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# Tensile and Flexural Properties of Kenaf Reinforced Polylactic Acid under Heat Effect

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ABSTRACT

*Biocomposite is a combination of natural reinforcement and natural matrix material consisting of kenaf reinforced with polylactic acid (PLA), where its mechanical properties will be affected when exposed to heat. This research investigates the effect of exposure of biocomposites to different temperatures on the mechanical properties of biocomposites, consisting of tensile and flexural properties. Before producing the sample, kenaf in the form of one-way yarn is conditioned with 40% RH humidity, and then the sample is produced using hot compression molding techniques by combining kenaf with PLA. Tensile and bending tests carried out in a heating chamber with the heat were studied using a Universal Testing Machine (UTM). The choice of heat temperature depends on the glass transition temperature of polylactic acid, where the study temperature ranges from 25 $^oC$ to 65 $^oC$. From the results of the study, it was found that the maximum bending strength and modulus (117 MPa, 5.8 GPa) and the maximum tensile strength and modulus (59 MPa, 3.2 GPa) were both obtained at low temperatures (25 $^oC$). While the modulus value decreases significantly at 55 $^oC$, the tensile and flexural properties both show a steady decrease with increasing temperature. Therefore, the presence of temperature has a significant effect on the tensile and flexural properties of kenaf-reinforced PLA biocomposites. When it is exposed to high temperatures, the mechanical quality deteriorates, and the risk of failure increases. Failure is caused by poor reinforcement and matrix bonding caused by the degradation of natural fiber properties of kenaf and the level of PLA plastic deformation.*

*Keywords: Biocomposite; kenaf; polylactic acid; tensile properties; flexural properties*

## INTRODUCTION

Biocomposite is an alternative material to reduce environmental pollution and depleting petroleum-based polymer sources (D. Tholibon et al. 2019). The low specific weight ratio, low cost, and strong thermal and acoustic insulating properties of natural fibers make them preferable to replace synthetic fibers, all of which contribute to biocomposite's wide use. As a result, biocomposites have seen growth applications in the automotive industries and consumer goods.

In this regard, kenaf reinforced polylactic acid (PLA) is a good combination of biocomposite to replace synthetic composites such as epoxy, polyester, vinyl ester, and phenolic (F. Hassan et al. 2017). Kenaf is a reinforcement to give strength and stiffness to the structure, while PLA is a matrix to distribute the load to kenaf fiber and hold the fiber in the form of biocomposite. At present, various research for kenaf reinforced PLA has been done, including optimization of processing parameters (F.Hassan et al. 2017), and mechanical properties (A. A. Yussuf et al. 2010; J. Wootthikanokkhan et al. 2013; Z. Sun et al. 2017; S. Ochi. 2008) surface treatment (M. S. Huda et al. 2008) and thermal effect (N. A. A. Hassan et al. 2019). All the research address improvement base on the issues in the development of biocomposites.

Instead of improvement, the main drawback of biocomposite application is environmental exposure which refers to the interaction between the biocomposite material and the environment. This interaction can cause biocomposites to degrade more quickly than synthetic materials, which can lead to a loss of strength and effectiveness (N. Graupner and J. Müssig 2011; O. Faruk et al. 2012). The application of biocomposite is restricted due to this weakness. The mechanical characteristics of natural fiber are mostly influenced by temperature and humidity, among the other variables (M. S. Huda et al. 2008; O. Faruk et al. 2012; N. Ezekiel et al. 2011). Furthermore, PLA has low thermal properties known to range from 60 $^{o}$C in the glass transition temperature. Therefore, exposure of composite components to elevated temperature can cause degradation of the reinforcement and depolymerization of resin[ (Z. Azwa and B. Yousif 2017).

In this study, the mechanical properties of kenaf/PLA were investigated to analyze the effect of the heat of biocomposites during the tensile and flexural tests. First, surface treatment has been done to improve the bonding properties between fiber and matrix (M. S. Huda et al. 2008; M. K. Joshy et al. 2007; R. Zulkifli et al. 2002; R. Zulkifli et al. 2009). They were then using a hot press process to produce the biocomposite sample. Finally, the behavior of kenaf/PLA at different temperatures during the mechanical test was plotted, and the failure mechanism was monitored using the scanning electron microscope.

