Building Engineering 2025, 3(2), 2598.
https://doi.org/10.59400/be2598

Article

Effect of chemical treatments on the mechanical and physical performance of corn straw fibers in cement mortar

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CITATION

Peng B, Bakri ZB. Effect of chemical treatments on the mechanical and physical performance of corn straw fibers in cement mortar. Building Engineering. 2025; 3(2): 2598. https://doi.org/10.59400/be2598

ARTICLE INFO

Received: 16 January 2025
Accepted: 26 March 2025
Available online: 7 April 2025

Abstract: This study investigates the effects of water, acetic acid (CH_3COOH), and sodium hydroxide (NaOH) treatments on the physical and mechanical properties of corn straw fibers in cement mortar. The use of natural fibers in cement composites offers a promising approach to reducing reliance on synthetic materials and utilizing agricultural byproducts. Chemical treatments like NaOH and CH_3COOH improve fiber-matrix bonding, which is critical for enhancing the mechanical properties of the composites. NaOH treatment resulted in the most significant improvements, with surface roughness increasing by 104.8% and compressive strength reaching 52.8 MPa at 1.5% fiber content after 28 days. CH_3COOH treatment boosted early-stage flexural strength, achieving 6.75 MPa at 7 days, but its long-term effect was limited. Water treatment showed minimal impact on fiber performance. These results indicate the potential for NaOH-treated fibers to enhance the strength and durability of cement-based materials.

Keywords: corn straw; fiber treatment; alkali treatment; mechanical properties; cement composites

1. Introduction

The incorporation of natural fibers into cement-based composites has gained considerable attention due to their potential to enhance the mechanical properties of construction materials while promoting sustainability [1]. Among these fibers, corn straw fibers have emerged as a promising alternative to synthetic fibers [2]. Corn straw, an agricultural byproduct, is not only abundant and cost-effective but also aligns with the principles of the circular economy [3]. Using corn straw fibers in construction materials addresses the dual challenges of agricultural waste management and carbon emission reduction, offering an environmentally friendly solution in line with global sustainability goals [4].

Corn straw fibers are primarily composed of cellulose, hemicellulose, lignin, and other organic compounds, which contribute to their structural integrity and mechanical properties [5,6]. However, untreated corn straw fibers exhibit several limitations when used in cementitious matrices. The smooth surface of untreated fibers, along with the presence of waxy layers, silica, and other surface impurities, reduces their compatibility with cement. These characteristics hinder effective bonding with the cement matrix, resulting in suboptimal mechanical performance of the composite [7–9]. Additionally, untreated fibers often exhibit high water absorption, which can lead to shrinkage and cracking in cement-based materials. Therefore, enhancing the physical and chemical properties of corn straw fibers through appropriate treatment methods is crucial to improving their performance in construction applications [10,11].

Chemical treatments have been widely studied as a means to improve the performance of natural fibers. Among the most commonly used treatments are water, acetic acid (CH_3COOH), and sodium hydroxide (NaOH). Each treatment method has distinct effects on the physical and chemical properties of fibers. Water treatment involves boiling fibers in water to remove loosely bound impurities and surface waxes. While water treatment serves as a baseline method, it has limited impact on the structural properties of fibers and does not significantly enhance their compatibility with cementitious materials [12–14]. Acetic acid treatment partially hydrolyzes hemicellulose and lignin, resulting in increased surface roughness and the formation of microcracks. These changes can improve early-stage bonding of fibers with cement but may compromise long-term performance due to the brittleness introduced by microcracks [15,16]. Sodium hydroxide treatment is particularly effective in removing lignin and hemicellulose, exposing the cellulose fibrils and significantly increasing surface roughness. These modifications enhance the mechanical interlocking of fibers with the cement matrix, leading to improved flexural and compressive strength. NaOH treatment is often regarded as the most effective method for optimizing fiber performance in cementitious materials [17–19].

The construction industry faces increasing pressure to adopt sustainable and cost-effective materials. Traditional construction practices heavily rely on synthetic fibers and non-renewable resources, which contribute to environmental degradation and carbon emissions. The integration of treated corn straw fibers into cement mortar represents a sustainable alternative, leveraging agricultural waste to produce high-performance composites [20–22]. By enhancing the mechanical properties of cement-based materials, treated natural fibers can reduce the need for synthetic reinforcements, thereby lowering the overall carbon footprint of construction projects [23,24].

