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Mechanical Properties of Damaged and Undamaged Arenga Pinnata Fibre Reinforced Epoxy Composite after Pre-Tensile Test

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ABSTRACT

Study on the properties and damage mechanisms of Arenga pinnata fibre reinforced epoxy composites are limited and they have been discovered in this study to seek and compare the performance of damaged and undamaged composite materials. They were investigated via x-ray analysis, dynamic mechanical analysis (DMA) and impact analysis. The composites were divided into two categories; undamaged and damaged specimens. The damaged specimens were being damaged into three levels of tensile strength by pulling the specimens up to 40%, 60% and 80% from the composite's ultimate tensile strength (UTS) value without causing it to fracture. The fibre content of unidirectional Arenga pinnata fibre used in fabricating the composite specimen was 20wt%. It was found that through x-ray analysis, there were no apparent defects found in both damaged and undamaged specimen. As in impact test and DMA, the results showed that the composite specimens exhibit the same pattern where undamaged specimens exhibit better impact and elastic properties compared to damaged specimens. Thus, the brittleness in polymer composite materials concludes that sudden failure can occur as no damage indications can be detected in the early stage although it has been damaged internally.

KEYWORDS: Composite Material, Arenga Pinnata Fibre, Damage Characterization.

INTRODUCTION

Recently, researches on sugar palm fibres as a potential filler in composite materials have increased. A sugar palm tree which is also known as Arenga pinnata (Figure 1) provides us many benefits to consumers as it is a versatile plant, where all parts of the tree can be utilized and turned into usable products. Arenga pinnata is widely used in many traditional applications such as in the making of gula enau, where it has to undergo a few processes before it can be commercialised [1]. It can also be used for the making of rope for ship cordages as they exhibit good resistance to sea water. They are also known for their high durability and high tensile strength [2, 3]. In this study, Arenga pinnata will be used as a reinforcement agent in polymer matrix composite with a fibre content of 20wt% and epoxy resin will be the matrix to produce strong composites. As an addition to that, the fibres will be treated with a silane solution as a coupling agent in order to improve the interfacial adhesion properties between fibres and matrix [4].

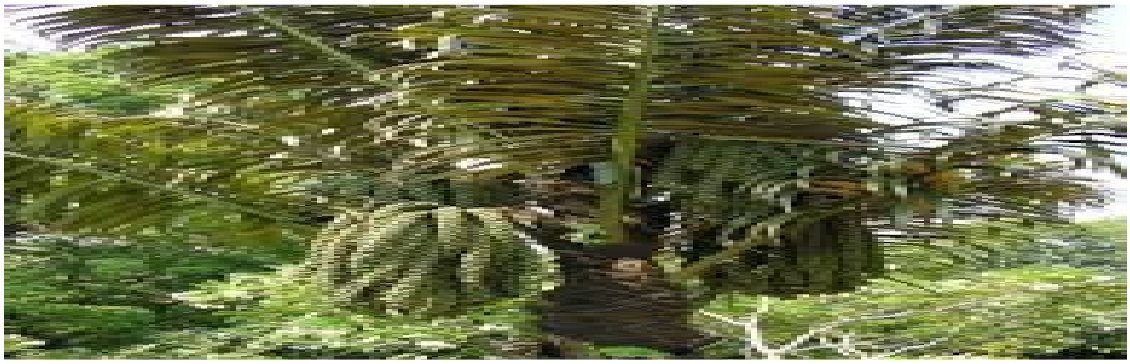

Figure 1: Sugar palm tree

The purpose of this study is to determine the tensile properties of 20wt% fibre fraction of Arenga pinnata fibre reinforced epoxy composite and its pre-tension properties to initiate damage as if they are internally damaged due to tension load for damage characteristics. They were divided into few levels of damage using tensile load at about 40%, 60% and 80% from the ultimate tensile strength (UTS) value which was then labelled as damaged specimen. The mechanical properties of the composite specimens were then compared between damaged and undamaged ones using x-ray analysis, dynamic mechanical analysis (DMA) and falling weight impact test.

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METHODOLOGY

Before the fabrication of the composite materials, the sugar palm fibres were firstly harvested in Kuala Pilah, Negeri Sembilan. The fibres were washed thoroughly to remove unwanted contaminants and impurities and then were treated by 0.5% of silane solution which is supplied by Euro Science Sdn Bhd. The epoxy used as the matrix was supplied by Miracon Sdn Bhd and finally the composite materials were fabricated using hand lay-up technique. The unidirectional 20wt% Arenga pinnata-epoxy composite specimens were then exposed to the following testing for damage characterization.

Tensile Test

In order to obtain the maximum strength of the composite, a reference destructive test was done on the undamaged specimens using the tensile test machine. The specimens were fabricated according to ASTM standard D3039 to determine its ultimate tensile strength (UTS). After the UTS value was known, the other new specimens which will be labelled as damaged specimens will be exposed to pre-tension loading in three batches. They were exposed to tensile load of about 40%, 60% and 80% from the UTS value without causing the specimen to fracture (Figure 2).

