)	297	≥ 225
Standard Consistency (%)	30%	-
Initial Setting Time (min)	150	≥ 30
Final Setting Time (min)	450	≤ 600
Soundness (mm)	4	≤ 10
Specific Gravity	3.15	-

C. *Bagasse Ash*

The bagasse ash used was supplied by Samarth Sahakari Sakhar Karkhana Ltd., Maharashtra. The ash was obtained as a by-product of sugarcane processing and used as a Supplementary Cementitious Material (SCM) because of its pozzolanic characteristics. The material used had a specific gravity of 1.89, a bulk density of 540 kg/m^3, and showed a retention of 20% when passed through a 45-micron sieve, indicating moderate fineness.

D. *Fine and Coarse Aggregates*

The fine aggregate used is crushed artificial sand falling under Zone I as per IS 383:1970, while the coarse aggregates consist of crushed basalt in 10 mm and 20 mm sizes.

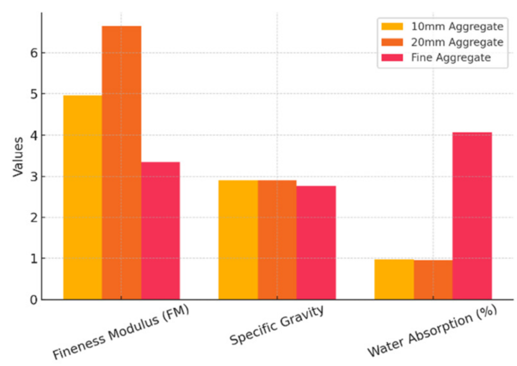

Fig. 1. Properties of aggregates.

TABLE III. PROPERTIES OF AGGREGATES

Property	10 mm aggregate	20 mm aggregate
Fineness Modulus (FM)	4.97	6.64
Specific gravity	2.90	2.90
Water absorption (%)	0.97	0.96

E. Recycled Coarse Aggregates (RCA)

RCA completely replaced natural aggregates as shown in Table IV. RCA exhibited a slightly lower specific gravity (2.52) compared to conventional natural aggregates (2.68) [31-35], which can contribute to a lighter concrete mix while maintaining adequate strength. This reduction in density, along with the sustainable reuse of materials, makes RCA a viable alternative for eco-friendly construction, reducing dependency on natural resources without compromising performance.

TABLE IV. PROPERTIES OF RECYCLED AGGREGATES

Property	10 mm recycled aggregate	20 mm recycled aggregate
Specific gravity	2.51	2.52
Water absorption (%)	4.61	4.61

F. Concrete Mix Design and Specimen Preparation

The mix design followed IS 10262:2019 for M40 concrete, incorporating bagasse ash as a cement replacement from 10% to 40% while fully replacing natural aggregates with RCA. Each specimen was tested at 7 and 28 days for compressive, flexural, and split tensile strengths. The mix design was according to Tables V and VI.

TABLE V. MIX DESIGNS OF M40 CONCRETE WITH PARTIAL REPLACEMENT WITH BAGASSE ASH

	Control sample	Test samples	
		20%	40%
Mix proportions	1:1.9:2.6	1:2.2:2.6	1:2.2:2.4
Cement	430 kg/m^3	307 kg/m^3	230 kg/m^3
Bagasse ash	-	77 kg/m3	154 kg/m3
Sand	823 kg/m^3	851 kg/m^3	831 kg/m^3
Aggregate	1122 kg/m3	944 kg/m^3	922 kg/m^3

TABLE VI. TEST SAMPLES

	Days	Samples
Cubes 150×150×150 mm	7	9
	28	9
Cylinders 150×300 mm	7	9
	28	9
Beams 100×100×500 mm	7	9
	28	9

III. TEST RESULTS

The specimens for M40-grade concrete were prepared for each percentage replacement with bagasse ash (0%, 10%, 20%, 30%, and 40%), with nine specimens cast for each testing age (7 and 28 days). The specimens included cubes (150×150×150 mm) for compressive strength, cylinders (150×300 mm) for split tensile strength, and beams (100×100×500 mm) for flexural strength. The mix proportions were adjusted accordingly for each replacement level to ensure consistency in material evaluation. Table VII shows the compressive, splitting tensile, and flexural strength results of M40-grade concrete at 7 and 28 days of curing for different levels of replacement with bagasse ash (0%, 10%, 20%, 30%, and 40%). These results provide a comparative evaluation of mechanical properties, helping to determine the optimal replacement percentage for sustainable concrete mix design.

