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Mechanical characteristics of green reinforced with polylactic acid and Kenaf Bast and Center natural fiber

Resham Taluja[1], Pravin P Patil[2]

[1]Department of Mechanical Engineering,Graphic Era Hill University, Dehradun, Uttarakhand India, 248002
[2]Department of Mechanical Engineering,Graphic Era Deemed to be University, Dehradun, Uttarakhand India, 248002

ABSTRACT

Green composites made of Polylactic Acid (PLA) were produced using melt compounding and compression moulding. Chemical and mechanical processes were used to prepare the kenaf bast and core fibres for manufacturing. Three different rotation speeds were used in an extrusion process in which PLA and kenaf fibres were combined at fibre loadings of 2%, 4%, and 6%. (60, 70 and 80 rpm). Flexural and impact tests were used to investigate the mechanical characteristics of both kenaf bast composites (KBC) and kenaf core composites (KCC). The flexural and impact strength of KBC and KCC after treatment with 1.0M acid at 60 rpm were significantly greater than those of untreated KBC and KCC. The stiffness of the fibre added to the PLA led to a greater flexural modulus in KBC at a loading of 6% fibre. When comparing KBC with 6 percent fibre loading with 4 percent fibre loading, the latter offers greater flexural strength. However, KCC with 2% fibre loading had the greatest flexural modulus and strength. On the other hand, both KBC and KCC were strongest when loaded with 4% fibre, which is the optimal percentage for impact characteristics.

Keywords: Polylactic acid, green composites, kenaf bast fibre, and kenaf

INTRODUCTION

An rising quantity of emissions to the environment have been attributed to the combustion of the vast quantities of petroleum-based plastic items that have been abandoned over the last few years across the globe . Critical difficulties in the development of new goods have been biocomposite materials that are both environmentally friendly and not reliant on fossil fuels . Polymers derived from renewable resources, or bio-based polymers, have recently entered the market as an alternative to polymers made from petroleum [1]. Polylactic acid (PLA) is an important bio-based polymer since it is a thermoplastic polymer that may be made by either the condensation of lactic acid or the ring-opening polymerization of the cyclic lactide dimer. Among PLA's positive effects on the environment are the material's biodegradability, low manufacturing energy, reduced greenhouse gas output, and renewability of the basic material. PLA also has high mechanical characteristics, thermal plasticity, and biocompatibility, and it can be easily recycled [2].

fabricated. However, the intrinsic brittleness, stiffness and limited dimensional stability impede the use of PLA in many applications. One of the potential ways to enhance these qualities is by the introduction of natural fibre as a reinforcing agent.

As one of the quickest-growing plants, kenaf may be cultivated in almost any climate. Despite these benefits, a key issue when working with natural fibre is the incompatibility between the hydrophilic natural fibres and the hydrophobic polymer matrix, which leads to poor qualities of the composites.

The qualities of the final products depend heavily on the compatibility between the reinforcing agent and polymer [3]. Consequently, it is necessary to enhance the interaction between natural fibres and polymer in order to enhance product qualities. The compatibility between natural fibres and the polymer seems to have been improved by the treatments used on the fibres. Several studies have documented a variety of techniques for this, including graft copolymerization, silane treatments, mercerization, esterification, the use of a compatibilizer, plasma treatments, electric discharge, benzoylation, and cyano ethylation. The treatment procedures are employed to enhance the hydrophilic character of the fibre and make it compatible with the hydrophobic nature of the polymer. Adhesion between the fibre and the polymer is determined by the strength of the interfacial bond.

The acetyl group of hemicelluloses, which interferes with the cellulose structure, was removed by treating the material with dilute acid [4]. Hydrogen bonding with other molecules in the cellulose structure may be inhibited due to the presence of the acetyl group. Accordingly, deacetylation was required for the preparation of the fibre polymer bonding site, in addition to enhancing the fibre's surface area.

The rough texture of kenaf fibre is the result of an alkaline process that eliminated both natural and synthetic contaminants. In addition, acidic treatment removed the acetyl groups, revealing the binding side of the cellulose [5]. Therefore, the excellent impact characteristics of the composites were governed by the strong interfacial bonding strength obtained between the treated fibre and polymer [6]. Impact strength, however, is not directly connected to adhesion between the fibre and the polymer Rather, it is dependent on the perfection of the polymer-fiber bundles, including the alignment of the fibres and the flaws, such as vacancies. Impact strength is related to toughness, which in turn is determined by the fibre, polymer, and interfacial adhesion. Improving the interfacial adhesion between the fibre and polymer by treatment seems to have prevented fracture development during impact testing [7].