Previous studies have highlighted the potential of natural fibers to improve the mechanical properties of cementitious materials. For example, research has demonstrated that alkali-treated fibers exhibit superior flexural and compressive strength due to improved fiber-matrix bonding. Acetic acid-treated fibers, on the other hand, have been shown to enhance early-stage flexural performance but may be less effective in long-term applications. Despite these findings, there remains a need for a comprehensive understanding of how different treatment methods influence the performance of corn straw fibers specifically [25–28]. This study seeks to fill this gap by systematically evaluating the effects of water, CH_3COOH, and NaOH treatments on the physical and mechanical properties of corn straw fibers.

The primary objective of this study is to investigate the influence of different treatment methods on the performance of corn straw fibers in cement mortar. Specifically, the study aims to:

Evaluate the physical changes in corn straw fibers, including surface morphology and chemical composition, resulting from water, CH_3COOH, and NaOH treatments.

Assess the impact of treated fibers on the flexural strength of cement mortar at both early (7-day) and long-term (28-day) curing stages.

Analyze the compressive strength of cement mortar specimens containing treated fibers.

Identify the most effective treatment method for optimizing the performance of corn straw fibers in cementitious applications.

This study contributes to the broader goals of sustainable development by promoting the use of agricultural waste in construction materials. By demonstrating the potential of treated corn straw fibers to enhance the mechanical properties of cement mortar, the research supports the transition to more sustainable construction practices. Additionally, the findings provide valuable insights into the optimization of fiber treatments, paving the way for the development of high-performance, eco-friendly construction materials.

The findings of this research have significant implications for the construction industry. By providing a detailed analysis of the effects of different treatment methods on corn straw fibers, the study offers practical guidance for optimizing fiber performance in cementitious materials. Moreover, the integration of treated natural fibers into construction materials aligns with global efforts to reduce waste and promote sustainability. As the demand for eco-friendly construction materials continues to grow, the insights gained from this study will be invaluable in driving innovation and advancing sustainable practices in the industry.

In summary, this introduction has laid the groundwork for a comprehensive investigation into the effects of chemical treatments on the performance of corn straw fibers in cement mortar. The subsequent sections will detail the materials and methods used in the study, followed by a presentation and discussion of the results, and conclude with recommendations for future research and practical applications.

2. Materials and methods

2.1. Materials

The primary material used in this study was corn straw fibers, sourced as agricultural waste from local farms. The fibers were manually cleaned to remove visible impurities such as dirt and debris before undergoing treatment. Ordinary Portland cement (Type I) conforming to ASTM (American Society for Testing and Materials) C150 standards was used as the binder. Fine aggregate in the form of natural river sand, with a fineness modulus of 2.5, was employed to ensure consistency in the mortar mix. Distilled water was used for both fiber treatment and cement mixing to eliminate the potential influence of impurities on the experimental outcomes.

The chemical reagents used for fiber treatments included:

Water: Used for boiling fibers as a baseline treatment to remove loosely bound impurities.

CH_3COOH: A 5% solution was used to chemically modify the fibers.

NaOH: A 4% solution was employed to alter the chemical composition and surface morphology of the fibers.

2.2. Fiber treatment methods

Three different treatment methods were applied to the corn straw fibers to evaluate their influence on physical and mechanical properties. Each treatment method was designed to address specific challenges associated with natural fiber utilization in cement-based composites:

Water treatment: The fibers were boiled in distilled water at 100 ℃ for one hour. After boiling, the fibers were rinsed thoroughly with distilled water and air-dried at ambient temperature for 48 h. This method serves as a baseline treatment.

CH_3COOH treatment: Fibers were soaked in a 5% acetic acid solution for 24 h at room temperature. After treatment, the fibers were rinsed with distilled water to remove any residual acid and air-dried for 48 h. This method is intended to partially hydrolyze hemicellulose and lignin, enhancing surface roughness.

NaOH treatment: Fibers were immersed in a 4% NaOH solution for 12 h at room temperature. After the treatment, the fibers were soaked in a dilute acetic acid solution to neutralize any remaining alkali, then rinsed with distilled water and air-dried for 48 h. NaOH treatment is effective in removing lignin and hemicellulose, exposing cellulose fibrils and significantly increasing surface roughness.

