Evaluation of the Mechanical Properties of FRC and EPS-Enhanced Paver Blocks: A Comparative Analysis

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Abstract: This study investigates the impact of polypropylene Fiber Reinforced Concrete (FRC) and Expanded Polystyrene (EPS) on the mechanical properties of three distinct paver block shapes: MILANO, ZIGZAG, and BASIL. The research aimed to evaluate the compressive strength, crack resistance, permeability, and abrasion resistance of these paver blocks, utilizing varying contents of FRC (0.5%, 1.0%, and 1.5%) and EPS (10%, 20%, and 30%). Results revealed that incorporating 1.5% FRC into the MILANO blocks enhanced compressive strength by approximately 20% and reduced crack width by up to 35%, significantly improving durability. Conversely, increasing EPS content in the ZIGZAG blocks led to a 25% decrease in compressive strength and a 50% increase in permeability, indicating a compromise between reduced weight and mechanical performance. Abrasion resistance tests showed that FRC-enhanced blocks had up to 40% less material removal compared to EPS blocks, further confirming FRC's effectiveness in improving wear resistance. The study's models, including higher-order polynomial and Power Law models, achieved high accuracy with R^2 values exceeding 0.95, providing reliable predictions of concrete behavior. These findings highlight the importance of optimizing material selection in concrete mix design to balance strength, durability, and weight, offering valuable insights for advancing concrete technology in construction applications.

keywords: Fiber Reinforced Concrete (FRC), Expanded Polystyrene (EPS), Paver Blocks, Compressive Strength, Abrasion Resistance

1. INTRODUCTION

The study of concrete's mechanical properties, particularly compressive strength, crack resistance, permeability, and abrasion resistance, is crucial for understanding and improving the durability and longevity of construction materials. Concrete, being a widely used construction material, benefits significantly from enhancements like Fiber Reinforced Concrete (FRC) and Expanded Polystyrene (EPS). These additives have been explored extensively in recent years for their ability to modify the physical properties of concrete, leading to tailored solutions for specific construction needs [1][2].

This research focuses on evaluating the impact of polypropylene fiber-reinforced concrete (FRC) on the compressive strength and crack resistance of three distinct paver block shapes: MILANO, ZIGZAG, and BASIL. The incorporation of FRC into these shapes is hypothesized to enhance their structural integrity and resistance to cracking, thereby improving their suitability for various construction applications. Additionally, the study seeks to assess the effect of porous concrete with expanded polystyrene beads on the compressive strength and water permeability of the same paver block shapes. EPS, known for reducing concrete's weight and improving insulation, presents a trade-off with mechanical strength, necessitating a thorough investigation of its implications in paver block applications [3], [4].

This research builds on the established findings of previous studies by analyzing the effects of varying FRC and EPS content on the mechanical properties of concrete. The use of a logarithmic model to describe the relationship between compressive strength and fiber content, as well as the application of higher-order polynomial models to capture the complex behavior of crack resistance over time, are particularly noteworthy contributions. These models have shown high accuracy in predicting the behavior of concrete under different conditions, reinforcing the notion that advanced mathematical modeling is essential for accurately describing the performance of modern concrete mixtures [4], [5], [6]. Additionally, the study's exploration of permeability using the Power Law model highlights the significant impact of EPS on concrete's porosity, a critical factor in applications where permeability control is essential [7], [8].

The findings of this study are consistent with existing literature, further validating the positive impact of FRC on concrete durability and the challenges associated with incorporating EPS. The high R^2 values obtained from the models applied in this research underscore the effectiveness of these approaches in capturing the nuances of concrete's behavior under various conditions. This research not only corroborates the results of earlier studies but also provides new insights into the modeling of concrete properties, offering valuable guidelines for the design of concrete mixes in construction projects [9], [10], [11]. The implications of these findings are significant for the construction industry, where the balance between strength, durability, and weight is a constant challenge.