## METHODOLOGY

### MATERIALS

As depicted in Figure 1, Innovative Pultrusion Sdn. Bhd. supplied kenaf fiber in the shape of yarn. The fiber was soaked for 24 hours in a 5 % NaOH solution before being rinsed and dried in an oven which is the purpose of soaking before rinsing and drying in an oven is to remove impurities and enhance the fiber's properties. This process is known as alkali treatment or mercerization and is a common method used to improve the mechanical and physical properties of natural fibers. The fiber was manually woven into a 20 mm x 20 mm unidirectional mat to match a hot press mold. The matrix was composed of Nature Works-supplied PLA and granulated Ingeo biopolymer 2003D. For the manufacturing of the composite, PLA granules were transformed into sheets using a hot press machine. 50 grams of PLA were used to create a sheet with a thickness of 1 millimeter, as shown in Figure 2.

FIGURE 1. Kenaf yarn fiber

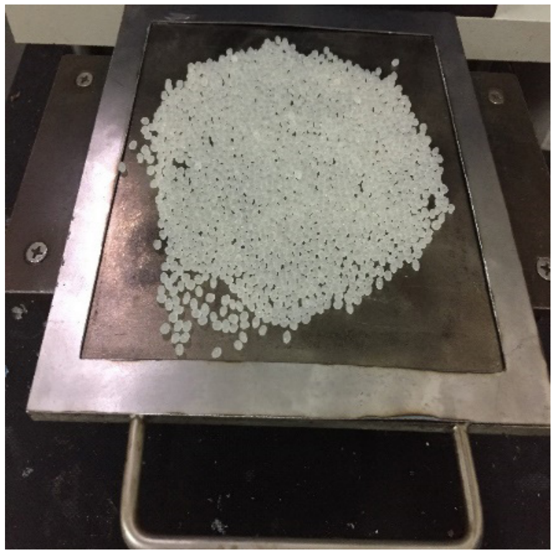

FIGURE 2. PLA bio-resin

### COMPOSITE FABRICATION

To prepare the unidirectional kenaf fiber for use in the production of the composite panel, it was first conditioned for twenty-four hours in a humidity room that had a relative humidity of 40 %. Figure 3 depicts the process of fabricating a kenaf/PLA composite using the compression method. The composite is constructed with two layers of laminated construction and contains thirty percent by weight of kenaf fiber. The compression process lasted for three minutes and was carried out at a temperature of 160 $^{o}$C with an optimization parameter pressure of 3 MPa (M. S. Meor Sha and R. Zulkifli 2022).

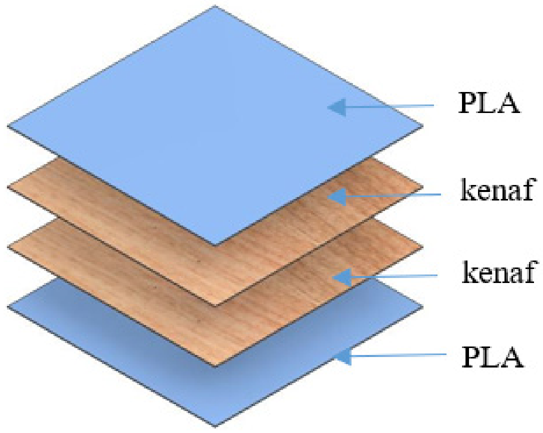


FIGURE 3. Arrangement of kenaf/PLA biocomposites of lamination

## TENSILE

The Instron Universal Testing Machine was applied to carry out the tensile test in accordance with ASTM D3039. The dimensions of the Kenaf/PLA biocomposite sample were as follows: the width measured 25 mm, the total length measured 175 mm, and the tab length measured 25 mm. A load cell capable of 10 kN capacity was used to maintain a constant speed of loading at 2 mm/min. The experiment was carried out within the heating chamber, which is seen in Figure 4, over a range of temperatures, including 25, 35, 45, 55, and 65 °C. These values were evaluated from the differential scanning calorimeter (DSC) results that tested to the PLA used. Figure 4 showed the DSC result when the sample of PLA was melted and then cooled at 0.1 $^{o}$C/min (M. S. Meor Sha and R. Zulkifli 2019). As seen in the figure, glass transition, Tg occurred around 65 $^{o}$C, and melting occurred with endothermic peaks starting at 153 $^{o}$C. During these peaks and forward, the PLA is in the melting phase. Therefore, the selected temperature was used with the variation from the DSC and previous study. All findings were calculated as the mean of the five replicates.

