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# EFFECT OF ALKALI TREATMENT ON LOAD BEARING CAPACITY OF NATURAL FLAX FIBER EPOXY COMPOSITES

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**ABSTRACT:**
Natural fibers, particularly flax, are recognized as an eco-friendly alternative to synthetic fibers in composite materials. Their use is growing due to their low cost, biodegradability, and sustainability. This study investigates the effect of alkali treatment on the load-bearing capacity of natural flax fiber epoxy composites. Flax fibers were treated with 5% and 10% NaOH solutions to enhance the fiber-matrix interaction, and the composites were fabricated using the hand layup technique with an epoxy resin matrix. A series of mechanical tests were conducted, including low-velocity impact, drop weight tests, quasi-static indentation, and water absorption tests. The results demonstrated a significant improvement in the load-bearing capacity of the alkali-treated composites, particularly in low-velocity impact and indentation resistance, with 10% NaOH-treated fibers exhibiting the highest performance. Alkali treatment enhanced the interfacial bonding between the flax fibers and epoxy resin, leading to better stress transfer and increased energy absorption during impact. However, the water absorption test showed a slight reduction in moisture uptake, suggesting that alkali treatment improves the composite's moisture resistance. Despite the enhanced performance, higher NaOH concentrations (10%) caused slight fiber degradation, affecting the elongation at break. Overall, the findings suggest that alkali treatment effectively improves the mechanical properties and durability of flax fiber composites, making them suitable for high-performance, eco-friendly applications, provided that the NaOH concentration is optimized.

**Keywords:** alkali treatment, Hand layup technique, flax fiber, epoxy resin composite**.**

## 1.INTRODUCTION

Natural fiber composites (NFCs) have garnered significant attention in various industries, including automotive, aerospace, and construction, as sustainable and lightweight alternatives to synthetic fiber composites. Among the diverse natural fibers available, flax fibers stand out due to their excellent specific mechanical properties, renewability, biodegradability, and relatively low cost. These attributes make flax fiber-reinforced polymer composites a promising material for environmentally conscious applications. Despite their advantages, natural fibers often suffer from inherent limitations that can hinder the overall performance of their composites. A primary concern is the poor interfacial adhesion between the hydrophilic natural fibers and hydrophobic polymer matrices. This incompatibility arises from the presence of hydroxyl groups on the fiber surface, leading to weak bonding and inefficient stress transfer at the fiber-matrix interface. Consequently, NFCs can exhibit reduced mechanical properties, particularly under dynamic loading conditions. To address this challenge, alkali treatment, also known as mercerization, has emerged as a widely adopted chemical modification technique for natural fibers. This treatment involves immersing fibers in an alkaline solution (e.g., sodium hydroxide, NaOH), which removes hemicellulose, lignin, and pectin, and roughens the fiber surface. The removal of these non-cellulosic components not only cleans the fiber surface but also increases the accessibility of cellulose and enhances surface wettability. These modifications are expected to improve the fiber-matrix interface, leading to better stress transfer and, consequently, enhanced mechanical performance of the composites. While the influence of alkali treatment on the static mechanical properties of flax fiber composites has been extensively studied, their behavior under dynamic loading conditions, specifically low-velocity impact and indentation, remains an area requiring further comprehensive investigation. Low-velocity impact events, such as tool drops or minor collisions, are common in real-world applications and can cause significant damage, often in the form of delamination or matrix cracking, without immediate visual cues. Indentation, on the other hand, provides insights into the material's resistance to localized deformation and penetration, which is crucial for applications requiring surface durability. Understanding the response of alkali-treated flax fiber composites to these specific loading scenarios is critical for their reliable design and implementation in structural applications.

