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JAMEA

http://penerbit.uthm.edu.my/ojs/index.php/jamea

e-ISSN: 2716-6201

Journal of Advanced Mechanical Engineering Applications

Investigation of Woven Orientation of Natural Fiber by Finite Element Method

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DOI: https://doi.org/10.30880/jamea.2022.03.02.007
Received 25 July 2022; Accepted 03 October 2022; Available online 13 December 2022

Abstract: Natural fiber is recognized for having a lower density than synthetic fiber, as well as being cheaper, more plentiful, and most significantly, renewable. In Malaysia, the focus on waste fiber somehow produces an abundance of bio waste in the form of leaves, mainly composted or burned, thus wasting the good potential of fiber sources. The burning of the leaves will lead to environmental pollution problems. Many researchers have investigated the potential of this waste and have demanded the development of new materials with enhanced strength, stiffness, density, and cost-effectiveness. Due to the various applications of natural fibers, especially bamboo and kenaf, in several industries, they may be exposed to cyclic load based on their preferred applications. Thus, this study implemented a finite element method by using ANSYS to investigate the characteristics of the notch at crack tip opening angle for bamboo and kenaf woven fiber under quasi static loading as well as the deformation, strain, stress, and mode I stress intensity factor (SIF) criteria. This simulation focuses on the three types of woven orientations, which include 0°/90°, 30°/-60°, and 45°/-45°. The result shows that Kenaf fiber with a 0°/90° orientation showed good results in terms of strength compared to bamboo fiber, and among the three woven orientations, the 0°/90° orientation showed the highest stress intensity factor followed by 30°/-60° and 45°/-45° for both bamboo and kenaf fiber.

Keywords: Crack criterion, finite element analysis, Bamboo, Kenaf, woven orientation

1. Introduction

Natural fiber is also known for having a lower density than synthetic fiber, as well as being less expensive, more abundant, and, most importantly, renewable. Aside from that, thanks to advancements in current technology, natural fiber processing is also more cost-effective and environmentally friendly than synthetic materials. Furthermore, because it does not require any special processing, natural fiber is far safer for human health than synthetic fiber [1].

Cellulose, hemicelluloses, pectin, and lignin are the main components of natural fibers. The proportion of each of these component's changes depending on the fiber type. Growing and harvesting circumstances might also influence this variance. Cellulose is a semicrystalline carbohydrate that gives natural fibers their hydrophilic properties. In comparison to cellulose, hemicellulose is a completely amorphous polysaccharide with a reduced molecular weight [2]. Hemicelluloses, the second major component of wood, are sugar polymers as well. Unlike

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cellulose, which is formed entirely of glucose, hemicelluloses are made up of glucose as well as a few other water-soluble sugars created during photosynthesis [3]. Pectin, like cellulose and hemicellulose, is a polysaccharide that holds the fiber together. Lignin is a three-dimensional polymer composed of phenylpropanoid units. Lignin provides structural strength to plant tissue and fibers, as well as cell wall rigidity. It helps to connect the network of cellulose and hemicellulose, which gives this matrix its flexibility [4,5].

Synthetic fibers, on the other hand, release massive amounts of carbon dioxide during basic material production along with product processing, which has a negative influence on green globalization [6]. In situations where the load range is low to medium, natural fiber-reinforced composites can be a viable substitute for composites reinforced with metal or synthetic fibers.

Other than that, natural fibers have a vast range of potential applications, which makes them acceptable in many places. The use of natural fiber composites in a variety of applications has opened new opportunities for academics and industry to create a sustainable module for future natural fiber composite uses [7]. They are also quickly becoming a viable alternative to metal or ceramic-based materials in a variety of industries, including automotive, aerospace, marine, sports goods, and electronics [8]. It plays an important role in helping industry achieve its aims of sustainability and ecologically friendly goods. The automotive sector is an example of how businesses may evolve and become more environmentally friendly by making tiny efforts toward a more sustainable future from natural fiber [9].