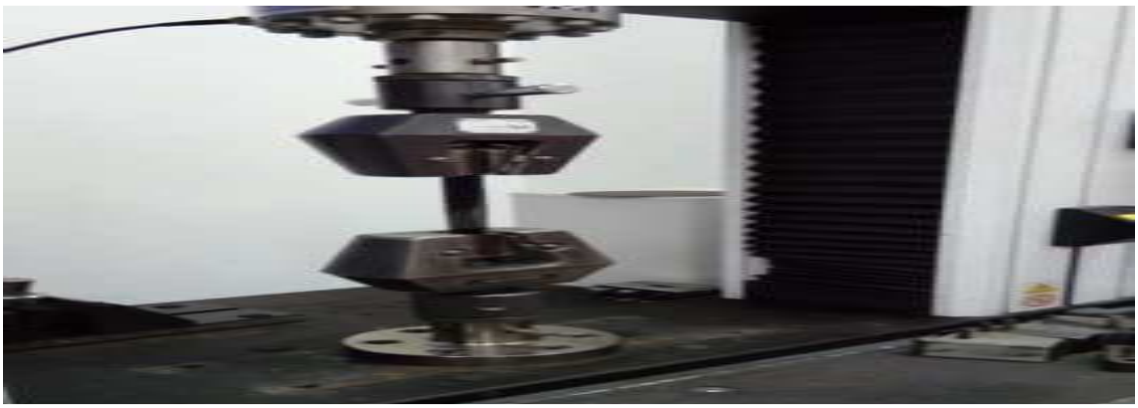


Figure 2: Tensile test was being conducted

X-Ray Analysis

X-ray is one of the alternatives that can be used to detect damages or defects in a composite that cannot be seen from the surface. The x-ray analysis was carried out in Pusat Kesihatan, Universiti Teknologi MARA, Shah Alam using the x-ray machine as shown in Figure 3 to observe possible defects that might have existed in both damaged and undamaged specimens.

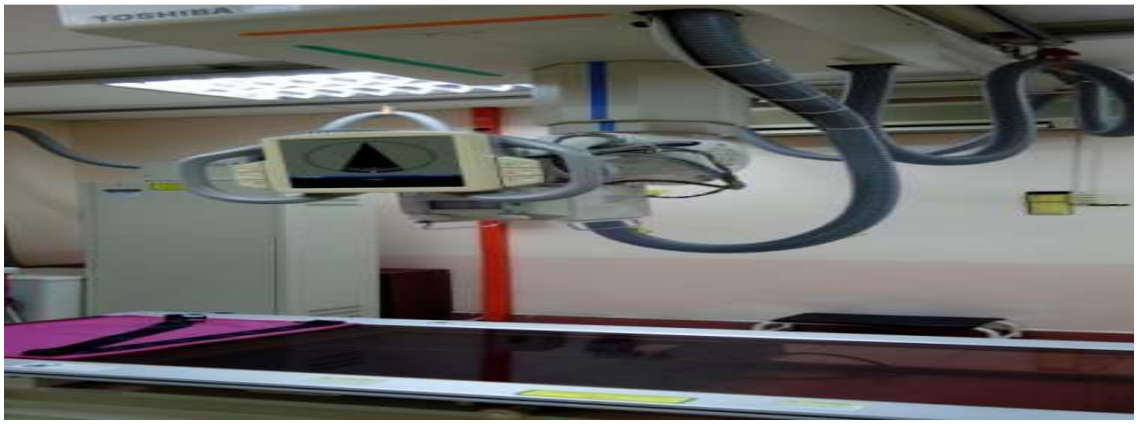


Figure 3: X-ray

Dynamic Mechanical Analysis

DMA was conducted in this study to further verify and make analysis on the viscoelastic properties of the composite materials. It is commonly used to study on the viscoelastic behaviour of polymer which is referring to

the matrix (epoxy) and its interaction with the fibres. The parameters in DMA will be emphasized on the storage modulus, loss modulus and tan delta. DMA tests can be analysed in either at a constant temperature such as at room temperature with a range of frequency set in an experiment or at a constant frequency with a range of temperature set that is going to expose on the specimen.

The storage modulus indicates the elastic properties and energy stored in composites and normally will be increased as the stiffness is increased. As for loss modulus, the peak of the graph provides us the glass transition, T_g of the composites. This is the state where the material changes its state from solid to rubbery state. Last but not least, the tan delta is the ratio of the loss modulus to the storage modulus that measures the amount of energy dissipated as heat [5]. Below is the DMA machine (Figure 4) used in this study, which has been carried out in Nano Sci-Tech Centre, Universiti Teknologi MARA, Shah Alam.

Figure 4: Dynamic mechanical analysis machine

Falling Weight Impact Test

Impact test is a destructive testing used to initiate impact damage and to study the impact resistance of a material in order to determine its toughness properties when it absorbs the energy. As in composite materials, impact load is one of the most important parameters that should be investigated in order to study its behaviour due to its complex structure. Its ability to absorb this impact energy is quite complicated to be studied. This is because during fracture of the material, composite material may experience different mode of failure; matrix crack, delamination, fibre pull-out and many other types of failure [6]. Thus, this is a concern to conduct more research in order to predict the expected mode of failure of the composite material as composite materials are very sensitive to impact load, especially when using natural fibre as a reinforcing agent in a composite [7, 8].

In a real application, impact test imitates as if the materials are exposed to any crashes that might possibly happen to the surface until fracture occurs. This will in turn reduce the strength of the material to withhold the load capacity [8, 9]. Impact analysis helps to improve the material properties as we are urged to investigate the mechanical properties of the composite materials and ensure that the bonding of the fibres and matrix are perfect. Typically, most research uses falling weight impact test or low velocity impact test to study the impact resistance. Figure 5 shows the falling weight impact test machine conducted at Strength Laboratory, Faculty of Mechanical Engineering, Universiti Teknologi MARA, Shah Alam.

