
EFFECT OF ALKALINE PRE-TREATMENT ON THE MECHANICAL STRENGTH AND BIODEGRADATION BEHAVIOUR OF COIR FIBRE REINFORCED CONCRETE

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ABSTRACT

Concrete is widely recognized for its high compressive strength, yet it suffers from low tensile capacity, brittleness and susceptibility to cracking under cyclic loading. Coir fibre offers a renewable and low-cost means of improving toughness; however, its high water absorption and vulnerability to alkaline and microbial attack limit long-term durability. This study examined the influence of NaOH pre-treatment on the workability, mechanical properties and biodegradation resistance of coir fibre reinforced concrete (CFRC). Fibres treated with 0, 5 and 10 % NaOH were incorporated at 0.5, 1.0 and 1.5 % by cement weight. Slump, compressive, flexural and split tensile strengths were determined, while fibre biodegradation was evaluated through soil-burial testing for up to 56 days. Workability decreased with increasing fibre content and alkali concentration. The combination of 1 % fibre and 5 % NaOH produced the highest mechanical strengths (22 N/mm² compressive, 4.25 N/mm² flexural and 2.89 N/mm² splitting tensile) together with the lowest mass loss (2.24 % after 56 days), compared with nearly 29 % for untreated fibre. Moderate alkaline treatment at 5 % NaOH with 1 % fibre therefore offers a practical balance of strength and durability for sustainable coir-fibre concrete.

Keywords: Coir fibre; Alkaline pre-treatment; Concrete; Biodegradation

1. INTRODUCTION

Sustainability was defined by the World Commission on Environment and Development (WCED) as meeting the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). One of the major challenges of the modern society is the impact of increasing world population on limited resources especially in the built industry. Demands for built infrastructure have caused significant waste generation, energy and material consumption by the construction industry. The building construction industry is not only a major consumer of energy, raw materials and land; it also contributes immensely to environmental pollution, especially greenhouse gas emission (Melchert, 2007). To improve sustainability in construction materials usage, the construction industry must embrace the reuse of industrial by-products and renewable materials in construction.

Presently, because of their proven performance, the use of synthetic fibres in cement composites is becoming increasingly popular. Cement research literature is replete with studies showing that the ductility, tensile strength, toughness, fatigue strength, impact resistance and absorbed energy of cement-based materials could be enhanced significantly through the addition of steel and polymer fibres. (Cui et al., 2023; Banthia et. al., 1994).

There are three types of natural fibres available for concrete reinforcement: animal-based, mineral-derived and plant-based. Animal fibers, comprising specific proteins, include silk, wool, and hair fibre. Mineral derived fibres include asbestos, wollastonite and palygorskite. Finally, plant-based fibres include cotton, hemp, jute, flax, ramie, sisal, bagasse, specialty fibres processed from wood and etc.

Major improvement in the properties of cementitious material is achievable through the incorporation of plant-based fibres described above. Fortunately, such fibres are gotten from renewable sources and are readily available at relatively low cost compared to synthetic fibres. There are huge benefits in terms of environmental, energy and resource conservation from large scale acceptance and

utilization of plant-based fibres as raw materials for cement-based composites. (Onuaguluchi & Banthia, 2016).

Although several studies have investigated the incorporation of coir fibre in cementitious composites, limited research has focused on the combined influence of fibre dosage and controlled NaOH pre-treatment on both the mechanical performance and long-term biodegradation resistance of coir fibre reinforced concrete. Most existing works have either examined untreated fibres or applied alkali treatment without systematically evaluating its effect on durability under soil burial conditions. Therefore, this study aims to address this gap by investigating the effect of different NaOH concentrations (0%, 5% and 10%) and fibre contents (0.5%, 1.0% and 1.5% by cement weight) on the workability, compressive strength, flexural strength and split tensile strength of coir fibre reinforced concrete. In addition, the biodegradation behaviour of the treated and untreated fibres was assessed through soil burial testing over a period of 56 days.

2. METHODOLOGY

2.1 Materials

Coir Fibre: Raw coconut husks were sourced from Lagos, South West Nigeria, and the fibre extraction was carried out at the National Institute for Chemical Technology (NARICT), Basawa, Zaria.