Some of the structures of natural composites may be subjected to different types of loads. They may experience cracks if there are forces exerted on them with some factors being considered. Due to the propagation and formation of cracks under cyclic, repetitive loads as well as quasi-static loads, it may lead to fatigue failure. Research done by [10] studied an experimental and computational analysis of the fracture behavior of bamboo fiber reinforced epoxy composites. Scanning Electron Microscopy (SEM) revealed fiber breakage, matrix cracking, fiber matrix debonding, and fiber pull out to be the primary causes of composite failure. The Finite Element Analysis (FEA) software ABAQUS was used to simulate model fracture propagation in a compact tension specimen, and the results were similar to the experimental value [10]. So, in this paper, the characteristics of the notch at the crack tip opening angle of the crack criterion of woven natural fiber as well as the properties will be discussed using a numerical solution approach.

2. Materials and Methods

The main materials that were used in this research are bamboo and kenaf fiber. The parameter of this model is the different types of the orientation of the fiber for each specimen, which is 0°/90°, 30°/-60°, and 45°/-45°.

2.1 Geometry and Model

Three models, including 0°/90°, 30°/-60° and 45°/-45° specimens, were constructed using Solidwork. The materials assigned to each of the specimens in the simulation were Kenaf and Bamboo fiber. table 2.1 shows the material properties of Bamboo and Kenaf fiber that were used in this project. While Fig. 2.1 depicts the geometry of all the woven orientation specimens.

Table 2.1 - Parameters for Bamboo and Kenaf fiber [11,12]

Fiber	Density (g/cm^3)	Tensile Strength (MPa)	Young's Modulus (GPa)	Poisson's Ratio
Bamboo	0.6-1.1 (0.85)	270-862 (566)	17-89 (53)	0.108
Kenaf	1.2	295-930 (612.5)	22-60 (41)	0.42