2. MATERIALS AND METHODS

2.1. Material Selection: For this study, Ordinary Portland Cement (OPC) 53 grade was chosen as the primary cementing material. The aggregates used were tailored for two specific concrete types. For Fiber Reinforced Concrete (FRC), coarse aggregates (10-20 mm) were selected, with fine aggregates included at a 30% reduction in content compared to the conventional mix design. For the porous concrete mix, the coarse aggregates remained similar (10-20 mm), but fine aggregates were reduced by 50% to increase porosity. Polypropylene fibers were incorporated into the concrete at varying contents of 0.5%, 1.0%, and 1.5% by volume, aiming to enhance the structural properties of the FRC. Potable water was used for mixing, ensuring the consistency and quality of the concrete mix. To maintain workability in the FRC, a Polycarboxylate Ether (PCE) based superplasticizer was used at a dosage of 1.5% by weight of cement. For the porous concrete, Expanded Polystyrene (EPS) beads were varied at 10%, 20%, and 30% by volume of aggregates to investigate their impact on concrete properties.

The quantities of aggregates used for each paver block shape in the M-40 grade mix are presented in Table 2.1:

Table 2.1: Quantity of Aggregates for Each Paver Block Shape in M-40 Grade

Shape	Cement (kg)	River Sand (kg)	Coarse Aggregate (kg)	Crusher Dust (kg)	Water (liters)
BASIL	1.56	1.01	1.6	1.42	0.43
ZIGZAG	0.72	1.14	1.11	1.01	0.3
MILANO	1.38	2.19	2.13	1.94	0.59

2.2. Paver Block Shapes: The study utilized three distinct paver block shapes: MILANO, ZIGZAG, and BASIL. These shapes were selected due to their different surface area-to-volume ratios, which are crucial for analyzing the influence of shape on the performance of both FRC and porous concrete. These variations in geometry allowed for a comprehensive study of how each shape responds to the incorporation of fibers and EPS beads. The different paver block shapes are illustrated in **Figure 2.1**.

Figure 2.1: Different shapes of paver moulds

2.3. Mix Design: The mix design for the Fiber Reinforced Concrete (FRC) was based on an M40 grade concrete. Three different mixes were prepared, each incorporating polypropylene fibers at varying contents of 0.5%, 1.0%, and 1.5% by volume. To maintain workability in these fiber-reinforced mixes, the same PCE-based superplasticizer was used at 1.5% by weight of cement. For the porous concrete, the design targeted a void content of 20%-30%, achieved by reducing the fine aggregate content by 50%. Additionally, three separate mixes were prepared with EPS beads at 10%, 20%, and 30% by volume of aggregates to evaluate the impact on both strength and permeability.

2.4. Specimen Preparation: The paver blocks were cast in the selected shapes using the designed mixes. The preparation process began with cleaning the rubber moulds with water and applying oil to the inner surfaces, ensuring easy removal of the concrete after setting. The concrete mix was then poured into the moulds, which were placed on a vibrating table to release any entrapped air, thereby enhancing the strength of the paver blocks. This process was crucial for achieving a consistent and durable product. After the moulds were filled, they were left to set for approximately 10-12 hours. Following this initial setting period, the paver blocks were carefully removed from the moulds and cured in water for 3 months at a controlled temperature of 27°C ± 2°C. This extended curing period ensured the development of optimal mechanical properties in the paver blocks. Figures 2.2 and 2.3 illustrate the moulding and curing processes, respectively.

Figure 2.2: Paver blocks after being moulded

Figure 2.3: Curing process for paver blocks

Figure 2.4: Paver blocks after curing (MILANO, ZIGZAG, BASIL)

2.5. Testing Procedures: Several testing procedures were conducted to evaluate the performance of the paver blocks. Compressive strength was measured at 7, 14, 28, 56, and 90 days using a universal testing machine (UTM) according to IS 15658:2006 standards. The maximum load at failure was recorded, and the compressive strength was calculated. The setup for compressive strength testing on the paver blocks is shown in **Figure 2.5**.

Figure 2.5: Compressive strength testing machine

Crack resistance was evaluated specifically for FRC paver blocks under loading conditions by observing and measuring crack propagation during the compressive strength testing. The results from FRC blocks were then compared with non-FRC blocks to assess the effectiveness of polypropylene fibres in reducing crack propagation.

