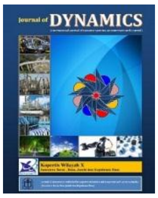
JOURNAL OF DYNAMICS
KOPERTIS WILAYAH X
http://ejournal.kopertis10.or.id/index.php/dynamics
Vol. 2, Issue. 1, May 2017
e-ISSN: 2502-0692



International Journal of Dynamic Systems, Measurement and Control

A Study on The Crack Behavior of Jute-Polyester Composites

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

doi.10.22216/JoD.2017.V2.39-44
Correspondence should be addressed to rozisaferi2015@gmail.com

Article Information

Received : 20 Jan 2017
Revised : 20 May 2017
Accepted : 29 May 2017
Published : 31 May 2017

Abstract

Natural fiber composites are an alternative for replacing environmentally harmful synthetic materials and help control pollution problems. In addition, they are low cost, have better mechanical properties and require low production energy consumption. Also, using such materials in construction works, it is possible to improve the sustainability by eliminating construction wastes. The purpose of this paper is to investigate the crack propagation of bending test on jute fiber-reinforced resin composites with orientation of 90° and 45°. In this study Jute fiber was spun with a diameter 1.5 mm and arranged into two layers with orientation 90° and 45° . It's used a matrix of clear resin type polyester with a volume fraction 5:95. Bending test specimen is based on ASTM D5045. The results showed that composites with 45° fiber orientation had greater value of crack propagation than composites with 90° fiber orientation. The elastic energy of composites with 45° fiber orientation tend to decrease dramatically as the initial crack length increases.

Keywords: Jute-polyester composite, crack propagation, elastic energy

1. Introduction

The world is in need of more eco-friendly material, therefore researchers around the globe focus on developing new materials that would improve the environmental quality of products. This need for new green materials has led to the utilization of composites made from raw natural fibers and polymer matrices, and this has become one of the most widely investigated research topics in recent times. Natural fiber composites are an alternative for replacing environmentally harmful synthetic materials and help control pollution problems. In addition, they are low cost, have better mechanical properties and require low production energy consumption. Also, using such materials in construction works, it is possible to improve the sustainability by eliminating construction wastes. Natural fibers have many advantages such as, lighter, recyclable and biodegradable when compared with synthetic fibers. Besides renewable, natural fibers have relatively high strength and stiffness. In some cases, natural fibers even have higher mechanical properties than glass fibers [1].

Natural fibers as a potential reinforced is jute. Because it has a short planting season (55 days) and high productivity (6 tons/harvest/ha) [2]. Hemp plants are easier to grow than cotton plants [3]. Jute including plants is easy to grow in various soil conditions but the current use of jute fiber in Indonesia was limited as the manufacture of apparel fabrics and paper. This condition would have more value if such fibers could be used to replace non natural fibers (fiber glass), which is still imported from abroad as a reinforcement of composite materials. Jute fiber was selected because its characteristics are strong, lightweight, and durable against solar radiation. its strength are unchanged, waterproof, and resistant to mildew, insects and bacteria [4]. Some early studies showed that the diameter of the fiber flax (flax china super types) of Garut is about 0:22 to

0:42 mm [4]. According to Mueller and Krobjilobsky [5], the density of the jute fiber is 1.5-1.6 g/cm³ and tensile strength of jute fiber ranges from 400-1050 MPa. Modulus of elasticity and strain is about 61.5GPa and 3.6%.

Tabel 1. Nature of Natural Fiber Compounds as Comparators Against Conventional Fiber [6]

Fibre	Density (g/cm³)	Elongation (%)	Tensile Strength (MPa)	Young's Modolus (GPa)
Cotton	1,5-1,6	7,0-8,0	287-597	5,5-12,6
Jute	1,3	1,5-1,8	393-773	26,5
Flax	1,5	2,7-3,2	345-1035	27,6
Hemp	-	1,6	690	-
Ramie	-	3,6-3,8	400-938	61,4-128
Sisal	1,5	2,0-2,5	511-635	9,4-22,0
Coir	1,2	30,0	175	4,0-6,0
Viscose (cord)	-	11,4	593	11,0
Soft wood kraft	1,5	-	1000	40,0
E-glass	2,5	2,5	2000-3500	70,0
S-glass	2,5	2,8	4570	86,0
Armide (normal)	1,4	3,3-3,7	3000-3150	63,00-67,0
Carbon (standard)	1,4	1,4-1,8	4000	230,0-240,0

2. Material and Methods

Fracture Toughness

Fracture toughness is a property that describes the ability of a material containing cracks to withstand fractures. If a material has a high fracture toughness price, a ductile fracture is likely to occur in the material. Fracture toughness is an indication of the amount of stress required to propagate the initial defects that exist in the material [7]

Some forms of crack loading mode can be seen in Figure 1 [8]

