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The Potential of Limestone as a Preserving Agent for Bamboo Fibre

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Abstract: Bamboo fibres have recently attracted a lot of attention as a viable substitute for synthetic fibres for composite building applications, due to the rising awareness of ecologically friendly biomaterials. Alkaline treatment is commonly known to chemical treatment procedure for modifying the texture of natural fibres. NaOH is a commonly used alkaline that is used to treat bamboo fibre. However, it is extremely caustic and can cause tissue damage if it comes into contact with skin. This research is to investigate the effectiveness of the limestone which is not a synthetic chemical to treat the bamboo fibre. The tensile strength of bamboo fibre is obtained via universal tensile machine (UTM). The morphological structure of untreated/controlled and treated bamboo fibre investigated using scanning electron microscope (SEM). Finally, research come into the functional group of the bamboo fibres using Fourier-transform infrared spectroscopy (FTIR). The bamboo fibre that had been soaked in 4 wt.% $CaCO_3$ for 4 hours exhibited the highest tensile strength. It is because the decreased of lignin makes the bamboo fibre more durable. In comparison to untreated bamboo fibre, the treated bamboo fibre has a rough surface morphology. $CaCO_3$ has been shown to be effective in the preservation of bamboo fibres. The chemical properties of limestone could be employed to improve the mechanical properties of bamboo fiber-reinforced composites, especially the interfacial adhesion between the fibres and the matrix.

Keywords: Bamboo Fibre, Limestone, Preserving Agent

1. Introduction

Due to a growing awareness of environmentally friendly biomaterials, bamboo fibres have recently gained a lot of interest as a possible option for synthetic fibres in composite building applications. Bamboo is a valuable forest resource that thrives throughout the world's tropical and semitropical zones, especially in Asia. Bamboo, on the other hand, is becoming more popular in the construction industry due to its rapid growth, high mechanical and thermal properties, tensile strength, low cost, light weight, and machinability efficiency [1].

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Compounds changing substances and mechanical testing are standard processes used to identify treated fibre from raw fibre. According to previous study, chemically altering cell walls removed at least 35 % of the cell wall components [2]. To overcome the difficulty, a chemical treatment at the fibre interface can change the properties of natural fibre. Specific chemical changing natural fibres has been demonstrated to increase composite mechanical properties, fibre-matrix adhesion, and natural fibre compatibility in various studies [3].

1.1 Limestone

Limestone is a sedimentary rock made mostly of calcium carbonate ($CaCO_3$). After the water has drained, stalagmites and stalactites are left behind in caves. Limestone is rarely seen in its pure white form since it is almost usually flecked with impurities. Limestone powder has also been used to build concrete in a few nations. The use of fine limestone powder appears to have increased cement hydration efficiency and development in durability [4], as well as the flexibility and endurance of new self-consolidating concrete (SCC) [5].

According to a study, applying limestone powder to self-compacting concrete increases the mix's workability by retaining water in the new mix and enhancing the durability and flexibility of the fresh self-consolidating concrete (SCC) mix, resulting in increased strengths. A stronger particle loading strategy, enhanced new mix water retention, and a possible chemical reaction involving concrete and calcium carbonate ($CaCO_3$) to produce carbon aluminate ($C\text{-}Al_2O_3$) can always be associated with this improvement [5].

1.2 Problem statement

Mercerization, which involves immersing natural fibres in a diluted sodium hydroxide (NaOH) solution, is one of the most common and valuable treatments. The hydroxyl group of natural strands reacts with NaOH to dissolve the cementing components that cover the outer layer of the fibre, such as hemicellulose, lignin, wax, and oils, resulting in increased surface roughness and the creation of fibrous bonds [6]. However, NaOH is exceedingly corrosive and can harm any tissue it comes into touch with. The nostrils, throat, and pulmonary airways can be irritated by small amounts of NaOH in the form of dusts, mists, or aerosols. Larger quantities of inhalation may produce oedema or bronchial contractions, resulting in bronchial blockage and the loss of detectable pulse, as well as pulmonary infection and fluid blockage [7].