TABLE VII. SUMMARY OF STRENGTH CHARACTERISTICS OF M40 CONCRETE AT DIFFERENT BAGASSE ASH REPLACEMENT LEVELS

M40 concrete										
Strength	7 days					28 days				
	0%	10%	20%	30%	40%	0%	10%	20%	30%	40%
Compressive	34.27	34.09	32.46	30.65	29.52	50.18	49.69	48.73	46.6	41
Splitting tensile	3.87	3.85	3.75	3.56	3.46	4.15	4.15	4.09	3.9	3.84
Flexural	6.55	6.48	6.33	6.07	5.69	8	8.1	7.82	7.54	7.39

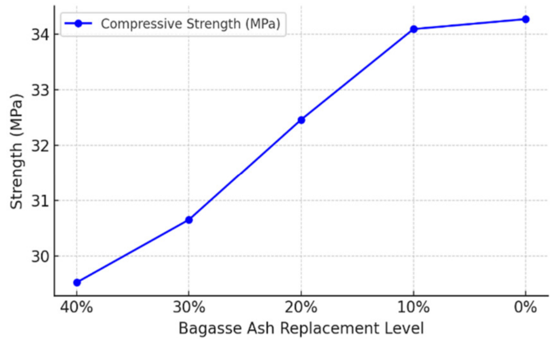

Fig. 2. Compressive strength of M40 concrete at 7 days.

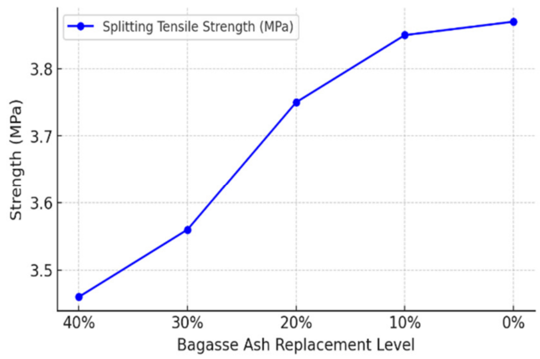

Fig. 3. Splitting tensile strength of M40 concrete at 7 days.

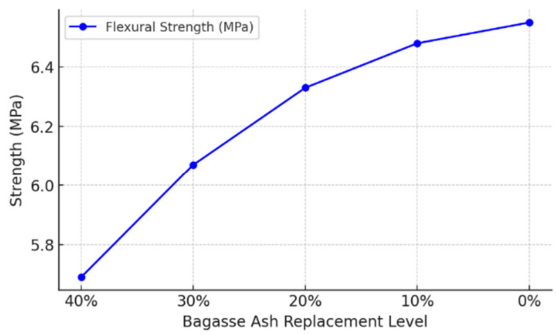

Fig. 4. Flexural Strength of M40 concrete at 7 days.

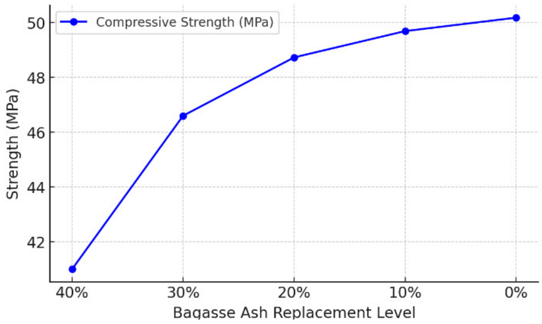

Fig. 5. Compressive strength of M40 concrete at 28 days.

