ISSN: 2393-8048
International Advance Journal of Engineering, Science and Management (IAJESM)
Multidisciplinary, Multilingual, Indexed, Double Blind, Open Access, Peer-Reviewed, Refereed-International Journal.
SJIF Impact Factor =8.152, January-June 2025, Submitted in May 2025

Strength and Durability Assessment of M40 Concrete Using Plastic Waste and Fly Ash as Partial Replacements

Nitesh, Student M-Tech Structural Engineering U.I.E.T, M.D.U Rohtak, niteshmahrolia1997@gmail.com

Abstract

This study evaluates the performance of M40 grade concrete using plastic waste (0–20%) as a fine aggregate replacement and fly ash (0–50%) as a cement substitute. Key parameters assessed include compressive strength, split tensile strength (STS), flexural strength (FS), and water absorption over curing periods of 7, 28, and 56 days.

Results show that compressive strength improves over time, with the highest strength (65 MPa) at 56 days achieved with 15% fly ash and 5% plastic waste. However, mixes with high plastic content (15–20%) exhibited reduced strength due to poor matrix bonding. Similarly, STS increased with moderate fly ash and plastic content, peaking at 6.5 MPa at 56 days. High plastic waste led to a noticeable drop in tensile strength.

Flexural strength followed a similar trend, with the best performance (10.0 MPa) observed at 56 days in the 15% fly ash + 5% plastic waste mix, indicating improved bending resistance and long-term performance. The water absorption test confirmed that mixes with higher plastic content and excessive fly ash had greater porosity, reducing durability. In contrast, mixes with 10–15% fly ash and 5% plastic waste showed lowest absorption (2.08%), indicating higher density and improved durability.

In conclusion, a mix of 15% fly ash and 5% plastic waste offers the best balance of strength, durability, and sustainability, supporting the use of eco-friendly concrete in sustainable construction. Excessive plastic waste (>10%) compromises mechanical properties, while moderate fly ash enhances long-term performance.

Keywords: Sustainable concrete, fly ash, plastic waste, compressive strength, tensile strength, flexural strength, water absorption, M40 concrete, durability, eco-friendly construction.

Introduction

The utilization of waste materials in construction has become a significant focus in the quest for more sustainable building practices. Two key waste materials that are gaining attention in this regard are fly ash and plastic waste. Fly ash, a byproduct of coal combustion, has long been used as a supplementary cementitious material (SCM) in concrete, offering benefits such as improved durability, reduced shrinkage, and lower environmental impact. On the other hand, plastic waste, which is a major environmental pollutant, is being increasingly explored as an alternative aggregate or reinforcement in concrete. By incorporating recycled plastics, concrete can be made more sustainable, with enhanced properties such as better workability, increased durability, and a reduction in plastic pollution. Both fly ash and plastic waste present valuable opportunities for waste valorization in the construction industry, contributing to a circular economy while reducing the reliance on traditional materials.

1.1 Fly Ash in Concrete

Fly ash, a byproduct of coal combustion, is a promising alternative material for sustainable construction. Its fine particles, rich in silica and alumina, react with calcium hydroxide in cement to enhance concrete by forming additional calcium silicate hydrate (C-S-H). Fly ash improves the durability and reduces long-term deformation in concrete. Bheel et al. (2020) studied the combined effects of rice husk ash and fly ash on concrete's mechanical properties. They found that the use of fly ash at a replacement level of 30% enhanced both compressive strength and water absorption resistance after 28 days of curing. Nayak et al. (2022) reviewed fly ash use in sustainable construction, emphasizing its role in reducing cement consumption. They concluded that fly ash blends, especially those replacing up to 30% of cement, improve the durability and strength of concrete over time, which is crucial for minimizing the environmental impact of construction. Khankhaje et al. (2023) focused on pervious concrete and the incorporation of fly ash as a partial cement replacement. Their review found that fly ash improved the mechanical properties and permeability of pervious concrete, making it more sustainable for urban infrastructure projects. Huang et al. (2021) explored the use of fly ash from thermal conversion of sludge as a cement substitute. Their findings showed that using fly ash significantly improved the frost resistance and compressive strength of concrete, especially when the fly ash content was kept at around 20-30%. Hafez et al. (2020) examined the environmental and energy-saving benefits of incorporating fly ash and nanoadditives in concrete. Their study showed that this combination enhanced the mechanical properties and overall performance of the concrete, highlighting the potential for sustainable construction practices.

Marshdi et al. (2020) studied the effect of fly ash combined with rice husk ash in pervious concrete. They concluded that this combination significantly improved the strength and sustainability of pervious concrete, with optimal replacement levels for fly ash being 20-30%. Borges et al. (2020) analyzed the performance of concrete with high-volume fly ash replacement (50-70%). They found that while high replacement levels delayed the initial strength development, long-term strength and durability benefits were observed, making it suitable for non-structural applications. De Maeijer et al. (2020) focused on ultra-fine fly ash and its potential as a cement replacement. Their study found that ultra-fine fly ash enhanced the durability and mechanical properties of concrete, with the best results seen at replacement levels of 20-30%. Panda and Sahoo (2021) reviewed the effects of fly ash and Ground Granulated Blast Furnace Slag (GGBS) in concrete. Their study indicated that replacing cement with these materials improved concrete's resistance to chloride penetration and its overall environmental footprint. Sandanayake et al. (2020) compared fly ash with other waste materials like rice husk ash in concrete. They concluded that fly ash's use as a partial replacement in high-strength concrete provided both economic and environmental benefits, especially when combined with other industrial by-products.

1.2 Plastic Waste in Concrete

Plastic waste, a non-biodegradable pollutant, is being explored as an alternative material for sustainable concrete. Akram et al. (2015) explored the effect of using plastic waste as a partial replacement for coarse aggregates in concrete at percentages of 5%, 10%, and 15%. The study concluded that the use of plastic waste improved the workability of concrete, although the strength was reduced as the replacement increased. However, concrete with up to 10% plastic waste showed reasonable mechanical performance. Sabău and Vargas (2018) examined the incorporation of e-plastic waste as a replacement for coarse aggregates. Their findings indicated that replacing up to 30% of aggregates with e-plastic waste resulted in acceptable compressive strength, but workability improved significantly, making it a sustainable option for non-structural applications. Sambhaji (2016) focused on the effect of waste plastic in concrete as aggregate replacement. Their work confirmed that up to 20% of plastic waste as aggregate replacement provided a balance between strength and sustainability, although further increases in plastic content resulted in a decrease in compressive strength. Al-Tayeb et al. (2022) explored the use of plastic waste in concrete mixtures, substituting fine aggregates with up to 40% plastic waste. The study showed that while plastic waste significantly improved the workability of the mix, the strength of concrete decreased as the percentage of plastic waste increased beyond 30%.