Therefore, this research is conducted to study on the effectiveness of the limestone as the potential preserving agent to replace and reduce the harmful reaction of synthetic chemical. The data of the tensile strength is analyzed to find the best strength of bamboo fibre. Furthermore, the analysis of the structure bamboo fibre structure and the presence of alkaline are observed.

1.3 Objectives

The objectives of this research are:

i. To investigate the mercerization effect of bamboo fibre.
ii. To determine the characteristic of the limestone as potential preserving agent for bamboo fibre.
iii. To examine the morphology of the treated/controlled and untreated bamboo fibre.

1.4 Scope of study

The study is to observe the bamboo fibre based on the concentration level which is 2, 4, 6 and 8 wt.% and immersion time in 1, 3, 6, 16 and 24 hours respectively. The treated bamboo fibre undergoes physical test such as tensile strength test via the Universal Tensile Machine (UTM) as well as its morphology is analyzed using scanning electron microscope (SEM). The presence of functional group in the bamboo fibre is determined via Fourier-transform infrared spectroscopy.

2. Materials and Methods

In order to achieve the required objectives, the preparation of bamboo fibre using the limestone as preserving agent and the testing for bamboo fibre is explained.

2.1 Method

Figure 1 shows the methodology of the flow chart that has been used as a guidance to achieve the objectives.

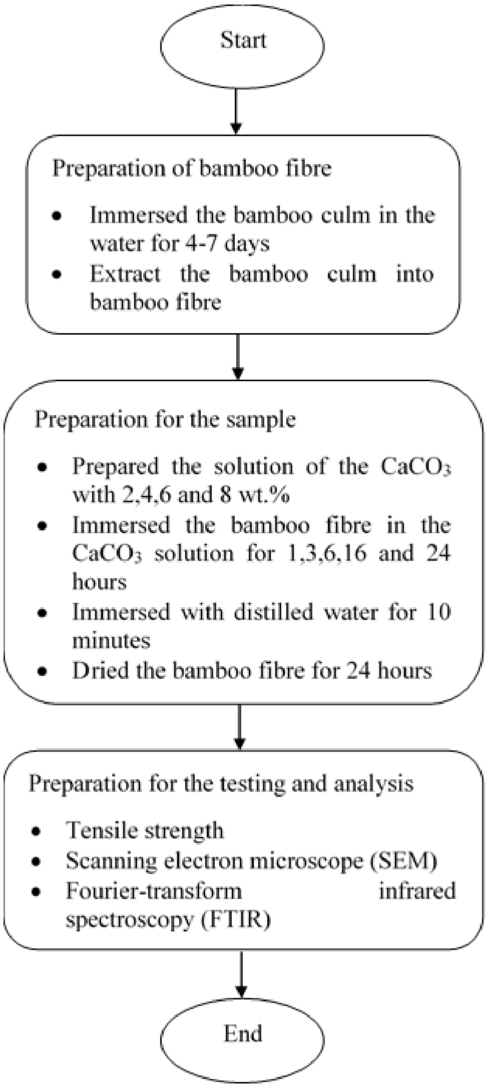

Figure 1: The flow chart of the methodology for the potential of limestone as preserving agent for a bamboo fibre

2.2 Materials

The materials needed and used in this research are shown in Table 1.

Table 1: Material and equipment for the research

Materials/Equipment	Description	Function
Bamboo culm	*Schizostachyum grande* bamboo	To investigate the effect with the preserving agent as bamboo fibre.
Limestone	Calcium carbonate, $CaCO_3$	To use as preserving agent.

Scanning electron microscope (SEM)	TESCAN	To examine the microstructure of the fibre.
Fourier-transform infrared spectroscopy (FTIR)	Shimadzu	To investigate the changes of functional group in bamboo fibre.
Universal tensile machine	Victor Manufacturing Sdn Bhd	To test the tensile strength.
Bamboo fibre extraction machine	Amcoweld	To extract the bamboo fibre.