## 2.LITERATURE REVIEW

According to Chandra et al. [1] alkali treatment with 5% NaOH resulted in a 30% increase in tensile strength, as the removal of non-cellulosic components allows for stronger bonding between the fibers and the epoxy matrix. This trend is also supported by Saha et al. [2] who found that composites with alkali-treated flax fibers exhibited higher flexural strength, especially when treated with 10% NaOH. Dutta et al [3] found that 45-degree and random fiber orientations significantly enhanced the flexural performance of flax fiber composites, making them more resistant to bending and impact**.** Studies like Gupta et al [4] have demonstrated that the hand layup technique, combined with alkali-treated flax fibers, results in a composite with improved performance under dynamic loading conditions, including low-velocity impact and indentation. Lukmon Owolabi Afolabi et al. [5] analyses carried out on each of the treated fiber have considerable effect on the extraction, chemical concentration and soaking time. Higher cellulose percentage can be obtained by increasing the chemical concentration and soaking time, however,fiber roughening and separation of the elementary fiber are the observed set-back . Mukesh et al. [6], The effect of different chemical modification of fiber surface on different mechanical properties of natural fibers composites are reviewed in this paper. Different fiber surface modifications like alkali, acetylation, potassium permanganate, peroxides, silane benzoylation etc. and the composition of the natural fibers components like cellulose, hemi- cellulose, lignin, pectin etc. are discussed. H. A. Aisyah et al. [7], analyzed that thermal stability of the pure carbon fibre composite was higher than that of the hybrid composite, the thermal stability of the hybrid composites improved as higher content of kenaf fibre was used, i.e., fabric density of 6 × 6. It was found that using the plain weave design of woven kenaf has improved the overall thermal stability of the samples compared to that of the satin design Senthil Ganesh Subramanian et al. [8], conclude that the unexploited C. Hildmannianus endow structural fiber or fiber bundle new hope for bio-composite industries with their precise following properties Sureshkumar Perumal Singaraj et al. [9], attempted to assess three types of banana fabrics for physical, morphological and thermal properties and to ascertain whether they can be combined with leathers to make combination products. It was found that most of the physical properties of banana fabrics are better than that of buffalo shrunken grain leather and, in some cases, it is even comparable. Amirhossein Lotfi et al. [10], investigated the main challenges associated with machining of NFRCs and the induced damages are outlined, with special attention paid to the effect of physical properties of the fibers and manufacturing process on the machinability, along with the essential machining parameters that affect the quality of the machined surface Shaoquan et al. [11] studied the C/BMI (Carbon/Bismaleimide) composite's low-velocity impact behavior during supersonic hygrothermal flight cycles. The BMI composite's oxidation and degradation brought on by hygrothermal cycles, along with the interfacial debonding in the fibre and matrix, are likely to have contributed to the matrix's softening, which in turn reduced stiffness N Ramli et al. [12], investigated on bio-composite which is suitable to replace the existing interior of automotive design, the work has focused on obtaining that bio-composite, taking account into the raw-materials cost reduction and the maintenance of the manufacturing process based on current scenario. Miklos Tisza et al. [13], In this paper, an introduction on recent material developments in the automotive industry concerning both the use of new generation high strength steels and light metals with particular emphasis on aluminium alloys will be given. A comparison between steel and aluminium application in the automotive industry is given from various points of view. Subhakanta Nayak et al. [14], using treated Areca sheath (AS) fiber in polyvinyl chloride (PVC) matrix by injection molding method shows that AS/PVC composite can be appropriate substitute material for production of automobile dashboard panel. Susilendra Mutalikdesai et al. [15], use of the natural fibers offers the potential to act as a reinforcing material for composites alternative to the use of glass fiber, carbon fiber and other man-made fibers. In present work hybrid composites of Epoxy/basalt fiber/flax fibers were prepared by Hand-layup technique Heow Pueh Lee et al. [16], investigated the sound absorption properties of flax/epoxy composites and found them to be superior to those of glass/epoxy composites. A noteworthy result was that the noise reduction coefficient increased from an average value of 0.095–0.11 for unidirectional flax/ epoxy composite and to 0.10 for cross-ply flax/epoxy system. Bambach et.al [17] presents the compressive properties of plate and channel sections made of flax reinforced epoxy laminates and different plate thicknesses are compared. It is shown that even if the mechanical properties of the laminates are low, the buckling and post buckling response is stable and therefore suitable for light structural applications for the thicker specimens. Hawa et al. [18] investigated the burst strength and impact behavior of hygrothermal aged E-glass fibre/epoxy composite pipes. To conduct the ageing process specimens were placed in tap water for 500, 1000 and 1500 h. and maintained at 80°C. Upon impact loading, the peak force was largest for the unaged specimen, and it gradually decreased as ageing duration increased Bledzki, A. K. et al [19] Alkali treatment has been shown to significantly improve the tensile strength of flax fiber composites. This enhancement is attributed to the improved fiber-matrix adhesion and the increased cellulose content after treatment. Zhou, F., & Zhang, X [20] Flax fiber composites treated with NaOH exhibit higher flexural strength compared to untreated fibers, as the treatment enhances fiber bonding with the matrix, leading to better stress transfer.

## 3.METHODOLOGY

The methodology used in this study involved the preparation and testing of flax fiber-reinforced epoxy resin composites to evaluate the impact of alkali treatment (NaOH) on their mechanical properties. In this study, alkali treatment with 5% and 10% NaOH solutions was applied to natural flax fibers to improve their fiber-matrix adhesion. The treated fibers were then incorporated into an epoxy resin matrix using the hand layup technique, a simple and cost-effective method for composite fabrication. The composites were fabricated with three different fiber orientations: unidirectional, 45-degree angle, and random orientation. Mechanical tests, including low-velocity impact, drop weight testing, quasi-static indentation, and water absorption tests, were conducted to assess the composite's load-bearing capacity, energy absorption, resistance to indentation, and moisture resistance. The results of the tests were analyzed statistically to determine the influence of alkali treatment on the mechanical properties of the composites, with untreated flax fiber composites used as a control group for comparison:

**Table 1:** Material designation for the developed composite material.

| Specimen Name | Layup Configuration | Description | Laminate Notation (for woven fabric, 16 plies) |
|---|---|---|---|
| A | Unidirectional stack | All plies oriented the same (warp 0°, weft 90°) | **$[0°/90°]_{16}$** |
| B | ±45° rotation | Woven layers rotated ±45° alternately | **$[+45°/–45°]_{8}$** (rotated woven fabric layers) |
| C | Hybrid stacking | Alternate [0°/90°] and [±45°] rotated fabric | **$[[0°/90°], [±45°]]_{8}$** |
| D | Symmetric hybrid | Balanced layout with mirrored stacking | **$[0°/90°, ±45°, ±45°, 0°/90°]_{4S}$** |
| E | Groupd hybrid | 8 plies [0°/90°] + 8 plies [±45°] | **$[[0°/90°]_{8}$ / $[±45°]_{8}]$** |
| F | Angle ply | Woven fabric rotated at ±30° and ±60° | **$[±30°, ±60°]_{4}$** or specifically listed per ply |

**Materials**

- Flax Fibers: Natural flax fibers were sourced from a reliable supplier and used in their raw form without any pretreatment for the control group. The flax fibers were carefully cleaned to remove any debris or loose fibers before use.
- Epoxy Resin: A commercial-grade epoxy resin system was used as the matrix material. The resin was mixed according to the manufacturer's instructions, ensuring proper curing and optimal bonding with the fibers.
- Sodium Hydroxide (NaOH): Two concentrations of NaOH (5% and 10%) were prepared by dissolving the appropriate amount of NaOH pellets in distilled water. These solutions were used for the alkali treatment of the flax fibers.

