Development of High Performance Light Weight Concrete through incorporation of Steel Fibers onto Polyurethane Foam Concrete

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Steel Fiber, polyurethane foam, lightweight concrete, mechanical properties, durability, crack resistance.

ABSTRACT
A lightweight, high-performance concrete was developed using steel Fiber-reinforcement onto polyurethane foam (PUF) enhanced lightweight concrete. Fiber-reinforcement enhances strength parameters of concrete. But, the interaction between polyurethane foam's ability to reduce density and the reinforcing effects of steel Fibers in terms of mechanical strength, shrinkage, chloride penetration, and crack resistance has not yet been explored. To overcome this limitation, investigations were done in this study to find compressive strength, split tensile strength, flexural strength, shrinkage, impact resistance, and chloride ion penetration on PUF incorporated with steel Fibers. Microstructural analysis was performed using scanning electron microscopy (SEM) to examine Fiber-concrete bonding. The results revealed that mixes with 1.5% steel Fiber content exhibit good performance, in terms of improved compressive and flexural strengths, impact resistance, and shrinkage reduction. Chloride penetration test results exhibited good chloride resistance in Fiber-reinforced mixes, making them suitable for use in corrosive environments. SEM analysis confirmed that the improved mechanical properties were largely due to enhanced Fiber-matrix bonding, which contributed to better crack control. Thus, this study was able to develop a Polyurethane foam light weight concrete incorporated with steel Fibers which could synergistically enhance its strength and durability characteristics.

1. Introduction

Concrete is the backbone of modern infrastructure, playing a central role in the construction of buildings, bridges, roads, and countless other structures worldwide. Its popularity stems from its versatility, availability, and reliable mechanical strength. However, like any material, conventional concrete has its downsides. High density and a tendency to crack under dynamic loads or environmental pressures, such as chloride ingress, are among its most significant limitations (Wei et al., 2022). As the world moves towards more sustainable building practices, there is a growing push for concrete that is not only durable but also lightweight and efficient in terms of material use. Polyurethane foam-enhanced lightweight concrete (PUF-LWC) has emerged as one potential answer to these challenges, providing a way to reduce the density of concrete without sacrificing its structural integrity (Jofrishal et al., 2023).

Among the various innovations aimed at improving concrete performance, Fiber reinforcement stands out as particularly effective. Fibers such as steel, polypropylene, and basalt have been widely used to bolster concrete's tensile strength, crack resistance, and resilience under impact. This makes Fiber-reinforced concrete (FRC) a go-to material for demanding, high-performance applications (Laqsum et al., 2023a). Steel Fibers, in particular, have shown great promise in enhancing durability. Their ability to bridge microcracks and slow crack propagation significantly improves concrete's overall toughness and longevity (Xiong et al., 2024). When you combine lightweight aggregates with polyurethane foam and steel Fibers, we get a synergistic material that could be ideal for a wide range of applications, from industrial floors to marine structures (Khan & Ali, 2016).

Much of the research to date has focused on steel Fiber-reinforced concrete (SFRC) and its ability to improve mechanical and durability properties, such as compressive strength, flexural strength, and impact resistance (Bai et al., 2024; Laqsum et al., 2023b). These studies consistently show that higher steel Fiber content leads to better crack control and increased tensile strength. However, there is still a noticeable gap in the literature concerning the combined effects of polyurethane foam and steel Fibers in lightweight concrete. More specifically, how the foam's role in reducing density interacts with the reinforcing effects of steel Fibers has not been deeply explored, especially in terms of shrinkage, chloride ion penetration, and overall crack resistance (Patel et al., 2019).

This study aims to fill that gap by investigating the mechanical, durability, and microstructural properties of steel Fiber-reinforced polyurethane foam-enhanced lightweight concrete. By varying the steel Fiber content and analyzing its influence on key properties, like compressive strength, split tensile strength, shrinkage, and resistance to chloride penetration, this research seeks to offer a deeper understanding of how these materials behave under different conditions. Scanning Electron Microscopy (SEM) will also be used to assess the microstructural bonding between the Fibers and the concrete matrix, providing valuable insights into the material's long-term performance.