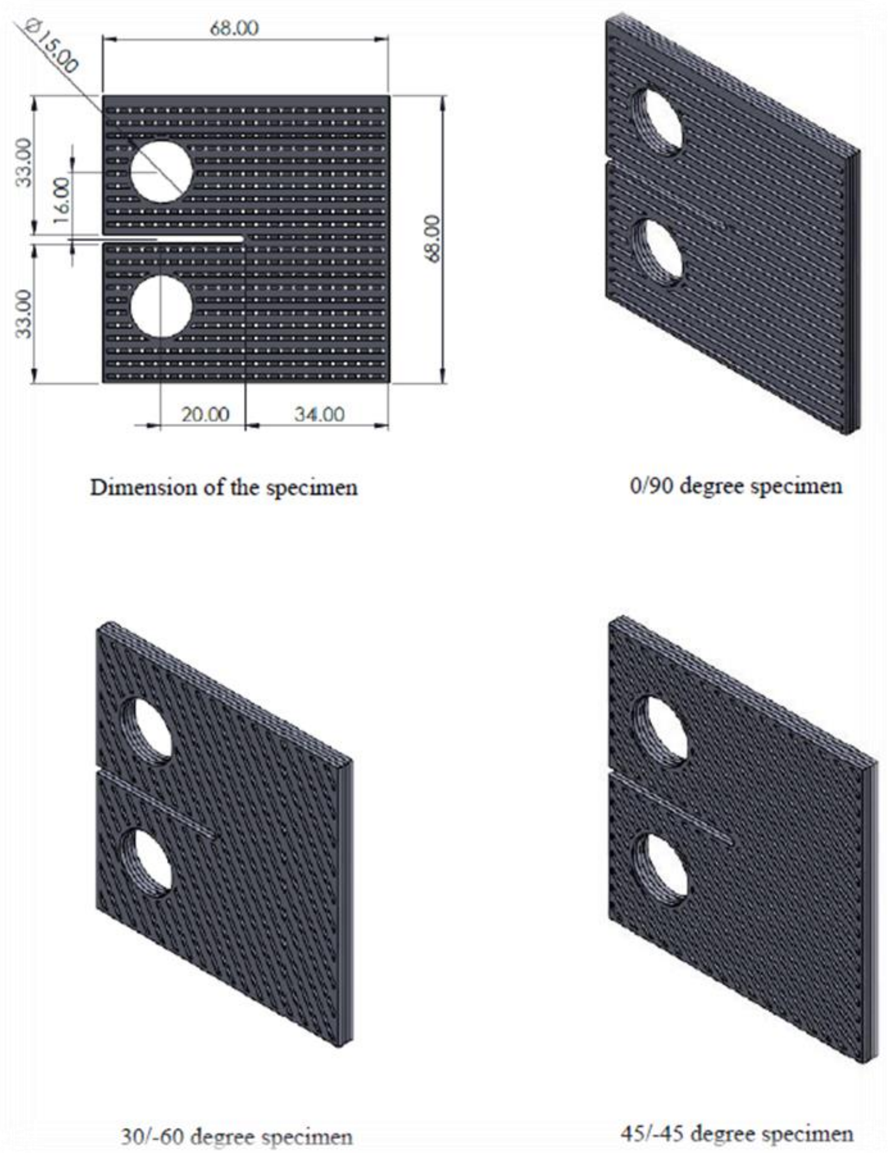


Fig. 2.1 - Geometry of the woven orientation specimens

2.2 Ansys Workbench 2022 R1 Program

The process continues once the Solidwork model for bamboo composite is developed. First and foremost, the file from the Solidwork application was imported into the Ansys program. Set up the technical data for the mechanical properties of the bamboo and kenaf woven fiber after importing the file. Another phase is to generate a mesh of the specimen. To execute the simulation, each model is configured with a boundary condition as shown in Fig. 2.2. Every model has a fixed support on the side face. An Opening Mode (Mode I) analysis is used by introducing opposing forces to the model's top and bottom surfaces. After that, the fracture criterion must be chosen. Finally, run the simulation and analyze the results. Meshing in simulation will have an impact on accuracy, convergence, and speed. The mesh influences the precision, convergence, and speed of the simulation. From the simulation, the results showed total deformation, equivalent stress, strain energy, maximum principal stress, and stress intensity factor (SIF). The mesh influences the precision, convergence, and speed of the simulation. Furthermore, the simpler and more automatic meshing methods typically require a significant amount of time to obtain simulation results.

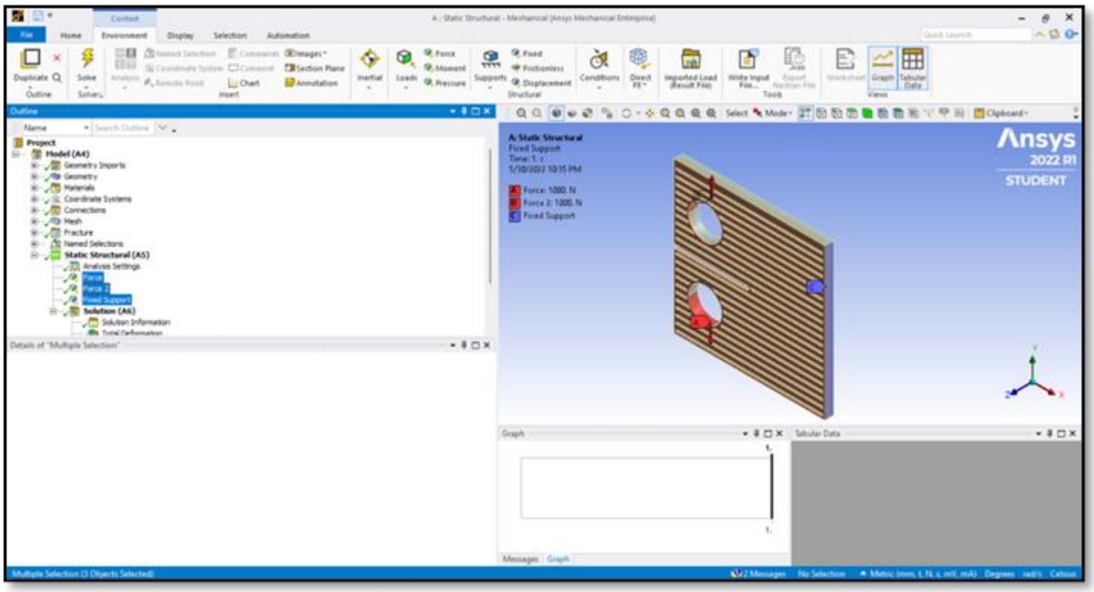
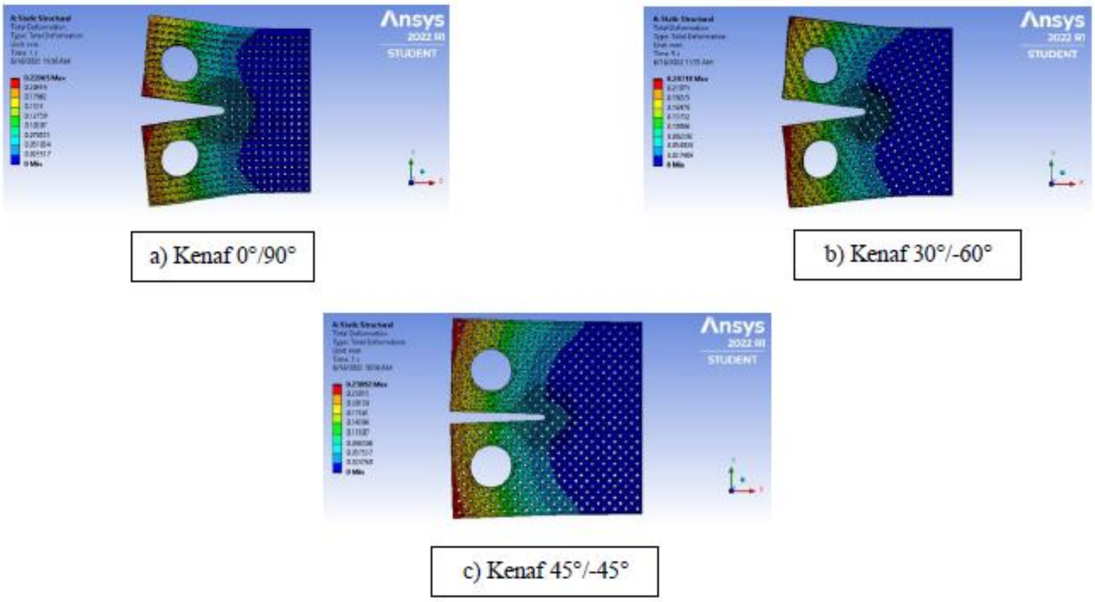