Sodium Hydroxide Pellets: The NaOH pellets used for the treatment were purchased in Zaria, Kaduna State.

Distilled Water: The distilled water used in the treatment process was obtained from the Chemistry Department, Ahmadu Bello University, Zaria.

Cement: The cement used in this research work was 42.5N Dangote brand of Ordinary Portland Cement and was obtained from open market in Samaru, Zaria, Nigeria.

Fine and Coarse Aggregate: Obtained from a local supplier in Zaria, Kaduna State, the aggregates were subjected to appropriate preliminary test to ensure they meet with standards for making concrete.

Water: Potable water was used for both mixing and curing.

2.2 Methods

2.2.1 Fibre Treatment

The coir fibres were fully immersed in separate containers containing 5% and 10% NaOH solutions at a fibre-to-solution ratio of 1:20 (w/v) and maintained at room temperature (approximately 28 ± 2 °C). Immersion was maintained for 2 hours as recommended by Widodo & Widodo (2024). The alkali treatment procedure adopted in this study follows the method proposed by Yan et al. (2016). Following the 2-hour immersion period, the fibres were removed and thoroughly washed several times with distilled water until a neutral pH was achieved. This step was necessary to eliminate residual alkali from the fibre surfaces and confirm the complete removal of excess alkalinity. Surplus water was carefully expelled by gently pressing the fibres in a sieve to minimise any mechanical damage. The treated fibres were subsequently oven-dried at approximately 70°C for 24 hours to achieve effective moisture removal while preserving their structural integrity.

2.2.2 Mixture Proportion

Table 1: Mix Proportion for Alkali Treated Coir Fibre Reinforced Concrete

Mix ID	Cement (Kg/m ³)	Water (kg/m ³)	Fine Aggregate (kg/m ³)	Coarse Aggregate (kg/m ³)	Fibre Content (%)	NaOH Content (%)
M0	320	160	480	960	0	0
M1	320	160	480	960	0.5	0
M2	320	160	480	960	1	0
M3	320	160	480	960	1.5	0
M4	320	160	480	960	0.5	5
M5	320	160	480	960	1	5
M6	320	160	480	960	1.5	5
M7	320	160	480	960	0.5	10
M8	320	160	480	960	1	10
M9	320	160	480	960	1.5	10

2.2.3 Testing of Alkali Pretreated Coir Fibre Reinforced Concrete

All the concrete batches cast underwent the following tests described below. Three trials are conducted, and the average is taken for each test performed for a specific fibre content and treatment concentration.

Slump test.

This is used to assess the workability of the concrete mixtures. The test was conducted in accordance to BS EN 12350-2:2019. The slump was measured from a mould height of 300mm.



Figure 1: Slump Test

Compressive strength test.

This is used to determine the compressive strengths of the composites used. The test was conducted in accordance to BS EN 12390-3:2019. The specimens used are 150mm concrete cubes, three sample were cast and the average taken.



Figure 2: Compressive Strength Test

Flexural strength test.

The flexural strength test is used to determine the bending capacity of the composite. It was conducted using the four-point load test in accordance to BS EN 12390-5:2019. A block size of 100mm width, 100mm depth, and a span of 500mm were used for the concrete specimens, and three sample were cast and the average taken.

Split tensile strength test.

This is used to determine the tensile strengths of the composites used. The test was conducted in accordance to BS EN 12390-6:2009. The specimens are 150×300mm concrete cylinders, and three sample were cast and the average taken.

Soil Burial Test

Biodegradation tests on treated and untreated coir fibre samples were carried out by a simple soil burial test, ASTM D570-98 (1998), to simulate the natural biodegradation of the fibre. Dog-bone-shaped samples were prepared according to ASTM 638-14 (2014); ASTM D5988-18 (2018) and were buried in natural soil in a plastic bag without any enzyme activity or any composting materials. The soil burial site was kept outdoors under an average ambient temperature of approximately 30°C, in a natural garden soil with pH value of 7.1 and average moisture content of 25% and natural organic matter and buried at a depth of 150mm. Test specimens were removed after exposure periods of 14, 28, and 56 days for further evaluation. At each retrieval stage, the samples were gently washed with water to remove any attached soil particles and subsequently air-dried at room temperature until a constant mass was obtained. Biodegradability was assessed by determining the percentage weight loss of the specimens, based on a comparison of their masses before and after the respective burial durations.



