# THE EFFECT OF ECO-FRIENDLY CHEMICAL TREATMENT ON MECHANICAL PROPERTIES OF PINEAPPLE LEAF FIBRE USING WEIBULL ANALYSIS

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**Abstract**. In the pursuit of eco-friendly composite materials, pineapple leaf fibre (PALF) emerges as a compelling candidate to be used as a degradable reinforcing material due to its outstanding intrinsic mechanical properties. However, due to their hydrophilic nature, alkaline treatment using sodium hydroxide (NaOH) is often used to improve interface bonding in the polymer matrix. Though, NaOH, can pose environmental risks if not handled with proper precautions during disposal. Thus, opting for sodium bicarbonate ($NaHCO_3$) could be regarded as an eco-friendly alternative. The aim of this study is to analyse the impact of various treatment processes on the strength and Young's modulus of the PALF. The PALF were subjected to an alkaline treatment using different concentrations of sodium bicarbonate (5 wt.% % and 10 wt.%) for 96 hours. Some of the PALF was also pre-treated in hot water (100 °C) for 30 minutes before the alkaline treatment. The tensile single fibre test was carried out using a 20 mm gauge length. Predicted tensile strength and modulus were determined through the utilization of Weibull analysis. Scanning electron microscopy (SEM) was used to analyse the surface morphology of the fibres. The results suggest that the fibres treated with a 5 wt.% $NaHCO_3$ solution at room temperature demonstrates a significant 43 % increase in tensile strength and a 24 % improvement in Young's modulus when compared to their untreated PALF counterparts. In summary, the alkaline treatment enhanced both the tensile and modulus strength of the fibre and $NaHCO_3$ can be considered as an alternative material for eco-friendlier surface treatment for natural fibre.

**Keywords:** Pineapple leaf fibre, tensile strength, eco-friendly, alkaline treatment, Weibull analysis

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## 1. INTRODUCTION

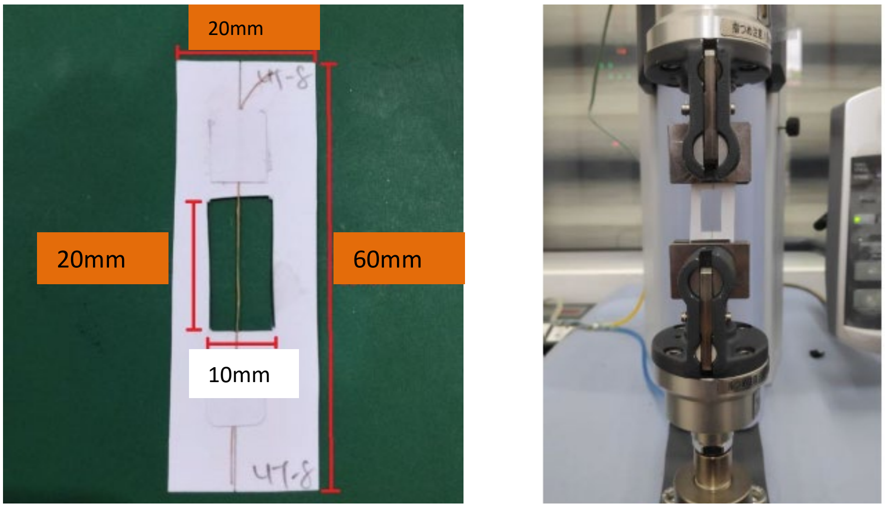
Composite materials derived from natural fibres offer extensive application across various industries, notably in engineering, automotive, furniture, and construction. Natural fibres like pineapple leaf fibre, flax, jute, and hemp, among others, present advantageous characteristics such as high specific strength, cost-effectiveness, and biodegradability [1]. These fibres are abundant, renewable, biodegradable, and exhibit a lower carbon footprint compared to synthetic counterparts. Their cultivation and processing require less energy and generate fewer greenhouse gases, aligning with the growing emphasis on sustainable manufacturing practices and circular economy principles.

