

Effect of Alkali Treatment on Mechanical Properties of Concrete Reinforced with Phragmites Australis Fibres

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Abstract

This paper investigates the influence of both untreated and alkali-treated *Phragmites australis* fibres (PAF) on the fresh and hardened properties of fibre-reinforced concrete. Various concrete mixes were prepared with fibre contents ranging from 0–2%, and the effects on workability, density, compressive strength, splitting tensile strength, and flexural strength were systematically evaluated over 7, 14, and 28 days of curing. Results showed that increasing PAF content led to reduced workability and density, with alkali-treated fibres exhibiting slightly better performance due to improved dispersion and reduced water absorption. Mechanical properties improved at low fibre dosages (0.5–1%), particularly with NaOH-treated fibres, which demonstrated superior bonding with the cement matrix. However, higher fibre volumes negatively impacted strength due to poor dispersion and increased porosity. Overall, the findings suggest that low to moderate contents of treated PA fibres can enhance concrete performance while promoting the use of sustainable, plant-based materials in construction applications.

1. Introduction

Concrete is among the most extensively utilised construction materials worldwide, attributed to its superior compressive strength, adaptability, and accessibility (Hadya et al., 2025; Padwad et al., 2025; Singh et al., 2025). Nonetheless, it is inherently weak and has poor tensile strength, making it prone to breaking under tensile stresses (Ali Aichouba et al., 2025; Sudheer & Rao, 2025). Fibres are commonly used into concrete to enhance its tensile properties, mitigate cracking, and augment ductility to address this limitation (Abdallah & Fan, 2017; Saleh et al., 2025). While glass and polypropylene, two materials, have historically been employed for this purpose, natural fibres have lately garnered attention as eco-friendly and sustainable alternatives (Abedi et al., 2025; Merve Tuncer & Canan Girgin, 2023; Suwanvitaya & Chotickai, 2024).

Phragmites australis, or commonly known as common reed, has emerged as a potential contender among the several natural fibres investigated for reinforcing cementitious composites (Khatib, Jamal et al., 2024). This perennial marsh grass is distinguished by its fibrous stem structure, high biomass yield, and quick development (Ramadan et al., 2024). Because *Phragmites australis* is regarded as an invasive species in many areas, its usage in building materials presents a chance for both value-added exploitation and ecological management (Shon et al., 2019). In addition to their mechanical advantages, *Phragmites australis* fibres (PAF) in concrete have the potential to be used in sustainable building methods (Durant et al., 2020).

The fibrous structure and chemical composition of *Phragmites australis* make it a promising natural reinforcing material for concrete and composite products (Khatib, Jamal M., ElKhatib, Sonebi et al., 2023). In fibre-reinforced concrete, the plant's fibres can be handled and treated to make them environmentally friendly alternatives to glass and synthetic fibres like polypropylene (Gwon et al., 2023). It has been discovered that adding natural fibres to concrete enhances some mechanical properties (Al-Mawed & Hamad, 2023; Zeng et al., 2022). Fibres such as those from *Phragmites australis* have been

demonstrated in experiments to improve the tensile strength, flexural strength, and fracture resistance of concrete by distributing loads and reducing stress concentrations (Khatib, Jamal M., ElKhatib, Elkordi et al., 2023; Suárez et al., 2023).

One of the most widely used techniques for increasing the endurance of natural fibers is alkali treatment, also referred to as mercerization (Hurtado-Figueroa et al., 2023; Maaze et al., 2025). The fibers are soaked in an alkaline solution, often sodium hydroxide (NaOH), to remove impurities such as lignin, hemicellulose, and other non-cellulosic components from the fiber surface (Ez-Zahraoui et al., 2023). Furthermore, alkali treatment roughens the fibers' surfaces, which improves their bond with the cementitious matrix in concrete (Lin et al., 2023). By increasing the fibers' resistance to the alkaline conditions present in concrete, it also stops fibre disintegration (Liang et al., 2025). By lowering water absorption by up to 50%, alkali treatment can enhance the long-term performance of fibre-reinforced concrete, according to (Lv & Liu, 2023).

This paper provides a comprehensive investigation into the effects of *Phragmites australis* fibres (PAF) treatment on the mechanical properties of concrete. The primary objective is to evaluate the physical and chemical characteristics of the fibres, assess their influence on both the fresh and hardened properties of concrete, and analyze the associated environmental and economic implications. Additionally, the study's results are compared with the recent experimental findings from the literature, highlights existing challenges, and identifies key research gaps that warrant further exploration.

2. Materials and Methodology

2.1. Materials

2.1.1. Cement

Ordinary Portland Cement (OPC) CEMI 42,5R type was used as the primary binder. The cement was characterized by a specific gravity of approximately 3.15 and a Blaine fineness of 386 m²/kg. This type of cement is commonly used in structural concrete applications and ensures compatibility with both natural and synthetic admixtures.

2.1.2. Fine and coarse Aggregates

Natural river sand was used as the fine aggregate, with a fineness modulus of 2.6 and a specific gravity of 2.63. The sand was washed and cleaned, well-graded, and free from deleterious materials such as clay lumps, silt, and organic matter, conforming to ASTM C33 requirements. The coarse aggregate comprised crushed gravel with a nominal maximum size of 12.5 mm. It had a specific gravity of 2.70 and an aggregate crushing value of less than 30%, indicating high strength. The coarse aggregate also met the grading and quality requirements of ASTM C33 and was washed and air-dried prior to use to eliminate dust and fines that might affect the concrete mix.

2.1.3. *Phragmites Australis* Fibres (PAF)

Fibres were obtained from mature *Phragmites australis* plants harvested from the Euphrates River and were thoroughly dried before use. The *Phragmites australis* plants were cut into small pieces using a chopping machine, as illustrated in Fig. 1. The extracted fibers were then cut into uniform lengths ranging from 40 to 50 mm, based on preliminary tests that identified this range as optimal for minimizing fibres balling and maximizing crack bridging in the matrix.

2.2. Fibre Treatment

To improve the interfacial bond between the fibers and cementitious matrix, an alkaline treatment was employed. The extracted fibers were soaked in a 1% sodium hydroxide (NaOH) solution for 24 hours at ambient temperature as shown in Fig. 2. This treatment helped remove hemicellulose, waxes, and surface impurities while enhancing surface roughness. After treatment, the fibres were thoroughly rinsed with clean water until a neutral pH was achieved, then oven-dried at 60°C for 24 hours. The treatment improved the fibres' mechanical interlock and chemical compatibility with the cement paste.

2.3. Mix Proportions

A standard concrete mix was designed to achieve a target compressive strength of 40 MPa at 28 days. The mix design adopted a constant water-to-cement ratio (w/c) of 0.50, ensuring consistency in workability and hydration conditions across all batches. This control allowed for an accurate evaluation of the influence of *Phragmites australis* fibers (PAF) on the mechanical and durability performance of concrete.

To investigate the effect of varying fibre content and treatment, four different concrete mixes were prepared for both untreated and treated PAF, as detailed in Table 1 below. The fibre content was expressed as a percentage of the total volume of concrete, ranging from 0% (control) to 2%. All other parameters including cement content, aggregates, and water quantity were kept constant in all nine mixes to isolate and quantify the sole effect of the PAF. No chemical admixtures, such as superplasticizers or water reducers, were introduced to the mix. This decision was made to observe the unaltered influence of PAF on workability and mechanical performance.