Figure 3: Soil Burial Test

2.2.4 Statistical Analysis (ANOVA)

The statistical analysis tool used for this research is the one-way ANOVA with 95% confidence level and probability value set at less than 5% are considered statistically significant while values more than 5% were considered not statistically significant.

3. RESULTS AND DISCUSSION

3.1 Slump Test Result

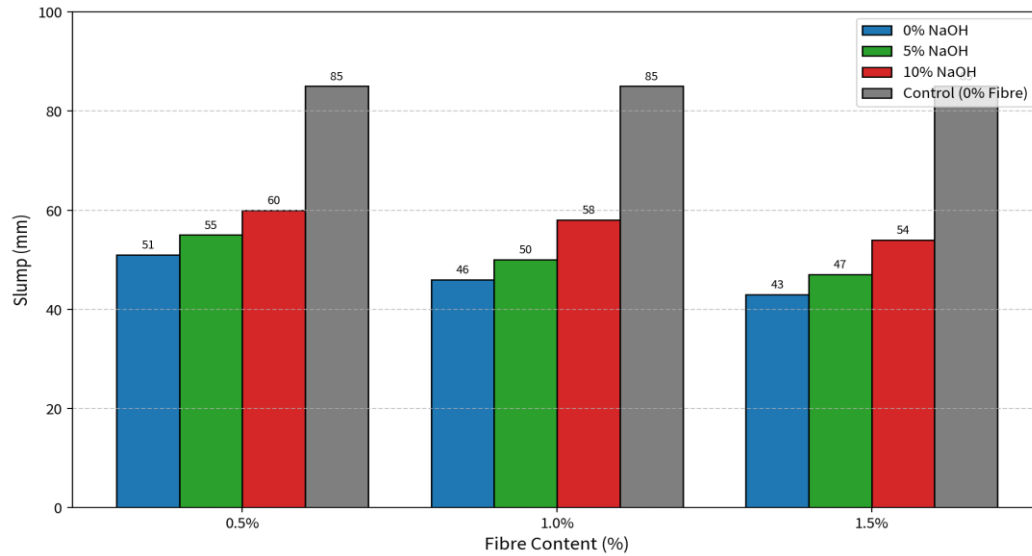


Figure 4: Comparison of Slump Test of Treated and Untreated Coir Fibre Reinforced Concrete

From the result in Figure 4, Slump decreased systematically with increasing fibre content and with higher NaOH treatment. All mixes were in the low–medium workability range (mainly S2 per EN 206), with the highest fibre (1.5%) at 10% NaOH approaching the S1/S2 boundary. The reduction is attributed to fibre water absorption and increased internal friction due to surface roughening from alkaline treatment, which improves fibre–matrix compatibility but lowers flow. For typical reinforced elements placed with vibration, S2 is acceptable; however, for congested reinforcement or pumping, admixture-based water reduction is recommended rather than increasing the water–cement ratio.