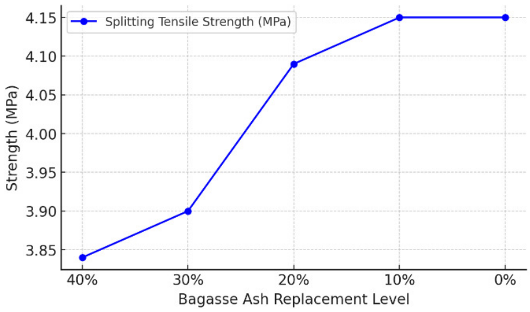

Fig. 6. Splitting tensile strength of M40 concrete at 28 days.

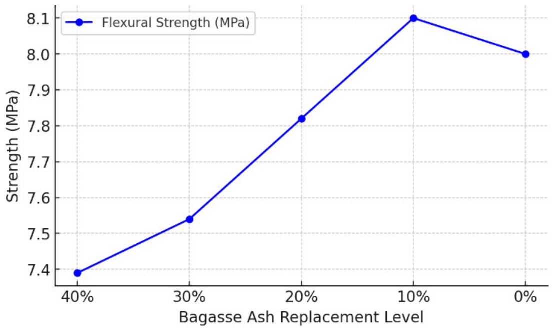

Fig. 7. Flexural strength of M40 concrete at 28 days.

Figures 2-7 show the influence of bagasse ash on the strength properties of M40 concrete at 7- and 28-day intervals. The compressive strength graphs show a steady decline in strength with an increase in replacement level; however, up to a 25% replacement level, the decline is minimal, reflecting an optimum range that provides a balance between strength and sustainability. The splitting tensile strength graph shows a similar pattern, with minimal variations in strength up to the 25% level, followed by a sharp decline. The flexural strength graph shows a slight improvement at 10% replacement (8.1 MPa at 28 days), indicating a potential strength benefit at lower replacement levels. Beyond 30-40% replacement, all strengths show a significant drop, indicating that excessive replacement may negatively affect concrete performance. The graphs also suggest that an optimal replacement with bagasse ash of around 20-25% can be considered to achieve a balance between strength, sustainability, and structural performance.

Figures 8-10 illustrate the impact of bagasse ash replacement on the compressive, splitting tensile, and flexural strengths of M40 concrete at 28 days, focusing on determining the optimum replacement percentage. As per the designed target strength calculation for M40 grade concrete

$$f'_{ck} = f_{ck} + 1.65S = 40 + 1.65(5) = 48.25 \text{ N/mm}^2$$

the target strength was set at 48.25 N/mm², which was considered to evaluate the performance of replacement with bagasse ash. Initially, based on the observed results, it was anticipated that the optimum replacement percentage could be between 20% and 25%. To validate the results, concrete samples with 0%, 20%, 21%, 22%, 23%, 24%, 25%, and 30% bagasse ash were carefully tested. The compressive strength curve indicated a gradual fall with higher replacement, but at 22%, the strength remained close to the target design strength, ensuring structural adequacy and sustainability. The splitting tensile strength curve indicated a consistent trend up to 25% and a sudden fall beyond that percentage. Likewise, the flexural strength curve indicated that the strength was consistent between 20% and 25%, but a sudden fall at 30% replacement. The results showed that 22% was the optimal replacement percentage, ensuring the desired strength parameters along with sustainability in the concrete design.