Ahmad et al. (2022) provided a comprehensive review on the use of plastic waste as both aggregates and fibers in concrete. Their research concluded that plastic waste can serve as a viable substitute, especially when used in lower proportions (10-20%) without compromising the concrete's structural integrity.. Mohamedsalih et al. (2024) studied the effects of substituting natural coarse aggregates with plastic waste. Their results indicated that up to 25% replacement of coarse aggregates with plastic waste enhanced the workability and reduced the overall environmental impact without significantly affecting strength. Manjunath (2016) investigated the use of mixed plastic waste as a replacement for fine aggregates. The study suggested that up to 15% replacement could be used for low-strength concrete, though it showed limited improvement in terms of durability and strength properties. Rahim et al. (2013) explored using HDPE plastic waste as coarse aggregate in concrete. They found that the mechanical properties of concrete reduced as the proportion of plastic waste increased, but the incorporation of plastic waste reduced the overall weight of concrete, making it a potential material for lightweight concrete applications. Shiuly et al. (2024) examined the replacement of both fine and coarse aggregates with plastic waste in concrete. They reported that the incorporation of plastic waste improved workability but negatively affected compressive strength beyond 30% replacement levels. Safi et al. (2018) conducted a study on using plastic waste as aggregate in concrete. They determined that the use of up to 20% plastic waste was feasible without a significant loss of compressive strength, thus contributing to waste reduction and providing a sustainable option for concrete production.

2. Experimental Study

In this study, a variety of materials were carefully selected and prepared to develop a sustainable concrete mix. The primary binder used was Ordinary Portland Cement (OPC) 43 grade, with a specific gravity of 3.15, incorporated at 404.34 kg/m³ to achieve desired strength and durability. Fly ash (Class C), with a specific gravity of 2.2, was used as a partial cement replacement at varying levels (0–50%) to enhance long-term performance and sustainability. Natural river sand, serving as fine aggregate, had a specific gravity of 3.63 and fineness modulus of 3.68, with a mix proportion of 940.79 kg/m³. Plastic waste, sourced from Ambala and processed into fine granules, replaced sand at levels up to 20%, promoting eco-friendly concrete. It had a specific gravity of 0.91 and a fineness modulus of 3.71. Crushed stone coarse aggregates, with a nominal size of 20 mm, specific gravity of 2.62, and fineness modulus of 6.13, were used at 1062.07 kg/m³ to ensure mechanical strength and load-bearing capacity. Additional ingredients like water and superplasticizer were used to enhance workability and overall performance of the mix.

2.1 Mix Design

The M40 concrete mix was meticulously designed to achieve a characteristic compressive strength of 40 MPa while ensuring workability, durability, and environmental sustainability. The design followed IS 10262:2019 and IS 456:2000 standards, incorporating Ordinary Portland Cement (OPC 43 grade) as the primary binder and Class C fly ash as a partial cement replacement at levels of 0%, 10%, 15%, 30%, and 50%. Locally sourced fine aggregate (natural river sand) and coarse aggregate (20 mm crushed stone) were used, with a 61% coarse aggregate ratio to ensure optimal gradation and structural integrity. Shredded plastic waste, collected from Ambala, was used as a partial fine aggregate replacement at 0%, 5%, 10%, 15%, and 20%, promoting sustainable construction practices by utilizing waste materials. The mix adopted a water-to-cement ratio of 0.42 and a water content of 190 liters, which was reduced to 169.82 kg/m³ through the use of a superplasticizer (1% dosage), enhancing workability without compromising strength. Final mix proportions per cubic meter included 404.34 kg of cement, 940.79 kg of fine aggregate, and 1062.07 kg of coarse aggregate. A total of 25 different mix combinations were prepared based on varying percentages of plastic waste and fly ash, allowing for a comprehensive evaluation of their influence on fresh and hardened concrete properties.

Table 1: Concrete Mix design

Mix Name	Plastic Waste (%)	Fly Ash (%)	Fly Ash (Kg/m^3)	Cement (Kg/m^3)	Plastic waste (Kg/m^3)	FA (Kg/m^3)	CA (Kg/m^3)	Water (Kg/m^3)
PW0_FA0	0	0	0	404.34	0	940.79	1062.1	170

ISSN: 2393-8048
International Advance Journal of Engineering, Science and Management (IAJESM)
Multidisciplinary, Multilingual, Indexed, Double Blind, Open Access, Peer-Reviewed, Refereed-International Journal.
SJIF Impact Factor =8.152, January-June 2025, Submitted in May 2025

PW0_FA10	0	10	40.434	363.906	0	940.79	1062.1	170
PW0_FA15	0	15	60.651	343.689	0	940.79	1062.1	170
PW0_FA30	0	30	121.3	283.038	0	940.79	1062.1	170
PW0_FA50	0	50	202.17	202.17	0	940.79	1062.1	170
PW5_FA0	5	0	0	404.34	47.04	893.75	1062.1	170
PW5_FA10	5	10	40.434	363.906	47.04	893.75	1062.1	170
PW5_FA15	5	15	60.651	343.689	47.04	893.75	1062.1	170
PW5_FA30	5	30	121.3	283.038	47.04	893.75	1062.1	170
PW5_FA50	5	50	202.17	202.17	47.04	893.75	1062.1	170
PW10_FA0	10	0	0	404.34	94.079	846.71	1062.1	170
PW10_FA10	10	10	40.434	363.906	94.079	846.71	1062.1	170
PW10_FA15	10	15	60.651	343.689	94.079	846.71	1062.1	170
PW10_FA30	10	30	121.3	283.038	94.079	846.71	1062.1	170
PW10_FA50	10	50	202.17	202.17	94.079	846.71	1062.1	170
PW15_FA0	15	0	0	404.34	141.12	799.67	1062.1	170
PW15_FA10	15	10	40.434	363.906	141.12	799.67	1062.1	170
PW15_FA15	15	15	60.651	343.689	141.12	799.67	1062.1	170
PW15_FA30	15	30	121.3	283.038	141.12	799.67	1062.1	170
PW15_FA50	15	50	202.17	202.17	141.12	799.67	1062.1	170
PW20_FA0	20	0	0	404.34	188.16	752.63	1062.1	170
PW20_FA10	20	10	40.434	363.906	188.16	752.63	1062.1	170
PW20_FA15	20	15	60.651	343.689	188.16	752.63	1062.1	170
PW20_FA30	20	30	121.3	283.038	188.16	752.63	1062.1	170
PW20_FA50	20	50	202.17	202.17	188.16	752.63	1062.1	170

The experimental program included a comprehensive series of tests to evaluate the fresh and hardened properties of M40 concrete with varying levels of fly ash and plastic waste. Workability was assessed using the slump test as per IS 1199:2018, ensuring the mix's ease of handling and placement. Mechanical properties were evaluated through compressive strength tests on cube specimens (IS 516:2018), split tensile strength tests on cylindrical specimens (IS 5816:1999), and flexural strength tests on beam specimens (IS 516:2018) at curing ages of 7, 28, and 56 days. Additionally, water absorption tests were performed following ASTM C642 to assess porosity and durability. All tests were conducted under controlled laboratory conditions to ensure accurate and reliable data for analyzing the impact of fly ash and plastic waste on concrete performance.

