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A Study on The Crack Behavior of Baggase-Polyester Composites

Rozi Saferi[1,*]
Department of Mechanical Engineering, Institut Teknologi Padang
Jl. Gajah Mada Kandis Nanggalo, Padang, Indonesia

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*Correspondence should be addressed to rozisaferi2015@gmail.com

Abstract

The development of composite technology has begun to change nowadays, from composite fiber-synthesized to composite natural fiber fabrics. Natural baggase fiber has the opportunity to be developed as a strengthening medium in polymer resins. The purpose of this study were to know the effect of fiber orientation to maximum critical load for different initial crack lengths, to know elastic energy of composite material having fiber orientation varied at the time of loading and to know the effect of fiber orientation on fracture toughness for composite material. In this paper, it's used 1.5mm diameter sugarcane fibers and the polyester matrix. The fraction volume of fiber and resin used is 5%: 95%. Fiber is given 20% NaOH treatment. Then the fiber is arranged with orientation 0/90º and 0/45º. While the bending test specimen is in accordance with ASTM-D5045 standard, the size of the specimen dimension is 125 mm long, 30 mm wide and 10 mm thick; with crack variations are 7mm, 9mm, 11mm, 13mm, and 15mm. It's could be concluded that the critical load will decrease as the initial crack length increases. Composite material with 0/90º fiber orientation has elastic energy greater than composite with 45º fiber orientation. And crack propagation rate in composite material with fiber orientation 0/90º is faster than composite with 0/45º orientation.

Keywords: baggase fibers, elastic energy, crack propagation

1. Introduction

Natural fiber used in this study is fiber baggase. Fiber baggase is a lot of organic waste produced in sugar cane processing factories in Indonesia. This fiber has several advantages i.e high economic value, easy to obtain, cheap, no harm to health, can be derived naturally (biodegradability) so that later with the utilization as fiber composite amplifier able to overcome environmental problems due to waste baggase. Utilization of baggase fiber material is very rarely used. Besides, the product utilization effort from baggase fiber to increase added value from baggase waste and reduce the pollution of solid waste. [1]

The form of baggase fiber almost resembles the synthetic fiber form available on the market. The content of baggase is made up of cellulose (52.42%), hemicellulose (25.8%), lignin (21.69%), ash (2.73%) and ethanol (1.66%) [2]. Composite materials containing defects may fail in their application. One of the most common defects in composite materials is cracking. In general, cracks in composite materials are caused by the manufacturing or production process. The crack can propagate if the material is subjected to static or periodic loading. The crack propagation is influenced by several factors such as crack lengths that exceed the critical value or the energy required for crack propagation has exceeded the critical energy released at the time the cracks begin to spread [3].

The objectives of this paper are to determine the effect of fiber orientation to the critical maximum load for different initial crack lengths, to determine the composite elastic material energy that has fiber orientation varies at the time of loadingg and to determine the effect of fiber orientation on fracture toughness for composite materials.

Sugarcane is one of the potential natural fibers with an abundant amount of about 30% of the weight of the sugarcane [4]. So far the utilization of baggase has not been maximal, mostly only used as fuel. Some studies suggest that baggase can be used as a booster for other materials such as synthetic fibers in shipbuilding, particle board; mortar and brake tread [5].

Figure 1. leaves, stems and sugarcane fibers

Chemical content and mechanical properties of sugarcane fiber can be seen in table 1 and table 2.

Table 1. Chemical content of sugarcane fibers [2].

Lignin	40-50 %
Selulosa	32-43 %
Hemiselulosa	0,15-0,25
Etanol	1,66 %

Table 2 mechanical properties of sugarcane fiber [6]

Tensile strength	140 mpa
elongation	25 %
Hardness	3200 mpa
Density	1.15 g/cm³

Defects on Composites

Defects can cause failure on a material. The defects in the material can increase the stress concentration. One defect in the material can cause the occurrence of cracks such as void as seen in Figure 2.5. Void is a defect in the material marked by the vacancy or vacancy atom. The void or cavity arisen from the trapping of air inside the material during the manufacture of the material. The void will be the source of the voltage concentration if the material is loaded and in this case becomes the initial crack.