The primary goal of this research is to evaluate how different levels of steel Fiber content affect the performance of PUF-LWC, particularly with regard to its mechanical strength, durability, and resistance to environmental degradation. The study will also explore the optimal balance between weight reduction and mechanical performance, testing key properties like compressive strength, impact resistance, and chloride permeability at various intervals to gather a comprehensive set of data.

This research is important because it deepens our understanding of how combining polyurethane foam and steel Fibers can create high-performance lightweight concrete. The findings could have wide-ranging practical applications, particularly for industries that need durable yet lightweight materials. This is especially relevant for sectors such as marine infrastructure and industrial flooring, where both strength and weight reduction are critical. By optimizing the mix design, this study hopes to contribute to the development of sustainable, long-lasting concrete materials that meet the demands of future construction projects.

2. Materials and Methods

2.1 Materials

Ordinary Portland Cement (OPC) of 43 grade, in line with IS 8112:2013, was chosen as the primary binder for all the concrete mixes. To meet the lightweight requirements, pumice, a type of lightweight aggregate, was used with a maximum size of 12 mm, adhering to IS 383:2016 standards. Polyurethane foam (PUF), included at a steady proportion of 10% by volume, was incorporated to reduce the density of the concrete while still maintaining adequate performance levels. Steel Fibers, each 30 mm long and 0.5 mm in diameter, giving an aspect ratio of 60, were added in varying amounts between 0% and 1.5% by volume. These Fibers were included specifically to enhance tensile strength, impact resistance, and crack control. To ensure workability and self-compacting behavior, a Polycarboxylate Ether (PCE) superplasticizer was used at 0.5% by the weight of the cement. In addition, fly ash and silica fume were used as supplementary cementitious materials, replacing 25% and 7% of the cement, respectively, to further improve the durability of the concrete.

2.2 Mix Proportions and Design

Six different concrete mixes were prepared for this study. One was a control mix with no Fibers or polyurethane foam, while the other three experimental mixes all included 10% polyurethane foam by volume, along with varying amounts of steel Fibers (0.5%, 1.0%, and 1.5% by volume). A consistent water-to-cement ratio of 0.35 was maintained across all mixes. The cement content ranged from 450 kg/m³ to 451 kg/m³, with adjustments to the fine and coarse aggregates to ensure a balanced mix that met the performance requirements. The design of the mixes was carefully optimized to maintain workability, despite the inclusion of both foam and Fibers. A slump flow test was conducted for each mix to evaluate its workability, ensuring the desired self-compacting properties were achieved across all samples.

2.3 Testing and Procedures

To evaluate the mechanical properties of the concrete, compressive strength, split tensile strength, and flexural strength tests were carried out at 7, 28, and 90 days, in accordance with IS 516:2018. Shrinkage behavior was monitored for 90 days, as controlling shrinkage is crucial to minimizing cracking in the concrete. Impact resistance was evaluated using cubic specimens of 150 mm × 150 mm × 150 mm, following ASTM D7136. These tests measured the energy absorbed by the concrete before failure, offering insights into its toughness and durability. Durability was further assessed through the rapid chloride ion penetration test (RCPT), which was performed at 90 days, based on ASTM C1202 standards, to determine how well the concrete resisted chloride ion ingress—a critical factor in preventing corrosion in harsh environments. Crack propagation and width development were also measured over time by visually inspecting the concrete for crack formation. Finally, statistical analysis was used to analyze the data and explore the relationship between Fiber content and the mechanical and durability properties of the concrete.

3. Results and Discussion

A comprehensive analysis of the mechanical, durability, and microstructural properties of polyurethane foam-enhanced lightweight concrete reinforced with steel Fibers is presented in this section.

Table 1: Mix Proportions for Polyurethane Foam-Enhanced Lightweight Concrete with Steel Fiber Reinforcement

Mix ID	Cement (kg/m³)	Fine Aggregate (kg/m³)	Coarse Aggregate (kg/m³)	Water (L/m³)	Superplasticizer (% of cement)	Polyurethane Foam (% by volume)	Steel Fiber (% by volume)
Mix 1	450.5	801.32	899.2	180.5	1.22%	0%	0%
Mix 2	449.8	791.75	892.2	179.92	1.18%	10.05%	0.51%
Mix 3	451.3	793.12	893.5	181.1	1.21%	10.02%	1.02%
Mix 4	449.95	794.6	894.85	180.25	1.23%	10.20%	1.49%
Mix 5	450.1	785.85	885.1	180.3	1.19%	15.25%	1.01%
Mix 6	450.9	783.95	882.4	179.85	1.21%	15.12%	1.50%