TABLE VIII. CUMULATIVE OPTIMAL PERCENTAGE CALCULATION FOR M40 GRADE OF CONCRETE

M40								
Strength	**28 Days**							
	0%	**20%**	**21%**	**22%**	**23%**	**24%**	**25%**	**30%**
Compressive	50.18	48.73	48.38	48.29	47.67	47.57	47.51	46.60
Splitting tensile	4.15	4.09	4.07	4.06	4.05	4.03	4.03	3.9
Flexural	8	7.82	7.8	7.78	7.77	7.75	7.73	7.54

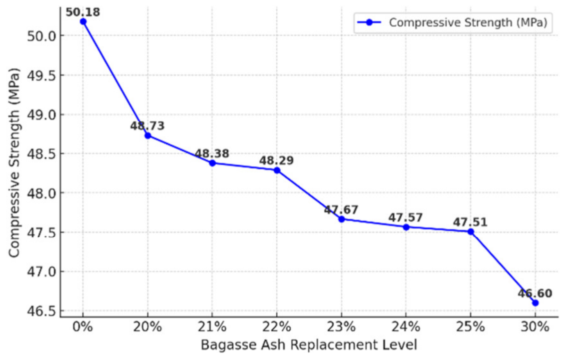

Fig. 8. Compressive strength for optimal replacement with bagasse ash.

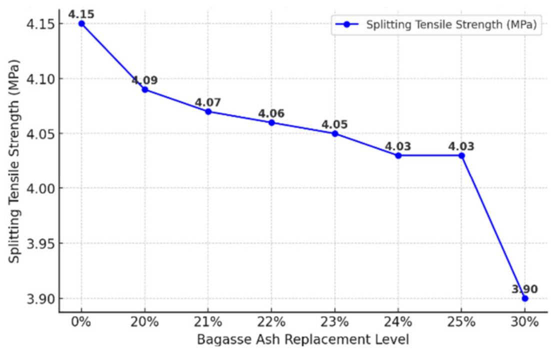

Fig. 9. Splitting tensile strength for optimal replacement with bagasse ash.

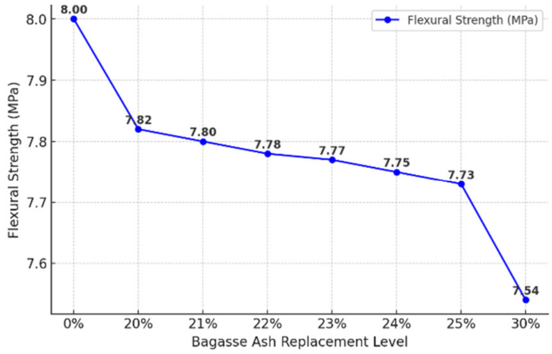

Fig. 10. Flexural strength for optimal replacement with bagasse ash.

IV. FUZZY LOGIC-BASED PREDICTIVE MODEL FOR VALIDATION

Fuzzy logic can handle uncertainty in decision-making. Instead of relying on exact numbers, it uses simple, human-like language and rules to understand and model complex systems more naturally [36-38]. A fuzzy logic-based predictive model was used to find the ideal percentage of bagasse ash to replace cement in M40-grade concrete. The goal was to examine whether the prediction of the model matched the results of lab experiments and study how this replacement affects the compressive strength of the concrete.

A. Fuzzy Logic Implementation for Optimum Replacement Percentage

A fuzzy logic system was developed in Python using the skfuzzy library. The strategy involved the creation of fuzzy sets, membership functions, and inference rules to analyze the variation of compressive strength with different percentages of cement replacement with bagasse ash.

B. Input and Output Variables

The fuzzy logic system was built around two main parameters: the input was the compressive strength of concrete (measured in N/mm²), and the output was the percentage of bagasse ash used to replace cement in the mix. Data were taken from experimental tests in which concrete samples with different replacement percentages with bagasse ash, ranging from 0% up to 30% (including 20, 21, 22, 23, 24, and 25%), were evaluated for compressive strength after 28 days.