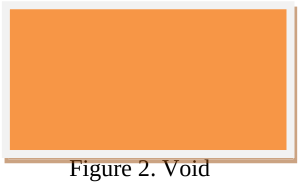


Figure 2. Void

The mechanisms by which voids can grow and cause failure in the material after being impregnated are seen when initially very small voids are charged and then the void begins to grow because of the loading. Void is increasingly widespread to meet with other voids to form dimples. If the load continues to increase then there is a failure in this material. The void growth mechanism can be seen in Figure 3

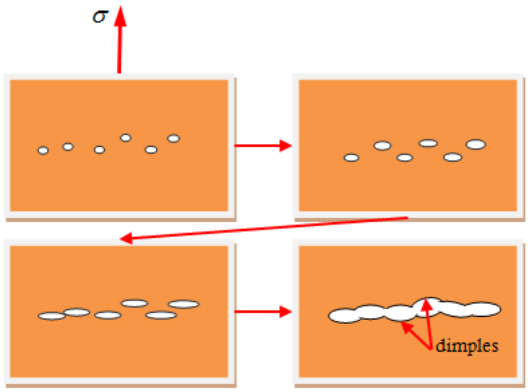


Figure 3. Void growth mechanisms

Meanwhile, the problems that are often found in composite materials are defects caused at the time of the process of manufacture and loading received material while performing its function (in service). At the time of the defect-making process can occur due to imperfect production processes such as air trapping, resin buildup, tangled fibers and others. At the time of composite loading, defects that often arise are translaminar cracks, transfiberous cracks or interlaminar cracks [7].

Translaminar cracks generally occur in the material with the direction of crack in the direction of fiber. This is because the adjacent laminar regions tend to have excessive resins rather than areas containing fibers. Interlaminar cracks are the most common cracks occurring during loading where cracks occur between the laminar (lining) of the composite material. This is due to the area between the laminar (layer) is the weakest area. In the area there is a tendency of air that trapped in the process of making composite materials. The defects in composites can be seen in Figure 4 Meanwhile, transfiberous cracks occur in materials with the direction of cracks perpendicular to the direction of the fibers.

A cracking defect of a material is very difficult to avoid, it can do is inhibit or reduce the rate of crack propagation. For that we need to know the toughness characteristics of a material to the crack by testing or experiment.

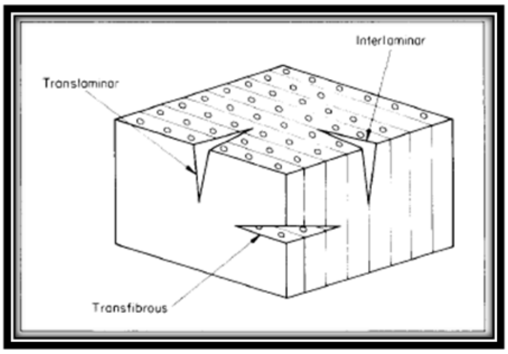


Figure 4. Defects in composite materials

Theory of Energy

The balance of energy comes not only from the potential energy of external load and elastic energy, but also influenced by other energies of surface energy [3]. For the first time Griffith introduced the energy theory of cracking for brittle materials. Griffith explains his energy theory through a plate of a certain thickness given the initial crack length of 2a and the tip is supported by a fixed pedestal as shown in fig. 5.

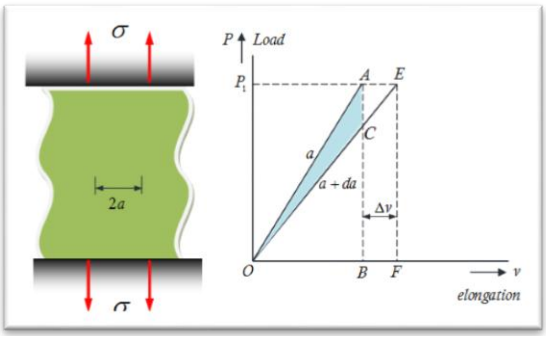


Figure 5. Griffith energy criteria for fixed grip (a) Crack with fixed tip,(b) Elastic Energy [8]

In figure b above shows that the elastic energy in the plate when the initial crack length of a is indicated by the area of OAB. If the crack is extended by da, then the stiffness of the plate will comply (OC line). While elastic energy with extended cracks is indicated by the area of OCB. The crack extension from a to a + da will produce the elastic energy released with a value of AOC area.