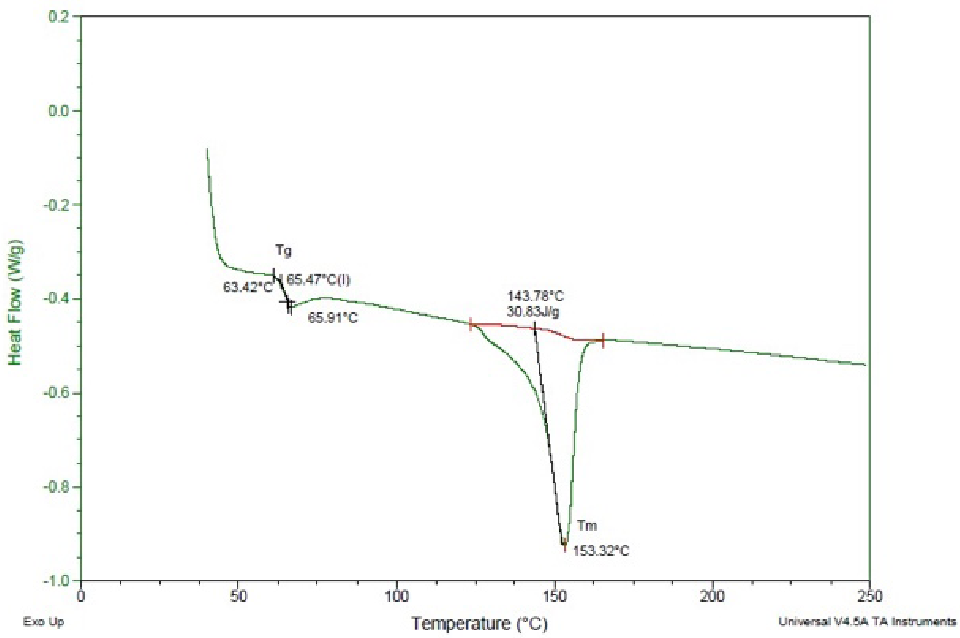


FIGURE 4. DSC results of PLA [15].

### FLEXURAL

A flexural or three-point bending test was conducted in accordance with the ASTM D-790 standard using an Instron universal testing machine. Average specimen measurements were 12 mm in width, 2.5 mm in thickness, and 45 mm in support span. As displayed in Figure 5, the test was conducted within the heat chamber at temperatures of 25, 35, 45, 55 and 65 °C, with a cross head speed of 2 mm/min. All data were expressed as the mean of five replicate samples.


FIGURE 5. Flexural test at 35°C inside the heating chamber

### MICROSTRUCTURAL ANALYSIS

The cross section of the failure sample from the tensile test was viewed using a Hitachi TM-1000 tabletop SEM scanning electron microscope. The image data were evaluated to determine the defect and interaction of kenaf fibers in the PLA matrix.

## RESULT AND DISCUSSION

### TENSILE AND FLEXURAL

Figure 6 and 7 demonstrate the tensile modulus and tensile strength of kenaf/PLA. Different heating chamber temperatures were examined to determine their effects on the tensile characteristics of kenaf/PLA. According to the graph, the linear result for tensile strength and modulus at 25 °C and 35 °C started to be decreased at 45 °C, with the extreme decrease occurring at 65 °C. It was shown that usage of kenaf/PLA beginning at 45 °C has a reduction of tensile properties. This is due to the thermal degradation of the composite matrix and/or the fibers at higher temperatures. The thermal degradation of the kenaf or PLA can lead to changes in the microstructure of the composite, such as the formation of cracks or voids as can see in microstructural analysis, which can reduce the strength and stiffness of the material. This result also agreed with the report of tensile strength for natural fiber reinforced polyester that shows a decrease of properties at elevated temperatures (Z. Azwa and B. Yousif 2017).