Despite the numerous advantages, challenges remain in optimizing the performance of natural fibre-reinforced composites. Due to their hydrophilic nature, they may develop weak interface bonding when used in a polymeric matrix, subsequently compromising the composite performance. Thus, surface modification, such as alkaline treatment is often used to enhance the capabilities of fibres to remove impurities, wax, and oil and soften the fibre itself [2-4]. It also uses to increase in the surface roughness of the natural fibre. The treatment increases the surface roughness of the fibres, which can improve the mechanical interlocking with matrices in composite materials. Unfortunately, due to their nature, natural fibres are more vulnerable to structural changes and/or degradation when receiving surface treatments. The alkaline treatment encompasses submerging the fibres in an alkaline solution, typically a strong base like sodium hydroxide (NaOH), for a specific duration [5-6]. This process modifies the surface chemistry of the fibres, resulting in several changes that can affect their mechanical behaviour [7]. When natural fibres are subjected to alkaline treatment, the goal is to selectively remove impurities, such as hemicellulose and lignin, from the fibre surface while preserving the integrity of the cellulose structure. NaOH is a strong base and may alter the intrinsic properties of the fibre as well as can have harmful effects if released into the environment without proper precautions.

Alternatively, the use of sodium bicarbonate ($NaHCO_3$) can be considered a more environmentally friendly option [8]. Sodium bicarbonate is non-toxic, environmentally friendly, and readily available. Its use reduces the chemical hazards associated with stronger alkalis, ensuring safer handling and processing. Additionally, the byproducts of sodium bicarbonate treatment are less harmful, making waste management easier and more sustainable. They are also milder alkaline compounds and have a lower pH. However, its effectiveness as a substitute for sodium hydroxide may vary depending on the specific application and desired modifications as it may not provide the same level of alkalinity or strength of surface modification as sodium hydroxide. Therefore, it is necessary to carefully optimize the treatment parameters for each specific application to achieve the desired mechanical properties in natural fibres. Thus, this study aimed to investigate the mechanical response to quasi-static tensile loading for both untreated pineapple leaf fibres and those treated with $NaHCO_3$ at various concentrations (5 wt.% and 10 wt.%) and under different conditions (at room temperate with and without pre-treatment using hot water).

## 2. MATERIALS AND METHODS

In this study, PALF fibre was supplied by Pultrusion Sdn Bhd (Malaysia) in the form of long fibre. The sodium bicarbonate used is domestic grade in powder form obtained from a local store. The sodium hydroxide pellet was purchased from Sigma Aldrich. The pineapple leaf fibres were immersed in sodium bicarbonate solution ($NaHCO_3$) solutions with varying concentrations (5 wt.% and 10 wt.%) for 96 hours at room temperature, as described in [8]. The specimen from this treatment condition is labelled as RT. Following that, the fibres were submerged in distilled water to rinse and remove any impurities. The fibres then were dried in a drying oven at 50 °C overnight. Some of the PALF was also pre-treated by soaking in hot water (100 °C) for 30 minutes before the sodium bicarbonate treatment and the specimen is labelled as HW. For comparison purposes, the PALF was also treated using a 5 % NaOH solution as detailed in our previous works [5]. Figure 1 shows rectangular card of fibres and mounted fibres on a Universal Tensile Tester. Individual fibres were extracted by hand, after which they were affixed to a rectangular card using adhesive (Figure 1(a)). Afterwards, the mounted fibre was put on a universal tensile tester (Shimadzu, Japan) with a capacity of 50N and the card was carefully cut with a pair of scissors (Figure 1(b)). The test was carried out using a 20 mm gauge length at a 1 mm/min crosshead speed. Approximately 20 fibres were tested for each parameter. The diameter of the fibres was measured using an optical microscope and was considered perfectly round.