The chosen fibres content range (0–2%) was based on a preliminary investigation and literature review (Khatib, Jamal et al., 2024), which identified that excessive fibre volume beyond 2 % may lead to poor workability, fibre clumping, and significant reductions in strength due to poor compaction and entrapped air (Ramadan, Khatib et al., 2023). All mix proportions (cement, sand, gravel, and water) were batched by weight and converted to volume using the known specific gravities of each material. The overall density of the fresh concrete mix was maintained within the range of 2100–2400 kg/m³.

Table 1
Concrete mix proportions for both untreated and treated PAF

Mix ID	Fibre Content Kg/m ³	Cement Kg/m ³	Fine aggregate Kg/m ³	Coarse aggregate Kg/m ³	Water Kg/m ³
PA0	0	375	795	970	185
PA0.5	3.33	375	795	970	185
PA01	6.65	375	795	970	185
PA1.5	9.98	375	795	970	185
PA02	13.28	375	795	970	185

2.4. Mixing Procedure

The concrete mixing process was conducted using a 60-liter capacity tilting pan mixer, which allowed efficient blending of materials and consistent mixing quality throughout each batch. The procedure was standardized as shown in Fig. 3.

As shown in Fig. 3., cement, fine aggregate (sand), and coarse aggregate (gravel) were added to a dry pan mixer and mixed for one minute to start the dry mixing phase of the mixing process. Prior to adding water and fibres, this stage made sure that the dry elements were combined uniformly. The water addition step involved adding 75% of water to the dry mix gradually over a one-minute period, then continuously mixing for two more minutes. Initiating cement hydration and attaining a consistent paste covering around the particles required this step.

In order to avoid balling and tangling, prepared PAFs were added and then followed by adding the remaining 25% of water. To make sure the fibres were evenly distributed throughout the concrete matrix, the mixing process was carried out for two more minutes.

After mixing, the freshly mixed concrete was examined visually to ensure consistency. Higher fibre volume blends (especially PA1.5 and PA02) showed decreased workability as anticipated, but they were still cohesive enough for correct casting with mechanical vibration.

2.5. Specimen Preparation and Curing

To comprehensively evaluate the effect of PAF incorporation on concrete, a variety of specimen types were prepared in accordance with relevant ASTM and BS standards. For compressive strength testing, standard cube specimens measuring 100 mm × 100 mm × 100 mm were cast and tested following ASTM C109 procedures. These cubes were assessed at curing intervals of 7, 14, and 28 days to monitor strength development over time. Flexural strength was evaluated using prismatic beam specimens of dimensions 100 mm × 100 mm × 500 mm, tested under four-point loading as prescribed by BS EN 12390-5:2009. These tests, conducted at 7, 14, and 28 days as well, aimed to determine the influence of

fibre addition on the flexural behavior and crack-bridging capabilities of the concrete. Additionally, cylindrical specimens with dimensions of 150 mm in diameter and 300 mm in height were prepared to assess tensile behavior of concrete incorporating PAF.

All concrete was cast into oiled steel molds in different successive layers. Each layer was compacted using a vibrating table for 15 to 20 seconds to ensure uniform density and eliminate entrapped air. This step was particularly critical for PAF mixes, where the presence of fibres especially at higher contents (PA1.5 and PA02) could impede proper compaction and lead to air void formation. Following casting, specimens were immediately covered with plastic sheets to prevent surface moisture loss and maintain consistent temperature conditions during the initial hydration phase. After 24 hours, the specimens were demolded and placed in a water curing tank maintained at $23 \pm 2^\circ\text{C}$, where they remained fully submerged until their respective testing ages. This water-curing method was selected to ensure uniform hydration, which is essential for accurate assessment of long-term strength and durability, particularly in concrete modified with natural fibers. Each test was conducted on three specimens, and the average value was reported.

3. Results and Discussion

3.1 Fresh properties

The workability of concrete mixes including both treated and untreated *Phragmites australis* fibres (PAF) shows a distinct trend, according to the findings of the slump test (see Fig. 4). The control mix (CM), which contained no PAF, exhibited the highest slump value of 7.5 cm indicating excellent workability in the absence of fibres. Slump gradually decreased for all mixes as the PAF concentration rose from 0.5–2%, which is consistent with the usual effect of fibre addition on the characteristics of fresh concrete. Slump values specifically dropped as the fibre volume rose, going from 7.1 cm to 5.5 cm for untreated fibres and from 7.3 cm to 5.7 cm for treated fibres. This reduction in slump is attributed to the increased internal friction caused by the fibres, which hinder the flow of the concrete mix and absorb part of the mixing water. Notably, the concrete mixes with treated fibres continuously showed somewhat greater slump values than those with untreated fibres for every level of fibre concentration. Even though this difference is small (around 0.2 cm), it indicates that alkali treatment enhances fibre dispersion in the mixture and may lessen water absorption and fibre clumping. Therefore, compared to their untreated counterparts, treated fibres assist preserve superior workability. This means that the use of alkali-treated fibres provides a little improvement, making them more appropriate for concrete applications where both reinforcement and sufficient workability are sought, even though the addition of PAF results in decreased workability as anticipated.

3.2 Hardened test results

3.2.1 Density

Figure 5 displays the density values for concrete mixes that contain both untreated and treated *Phragmites australis* fibres (PAF). As expected, the reference mix without fibres (PA0) exhibited the highest density, measuring 2420 kg/m³. The thick packing of typical concrete without the impact of fibres is reflected in these data, which serve as the baseline for comparison.

Both untreated and treated mixtures show a distinct declining trend in density as the fibre content rises with the addition of PAF. Densities decreased to 2370 kg/m³ (untreated) and 2340 kg/m³ (treated) at 0.5% fibre content. They then continued to decline at 1% fibre content, reaching 2240 kg/m³ and 2235 kg/m³, respectively. The natural fibres lower specific gravity in comparison to the concrete matrix and the additional air content they add are the main causes of this density decrease.

Interestingly, the treated fibre mixes typically maintained somewhat greater densities than their untreated counterparts at higher fibre contents, despite the general trend showing a decrease in density with increasing fibre volume. For instance, at 2% PAF, the treated mix's density (2130 kg/m³) was slightly greater than the untreated mix's (2105 kg/m³). According to this, alkali treatment may strengthen the link between the fibres and the cement matrix, lowering the possibility of air entrapment or fibre clustering and preserving the mix's integrity and compaction.

This indicates that because of the fiber's small weight and the disruption they cause to the mix, adding more PAF gradually lowers the density of the concrete. Nonetheless, alkali-treated fibres have a little edge in preserving greater densities, suggesting enhanced mix homogeneity and fibre-matrix interaction.

3.2.1 Compressive strength

The compressive strength of concrete mixtures incorporating *Phragmites australis* fibres (PAF) was evaluated at 7, 14, and 28 days of curing as shown in Fig. 6. Nine mixes were used in the study: one control mix, four with untreated PAF, and four with fibres treated with sodium hydroxide (NaOH). The findings showed that the mixes compressive strengths varied significantly, emphasising the impact of fibres dosage and treatment on performance.

After seven days, the unfibred control mix (PA0) achieved a compressive strength of 23 MPa. The strength of the untreated and treated mixtures decreased to 11 MPa and 13 MPa, respectively, as the fibre content rose to 2%. At 14 days, this decreasing tendency persisted, with the 2% PA fibre mixes only reaching 15 MPa and 17 MPa, whereas the control mix achieved a compressive strength of 31 MPa. While the compressive strength of the control mix increased significantly to 43 MPa after 28 days, the mixes containing 2% PAF achieved only 19 MPa (untreated) and 25 MPa (treated), respectively.