Figure 5: Falling weight impact test equipment

RESULTS AND DISCUSSION

The results obtained are compared and analysed between undamaged and damaged specimens. From the destructive tensile test conducted, the mean UTS value obtained for 20wt% Arenga pinnata fibre reinforced epoxy composites was 38.24 MPa. Figure 6 shows the tensile graph of the specimens and it clearly indicates the specimens are brittle as no elastic region can be found.

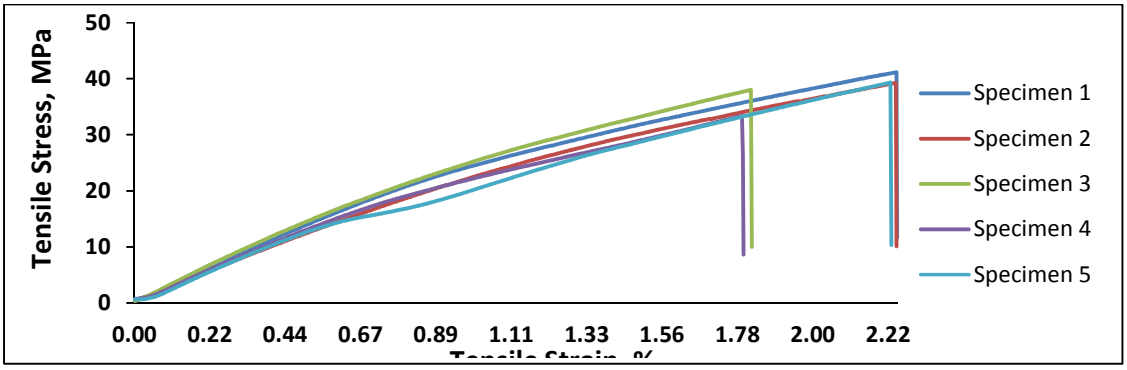
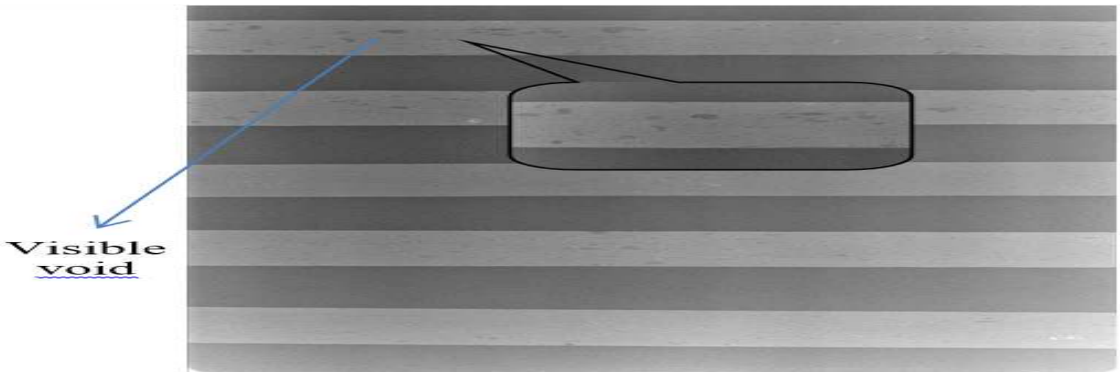


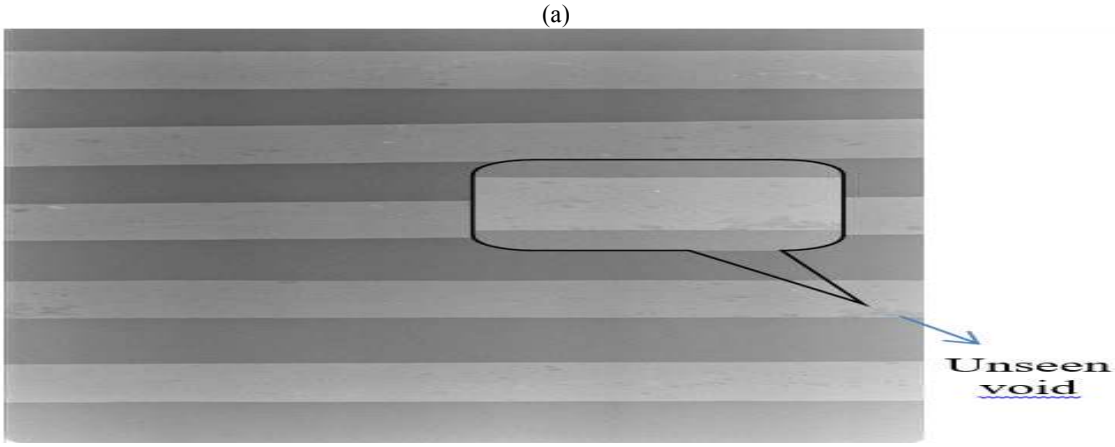
Figure 6: Tensile behaviour of Arenga pinnata epoxy composites

X-Ray Analysis

From the images captured by the x-ray machine, it was found that no apparent defects can be seen in damaged specimens that are caused by the pre-tensile load. Further analysis also found that the only defects that can be observed through the x-ray were only voids or bubbles which can or cannot be seen with naked eyes. Thus, the defects that can be observed in undamaged specimens were also voids that might have been produced during the composite fabrication or during the curing process. The images of five specimens for each of undamaged and damaged specimens can be observed in Figure 7 (light grey region).