2.3. Specimen preparation

The treated fibers were incorporated into cement mortar at varying proportions (0.5%, 1%, 1.5%, and 2% by weight of cement) to evaluate their influence on mechanical properties. A standard water-to-cement ratio of 0.5 was maintained for all mixes to ensure consistency. The mortar mixtures were thoroughly blended to achieve uniform fiber distribution.

Specimens for testing were prepared as follows:

Flexural Strength Specimens: Prismatic molds (40 mm × 40 mm × 160 mm) were used to cast specimens for three-point bending tests.

Compressive Strength Specimens: Cylindrical molds (50 mm × 100 mm) were employed to cast specimens for compression tests.

After casting, all specimens were allowed to cure in water at 23 °C ± 2 °C until the designated testing periods of 7 days and 28 days.

2.4. Testing procedures

The following tests were conducted to evaluate the physical and mechanical properties of the treated fibers and their effect on cement mortar:

Physical analysis:

Surface morphology: The surface characteristics of untreated and treated fibers were examined using optical microscopy. Changes in surface roughness, cracks, and structural modifications were documented. Images from optical microscopy were included to visualize the differences in surface features between treated and untreated fibers.

Chemical composition: The cellulose, hemicellulose, and lignin content of the fibers were analyzed before and after treatment. These analyses were performed to quantify the chemical changes and determine the extent to which the treatments modified the fiber structure.

Flexural strength test: Flexural strength was measured using a universal testing machine in a three-point bending configuration. The loading rate was set at 1 mm/min. Testing was conducted on specimens after 7 and 28 days of curing. The flexural strength results provide insight into the impact of fiber treatment on the material's ability to withstand bending forces.

Compressive strength test: Compressive strength tests were performed using a hydraulic press at a loading rate of 2 kN/s. Cylindrical specimens were tested after 7 and 28 days of curing. The compressive strength is a critical parameter for evaluating the overall strength and durability of fiber-reinforced cement mortar.

2.5. Data analysis

The experimental data collected were subjected to statistical analysis to determine the mean, standard deviation, and coefficient of variation for each test group. Comparative analyses were conducted to evaluate the effects of different fiber treatments and fiber content levels on the physical and mechanical properties of the cement mortar. Trends were identified, and performance metrics for each treatment method were calculated to provide a basis for optimization.

The methodology described ensures repeatability and reliability, enabling a comprehensive assessment of the influence of treated corn straw fibers on cement mortar performance. Moreover, the analysis of the treatment impact, including potential variations with different fiber contents, allows for identifying the most effective approach for future optimization of fiber-reinforced cementitious materials.

3. Results and discussion

3.1. Physical properties of treated fibers

3.1.1. Surface morphology analysis

The surface morphology of corn straw fibers underwent significant transformations following different treatments. The surface characteristics of the fibers were shown in **Figure 1**, with quantitative data summarized in **Table 1**. Untreated fibers exhibited smooth surfaces, with limited roughness and noticeable waxy layers. These surface characteristics hinder effective bonding with the cement matrix, as the smoothness reduces mechanical interlocking and adhesion.

Table 1. Physical properties of treated and untreated fibers.

Treatment	**Surface Roughness (μm)**	**Contact Angle (°)**	**Water Absorption (%)**	**Weight Loss (%)**
Untreated	2.31 ± 0.3	68.5 ± 2.8	182.3 ± 8.5	-
Water	2.84 ± 0.3	65.2 ± 2.4	175.6 ± 7.8	2.1 ± 0.3
CH_3COOH	3.52 ± 0.4	58.7 ± 2.6	156.4 ± 6.9	5.8 ± 0.5
NaOH	4.73 ± 0.4	45.3 ± 2.2	143.2 ± 6.4	8.4 ± 0.6