The reduction in compressive strength with increasing fibre content can be attributed to several factors. The addition of PAF mostly results in weak zones and increased porosity at the fibre-matrix contact. The concrete's capacity to effectively support compressive stresses is hampered by the more noticeable discontinuity in the cement matrix at greater volumes. Furthermore, because untreated fibres are hydrophilic, they may absorb some of the mixing water, which would decrease the amount of water available for cement hydration and have a detrimental effect on strength development.

However, the findings also show that, at all curing ages, the NaOH treatment considerably raises the compressive strength of PA fibre-reinforced concretes. The strength values of the treated fibres were consistently greater than those of the untreated fibres. For example, the compressive strength of concrete containing 1% PA fibres rose from 32 MPa (untreated) to 34 MPa (treated) after 28 days, and from 19 MPa to 25 MPa for the 2% fibre mix. The removal of surface contaminants, waxes, and hemicellulose by the alkali treatment is probably what caused this improvement. A rougher surface texture encourages greater mechanical interlocking and bonding with the cement paste. Furthermore, treated fibres could absorb less water, leaving more free water in the mixture to promote cement hydration.

All mixtures showed a noticeable increase in strength over time, which was indicative of continuous matrix densification and hydration. Despite the fact that all mixtures demonstrated increased strength over extended curing times, the percentage gain peaked early on (between 7 and 14 days) and then dropped down after 28 days. High-fibre content mixes displayed reduced gains because of poor matrix integrity, whereas the control and low-fibre mixes retained comparatively higher strength growth. These results align with the trend reported by (Machaka et al., 2022)

The findings imply that although large amounts of PAF lower compressive strength, alkali treatment can somewhat offset these drawbacks. The treated fibre blends showed respectable compressive strength values, particularly at lower doses (0.5–1%), and might be a good choice for applications that also benefit from natural fibres toughness and crack-bridging properties. Therefore, it is advised to utilise low to moderate doses of NaOH-treated PA fibres in structural concrete for best results.

3.2.2 Splitting Tensile strength

The splitting tensile strength of the concrete mixes, including the control mix, untreated PA fibre mix, and NaOH-treated fibre mix, was evaluated at 7, 14, and 28 days of curing (see Fig. 7). At all curing ages, the data showed a steady trend of fibre-reinforced mixtures outperforming the control, with the most notable improvement coming from fibres treated with NaOH.

At seven days of curing, the results showed that adding PAF up to 1% content significantly increased the material's tensile strength. The splitting tensile strength of the fibre-free (control) mix was 1.95 MPa. Tensile strength improved as fibre content rose, reaching a high of 2.21 MPa (untreated) and 2.30 MPa (treated) for the 1% fibre mixtures. After this, the strength started to somewhat decrease, but the numbers were still higher than the control. Strength decreased to 2.05 MPa (untreated) and 2.10 MPa (treated) at 2% fibre content, suggesting that extremely large fibre quantities may start to impair tensile performance because of inadequate dispersion or fibre clumping.

At 14 days, the tendency stayed mostly the same. The control mix achieved a tensile strength of 2.13 MPa. The treated 0.5% mix achieved the maximum strength at 2.62 MPa, whereas the 0.5% and 1% fibre mixes once again demonstrated improved tensile performance. However, additional increases in fibre content led to a progressive drop, much like the 7-day results. This implies that there is an ideal fibre

concentration, between 0.5% and 1%, where the benefits of fibre reinforcement are maximised without sacrificing the integrity of the matrix.

At 28 days, the tensile strengths of all mixtures continued to improve due to sustained hydration and fibre-matrix bond formation. The control mix exhibited a tensile strength of 2.81 MPa. The treated 0.5% mix had the greatest overall strength value, measuring 3.14 MPa. This suggests that a minor amount of treated PAF greatly increases tensile capability. The 2% fibre mixes displayed the lowest strengths across both series, at 2.03 MPa (untreated) and 2.23 MPa (treated), whereas the untreated mixes peaked at 2.94 MPa for 0.5% fibre content. The same mechanisms previously noted fibre agglomeration, increased void content, and reduced interfacial bonding at higher dose levels which are probably responsible for this ongoing performance deterioration at higher dosage levels. This finding supports the observations made by (Ramadan, Jahami et al., 2023)

The treated fibre mixtures performed better than their untreated counterparts in every curing phase. By enhancing surface roughness and eliminating undesirable surface chemicals, the NaOH treatment seems to have been essential in strengthening the link between the fibres and the cementitious matrix. The fibres can absorb tensile loads, postpone fracture propagation, and bridge cracks more successfully thanks to this improved connection.

The splitting tensile strength test findings show that adding PAF enhances the tensile performance of concrete, especially when the fibres are used in modest quantities and are alkali-treated. It seems that a fibre concentration of 0.5–1% is ideal for maximising tensile strength. The mechanical advantages start to wane beyond this range. These results demonstrate the potential of treated PAF as environmentally friendly reinforcement that may enhance concrete's tensile qualities while also promoting waste reduction and the creation of sustainable materials.

3.2.3 Flexural strength

The flexural tensile strength test results further confirmed the positive influence of PAF on concrete performance as shown in Fig. 8. The control mix exhibited slight strength development over time, increasing from 6.29 MPa at 7 days to 7.85 MPa at 28 days. In contrast, the inclusion of PAF especially in treated form led to significant strength gains throughout the curing period.

The results showed that, up to a particular fibre percentage, adding PAF to concrete increased its flexural strength after seven days of curing. This significant difference highlights how NaOH treatment improves fibre-matrix interaction at an early age. The addition of 0.5% and 1% PAF led to an increase in flexural strength. The untreated mixes achieved 7.39 MPa and 7.89 MPa, while the treated mixes reached 7.65 MPa and 7.96 MPa, respectively. However, the flexural strength started to decrease around 1.5% and especially at 2% fibre content. For example, the treated mix decreased to 4.78 MPa while being greater than the untreated 2% mix, which fell precipitously to 3.52 MPa. According to this pattern, an excessive amount of fibre may make it more difficult to distribute stress effectively because of poor dispersion,

fibre clumping, or more voids in the matrix. This is consistent with the trend observed by (Shon et al., 2019)

At 14 days, the upward trend in strength continued as hydration progressed. The flexural strength of the control mix improved slightly to 7.08 MPa. Notably, the treated 0.5% fibre mix achieved the highest flexural strength at this age, recording 10.25 MPa. The untreated mix also performed well at this fibre dosage (9.23 MPa). Notably, the 1% fibre mixes achieved commendable flexural strengths of 8.73 MPa (untreated) and 9.23 MPa (treated), though the improvements were less significant than those recorded at 0.5% fibre content. Mixes with 1.5% and 2% fibre contents again exhibited reduced strength values, further supporting the observation that fibre reinforcement beyond a certain limit becomes detrimental rather than beneficial to flexural behavior.

By 28 days, all mixes showed further improvements in flexural strength as a result of continued hydration and the development of stronger fibre-matrix bonds. The control mixes reached 7.85 MPa, demonstrating the maturity of the plain concrete matrix. The treated 0.5% fibre mix retained the highest flexural strength overall at 10.35 MPa, indicating that moderate fibre inclusion combined with NaOH treatment has a sustained positive impact on flexural performance. The 1% fibre mixes also remained relatively strong at 8.92 MPa (untreated) and 9.95 MPa (treated), while the 2% fibre mixes again recorded the lowest values 5.2 MPa and 6.23 MPa, respectively.