(a) (b)

**Figure 1:** (a) Rectangular card of fibres and (b) mounted fibres on a Universal Tensile Tester

The two-parameter Weibull distribution was used to ascertain the predictive strength and Weibull modulus as shown in Equation 1:

$$P(\sigma)=1-\exp\left(-\frac{x}{\beta}\right)^{m} \tag{1}$$

where P (σ) denotes the probability of stress failure at x, ß is the scale parameter and m is the shape parameter or Weibull modulus. Their value can be determined by rewriting Equation 1 to form a linear relationship as in Equation 2 [9-10]:

$$\ln\left[\ln \frac{1}{1-P(\sigma)}\right] = m \ln (x) - m \ln(\beta) \tag{2}$$

The failure probability can be determined from Equation (3) [11]:

$$P(\sigma)=\frac{i-0.3}{n+0.4} \tag{3}$$

where $n$ is the total specimens and $i$ is a serial number of strengths at failure, referring to the tensile strength of the fibre obtained from the experiment. The Weibull modulus (m) is distinctly tied to the failure of the most conspicuous flaws observable on the fibre surface [12].

## 3. RESULTS AND DISCUSSION

### *3.1 Tensile Test*

The stress–strain plot for untreated and treated single PALF is shown in Figure 2 and the maximum strength value is observed when using 5% $NaHCO_3$ at room temperature. All fibres exhibit a brittle mode of failure. The peak stress of the treated fibre is twice as high as that of the untreated fibre.

Figure 3 displays the tensile strength and tensile modulus values for both treated and untreated single PALF. The mechanical properties of the treated PALF exhibit a notably higher tensile strength compared to the untreated fibre. Specifically, the treated fibre demonstrates an enhancement of up to 40 % in tensile strength and 24 % in modulus compared to untreated samples when treated with 5 % $NaHCO_3$. In the treatment process, the removal of hemicellulose and lignin softens the interfibrillar structure. This allows for easy rearrangement of fibrils along the axial direction of loading, leading to improved load sharing across the fibre surface and a substantial increase in tensile strength. As observed by Izani et al. [13], alkali treatment significantly enhances fibre tensile strength, potentially due to the improved crystallinity resulting from the treatment. It was noted that large variations in the average value of the tensile strength and modulus are due to the variability of the natural fibre properties, fibre surface and others [14].

However, the fibre starts to show degradation with an increase in $NaHCO_3$ concentration. At 10% $NaHCO_3$, the tensile strength and modulus reduce to 171.73 MPa and 8.67 GPa, approximately 34 % and 2 8% decrease compared to the untreated fibre. Introduction of hot water pre-treatment before the 5 wt.% $NaHCO_3$ solution resulting in a decrease in strength and modulus to 175.01 MPa and 9.76 GPa respectively. At 10 wt.% $NaHCO_3$ with hot water pre-treatment resulted in the lowest tensile strength and modulus at 99.12 MPa and 7.41 GPa. The reduction in strength of the fibre could be due to the degradation of the internal structure of the fibre. Removal of impurities using alkaline treatment increases mechanical properties but excessive removal can cause fibre degradation and loss of structural strength of the fibre. These results are similar to those reported by previous study [13]. It was also observed that the tensile strength of the $NaHCO_3$ treated fibre at room temperature is still superior in comparison to the NaOH-treated fibre indicating a more severe degradation occurred in NaOH-treated fibre due to alkaline treatment.