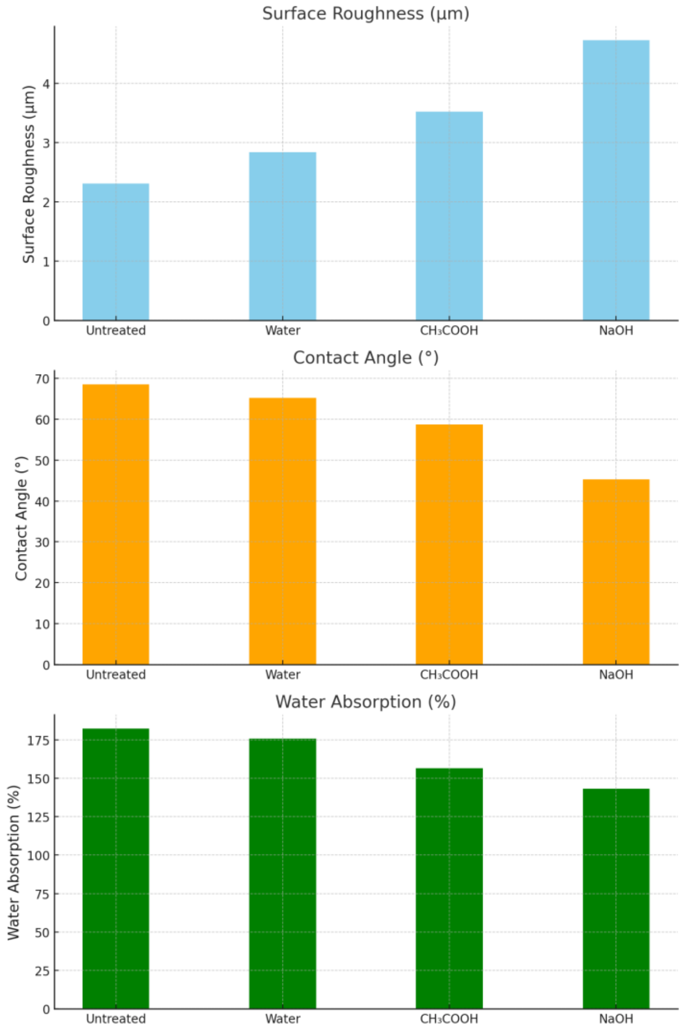

Figure 1. Physical properties of treated fibers.

Water-treated fibers showed marginal increases in surface roughness (2.84 ± 0.28 μm) due to the removal of loosely bound impurities. However, the effect was insufficient to significantly enhance fiber-matrix bonding. CH_3COOH-treated fibers displayed more pronounced changes, with an increased roughness (3.52 ± 0.35 μm) and visible microcracks on the surface. These modifications are attributed to the partial hydrolysis of hemicellulose and lignin, which weakened the structural integrity of the fibers.

NaOH-treated fibers experienced the most substantial alterations, with roughness increasing to 4.73 ± 0.41 μm, representing a 104.8% enhancement compared to untreated fibers. This dramatic change is primarily due to the removal of non-cellulosic components, such as lignin and hemicellulose, exposing the cellulose fibrils. These modifications improve the fibers' compatibility with cementitious materials by increasing surface area and enhancing mechanical interlocking potential.

3.1.2. Chemical composition analysis

Chemical composition analysis revealed significant modifications in the cellulose, hemicellulose, and lignin content of fibers after treatments, as shown in

Table 2. Untreated fibers comprised 42.5% ± 1.2% cellulose, 28.3% ± 0.9% hemicellulose, and 18.2% ± 0.7% lignin. Water treatment had minimal impact, slightly increasing cellulose content to 43.1% ± 1.0% while reducing hemicellulose and lignin to 27.8% ± 0.8% and 17.9% ± 0.6%, respectively.

CH_3COOH treatment resulted in a notable increase in cellulose (45.3% ± 1.1%) and reductions in hemicellulose (25.2% ± 1.0%) and lignin (16.8% ± 0.8%). This indicates partial removal of lignin and hemicellulose, enhancing fiber rigidity. However, NaOH treatment yielded the most pronounced effects, increasing cellulose to 48.7% ± 1.3% while significantly reducing hemicellulose and lignin to 21.4% ± 0.9% and 14.5 ± 0.7%, respectively. The enhanced cellulose content and reduced lignin facilitate better mechanical properties by improving the fiber's compatibility with cement.

Table 2. Chemical composition of fibers before and after treatments (%).