Figure 1: Experimental analysis

3. Results and Discussion

3.1 Workability

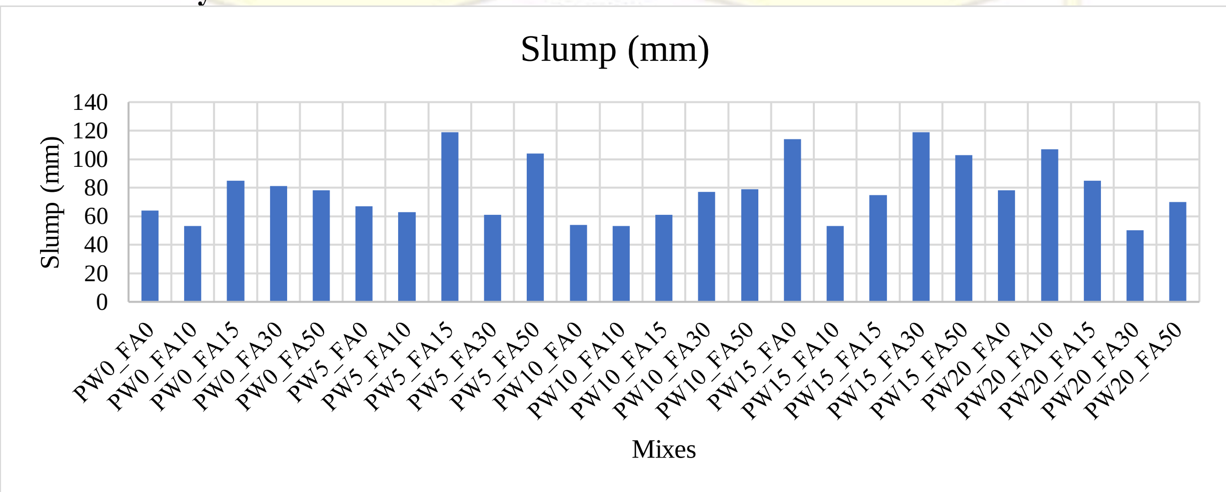

Figure 0.1: Workability analysis

The workability trends observed in the results highlight a complex interaction between fly ash and plastic waste. The optimum workability was found in mixes with 5-10% plastic waste combined with 10-15% fly ash, where slump values remained between 75-100 mm, ensuring good flowability while maintaining structural integrity. Additionally, some mixes with high fly ash content (50%) and moderate plastic waste (5-10%) exhibited slump values above 90 mm, likely due to the lubricating effect of fly ash counteracting the reduced cohesion caused by plastic waste

3.2 Compressive Strength

The 7-day compressive strength results reveal noticeable variations across different concrete mixes, influenced primarily by the replacement levels of plastic waste and fly ash. The recorded compressive strength values range from 25 MPa to 40 MPa, indicating how these materials impact the early-age strength development of concrete.

The compressive strength results indicated a clear relationship between plastic waste and fly ash replacement levels. At 7 days, the compressive strength ranged from 25 MPa to 40 MPa, with the highest strength recorded in mixes containing 10-15% fly ash and 5% plastic waste. High fly ash replacements (30-50%) resulted in lower early-age strength due to the slow

ISSN: 2393-8048
International Advance Journal of Engineering, Science and Management (IAJESM)
Multidisciplinary, Multilingual, Indexed, Double Blind, Open Access, Peer-Reviewed, Refereed-International Journal.
SJIF Impact Factor =8.152, January-June 2025, Submitted in May 2025

pozzolanic reaction. However, by 28 days, compressive strength improved, ranging from 40 MPa to 55 MPa, with optimal strength found at 15% fly ash and 5% plastic waste. At 56 days, compressive strength values peaked at 50 MPa to 65 MPa, confirming that fly ash enhances long-term strength development. Conversely, mixes with high plastic waste content (15-20%) showed a notable reduction in compressive strength, as plastic disrupted the matrix bonding. The optimal mix for compressive strength was found to be 15% fly ash and 5% plastic waste, ensuring structural adequacy while maintaining sustainability.