(a)



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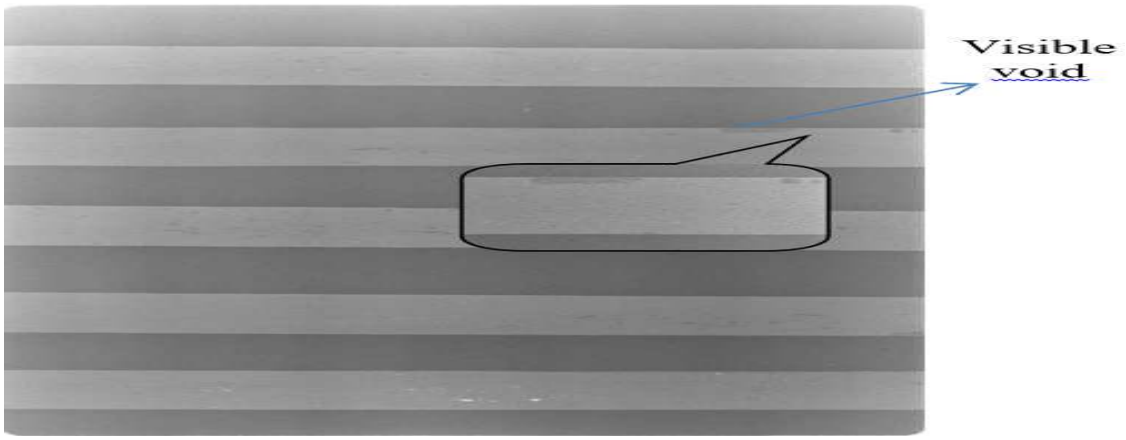

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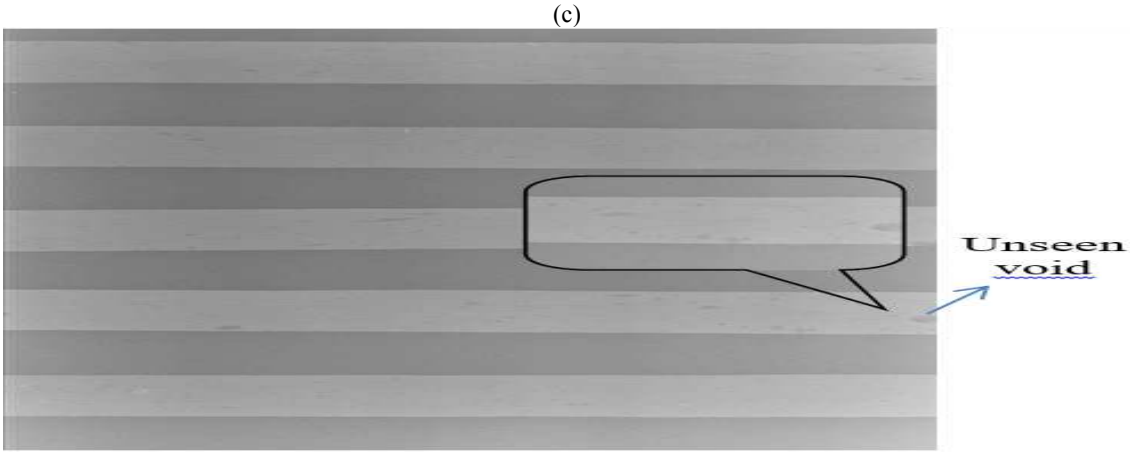

(d)

Figure 7: (a) 0% damaged specimens; (b) 40% damaged specimens; (c) 60% damaged specimens and (d) 80% damaged specimens

From all images viewed by the x-ray, a good reason for this finding shows that the material does not exhibit any visible signs of failure as it is brittle and ended up to fracture immediately. Somehow, although there is no significant defect found in the specimens that was caused by the pre-tension test, the indications of defects can be seen through our naked eyes (Figure 7a and 7c) and can be confirmed through x-ray method to capture the images of any defects that cannot be seen by our naked eyes (Figure 7b and 7d). Thus, from this analysis, it is sufficient to interpret the quality level possessed by the composite specimens.

Dynamic Mechanical Analysis (DMA)

Dynamic mechanical analysis was conducted to study on the composite's viscoelastic properties. The DMA parameters that are to be discussed are the storage modulus, loss modulus and tan delta ranging from -10°C to 100°C at a fixed frequency of 1 Hz.

From Figure 8, the graph shows that 0% damaged specimen has the highest storage modulus value compared to 40%, 60% and 80% damaged specimens and their stiffness properties decreased with increasing temperature. This clearly shows that the undamaged specimen has better stiffness compared to the damaged ones in terms of energy stored, as the damaged specimens have become less stiff and exhibit weak stress transfer from matrix to fibre due to pre-tension load exposed before.