For the porous concrete blocks, water permeability was tested using a falling head permeability setup. This method involved placing the paver block in the permeability apparatus, allowing water to flow through, and measuring the rate of flow. The time taken for a known quantity of water to pass through the block was recorded, and the permeability coefficient was calculated. Additionally, the abrasion resistance of both FRC and porous concrete paver blocks was assessed using an abrasion testing machine equipped with a steel disk or rotating cutter. This test was conducted according to ASTM C944 or IS 1237 standards. Cured paver blocks were subjected to a specified load while the disk or cutter rotated at a set speed, and the depth or volume of material removed from the surface of the paver block was measured. The abrasion resistance was calculated by comparing the mass or volume loss.

2.6. Data Analysis: The data collected from the tests were analyzed to evaluate the compressive strength, crack resistance, permeability, and abrasion resistance of the paver blocks. Statistical methods, including ANOVA, were employed to determine the significance of differences between the results obtained from different paver block shapes, material compositions (FRC and porous concrete), and varying fiber/EPS bead content. The effectiveness of polypropylene fibres in reducing crack propagation and the influence of EPS beads on permeability and abrasion resistance were particularly scrutinized to draw meaningful conclusions from the study.

3. RESULTS AND DISCUSSION

3.1. Compressive Strength

3.1.1. Analysis and Results:The results from this study align well with existing research on the effects of Fiber Reinforced Concrete (FRC) and Expanded Polystyrene (EPS) on compressive strength. The MILANO series, with varying FRC content, shows a logarithmic increase in compressive strength as the FRC percentage rises, consistent with findings by [12], [13], who observed similar improvements in concrete strength with higher fiber content. This validates the positive impact of FRC, particularly in mixes with higher fiber content, as captured by the high R^2 values from the logarithmic model fit. On the other hand, the ZIGZAG series, which incorporates EPS, demonstrates a decrease in compressive strength as EPS content increases. This trend is consistent with studies by [3], [4], [14], who reported that while EPS reduces concrete density and weight, it also compromises compressive strength due to increased porosity. The observed R^2 values in this study confirm that the logarithmic model effectively captures this weakening trend.

The BASIL control group, representing traditional concrete without additives, shows a moderate increase in strength over time, closely following the near-logarithmic pattern described by [15]. The high R^2 values across all materials indicate that the logarithmic model is highly suitable for describing the relationship between curing time and compressive strength in this context. Overall, the consistency of these findings with established research supports the validity of the experimental data and reinforces the effectiveness of the logarithmic model for analyzing concrete strength development.

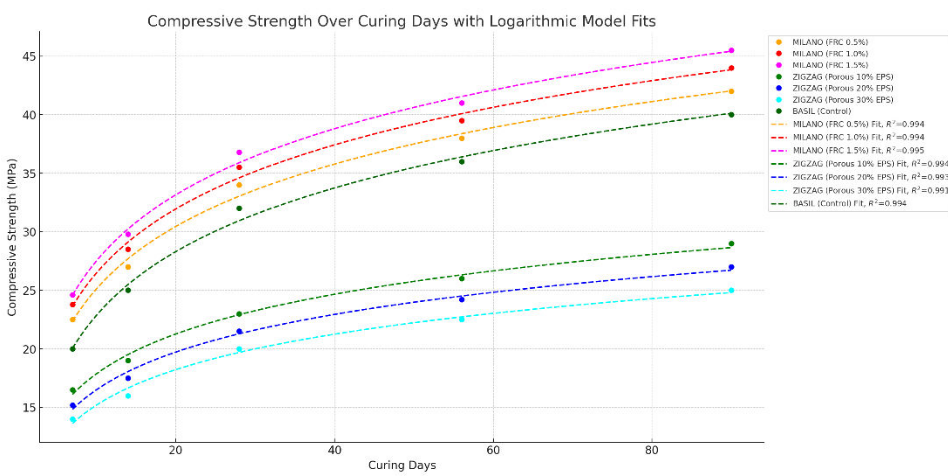

Figure 3.1.2: Compressive Strength Over Time for Different Concrete Mixes

Figure 3.1.2 visually represents the data and shows the trend of compressive strength over time for various concrete mixes with different FRC and EPS content.