C. Membership Functions for Fuzzy Variables

Fuzzy membership functions were used to handle the uncertainty in both compressive strength and bagasse ash content. The output variable (replacement percentage) was categorized into three ranges: Low Replacement (0 to 8%), Medium Replacement (18 to 30%), and Optimal Replacement (a narrower band between 20 and 25%, identified from experimental results as potentially ideal). On the input side, compressive strength was also grouped into three categories: Low Strength (below 40 N/mm²), Medium Strength (between 38 and 52 N/mm², considered acceptable), and High Strength (above 48 N/mm², meeting the M40-grade requirements). These fuzzy classifications help to analyze how different bagasse ash contents affect strength, guiding the selection of an optimal strength-sustaining and eco-friendly mix.

D. Fuzzification of Experimental Data

Using the fuzz.interp_membership function, the compressive strength values from the experimental data were converted to fuzzy values. This process, known as fuzzification, helped identify how strongly each strength value belonged to the defined categories. In this way, the model could better interpret the real-world variation in strength and assess the degree to which each value fits into these fuzzy sets, making the analysis more intuitive and practical.

E. Fuzzy Inference System and Rule Formulation

A rule-based fuzzy inference system was developed to determine the percentage of bagasse ash that is the most appropriate according to the compressive strength of the concrete. The system was guided by three intuitive rules. When compressive strength was found to be high, the replacement percentage was selected from the optimal range of 20-25%. In cases where strength was low, a minimal replacement level, generally below 10%, was considered to prevent any compromise in structural integrity. For medium strength values, a moderate replacement between 10% and 20% was preferred to strike a balance between maintaining adequate strength and promoting sustainability. These rules were applied using fuzzy logic operators, which helped to logically combine the results and arrive at a reliable and practical replacement recommendation.

F. Defuzzification and Optimum Replacement Determination

The centroid defuzzification method was applied to obtain an exact crisp numerical value for the optimum replacement percentage. The final optimum percentage of bagasse ash was found to be 22%, aligning with the experimental observations.

G. Model Validation and Results

Once the fuzzy model identified 22% as the optimal replacement percentage, it was compared with the experimental test results. The validation process confirmed that the predicted optimal percentage matched the experimentally determined value, thereby reinforcing the accuracy and reliability of the fuzzy logic approach.

V. CONCLUSIONS

The study concludes that the optimal replacement of cement with bagasse ash to achieve the target strength of the M40 concrete is 22%, beyond which a significant decline in compressive, tensile, and flexural strength is observed. Complete replacement of natural aggregates with recycled aggregates demonstrates feasibility without compromising the structural integrity of concrete. A fuzzy logic-based predictive model effectively validated the experimental findings, confirming the optimal replacement of 22% cement with bagasse ash. The incorporation of bagasse ash and recycled aggregates into sustainable concrete contributes to resource conservation and waste management, enhancing the durability and environmental benefits of pavement structures. The high silica content in bagasse ash makes it suitable as a pozzolanic material, and proper processing and sieving further improve its reactivity and strength development. However, the workability of concrete decreases with a higher percentage of bagasse ash due to increased water absorption, and the setting time is reduced compared to conventional concrete, leading to an improvement in early-age strength gain. The compressive strength of M40 concrete gradually decreases with increasing bagasse ash content, but up to 22% remains within acceptable limits. The lower specific gravity of bagasse ash compared to cement results in a lighter concrete mix, making it ideal for sustainable pavement construction. The modulus of elasticity remains within an acceptable range, ensuring structural stability in pavement applications. The optimized mix design with 22% replacement of cement with bagasse ash balances strength, durability, and sustainability, making it a viable alternative for eco-friendly concrete. The use of a fuzzy logic-based predictive model enhances the accuracy of mix design optimization, providing a robust framework for sustainable pavement concrete through both experimental and computational approaches.

REFERENCES

[1] X. Ge, R. T. Goodwin, J. R. Gregory, R. E. Kirchain, J. Maria, and L. R. Varshney, "Accelerated Discovery of Sustainable Building Materials." arXiv, 2019, https://doi.org/10.48550/ARXIV.1905.08222.