3.2 Compressive Strength

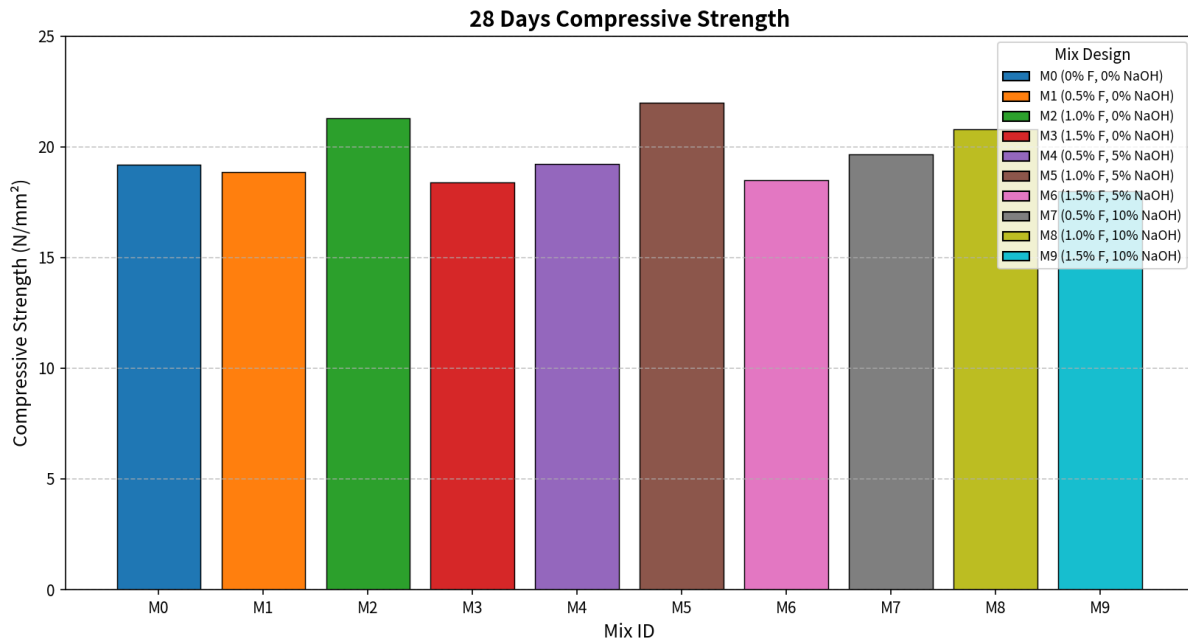


Figure 5: Compressive Strength Test of Treated and Untreated Coir Fibre Reinforced Concrete

The 28-day compressive strength results as shown in Figure 5 indicate that both fibre dosage and alkaline surface treatment significantly modulate concrete performance. At a fixed NaOH dosage, increasing coir fibre content from 0.5% to 1.0% enhanced strength, while further increase to 1.5% led

to a decline suggesting that moderate fibre addition improves reinforcement via crack-bridging and stress transfer, whereas excessive fibre induces agglomeration, impairs workability, and creates microstructural weaknesses. This trend aligns with observations in waste tyre steel fibre-reinforced concrete, where strength improved up to around 1.5% fiber content before declining due to bonding issues and poor dispersion (Augustino et. al., 2023).

The optimum mix (M5) achieved a mean compressive strength of 22 N/mm² at 28 days. According to BS EN 206, Grade C20/25 concrete requires a characteristic cylinder strength of 20 N/mm² (or characteristic cube strength of 25 N/mm²). The obtained mean strength of 22 N/mm² is therefore slightly below the typical target mean strength required for C20/25 concrete under normal production conditions. However, it satisfies the strength requirement for lower-grade applications

3.3 Flexural Strength Test

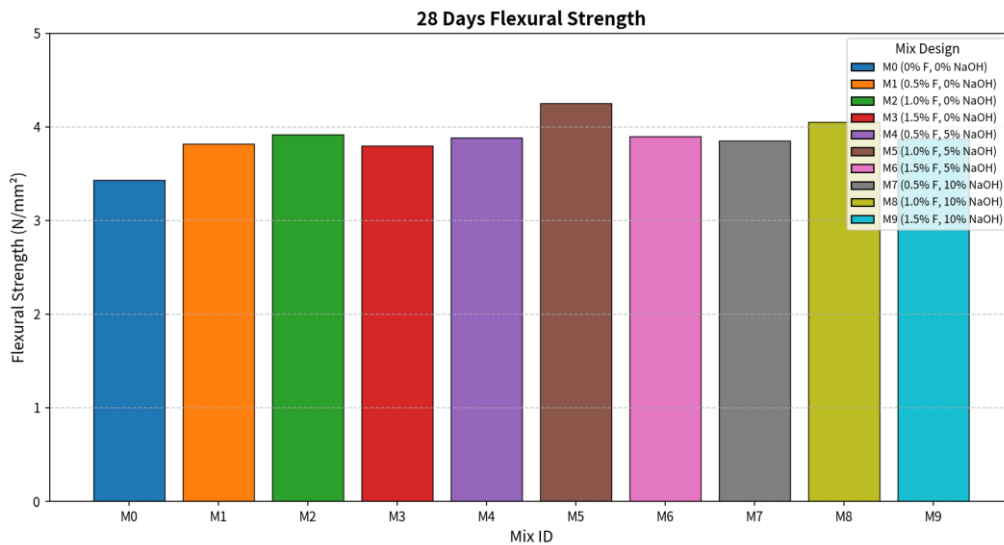


Figure 6: Flexural Strength Test of Treated and Untreated Coir Fibre Reinforced Concrete