- opening Mode, in this mode the voltage or loading is perpendicular to the cracking crack.
- Sliding Mode, in this second mode, the voltage or loading is perpendicular to the crack tip.
- Tearing Mode, in this mode, the voltage or loading is parallel to the crack tip line

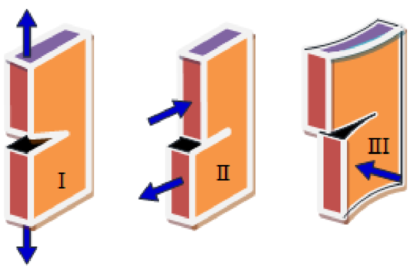


Figure 1 Types of loading. (I) opening Mode, (II) Sliding Mode, (III) Tearing mode [8]

Composite materials containing defects would be failed in application. One of the most common defects in composite materials is crack. 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 including crack lengths that exceed the critical value or the required energy for crack propagation has exceeded the critical energy released when the crack begins to propagate [9]

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 [9]. 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 Figure 2.

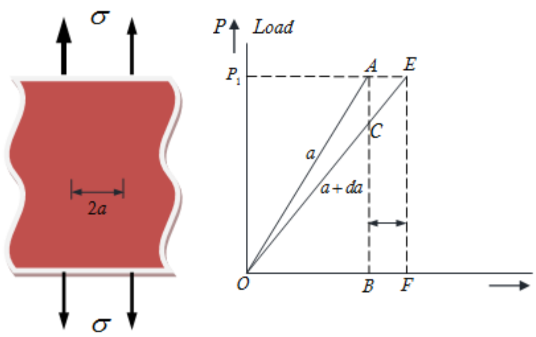


Figure 2. Griffith energy criterion for fixed grip (a) Crack with fixed tip, (b) Elastic energy [10]

Figure 2.10 b 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 be according to (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 [10]. The conditions for crack growth can be expressed in equation (1) [10].

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

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).

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

where E is the modulus of elasticity of the material

Meanwhile, the energy absorbed in the crack propagation can be defined as the required energy change per increase of crack 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 will not occur until the elastic energy reaches the energy required for the 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 G_{Ic} can be calculated using equation (3)

$$G_{Ic} = (1-\nu^2)\frac{\sigma^2 \pi a}{E} \quad (3)$$

Where ν is the position ratio

Crack criteria can be drawn graphically as shown in Figure 3. Crack growth resistance R represents the size of free crack shown by horizontal straight line $R = G_{Ic}$

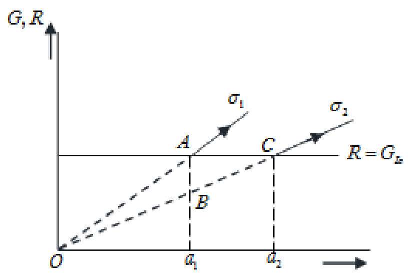


Figure 3. Graph of energy criteria [9]

In Figure 2 it is seen that the crackability R of a material is always the same or constant for a different initial crack. If given the first stress σ_1 with the crack size a1, then the strain energy rate illustrated by the line OA, while in the second strain σ_2 ($\sigma_1 > \sigma_2$) with the crack size a_2, the energy is delineated by the OC line.Figure shown that the initial crack of a_1 is the crack will propagate if the strain energy rate released has satisfied the condition G = R (on the titk A). Meanwhile for the voltage σ_2 at crack of a_1 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 (titk C).

Standard of Fracture Reliability Testing

The tests will be based on ASTM D5045 with a single edge notched bend specimen (SENB) as shown in Figure 4. 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 pree 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.

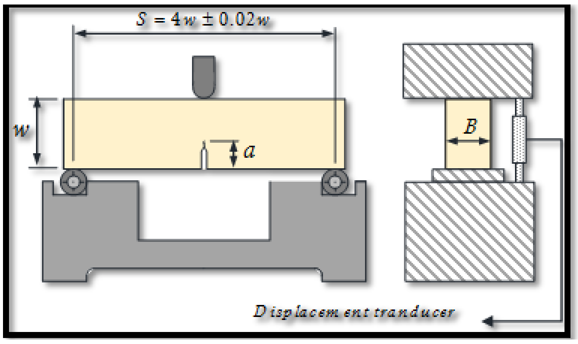


Figure 4. Crack testing standards ASTM D5045

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

$$G_{-P_{max}} = \frac{U}{Bw\phi} \quad (4)$$

Where U is an elastic energy comparable to outside the area under the load curve with the deflection at critical loading [11], B and W is the dimension of the specimen as shown in Fig., And is an energy-calibrating factor corresponding to ASTM D5045 shown by equation (5) [12]

$$\phi = \frac{A + 18.64}{dA/dx}, \quad (5)$$

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).