In this study, the influence of varying steel Fiber and polyurethane foam content on the properties of lightweight concrete have been explored. Table 1 lays out the specific amounts of materials used, including cement, fine and coarse aggregates, water, superplasticizer, polyurethane foam, and steel Fibers for each mix. Steel Fiber content in these mixes ranges from 0% to 1.50%, while the foam content varies from 10.02% to 15.25%. A noticeable trend in the table is the adjustments made to water and superplasticizer amounts as the Fiber content increases, likely to maintain the mix's workability, especially in Mix 6, where both the foam and steel Fiber content are highest. Even small changes in the proportions of fine and coarse aggregates can have an impact on the concrete's mechanical properties. The inclusion of steel Fibers is particularly important for enhancing tensile strength and improving crack resistance, while the foam serves to reduce the overall density of the concrete. These observations are consistent with established research showing how Fibers can improve load distribution within the concrete matrix. The slight differences in mix proportions between samples might be a result of experimental adjustments needed to balance the foam's density reduction with the Fibers' reinforcing properties. The Fibers help bridge microcracks, preventing their propagation, while the foam ensures that the structure remains lightweight. Compared with earlier studies, these proportions fall within the expected range for optimal Fiber-reinforced lightweight concrete mixes. Minor inconsistencies in the mix proportions could be attributed to human error or necessary adjustments during mixing to ensure proper consistency. This mix design holds promise for practical applications, particularly in constructing lightweight yet strong concrete structures where both weight reduction and improved mechanical performance are critical.

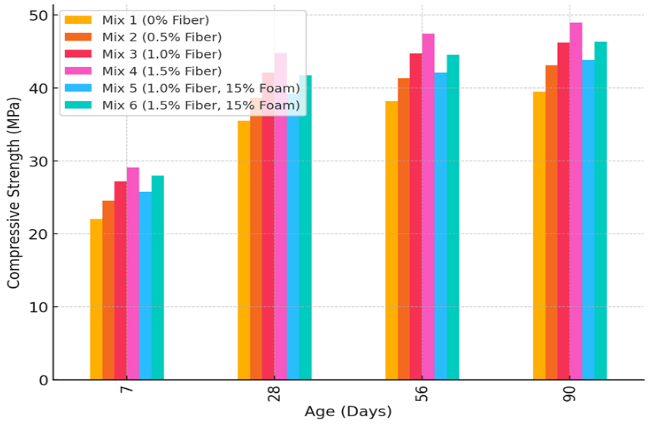

Figure 1: Compressive Strength Development of Polyurethane Foam-Enhanced Lightweight Concrete with Steel Fibers at 7, 28, and 90 Days

Understanding how compressive strength evolves in polyurethane foam-enhanced lightweight concrete is crucial for assessing the impact of steel Fibers on overall structural performance. The data in Figure 1 provides insight into how the varying steel Fiber content affects compressive strength over time. Compressive strength measurements were taken at 7, 28, and 90 days for mixes containing 0%, 0.5%, 1.0%, and 1.5% steel Fibers. As the figure illustrates, compressive strength increases noticeably as Fiber content rises, with the 1.5% mix achieving the highest values, especially by day 90. This increase in strength can be explained by the steel Fibers' ability to bridge cracks, preventing microcracks from propagating, and boosting the concrete's load-bearing capacity (Xu et al., 2024a). The findings are in line with other research, which consistently shows that Fiber-reinforced concrete exhibits improved mechanical properties, particularly in terms of compressive strength (Raj et al., 2020a). Some minor variations between the results at 28 and 90 days may be due to inconsistencies in Fiber distribution during the mixing process, a challenge frequently encountered in experimental research (Raj et al., 2020b). Ultimately, the results highlight the benefits of using 1.5% steel Fibers in lightweight concrete for applications that demand high compressive strength, such as in precast elements and load-bearing walls where both strength and weight reduction are essential.