The 28-day flexural strength results from Figure 6 demonstrate that both fibre content and NaOH treatment play significant roles in enhancing the mechanical performance of coir fibre reinforced concrete. At 0.5% fibre content, untreated fibre recorded 3.82 N/mm², while NaOH treatment increased strength to 3.88 N/mm² (5% NaOH) and 3.85 N/mm² (10% NaOH). This trend indicates that alkali treatment improved fibre-matrix adhesion by removing surface impurities such as lignin, hemicellulose, and waxes, thereby promoting better stress transfer between fibre and concrete matrix. The improvement aligns with recent findings that alkali treatment enhances the interfacial bonding of natural fibres in cementitious composites, leading to improved flexural performance (Gupta et al., 2023).

At 1.0% fibre content, flexural strength increased further, with untreated fibre yielding 3.92 N/mm² and 5% NaOH-treated fibre reaching the maximum strength of 4.25 N/mm². This demonstrates that an optimal fibre dosage combined with moderate alkali treatment provides the best reinforcement effect. However, at higher treatment levels (10% NaOH), the flexural strength slightly declined to 4.05 N/mm², suggesting that excessive alkali concentration could damage fibre structure, reducing its reinforcing efficiency. These observations are consistent with recent studies that reported diminishing mechanical properties when fibres are over-treated due to cellulose degradation (Luqman et al., 2023).

Beyond 1.0% fibre content, a further increase to 1.5% resulted in a reduction in flexural strength (ranging between 3.80 and 3.90 N/mm²), indicating that excessive fibre dosage may lead to poor dispersion and increased voids within the matrix. Overall, the results confirm that the synergy of fibre content and controlled alkali treatment enhances flexural strength, with the best performance achieved at 1.0% fibre content treated with 5% NaOH, Mix ID M5 (1% F, 5% NaOH).

3.4 Split Tensile Strength

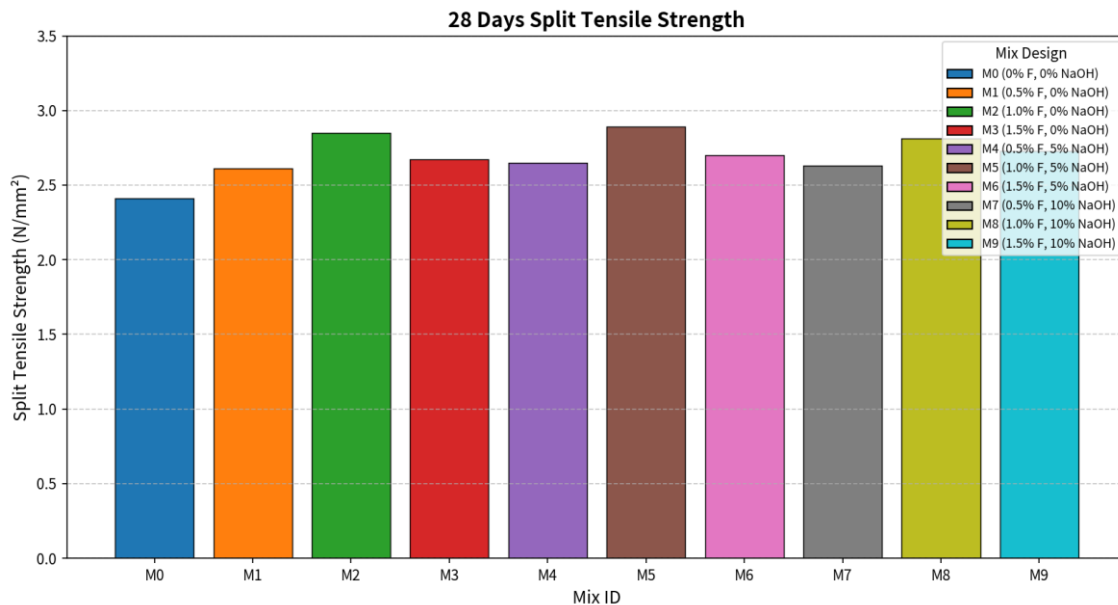


Figure 7: Split Tensile Strength Test of Treated and Untreated Coir Fibre Reinforced Concrete