Fig. 2.2 - Boundary condition of all the specimens

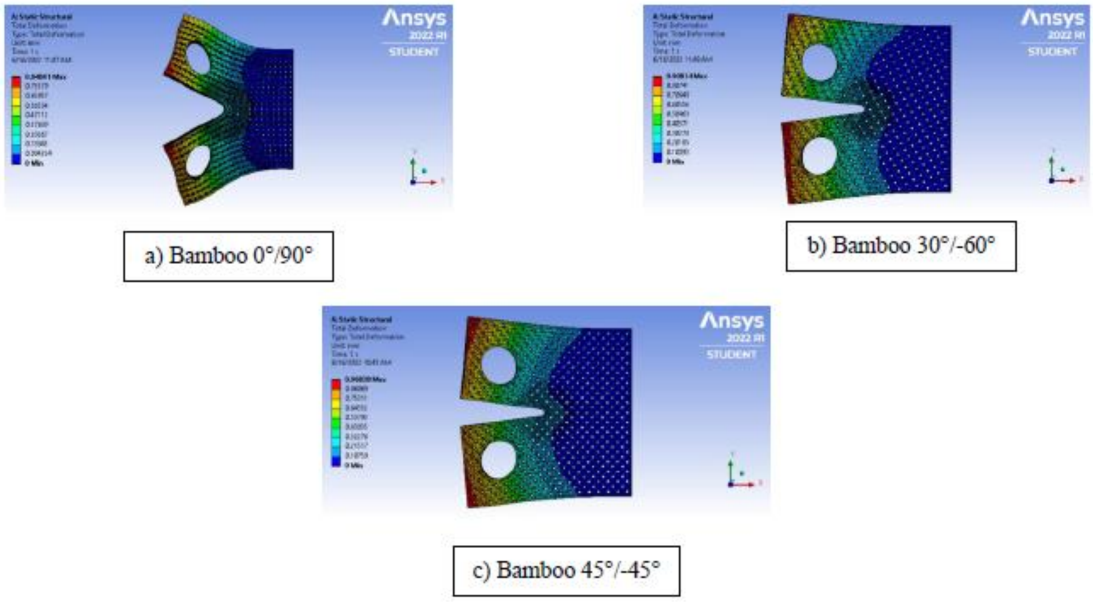
3. Results and Discussion

3.1 Total Deformation

Total deformation is a deformation option that displays all of the deformation data associated with your model in three coordinates (X, Y, and Z). Based on simulation results in Fig. 3.1, the damage occurs at the crack tip and geometry near both holes of the specimen. From there, it can be seen that the 45°/-45° woven orientation produced the smallest gap in between the two holes regarding the total deformation in the specimen for both bamboo and kenaf fiber. While 0°/90° specimens produced the biggest gap after experienced mode I loading.