Component	**Untreated**	**Water**	**CH_3COOH**	**NaOH**
Cellulose	42.5 ± 1.2	43.1 ± 1.0	45.3 ± 1.1	48.7 ± 1.3
Hemicellulose	28.3 ± 0.9	27.8 ± 0.8	25.2 ± 1.0	21.4 ± 0.9
Lignin	18.2 ± 0.7	17.9 ± 0.6	16.8 ± 0.8	14.5 ± 0.7
Other	11.0 ± 1.1	11.2 ± 1.1	12.7 ± 1.2	15.4 ± 1.4

3.2. Mechanical properties

3.2.1. Flexural strength development

Flexural strength results for treated and untreated fibers at different curing times are presented in **Figure 2** and summarized in **Table 3**. At 7 days, CH_3COOH-treated fibers exhibited the highest flexural strength across all fiber content levels, with a peak of 6.75 ± 0.44 MPa at 1.5% fiber content. NaOH-treated fibers showed moderate performance, reaching 5.94 ± 0.39 MPa at the same content. Water-treated fibers displayed the lowest flexural strength, decreasing as fiber content increased.

At 28 days, NaOH-treated fibers demonstrated superior performance, with a maximum flexural strength of 8.34 ± 0.54 MPa at 1.5% fiber content. CH_3COOH-treated fibers exhibited a slight decrease in flexural strength over time but remained higher than water-treated fibers.

Table 3. Flexural strength development (MPa).

Curing Time	**Fiber Content (%)**	**Water**	**CH_3COOH**	**NaOH**
7 days	0.5	4.8 ± 0.31	5.9 ± 0.38	5.4 ± 0.35
	1.0	4.5 ± 0.29	6.3 ± 0.41	5.7 ± 0.37
	1.5	4.2 ± 0.27	6.7 ± 0.44	5.9 ± 0.39
	2.0	3.9 ± 0.25	6.4 ± 0.42	5.8 ± 0.38
28 days	0.5	7.1 ± 0.46	7.3 ± 0.48	7.6 ± 0.49
	1.0	6.8 ± 0.44	7.5 ± 0.49	8.1 ± 0.53
	1.5	6.54 ± 0.42	7.4 ± 0.48	8.3 ± 0.54
	2.0	6.2 ± 0.40	7.2 ± 0.47	7.9 ± 0.51

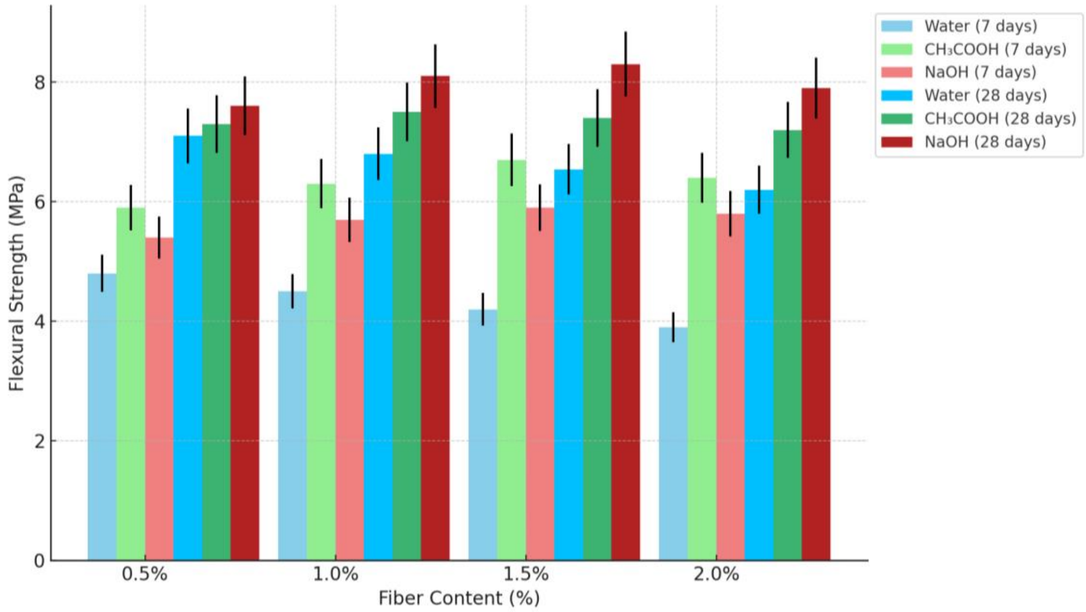

Figure 2. Flexural strength bar chart.

3.2.2. Compressive strength results

Compressive strength results are shown in **Figure 3** and summarized in **Table 4**. At 7 days, NaOH-treated fibers achieved the highest compressive strength (34.8 ± 2.3 MPa at 1.5% fiber content), followed by CH_3COOH-treated fibers (30.2 ± 2.0 MPa). Water-treated fibers showed the lowest compressive strength, which declined with increasing fiber content.