In this research, we focus on making PLA composites using kenaf fibre reinforcement and analysing their results. The characteristics of bio-composites are investigated as a function of acid content, rotation speed, and fibre loading. Optimal acid content, rotation speed, and fibre loading on the characteristics of the composites are identified by an examination of the composites' mechanical performance. When composites fail, their surface morphology is revealed by SEM.

EXPERIMENTAL

within the range of 150 C to 160 C. As a result, rotation speeds of 60, 70, and 80 rpm were tried out to identify the best processing parameter. Prism TSE System cutters were then used to pelletize the extrudate (No. 2094). After that, compression moulding took performed after the pellet had been dried in a desiccator. The rotation speed and fibre loading were held constant at 60 rpm and 2% loading for the purpose of determining the treatment concentration, whereas the rotation speed was determined using a 1.0M concentration and 2% loading for the fibres. Using a 1.0M treatment concentration and 60rpm processing speed, the optimal fibre loading of the composite was determined. For each of the attributes, a polymer composite measuring 150 mm × 150 mm x 3 mm was produced. Hung Ta Instrument Co., Ltd.'s Type HT-8122 A (No. 2260) was used to compress the gathered pellet for 8 minutes at 175 degrees Celsius. In the first five minutes, the material was heated up, and in the last three minutes, it was compressed under 800 psi (50bar). The composites were then subjected to pressure cooling while still hot. The composites were then sliced for preliminary testing. The PLA/kenaf composites employed.

Materials

Chinese company Shenzen Bright China Industrial Co., Ltd. offered 1.31 g/cm3 density poly lactic acid (PLA) in the form of ESUNTM extrusion grade. The kenaf bast used in this study was gathered from the INTROP of the Universiti Putra Malaysia (UPM) in Serdang. The Merck Group Malaysia offered a number of chemicals, including sodium hydroxide (NaOH) and hydrochloric acid (HCl).

Methods Using Both Chemicals and Machines to Treat Illness

A fibre to solution ratio of 1:25 was used to treat the kenaf bast and core fibre. The fibres were soaked in a 6 percent w/w NaOH solution and then washed several times to get rid of the surplus NaOH. After that, the fibres underwent acidic treatment at three distinct acid concentrations (0.5M, 1.0M and 1.5M) (0.5M, 1.0M and 1.5M). The method used on the bast and the core fibre was the same. Following that, the bast and core fibre were mechanically beaten to minimise the fibre size. Dried fibres were first crushed in a freezer mill, Spex Sample Prep, model 6770, before being further processed in a Fristch pulverisette.

Manufacturing Composites

Three different proportions of PLA to kenaf fibres were used in the experiment (2 percent , 4 percent and 6 percent loading). Then, the material was pre-mixed before being put in the Prism TSE System Type DSR 28 (No. 966195M02), twin-screw extrusion at a temperature

Characterization

Following ASTM D790-03 and at a crosshead speed of 5mm/min, we conducted a flexural test on KBC and KCC using an Instron 1195 Universal Testing Machine (capacity: 100kN). Samples measured 127mm in length, 12.7mm in width, and 3mm in depth. A minimum of five samples were analysed.

A Ray-Ran RR2500 Universal Pendulum Impact System was used to test the KBC and KCC's impact strength, with the standard ASTM D256 serving as a guide. The samples measured at 63.5mm x 12.7mm x 3mm in size. A minimum of five samples were examined and analysed. Using a Philips XL40 FESEM at 20 Kv acceleration voltage at room temperature, we studied the KBC and KCC fracture surfaces.

The crystalinity percentage was calculated using a differential scanning calorimeter (DSC) from a Perkin Elmer analyzer and a Perkin Elmer thermal analysis system. We weighed the samples and put them on the metal pan, and each sample weighed between 8 and 10 milligrammes. The temperature was adjusted between 20 and 200 degrees Celsius, with a heating rate of 10 degrees Celsius per minute. Using the following formula, we were able to get the crystalinity percentage:

Discussion and Results

The flexural modulus of PLA/kenaf green composites varies with the concentration of the treatment. The treated KBC had a greater flexural modulus than the untreated KBC. The treated KBC had a 16.4% rise in modulus, from KBC0.5 to KBC1.0. Flexural modulus was shown to be decreased, however, when treatment concentration was increased to 1.5 M. This was owing to the damage to the fibre structure induced by the high concentration of acid employed to remove the fibrils which likely function as a binding site on the surface of the fibre.