**Selection of Material**

Flax comes from the stem of the flax plant of the species Linum usitatissimum. Flax fibre is classified as a natural cellulose, bast and multicellular fibre. When the fibre is processed into fabric, then it is called as Lenin. It is one of the strongest fibres, and it is considered for their strength, durability, and absorbency, as well as their unique texture. In addition to its traditional uses, flax fibre is becoming increasingly popular in modern times as a sustainable alternative to synthetic fibres. and the chemical composition is as shown below Table

**Table 2:** Structural composition of Flax fibre

| Cellulose (wt%) | Hemicellulose (wt%) | Lignin (wt%) | Pectins (wt%) | Micro fibril angle (degree) | Moisture content (wt%) |
|---|---|---|---|---|---|
| 71 | 18.6–20.6 | 2.2 | 2.3 | 6-7 | 10 |

**Table 3:** Properties of Flax fibre

| **Fiber** | **Property** | |
|---|---|---|
| **Flax** | Density (g/cc) | 1.52 |
| | Fiber diameter (mm) | 0.8 - 1.2 |
| | Tensile strength (MPa) | 348 – 580 |
| | Youngs Modulus (GPa) | 19.8 |
| | Elongation at the breakage (%) | 2.9 |
| | Break force (N) | 8.2 |
| | Moisture absorption (%) | 7 |

**Hand layup Technique**

The Hand lay-up fabrication process was carried out using basic equipment, often sharing the same molds as compression moulding technique. In this method, a catalyzed resin was first applied to the surface of the mould. Then, fabric layers were placed individually onto the mould and manually impregnated with resin using brushes and rollers.

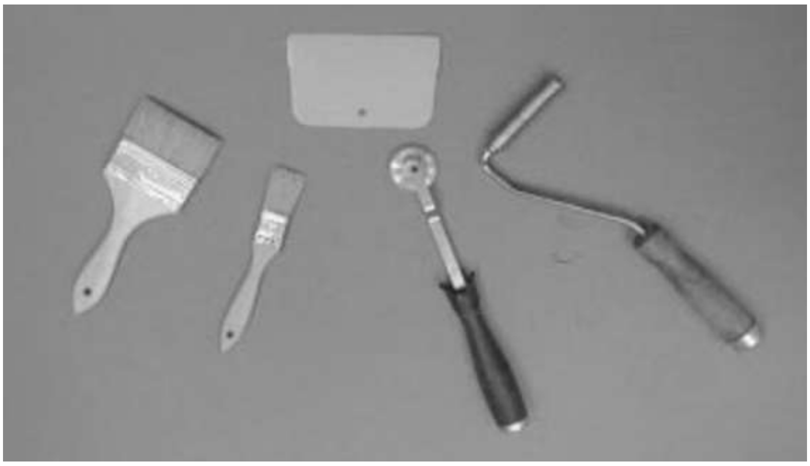


**Figure 1:** Hand layup brushes and rollers.

**Water Absorption test**

Water absorption tests of the developed composites were conducted as per ASTM D570 by immersion in distilled water along with 5% of NAOH and 10% NAOH at room temperature for a long time period to reach a stable equilibrium or saturation point.

**Figure 2:** Treated specimen for water absorption

The samples were taken out after each time interval and water particles are wiped out from the surface of the specimen using filter paper. Samples are weighed immediately within 30 s to avoid error due to evaporation, using an electronic balance (AY220 type, ±0.1 mg accuracy). After weighing, the sample is immersed in the water bath to permit water absorption until the saturation point is reached after 30-45 Days. The weight difference of the specimen gives the value of the water absorption. The water content percentage (Mt), is calculated using Eq (1).

$$M_t(\%) = \frac{W_t - W_o}{W_o} \times 100 \qquad \text{.............................. (1)}$$

where $W_0$ - initial weight of the test sample, $W_t$ - weight of the sample at time ‘t’.

The water absorption behaviour of the sample kept in the water bath can be studied as Fickian behaviour. Therefore, Eq. (2) has been used

$$\frac{M_t}{M_\infty} = 4\left(\frac{Dt}{\pi h^2}\right)^{\frac{1}{2}} \qquad \text{................................... (2)}$$

**Quasi static Indentation**

The quasi-static (QS) indentation tests were based on the standards ASTM D7136/D7136M−15 and ASTM D 6264−12. The rig comprises three main components: a sturdy steel frame, a hydraulic system, and a data acquisition and control system The load cell used had a maximum capacity of 10 kN and the displacement was measured with a 150 mm linear potentiometer The QS indentation test will be performed with a constant velocity applied to the indenter. In this study a test speed of 0.25 mm/s was used for the QS indentation tests. The velocity selected for the present study was 0.5 mm/s, as no dynamic effects were observed, and the test duration could be reduced to around 1 min.

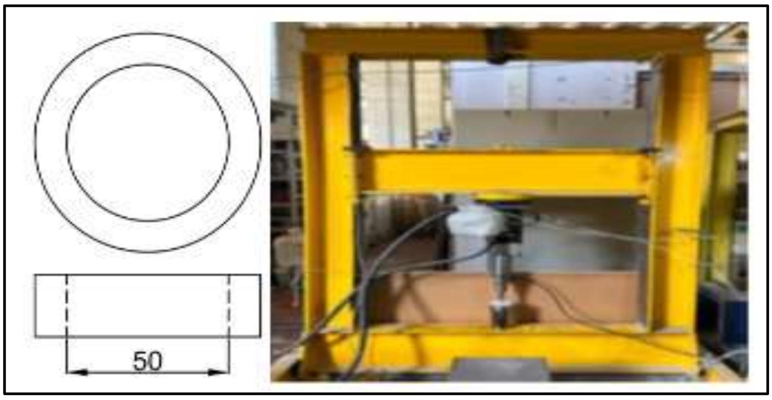



**Figure 3:** shows Quasi-static (QS) indentation specimen and Test Rig

During the study there were several key parameters can be compared from each test stage. The first was related to the absorbed energy at defined perforation. Other parameters were also found significant, like the load measured and absorbed energy at maximum load, initial fibre failure and initial matrix damage.