3. Results and Discussion

In this section, the outcomes of this research were investigated and discussed. This chapter presented the data and discussion which are the tensile strength, the structure of bamboo fibre and observation of the presence of functional groups in bamboo fibre.

3.1 Tensile strength

Figure 2 shows the result of tensile strength for the bamboo fibre with different concentration (2, 4, 6 and 8 wt.%) of calcium carbonate ($CaCO_3$) and different soaking time (1, 3, 6 16 and 24 hours), compared to the control. The 4 wt.% concentration of calcium carbonate for 3 hours produced the highest tensile strength while similar concentration with 24-hours exposure shows contradictory results. Study conducted by Wang et.al (2018) discovered that at 4 wt.% alkali treatment, the maximum tensile strength is achieved as a consequence of low removal of hemicellulose, lignin, and other impurities, which tends to increase the ability of those fibrils to restructure themselves in the orientation of tensile stress, leading to improved cellulose chain packing [8].

Wang et.al (2018) also discovered that increasing the alkali concentration to 7 wt.% reduced tensile strength by 4 wt.%, leading to weaker fibre with a high alkali content [8]. Because of the interaction with calcium carbonate, the tensile strength is still increasing at 4wt.%, according to the results. Calcium carbonate has the ability to maintain excellent mechanical properties [9].

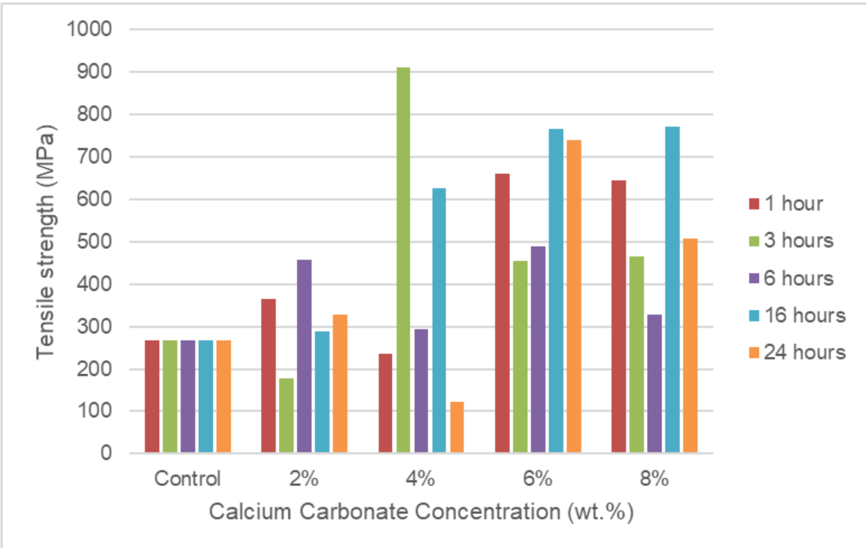

Figure 2: The tensile strength of bamboo fibre with various concentration and immersion duration

Figure 3 shows that the tensile modulus grew gradually up to the 8 wt.% concentration, maintaining the same pattern as the tensile strength. Furthermore, the length of treatment appeared to have a significant impact. At an 8 wt.% concentration and 6 hours of immersion, the maximum rise in tensile modulus was obtained. In previous research, they discovered that by raising penetration levels of alkali to 20.0 % resulted in a 10.0 % decrease in tensile strength toughness and a 66.0 % decrease in tensile modulus due to cellulose breakdown [10].