At 28 days, NaOH-treated fibers retained their superior performance, with a maximum compressive strength of 52.8 ± 3.4 MPa at 1.5% fiber content. CH_3COOH-treated fibers demonstrated consistent results, achieving 49.1 ± 3.2 MPa, while water-treated fibers remained the least effective.

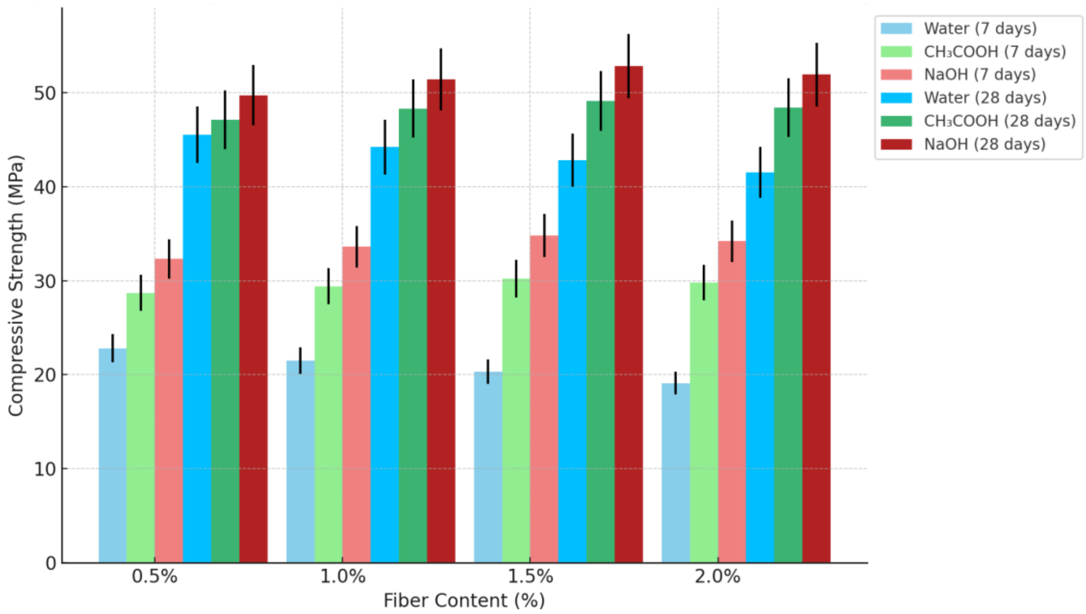

Figure 3. Compressive strength bar chart.

Table 4. Compressive strength development (MPa).

Curing Time	Fiber Content (%)	Water	CH_3COOH	NaOH
7 days	0.5	22.8 ± 1.5	28.7 ± 1.9	32.3 ± 2.1
	1.0	21.5 ± 1.4	29.4 ± 1.9	33.6 ± 2.2
	1.5	20.3 ± 1.3	30.2 ± 2.0	34.8 ± 2.3
	2.0	19.1 ± 1.2	29.8 ± 1.9	34.2 ± 2.2
28 days	0.5	45.5 ± 3.0	47.1 ± 3.1	49.7 ± 3.2
	1.0	44.2 ± 2.9	48.3 ± 3.1	51.4 ± 3.3
	1.5	42.8 ± 2.8	49.1 ± 3.2	52.8 ± 3.4
	2.0	41.5 ± 2.7	48.4 ± 3.1	51.9 ± 3.4

Figures 2 and **3** illustrate the above trends, highlighting the superior performance of NaOH-treated fibers in both flexural and compressive strength. CH_3COOH-treated fibers provided enhanced early-stage flexural strength, while water-treated fibers exhibited minimal improvements across all metrics.

4. Discussion

4.1. Interpretation of results

The findings of this study underscore the significant influence of chemical treatments on the performance of corn straw fibers in cement mortar composites. Among the treatments studied, NaOH demonstrated the most substantial enhancements in mechanical properties, while CH_3COOH provided notable early-stage flexural improvements. Water treatment, by contrast, exhibited minimal effects, emphasizing the limited potential of boiling alone as a fiber modification technique.