The 28-day split tensile strength results from Figure 7 for NaOH-treated coir fibre-reinforced concrete reveal significant influences of fibre content (0.5%, 1%, 1.5%) and NaOH treatment (0%, 5%, 10%) on tensile performance. The highest tensile strength of 2.89 N/mm² was achieved with 1% fibre content and 5% NaOH, surpassing the untreated sample at the same fibre dosage (2.85 N/mm²) and the 10% NaOH-treated sample (2.81 N/mm²). This suggests an optimal fibre content of 1%, where coir fibres effectively bridge micro-cracks, enhancing tensile capacity without causing fibre agglomeration (Sanjay et al., 2018).

At 0.5% fibre content, NaOH treatment produced a modest improvement in strength, increasing from 2.61 N/mm² (0% NaOH) to 2.65 N/mm² (5% NaOH) and 2.63 N/mm² (10% NaOH). This indicates improved fibre-matrix bonding due to NaOH's removal of lignin and increased fibre surface roughness (Yan et al., 2016). However, at 1.5% fibre content, strengths remained relatively lower (2.67 N/mm², 2.70 N/mm² and 2.73 N/mm² for 0%, 5% and 10% NaOH respectively), suggesting that higher fibre volumes may lead to uneven distribution or reduced matrix cohesion, limiting reinforcement benefits. Overall, the results confirm that Mix ID M5 (1% F, 5% NaOH) a combination of 1% fibre content with moderate (5%) NaOH treatment provides the most effective enhancement of split tensile strength.