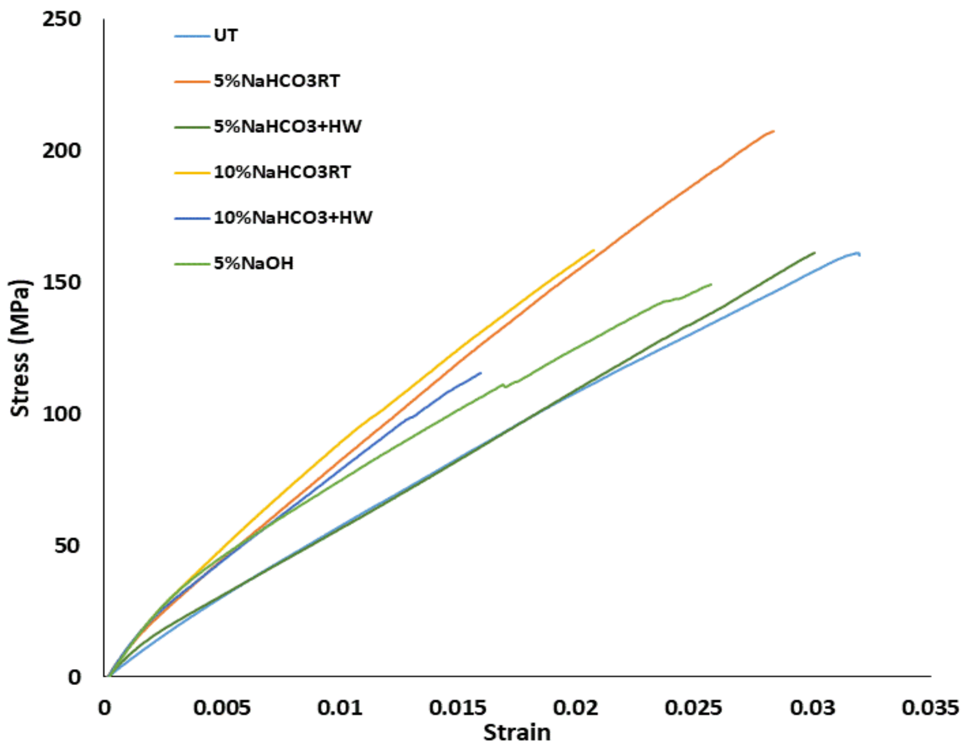



**Figure 2:** Stress–strain plot for untreated and treated PALF fibre

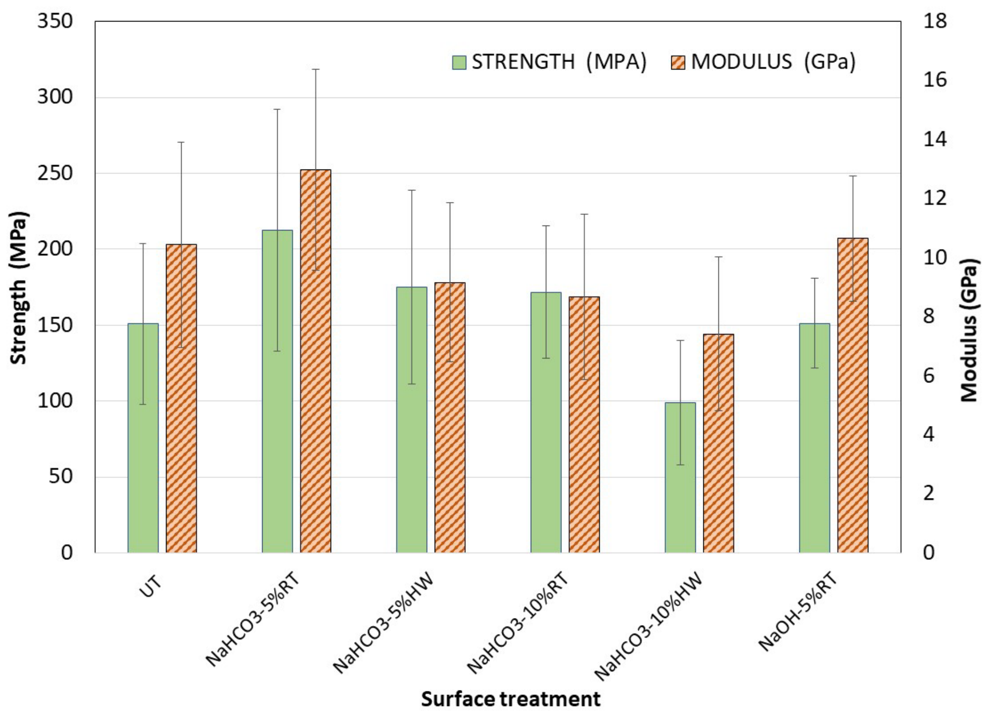



**Figure 3:** Effect of various alkali treatment conditions on the tensile strength and modulus of PALF fibres

### *3.2 Morphological Analysis*

Figure 4 presents micrographs of the untreated and alkaline-treated PALF. The untreated PALF surface appears to be rough with impurities (Figure 4(a)). The alkaline treatment induces irreversible mercerization, eliminating natural and artificial impurities and revealing cleaner and more distinct fibrils on the surface topography (Figure 4(b)). Mercerization with 5 wt.% $NaHCO_3$ effectively cleans the fibre surface from the impurity. However, it does not eliminate the outer layer or reveal the internal structure of protrusions or fibrils. This treatment is accompanied by an increase in the tensile strength and modulus (Figure 3). Numerous studies have demonstrated that alkali treatment can effectively wash out impurities present in natural fibres [15-16].

With an increase in the concentration of the $NaHCO_3$ solution to 10 wt.%, the PALF surface becomes rougher possibly due to more extensive removal of the outer fibre layer. This exposure reveals the fibre protrusions and fibrils, which may damage the structure of the fibre (Figure 4c) and may contribute to the decrease of their tensile and modulus properties. This finding is similar to reported by d'Almeida et al. [17].