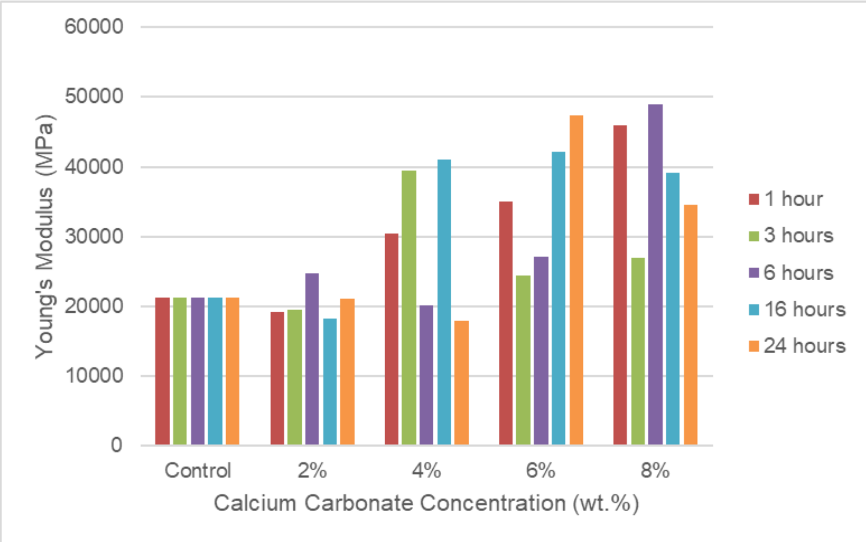

Figure 3: Young's modulus of the bamboo fibre with various concentration and immersion duration

Alkali treatment of sisal fibres enhanced crystallinity of cellulose as well as eliminating contaminants including hemicellulose and lignin. This is due to enhanced crystallization of the hard cellulose, the sisal fibres became much more durable when some of the impurities were removed, lead to significantly improved fibre toughness. Similar principle is responsible for the increased tensile modulus of bamboo fibre strips [11].

The strain at break data for various calcium carbonate concentrations and soaking times are shown in Figure 4. The strain rates of the fibres with the 2, 4, 6, and 8 wt.% solutions showed no significant changes. The differences ranged between the highest and the lowest of the percentage strain at break are from 0.85 % to 2.65 %. The mechanical strength and elastic modulus of the fibres had enhanced, according to the analysis of the collected data. The fibre with the 6 wt.% calcium carbonate concentration and 6 hours of immersion has the highest strain at break which is 2.65 %, whereas the fibre with the 8 wt.% calcium carbonate concentration and 6 hours of immersion had the lowest strain at break which is 0.85 %. There was no observable change in the pattern for fracture strain as a consequence of immersion duration.

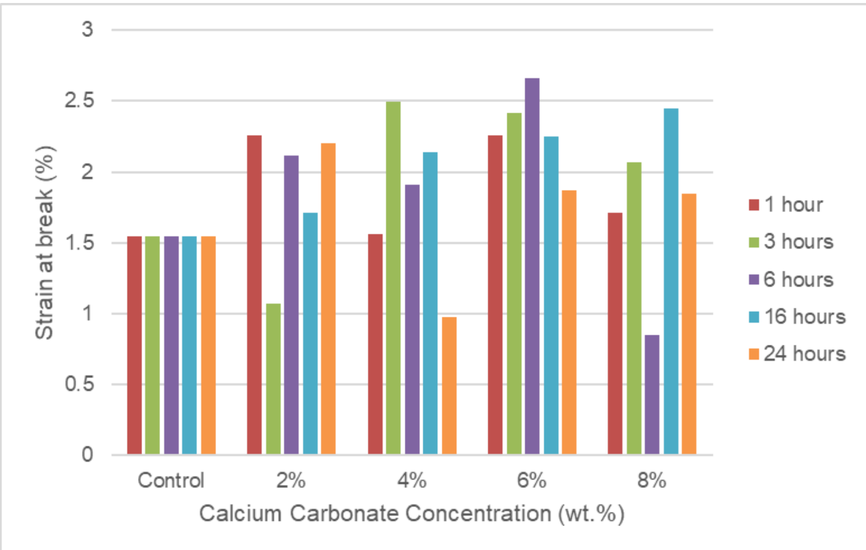

Figure 4: Percentage of the strain-a-break of the bamboo fibre with various concentration and immersion duration

Bamboo fibres have a tensile strength of 450-800 MPa, a tensile elastic modulus of 11000- 30000 MPa, and a strain to failure of 1.00-3.00 % [12]. Therefore, the test findings were rather accurate with the previous research.