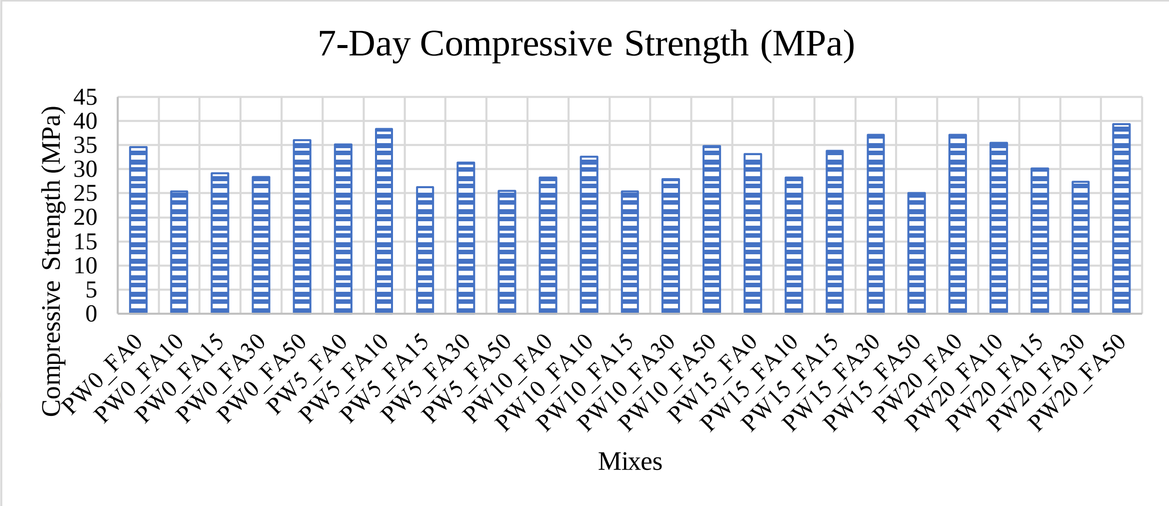

Figure 2: 7-day compressive strength analysis

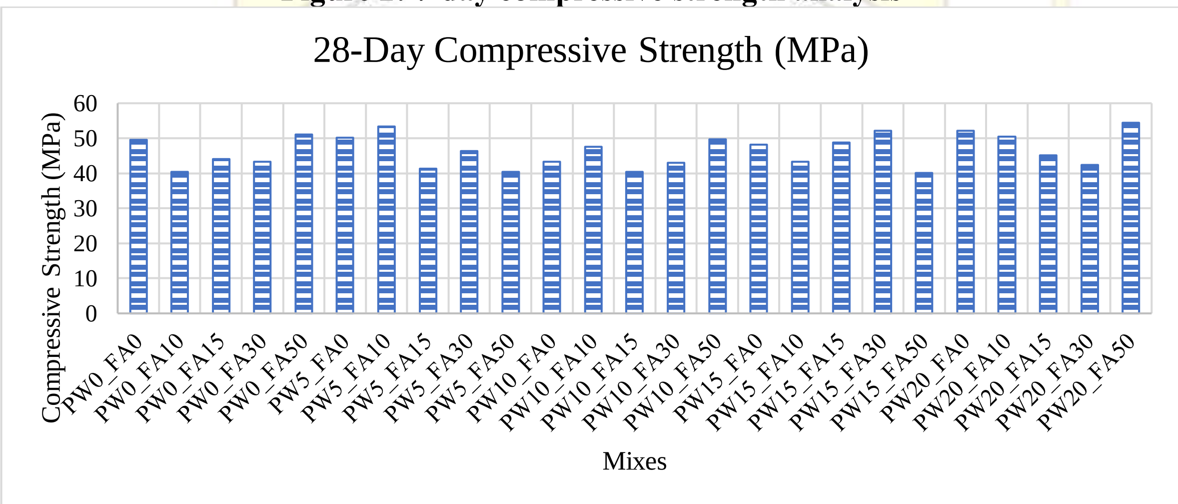

Figure 3: 28-day compressive strength analysis

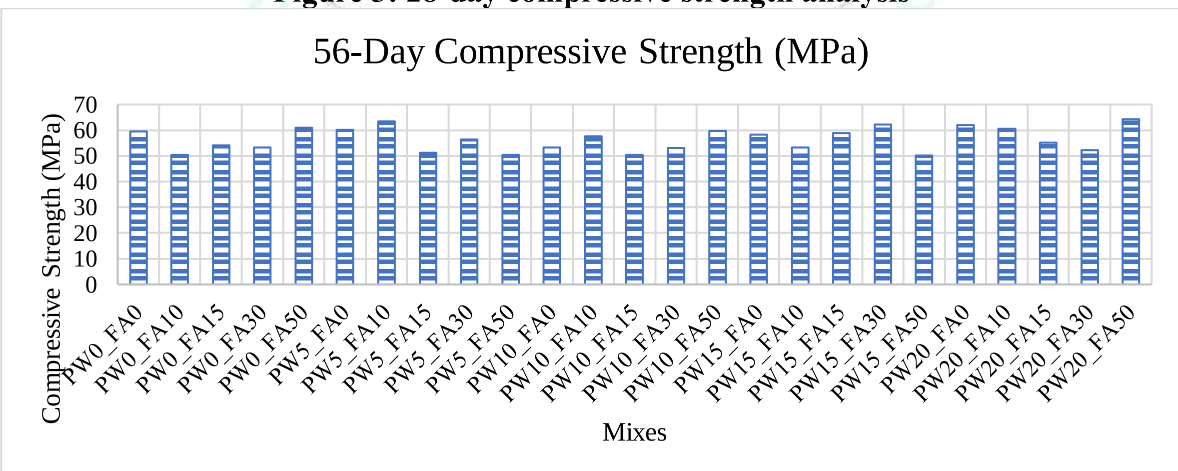

Figure 4: 56-day compressive strength analysis

ISSN: 2393-8048
International Advance Journal of Engineering, Science and Management (IAJESM)
Multidisciplinary, Multilingual, Indexed, Double Blind, Open Access, Peer-Reviewed, Refereed-International Journal.
SJIF Impact Factor =8.152, January-June 2025, Submitted in May 2025