4.1.1. Surface morphology and chemical composition

The surface morphology analysis revealed that NaOH-treated fibers underwent the most pronounced structural changes, with a significant increase in surface roughness (4.73 ± 0.41 μm) compared to untreated fibers. This enhancement was attributed to the removal of lignin and hemicellulose, exposing cellulose fibrils and creating a rougher surface that promotes mechanical interlocking with the cement matrix [18,19]. The chemical composition analysis further supported these findings, showing that NaOH treatment significantly increased cellulose content (48.7% ± 1.3%) while reducing hemicellulose (21.4% ± 0.9%) and lignin (14.5% ± 0.7%).

In contrast, CH_3COOH treatment resulted in moderate surface roughness (3.52 ± 0.35 μm) and the formation of microcracks. While these microcracks improved early-stage flexural strength due to better fiber-matrix bonding, they also introduced potential weaknesses that could compromise long-term performance [15,16]. CH_3COOH treatment achieved a modest increase in cellulose content (45.3% ± 1.1%), along with reductions in hemicellulose (25.2% ± 1.0%) and lignin (16.8% ± 0.8%).

Water treatment, serving as a baseline, caused minimal changes in both surface morphology (2.84 ± 0.28 μm) and chemical composition. The limited removal of impurities and the persistence of waxy layers likely explain the inferior performance of water-treated fibers in mechanical tests [12,14].

4.1.2. Mechanical properties

The mechanical performance of cement mortar specimens reflected the physical and chemical transformations of the fibers. NaOH-treated fibers exhibited superior flexural and compressive strength across all curing times. At 28 days, specimens with NaOH-treated fibers achieved a maximum flexural strength of 8.34 ± 0.54 MPa and a compressive strength of 52.8 ± 3.4 MPa at 1.5% fiber content. These results demonstrate the effectiveness of NaOH treatment in enhancing both short-term and long-term mechanical performance [29,30].

CH_3COOH-treated fibers excelled in early-stage flexural strength, reaching 6.75 ± 0.44 MPa at 7 days with 1.5% fiber content. However, their performance declined slightly over time, likely due to the brittleness introduced by microcracks. Despite this limitation, CH_3COOH-treated fibers remained more effective than water-treated fibers, which consistently showed the lowest mechanical properties. The poor performance of water-treated fibers highlights the need for more robust chemical treatments to optimize fiber-cement interactions [31].

4.2. Comparison with previous studies

The results of this study align with existing literature on the benefits of chemical treatments for natural fibers in cementitious applications. Previous research has consistently shown that alkali treatments, such as NaOH, improve fiber-matrix bonding by removing non-cellulosic components, thereby enhancing mechanical properties. This study reinforces these findings by demonstrating that NaOH treatment significantly improves both flexural and compressive strength in cement mortar specimens [19,29,30].

Similarly, the observed benefits of CH_3COOH treatment for early-stage performance align with prior studies highlighting the potential of acid treatments to enhance initial bonding. However, the decline in long-term performance observed in this study underscores the need for further optimization of acid treatment parameters to minimize the formation of microcracks. The limited efficacy of water treatment observed here is also consistent with existing research, which has shown that boiling alone is insufficient to achieve meaningful improvements in fiber performance [15,16,31,32].

4.3. Practical implications

The findings of this study have important implications for the construction industry, particularly in the context of sustainable material development. NaOH-treated corn straw fibers offer a viable alternative to synthetic fibers for applications requiring high flexural and compressive strength. By leveraging agricultural waste, this approach not only reduces environmental impact but also provides a cost-effective solution for enhancing the performance of cement-based materials.

CH_3COOH-treated fibers, with their superior early-stage performance, may be better suited for temporary or non-load-bearing applications where rapid strength development is prioritized. However, their long-term durability remains a concern, necessitating further research to address this limitation.

Water-treated fibers, while less effective, could still find use in low-performance applications where minimal modification is sufficient. For example, they may be suitable for non-structural elements or applications where cost constraints outweigh performance requirements.

4.4. Limitations of the study

While this study provides valuable insights into the effects of chemical treatments on corn straw fibers, several limitations should be acknowledged:

Durability analysis: The study did not evaluate the long-term durability of treated fibers under varying environmental conditions, such as freeze-thaw cycles, moisture exposure, and temperature fluctuations.

Treatment optimization: The study focused on fixed concentrations and durations for CH_3COOH and NaOH treatments. Future research should explore the effects of varying these parameters to identify optimal treatment conditions.