The trend continues to decrease until 80% damaged specimens show almost similar storage modulus properties with 60% damaged specimens. This can be assumed that both exposed to pre-tension load specimen at 60% and 80% from the UTS value exhibit the same damaged properties and their stiffness and elasticity are low compared to 0% and 40% damaged specimens. It can also be observed that the storage modulus graph trends show almost similar significant fall for 0% and 40% at a temperature range of 55-72°C and 60% and 80% at a temperature range of 50-60°C.

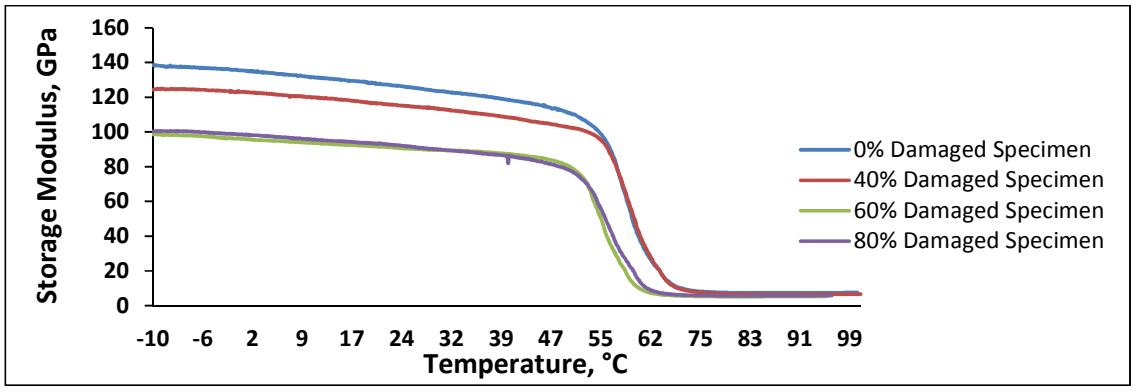

Figure 8: Graph of storage modulus, GPa versus temperature, °C

Next, Figure 9 shows the loss modulus of the specimens at different damaged level of pre-tensile load. From the graph, the highest loss modulus exhibit in 0% damaged specimen, followed by 40%, 60% and finally 80% damaged specimens respectively. This indicates a higher viscous energy dissipation ability [5] in 0% damaged specimen compared to the rest of damaged specimens as it proves that in 0% damaged specimen, the fibre-matrix interaction doing well than in 40%, 60% and 80% damaged specimen.

Not only that, the graph also shows that the glass transition (T_g) of the composite is higher at 0% and 40% damaged specimen compared to 60% and 80% damaged specimen which have been shifted to a lower T_g values. This proves that the mobility of the polymer chains lower in 0% damaged specimen, which result in higher T_g value as less tension load has been exposed to the composite compared to damaged specimens. Thus, more energy is needed to transform the solid state of the material into rubbery state [10].

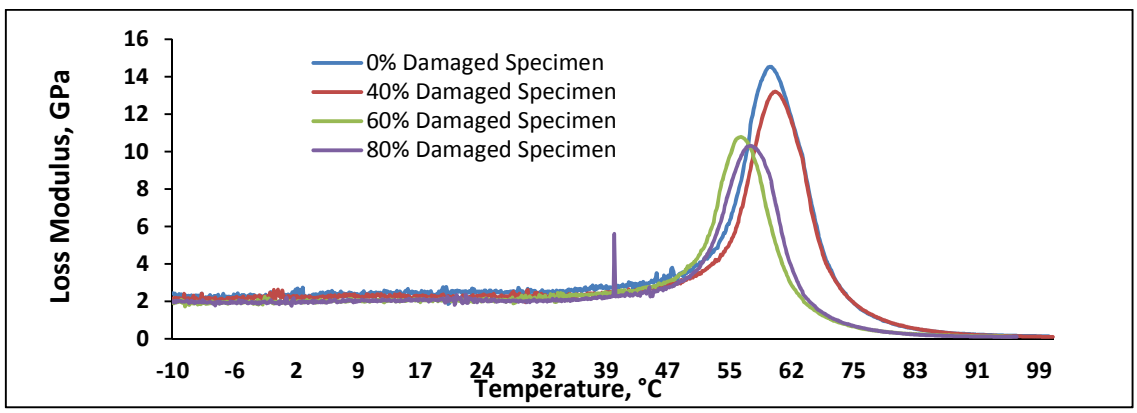

Figure 9: Graph of loss modulus, GPa versus temperature, °C

Last but not least, the tan delta for all specimens show the same ratio of about 0.48 as the fibre composition of 20wt% Arenga pinnata fibre mixed with epoxy are all constant in all specimens as shown in Figure 10. Tan delta or also known as damping factor is a ratio between loss modulus to storage modulus and is used to investigate the effectiveness of energy dissipation of the specimens which is also defined as damping [11]. Damping is one of the most critical parameters to be studied and the results show that all specimens either damaged or undamaged exhibit the same damping behaviour or good mobility of polymer chains [12], but occurred at different glass transition (T_g) value.

Overall, it can be summarized that the tan delta effects are constant for all composite specimens from -10°C to 50°C. Next, for 0% and 40% damaged specimen, the tan delta is increasing from 50°C until 67°C while for 60% and 80% damaged specimens, the tan delta is increasing from 50°C to 60°C. It can be observed the peak values of tan delta for 0% and 40% damaged specimen are 67°C while 60°C is the peak value of tan delta for 60% and 80% damaged specimen. The effect of tan delta can be clearly seen between the temperature ranges of 46°C to 90°C. Finally, it can be seen that the effect of tan delta going back to its original condition where the tan delta is constant again after a temperature of 91°C.