3.2 Morphology of the bamboo fibre

Figures 5 illustrate the surface characteristics of untreated/controlled and treated bamboo fibre with a calcium carbonate. The surface morphology of the untreated bamboo fibre was smooth and scattered with a smattering of lumpy substances meanwhile the surface structure of the treated bamboo fibre are rough. Hemicelluloses, lignin, pectin, wax, and other contaminants might well be found upon those surfaces [13]. According to previous research, contaminants have been eliminated, resulting in a smoother and harder surface. Fracture towards the fibre can be seen in a few areas. Alkaline treatment removes waxy coating, contaminants, and components including lignin and hemicellulose [14]. Nonetheless, when the $CaCO_3$ concentration and time immersed started rising, the surface degradation had become more extremely severe to the alkaline solution's destructive impact. Fibre degeneration was associated with excessive delignification, which made the fibre fragile and reduced its physical qualities

When the lignin was decrease, the tensile strength starts to increase. Since hemicellulose and other interface contaminants are removed, treated fibres have rough surface morphologies. As a consequence of the alkali treatment, significant modifications in the fibre surface microstructure might occur, leading to a rise in fibre water content. According to a previous research, the significant loss of cellulose leads to a reduction in fibre strength after treatment with strongly alkaline concentration [15]. The toughness of bamboo fibre might be harmed by an excessive alkali treatment and immersion duration.