3.3 Tensile strength

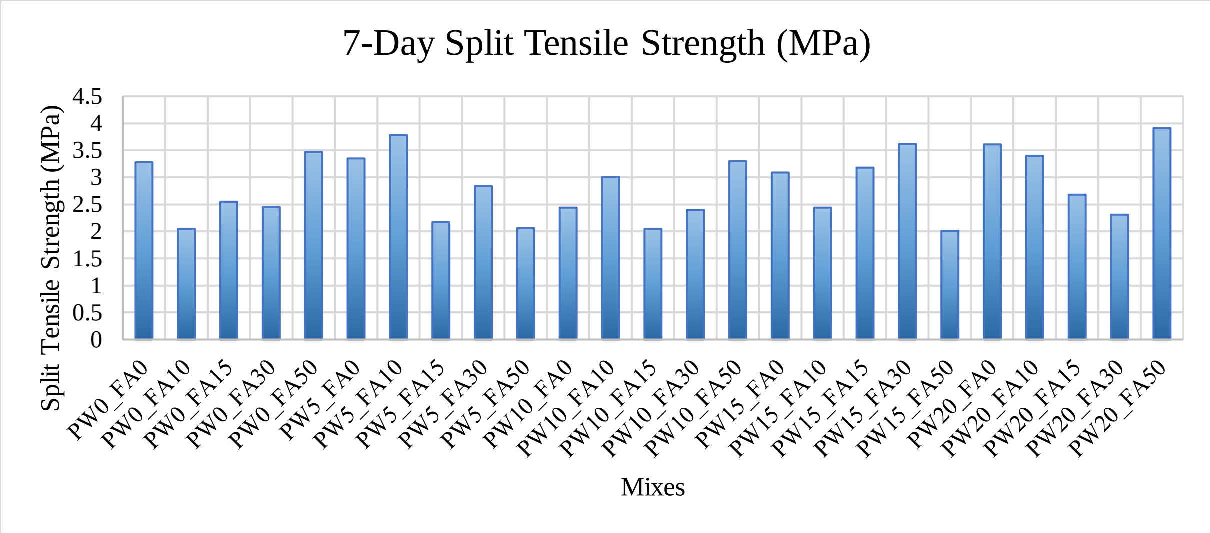

Figure 5: 7-Day Split Tensile Strength

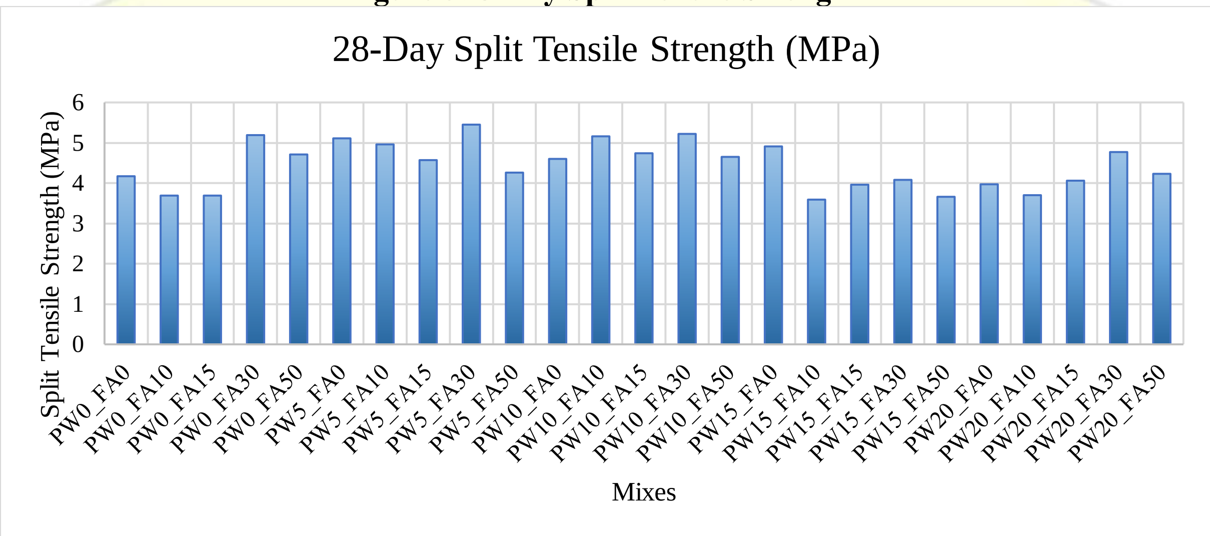

Figure 6: 28-Day Split Tensile Strength

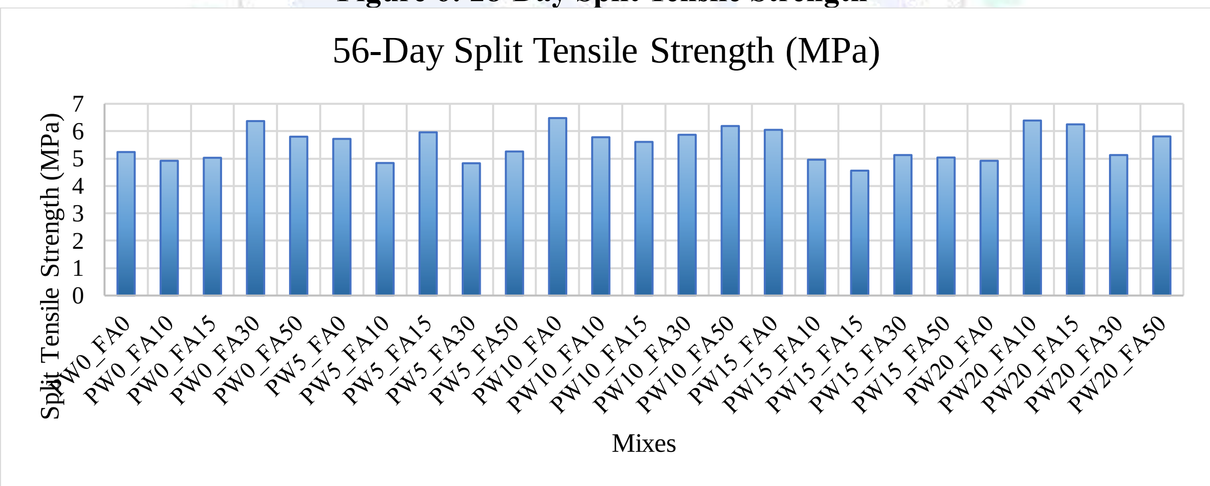

Figure 7: 56-Day Split Tensile Strength

The split tensile strength results followed a similar trend to compressive strength. At 7 days, values ranged from 2.0 MPa to 4.0 MPa, with high plastic waste content significantly reducing tensile strength due to poor adhesion between plastic particles and the cementitious matrix. By 28 days, split tensile strength improved to 3.5 MPa to 5.5 MPa, and at 56 days, it peaked at 4.5

ISSN: 2393-8048
International Advance Journal of Engineering, Science and Management (IAJESM)
Multidisciplinary, Multilingual, Indexed, Double Blind, Open Access, Peer-Reviewed, Refereed-International Journal.
SJIF Impact Factor =8.152, January-June 2025, Submitted in May 2025

MPa to 6.5 MPa. The best-performing mix contained 10-15% fly ash and 5% plastic waste, achieving a balance between tensile resistance, durability, and sustainability. High plastic waste (>10%) resulted in excessive loss of cohesion, reducing the split tensile strength beyond acceptable limits.