(a)



(b)

Fig. 3.1 - Total deformation simulation results (a) Bamboo fiber; (b) Kenaf fiber

3.2 Equivalent Stresses

Equivalent stress is used to estimate material yielding under multiaxial loading circumstances using the results of simple uniaxial tensile tests. Based on table 3, among three types of fiber orientation, 30°/-60° holds the highest maximum equivalent stress, followed by 0°/90° and 45°/-45° for both bamboo and kenaf fiber. This demonstrates that the 30°/-60° specimen is stronger when tension is applied to it and has a high load-bearing capacity. This can be proved by the studies from [13], which investigated the effects of ply orientation (0°/45°/0° and 0°/30°/60°, named Plate 1 and Plate 2) on equivalent stress and damage of each layer of carbon fiber composite. They discovered that under the same load, Plate 1 has less deformation than Plate 2. Furthermore, even within the same plate, comparable stress and damage vary depending on ply orientation. As a result, Plate 1 has greater strength than Plate 2 [13].

Table 3.1 - Equivalent stress for all specimens

Types of fibers	0°/90°	30°/-60°	45°/-45°
Bamboo (MPa)	260.52	311.67	254.61
Kenaf (MPa)	248.68	305.41	241.33

3.3 Strain Energy

Strain energy is a type of potential energy that is stored within materials that have been subjected to strain, in other words, some change in dimension. Fig. 3.2 shows a large gap between the lines where the line graph for bamboo is positioned above the kenaf line and leads to bamboo having a large potential energy value that is stored within fibers that have been subjected to strain or some change in dimension. The physical and mechanical properties of woven kenaf and bamboo fiber mat reinforced epoxy hybrid composites were also investigated [14]. The result showed that kenaf is stronger than bamboo. They found that kenaf composites outperformed bamboo composites in terms of impact strength (40.6 J/m vs. 37.8 J/m). The kenaf mat's geometric structure gives it more impact strength than the bamboo composite [14].