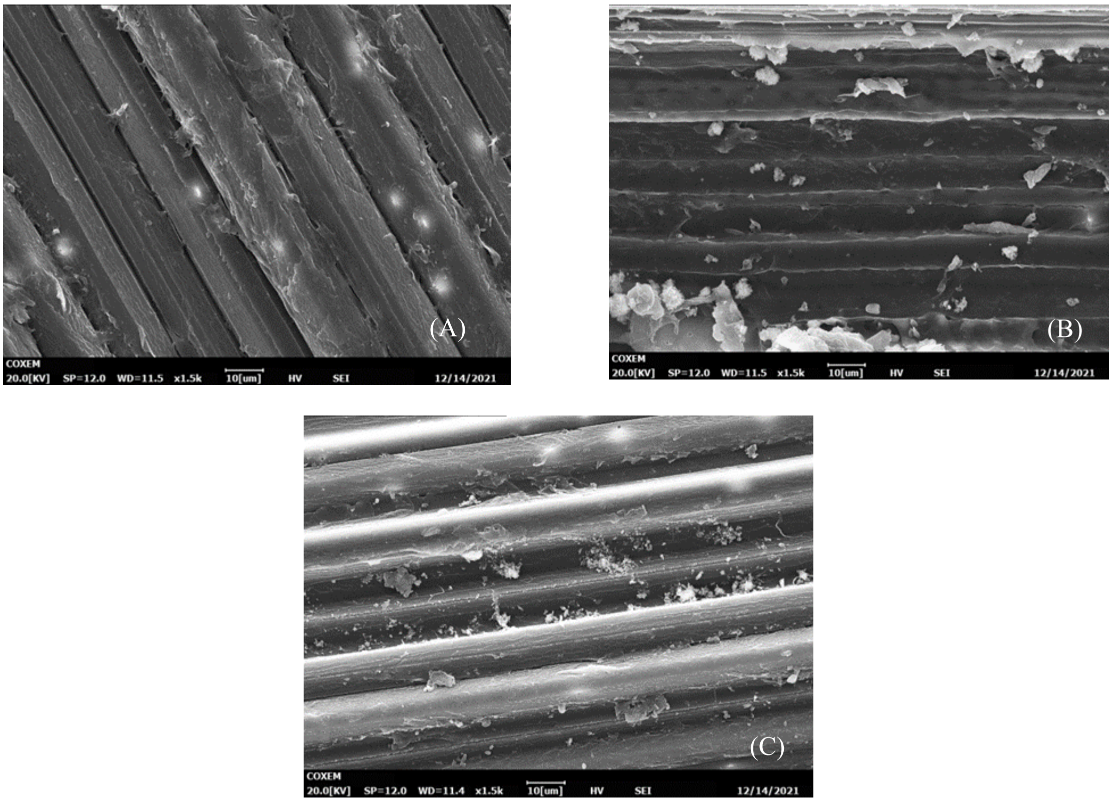

Figure 5: Morphology of bamboo fibre where (A) untreated/controlled; (B) 4 wt.% concentration of $CaCO_3$ for 3 hours; (c) 4 wt.% concentration of $CaCO_3$ for 24 hours

Since hemicellulose and other interface contaminants are removed, treated fibres have rough surface morphologies. As a consequence of the alkali treatment, significant modifications in the fibre surface microstructure might occur, leading to a rise in fibre water content. The significant loss of cellulose leads to a reduction in fibre strength after treatment with strongly alkaline concentration [15]. The toughness of bamboo fibre might be harmed by an excessive alkali treatment and immersion duration.

3.3 Fourier-transform infrared spectroscopy analysis

Figure 6 shows the functional groups were determined by FTIR investigation of the impact of alkali treatments on bamboo fibre. The hydrogen bound O-H bending the frequency of cellulose, which has been found throughout all natural fibres, was responsible for the absorption peak of 3280 cm^{-1}. This peak was also discovered to have a little shift and fluctuation in terms of strength upon on the treated fibres, and also was assigned to 3280 cm^{-1} for untreated fibres. This indicates that the alkali treatment reduced hydrogen bonding in cellulose hydroxyl groups, leading to reduced hydrophilic characteristic [16], and that the amount of excessive -OH in carboxylic groups does not involved in hydrogen bonding production [17].