3.4 Flexural Strength

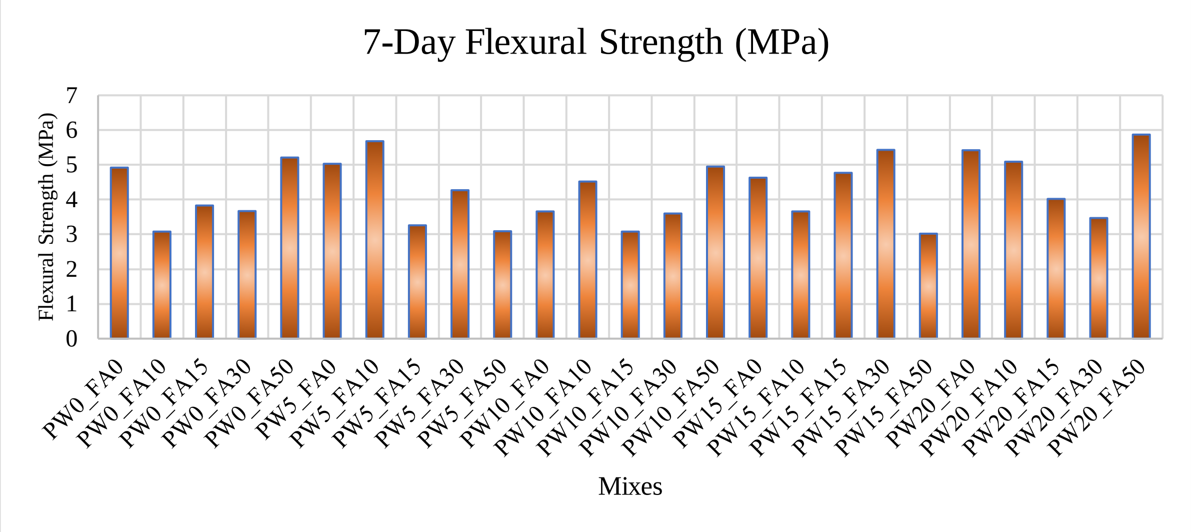

Figure 8: 7-Day Flexural Strength analysis

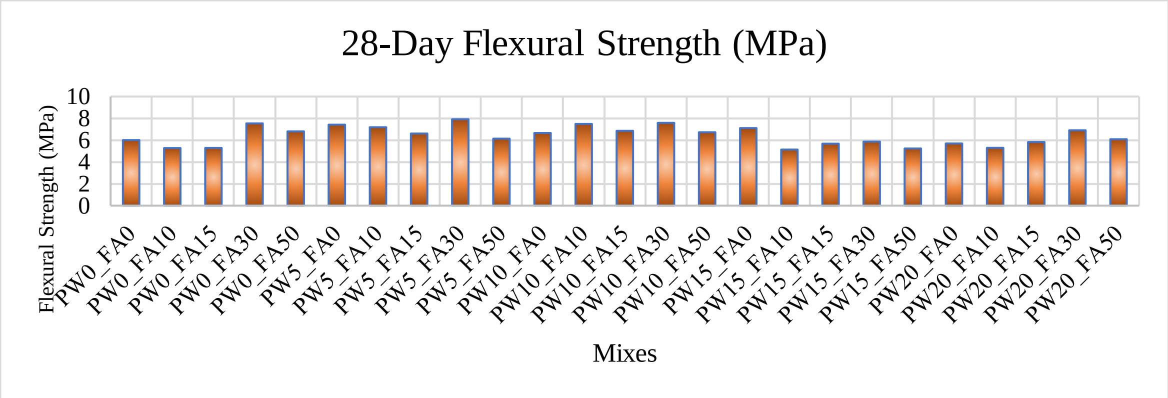

Figure 9: 28-Day Flexural Strength analysis

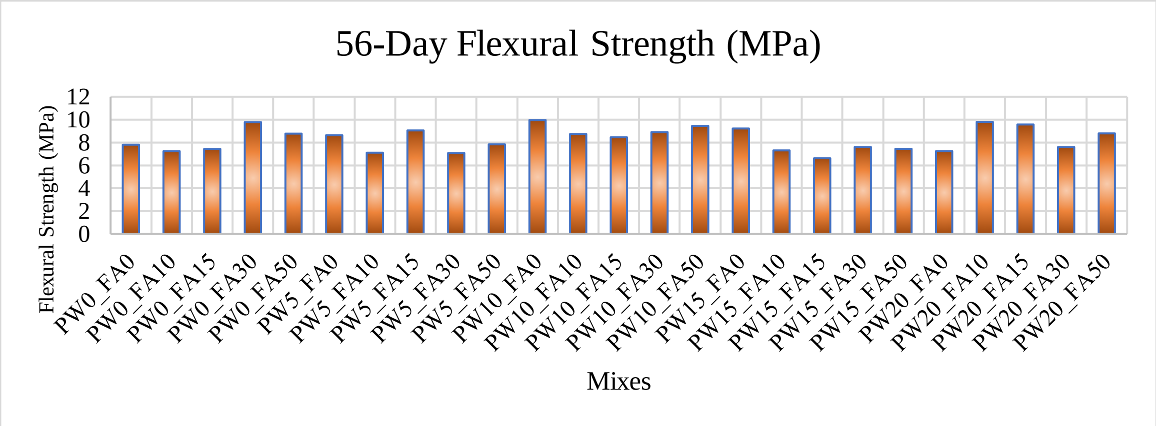

Figure 10: 56-Day Flexural Strength

Flexural strength tests revealed that plastic waste and fly ash significantly influenced the bending resistance of concrete. At 7 days, flexural strength values ranged from 3.0 MPa to 6.0 MPa, while 28-day values varied from 5.0 MPa to 8.0 MPa. By 56 days, the flexural strength was recorded between 6.5 MPa and 10.0 MPa, with the best performance seen at 15% fly ash and 5% plastic waste. The reduction in flexural strength at high plastic waste levels (15-20%)

was attributed to increased voids and weaker bonding between aggregate and cement paste. The recommended mix for achieving high flexural performance was 10-15% fly ash and 5% plastic waste, ensuring structural resilience while maintaining sustainability.

3.5 Durability

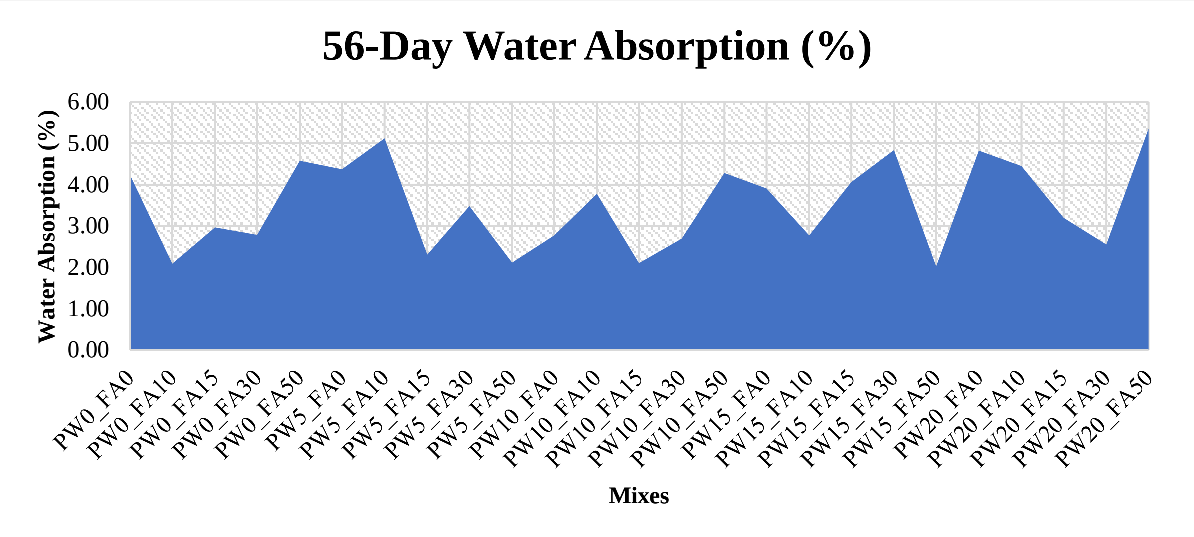

Figure 11: 56-day water absorption analysis

Water absorption tests conducted at 56 days demonstrated the effect of plastic waste and fly ash on the permeability of concrete. The lowest water absorption (2.08%) was observed in mixes with 10-15% fly ash and 5% plastic waste, indicating a denser and more durable concrete matrix. High plastic waste replacement levels (>10%) led to higher water absorption values (above 4.5%), suggesting an increase in porosity and reduced resistance to moisture ingress. Similarly, excessive fly ash replacement (50%) resulted in higher absorption (above 5.0%), confirming that while fly ash enhances long-term strength, excessive use may lead to increased porosity. The optimal mix for durability was identified as 15% fly ash and 5% plastic waste, achieving the best balance between low permeability, improved density, and environmental benefits.

The findings from this study confirm that M40 concrete incorporating 10-15% fly ash and 5-10% plastic waste offers an optimal balance between strength, durability, and sustainability. While plastic waste above 10% negatively impacts mechanical properties, controlled use within 5-10% maintains strength and contributes to environmental sustainability. Fly ash improves long-term strength and durability, but excessive replacement (>30%) delays early strength gain. Thus, a mix of 15% fly ash and 5% plastic waste is recommended for practical applications, ensuring high strength, durability, and sustainable resource utilization.

This study highlights the potential for utilizing waste materials in concrete, reducing dependence on natural resources, and minimizing plastic pollution, paving the way for eco-friendly and cost-effective construction practices in the future.

Conclusion

This study successfully demonstrates the potential of incorporating plastic waste and fly ash into M40 grade concrete to enhance sustainability without significantly compromising mechanical and durability performance. Through comprehensive experimental analysis, including compressive, tensile, and flexural strength testing, as well as water absorption evaluations, the study identifies the optimal mix design that offers a balance between strength development, workability, and environmental benefits.

The findings revealed that replacing cement with 15% fly ash and fine aggregate with 5% plastic waste produced the most favorable results in terms of strength and durability. At this level, the concrete achieved a peak compressive strength of 65 MPa, tensile strength of 6.5

MPa, and flexural strength of 10 MPa at 56 days of curing values that meet or exceed the requirements for M40 grade concrete. Moreover, this mix showed the lowest water absorption (2.08%), indicating reduced porosity and enhanced durability.

However, the study also notes that higher plastic waste content (above 10%) negatively affects the concrete's mechanical performance due to poor interfacial bonding between plastic particles and the cementitious matrix. Similarly, high fly ash content (30–50%) led to delayed strength gain, especially at early ages, due to slower pozzolanic reactions. These outcomes highlight the importance of maintaining optimal replacement levels to achieve durable and structurally sound concrete.