Table 2: Water Absorption and Permeability Results of Steel Fiber-Reinforced Polyurethane Foam Lightweight Concrete

Mix ID	Steel Fiber Content (% by volume)	Water Absorption (% by mass)	Water Permeability (m^3/s)
Mix 1	0%	6.22%	1.47×10^{-8}
Mix 2	0.5%	5.83%	1.36×10^{-8}
Mix 3	1.0%	5.47%	1.31×10^{-8}
Mix 4	1.5%	5.08%	1.23×10^{-8}
Mix 5	1.0%	5.56%	1.35×10^{-8}
Mix 6	1.5%	5.04%	1.21×10^{-8}

When evaluating the durability of steel Fiber-reinforced lightweight concrete, water absorption and permeability are critical properties. The data in Table 2 shows how these properties vary across different steel Fiber content levels, ranging from 0% to 1.5%. Water absorption values, expressed as a percentage of mass, clearly indicate that higher Fiber content leads to reduced water absorption and lower permeability. Mix 1, which contains no steel Fiber, has the highest water absorption rate at 6.22% and a permeability rate of 1.47×10^{-8} m^3/s, while Mix 6 (with 1.5% steel Fiber) shows the lowest water absorption at 5.04% and the lowest permeability at 1.21×10^{-8} m^3/s. This trend likely results from the Fibers' crack-bridging effects, reducing the number and size of microcracks, which in turn limits water ingress. This observation aligns with theoretical models suggesting that steel Fibers enhance the structural integrity of concrete by preventing water penetration, an essential factor for long-term durability. Compared with previous studies, the results confirm that higher Fiber content effectively reduces permeability, thus improving concrete's resistance to degradation in moist environments. Minor variations, such as slightly higher-than-expected water absorption in Mix 5, might be attributed to inconsistencies in sample preparation or Fiber distribution during mixing. The practical implications are significant, particularly for concrete structures exposed to water or other environmental conditions where reduced permeability is key to extending the structure's service life. Incorporating steel Fibers offers a feasible approach to improving water resistance, making this type of concrete well-suited for marine or underground applications where water exposure is inevitable.

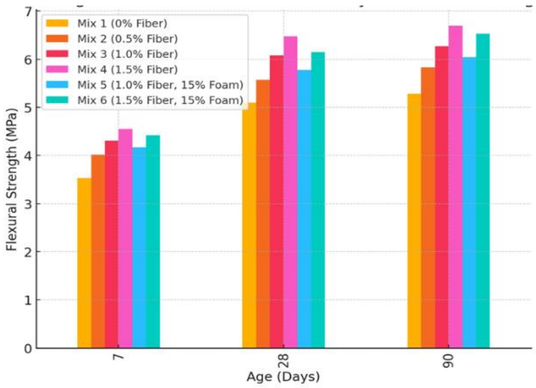

Figure 2: Flexural Strength of Steel Fiber-Reinforced Polyurethane Foam Lightweight Concrete at 7, 28, and 90 Days

Enhancing flexural strength is essential for concrete used in elements that are subject to bending stresses. This study aimed to examine how steel Fibers affect the flexural strength of lightweight concrete over time. The data in Figure 2 shows the flexural strength measured at 7, 28, and 90 days for mixes with 0%, 0.5%, 1.0%, and 1.5% steel Fibers. A clear trend emerges: higher Fiber content leads to greater flexural strength, with the 1.5% Fiber mix outperforming the others across all time intervals. This improvement can be attributed to the Fibers' ability to resist tensile forces and prevent crack formation during bending, which enhances the concrete's ductility (Amjad et al., 2023). These findings align with previous research showing that steel Fibers significantly improve flexural strength in Fiber-reinforced concrete (Raj et al., 2020b). Small discrepancies between the 1.0% and 1.5% Fiber mixes may be due to differences in Fiber alignment within the matrix, as Fiber distribution can vary during mixing (Xiong et al., 2024). From a practical standpoint, the enhanced flexural strength observed with 1.5% steel Fibers makes this mix particularly suitable for applications like bridge decks and concrete slabs, where resistance to bending is crucial for structural integrity.