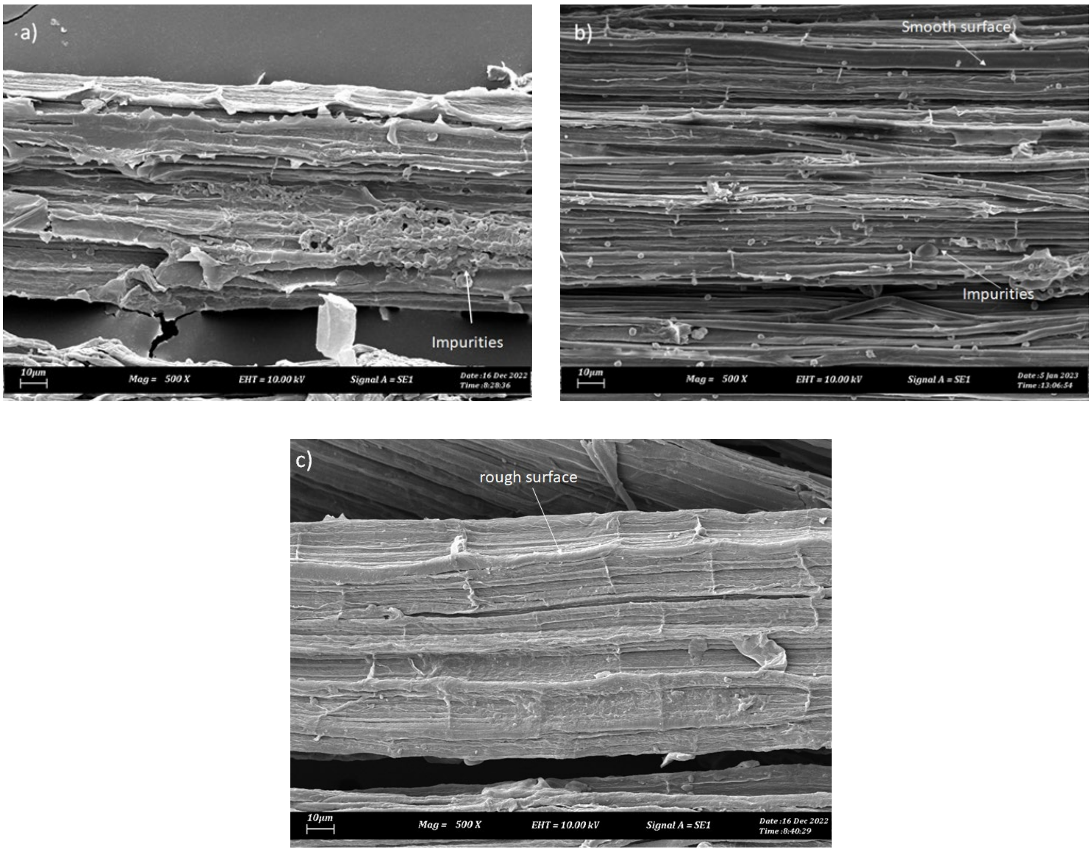



**Figure 4:** SEM micrographs of (a) untreated and (b) treated PALF with 5wt.% $NaHCO_3$ and (c) treated PALF with 10 wt.% $NaHCO_3$ (scale bar = 10μm)

### *3.3 Weibull Analysis*

Figure 5 illustrates the relationship between ln {ln [1/(1-P(σ))]} and ln (strength) for both untreated and treated samples. Notably, all the data in Figure 5 follows an unimodal pattern, with a single straight line corresponding to datapoint. The investigation revealed that the shape parameter (Weibull modulus) of alkali treated PALF fibres was lower than that of the untreated PALF fibres, as outlined in Table 1. A lower value of the shape parameter points to higher scattering data in tensile strengths, consistent with the findings by [7]. This could be attributed to the uneven treatment of the surface area of PALF fibres with alkali, given that these fibres are occasionally found in bundles [18]. According to Belaadi et al. [19], the reported Weibull modulus falls within the range of 1.2 to 3.6 and is 10 % smaller than values found in the open literature. This difference could be attributed to the presence of inconsistencies or severe flaws at the surface, serving as weak links in the fibre's collapse.

As the likelihood of a flaw increases with the increase of the alkaline concentration, this leads to the decrease in the characteristic strength (Weibull strength) of the PALF with the increase of $NaHCO_3$ solution concentration. Nevertheless, there is an excellent agreement between the Weibull strength and experimental tensile strength, as indicated in Table 1, with less than 10% error. These findings strongly suggest that the two-parameter Weibull distribution is highly suitable for predicting the tensile strength of both untreated and alkali-treated PALF fibres.