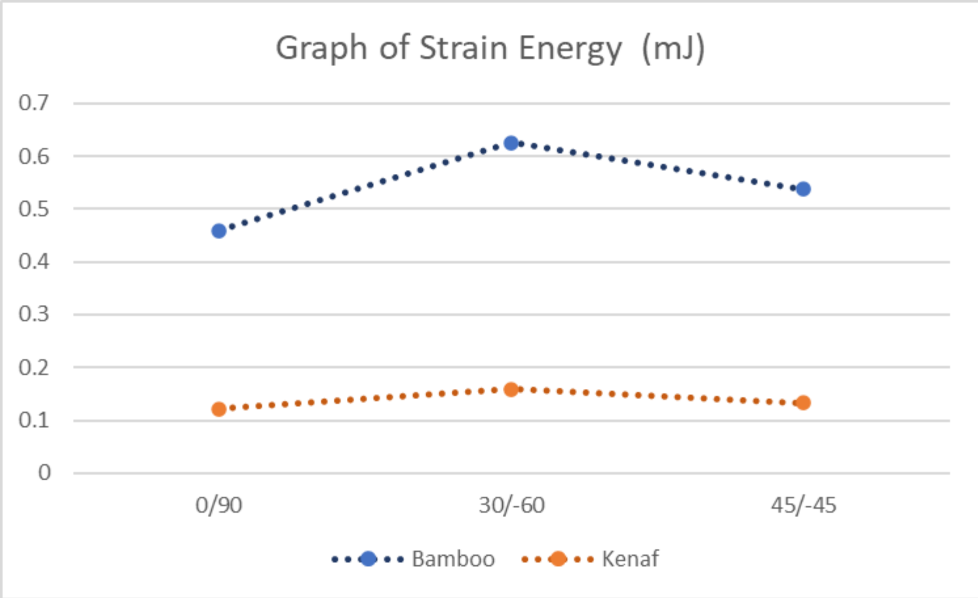


Fig. 3.2 - Graph of strain energy

3.4 Maximum Principal Stress

Based on table 3.2, among three types of fiber orientation, 30°/-60° holds the highest maximum principal stress compared to 0°/90° and 45°/-45° for both bamboo and kenaf fiber. Then, among the materials in a 30°/-60° specimen, the value of maximum principal stress for kenaf is higher than bamboo. According to [15], the maximum principal stress criteria implies that fracture development will occur perpendicular to the maximum principal stress, and the criterion does not take into consideration the discreteness of the numerical modelling of the crack-extension technique. This research found out that Kevlar reinforced epoxy is the strongest among the other two synthetic fibers (Glass and Carbon reinforced epoxy). This is due to the fact that the maximum principal stresses of Kevlar reinforced epoxy were 29.63 MPa at load 39.24N, while carbon and glass reinforced epoxy were 23.71 MPa at load 657.27 N and 36.353MPa at load 412.02N, respectively.

Table 3.2 - Maximum principal stress for all specimens

Types of fibers	0°/90°	30°/-60°	45°/-45°
Bamboo (MPa)	294.2	308.83	291.39
Kenaf (MPa)	331.59	333.2	317.92

3.5 Stress Intensity Factor, K_1

The stress intensity factor (SIF) is defined as the amplitude of the asymptotic elastic stress field ahead of the fracture, which has a distinctive singularity. This research is focused on the mode 1 tensile load (opening mode), where the value of SIF is very important to acquire. The stress intensity factor along the fracture front can be calculated using the solver output. In a study by [16] on reinforced polymeric composites, they investigated SIF at different fracture modes (mode I, II, and Charpy). It was found that Specimen I has the smallest stress intensity factor with a thickness of 10.3 mm at a maximum load of 0.91 kN. The crack tip state will be totally defined by the stress intensity component. Fig. 3.3 (a) shows the stress intensity factor for bamboo fiber, while Fig. 3.3 (b) shows the stress intensity for kenaf fiber with different orientations. Among three types of fiber orientation, 0°/90° holds the highest stress intensity factor, followed by 30°/-60° and 45°/-45° for both bamboo and kenaf fiber. Then, by considering a 0°/90° type of orientation, kenaf has a higher stress intensity factor compared to bamboo. This indicates that cross plies (0°/90°) will be stronger against fracture failure than inclined plies (45°/-45° and 30°/-60°). It could be due to the high blockage caused by the transverse plies as the crack propagates [17]. Another researcher investigated the fracture and mechanical behavior of a vacuum-assisted microwave-cured unidirectional carbon/epoxy woven fabric composite on cross and inclined plies. The compact tension model's critical SIF (KIC) values are predicted and compared to the experimental data. The values for the inclined plane are greater and in line with the computational results [18].