The findings indicate that NaOH-treated fibres performed better than untreated ones in almost every combination during all curing times. By removing non-cellulosic substances that prevent adhesion and increasing surface roughness, the alkali treatment clearly strengthened the connection between the PAF and the cement matrix. The modified fibres were therefore better able to resist flexural loads and bridge fractures. The findings also show that the ideal fibre content range for flexural performance is between 0.5% and 1%. The reinforcing fibres improve load transmission and fracture resistance within this range without sacrificing the matrix's structural integrity. However, the mechanical interlock between the fibres and matrix may become ineffective at greater doses, resulting in decreased performance.

In Fig. 9a, the concrete sample with 1% untreated PAF shows clear evidence of fibre pull-out as well as some instances of fibre rupture. The prevalence of fibre pull-out signifies a diminished interfacial connection between the untreated fibres and the cementitious matrix. This inadequate bonding leads to fibre slippage under load, diminishing the fibres efficacy in bridging fractures and absorbing tensile stress. The existence of ruptured fibres indicates some interaction with the matrix, nonetheless, the overall performance demonstrates a restricted load-transfer capability resulting from inadequate fibre-matrix adhesion.

Conversely, Fig. 9b illustrates the concrete sample reinforced with 1% treated PAF, which largely demonstrates fibre breakage with scant evidence of fibre pull-out. This behaviour indicates that the alkali treatment (e.g., NaOH) markedly enhanced the fibre-matrix adhesion by augmenting the surface roughness of the fibres and eliminating contaminants such as waxes and lignin. The enhanced bond strength allows the fibres to develop higher tensile stress, leading to fibre breakage instead of pull-out.

This failure mode is desirable, as it indicates better stress transfer and effective reinforcement, contributing to improved flexural performance of the composite. These observations confirm that alkali-treated PAF contribute to enhanced mechanical interaction with the matrix, thereby improving the post-cracking behaviour and ductility of the fibre-reinforced concrete.

3.2.4 Ultra-Pulse Velocity

Ultrasonic Pulse Velocity (UPV) testing was conducted to assess the internal quality and homogeneity of concrete specimens containing untreated and treated *Phragmites australis* fibres (PAF) at different curing ages (7, 14, and 28 days). The UPV values serve as a non-destructive measure of concrete integrity, where higher velocities typically indicate improved density and continuity of the matrix, while reductions may be associated with internal defects or increased porosity.

At 7 days of curing, the control mix (PA0) exhibited identical UPV values of 4.48 km/s, serving as a benchmark for comparison (see Fig. 10a). As fibre content increased from 0.5–2%, a general decline in UPV was observed for both untreated and treated PAF mixes. This reduction is expected due to the disruptive effect of fibres on the concrete matrix, which can lead to increased air voids and hindered compaction. However, it is notable that the decline was consistently less pronounced in the treated fibre mixes. For instance, at 1% fibre content, the UPV increased from 4.24 km/s (untreated) to 4.38 km/s (treated), while at 2%, the treated mix reached 4.10 km/s compared to 4.02 km/s in the untreated mix. These results suggest that alkali treatment of PAF improves fibre dispersion and interfacial bonding, thereby enhancing the early-age matrix continuity and reducing internal flaws.

The trend continued at 14 days of curing, where an overall increase in UPV values was observed across all mixes, attributed to the progression of cement hydration and densification of the microstructure. The control mix (PA0) maintained a constant value of 4.50 km/s (see Fig. 10b). The most significant improvements due to fibre treatment were again observed at higher fibre contents. For example, at 1.5% fibre inclusion, the treated mix demonstrated a UPV of 4.30 km/s compared to 4.25 km/s in the untreated counterpart. These results indicate that the benefits of PAF treatment extend beyond the initial stages of hydration and contribute to continued improvements in the internal quality of the concrete.

By 28 days, UPV values reached their peak across all mixes, reflecting the maturity and densification of the concrete matrix (see Fig. 10c). The control mix registered the highest velocity of 4.65 km/s, reaffirming its compact structure free of fibre-induced defects. Among the reinforced mixes, those incorporating treated fibres consistently showed higher UPV values than their untreated equivalents, especially at elevated fibre contents. Notably, at 2% fibre content, the UPV increased from 4.10 km/s (untreated) to 4.22 km/s (treated), a clear indication of improved structural integrity due to surface modification of fibres. The results at this age strongly support the efficacy of the alkali treatment in mitigating the negative effects typically associated with high fibre content, such as poor dispersion and increased porosity. This trend is consistent with the findings reported by (Machaka et al., 2022).

The UPV results demonstrate that while the inclusion of PAF can reduce pulse velocity due to potential microstructural disruptions, proper fibre treatment significantly offsets these drawbacks. Treated fibres contribute to enhanced bonding at the fibre-matrix interface, reduce air voids, and promote a denser, more uniform internal structure. The findings also suggest that the optimal fibre content lies between 0.5% and 1%, where improvements in internal quality are most pronounced without significant compromise to workability or matrix compactness. These conclusions are consistent with previous literature (Khalid et al., 2021; Thyavihalli Girijappa et al., 2019) on natural fibre-reinforced concrete, reinforcing the importance of fibre pre-treatment in sustainable concrete development.

4. Conclusions

This study investigated the influence of incorporating both untreated and alkali-treated *Phragmites australis* fibres (PAF) on the fresh and mechanical properties of concrete. The following conclusions can be drawn:

1. The inclusion of PAF led to a reduction in workability across all mixes, as reflected in decreased slump values with increasing fibre content. However, NaOH-treated fibres consistently showed slightly higher slump values than untreated fibres, suggesting improved dispersion and reduced water absorption. This indicates that alkali treatment enhances fibre compatibility with the cement matrix, contributing to better workability for treated mixes.
2. The density of concrete decreased with the addition of PAF due to the lower specific gravity of the fibres and increased air entrapment. Nonetheless, mixes containing treated fibres generally retained slightly higher densities compared to untreated ones, likely due to improved fibre-matrix bonding and reduced void formation. This demonstrates that alkali treatment helps maintain better mix homogeneity.
3. The addition of untreated PAF led to a reduction in compressive strength, particularly at higher fibre contents. However, NaOH-treated fibres mitigated this strength loss to a notable extent. Treated mixes consistently outperformed their untreated counterparts at all curing ages, especially at lower fibre dosages (0.5-1%). This enhancement is attributed to improved fibre-matrix interfacial bonding, reduced fibre clumping, and lower water absorption after alkali treatment.
4. PAF mixes exhibited enhanced tensile strength compared to the control mix, with peak performance observed at 0.5-1% fibre content. Beyond this range, tensile strength declined due to poor fibre dispersion and increased voids. Treated fibres provided superior performance at all ages, confirming the role of surface modification in enhancing tensile load transfer and crack-bridging capacity.
5. Flexural strength was significantly improved by the incorporation of treated PAF, particularly at 0.5% content, where the best results were recorded. Similar to tensile strength, excessive fibre inclusion beyond 1% led to performance deterioration. The superior performance of alkali-treated fibres is attributed to better mechanical interlock and adhesion with the cement matrix.
6. Across all mechanical tests, the optimal PAF content was found to be between 0.5% and 1%. Within this range, treated fibres notably improved compressive, tensile, and flexural performance without

compromising mix integrity. At higher dosages, fibre clustering and increased porosity led to diminished performance.