Environmental Impact: The environmental implications of chemical treatments, particularly the use of NaOH and CH_3COOH, were not assessed. A life cycle analysis could provide a more comprehensive evaluation of the sustainability of these treatments.

4.5. Future research directions

To build on the findings of this study, future research should focus on the following areas:

Durability testing: Investigate the performance of treated fibers under harsh environmental conditions to evaluate their long-term suitability for real-world applications.

Optimization of treatment parameters: Explore different concentrations, durations, and combinations of chemical treatments to maximize the mechanical performance of corn straw fibers.

Hybrid composites: Examine the potential of combining treated natural fibers with other reinforcement materials, such as synthetic fibers or nanoparticles, to achieve synergistic effects.

Sustainability assessment: Conduct a life cycle analysis to evaluate the environmental impact of treated fibers, considering factors such as energy consumption, chemical waste, and recyclability.

Scaling up: Investigate the feasibility of scaling up the treatment and integration of corn straw fibers into commercial construction projects.

4.6. Contribution to sustainable development

The integration of treated corn straw fibers into cement-based materials aligns with global efforts to promote sustainable construction practices. By utilizing agricultural waste, this approach reduces reliance on synthetic materials, minimizes environmental impact, and supports circular economy principles. Furthermore, the insights gained from this study provide a foundation for the development of innovative and eco-friendly construction materials that meet the growing demand for sustainability in the construction industry.

In conclusion, this study highlights the potential of chemical treatments to transform agricultural waste into high-performance construction materials. NaOH-treated corn straw fibers, in particular, offer a promising solution for enhancing the mechanical properties of cement mortar while contributing to environmental sustainability. By addressing the identified limitations and exploring new research directions, future studies can further advance the application of treated natural fibers in sustainable construction.

5. Conclusion

This study systematically evaluated the effects of water, CH_3COOH, and NaOH treatments on the physical and mechanical performance of corn straw fibers in cement mortar. The findings confirm that chemical treatments significantly alter fiber morphology and composition, directly influencing the mechanical behavior of fiber-reinforced cement composites.

Among the treatments, NaOH proved to be the most effective, as it enhanced surface roughness (4.73 ± 0.41 μm) and increased cellulose content (48.7% ± 1.3%), leading to superior fiber-matrix bonding. As a result, NaOH-treated fibers achieved the highest flexural strength (8.34 ± 0.54 MPa) and compressive strength (52.8 ± 3.4 MPa) at 1.5% fiber content after 28 days of curing. These findings suggest that alkali-treated fibers are well-suited for structural applications requiring enhanced durability and mechanical stability.

On the other hand, CH_3COOH-treated fibers exhibited superior early-stage flexural performance (6.75 ± 0.44 MPa at 7 days) due to improved surface roughness and partial lignin removal. However, the presence of microcracks introduced during acid treatment resulted in a slight decline in long-term mechanical performance, highlighting the need for further optimization of acid treatment conditions.

Water-treated fibers demonstrated the weakest performance, showing limited improvements in fiber morphology and mechanical properties, reinforcing the necessity of stronger chemical modifications to enhance fiber effectiveness.

This study contributes to the sustainable development of construction materials by demonstrating that chemically treated corn straw fibers can serve as viable alternatives to synthetic fibers. The findings provide new experimental evidence on the role of fiber treatment in improving cementitious composites, particularly in relation to the interaction between fiber morphology, chemical composition, and mechanical performance.

However, certain limitations remain, including the need for long-term durability assessments under real-world environmental conditions. Future research should also explore optimal treatment parameters and alternative eco-friendly modification techniques to further enhance the sustainability and performance of bio-based fiber reinforcements.

Author contributions: Conceptualization, BP and ZBB; methodology, BP; software, ZBB; validation, BP; formal analysis, BP; investigation, BP; resources,

BP; data curation, BP; writing—original draft preparation, BP; writing—review and editing, BP; visualization, BP; supervision, ZBB; project administration, BP; funding acquisition, BP. All authors have read and agreed to the published version of the manuscript.

Funding: This work was financially supported by the Basic Scientific Research Business Expenses Project for Provincial Higher Education Institutions in Heilongjiang Province (No. YWK10236210226): "Study on the Effect of Low-Temperature Pretreatment of Corn Straw Ash on the Mechanical Properties of Concrete."

Institutional review board statement: Not applicable.

Informed consent statement: Not applicable.

Conflict of interest: The authors declare no conflict of interest.

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