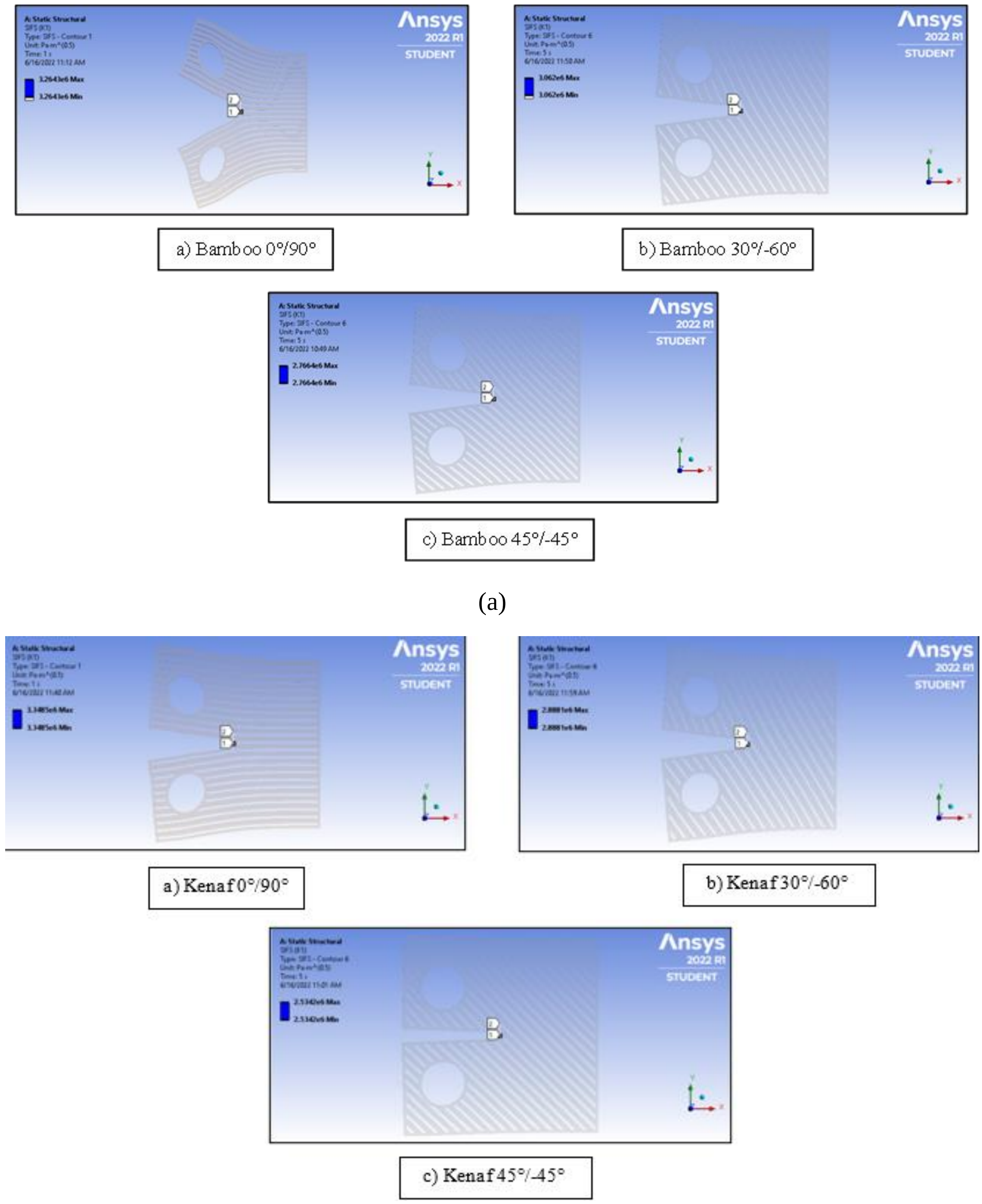


Fig. 3.3 - Stress intensity factor simulation results (a) Bamboo fiber; (b) Kenaf fiber

4. Conclusion

The goal of this study is met by studying the characteristics of the notch at the crack tip opening angle for woven fibers made from bamboo and kenaf. All specimens showed a positive reaction to the force that had been applied by describing certain effects on the fiber where an opening gap can be detected. Then, the deformation, strain, stress, and mode I stress intensity factor criteria of bamboo and kenaf woven fiber can also be achieved.

This research shows bamboo woven fiber is stronger than kenaf woven fiber especially for 0°/90° specimen with reasonable grounds for the statement. This is because of the data obtained for bamboo woven fiber were higher in stresses, strain and stress intensity. Same goes to the 0°/90° specimen where it showed good results in term of strength that due to the orientation which arranged crosswise and perpendicular against the applied force.

Acknowledgement

The authors would also like to thank the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia for its support.

References

[1] L. Kerni, S. Sarbjeet, P. Amar and K. Narinder, "A review on natural fiber reinforced composites", Materials Today Proceeding, vol. 28, no. 3, pp. 1616–1621, 2020.

[2] H. A. J. Sadiq Sha and P.P.Patil, "A Review on Natural Fiber Composites," *Journal of Xidian University*, vol. 14, no. 6, pp. 2844–2849, 2020.

[3] M. Asif, "Sustainability of timber, wood and bamboo in construction," *Sustainability of Construction Materials*, vol.1, pp. 31–54, 2009.