7. The results highlight the potential of NaOH-treated *Phragmites australis* fibres as a sustainable, bio-based reinforcement material for concrete. When properly processed and used at optimal dosages, these fibres can enhance the mechanical performance of concrete while promoting environmental sustainability and resource efficiency.

Declarations

Ethics approval and consent to participate

Competing interests

No competing interests exists in the submission of this manuscript, and manuscript is approved by all authors for publication. The author declare that the work described was original research that has not been published previously, and not under consideration for publication elsewhere, in whole or in part.

Consent for publication

Manuscript is approved by all authors for publication.

Availability of Data and Materials

All data generated or analyzed during this study are included in this published article.

Competing Interests

The authors declare that they have no competing interests.

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Authors' contributions

Sadoon Abdallah: Conceptualization, Methodology Writing – original draft, **Baydaa Hamdi Salih:** Experimental works, **Abdulrahman S. Mohammed:** Data curation, Formal analysis. **Mizi Fan:** Supervision, Writing – review & editing, Validation. **Ameer A. Hilal:** Methodology, Investigation, Writing – review & editing. **Philip E.F. Collins:** Project administration. **Jamal O. Sameer:** Visualization, Data curation.

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References

1. Abdallah, S., & Fan, M. (2017). Anchorage mechanisms of novel geometrical hooked-end steel fibres. *Materials and Structures*, 50(2), 139.
2. Abedi, M., Rojas, G., Domingo, M., Martius-Hammer, T. A., Kanstad, T., & Ji, G. (2025). Steel fiber distribution and orientation in full-scale walls cast from FRC with various consistencies and casting procedures: evaluation by the inductive method. *Materials and Structures*, 58(3), 81.
3. Ali Aichouba, A., Benzaamia, A., Ezziane, M., Ghrici, M., & Mouli, M. (2025). TabNet-based prediction of residual compressive and flexural strengths in hybrid fiber-reinforced self-compacting concrete (HFR-SCC) exposed to elevated temperatures. *Asian Journal of Civil Engineering*, , 1–20.
4. Al-Mawed, L. K., & Hamad, B. S. (2023). Experimental and numerical assessments of slab-column connections strengthened using bonded hemp fiber fabric sheets. *International Journal of Concrete Structures and Materials*, 17(1), 8.
5. Durant, D., Farruggia, A., & Tricheur, A. (2020). Utilization of common reed (*Phragmites australis*) as bedding for housed suckler cows: practical and economic aspects for farmers. *Resources*, 9(12), 140.

6. Ez-Zahraoui, S., Hassani, F. S. A., El Achaby, M., & Bouhfid, R. (2023). Natural fiber reinforcements: classification, extraction, treatment, and properties. *Multiscale textile preforms and structures for natural fiber composites* (pp. 3–29). Elsevier.
7. Gwon, S., Han, S. H., Vu, T. D., Kim, C., & Shin, M. (2023). Rheological and mechanical properties of kenaf and jute fiber-reinforced cement composites. *International Journal of Concrete Structures and Materials*, 17(1), 5.
8. Hadya, K. A., Ramanan, T. R., & Sushama, C. M. (2025). Performance analysis of fiber reinforced concrete using DEA and TOPSIS. *Asian Journal of Civil Engineering*, , 1–14.
9. Hurtado-Figueroa, O., Cobo Escamilla, A., & Varum, H. (2023). The Mercerization Process and Its Impact on Rice Straw Surface Topography. *Buildings*, 13(7), 1573.
10. Khalid, M. Y., Imran, R., Arif, Z. U., Akram, N., Arshad, H., Al Rashid, A., & García Márquez, F. P. (2021). Developments in chemical treatments, manufacturing techniques and potential applications of natural-fibers-based biodegradable composites. *Coatings*, 11(3), 293.
11. Khatib, J. M., ElKhatib, L. W., Elkordi, A., & Sonebi, M. (2023). Length change of mortar containing Phragmites Australis Ash (PAA). *Materials Today: Proceedings*,
12. Khatib, J. M., ElKhatib, L. W., Sonebi, M., & Elkordi, A. (2023). Correlation Between Length Change and Mechanical Properties of Mortar Containing Phragmites Australis Ash (PAA). Paper presented at the *International Conference on Bio-Based Building Materials*, 29–41.
13. Khatib, J., Ramadan, R., Ghanem, H., & Elkordi, A. (2024). Effect of adding Phragmites-Australis Fiber on the mechanical properties and volume stability of mortar. *Fibers*, 12(2), 14.
14. Liang, J., Wang, X., Fu, Z., Li, Z., Liang, L., Luo, Q., & Long, W. (2025). Enhancing the applicability of sisal fibers in cement-based materials through alkali treatment and penetrating crystallization. *Journal of Cleaner Production*, , 144736.
15. Lin, C., Kanstad, T., Jacobsen, S., & Ji, G. (2023). Bonding property between fiber and cementitious matrix: A critical review. *Construction and Building Materials*, 378, 131169.
16. Lv, C., & Liu, J. (2023). Alkaline degradation of plant fiber reinforcements in geopolymer: a review. *Molecules*, 28(4), 1868.
17. Maaze, M. R., Das, S. K., Garg, N., & Shrivastava, S. (2025). Economic-Environmental and Multi-Criteria Optimization for Predicting Alkaline Ratios in Waste Cement Concrete-Based Geopolymer Using Central Composite Design. *International Journal of Concrete Structures and Materials*, 19(1), 1–31.
18. Machaka, M., Khatib, J., Baydoun, S., Elkordi, A., & Assaad, J. J. (2022). The effect of adding phragmites australis fibers on the properties of concrete. *Buildings*, 12(3), 278.
19. Merve Tuncer, H., & Canan Girgin, Z. (2023). Hemp fiber reinforced lightweight concrete (HRLWC) with coarse pumice aggregate and mitigation of degradation. *Materials and Structures*, 56(3), 59.
20. Padwad, H., Puri, N., Sahare, S. A., Gote, A. C., Patil, T. R., & Kakade, N. T. (2025). Hybrid metaheuristic optimization algorithm for prediction of fatigue life performance of fiber-reinforced concrete. *Asian Journal of Civil Engineering*, , 1–12.