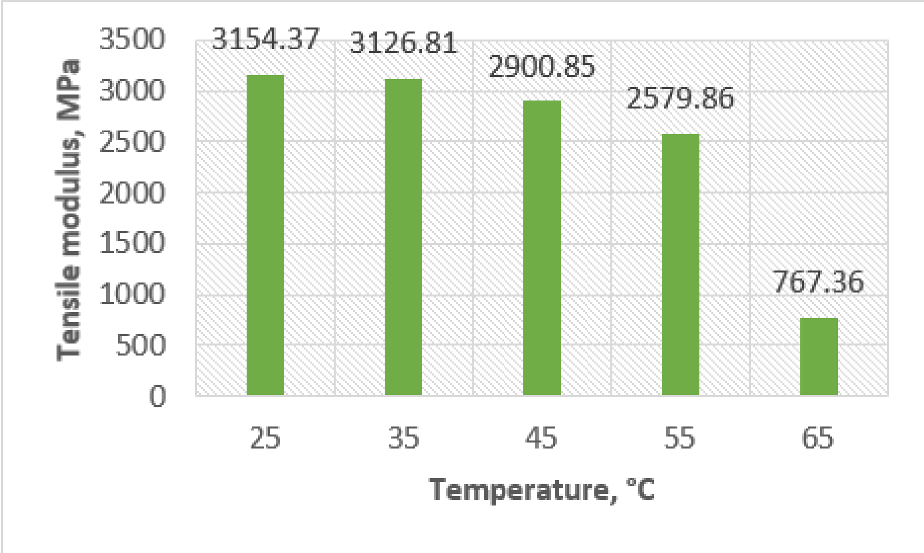


FIGURE 6. Tensile modulus of a PLA biocomposite reinforced with kenaf

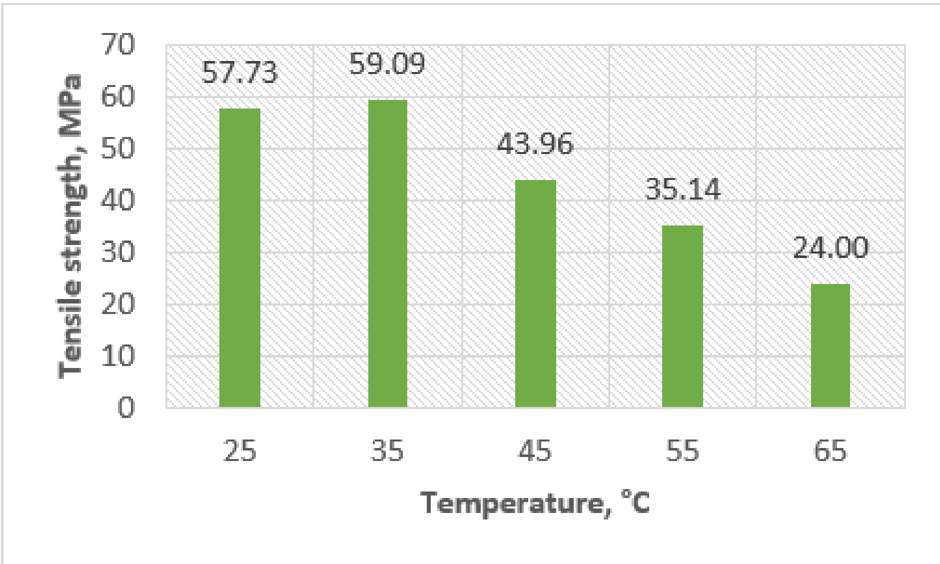


FIGURE 7. Tensile strength of kenaf reinforced PLA biocomposite

Figure 8 and 9 show the flexural strength and modulus result for kenaf/PLA. The exact temperature and procedure were used with a tensile test. However, the test for 65 °C cannot acquire the result due to the deformation of PLA into the glass transition phase. As a result, the value of flexural strength and modulus decreased as temperature increased. Even though flexural modulus displays a nonlinear drop and a slightly higher value at 35 °C, the value is consistent with the research summary of flexural characteristics (F. Hassan et al. 2017). The summary of the study on kenaf reinforced with synthetic polymer also shows that the characteristics decline with increasing temperature during the flexural test and that the flexural strength is good at ambient temperature (B. M. Yassin et al. 2016)