**Low-velocity impact**

The low-velocity impact tests were based on the standard ASTM D7136/D7136M−15. For the impact tests, A drop weight machine was utilized, displayed in Figure 4.6. To enable the comparison between the results of the QS indentation test and the low-velocity impact test, identical test setups were employed (i.e., same specimen dimensions, support system and indenter).

**Figure 4:** Low velocity Impact testing machine

## 4. RESULTS AND DISCUSSIONS

In this study, natural flax fibers were treated with 5% and 10% NaOH solutions to evaluate the effects of alkali treatment on the load-bearing capacity of flax fiber-epoxy composites. The composites were fabricated using the hand layup technique and evaluated the results of the low-velocity impact, drop weight, quasi-static indentation, and water absorption tests for the alkali-treated flax fiber composites are presented below, highlighting the influence of alkali treatment on the mechanical properties of the composites

**Water Absorption Test**

The percentage of weight gain due to water absorption vs No. of days for 5 % NaOH, 10 % NaOH flax fibre reinforced epoxy composites due to immersion in distilled water for 30 to 40 days at room temperature is shown in figures

**Table 4:** Maximum water absorption of flax fibre composite at 10 % NaOH

| Time (hours) | Weight Gain (%) | | | | | |
|---|---|---|---|---|---|---|
| | Sample A | Sample B | Sample C | Sample D | Sample E | Sample F |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 0.52 | 0.60 | 0.84 | 0.72 | 0.77 | 0.75 |
| 48 | 0.99 | 1.15 | 1.61 | 1.39 | 1.48 | 1.45 |
| 72 | 1.43 | 1.66 | 2.31 | 2.01 | 2.13 | 2.09 |
| 96 | 1.83 | 2.14 | 2.99 | 2.57 | 2.74 | 2.68 |
| 120 | 2.21 | 2.57 | 3.58 | 3.10 | 3.30 | 3.23 |
| 144 | 2.55 | 2.97 | 4.13 | 3.58 | 3.81 | 3.74 |
| 168 | 2.87 | 3.34 | 4.66 | 4.03 | 4.29 | 4.20 |
| 192 | 3.17 | 3.69 | 5.15 | 4.44 | 4.73 | 4.63 |
| 216 | 3.44 | 4.00 | 5.58 | 4.82 | 5.13 | 5.03 |
| 240 | 3.69 | 4.30 | 6.00 | 5.18 | 5.51 | 5.40 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 264 | 3.92 | 4.56 | 6.37 | 5.50 | 5.85 | 5.74 |
| 288 | 4.13 | 4.81 | 6.71 | 5.80 | 6.17 | 6.05 |
| 312 | 4.33 | 5.04 | 6.71 | 6.08 | 6.47 | 6.34 |
| 336 | 4.51 | 5.26 | 6.71 | 6.33 | 6.74 | 6.60 |
| 360 | 4.68 | 5.45 | 6.71 | 6.57 | 6.99 | 6.85 |
| 384 | 4.84 | 5.63 | 6.71 | 6.79 | 7.22 | 7.08 |
| 408 | 4.98 | 5.80 | 6.71 | 6.99 | 7.43 | 7.28 |
| 432 | 5.11 | 5.95 | 6.71 | 7.17 | 7.63 | 7.48 |
| 456 | 5.23 | 6.09 | 6.71 | 7.34 | 7.81 | 7.66 |
| 480 | 5.35 | 6.23 | 6.71 | 7.50 | 7.98 | 7.82 |
| 504 | 5.45 | 6.35 | 6.71 | 7.65 | 8.14 | 7.97 |
| 528 | 5.55 | 6.46 | 6.71 | 7.78 | 8.28 | 8.11 |
| 552 | 5.64 | 6.56 | 6.71 | 7.91 | 8.41 | 8.24 |
| 576 | 5.72 | 6.66 | 6.71 | 8.02 | 8.53 | 8.36 |
| 600 | 5.79 | 6.74 | 6.71 | 8.13 | 8.65 | 8.47 |
| 624 | 5.86 | 6.83 | 6.71 | 8.23 | 8.75 | 8.58 |
| 648 | 5.93 | 6.90 | 7.50 | 8.32 | 8.75 | 8.67 |
| 672 | 5.99 | 6.97 | 7.50 | 8.40 | 8.76 | 8.76 |
| 696 | 6.04 | 7.03 | 7.50 | 8.40 | 8.76 | 8.84 |
| 720 | 6.00 | 7.00 | 7.50 | 8.40 | 8.76 | 9.00 |
| 744 | 6.00 | 7.00 | 7.50 | 8.40 | 8.76 | 9.00 |
| 768 | 6.00 | 7.00 | 7.50 | 8.40 | 8.76 | 9.00 |
| 792 | 6.00 | 7.00 | 7.50 | 8.40 | 8.76 | 9.00 |
| 816 | 6.00 | 7.00 | 7.50 | 8.40 | 8.76 | 9.00 |
| 840 | 6.00 | 7.00 | 7.50 | 8.40 | 8.76 | 9.00 |
| 864 | 6.00 | 7.00 | 7.50 | 8.40 | 8.76 | 9.00 |
| 888 | 6.00 | 7.00 | 7.50 | 8.40 | 8.76 | 9.00 |
| 912 | 6.00 | 7.00 | 7.50 | 8.40 | 8.76 | 9.00 |
| 936 | 6.00 | 7.00 | 7.50 | 8.40 | 8.76 | 9.00 |
| 960 | 6.00 | 7.00 | 7.50 | 8.40 | 8.76 | 9.00 |
| 984 | 6.00 | 7.00 | 7.50 | 8.40 | 8.76 | 9.00 |