21. Ramadan, R., Elkordi, A., Ghorbel, E., Ghanem, H., & Khatib, J. (2024). Investigating volume stability Performance of paste with Phragmites Australis (PA) Fibers. *Procedia Structural Integrity*, 64, 1927–1934.
22. Ramadan, R., Jahami, A., Khatib, J., El-Hassan, H., & Elkordi, A. (2023). Improving structural performance of reinforced concrete beams with phragmites australis fiber and waste glass additives. *Applied Sciences*, 13(7), 4206.
23. Ramadan, R., Khatib, J., Ghorbel, E., & Elkordi, A. (2023). Effect of adding Phragmites-Australis plant on the chemical shrinkage and mechanical properties of mortar. Paper presented at the *International Conference on Bio-Based Building Materials*, 573–584.
24. Saleh, M. A., Kazemi, F., Abdelgader, H. S., & Isleem, H. F. (2025). Optimization-based multitarget stacked machine-learning model for estimating mechanical properties of conventional and fiber-reinforced preplaced aggregate concrete. *Archives of Civil and Mechanical Engineering*, 25(4), 185.
25. Shon, C., Mukashev, T., Lee, D., Zhang, D., & Kim, J. R. (2019). Can common reed fiber become an effective construction material? Physical, mechanical, and thermal properties of mortar mixture containing common reed fiber. *Sustainability*, 11(3), 903.
26. Singh, M. P., Kumar, A., & Sinha, S. (2025). Machine learning-based prediction of compressive strength of plastic optical fiber embedded transparent concrete. *Asian Journal of Civil Engineering*, 26(6), 2527–2545.
27. Suárez, L., Barczewski, M., Kosmela, P., Marrero, M. D., & Ortega, Z. (2023). Giant reed (*Arundo donax* L.) fiber extraction and characterization for its use in polymer composites. *Journal of Natural Fibers*, 20(1), 2131687.
28. Sudheer, M., & Rao, B. C. M. (2025). Machine learning based boosting models for predicting flexural strength of steel fiber reinforced concrete. *Asian Journal of Civil Engineering*, , 1–11.
29. Suwanvitaya, P., & Chotickai, P. (2024). Effect of elevated temperature exposure on the flexural behavior of steel–polypropylene hybrid fiber-reinforced concrete. *Materials and Structures*, 57(3), 43.
30. Thyavihalli Girijappa, Y. G., Mavinkere Rangappa, S., Parameswaranpillai, J., & Siengchin, S. (2019). Natural fibers as sustainable and renewable resource for development of eco-friendly composites: a comprehensive review. *Frontiers in Materials*, 6, 226.
31. Zeng, H., Zhang, J., Li, Y., Su, X., Gu, C., & Zhang, K. (2022). Mechanical properties and microstructure of basalt fiber reinforced concrete under the single-side salt-freezing–drying–wetting cycles. *International Journal of Concrete Structures and Materials*, 16(1), 44.

Figures



Figure 1

depicts the process of preparing PAF, starting from collection and ending with its conversion into short fibres.



(a) PAF soaked in NaOH solution

(b) PAF rinsed with clean water

Figure 2

Treatment process of *Phragmites australis* fibres (PAF): (a) soaking in NaOH solution and (b) rinsing with clean water.