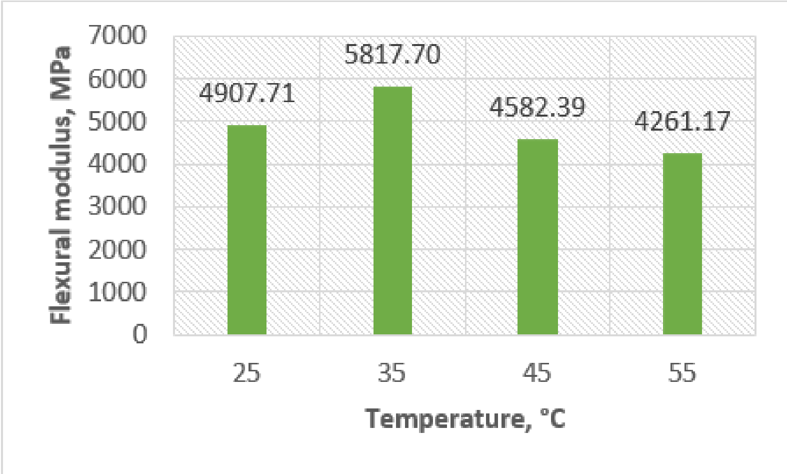


FIGURE 8. Flexural modulus of kenaf reinforced PLA biocomposite

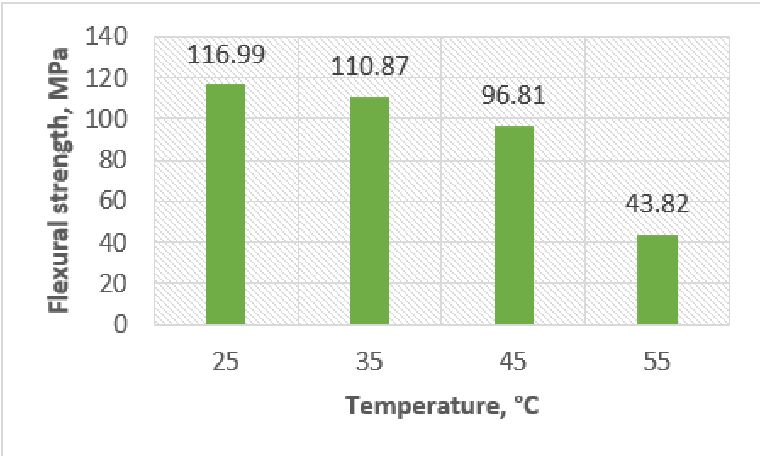


FIGURE 9. Flexural strength of kenaf reinforced PLA biocomposite

Tensile and flexural tests revealed a strong pattern of declining performance when exposed to increased temperatures. The responsibility is shared by both composite components: kenaf as a reinforcement and PLA as a matrix. Kenaf is a cellulose fiber that can be manufactured and applied at lower temperatures (M. Zampaloni et al. 2007). When the biocomposite is exposed to high temperatures and the reinforcement itself is unable to withstand the load from both tension and flexure, fiber breakdown or volatile emission occurs (N. Ezekiel et al. 2011). In comparison to plain PLA, the reinforcement of synthetic fibers such as fiberglass reinforced PLA will improve the thermal stability of the composite construction (M. S. Huda et al. 2006).

PLA, on the other hand, is a biopolymer that changes its behavior when subjected to heat. PLA is brittle at temperatures below the glass transition (Tg) and creates a rubbery surface at temperatures above the Tg. As a result of actions of this, as the temperature of the solid PLA matrix rises, a fragile adhesive composed of kenaf fiber forms. Although the PLA does not go beyond the Tg, the tensile and flexural at 45 $^{o}$C are somewhat lower the cause of energy of biopolymer when subjected to high temperature. This results in glass transition, but there is no phase change that takes place.

## SCANNING ELECTRON MICROSCOPE

The cross section of the sample that broke during the tensile test is shown in Figure 10. Because the sample does not break during failure owing to severe strain elongation after reaching the glass transition of PLA, the image includes exposures at all temperatures except 65 $^{o}$C.

After failure, the brittleness structure is clearly visible in the images of Figures 10 (a), (b), and (c), demonstrating that the solid region of PLA is unaffected by temperature. Similar research on the impact of low temperature processing on kenaf/PLA morphology reveals the presence of homogenous and stiff structures (N. A. A. Hassan et al. 2019). Meanwhile, Figure 10(d) pictured the ductile structure because of PLA beginning to form a rubbery phase and a lower density area.

In addition, morphological images of short kenaf demonstrate the abrupt break because of the loss of matrix role prior to reaching the high failure threshold. From the figure 10 (a), (b), and (c), it is evident that the kenaf fibers have undergone a significant transformation, displaying a distinctly fibrous appearance. The matrix material has demonstrated an impressive ability to hold the kenaf yarn. Figure 10 (a), (b), and (c) depict the fibrous kenaf and effective kenaf yarn retention by the matrix. Deformation begins at 55°C and leads to a sudden break before the kenaf's maximum failure point. The images demonstrate that the biocomposite's mechanical properties decrease when exposed to temperatures above 55°C.