[2] "Greenhouse gas emissions," *Wikipedia*. Feb. 06, 2025, [Online]. Available: https://en.wikipedia.org/w/index.php?title=Greenhouse_gas_emissions&oldid=1274236027.

[3] "Green building," *Wikipedia*. Jan. 31, 2025, [Online]. Available: https://en.wikipedia.org/w/index.php?title=Green_building&oldid=1273131344.

[4] Y. Xiong, H. Guo, D. D. M. M. Nor, A. Song, and L. Dai, "Mineral resources depletion, environmental degradation, and exploitation of natural resources: COVID-19 aftereffects," *Resources Policy*, vol. 85, Aug. 2023, Art. no. 103907, https://doi.org/10.1016/j.resourpol.2023.103907.

[5] F. Belaïd, "How does concrete and cement industry transformation contribute to mitigating climate change challenges?," *Resources, Conservation & Recycling Advances*, vol. 15, Nov. 2022, Art. no. 200084, https://doi.org/10.1016/j.rcradv.2022.200084.

[6] R. R. Z. Tarpani *et al.*, "Environmental assessment of cement production with added graphene," *Cleaner Environmental Systems*, vol. 14, Sep. 2024, Art. no. 100206, https://doi.org/10.1016/j.cesys.2024.100206.

[7] M. Yang *et al.*, "Advancing environmental sustainability in construction through innovative low-carbon, high-performance cement-based composites: A review," *Materials Today Sustainability*, vol. 26, Jun. 2024, Art. no. 100712, https://doi.org/10.1016/j.mtsust.2024.100712.

[8] L. Farahzadi, L. G. F. Tellnes, B. Shafei, and M. Kioumarsi, "Life-cycle environmental assessment of ultra-high-performance concrete with sustainable materials and fiber substitutions," *Cleaner Engineering and Technology*, vol. 23, Dec. 2024, Art. no. 100846, https://doi.org/10.1016/j.clet.2024.100846.

[9] 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, https://doi.org/10.1016/j.conbuildmat.2009.06.030.

[10] R. P. A. Almeida and G. C. Cordeiro, "Sustainable approach to simultaneously improve the pozzolanic activity of sugarcane bagasse ash and the vinasse fertilization potential," *Cleaner Engineering and Technology*, vol. 13, Apr. 2023, Art. no. 100617, https://doi.org/10.1016/j.clet.2023.100617.

[11] P. De Azevedo Basto, V. Estolano De Lima, and A. De Melo Neto, "Capability of R3 test to evaluate pozzolanicity of ground raw and calcined sugarcane bagasse ashes," *Materials Today: Proceedings*, Apr. 2023, Art. no. S2214785323019430, https://doi.org/10.1016/j.matpr.2023.04.048.

[12] S. Martins Torres, V. Estolano De Lima, P. De Azevedo Basto, N. T. De Araújo Júnior, and A. A. De Melo Neto, "Assessing the pozzolanic activity of sugarcane bagasse ash using X-ray diffraction," *Construction and Building Materials*, vol. 264, Dec. 2020, Art. no. 120684, https://doi.org/10.1016/j.conbuildmat.2020.120684.

[13] 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, https://doi.org/10.1016/j.cemconcomp.2014.11.002.

[14] G. C. Cordeiro, P. V. Andreão, and L. M. Tavares, "Pozzolanic properties of ultrafine sugar cane bagasse ash produced by controlled burning," *Heliyon*, vol. 5, no. 10, Oct. 2019, Art. no. e02566, https://doi.org/10.1016/j.heliyon.2019.e02566.

[15] J. Styer, L. Tunstall, A. Landis, and J. Grenfell, "Innovations in pavement design and engineering: A 2023 sustainability review," *Heliyon*, vol. 10, no. 13, Jul. 2024, Art. no. e33602, https://doi.org/10.1016/j.heliyon.2024.e33602.