Concrete Mixing Process



Figure 3

shows the mixing procedure

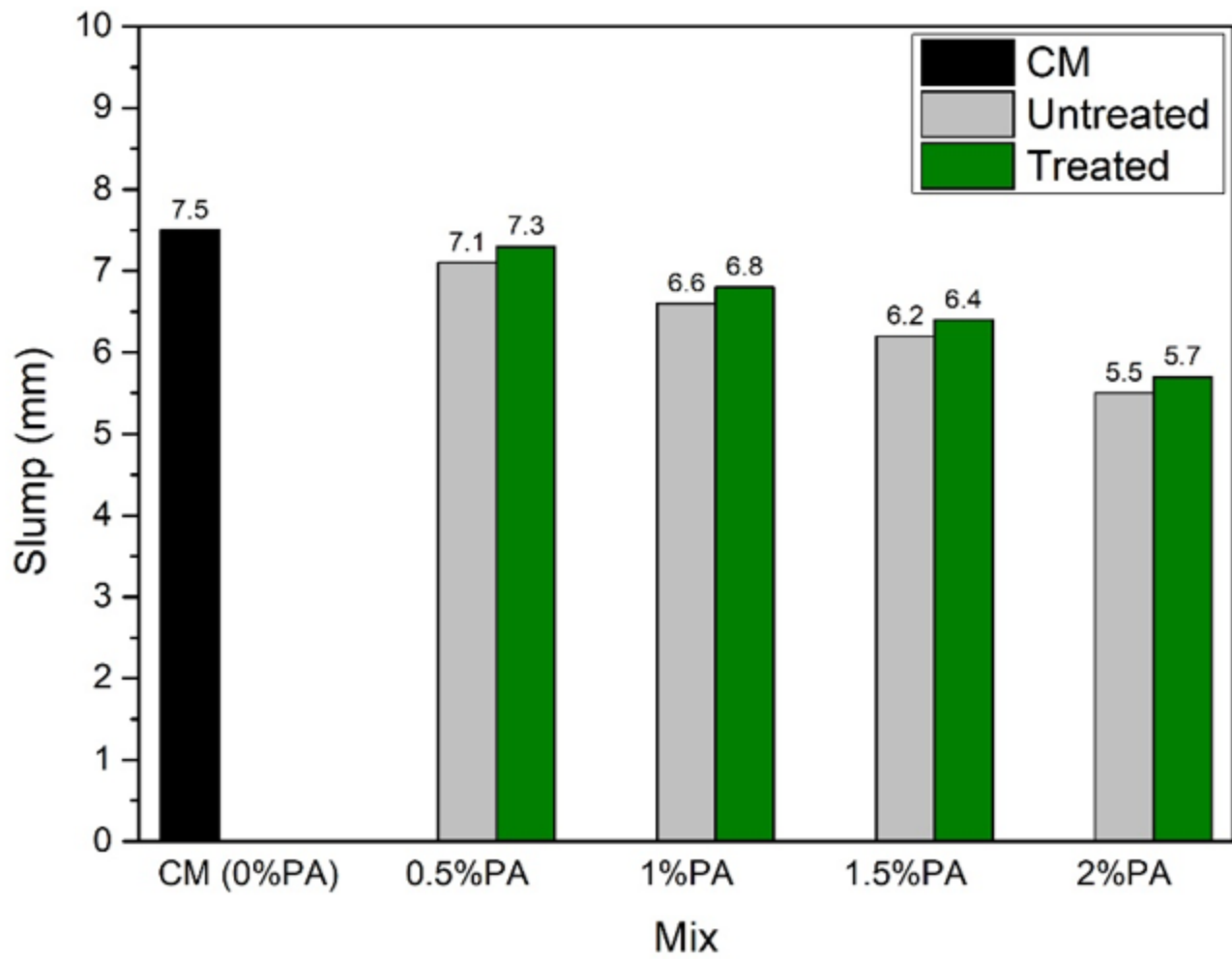


Figure 4

shows the slump test results

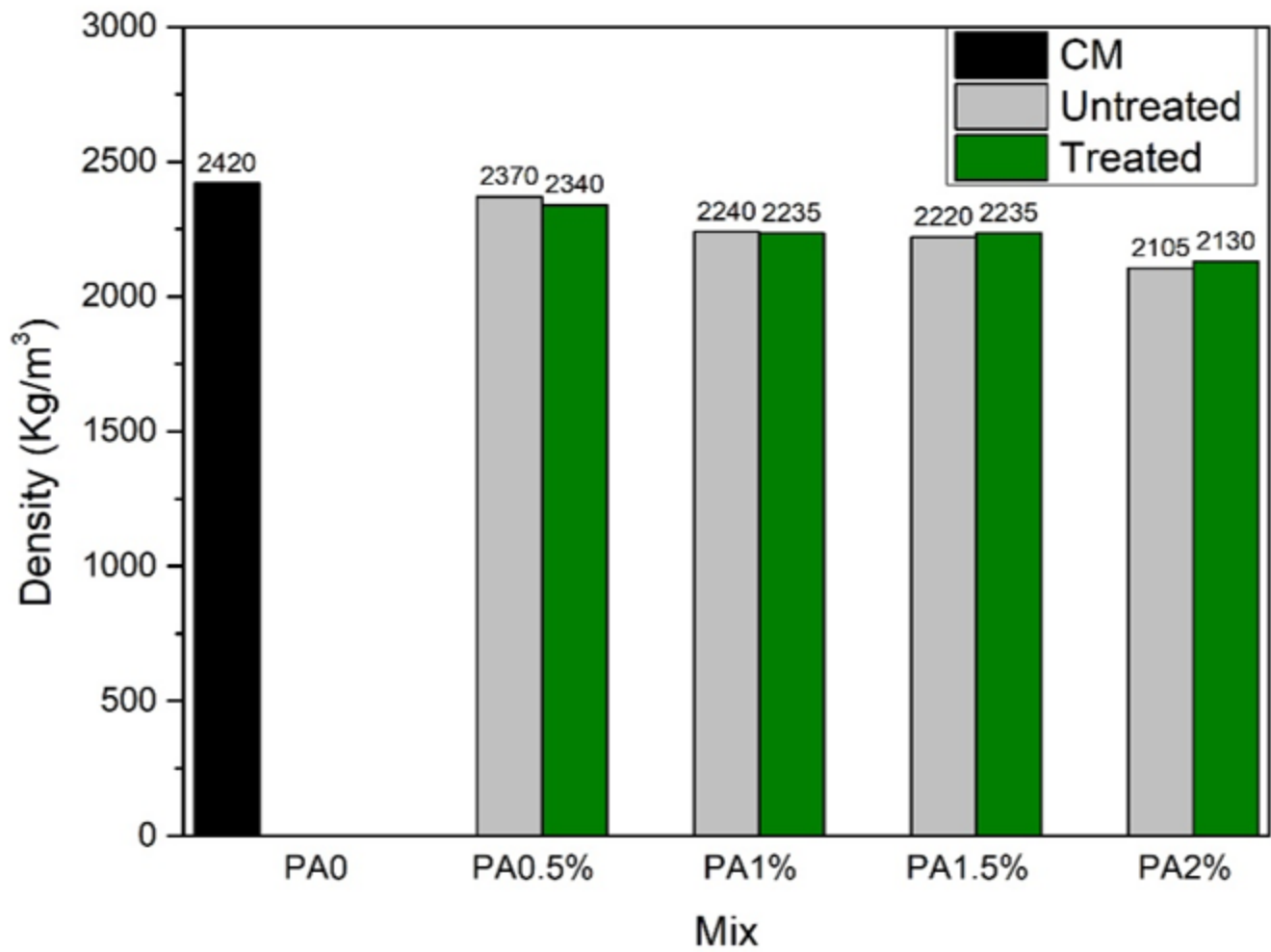
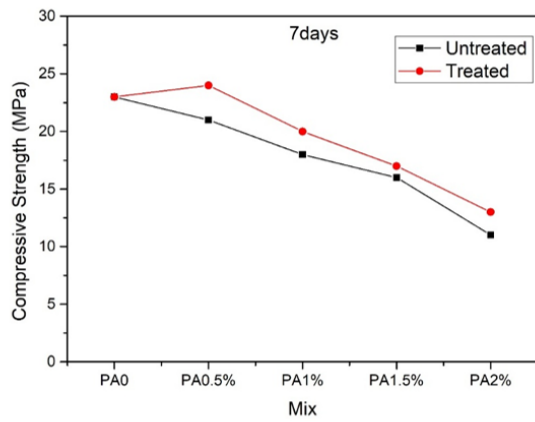
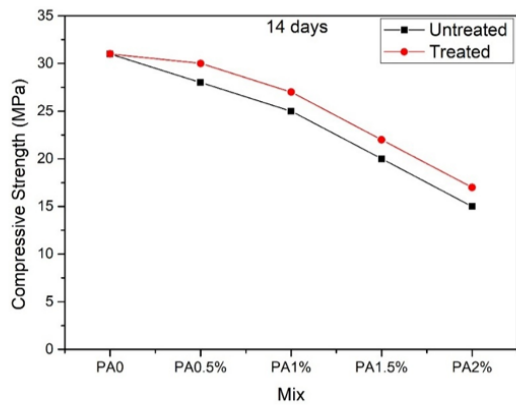


Figure 5

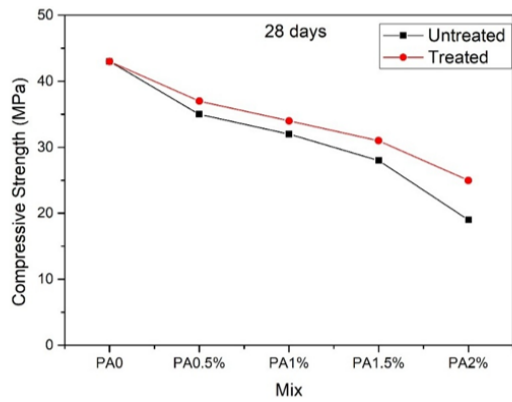
displays the density test results for the treated and untreated samples



a) 7 days of curing



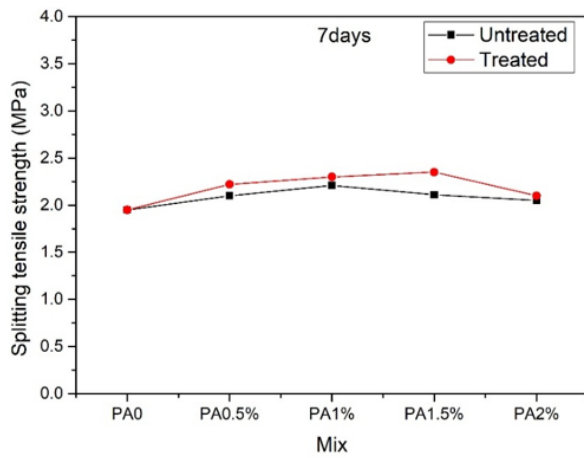
b) 14 days of curing



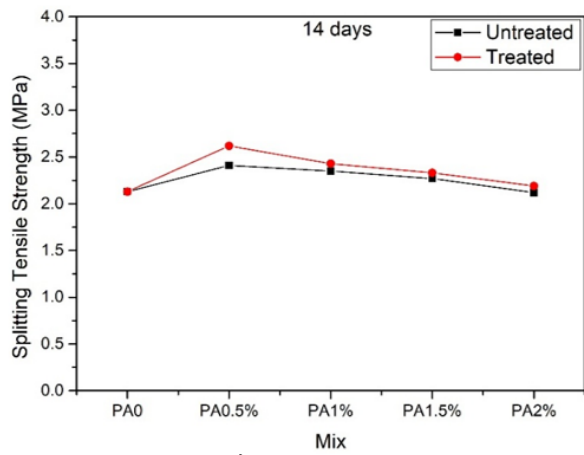
c) 28 days of curing

Figure 6

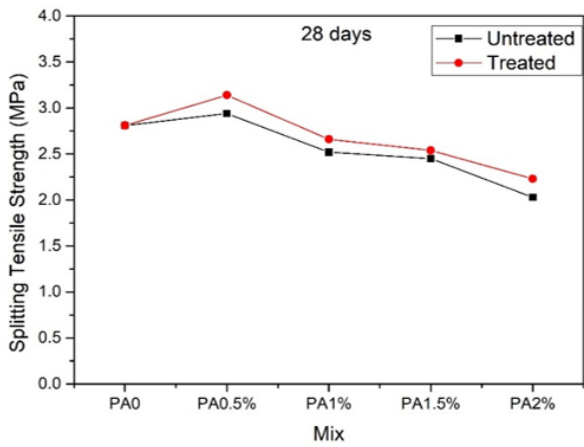
Compressive strength test results at 7, 14, and 28 days of curing.