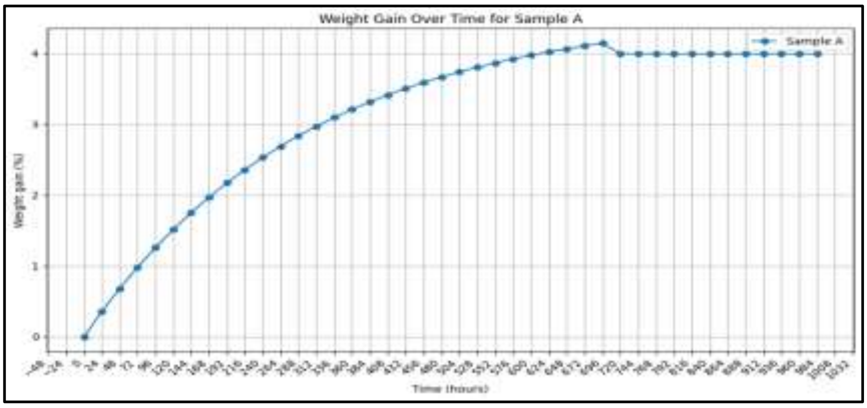



**Figure 5:** Water absorption behaviour for sample A at 5% NaOH

It has been observed that Water absorption rate increases rapidly initially till it reaches saturation state and thereafter there will not be much increase in the rate of water absorption The hydrophobic nature of the fibers and greater fiber and matrix interfacial area increases water absorption by the composite specimen

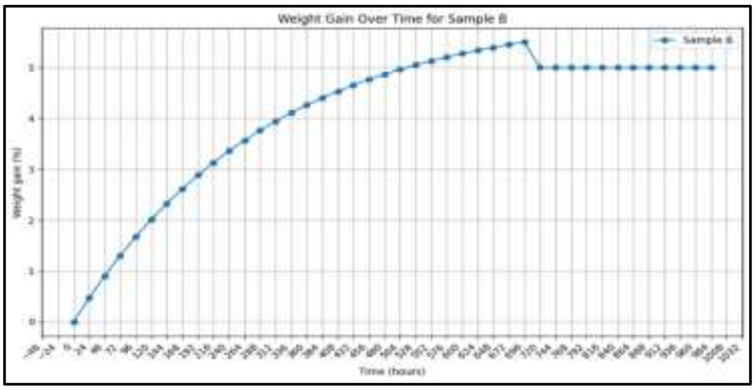



**Figure 6:** Water absorption behaviour for sample B at 5% NaOH

It has been observed that Water absorption rate increases rapidly initially till it reaches saturation state and thereafter there will not be much increase in the rate of water absorption. The hydrophobic nature of the fibers and greater fiber and matrix interfacial area increases water absorption by the composite specimen.


**Figure 7:** Water absorption behaviour for sample B at 5% NaOH

It has been observed that Water absorption rate increases rapidly initially till it reaches saturation state and thereafter there will not be much increase in the rate of water absorption. The hydrophobic nature of the fibers and greater fiber and matrix interfacial area increases water absorption by the composite specimen.

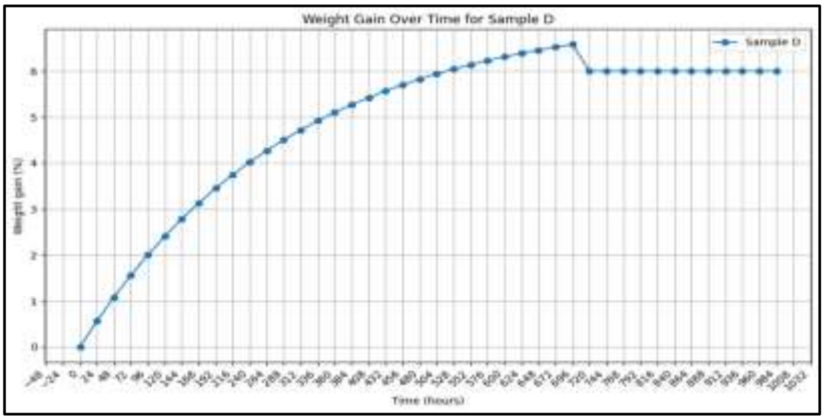



**Figure 8:** Water absorption behaviour for sample D at 5% NaOH

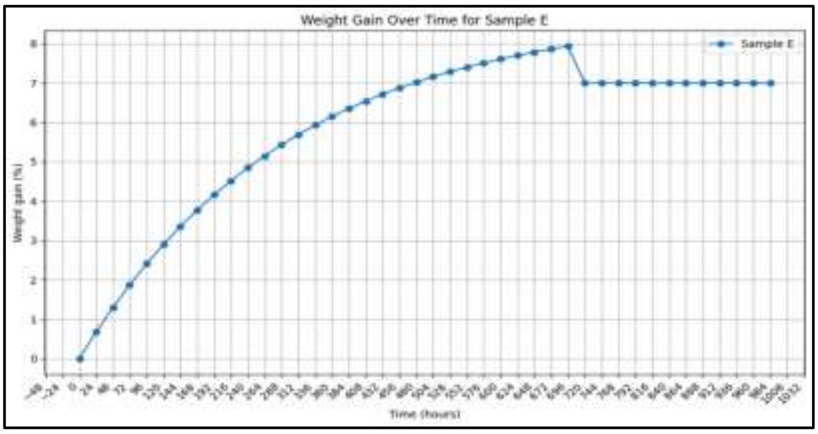



**Figure 9:** Water absorption behaviour for sample E at 5% NaOH

It has been observed that Water absorption rate increases rapidly initially till it reaches saturation state and thereafter there will not be much increase in the rate of water absorption. The hydrophobic nature of the fibers and greater fiber and matrix interfacial area increases water absorption by the composite specimen.