Although the KCC's tensile modulus increased with treatment, the flexural modulus exhibited a distinct pattern of behaviour, with treated KCC having a slightly lower value than untreated KCC across all concentrations. The fibre's ductility and the atomic bond strength are at the heart of the concept of flexural modulus. According to the findings, untreated core is more flexible than treated core because the connection between the fibres has not been disrupted, which aids in the bending of the fibres and the composites. Even though the treated KCC's flexural modulus improved by 2.3% from KCC0.5 to KCC1.0, raising the acid concentration to 1.5 M decreased the KCC's flexural modulus. This was likely due to the effect of highly reactive hydrolysis of fibre, which tends to damage the surface of the fibre [8].

we see the effect of treatment concentration on the flexural strength of PLA/kenaf green composites. The treated KBC has greater flexural strength than the untreated KBC. Because of the fibre surface treatment, the flexural strength rose to around 26.7% from the 0.5 M concentration, and the concentration was raised to 1.0 M, which further boosted the strength. The flexural strength of the KBC was diminished when the acid content was increased. The flexural strength decreased by 18.9% after the 1.5 M treatment, which was likely due to the therapy.

The treated fibre exhibited a higher KCC flexural strength than the untreated fibre. Flexural strength in the KCC also increased when reinforced with 1.0M treated fibre compared to 0.5 M and 1.5 M concentrations, as was the case with the KBC. The flexural strength of KCC1.0 increased by 43.4% when compared to KCC0.5; however, the strength attributes of KCC1.5 decreased by around 17.0% when compared to the strength of KCC1.0.

flexural characteristics of composites reinforced with treated bast and core fibre are superior than those of composites reinforced with untreated bast and core fibre, with the exception of the modulus of untreated core fibre. These findings suggest that the flexural characteristics of PLA/kenaf green composites are enhanced by an alkaline treatment followed by a 1.0M acid concentration. Bonding sites may be increased in number when acid concentration increases, as explained. Flexural modulus and strength are two measures of mechanical performance that can be shown to have increased as the number of bonding sites, and hence the number of adhesions, between the fibre and polymer increased. In contrast, raising the acid concentration up to 1.5M causes the decline in flexural characteristics for both KBC and KCC. According , fibre surface degradation occurs because a high concentration of acid leads to a quicker kinetic response that is difficult to manage. Lack of reaction control results in cellulose deterioration due to the delamination effect of the strong acid. In addition, the amorphous domains are eliminated more efficiently and the crystalline size is reduced at greater acid concentrations. This is because the hydrolysis of the fibre is stronger at higher concentrations.

he treated KBC and KCC exhibited somewhat higher values for impact characteristics than the untreated KBC and KCC. A parallel trend between KBC and KCC, demonstrating that both compounds showed a 100 percent and 93 percent improvement in impact characteristics when raised from a 0.5M treatment concentration to a 1.0M treatment concentration, respectively. However, a rise in concentration to 1.5M treatment led to a decline in the

Fibers

Impact strength was observed to be reduced by 59% for KBC and 58% for KCC at a treatment concentration of 1.5M. mobility, which has a knock-on impact on the crystallinity level [9]. The amount of energy necessary for a crack to spread is known as the notch-Izod impact strength. Notched impact characteristics, among others, are improved in 1.0M treated bast and core fibre. Flexural characteristics also show a similar pattern to this outcome. The impact characteristics of composites are determined by the interfacial adhesion of the fibre and polymer, as well as the aspect ratios, distribution, and orientation of the fibres. Thus, given the microscopic nature of the fibres, impact strength may be directly correlated with fibre-polymer adhesion. Fibers are able to distribute stress throughout the composites with efficiency if the materials adhere well. The impact strength of the composites was improved because to the reinforcement fibres and their distribution.

The crystallinity percent of KBC and KCC before and after treatment at several concentrations. In unprocessed KBC, the crystallinity percentage of the composites is 30.29 percent. However concentrated the treatment, the incorporation of treated fibre results in a higher proportion of crystalinity. When the treatment concentration was raised, the percentage of crystallinity rose accordingly. The percentage of crystallinity of bast fibre treated with 0.5M and 1.0M is much higher than that of untreated bast fibre (31% and 63%, respectively). However, the proportion of cyrstalinity has decreased marginally when the concentration is raised to 1.5M [10].