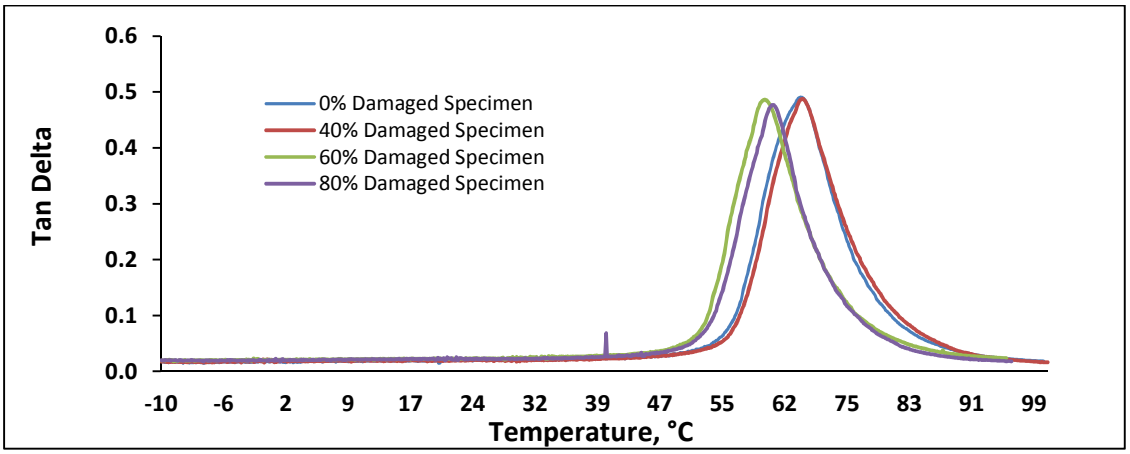

Figure 10: Graph of tan delta versus temperature, °C

Falling Weight Impact Test

Figure 11 shows the typical load and energy versus deflection graph for impact analysis. The red line belongs to load versus deflection graph and the blue line belongs to energy versus deflection graph. The total energy exposed on the specimen indicates the amount of energy that has been impacted on the specimen using 6 kg impactor at 80 cm falling impact height. Among the important parameters to be analysed in this study are the Maximum load (kN) and maximum deflection (mm). Both parameters are needed to analyse in terms of their mechanical impact properties. Figure 12 and 13 show the average values calculated for all 0%, 40%, 60% and 80% damaged specimens.

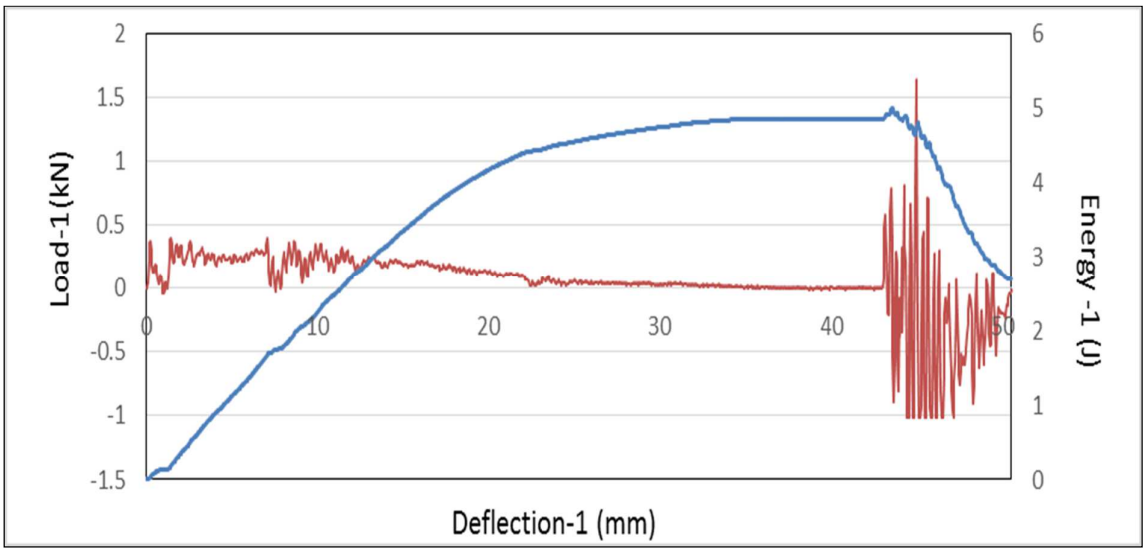

Figure 11: Impact Analysis graph for Arenga Pinnata fibre reinforced epoxy composites

From Figure 12, it can be observed that the maximum load decreases from 0% damaged specimen to 60% damaged specimen. The graph, then indicates a slight increase of maximum load in 80% damaged specimen than in that of 60% damaged specimen but it is not too significant. This pattern directly describes that both 60% and 80% damaged specimen exhibit the same impact damage properties which has been discussed earlier, where both are unsafe to be used in real applications. This trend too shows the same properties as in the storage modulus in DMA technique where 60% and 80% damaged specimen has the same stiffness properties.