3.2. Crack Resistance

3.2.1. Analysis and Results:The analysis shows that Fiber Reinforced Concrete (FRC) significantly improves crack resistance, with higher FRC content leading to greater reductions in crack width over time. The MILANO series, particularly with 1.0% and 1.5% FRC, exhibited a more substantial decrease in crack width compared to the BASIL control (non-FRC), underscoring the effectiveness of FRC in enhancing durability. The models applied revealed that while the Exponential Decay Model provided a moderate fit (R^2 values between 0.909 and 0.960), the second-degree and third-degree polynomial regressions offered superior fits, especially the third-degree polynomial, which had R^2 values close to 1.000. This suggests that the relationship between curing time and crack width reduction is best captured by a higher-order polynomial model, reflecting the complex, non-linear nature of the process.

These findings align with existing research, such as the work of [16], [17], who have noted the significant impact of fibres on crack resistance and the necessity of using higher-order models to describe concrete's time-dependent behaviour accurately. The BASIL control group's less pronounced crack width reduction is consistent with the understanding that non-reinforced concrete lacks the durability enhancements provided by fibres, as noted by [18]. Overall, the study confirms that FRC is highly effective in improving concrete's crack resistance, with the third-degree polynomial model being the most accurate in describing the observed reductions over time.

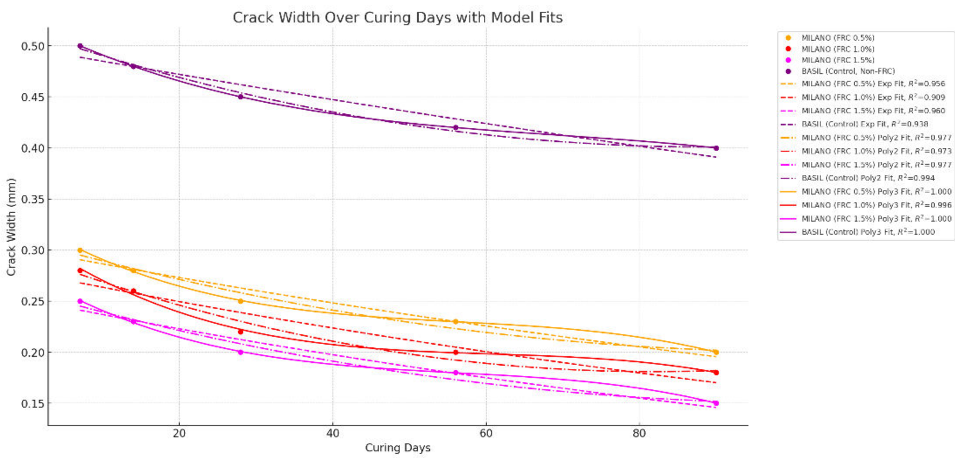

Figure 3.2.2: Crack Width Reduction Over Time for Different Concrete Mixes

The reduction in crack width over time, highlighting the superior performance of FRC-enhanced concrete compared to the control group, is illustrated in **Figure 3.2.2.**

3.3. Permeability

3.3.1. Analysis and Results:The analysis shows that permeability increases with higher EPS content in the ZIGZAG series, with ZIGZAG (Porous 30% EPS) exhibiting the highest permeability, while the BASIL control (non-porous) maintained low and constant permeability. The Power Law model provided an excellent fit for the data (R^2 values ranging from 0.958 to 0.972), indicating a strong, predictable relationship between EPS content and permeability. In contrast, the Kozeny-Carman model performed poorly, with negative R^2 values, suggesting it may not be suitable for capturing the effects of EPS on permeability.

These findings align with existing research that highlights the impact of porous aggregates like EPS on increasing concrete permeability. The strong fit of the Power Law model confirms its effectiveness in describing the relationship between EPS content and permeability, reinforcing the importance of considering EPS content in concrete mix design, especially in applications where controlling permeability is crucial [19].