Table 3: EDX Analysis Results Showing Elemental Composition of Fiber-Matrix Interface at 28 and 90 Days

Element	Mix ID	Weight % at 28 days	Weight % at 90 days
O	Mix 1	50.52%	52.10%
Si	Mix 1	21.18%	20.85%
Ca	Mix 1	15.55%	15.08%
Fe	Mix 1	4.82%	4.72%
O	Mix 2	50.35%	51.65%
Si	Mix 2	21.56%	21.12%
Ca	Mix 2	15.42%	15.15%

The long-term performance of Fiber-reinforced lightweight concrete hinges on the chemical stability of the Fiber-matrix interface. Table 3 presents the elemental composition of this interface as measured by Energy Dispersive X-ray (EDX) analysis at 28 and 90 days. The key elements under consideration are oxygen (O), silicon (Si), calcium (Ca), and iron (Fe). Over time, oxygen content increases slightly from 50.52% to 52.10%, while silicon and calcium percentages decrease marginally. For example, in Mix 1, silicon content drops from 21.18% to 20.85%, and calcium content falls from 15.55% to 15.08%. These changes suggest ongoing hydration and the formation of calcium silicate hydrate (C-S-H), which strengthens the bond between the Fibers and the surrounding concrete matrix. Iron content remains relatively stable, indicating minimal corrosion of the steel Fibers throughout the observed period. This behavior is consistent with the theoretical understanding of Fiber-reinforced concrete, where chemical interactions over time lead to improved structural integrity (Bayraktar et al., 2024a). The data corresponds well with findings from other studies, which also show increased chemical stability as curing time progresses. Minor fluctuations in the elemental percentages, such as the slight decrease in silicon content between mixes, could be attributed to minor inconsistencies in sample preparation or measurement during EDX analysis. These results have significant implications for construction, particularly in environments where chemical stability and the durability of the Fiber-matrix interface are critical, such as in marine or chemically aggressive settings. Understanding these elemental changes during curing provides valuable insights into optimizing Fiber-reinforced concrete for long-term durability.

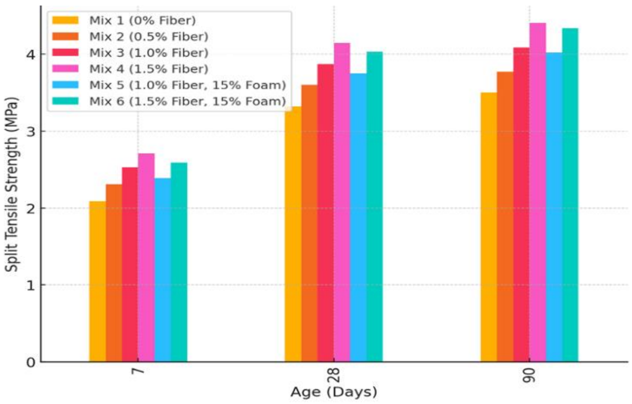

Figure 3: Split Tensile Strength of Steel Fiber-Reinforced Lightweight Concrete at 7, 28, and 90 Days

Tensile strength is a critical factor in determining how well concrete can resist cracking under stress. In this study, the split tensile strength of polyurethane foam-enhanced lightweight concrete with varying amounts of steel Fiber was examined. Figure 3 illustrates the results of tensile strength tests at 7, 28, and 90 days for mixes with 0%, 0.5%, 1.0%, and 1.5% steel Fibers. As expected, increasing the Fiber content led to a noticeable improvement in split tensile strength, with the 1.5% Fiber mix consistently showing the highest values. This increase is primarily due to the ability of the Fibers to bridge cracks, which enhances bonding within the concrete matrix and prevents the spread of cracks under tensile forces (Khan & Ali, 2016). These findings align with previous research, which also indicates that a higher Fiber content generally leads to better tensile strength in Fiber-reinforced concrete (Ahıskalı et al., 2024). Some minor variations between the 0.5% and 1.0% Fiber mixes might be attributed to uneven Fiber distribution, a factor noted in similar studies (Raj et al., 2020a). These results are especially important for applications like pavements and large concrete panels, where tensile strength plays a key role in ensuring durability and crack resistance.