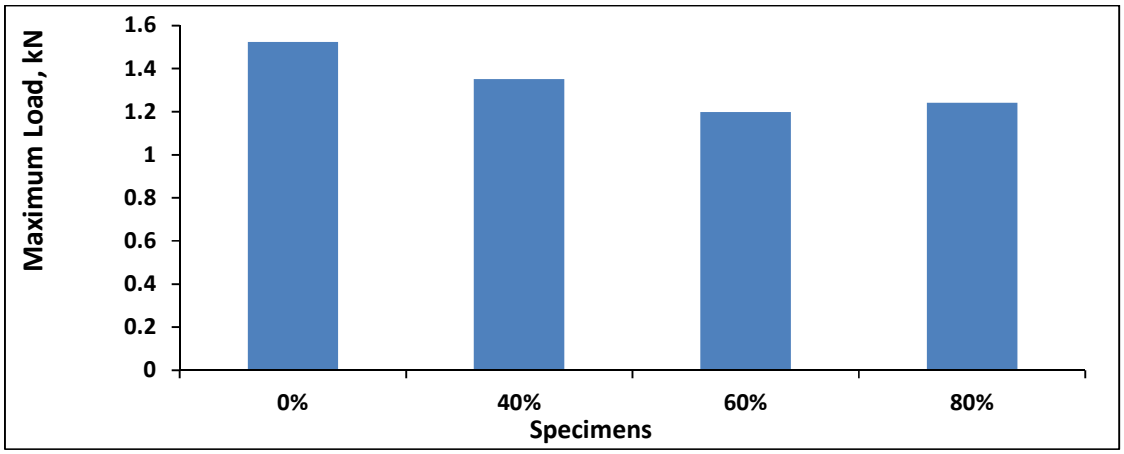

Figure 12: Graph of load, kN versus specimens

As for maximum deflection in Figure 13, all specimens show an irregular pattern where the values fall within the range of 44.8 mm to 45.3 mm. This is due to the brittle nature of the composite materials and the adhesion between fibres and matrix plays important roles to have a perfect bonding in order to have good mechanical properties of composite materials. Figure 14, 15, 16 and 17 show the state of the damaged specimens after being exposed to impact load.

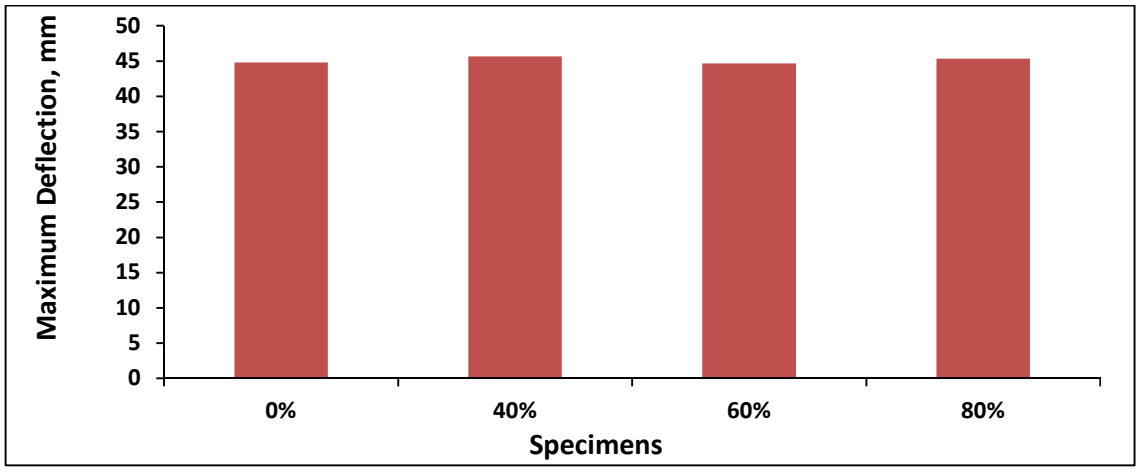

Figure 13: Graph of maximum deflection versus specimens

Figure 14: Impacted 0% damaged specimens

Figure 15: Impacted 40% damaged specimens

Figure 16: Impacted 60% damaged specimen

Figure 17: Impacted 80% damaged specimens

An obvious analysis can be made when 0% damaged specimens constantly breaks into two, while the other damaged specimens will either break into two or three. This shows that 0% damaged specimen has better strength or mechanical properties compared to the specimens, which have been damaged by pre-tension test. Figure 18 and 19 show among the mode of failures on the composite specimens after exposed to impact load.