3.5 Soil Burial Degradation

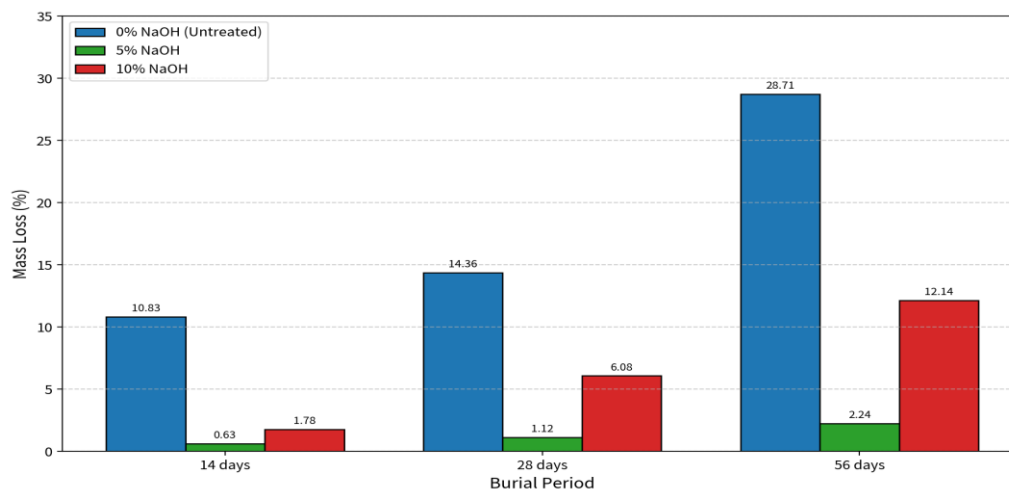


Figure 8: Soil Burial Degradation Test of Treated and Untreated Coir Fibre

The soil burial degradation test results as shown in Figure 8 demonstrate the impact of NaOH treatment on coir fiber durability, critical for their application in alkaline pretreated fiber-reinforced concrete. Untreated coir fibers (0% NaOH) exhibited significant mass loss, with 10.83% after 14 days, 14.36% after 28 days, and 28.71% after 56 days, reflecting high biodegradability due to microbial degradation of hemicellulose and cellulose in lignocellulosic fibres. This rapid degradation limits their suitability for concrete reinforcement, where moisture and alkalinity accelerate fiber breakdown (Ali et al., 2012). Conversely, 5% NaOH-treated fibers showed minimal mass loss (0.63% at 14 days, 1.12% at 28 days, 2.24% at 56 days), indicating enhanced resistance to biodegradation. Alkaline treatment removes hemicellulose and lignin, increasing cellulose crystallinity and reducing microbial attack sites (Mwaikambo & Ansell, 2002). The 10% NaOH-treated fibers had higher mass loss (1.78% at 14 days, 6.08% at 28 days, 12.14% at 56 days), suggesting structural damage from excessive alkali (Sawpan et al., 2011). It is important to note that the soil burial test in this study was conducted on free fibre specimens rather than fibres embedded within hardened concrete. Consequently, the measured mass loss represents the biodegradation behaviour of the fibres under direct soil exposure and should not be interpreted as a direct measure of fibre degradation within the concrete matrix

3.6 Analysis of Variance (ANOVA)

One-way analysis of variance (ANOVA) was conducted to evaluate the statistical significance of differences in mechanical properties among the various mixes. The results indicated statistically significant differences in compressive strength ($F = 13.45$, $p < 0.001$), flexural strength ($F = 4.65$, $p = 0.002$) and split tensile strength ($F = 2.61$, $p = 0.035$). Post-hoc Tukey's Honest Significant Difference (HSD) test further revealed that the mix containing 1% coir fibre treated with 5% NaOH (M5) generally exhibited significantly higher strengths compared to the control mix (M0) and several other combinations. These findings confirm that the observed improvements in mechanical performance, particularly for the optimal mix (M5), are statistically significant and not attributable to random variation.

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4. CONCLUSION

From the research, the following are the conclusions:

- i. Workability of the concrete decreased progressively with increasing coir fibre content and higher NaOH treatment concentrations, primarily due to increased water absorption by the fibres and greater internal friction resulting from surface roughening.
- ii. The optimum mechanical performance was achieved with 1.0 % fibre content treated with 5 % NaOH. This mix recorded the highest compressive strength (22 N/mm²), flexural strength (4.25 N/mm²) and splitting tensile strength (2.89 N/mm²), satisfying the requirements for Grade 20 concrete.
- iii. The adoption of 5 % NaOH-treated coir fibre at 1 % dosage offers a cost-effective and environmentally sustainable alternative for improving the tensile and flexural performance of plain concrete, particularly in low- to medium-strength applications such as non-structural elements, rural infrastructure and secondary members.
- iv. It should be noted that this study was limited to laboratory-scale testing using coir fibres obtained from a single source. No field application or long-term structural performance evaluation was conducted. Future studies are recommended to investigate the performance of NaOH-treated coir fibre reinforced concrete under real environmental conditions and with fibres from different geographical sources.

5. REFERENCES

- Ali, M., Liu, A., Sou, H., & Chouw, N. (2012). Mechanical and dynamic properties of coconut fibre reinforced concrete. *Construction and Building Materials*, 30, 814–825.
<https://doi.org/10.1016/j.conbuildmat.2011.12.068>