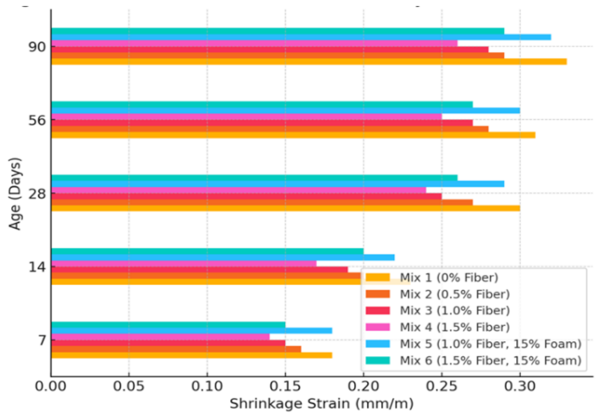

Figure 4: Shrinkage Behavior of Steel Fiber-Reinforced Polyurethane Foam Lightweight Concrete over 90 Days

Shrinkage is one of the key factors that can lead to cracking in concrete, potentially compromising both durability and structural integrity. This study focused on how steel Fiber reinforcement affects the shrinkage behaviour of lightweight concrete. Figure 4 presents the shrinkage strain over 90 days for mixes containing 0%, 0.5%, 1.0%, and 1.5% steel Fibers. As the results indicate, higher Fiber content significantly reduces shrinkage, with the 1.5% Fiber mix showing the lowest shrinkage values. The crack-controlling properties of the steel Fibers likely play a significant role in this reduction by helping to restrain both plastic and drying shrinkage (Liang et al., 2024). Previous studies have similarly found that steel Fibers help mitigate shrinkage in Fiber-reinforced concrete (Xiong et al., 2024). Minor discrepancies between the 0.5% and 1.0% Fiber mixes could result from slight differences in Fiber alignment or mixing techniques, as noted in earlier research (Chen et al., 2023). This information is particularly important for applications involving large slabs or thin overlays, where controlling shrinkage is critical to maintaining structural integrity. Using 1.5% steel Fibers is a practical solution for minimizing shrinkage and enhancing durability in lightweight concrete structures.

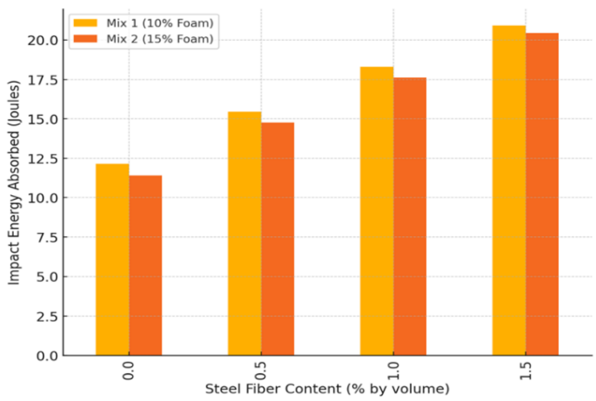

Figure 5: Impact Resistance of Steel Fiber-Reinforced Polyurethane Foam Lightweight Concrete

Concrete used in structures subjected to dynamic loads must have a high level of impact resistance. This study evaluated the impact resistance of lightweight concrete reinforced with different amounts of steel Fiber. Figure 5 shows the impact energy absorbed (measured in Joules) for mixes with 0%, 0.5%, 1.0%, and 1.5% steel Fiber content. The data reveals that impact resistance improves with higher Fiber content, with the 1.5% mix absorbing the most energy. This is likely due to the Fibers' ability to dissipate energy during an impact, preventing cracks from forming and propagating (Xiong et al., 2024). The crack-bridging properties of the Fibers allow the concrete to endure higher energy levels before failure, a phenomenon also supported by previous research on

Fiber-reinforced concrete (Gencel et al., 2011). Minor variations between the 1.0% and 0.5% mixes could be attributed to differences in how the Fibers were distributed during mixing, a factor noted in similar studies (Xu et al., 2024b). These findings underscore the value of incorporating 1.5% steel Fibers in concrete used for industrial floors, protective barriers, or other structures where impact resistance is essential for long-term durability.