4. References

1. S. Abu-Melha, "Preparation of photochromic and afterglow concrete from recycled polystyrene plastic waste immobilized with strontium aluminate nanoparticles," J. Photochem. Photobiol. A Chem., vol. 450, no. December 2023, p. 115435, 2024, doi: 10.1016/j.jphotochem.2023.115435.
2. R. Alzein et al., "Polypropylene waste plastic fiber morphology as an influencing factor on the performance and durability of concrete: Experimental investigation, soft-computing modeling, and economic analysis," Constr. Build. Mater., vol. 438, no. July, p. 137244, 2024, doi: 10.1016/j.conbuildmat.2024.137244.
3. R. Haigh, "The mechanical behaviour of waste plastic milk bottle fibres with surface modification using silica fume to supplement 10% cement in concrete materials," Mech. Behav. waste Plast. milk bottle fibres with Surf. Modif. using silica fume to Suppl. 10% Cem. Concr. Mater., vol. 416, no. January, p. 135215, 2024, doi: 10.1016/j.conbuildmat.2024.135215.
4. U. Asif, M. Faisal, D. Mohammed, F. Aslam, D. Salama, and A. Elminaam, "Data-driven evolutionary programming for evaluating the mechanical properties of concrete containing plastic waste.," Case Stud. Constr. Mater., vol. 21, no. April, p. e03763, 2024, doi: 10.1016/j.cscm.2024.e03763.
5. A. J. Babafemi, C. Norval, J. T. Kolawole, S. Chandra Paul, and K. A. Ibrahim, "3D-printed limestone calcined clay cement concrete incorporating recycled plastic waste (RESIN8)," Results Eng., vol. 22, no. April, p. 102112, 2024, doi: 10.1016/j.rineng.2024.102112.
6. J. Cao, N. Tu, T. Liu, Z. Han, B. Tu, and Y. Zhou, "Prediction models for creep and creep recovery of fly ash concrete," Constr. Build. Mater., vol. 428, no. April, p. 136398, 2024, doi: 10.1016/j.conbuildmat.2024.136398.
7. M. R et al., "Performance of recycled Bakelite plastic waste as eco-friendly aggregate in the concrete beams," Case Stud. Constr. Mater., vol. 18, 2023, doi: 10.1016/j.cscm.2023.e02200.
8. Z. Chao, H. Wang, S. Hu, M. Wang, S. Xu, and W. Zhang, "Permeability and porosity of light-weight concrete with plastic waste aggregate: Experimental study and machine learning modelling," Constr. Build. Mater., vol. 411, no. October 2023, p. 134465, 2024, doi: 10.1016/j.conbuildmat.2023.134465.
9. N. B. Frahat, A. S. Malek, A. Ali, and O. M. O. Ibrahim, "New strategy for closing the plastic loop: Lightweight concrete by the waste of recycled synthetic fibers," Constr. Build. Mater., vol. 423, no. December 2023, p. 135896, 2024, doi: 10.1016/j.conbuildmat.2024.135896.
10. M. Grzegorczyk-Frańczak, M. Janek, M. Szeląg, R. Panek, and K. Materak, "Modification of the polymeric admixture based on polycarboxylate ether using silica-derived secondary materials obtained from fly ash and the efficiency of its application in concrete," Case Stud. Constr. Mater., vol. 21, no. July, 2024, doi: 10.1016/j.cscm.2024.e03903.

11. Z. Guo, Q. Sun, L. Zhou, T. Jiang, C. Dong, and Q. Zhang, "Mechanical properties, durability and life-cycle assessment of waste plastic fiber reinforced sustainable recycled aggregate self-compacting concrete," J. Build. Eng., vol. 91, no. May, p. 109683, 2024, doi: 10.1016/j.jobe.2024.109683.
12. H. M. Hamada et al., "Enhancing sustainability in concrete construction: A comprehensive review of plastic waste as an aggregate material," Sustain. Mater. Technol., vol. 40, no. December 2023, p. e00877, 2024, doi: 10.1016/j.susmat.2024.e00877.
13. D. Hu, N. Hu, S. Ben, H. Zhao, S. Chen, and Y. Xiang, "Jo ur f," Multiscale Predict. Model Autogenous Shrinkage High-Volume Fly Ash Concr., p. 111281, 2024, doi: 10.1016/j.jobe.2024.111281.
14. U. Hule, S. Rathnarajan, R. G. . Pillai, R. Gettu, and M. Santhanam, "10-year natural carbonation of concretes with limestone, flyash, volcanic ash, and slag and exposed to tropical climate in India," Mendeley Data, v1, vol. 57, p. 111006, 2024, doi: 10.1016/j.dib.2024.111006.
15. A. K. Krishnan, Y. C. Wong, Z. Zhang, and A. Arulrajah, "Jo ur na l P re r f," A Transit. Towar. Circ. Econ. with Util. Recycl. fly ash waste Mater. clay, Concr. fly ash bricks A Rev., p. 111210, 2024, doi: 10.1016/j.jobe.2024.111210.
16. V. V. P. Kumar et al., "Chemistry of Inorganic Materials A systematic analysis of binary blend cement concrete infused with lime sludge and fl y ash," A Syst. Anal. Bin. blend Cem. Concr. infused with lime sludge fly ash, vol. 4, no. July, p. 100065, 2024, doi: 10.1016/j.cinorg.2024.100065.
17. A. Lekhya and N. S. Kumar, "A study on the effective utilization of ultrafine fly ash and silica fume content in high-performance concrete through an experimental approach," Heliyon, vol. 10, no. 22, p. e39678, 2024, doi: 10.1016/j.heliyon.2024.e39678.
18. J. Li, W. Zha, W. Lv, T. Xu, B. Wang, and B. Wang, "Mechanical properties and sulfate resistance of basalt fiber-reinforced alkali-activated fly ash-slag-based coal gangue pervious concrete," Case Stud. Constr. Mater., vol. 21, no. November, p. e03961, 2024, doi: 10.1016/j.cscm.2024.e03961.
19. S. M. Lim, M. He, G. Hao, T. C. A. Ng, and G. P. Ong, "Recyclability potential of waste plastic-modified asphalt concrete with consideration to its environmental impact," Constr. Build. Mater., vol. 439, no. April, p. 137299, 2024, doi: 10.1016/j.conbuildmat.2024.137299.
20. L. Miao, M. Wen, C. Jiao, S. He, and X. Guan, "Concrete microstructure characterized by multi-measurement techniques considering fly ash contents and concrete sample sizes," Case Stud. Constr. Mater., vol. 20, no. April, p. e03315, 2024, doi: 10.1016/j.cscm.2024.e03315.
21. N. Miyan, N. M. A. Krishnan, and S. Das, "Integrating data imputation and augmentation with interpretable machine learning for efficient strength prediction of fly ash-based alkali-activated concretes," J. Build. Eng., vol. 98, no. November, p. 111248, 2024, doi: 10.1016/j.jobe.2024.111248.
22. T. Mohammed, A. Torres, F. Aguayo, and I. K. Okechi, "Evaluating carbonation resistance and microstructural behaviors of calcium sulfoaluminate cement concrete incorporating fly ash and limestone powder," Constr. Build. Mater., vol. 442, no. May, p. 137551, 2024, doi: 10.1016/j.conbuildmat.2024.137551.
23. M. Murtaza, J. Zhang, C. Yang, C. Su, and H. Wu, "Durability of high strength self-compacting concrete with fly ash , coal gangue powder , cement kiln dust , and recycled concrete powder," vol. 449, no. July, 2024.
24. L. A. Parsons and S. O. Nwaubani, "Mechanical and durability performance of concrete made using acrylonitrile butadiene styrene plastic from waste-EEE as a partial replacement