The proportion of crystalinity in treated core composites is greater than in untreated core composites, a finding that holds true for KCC composites as well. Raw KCC has a crystallinity percentage of 34.38%. The percentage of crystallinity was improved by 8% and 38%, respectively, after including 0.5M and 1.0M treated core. Contrarily, decreasing crystalinity percentages when concentration is increased may indicate insufficient contact between the fibre and polymer.

The findings were consistent with the mechanical characteristics of the composites, which improved with a higher proportion of crystalinity. Matrix chain reduction is indicative of improved compatibility between fibres and matrices after fibre treatments.

Mechanical Properties of PLA/Kenaf Green Composites as a Function of Rotational Speed displays the flexural modulus of the PLA/kenaf green composites for a range of rotational speeds. Varying flexural characteristics were achieved by treating the KBC and KCC at different rotation rates. The KBC's flexural modulus grew by 7% between the KBC60 and KBC70, but decreased by 8.5% between the KBC80 and KBC100. As processing speed rose, the KCC flexural modulus decreased. We calculated that the modulus decreases by 3.3% for KCC70 and by 16.9% for KCC80 compared to KCC60.

a similar pattern between the flexural strength of KBC and KCC processed at various speeds, indicating that 60 rpm was the optimal speed for processing composites for both materials. When the speed was raised, the KBC and KCC became weaker. KBC70 and KBC80 strength were found to decrease by 4.6% and 26.3%, respectively, while KCC70 and KCC80 strength were found to decrease by 3.9% and 20%, respectively.

Generally speaking, processing at a greater speed will result in improved strength characteristics. This is because the polylactic acid has a high viscosity, allowing it to go through the faster processing speed and compound readily with the fibre. An increase in shear rate and temperature increases the viscosity of PLA, facilitating its flow. This behaviour is due to the high viscosity of the polymer and the high energy of the molecules inside it, both of which break the molecular chain during the extrusion process. Moreover, as pointed out, increasing the screw speed results in an increase in shear stress, which in turn facilitates a more even distribution of the strengthening agent throughout the polymer.

In relation to the aforementioned statement, increased shear heating and heat conduction inside the extruder aid in dispersing the filler, leading to greater mechanical characteristics and a higher polymer viscosity. Increasing the screw speed reduces the flexural modulus and flexural strength of the composites. Higher screw speeds raise the temperature and heat generated by the barrel, which in turn raises the viscosity of the polymer. Keep in mind that PLA tends to thermally deteriorate at high temperatures. The process temperature and the residence time in the extruder might lead to thermal degradation of PLA, as pointed out back up the idea that processing PLA at high temperatures may significantly reduce molecular weight, which in turn reduces the strength of the composites. In this case, processing at a higher screw speed (for example, 80rpm) results in increased shear heating and convection. This will raise the temperature within the barrel, which will hasten the decomposition of PLA.

Pressure and fibre self-heating during processing with twin-screw extrusion are other potential factors that might degrade flexural characteristics . The impact of screw speed on the mechanical characteristics of wood flour and polypropylene is investigated. Fibre failure was seen when screw speed was increased, leading the researchers to infer that adding energy to the composite during manufacturing reduces its mechanical qualities.

The impact characteristics of PLA/kenaf fibre extruded at various rotation speeds are shown KBC60 and KBC80 both have an impact strength of 4.4 J/m, however KBC70 is much weaker, with an impact strength that is almost 27% lower than that of KBC60. When 60 rpm was used in the extruder, KCC's impact characteristics increased to 5.8 J/m. When the rotation speed was increased, the impact strength decreased; KCC70 had 3.4 J/m of strength, while KCC80 had 3.8 J/m.

Composites with visible fibre pull out are hypothesised to have lower impact strength than those without, since fibre pull out may often dissipate more energy than fibre fracture. Since the fibre in kenaf/PLA green composites has been treated to enhance its bonding capabilities with the polymer, it is anticipated that more energy will be lost through stress transfer from the matrix to the fibre, offsetting the composite's energy-absorbing potential. Potentially weak energy dissipation at the interface may account for the poor impact toughness. Fibers were woven into the polymerand some of them were jarred loose by the impact force imparted to the sample. Strong contact between the fibre and polymer indicates high compatibility, which is desirable in composites. The fibre network, which served as a bridge to keep the polymer together before being dragged out under the influence of an impact force.

the proportion of crystallinity of KBC and KCC at various rotation speeds. The degree of crystallinity varied with the uniformity with which the filler was distributed. The nucleating impact of the filler allowed for a greater proportion of crystallinity to develop inside the composites as the fibre was disseminated.