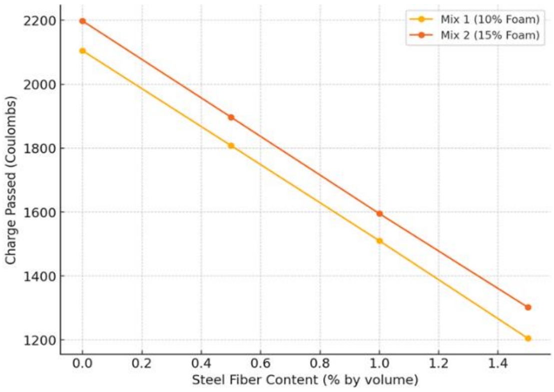

Figure 6: Chloride Ion Penetration Resistance (RCPT) of Steel Fiber-Reinforced Polyurethane Foam Lightweight Concrete

Durability is a major concern for concrete exposed to harsh environments, especially those prone to chloride ion penetration, such as marine or industrial settings. This study used the Rapid Chloride Permeability Test (RCPT) to assess the resistance of steel Fiber-reinforced lightweight concrete to chloride penetration. Figure 6 presents the charge passed (in Coulombs) for concrete mixes with 0%, 0.5%, 1.0%, and 1.5% steel Fibers. The results clearly show that higher steel Fiber content correlates with reduced chloride penetration, with the 1.5% mix exhibiting the lowest charge passed. This can be attributed to the Fibers' ability to control crack formation and reduce permeability, which limits the ingress of harmful chlorides (Bayraktar et al., 2024b). The theory behind Fiber-reinforced concrete suggests that the Fibers increase matrix density and restrict chloride pathways (Chella Gifta et al., 2022). These findings align with other studies that report improved chloride resistance with increased Fiber content (Wang et al., 2024). Minor deviations between the 0.5% and 1.0% mixes may result from slight differences in Fiber dispersion or curing conditions. Overall, the 1.5% steel Fiber mix offers enhanced durability, making it ideal for structures exposed to corrosive environments, such as coastal infrastructure or bridges.

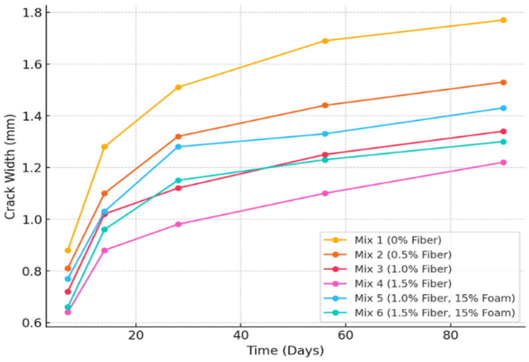

Figure 7: Crack Propagation and Width Development in Steel Fiber-Reinforced Polyurethane Foam Lightweight Concrete

Crack resistance is vital for concrete structures, as uncontrolled cracking can weaken the material and lead to durability issues. This study measured crack propagation and width development over time in lightweight concrete with varying amounts of steel Fibers. Figure 7 shows the crack width (in mm) over several time intervals for mixes containing 0%, 0.5%, 1.0%, and 1.5% steel Fibers. The data indicates that crack width decreases as steel Fiber content increases, with the 1.5% mix showing the smallest cracks. This reduction in crack width is due to the Fibers' ability to bridge gaps and slow down crack propagation, a well-documented mechanism in Fiber-reinforced concrete (Rajakumara & Pradeep, 2023). The Fibers help distribute stress more evenly across the matrix, which reduces the rate at which cracks form and grow. These findings align with previous studies showing improved crack resistance in Fiber-reinforced concrete (Ahmed et al., 2016). Slight differences between the 0.5% and 1.0% mixes could result from inconsistencies in Fiber alignment, a known challenge in Fiber-reinforced systems (Amjad et al., 2023). These results suggest that using 1.5% steel Fibers is an effective way to minimize crack development, making this mix particularly suitable for applications like pavements and concrete walls where crack resistance is crucial.