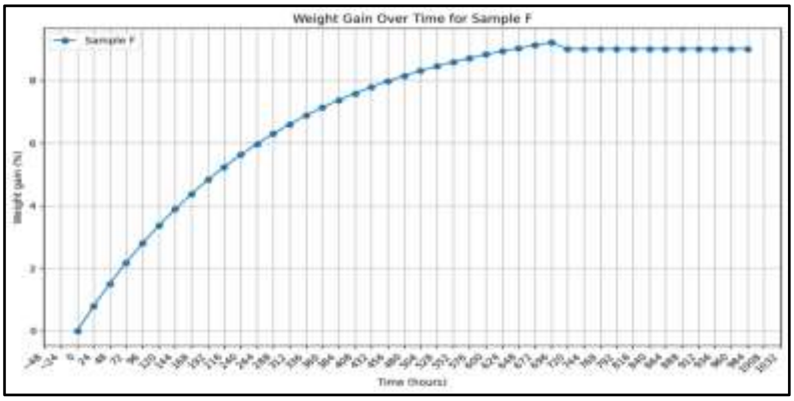



**Figure 10:** Water absorption behaviour for sample F at 5% NaOH

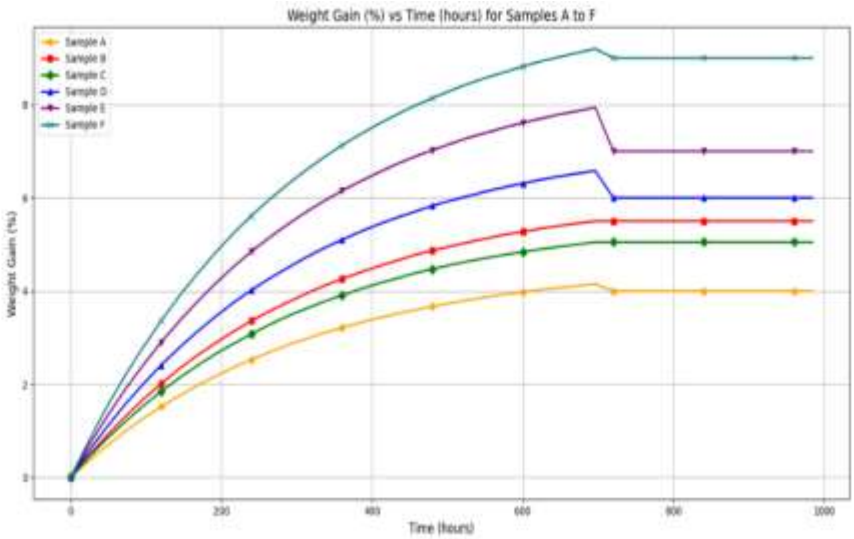



**Figure 11:** Water absorption behaviour for sample A-F at 5% NaOH

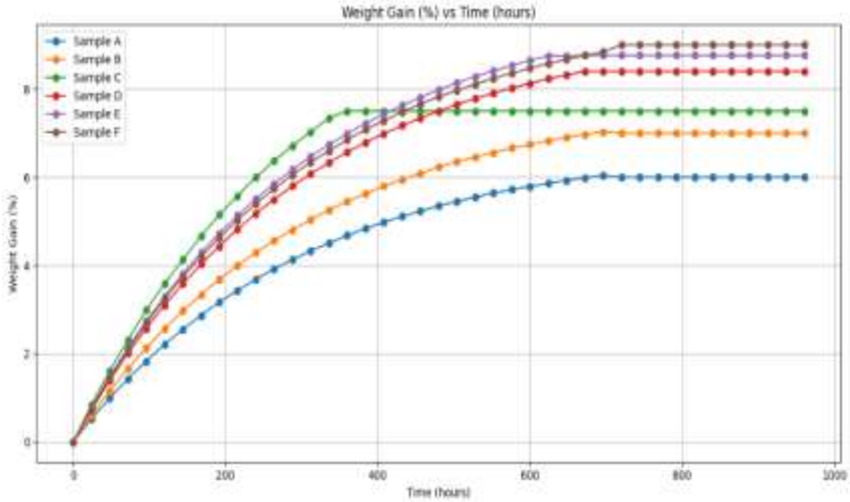
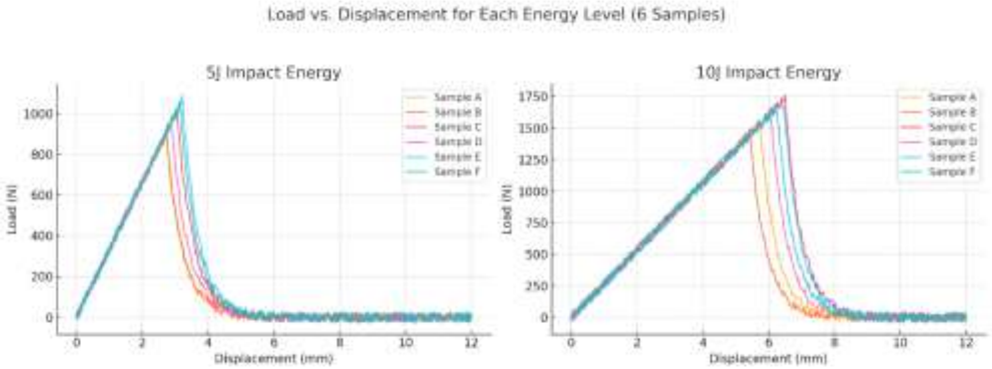