a) 7 days of curing



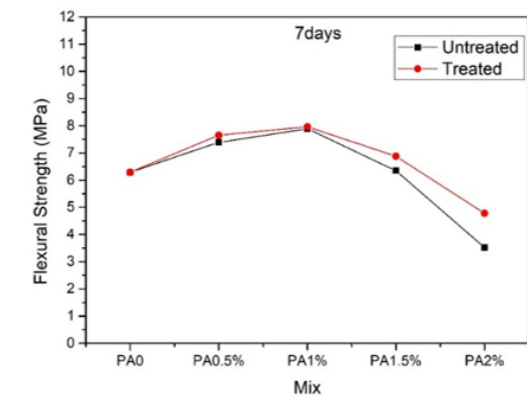
b) 14 days of curing



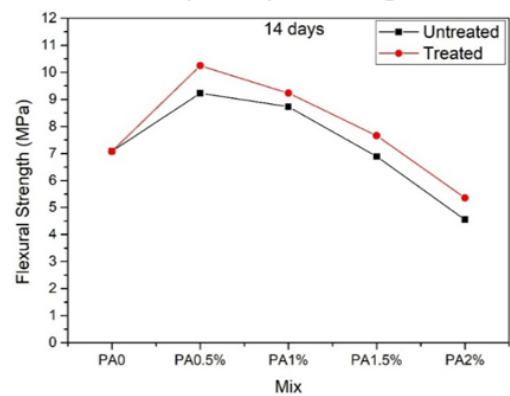
c) 28 days of curing

Figure 7

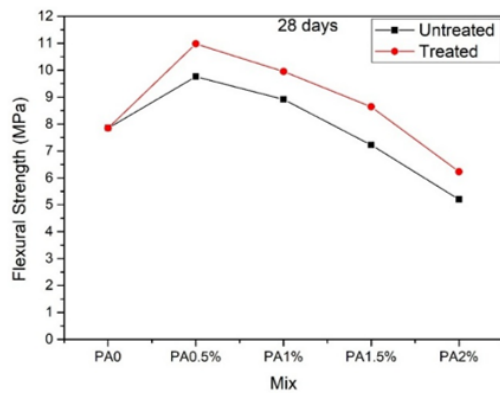
Splitting tensile strength test results at 7, 14, and 28 days of curing.



a) 7 days of curing



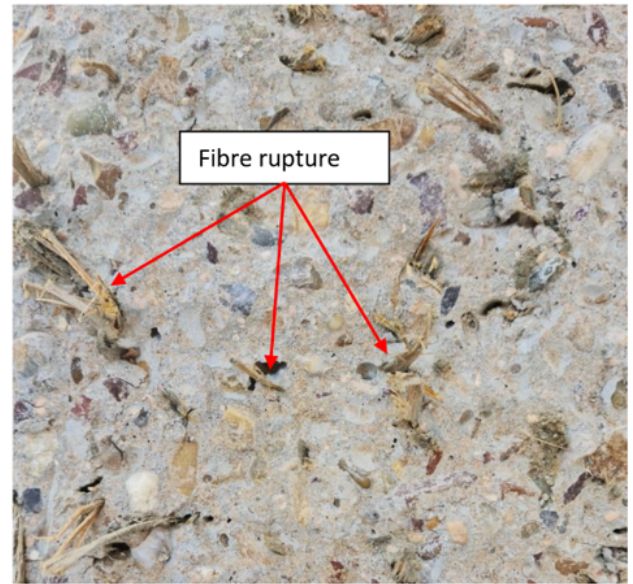
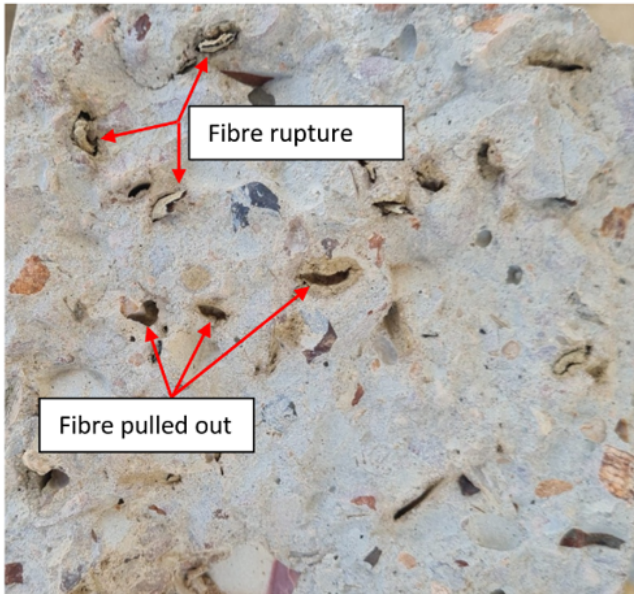
b) 14 days of curing



c) 28 days of curing

Figure 8

Flexural strength test results at 7, 14, and 28 days of curing.

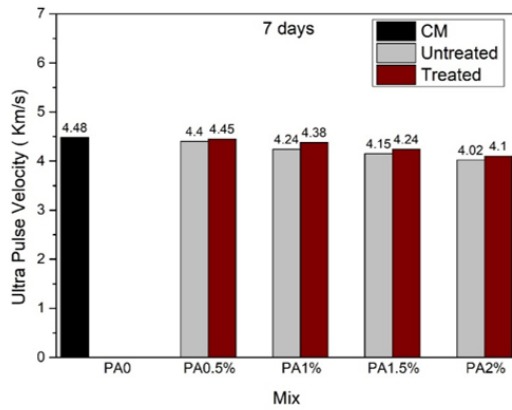


(a) 1% untreated PAF cross-section

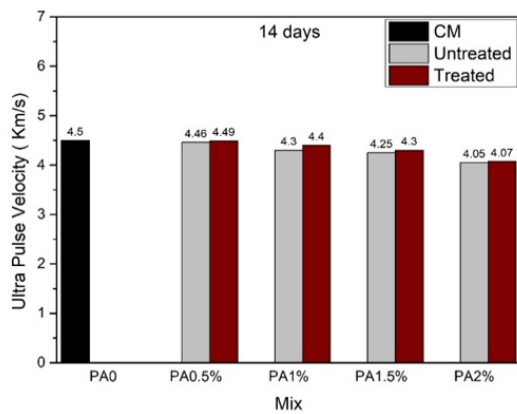
(b) 1% treated PAF cross-section

Figure 9

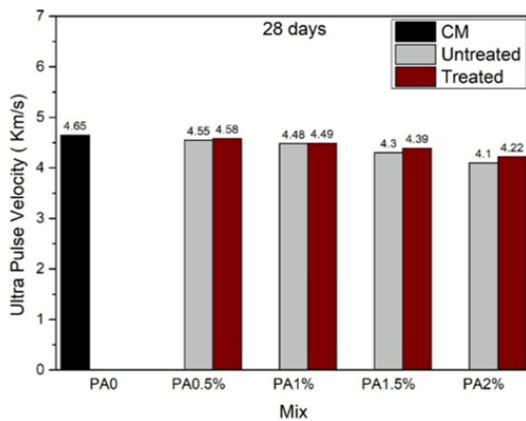
Failure modes of concrete beams with 1% untreated (a) and treated (b) *Phragmites australis* fibres after flexural testing.



a) 7 days of curing



b) 14 days of curing



c) 28 days of curing

Figure 10

Comparison of UPV values for concrete containing untreated and treated PAF at different curing ages.