A crystallinity percentage of 32.02% was achieved while processing KBC at 60rpm. The proportion of KBC crystallisation doubled when the speed was increased to 70 rpm. The distribution of the filler inside the composites, in which the filler serves as a nucleating site for the crystallisation, was likewise associated to the generation of crystalinity. This is because 70rpm has successfully disseminated the fibre throughout the composites and provided a suitable location for crystallisation to take place. However, the fraction of crystallinity decreases as speed climbs more. One possible explanation is that the processing heat degrades the matrix, causing a break in the polymer molecular chain and therefore preventing the formation of crystals.

Fibers

The proportion of crystallinity for KCC remains the same regardless of processing speed, however it is greater at 70 rpm. Compared to the crystalinity of 70rpm composites, the crystalinity of KCC processed at 60rpm is just 30.83 percent. As was said before, the percentage of crystalinity decreased as the speed increased; this trend is consistent with the heat breakdown of the polymer that was discussed before. When figuring up these parameters, the extruder's speed was the most important consideration for fibre dispersion. The crystalinity % and mechanical characteristics, the optimum fibre dispersion is achieved at 70rpm, wherein both the mechanical properties and the percentage of crystalinity are enhanced.

Mechanical Properties of PLA/Kenaf Green Composites as a Function of Fibre Loading

The flexural modulus of green composites made from PLA and kenaf fibre at varying fibre loadings. Flexural modulus for both KBC and KCC is greater for fibre reinforced PLA than for unreinforced PLA. The flexural modulus of KBC increased progressively with increasing fibre loading. When compared to unreinforced PLA, KBC2, KBC4, and KBC6 exhibit respective increases of 18%, 31%, and 38%.

The modulus of unreinforced PLA has been raised by kenaf core reinforcement, and the modulus of the composites has been increased through increased fibre loading. The modulus of KCC2 is higher than that of unreinforced PLA by 12%. However, the addition of KCC4 and KCC6 has enhanced the modulus by around 27% and 31% from unreinforced PLA, respectively.

The inherent structure of natural fibres is rigid. When PLA was reinforced with kenaf fibre, the PLA became more rigid owing to the action of the hard natural fibre. In addition an increase in the loading of natural fibres led to a linear improvement in the modulus. Researchers used abaca MCC in their study, came to the conclusion that the greater pliability of natural fibres makes it possible to increase the modulus of composites made from them.

Plus, kenaf fibre decreased the PLA chain mobility, leading to composites with greater rigidity and toughness.

Fibre geometry inside the composites explains the decrease in strength of the reinforced composites. Potentially present as material faults, agglomerations of kenaf fibre may generate a brittle reaction in the composites and, ultimately, premature material failure. When more kenaf fibre is added, the material's flexural strength decreases linearly. The increased fibre content drove this behaviour by promoting the clustering of kenaf fibres inside of synthetic matrixes. This happened because the chemical agglomerated during the extrusion stage of the preparation process.

The flexural strength of the composites decreases with the addition of fibre to PLA, however it increases with increasing fibre loading in KBC up to a particular loading threshold (i.e 4 percent). An increase in fibre loading allowed for a greater number of fibres to establish bonds with the polymer, leading to a higher degree of contact. This allowed for a higher fiber-to-polymer binding strength, which improved the composites' ability to disperse stress. However, the strength decreased when the loading quantity was increased, perhaps because to fibre aggregation. Putting tension on an area where fibres have clumped together might cause cracking because of the concentration of force.

KCC's strength was shown to decrease gradually when fibre loading was increased. This behaviour is associated with the shape of the fibres, which persist in aggregate form even after processing. As a result, the flexural strength of composites was diminished because of the agglomeration of fibres, which lowered the threshold at which they broke. On top of this, PLA are very sensitive to moisture, to the point that they may hydrolyze in its presence. The molecular weight of PLA decreases significantly during hydrolysis, which in turn weakens the composites. Moisture's impact on PLA's melocular weight has been investigated.