- ASTM International. (1998). *ASTM D570-98: Standard Test Method for Water Absorption of Plastics*. West Conshohocken, PA: ASTM International.
- ASTM International. (2014). *ASTM D638-14: Standard Test Method for Tensile Properties of Plastics*. West Conshohocken, PA: ASTM International.
- ASTM International. (2018). *D5988-18: Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials in Soil*. West Conshohocken, PA: ASTM International. <https://doi.org/10.1520/D5988-18>
- Augustino DS, C Kanali, RO Onchiri, C Kabubo (2023). Simplified shear equation of deep concrete beam considering orientation effect of opening and mechanical properties of fibre-concrete interface Heliyon.
- Banthia N, Moncef A, Chokri K, Sheng J. (1994). Micro-fiber reinforced cement composites. I. Uniaxial tensile response. *Can J Civil Eng.* 21(6): 999–011. <https://doi.org/10.1139/194-105>
- British Standards Institution. (2009). *BS EN 12390-6:2009 Testing hardened concrete. Tensile splitting strength of test specimens*. London: BSI. <https://doi.org/10.3403/bsen1239062009>
- British Standards Institution. (2019). *BS EN 12350-2:2019 Testing fresh concrete. Slump test*. London: BSI. <https://doi.org/10.3403/bsen123502019>
- British Standards Institution. (2019). *BS EN 12390-3:2019 Testing hardened concrete. Compressive strength of test specimens*. London: BSI. <https://doi.org/10.3403/bsen1239032019>
- British Standards Institution. (2019). *BS EN 12390-5:2019 Testing hardened concrete. Flexural strength of test specimens*. London: BSI. <https://doi.org/10.3403/bsen1239052019>
- BS EN 206:2013+A2:2021 — Concrete: Specification, performance, production and conformity. London: British Standards Institution (BSI), 2021
- Cui K., L Xu, L Li, Y Chi (2023). Mechanical performance of steel-polypropylene hybrid fiber reinforced concrete subject to uniaxial constant-amplitude cyclic compression: fatigue behavior and unified fatigue equation. *Compos. Struct.* <https://doi.org/10.1016/j.compstruct.2023.116795>
- Gupta, N. K., Joshi, S. K., Dhama, S., & Aggarwal, S. (2023). Enhancing mechanical properties of natural fiber composites: a study on the effects of fiber loading and filler addition. *Engineering Research Express*, 5(4), 045088. <https://doi.org/10.1088/2631-8695/ad112c>
- Luqman, R. M., Suhot, M. A., & Hassan, M. Z. (2023). Effect of alkaline treatment on the single natural fiber strength using Weibull analysis probabilistic model. *Materials Today: Proceedings*. <https://doi.org/10.1016/j.matpr.2023.01.108>
- Melchert L. (2007). The Dutch sustainable building policy: a model for developing countries? *Build Environ*, 42: 893–01. <https://doi.org/10.1016/j.buildenv.2005.10.007>
- Mwaikambo, L. Y., & Ansell, M. P. (2002). Chemical modification of hemp, sisal, jute, and kapok fibers by alkalization. *Journal of Applied Polymer Science*, 84(12), 2222–2234. <https://doi.org/10.1002/app.10460>
- Onuaguluchi, O., & Banthia, N. (2016). Plant-based natural fibre reinforced cement composites: A review. *Cement and Concrete Composites*, 68, 96–108. doi:10.1016/j.cemconcomp.2016.02.014
- Sanjay, M. R., Madhu, P., Jawaaid, M., Senthamaraiannan, P., Senthil, S., & Pradeep, S. (2018). Characterization and properties of natural fiber polymer composites: A comprehensive review. *Journal of Cleaner Production*, 172, 566–581. <https://doi.org/10.1016/j.jclepro.2017.10.101>
- Sawpan, M. A., Pickering, K. L., & Fernyhough, A. (2011). Effect of fibre treatments on interfacial shear strength of hemp fibre reinforced polylactide and unsaturated polyester composites. *Composites Part A: Applied Science and Manufacturing*, 42(9), 1189–1196. <https://doi.org/10.1016/j.compositesa.2011.05.003>
- Widodo, E., Pratikto, Sugiarto, & Widodo, T. D. (2024). Comprehensive investigation of raw and NaOH alkalinized sansevieria fiber for enhancing composite reinforcement. *Case Studies in*

Chemical and Environmental Engineering, 9, Article 100546.
<https://doi.org/10.1016/j.cscee.2023.100546>

- World Commission on Environment and Development (WCED). (1987). *Our Common Future: The Brundtland Report on Environment and Development*. Oxford: Oxford University Press.
- Yan, L., Chouw, N., Huang, L., & Kasal, B. (2016). Effect of alkali treatment on microstructure and mechanical properties of coir fibres, coir fibre reinforced-polymer composites and reinforced-cementitious composites. *Construction and Building Materials*, 112, 168–182. <https://doi.org/10.1016/j.conbuildmat.2016.02.182>
- Yan, L., Kasal, B., & Huang, L. (2016). A review of recent research on the use of cellulosic fibres, their fibre–matrix interface and their composites in civil engineering applications. *Composites Part B: Engineering*, 92, 94–132. <https://doi.org/10.1016/j.compositesb.2016.02.014>