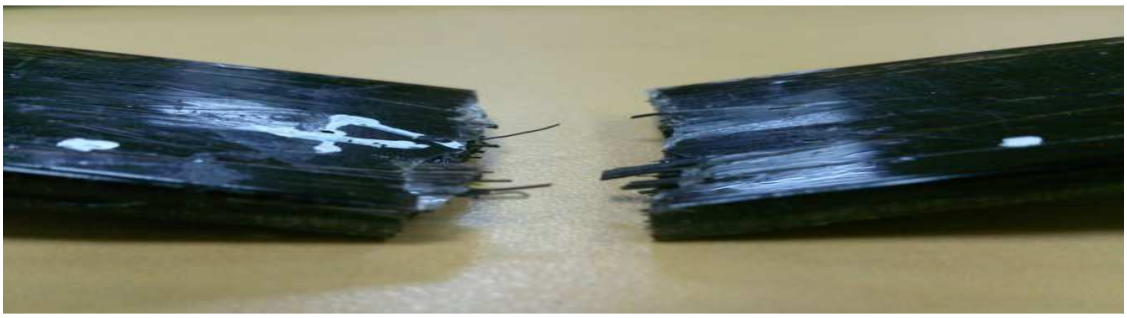

Figure 18: Fibre pull-out

Figure 19: Matrix failure

Thus, it can be concluded that the mode of failure of fibre pull-out on the composite specimen (Figure 18) exhibits brittle properties as it breaks immediately and the fibres become the main load bearing to withstand the forces exerted on it. Due to the direct impact forces, some of the fibres were pulled-out because of the weak bonding between fibres and the epoxy. The matrix failure in Figure 19 shows that the composite specimen still remains intact as the fibres are still holding the composite due to the effect of impact loading.

CONCLUSION

Overall, the objectives of this study have been achieved. The properties of 20wt% of Arenga pinnata fibre reinforced epoxy composite between damaged and undamaged specimens have been discussed. The damaged specimens are damaged physically due to pre-tensile load. However, the analysis to investigate the properties between damaged and undamaged are not so significant, but the results indicated that the damaged specimens exhibit lower mechanical properties compared to undamaged specimen as the maximum load in the impact test for damaged specimens is lower than that of the undamaged specimen. In x-ray technique too, no apparent defects can be found in all specimens.

Furthermore, DMA analysis shows the same pattern of viscoelastic properties of the composite materials for damaged and undamaged specimen. Thus, a method of analysis using x-ray, DMA and impact analysis can be used, but it is not fully described the mechanical properties of damaged and undamaged composite specimens since the composite exhibit brittle properties in nature where its failure indication is hardly to be detected in the early stage and will suddenly experience a sudden fracture. Another method of testing can be carried out for further verification of damage mechanisms between damaged and undamaged Arenga pinnata-epoxy composite specimens.

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REFERENCES

1. Bachtiar, D., S.M. Sapuan and M.M. Hamdan, 2008. The Effect of Alkaline Treatment on Tensile Properties of Sugar Palm Fibre Reinforced Epoxy Composites. Materials and Design, 29 (7): 1285-1290.
2. Ishak, M.R., S.M. Sapuan, Z. Leman, M.Z.A. Rahman, U.M.K. Anwar and J.P. Siregar, 2012. Sugar Palm (Arenga Pinnata): Its Fibres, Polymers and Composites. Carbohydrate Polymers, 91 (2): 699-710.
3. Ishak, M.R., S.M. Sapuan, Z. Leman, M.Z.A. Rahman and U.M.K. Anwar, 2012. Characterization of Sugar Palm (Arenga Pinnata) Fibers, Tensile and Thermal Properties. Journal of thermal analysis and calorimetry, 109 (2): 981-989.
4. Xie, Y., C.A.S. Hill, Z. Xiao, H. Militz and C. Mai, 2010. Silane Coupling Agents Used Natural Fiber/Polymer Composites: A Review. Composites Part A: Applied Science and Manufacturing, 41 (7): 806-819.
5. Patnaik, A. and S. Tejyan, 2012. Mechanical and Visco-Elastic Analysis of Viscose Fiber Based Needle-Punched Nonwoven Fabric Mat Reinforced Polymer Composites: Part 1. Journal of Industrial Textiles, 43 (3): 440-457.
6. Santulli, C., G. Jeronimidis, I.M. De Rosa and F. Sarasini, 2009. Mechanical and Falling Weight Impact Properties of Unidirectional Phormium Fibre/Epoxy Laminates. Express Polymer Letters, 3 (10): 650-656.

7. Santulli, C. and A.P. Caruso, 2009. A Comparative Study on Falling Weight Impact Properties of Jute/Epoxy and Hemp/Epoxy Laminates. Malaysian Polymer Journal, 4 (1): 19-29.
8. Dhakal, H.N., Z.Y. Zhang, M.O.W. Richardson and O.A.Z. Errajhi, 2007. The Low Velocity Impact Response of Non-Woven Hemp Fibre Reinforced Unsaturated Polyester Composites. Composite Structures, 81 (4): 559-567.
9. Reghunath, R., M. Lakshmanan and K.M. Mini, 2015. Low Velocity Impact Analysis on Glass Fiber Reinforced Composites with Varied Volume Fractions. IOP Conference Series: Materials Science and Engineering, 73 (1): 1-8.
10. Rwawiire, S., J. Okello and G. Habbi, 2014. Comparative Evaluation of Dynamic Mechanical Properties of Epoxy Composites Reinforced with Woven Fabrics from Sansevieria (Sansevieria Trifasciata) Fibers and Banana (Musa Sapientum) Fibers. Tekstilec, 57 (4): 315-320.
11. Etaati, A., S. A. Mehdizadeh, H. Wang and S. Pather, 2013. Vibration Damping Characteristics of Short Hemp Fiber Thermoplastic Composites. Journal of Reinforced Plastic and Composites, 33 (4): 330-341.
12. Boumbimbaa, R.M., C. Froustey, P. Viot, J.M. Olive, F. Léonardi, P. Gerard and R. Inoubli, 2014. Preparation and Mechanical Characterisation of Laminate Composites Made of Glass Fibre/Epoxy Resin Filled With Tri Bloc Copolymers. Composite Structures, 116 (1): 414-422.