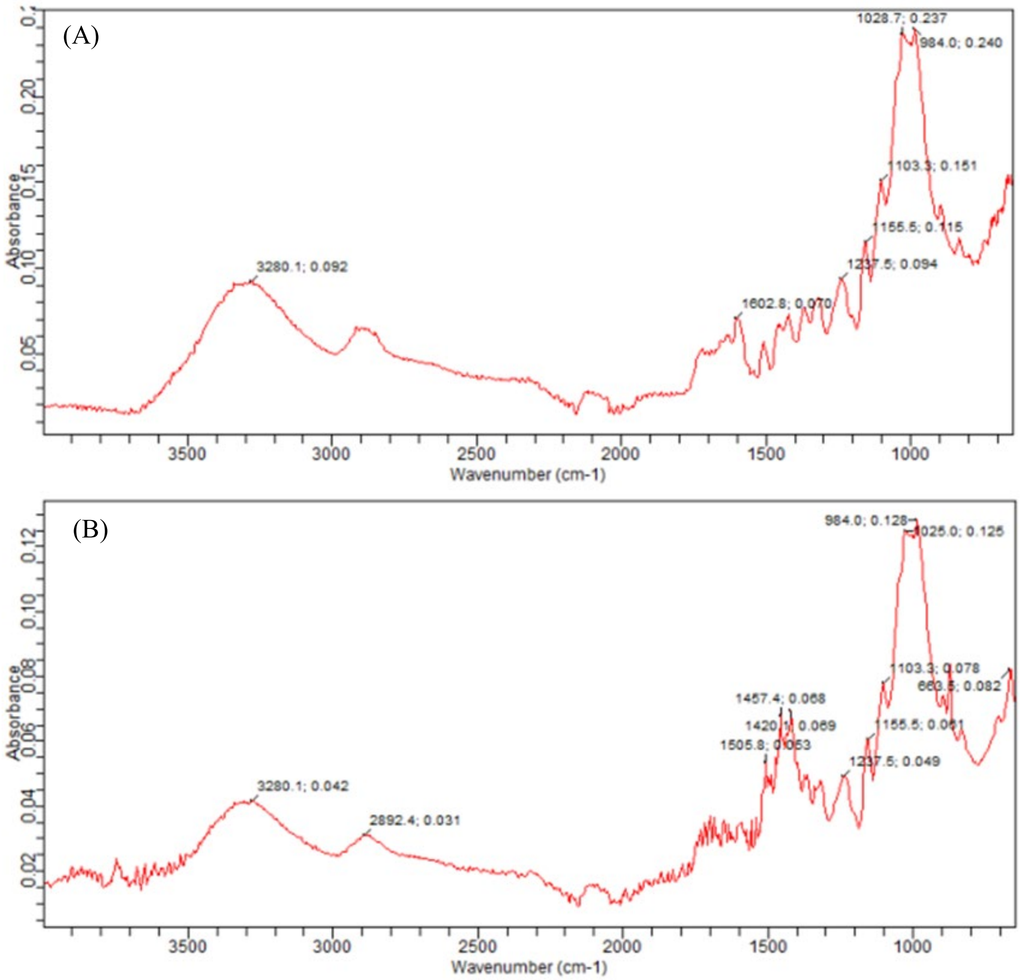

Figure 6: The graph of FTIR analysis where (A) untreated bamboo fibre; (B) treated bamboo fibre

The investigation peak at 2892 cm^{-1} was produced in a treatment of alkali, demonstrating that C-H extended the frequency due to existence of ether, according to the analysis. The hydroxyl groups inside cellulose form hydrogen bonds with one another, lowering the polysaccharide's sensitivity [18]. The alkaline treatment generates additional -OH groups as an outcome of having to break the crosslink amongst lignin and hemicelluloses.

The C-H extending frequencies of methyl and methylene groups within cellulose and hemicellulose were indicated by the peaks at 2892 cm^{-1}. In the untreated fibre, the peak at 1602 cm^{-1} had been explicitly identified. According to previous research, this peak showed C=O extending in the ester bonds of carboxylic groups in lignin [19]. It was also discovered to be linked with hemicellulose C=O stretching. Despite this, according to the dissolution of lignin and hemicellulose in alkaline medium, there was no indication of this peak in the treated fibre. The existence of C-O-C stretching vibration in the cellulose molecule is connected with the peak at 1237 cm^{-1} for untreated fibre. Nonetheless, the peak at 1602 cm^{-1} was abolished in alkali-treated fibres, but a small proportion of the peak at 1235 cm^{-1} was observed. These observations indicated that alkaline pre-treatment removed hemicelluloses and lignin.

4. Conclusion

Bamboo fibres have recently attracted a lot of attention as a potential replacement for synthetic fibres in polymeric composites in the construction industry, thanks to a growing awareness of environmentally friendly biomaterials. The most common chemical treatment conducted on bamboo fibres is alkaline treatment, also known as mercerization. As a consequence, according to this study, the qualities of limestone might be used as chemical techniques to improve the mechanical properties of bamboo fiber-reinforced composites, particularly the interfacial adhesion between the fibres and the matrix.

A total of 21 samples of bamboo fibre, both untreated and treated, were utilized in this experiment, with varied wt.% concentrations and immersion periods. The bamboo fibre containing 4 wt.% $CaCO_3$ was found to have the maximum tensile strength after a 3-hour soaking. This might be due to the hemicellulose, wax, lignin, oils, and other contaminants that surround the fibre's outer surface being reduced. It has been demonstrated that $CaCO_3$, an organic molecule, may be employed as a preservative.

For the future studies, researchers can investigate to determine the optimization of the bamboo fibre. This recommendation is to make sure the best results that has been recorded. Moreover, researchers can research at the compressive properties of bamboo fibre in future studies. The volume of the structure as well as the roughness of the fibrous structures affect the compression characteristics, with a linear flexibility relationship due to fibre length and an implicit relationship when outer irregularity rises. Lastly, researchers can conduct the assessment using Thermogravimetric Analysis (TGA) for analyses chemical, physical, and structural changes in a material as a result of temperature differences

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