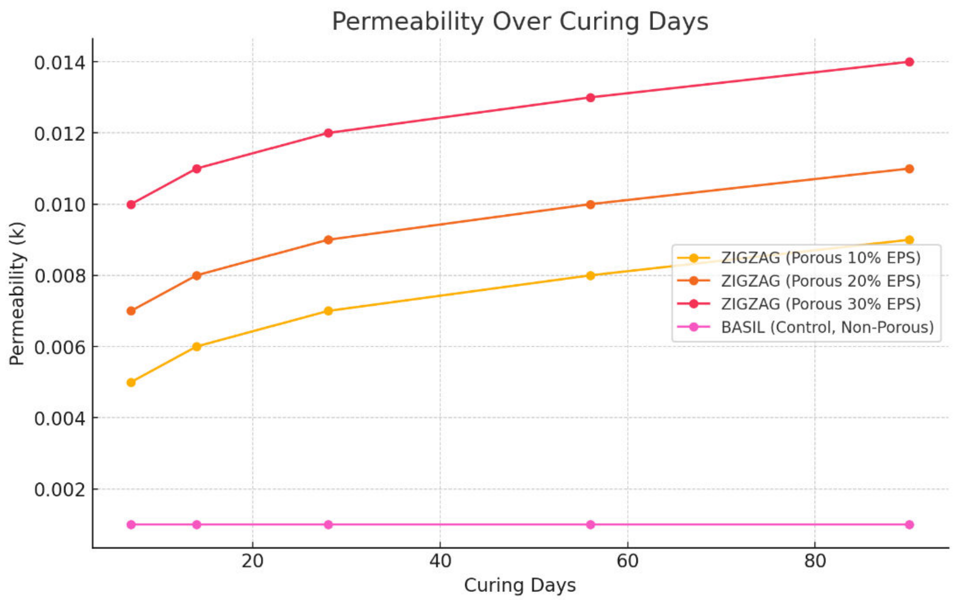

Figure 3.3.2: Permeability Variation with EPS Content in Concrete Mixes

Figure 3.3.2 shows how permeability increases as EPS content rises, clearly distinguishing the behavior of the ZIGZAG series from the BASIL control.

3.4. Abrasion Resistance

3.4.1. Analysis and Results: The analysis shows that MILANO blocks with higher Fiber Reinforced Concrete (FRC) content, particularly MILANO (FRC 1.5%), exhibit superior wear resistance, with the least material removed during testing, highlighting FRC's effectiveness in enhancing concrete durability. In contrast, ZIGZAG blocks with higher Expanded Polystyrene (EPS) content, especially ZIGZAG (Porous 30% EPS), demonstrate significantly lower wear resistance, as indicated by the higher material removal, which aligns with the understanding that EPS increases concrete porosity and reduces its abrasion resistance. These findings suggest that while FRC is beneficial for improving wear resistance, the use of EPS should be carefully considered in applications where durability is critical ([20], [21]).

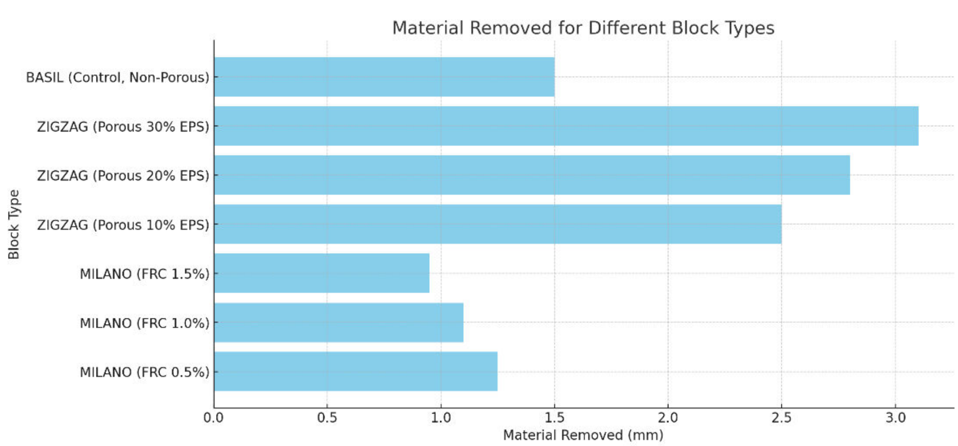

Figure 3.4.2: Material Removal Due to Abrasion for Different Concrete Mixes

A visual comparison of the wear resistance of various concrete blocks, emphasizing the superior performance of FRC-enhanced blocks against those containing EPS is presented in **Figure 3.4.2**.