of the coarse aggregate," J. Build. Eng., vol. 85, no. January, p. 108635, 2024, doi: 10.1016/j.jobe.2024.108635.
25. L. A. Parsons and S. O. Nwaubani, "Abrasion-wear resistance of precarbonated and water-cured concrete made using ABS plastic derived from waste electrical and electronic equipment," Cem. Concr. Res., vol. 179, no. February, p. 107470, 2024, doi: 10.1016/j.cemconres.2024.107470.
26. M. R. M. Al-Alusi, N. H. Kurdi, A. I. Al-Hadithi, and A. Hammad, "An experimental investigation of the mechanical characteristics and drying shrinkage of a single-size expanded polystyrene lightweight concrete reinforced with waste plastic fibres," Constr. Build. Mater., vol. 415, no. January, p. 135048, 2024, doi: 10.1016/j.conbuildmat.2024.135048.
27. S. Saha, D. Sau, and T. Hazra, "Economic viability analysis of recycling waste plastic as aggregates in green sustainable concrete," Waste Manag., vol. 169, no. February, pp. 289–300, 2023, doi: 10.1016/j.wasman.2023.07.023.
28. L. S. R. Maradani and B. Pradhan, "Effect of chloride and sulphate on ionic concentration of aqueous pore solution and microstructural properties of fly ash-GBFS geopolymer concrete," Constr. Build. Mater., vol. 440, no. May, p. 137422, 2024, doi: 10.1016/j.conbuildmat.2024.137422.
29. P. Saingam et al., "Synergizing Portland Cement, high-volume fly ash and calcined calcium carbonate in producing self-compacting concrete: A comprehensive investigation of rheological, mechanical, and microstructural properties," Case Stud. Constr. Mater., vol. 21, no. August, p. e03832, 2024, doi: 10.1016/j.cscm.2024.e03832.
30. U. Salini and A. Parayil, "Behavior of controlled low-strength material incorporating industrial by-products fly ash, quarry waste and concrete waste," Constr. Build. Mater., vol. 447, no. May, p. 138057, 2024, doi: 10.1016/j.conbuildmat.2024.138057.
31. V. Shobeiri, B. Bennett, T. Xie, and P. Visintin, "A comprehensive data driven study of mechanical properties of concrete with waste-based aggregates: Plastic, rubber, slag, glass and concrete," Case Stud. Constr. Mater., vol. 20, no. August 2023, p. e02815, 2024, doi: 10.1016/j.cscm.2023.e02815.
32. A. R. Shrestha, J. Xia, L. Di Sarno, and C. S. Chen, "Feasibility study of utilizing Autoclaved Aerated Concrete (AAC) waste for the production of cold bonded lightweight artificial aggregate using high volume fly ash (HVFA) binders," Constr. Build. Mater., vol. 449, no. May, p. 138414, 2024, doi: 10.1016/j.conbuildmat.2024.138414.
33. J. Sidhu and P. Kumar, "Experimental investigation on the effect of integral hydrophobic modification on the properties of fly ash-slag based geopolymer concrete," Constr. Build. Mater., vol. 452, no. October, p. 138818, 2024, doi: 10.1016/j.conbuildmat.2024.138818.
34. Q. Song et al., "Novel high-efficiency solid particle foam stabilizer: Effects of modified fly ash on foam properties and foam concrete," Cem. Concr. Compos., vol. 155, no. July 2024, p. 105818, 2025, doi: 10.1016/j.cemconcomp.2024.105818.
35. I. Wahab et al., "Effect of crumb rubber and polyethylene fiber on the strength and toughness of fly ash / slag-based geopolymer concrete," Constr. Build. Mater., vol. 455, no. August, p. 139133, 2024, doi: 10.1016/j.conbuildmat.2024.139133.
36. M. Wang et al., "Performance comparison of several explainable hybrid ensemble models for predicting carbonation depth in fly ash concrete," J. Build. Eng., vol. 98, no. July, p. 111246, 2024, doi: 10.1016/j.jobe.2024.111246.
37. Y. Yılmaz and S. Nayır, "Machine learning based prediction of compressive and flexural strength of recycled plastic waste aggregate concrete," Structures, vol. 69, no. June, 2024, doi: 10.1016/j.istruc.2024.107363.

38. H. Zhang et al., “Rheology, shrinkage, mechanical properties and microstructure of ultra-light-weight concrete with fly ash cenospheres,” J. Build. Eng., vol. 98, no. August, 2024, doi: 10.1016/j.jobe.2024.111258.
39. M. Zhao, J. Li, C. Li, and J. Shen, “Experimental study and prediction of the long-term strength development of high-flowability concrete made of mixed sand and high-content fly ash,” Constr. Build. Mater., vol. 437, no. December 2023, p. 137043, 2024, doi: 10.1016/j.conbuildmat.2024.137043.
40. Bheel, N., Jokhio, M. A., & Abbasi, J. A. (2020). Rice husk ash and fly ash effects on the mechanical properties of concrete. ResearchGate.
41. Nayak, D. K., Abhilash, P. P., Singh, R., Kumar, R., & Kumar, V. (2022). Fly ash for sustainable construction: A review of fly ash concrete and its beneficial use case studies. Cleaner Materials. Elsevier.
42. Khankhaje, E., Kim, T., Jang, H., Kim, J., & Kumar, R. (2023). Properties of pervious concrete incorporating fly ash as partial replacement of cement: A review. Developments in the Built Environment. Elsevier.
43. Huang, Z., Zhu, J., Liu, J., & Liu, W. (2021). Fly ash from thermal conversion of sludge as a cement substitute in concrete manufacturing. Sustainability. MDPI.
44. Hafez, H., Kurda, R., & Cheung, W. M. (2020). Energy savings associated with the use of fly ash and nanoadditives in the cement composition. Energies. MDPI.
45. Marshdi, Q. S. R., & Al-Sallami, Z. (2020). Effect of cement replacement by fly ash and epoxy on the properties of pervious concrete. Asian Journal of Civil Engineering. Springer.
46. Borges, P. M., Vieira, G. L., Schiavon, J. Z., da Silva, S. R. (2020). Influence of recycled aggregate replacement and fly ash content in performance of pervious concrete mixtures. Journal of Cleaner Production. Elsevier.
47. De Maeijer, P. K., Craeye, B., & Snellings, R. (2020). Effect of ultra-fine fly ash on concrete performance and durability. Materials and Structures. Springer.
48. Panda, R., & Sahoo, T. K. (2021). Effect of replacement of GGBS and fly ash with cement in concrete. Materials Today: Proceedings. Elsevier.
49. Sandanayake, M., Gunasekara, C., & Law, D. (2020). Sustainable criterion selection framework for green building materials–An optimisation-based study of fly-ash geopolymer concrete. Sustainable Materials and Technologies. Elsevier.