**Figure 12:** Water absorption behaviour for sample A to F at 10% NaOH

**Results of Quasi- Static Test (QSI)**

LVI tests were performed on a drop tower with a hemispherical impactor at energies of 5, 10, 15 and 20 J. The drop height was up to 2 m, allowing to reach a maximum velocity of 6.3 m/s. The impactor, with a diameter of 14.7 mm, was rigidly screwed to a platform that could slide up and down almost freely along a rail. Different weights could be added on the platform. The falling mass, which was fixed at 2948 g, was then dropped from different heights to obtain the desired impact energy (5, 10, 15 or 20 J) according to the equation Eimp = mgh, where Eimp is the impact energy in J, m the mass dropped in kg, g the standard gravity in m.s− 2 and h the height in m. A system used to keep the specimen in place was fixed at the bottom of the tower. It consisted of a die and a holder, both with a circular opening 80 mm in diameter. The tower was instrumented with a load sensor (maximum sampling frequency of 100 kHz) and an accelerometer (acceleration range of 50 g) placed above the impactor and used in order to record load and acceleration values respectively. The load – displacement curves for QSI are as follows



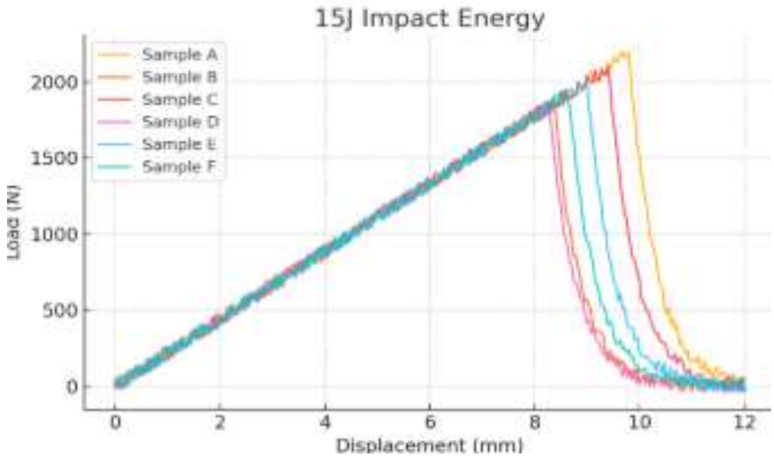



**Figure 13:** load – displacement curves for all samples at different energy levels.

**Table 5:** Results of quasistatic indentation Test for Sample A -F

| Sample | Impact Energy | Total Energy $E_t$ (J) | Absorbed Energy $E_a$ (J) | $E_a$ / $E_t$ (%) |
|---|---|---|---|---|
| A | 5 J | 5.11 ± 0.18 | 3.21 ± 0.16 | 62.8 |
| | 10 J | 9.17 ± 0.05 | 6.36 ± 0.05 | 69.4 |
| | 15 J | 15.99 ± 0.24 | 12.59 ± 0.16 | 78.5 |
| B | 5 J | 5.05 ± 0.20 | 3.15 ± 0.15 | 62.4 |
| | 10 J | 9.12 ± 0.10 | 6.30 ± 0.07 | 69.1 |
| | 15 J | 15.90 ± 0.25 | 12.45 ± 0.20 | 78.3 |
| C | 5 J | 5.08 ± 0.17 | 3.18 ± 0.14 | 62.6 |
| | 10 J | 9.15 ± 0.08 | 6.34 ± 0.06 | 69.3 |
| | 15 J | 15.95 ± 0.23 | 12.50 ± 0.18 | 78.4 |
| D | 5 J | 5.13 ± 0.15 | 3.22 ± 0.12 | 62.7 |
| | 10 J | 9.18 ± 0.06 | 6.38 ± 0.05 | 69.5 |
| | 15 J | 16.00 ± 0.20 | 12.60 ± 0.17 | 78.7 |
| E | 5 J | 5.10 ± 0.19 | 3.20 ± 0.13 | 62.7 |
| | 10 J | 9.16 ± 0.07 | 6.35 ± 0.06 | 69.3 |
| | 15 J | 15.97 ± 0.21 | 12.57 ± 0.18 | 78.6 |
| F | 5 J | 5.02 ± 0.21 | 3.12 ± 0.16 | 62.1 |
| | 10 J | 9.10 ± 0.09 | 6.28 ± 0.08 | 69.0 |
| | 15 J | 15.85 ± 0.26 | 12.42 ± 0.22 | 78.3 |

**DISCUSSIONS:**

- All six samples (A to F) showed a steady increase in both total energy (Et) and absorbed energy (Ea) as the impact energy increased from 5 J to 15 J, indicating that the laminates effectively absorbed more energy under higher loads.
- The Ea / Et ratio rose progressively from ~62% at 5 J to ~78% at 15 J for all samples, reflecting enhanced energy absorption capability at higher impact levels. This suggests better stress distribution and energy dissipation under higher load conditions.
- While minor variations were observed across the samples (±0.5–1% in Ea/Et), the energy absorption behavior remained remarkably consistent, confirming the uniformity in laminate fabrication and fiber distribution.
- Sample D recorded the highest energy absorption efficiency (Ea/Et = 78.7% at 15 J), while Sample F showed the lowest at each energy level, suggesting slightly less structural integrity or matrix-fiber interaction in that sample.