Griffith states that cracks will occur if the energy released at crack growth is sufficient to supply all the energy required for crack growth [8]. The conditions for crack growth can be expressed in equation (1) [8].

$$\frac{dU}{d\alpha} = \frac{dW}{d\alpha} \qquad (1)$$

Where U is an elastic energy, while W is the energy required for the growth of cracks. Griffith defines dU / dα as G, ie strain energy release rate and that energy can be calculated using equation (2).

$$G = \frac{\pi\sigma^2 a}{E} \qquad (2)$$

where E is the modulus of elasticity of the material. Meanwhile, the energy absorbed in the crack propagation can be defined as the energy change required per crack increase and denoted by R = dW / da which is also called crack resistance.

In the initial approach it is assumed that the energy required to produce the crack is the same for each increase of da which means that the R value is constant. In the case of equation (1), crack propagation does not occur before the elastic energy reaches the energy required for crack propagation (G> R). the crack will begin to propagate if G passes the critical value of G_{Ic} in other words R = G_{Ic}. the critical value of the G_{Ic} released energy rate can be determined by measuring the value of the voltage required to make the crack propagate.

Equation (2) can be used for cases under plane stress. In the case of the field stresses the thickness of the specimen is assumed to be very thin. While for plane strain conditions, the critical strain energy rate released by Gic can be calculated using equation (3)

$$G_{ic} = (1 - \nu^2)\frac{\sigma^2\, \pi\, a}{E} \qquad (3)$$

Where ν is the position ratio

Crack criteria can be graphically depicted as shown in the figure 6. Crack growth resistance R represents the size of free crack shown by horizontal straight line R = G_{Ic}

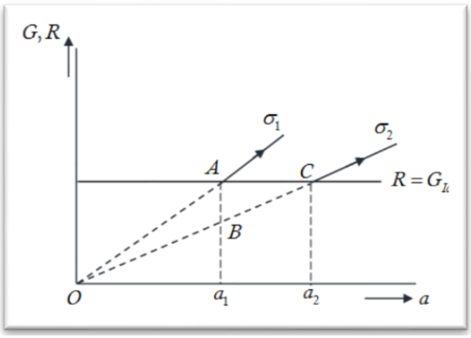


Figure 6 graph of energy criteria [9]

In the picture, it can be seen that the crack ability R of a material is always the same or constant for different initial cracks. If the first stress σ1 is given by the crack size a_1, the strain energy rate is represented by the OA line, whereas in the second strain σ_2 ($\sigma_1 > \sigma_2$) with the crack size a_2, the energy is represented by the OC line. In the figure it is shown that the initial crack of a1 is the crack will propagate if the strain energy rate released has satisfied the condition G = R (on the point A). Meanwhile for the voltage σ_2 at crack of a1 the crack has not spread because the critical condition has not been met (at point B), but for the initial crack a_2, the crack will spread as the release rate of the released strain energy has reached its critical condition (point C).

2. Material and Methods

The test will be performed ASTM D5045 with a single edge notched bend specimen (SENB) as shown in the figure 7. This test is assumed to be a test with a field strain consistency. Dimension of test specimen where w is width, B is thickness and S represents distance between pedestals, fiber a is initial crack length. The rules to be met are B = (0.25-1) w, a = (0.45-0.55) w, and S = 4w ± 0.02 w.