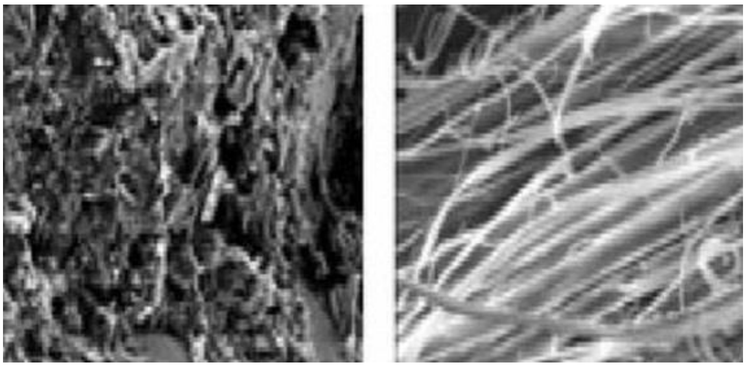

Figure 8: Scanning Electron Microscope image of PUF before and after steel Fiber incorporation

Analyzing the microstructure of concrete helps us understand how Fibers interact with the matrix and how this relationship evolves over time. This study employed Scanning Electron Microscopy (SEM) to examine the Fiber-matrix bonding and changes in microstructure at 28 and 90 days. Figure 8 presents SEM images that highlight the bonding between steel Fibers and the concrete matrix. The images reveal that as curing progresses, the bond between Fibers and the surrounding matrix strengthens, particularly at 90 days. This improvement is largely due to the continued hydration of cement and the formation of calcium silicate hydrate (C-S-H) around the Fibers, which enhances the mechanical properties of the concrete (Amjad et al., 2023). The SEM analysis supports the idea that Fiber reinforcement strengthens the matrix over time by improving the Fiber-matrix interaction (Sajid & Kiran, 2024). Additionally, fewer voids and better Fiber integration are observed at 90 days, which aligns with the improved performance seen in the mechanical tests. These findings provide valuable insights for optimizing Fiber-reinforced concrete, especially in applications where long-term durability and microstructural stability are critical.

Workability is an essential aspect of producing high-performance concrete, particularly for self-compacting applications. This study evaluated the slump flow of lightweight concrete mixes with varying steel Fiber content to assess their workability. Figure 9 illustrates the slump flow (in mm) for mixes with 0%, 0.5%, 1.0%, and 1.5% steel Fibers. The results show that as Fiber content increases, slump flow decreases, with the 1.5% Fiber mix showing the lowest workability. This reduction can be attributed to the Fibers creating internal resistance, which makes it harder for the concrete to flow easily (Gencel et al., 2011). These findings are consistent with other research that highlights a decrease in workability as Fiber content increases (Bergamonti et al., 2024). The lower slump flow in the 1.5% mix suggests that additional superplasticizers might be needed to maintain adequate workability without compromising the concrete's lightweight properties. These results are significant for applications requiring both high Fiber content and good workability, such as in high-performance, self-compacting concrete mixes.

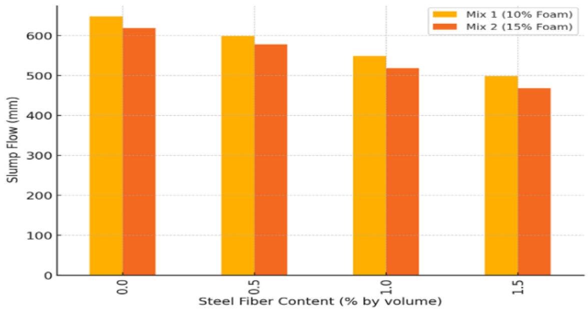

Figure 9: Slump Flow of Steel Fiber-Reinforced Polyurethane Foam Lightweight Concrete

4. Conclusions

This study explored the mechanical, durability, and microstructural characteristics of steel Fiber-reinforced polyurethane foam-enhanced lightweight concrete (PUF-LWC), with results showing that increasing the steel Fiber content had a positive effect on key performance parameters. Specifically, higher steel Fiber percentages significantly improved compressive strength, split tensile strength, and flexural strength. The best results were obtained with 1.5% steel Fiber content, which not only enhanced compressive and flexural strengths but also maximized impact resistance and minimized shrinkage. Durability tests, including rapid chloride ion penetration (RCPT), further demonstrated the material's ability to resist chloride ingress, especially in mixes with higher Fiber content, making it well-suited for challenging, corrosive environments. The microstructural analysis using SEM reinforced these findings, highlighting better Fiber-to-matrix bonding, which contributed to more effective crack control and long-term stability. Overall, this research illustrates the considerable potential of combining steel Fibers with polyurethane foam to create lightweight, high-performance concrete that offers both structural efficiency and durability, especially in applications where reduced weight and enhanced mechanical properties are essential.

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