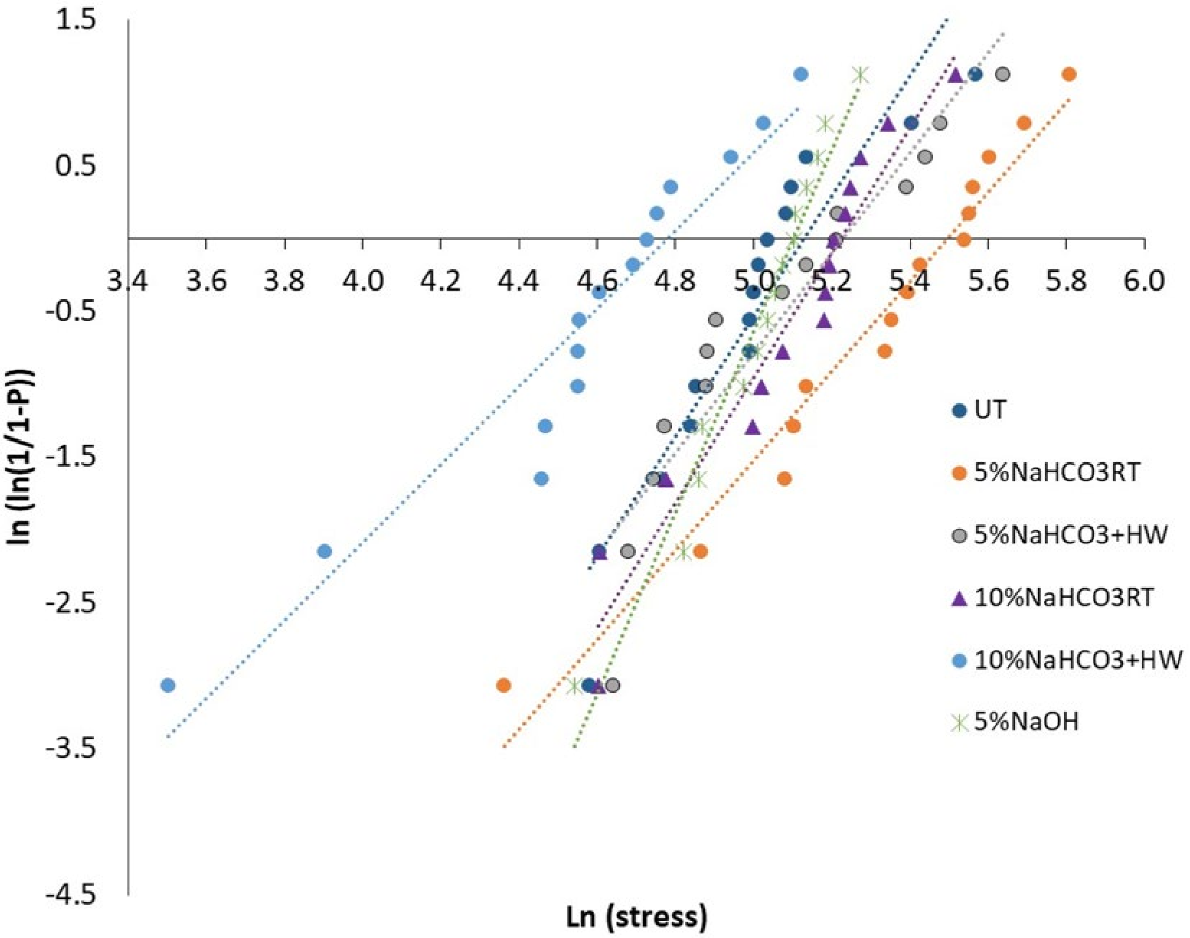



**Figure 5:** Two-parameter Weibull distribution of mechanical properties of the untreated and treated with different concentrations of alkaline solutions.

**Table 1:** The tensile strength properties and Weibull distribution parameter of PALF fibres under different alkaline treatment

| Alkaline treatment | Weibull strength, $\sigma_o$ (MPa) | Weibull modulus, m | Average tensile strength, $\sigma$ (MPa) | Percentage of error (%) |
|---|---|---|---|---|
| Untreated | 168.53 | 4.12 | 164.06 | 2.66 |
| 5 wt.% $NaHCO_3$+ RT | 243.73 | 3.07 | 227.43 | 6.69 |
| 5 wt.% $NaHCO_3$+HW | 186.63 | 3.43 | 182.93 | 1.99 |
| 10 wt.% $NaHCO_3$+RT | 189.59 | 4.06 | 179.73 | 5.20 |
| 10 wt.% $NaHCO_3$+HW | 118.73 | 2.67 | 113.56 | 4.35 |
| 5 wt.% NaOH | 164.01 | 6.23 | 157.66 | 3.87 |

## 4. CONCLUSIONS

The impact of $NaHCO_3$ fibre treatments on the analysis of single-fibre tensile strength and modulus was thoroughly examined. Tensile tests were conducted on fibres treated with 5 wt.% and 10 wt.% $NaHCO_3$ concentrations revealed that alkali-treated fibres exhibited higher tensile strength than untreated fibres. The $NaHCO_3$ treatment effectively removed impurities from the surface of the fibre, leading to surface modifications and enhancing their mechanical strength. Subsequently, the experimental data were analysed using a two-parameter Weibull distribution. The Weibull modulus parameter for all $NaHCO_3$ treated samples is below the value of 5 with the % error between the experimental and predicted is less than 10. This study confirms the accurate predictive capability of the Weibull probability statistic for determining the specific mechanical properties of a single PALF fibre instead of using average tensile strength. It also is evident that alkaline treatment significantly enhances the tensile properties of PALF fibres.

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**Author Contributions**

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

**Disclosure of Conflict of Interest**

The authors have no disclosures to declare.

**Compliance with Ethical Standards**

The work is compliant with ethical standards.

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