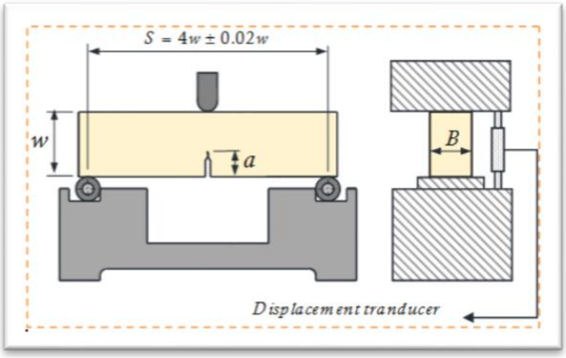


Figure 7. Standard cracking test ASTM D5045

In this test, to obtain the value of the critical energy released (G-Pmax) can be calculated by equation 4

$$G_{-P_{\max}} = \frac{U}{Bw\phi} \tag{4}$$

Where U is an elastic energy comparable to outside the area under the load curve with deflection during critical loading [10], B and W are the dimensions of the specimen as shown in the figure, as well as the energy factor factor corresponding to ASTM D5045 as indicated by equation [11].

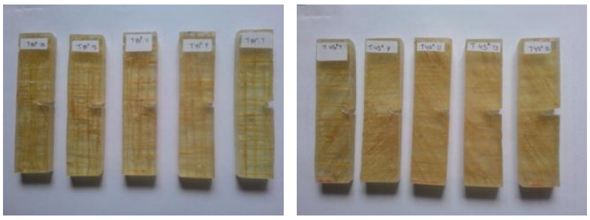
$$\phi = \frac{A+18.64}{dA/dx}, \tag{5}$$

Where the values of A and dA /dx can be calculated by equation (6) and equation (7). The value of x is the ratio between the initial crack (a) to the specimen width (w).

$$A=\left[\frac{16x^2}{(1-x)^2}\right]\cdot\left[8.9-33.717x+79.616x^2-112.952x^3+84.815x^4-25.672x^5\right] \tag{1}$$

$$\begin{aligned} dA/dx = &\left[\frac{16x^2}{(1-x)^2}\right]\cdot\left[-33.717+159.232x-338.856x^2+339.26x^3-128.36x^4\right] \\ &+16\left[8.9-33.717x+79.616x^2-112.952x^3+84.815x^4-25.672x^5\right] \\ &\cdot\left\{\frac{\left[2x\cdot(1-x)+2x^2\right]}{(1-x)^3}\right\} \end{aligned} \tag{2}$$

Tests were conducted on two types of test variations, namely variations of fiber orientation with orientation orientation directions 0/90^0 and 0/45^0. The initial crack or a value is given with five variations: 7mm, 9mm, 11mm, 13mm, and 15mm. The fraction volume of fiber and matrix is 5:95 where 5% for fiber and 95% for matrix. Furthermore, bending test specimens were prepared based on ASTM-D5045. The form of bending test specimens can be seen in Fig.8.



(a) (b)

Figure 8. (a) specimens with orientation 0/90^0 and (b) specimens with orientation 0/45^0

3. Results and Discussion

It's can be can be seen in figure 9 that on the initial 7 mm crack has the highest critical load among the other initial cracks with 588 N. whereas the smallest critical load was experienced in the initial crack 15 mm with the value 470.4 N. in Figure 7 is seen that all curves have a long tendency of the initial crack inversely proportional to the critical load.

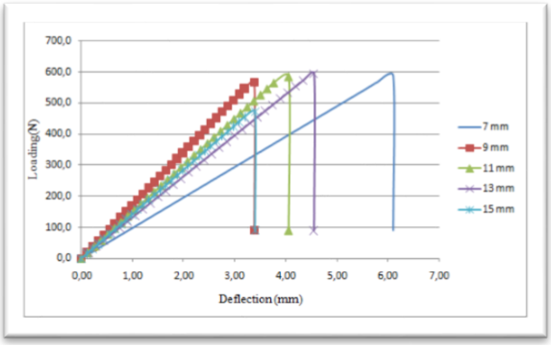


Figure 9. Graph of fiber orientation test results 0/90^0

The same condition of the 0/45^0 fiber orientation test shown in Figure 10 where the basic critical load was subjected to the initial 7 mm crack 780.73 N and the smallest critical load experienced by the initial 15 mm crack with a value of 558.6 N.