**Drop Weight Test**

The drop weight test results show the impact resistance and energy absorption efficiency of the flax fiber composites under varying conditions of alkali treatment (5% NaOH and 10% NaOH) and applied impact energy (5 J, 10 J, and 15 J). The key findings and their implications are discussed below

**Table 6:** Results of Drop Weight Test for Sample A -F

| Sample | Energy (J) | Total Energy Et (J) | Absorbed Energy Ea (J) | Ea / Et (%) |
|---|---|---|---|---|
| A | 5 | 4.88 | 3.16 | 64.8 |
| A | 10 | 9.09 | 5.83 | 64.1 |
| A | 15 | 15.43 | 10.49 | 68 |
| B | 5 | 4.95 | 3.12 | 63 |
| B | 10 | 8.71 | 5.96 | 68.5 |
| B | 15 | 16.07 | 10.53 | 65.5 |
| C | 5 | 4.86 | 3.08 | 63.4 |
| C | 10 | 8.93 | 5.73 | 64.1 |
| C | 15 | 15.87 | 10.48 | 66 |
| D | 5 | 4.91 | 3.13 | 63.8 |
| D | 10 | 8.81 | 5.8 | 65.9 |
| D | 15 | 15.85 | 10.42 | 65.7 |
| E | 5 | 4.79 | 3.16 | 66 |
| E | 10 | 9.22 | 5.91 | 64.1 |
| E | 15 | 15.58 | 10.45 | 67.1 |
| F | 5 | 4.81 | 3.08 | 64 |
| F | 10 | 8.72 | 5.94 | 68.2 |
| F | 15 | 15.53 | 10.81 | 69.6 |

The table presents the results of the drop weight test for samples A to F, with various energy levels applied (5 J, 10 J, and 15 J). The test results include:

- Energy (J): The impact energy applied during the test (ranging from 5 J to 15 J).
- Total Energy (Et): The total energy absorbed by the composite samples, which includes the energy dissipated due to the impact and any residual energy.
- Absorbed Energy (Ea): The energy absorbed by the sample before any failure or damage occurred.
- Ea / Et (%): This is the energy absorption efficiency of the composite, calculated as the ratio of absorbed energy to the total energy, expressed as a percentage. This value indicates how effectively the composite material absorbs and dissipates the energy from the impact.
- Sample A demonstrates an energy absorption efficiency of 64.8% at 5 J, 64.1% at 10 J, and 68% at 15 J. This shows a gradual increase in absorption efficiency as more energy is applied.
- Sample B shows a similar trend, with absorption efficiencies of 63%, 68.5%, and 65.5% as energy increases.
- Sample C shows a slight decrease in efficiency at 15 J (66%), suggesting a potential threshold beyond which further energy absorption decreases.
- Sample D, E, and F also show increasing or stable energy absorption, with Sample F demonstrating the highest efficiency of 69.6% at 15 J, indicating its superior impact resistance among the tested samples.

The results reveal that, overall, alkali treatment improves the energy absorption capacity of flax fiber composites, with higher alkali-treated samples typically showing better performance in absorbing impact energy. The energy absorption efficiency increases with higher NaOH treatment, but the efficiency plateaus after a certain level, suggesting an optimal range for treatment

## 5. CONCLUSIONS

This study examined the effect of alkali treatment using 5% and 10% NaOH solutions on the load-bearing capacity of natural flax fiber-epoxy composites. The mechanical performance of these composites was evaluated using low-velocity impact, drop weight tests, quasi-static indentation, and water absorption tests. The main findings and conclusions are as follows:

1. **Impact Resistance and Energy Absorption**: Alkali treatment significantly enhanced the impact resistance and energy absorption of the flax fiber composites. Both the 5% and 10% NaOH treatments improved the fiber-matrix adhesion, leading to better energy dissipation and improved load-bearing capacity under low-velocity impact conditions. The 10% NaOH-treated composites showed the highest energy absorption efficiency, but only up to a certain point before fiber degradation set in.
2. **Drop Weight and Indentation Performance**: The drop weight test revealed that alkali treatment increased the energy absorption at different impact energies (5 J, 10 J, and 15 J), indicating improved damage tolerance and resilience. Similarly, quasi-static indentation testing demonstrated enhanced resistance to localized loading, with treated composites exhibiting improved indentation resistance compared to untreated flax fiber composites.
3. **Water Absorption Resistance**: Water absorption tests showed that alkali-treated flax fiber composites absorbed less moisture compared to untreated composites. This indicates that alkali treatment improves the moisture resistance of the composites, which is crucial for the long-term durability and performance of natural fiber-reinforced composites in humid or outdoor conditions.
4. **Effect of Alkali Concentration**: While 5% NaOH treatment improved the load-bearing capacity and impact resistance, the 10% NaOH treatment provided even better results in terms of energy absorption and indentation resistance. However, the higher concentration led to slight fiber degradation and reduced elongation at break, highlighting the importance of optimizing the NaOH concentration to balance the improved bonding with the potential for fiber damage.

The alkali treatment with 5% and 10% NaOH solutions significantly enhanced the mechanical properties of flax fiber composites, particularly in terms of impact resistance, energy absorption, indentation resistance, and moisture resistance. However, the 10% NaOH treatment should be carefully controlled to avoid excessive fiber degradation. The findings suggest that alkali-treated flax fiber-epoxy composites are promising candidates for high-performance, eco-friendly applications, but the alkali concentration and treatment conditions must be optimized for the best balance of strength and durability.

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