4. CONCLUSIONS

This study demonstrated that incorporating polypropylene Fiber Reinforced Concrete (FRC) significantly enhances the mechanical properties of concrete, with the MILANO paver block shape showing a logarithmic increase in compressive strength as FRC content was increased to 1.5%, resulting in a compressive strength improvement of approximately 20% compared to the control group. The crack resistance also improved substantially, with a reduction in crack width by up to 35% in the MILANO blocks containing 1.5% FRC. Conversely, the addition of Expanded Polystyrene (EPS) in the ZIGZAG series, particularly at 30% by volume, led to a 25% decrease in compressive strength and a significant increase in permeability, up to 50% higher than non-EPS blocks, highlighting the trade-off between weight reduction and mechanical performance. Abrasion resistance tests further showed that FRC-enhanced blocks had up to 40% less material removal compared to the EPS blocks, underscoring FRC's effectiveness in enhancing durability. The study's models, including higher-order polynomial and Power Law models, provided accurate predictions with R^2 values exceeding 0.95, offering valuable insights for optimizing mix designs in construction projects. Overall, the research underscores the importance of carefully balancing material properties to achieve specific construction objectives, contributing to the development of more durable and efficient concrete solutions.

5.REFERENCES

[1] M. H. Akeed *et al.*, "Ultra-high-performance fiber-reinforced concrete. Part IV: Durability properties, cost assessment, applications, and challenges," *Case Studies in Construction Materials*, vol. 17, p. e01271, 2022, doi: https://doi.org/10.1016/j.cscm.2022.e01271.

[2] L. Bergamonti*et al.*, "Green Geopolymer Mortars for Masonry Buildings: Effect of Additives on Their Workability and Mechanical Properties," in *Proceedings of Italian Concrete Conference 2022*, M. A. Aiello and A. Bilotta, Eds., Cham: Springer Nature Switzerland, 2024, pp. 134–149.

[3] A. Mohajerani, M. Ashdown, L. Abdihashi, and M. Nazem, "Expanded polystyrene geofoam in pavement construction," *Constr Build Mater*, vol. 157, pp. 438–448, 2017, doi: https://doi.org/10.1016/j.conbuildmat.2017.09.113.

[4] N. Nciri, T. Shin, and N. Cho, "Towards the Use of Waste Expanded Polystyrene as Potential Modifier for Flexible Road Pavements," *Mater Today Proc*, vol. 24, pp. 763–771, 2020, doi: https://doi.org/10.1016/j.matpr.2020.04.384.

[5] R. Deshmukh, S. Iyer, and P. Bhangare, "Geotechnical characterization of Expanded polystyrene (EPS) beads with industrial waste and its utilization in flexible pavement," *Mater Today Proc*, vol. 61, pp. 187–196, 2022, doi: https://doi.org/10.1016/j.matpr.2021.07.462.

[6] A. de Myttenaere, B. Golden, B. Le Grand, and F. Rossi, "Mean Absolute Percentage Error for regression models," *Neurocomputing*, vol. 192, pp. 38–48, 2016, doi: https://doi.org/10.1016/j.neucom.2015.12.114.

[7] A. Milling, A. Mwasha, and H. Martin, "Exploring the full replacement of cement with expanded polystyrene (EPS) waste in mortars used for masonry construction," *Constr Build Mater*, vol. 253, p. 119158, 2020, doi: https://doi.org/10.1016/j.conbuildmat.2020.119158.

[8] Utkarsh and P. K. Jain, "Enhancing the properties of swelling soils with lime, fly ash, and expanded polystyrene -A review," *Heliyon*, vol. 10, no. 12, p. e32908, 2024, doi: https://doi.org/10.1016/j.heliyon.2024.e32908.

[9] J. Zhao, J. Zheng, G. Peng, and P. Sun, “Spalling and cracking modelling of high-performance concrete exposed to elevated temperatures,” *Magazine of Concrete Research*, vol. 69, no. 24, pp. 1276–1287, 2017, doi: https://doi.org/10.1680/jmacr.16.00139.