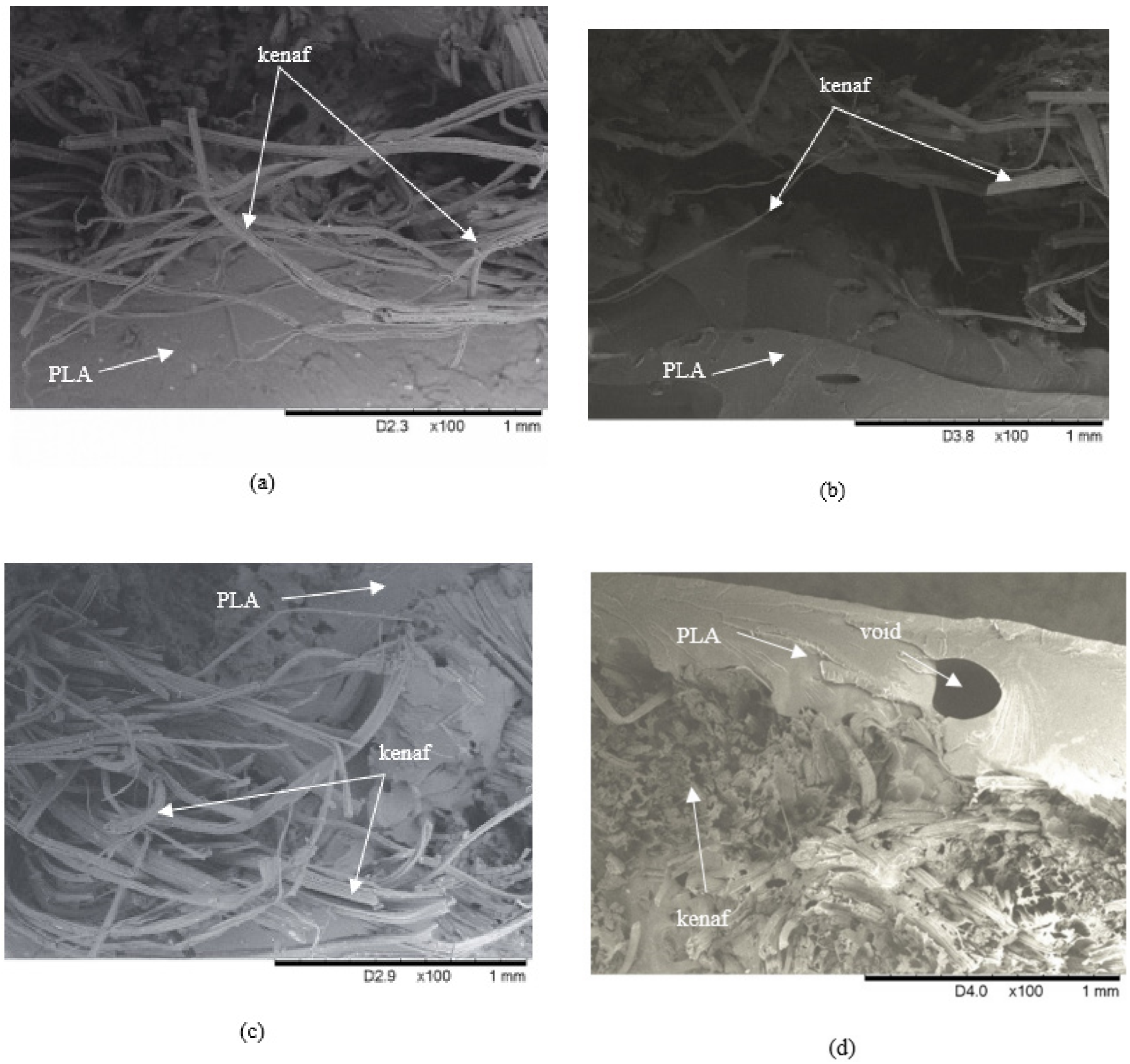


FIGURE 10. SEM images for kenaf/PLA at (a) 25°C (b) 35°C (c) 45°C (d) 55°C

## CONCLUSION

According to the findings of the study that was carried out, the presence of temperature had a substantial impact on the tensile and flexural properties of the unidirectional kenaf yarn reinforced PLA biocomposite. When exposed to high temperatures, mechanical qualities degrade, and the risk of failure increases. The failure is caused by poor reinforcing and matrix bonding. But at room temperature or lower, the kenaf/PLA retains its useful qualities. Additionally, referring to thermal analysis of PLA, the transition from a solid to a rubbery phase at Tg (65 $^{o}$C) this temperature also serves as the upper limit for kenaf/PLA. Therefore, this study's significance lies in its ability to determine the temperature behavior of kenaf/PLA and aid in the development of optimal applications for biocomposites.

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## DECLARATION OF COMPETING INTEREST

None

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