[16] A. Hasheminezhad, H. Ceylan, and S. Kim, "Sustainability promotion through asphalt pavements: A review of existing tools and innovations," *Sustainable Materials and Technologies*, vol. 42, Dec. 2024, Art. no. e01162, https://doi.org/10.1016/j.susmat.2024.e01162.

[17] X. Ma, H. Hu, Y. Luo, W. Yao, Y. Wei, and A. She, "A carbon footprint assessment for usage of recycled aggregate and supplementary cementitious materials for sustainable concrete: A life-cycle perspective in China," *Journal of Cleaner Production*, vol. 490, Jan. 2025, Art. no. 144772, https://doi.org/10.1016/j.jclepro.2025.144772.

[18] K. Hu, S. T. A. Gillani, X. Tao, J. Tariq, and D. Chen, "Eco-friendly construction: Integrating demolition waste into concrete masonry blocks for sustainable development," *Construction and Building Materials*, vol. 460, Jan. 2025, Art. no. 139797, https://doi.org/10.1016/j.conbuildmat.2024.139797.

[19] K. Ganesan, K. Rajagopal, and K. Thangavel, "Evaluation of bagasse ash as supplementary cementitious material," *Cement and Concrete Composites*, vol. 29, no. 6, pp. 515–524, Jul. 2007, https://doi.org/10.1016/j.cemconcomp.2007.03.001.

[20] I. Martínez-Lage, F. Martínez-Abella, C. Vázquez-Herrero, and J. L. Pérez-Ordóñez., "Properties of plain concrete made with mixed recycled coarse aggregate," *Construction and Building Materials*, vol. 37, pp. 171–176, Dec. 2012, https://doi.org/10.1016/j.conbuildmat.2012.07.045.

[21] Md. H. R. Sobuz *et al.*, "Assessing the influence of sugarcane bagasse ash for the production of eco-friendly concrete: Experimental and machine learning approaches," *Case Studies in Construction Materials*, vol. 20, Jul. 2024, Art. no. e02839, https://doi.org/10.1016/j.cscm.2023.e02839.

[22] J. Xiao, J. Li, and Ch. Zhang, "Mechanical properties of recycled aggregate concrete under uniaxial loading," *Cement and Concrete Research*, vol. 35, no. 6, pp. 1187–1194, Jun. 2005, https://doi.org/10.1016/j.cemconres.2004.09.020.

[23] V. A. Ulloa, E. García-Taengua, M. J. Pelufo, A. Domingo, and P. Serna, "New Views on Effect of Recycled Aggregates on Concrete Compressive Strength," *ACI Materials Journal*, vol. 110, no. 6, 2013, https://doi.org/10.14359/51686336.

[24] A. Bahurudeen, D. Kanraj, V. Gokul Dev, and M. Santhanam, "Performance evaluation of sugarcane bagasse ash blended cement in concrete," *Cement and Concrete Composites*, vol. 59, pp. 77–88, May 2015, https://doi.org/10.1016/j.cemconcomp.2015.03.004.

[25] S. Yehia, K. Helal, A. Abusharkh, A. Zaher, and H. Istaitiyeh, "Strength and Durability Evaluation of Recycled Aggregate Concrete," *International Journal of Concrete Structures and Materials*, vol. 9, no. 2, pp. 219–239, Jun. 2015, https://doi.org/10.1007/s40069-015-0100-0.

[26] S. Senaratne, G. Lambrousis, O. Mirza, V. W. Y. Tam, and W. H. Kang, "Recycled Concrete in Structural Applications for Sustainable Construction Practices in Australia," *Procedia Engineering*, vol. 180, pp. 751–758, 2017, https://doi.org/10.1016/j.proeng.2017.04.235.

[27] F. Agrela, A. Barbudo, A. Ramírez, J. Ayuso, M. D. Carvajal, and J. R. Jiménez, "Construction of road sections using mixed recycled aggregates treated with cement in Malaga, Spain," *Resources, Conservation and Recycling*, vol. 58, pp. 98–106, Jan. 2012, https://doi.org/10.1016/j.resconrec.2011.11.003.