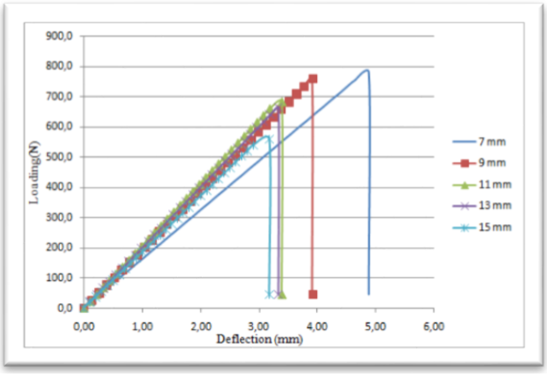


Figure 10 graph of 0/45^0 fiber test results

Figure 11 showed the comparison of the test results between fiber orientation 0/90^o with 0/45^o fiber orientation. Where a specimen with a fiber orientation of 0/90^o with an initial crack of 7 mm, has a smaller critical load compared to 0/45^o fiber orientation with the same initial crack length. But as the initial crack lengthens, the critical load value on the fiber orientation 0/90^o becomes larger than the specimen with the 0/45^o orientation, as seen at the initial crack length of 13 mm and 15 mm.

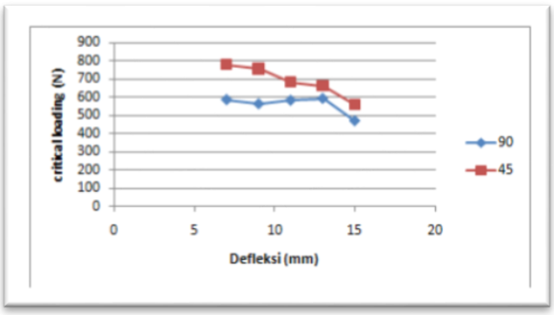


Figure 11. Graph of orientation of fiber 0/90^o with fiber orientation 0/45^o

The elastic energy of each specimen can be calculated from the test result graph, which is equivalent to the area under the load curve and the deflection during critical loading. The values below the curve can be calculated by the trapezium method as in equation 8. The calculation values can be seen in Table 2 for the average energy at each different crack length

$$I = \frac{h}{2}\left[f(x_0) + 2\sum_{i=1}^{n-1} f(x_i) + f(x_n)\right] \quad (8)$$

Table 2. Elastic energy

Initial	G-pmax	
Crack (mm)	90	45
7	2058	2732.555
9	2543.085	3410.37
11	3216.015	3755.015
13	3864.445	4310.345
15	3528	4189.5

Table 2 showed that the elastic energy in the specimen at the initial crack (7 mm) has the smallest value for the 0/90^o oriented specimen that is 2058 N.mm. while at the initial fracture of 15 mm at orientation 0/90^o and 0/45^o has the greatest elastic energy value between different initial crack lengths of 3528 N.mm for initial crack 15 mm with orientation of 0/90^o and 0/45^o is 4189.5 N.mm. From table 2 it can be concluded that the elastic energy at a 0/90^o fiber orientation with an initial crack 15 mm is greater than the initial 15 mm crack specimen with 0/45^o fiber orientation. For more details can be seen in figure 11. In Figure 12 it can be seen that the elastic energy is directly proportional to the initial crack value and applies to both orientation of fiber that is 0/45^o orientation and 0/90^o orientation.

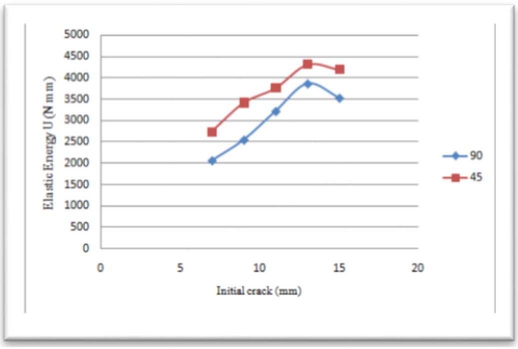


Figure 12. Elastic energy vs. initial crack

To determine the value of crack resistance equivalent to the critical released energy (G_{IC}), it is necessary to calculate the energy released (G). The complete results of the energy calculations released for two different fiber orientations can be seen in Figure 12.