They discovered that even when dry PLA was utilised, the material could react with moisture and dramatically lose molecular weight. When fibre was added to PLA, the molecular weight dropped noticeably.

we see a SEM micrograph of the flexural surface failure of pure PLA, KBC, and KCC at 2% fibre loading. In contrast to reinforced composites, the surface of unreinforced PLA is not compacted which depict the fibre pull out and the fibre-matrix bridge. Strength in pure PLA was similarly dependent on the fiber's distribution, thus the reinforced composites aren't quite as strong as the pure material. The composites also exhibit ductile behaviour, as shown by the presence of fibre-matrix bridges.

The impact strength of green composites made from PLA and kenaf fibre at varying fibre loadings. Reinforcing PLA using kenaf bast fibre increases its impact strength. The impact strength of KBC2 is 17% higher than the value of virgin PLA. Impact strength in KBC has increased by 61% when bast fibre loading is raised to 4% compared to impact strength in PLA. But the KBC6 seems to reduce the composites' impact strength.

Adding more fibres resulted in a larger percentage of the fibre's surface making contact with the matrix, which improved the material's impact strength. Therefore, greater surface area allows for more efficient transmission of applied stress. Stress transport across the fibre-matrix interface may be improved if there are a greater number of wet fibres in the composites. Nevertheless, composites with a 4 percent bast fibre loading are able to compensate for the reduction in impact strength produced by the presence of fibre, resulting in composites with balanced stiffness and toughness. Agglomeration of fibre after reinforcing with a greater fibre loading may lead to a drop in impact strength. When an impact occurs, the agglomeration acts as a stress concentrator, creating micro-spaces between the fibre and polymer and triggering multiple micro-cracks. This in turn promotes crack propagation and reduces the impact strength. However, the impact strength of PLA-reinforced kenaf core fibre has been decreasing over time. However, the impact strength qualities have been enhanced by increasing the core fibre loading, with the KCC4 and KCC6 showing 50% and 30% increase over the KCC2, respectively.

Because of its layered structure, kenaf core (KCC) has lower impact strength than unreinforced PLA. Even though the fibres were very small in size, the layered structure was clear, and the polymer did not fill up the spaces between the layers. This gap served as a vacuum, so it couldn't transmit stress in any way. as a result, the composite's impact resistance is diminished. However, the impat strength improved when the fibre loading was increased. Boosting the impact strength of composites is as simple as increasing the fibre loading, since this will increase the number of fibre surfaces in contact with the matrix. Just as with KBC, the impact strength decreases with increasing fibre loading (in this case, 6 percent fibre loading). Fibre agglomeration, which acts as a stress concentrator and causes fracture propagation and reduced impact strength, is more likely to occur with higher fibre loading.

The percentage of crystallinity of KBC and KCC at various fibre loadings. In its natural state, PLA has a crystallinity of 22.51%. With fibre added, PLA's crystallinity increased independent of loading. This is because the fibre itself is now the nucleating location for the crystallisation to take place.

Fiber loading over 4% has resulted in a rise in KBC's crystallinity, whereas loading beyond 6% has resulted in a drop. In contrast, KCC's crystallinity has gone down as its fibre loading has gone up.

Fibre aggregation is to blame for the drop in crystallinity % within this range. In composites, fibre agglomeration was more likely to develop as the fibre loading rose because of the interaction between the fibres.

When fibres clump together, there are fewer sites at which crystallisation may start, lowering the crystallinity %. Crystallinity was shown to correlate positively with mechanical qualities, suggesting that more crystallinity correlates with greater mechanical strength.

CONCLUSION

NaOH treatment followed by 1.0M acid treatment resulted in improved mechanical characteristics for both KBC and KCC, suggesting that this acid concentration is optimal for fibre treatment. When compared to untreated fibre composites, KBC showed a 140 percentage point increase in flexural strength, while KCC saw a 22 percentage point increase. After just 1 millimetre of fibre treatment, the impact strength of fiber-reinforced PLA was increased by as much as 120 percent for KBC and 190 percent for KCC compared to the untreated fiber-reinforced PLA. When testing the optimal rotation speed, 60 rpm was shown to be the best for both KBC and KCC in terms of mechanical strength. However, flexural modulus was increased by 38% in KBC with a 6% fibre loading. However, compared to unreinforced PLA, the flexural modulus of KCC increased by 31% when loaded with 2% fibre.

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