[28] J. Tavira, J. R. Jiménez, J. Ayuso, M. J. Sierra, and E. F. Ledesma, "Functional and structural parameters of a paved road section

constructed with mixed recycled aggregates from non-selected construction and demolition waste with excavation soil," *Construction and Building Materials*, vol. 164, pp. 57–69, Mar. 2018, https://doi.org/10.1016/j.conbuildmat.2017.12.195.

[29] A. Rajasekar, K. Arunachalam, M. Kottaisamy, and V. Saraswathy, "Durability characteristics of Ultra High Strength Concrete with treated sugarcane bagasse ash," *Construction and Building Materials*, vol. 171, pp. 350–356, May 2018, https://doi.org/10.1016/j.conbuildmat.2018.03.140.

[30] A. Arulrajah, J. Piratheepan, M. M. Disfani, and M. W. Bo, "Geotechnical and Geoenvironmental Properties of Recycled Construction and Demolition Materials in Pavement Subbase Applications," *Journal of Materials in Civil Engineering*, vol. 25, no. 8, pp. 1077–1088, Aug. 2013, https://doi.org/10.1061/(ASCE)MT.1943-5533.0000652.

[31] J. Zhang, X. An, and D. Nie, "Effect of fine aggregate characteristics on the thresholds of self-compacting paste rheological properties," *Construction and Building Materials*, vol. 116, pp. 355–365, Jul. 2016, https://doi.org/10.1016/j.conbuildmat.2016.04.069.

[32] M. Limbachiya, M. S. Meddah, and Y. Ouchagour, "Use of recycled concrete aggregate in fly-ash concrete," *Construction and Building Materials*, Sep. 2011, Art. no. S0950061811003771, https://doi.org/10.1016/j.conbuildmat.2011.07.023.

[33] M. Aslam, P. Shafigh, M. Alizadeh Nomeli, and M. Zamin Jumaat, "Manufacturing of high-strength lightweight aggregate concrete using blended coarse lightweight aggregates," *Journal of Building Engineering*, vol. 13, pp. 53–62, Sep. 2017, https://doi.org/10.1016/j.jobe.2017.07.002.

[34] E. Rahmani, M. Dehestani, M. H. A. Beygi, H. Allahyari, and I. M. Nikbin, "On the mechanical properties of concrete containing waste PET particles," *Construction and Building Materials*, vol. 47, pp. 1302–1308, Oct. 2013, https://doi.org/10.1016/j.conbuildmat.2013.06.041.

[35] I. A. Malak, T. D. Narwani, B. A. Memon, J. M. Wato, N. A. Jokhio, and S. A. Mallah, "Effect of Coarse Aggregate Gradation on the Strength Properties of Bagasse Ash Concrete," *Engineering, Technology & Applied Science Research*, vol. 13, no. 3, pp. 10820–10827, Jun. 2023, https://doi.org/10.48084/etasr.5807.

[36] K. Abuhishmeh and H. H. Jalali, "Risk Assessment of Infrastructure Using a Modified Adaptive Neurofuzzy System: Theoretical Application to Sewer Mains," *Journal of Pipeline Systems Engineering and Practice*, vol. 15, no. 2, May 2024, Art. no. 04024005, https://doi.org/10.1061/JPSEA2.PSENG-1560.

[37] A. R. Fayek, "Fuzzy Logic and Fuzzy Hybrid Techniques for Construction Engineering and Management," *Journal of Construction Engineering and Management*, vol. 146, no. 7, Jul. 2020, Art. no. 04020064, https://doi.org/10.1061/(ASCE)CO.1943-7862.0001854.

[38] M. Malek, M. Tumeo, and J. Saliba, "Fuzzy Logic Approach to Risk Assessment Associated with Concrete Deterioration," *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering*, vol. 1, no. 1, Mar. 2015, Art. no. 04014004, https://doi.org/10.1061/AJRUA6.0000811.