[4] F.A. Antunes,T.M. Rocha,R.R. Philippini, S.E. Martiniano, C. A. Mier-Alba, A.F. Hernandez-Perez, F. M., Abdeshahian, P., Ribeaux, D. R., Castro-Alonso, M. J., Balbino, T. R., Dussán, K. J., Da Silva, D. D. V., De Souza, J. P., Sanchez-Muñoz, S., Reyes-Guzman, R., Ingle, A. P., Felipe, M. G. A., … Da Silva, S. S, "The Potential of Vegetal Biomass for Biomolecules Production. Reference Module in Earth Systems and Environmental Sciences," *Comprehensive Renewable Energy*, vol. 2, no.5, pp. 139-164, 2021.

[5] O. Adekomaya, T. Jamiru, R. Sadiku and Z.Huan. "A review on the sustainability of natural fiber in matrix reinforcement – a practical perspective", *J Reinforc Plast Compos*., vol 3, no 12, pp. 3–7, 2016.

[6] S. Shahinur and M. Hasan, "Natural Fiber and Synthetic Fiber Composites: Comparison of Properties, Performance, Cost and Environmental Benefits", *Encyclopedia of Renewable and Sustainable Materials*, 794–802, 2020.

[7] M. R. Sanjay, G.R. Arpitha, L.L Naik, K. Gopalakrishna, and B. Yogesha, "Applications of Natural Fibers and Its Composites: An Overview", *Natural Resources*, vol. 7, no. 3, pp. 108–114, 2016.

[8] V. K. Thakur and M. K. Thakur, "Processing and characterization of natural cellulose fibers/thermoset polymer composites," *Carbohydrate Polymers*, 109, 102–117, 2014.

[9] R. Dunne, D. Desai, R. Sadiku and J. Jayaramudu, "A review of natural fibres, their sustainability and automotive applications", *J Reinforc Plast Compos*., vol. 35, no. 13, pp. 3–11, 2016.

[10] K.Ziaullah, B.F. Yousif and I.Mainul, "Fracture behaviour of bamboo fiber reinforced epoxy composites," *Composites*, vol. 116, pp. 186–199, 2017.

[11] S.S. Chee, M.Jawaid and M.S.M.Thariq, "Thermal Stability and Dynamic Mechanical Properties of Kenaf/Bamboo Fibre Reinforced Epoxy Composites," *Bioresources*, vol. 12, no. 4, pp. 7118–7132, 2017.

[12] S. K. Lee, E. Y. Park, T. S. Park and S.K. An, "Mechanical Properties of PP/Glass Fiber/Kenaf/Bamboo Fiber-reinforced Hybrid Composite," *Fibers and Polymers*, vol. 22, pp. 1460–1465, 2021.

[13] A. Karale and M. Bansode, "Layerwise Damage Investigation of Ply Orientation on Strength Characteristics of Carbon Fibre Composite," *International Journal for Research in Applied Science & Engineering Technology*, vol.7, pp. 444-453, 2019.

[14] A. S. Ismail, M. Jawaid, M.T.H Sultan and A. Hassan, "Physical and mechanical properties of woven kenaf/bamboo fiber mat reinforced epoxy hybrid composites," BioResources, vol.14, no.1, pp. 1390–1404, 2019.

[15] M. A. Azad, A. Saber and Y.I. Khatoon, "Experimental Stress Analysis for Woven Carbon, Glass, and Kevlar Laminate Shells;" *Diyala Journal of Engineering Sciences*, vol. 11, no.4, pp. 60-66. 2018.

[16] D. D. Olodu and C.O.Aliyegbenom, "Investigation Of The Stress Intensity Factors Of A Reinforced Polymeric Composite At Different Fracture Modes," *International Journal Of Engineering Science And Application*, vol. 5, no. 1, pp. 7–14, 2021.

[17] M. Rajesh, M.T. Hameed Sultan, M. Uthayakumar, K. Jayakrishna and A.U. Md. Shah, "Dynamic Behaviour of Woven Bio Fiber Composite", *Bioresources*, vol. 13, no. 1, pp. 1951–1960, 2018.

[18] R. Vijayanandh, K.Venkatesan, M. Ramesh, G. Raj Kumar and M. Senthil Kumar, "Optimization of orientation of carbon fiber reinforced polymer based on structural analysis," *International Journal of Scientific and Technology Research*, vol.8, no. 11, 3020–3029, 2019.