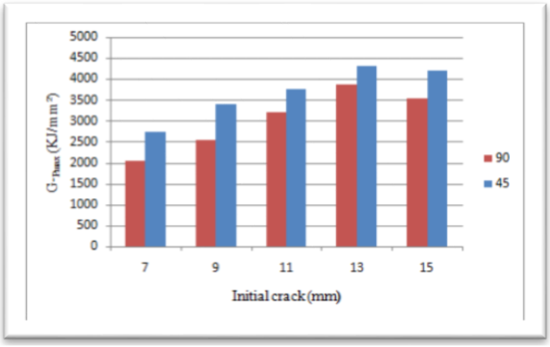


Figure 13. G-$_{Pmax}$ vs. initial crack

Figure 13 showed the critical energy ratios released by the initial crack for specimens with fiber orientations 0/90° and 0/45°. In figure 10 it is seen that the critical energy released by the test specimen with orientation 0/90° tends to be smaller when compared to the test specimen with the 0/45° orientation. With a G-pmax value that is proportional to the crack resistance value of the material, a composite specimen with 0/45° fiber orientation has better crack resistance than a specimen with a fiber orientation of 0/90°. This proved that the crack will be easily spread on composites with a fiber orientation of 0/90°.

4. Conclusion

The conclusions of the paper are the critical load relationship with the initial crack is inversely proportional to which the critical load will decrease as the initial crack length increases; composite materials with 90° fiber orientation have greater elastic energy than 45° oriented composites. And crack propagation rate in composite material with fiber orientation 90° faster than composite with 45° orientation.

References

[1] Farid, M., Putra, A., Abdullah, Y., Efendy, H., Ayob, R., dan Sajidin, M., 2013, Untilizing Sugarcane Wasted Fibers As A Sustainable Acoustic Absorber, *Procedia Engineering*, Volume 53, Elsevier, hal 632-638.

[2] Tewari, M., Singh, V.K., Gope, P.C., & Chaudhary, A.K. (2012). Evaluation of Mechanical Properties of Bagasse-Glass Fiber Reinforced Composite. *J. Mater. Environ. Sci*., 3(1): 187-194

[3] Griffith, A.A.*The Phenomena of Rupture and Flow in Solids*. Philos. Trans. R. Soc. London A. 221. (1921). pp. 163-198

[4] Purnawan, C., Hilmiyana, D., Wantini., & Fatmawati, E. (2012). Pemanfaatan Limbah Ampas Tebu Untuk Pembuatan Kertas Dekorasi Dengan Metode Organosolv. *Jurnal EKOSAINS*, 4(2): 1-6

[5] Andriyanti, R., Suyanti, & Ngasifudin. (2012). Pembuatan dan Karakterisasi Polimer Superabsorben dari Ampas Tebu. *Prosiding Pertemuan dan Presentasi Ilmiah Teknologi Akselerator dan Aplikasinya*, 13(1): 1-7.

[6] Heri Iswanto. 2009. Papan partikel dari ampas tebu (*saccarum officinarum)* Sumatera : skripsi. Universitas sumatera utara

[7] Adams, R.D. andCawley, P. *A review of defect types and nondestructive testing techniques for composite and bonded joints*. NDT International. Volume 21. 4. (1988). pp 208-222.

[8] Broek, D. *Elementary Engineering Fracture Mechanics Third Revised Edition*. Martinus Nijhoff Publishers: Dordrecht. (1982)

[9] Hellan, K. *Introduction to Fracture Mechanics*. McGraw-Hill Co : Singapore. (1985).

[10] Silva, R.V.et al. *Fracture Toughness of Natural Fibers/Castor Oil Polyurethane Composites*. *Journal of Composites Science and Technology*. 66. (2006). pp. 1328–1335.

[11] ASTM D 5045-99. *Standard Test Methods for Plane-Strain Fracture Toughness and Strain Energy Release te of Plastic Materials*. (1999).