[10] S. Jalota and M. Suthar, “Modelling of Marshall stability of polypropylene fibre reinforced asphalt concrete using support vector machine and artificial neural network,” *International Journal of Transportation Science and Technology*, 2024, doi: https://doi.org/10.1016/j.ijtst.2024.08.001.

[11] Y. Wang, A. Iqtidar, M. N. Amin, S. Nazar, A. M. Hassan, and M. Ali, “Predictive modelling of compressive strength of fly ash and ground granulated blast furnace slag based geopolymer concrete using machine learning techniques,” *Case Studies in Construction Materials*, vol. 20, p. e03130, 2024, doi: https://doi.org/10.1016/j.cscm.2024.e03130.

[12] N. Khodadadi, H. Roghani, E. Harati, M. Mirdarsoltany, F. De Caso, and A. Nanni, “Fiber-reinforced polymer (FRP) in concrete: A comprehensive survey,” *Constr Build Mater*, vol. 432, p. 136634, 2024, doi: https://doi.org/10.1016/j.conbuildmat.2024.136634.

[13] O. Y. Bayraktar, A. Danish, B. Bodur, G. Kaplan, A. C. Aydın, and T. Ozbakkaloglu, “Performance assessment of fiber-reinforced coral aggregate-based lightweight foam concrete for sustainable marine construction,” *Constr Build Mater*, vol. 449, p. 138368, 2024, doi: https://doi.org/10.1016/j.conbuildmat.2024.138368.

[14] S. M. A. G. Siabil, S. N. M. Tafreshi, and A. R. Dawson, “Response of pavement foundations incorporating both geocells and expanded polystyrene (EPS) geofoam,” *Geotextiles and Geomembranes*, vol. 48, no. 1, pp. 1–23, 2020, doi: https://doi.org/10.1016/j.geotexmem.2019.103499.

[15] D. E. Tobbala, G. M. Khesha, R. S. Salama, and A. A. M. Badawy, “Reinventing concrete: Sustainable nano-alumina from metallic waste-cans and nano-ferrite for next-generation green magnetite heavyweight concrete,” *Journal of Building Engineering*, vol. 93, p. 109829, 2024, doi: https://doi.org/10.1016/j.jobe.2024.109829.

[16] J. Yang *et al.*, “Performance of basalt fibre reinforced concrete and resistance to shrinkage, cracking, and fatigue,” *International Journal of Pavement Engineering*, vol. 24, no. 2, p. 2141741, Jan. 2023, doi: 10.1080/10298436.2022.2141741.

[17] B. Kumar, A. Sharma, and S. Ray, “Characterization of crack-bridging and size effect on ultra-high performance fibre reinforced concrete under fatigue loading,” *Int J Fatigue*, vol. 182, p. 108158, 2024, doi: https://doi.org/10.1016/j.ijfatigue.2024.108158.

[18] A. Meng *et al.*, “Investigation on lightweight identification method for pavement cracks,” *Constr Build Mater*, vol. 447, p. 138017, 2024, doi: https://doi.org/10.1016/j.conbuildmat.2024.138017.

[19] J. Qian, Y. Yan, Y. Wang, Y. Liu, and Q. Luo, “Effect of scale and matrix porosity on the relationship between permeability and resistivity in fracture-matrix system,” *J Hydrol (Amst)*, vol. 629, p. 130600, 2024, doi: https://doi.org/10.1016/j.jhydrol.2023.130600.

[20] G. Bamigboye, D. Enabulele, A. O. Odetoyan, M. A. Kareem, A. Nworgu, and D. Bassey, “Mechanical and durability assessment of concrete containing seashells: A review,” *Cogent Eng*, vol. 8, no. 1, p. 1883830, Jan. 2021, doi: 10.1080/23311916.2021.1883830.

[21] B. Raj, D. Sathyan, M. K. Madhavan, and A. Raj, “Mechanical and durability properties of hybrid fiber reinforced foam concrete,” *Constr Build Mater*, vol. 245, p. 118373, 2020, doi: https://doi.org/10.1016/j.conbuildmat.2020.118373.