$$A = \left[\frac{16x^2}{(1-x)^2}\right] \cdot \left[8.9 - 33.717x + 79.616x^2 - 112.952x^3 + 84.815x^4 - 25.672x^5\right] \quad (6)$$

$$\frac{dA}{dx}=\left[\frac{16x^2}{(1-x)^2}\right]\cdot\left[-33.717+159.232x-338.856x^2+339.26x^3-128.36x^4\right]$$
$$+16\left[8.9-33.717x+79.616x^2-112.952x^3+84.815x^4-25.672x^5\right]$$
$$\cdot\left\{\frac{\left[2x\cdot(1-x)+2x^2\right]}{(1-x)^3}\right\} \quad (7)$$

The test was performed on two types of test variation, i.e. fiber orientation with orientation direction 0º/90º and 0º/45º as shown in Figure 5. The initial crack or a value is given with five variations: 7mm, 9mm, 11mm, 13mm, and 15mm. The volume fraction of fiber with matrix is 5:95 where 5% for fiber and 95% for matrix.

Figure 5. Fiber orientation (a) 0º/90º and (b) 0º/45º

The data obtained during the test is a comparison between the loads assigned to the deflection occurring during the loading process which is picked up by the entire Universal Testing Machine device for each of the various initial crack lengths. The area under the curve is defined as the elastic energy possessed by the specimen having an initial crack. The strain energy difference per gap of the crack length between the initial cracks given is the rate of elastic energy released

3. Results and Discussion

In Figure 6 it is seen that a specimen with a small 7 mm inlet crack has the largest critical load of test specimens with the other crack length of the other at the same fiber orientation of 499.8 N. whereas at the greatest initial crack 15 mm has the smallest critical load of 388 N. When seen from the overall curve of Figure 6, it is seen that the initial crack length is given inversely proportional to the given loading. Meanwhile, for the overall trend, there is a deviation shown by the curve with an initial crack length of 13 mm, i.e. the deflection experienced is shorter than the initial crack of 15 mm. This is due to the lack of precision of the initial crack dimensions given at the time of the initial cracking itself.

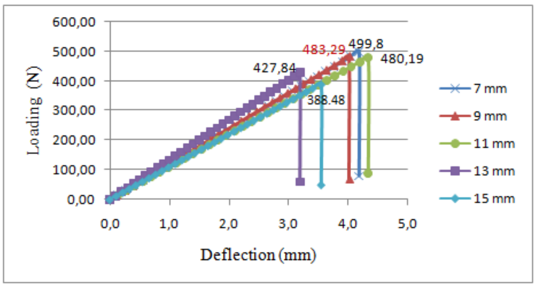


Figure 6. Graph of test result on fiber orientation 0/90º

In Fig. 7 the test charts on specimens with orientation of 0/45º, where the critical loading nile is also inversely proportional to the initial crack length given. Where the most critical load experienced by the specimen with the initial 7 mm crack is 617 N while at the initial crack 15 mm the critical load experienced is 365.7 N.

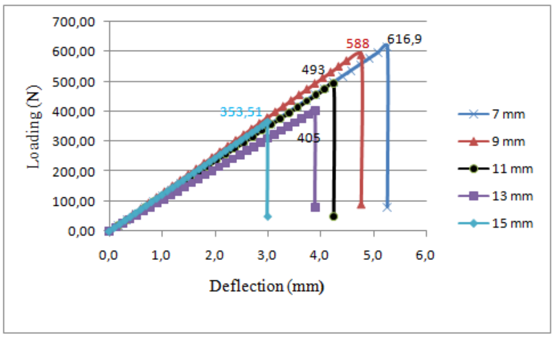


Figure 7. Graph of test results at 0/45º fiber orientation

Figure 8 shows the comparison of the test results between fiber orientation 0/90º with 0/45º fiber orientation. Where a specimen with a fiber orientation of 0/90º with an initial crack of 7 mm, has a smaller critical load compared to 0/45º fiber orientation with the same initial crack length. But as the initial crack lengthens, the critical load value on the fiber orientation 0/90º becomes larger than the specimen with the 0/45º orientation, as seen at the initial crack length of 13 mm and 15 mm.

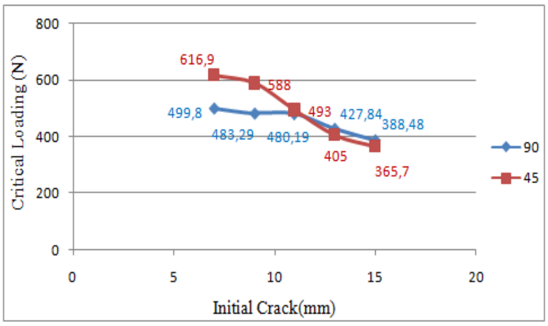


Figure 8. Graph of orientation of fiber 0/90º with fiber orientation 0/45º

From Figure 8 it can show a comparison between two 45o fiber orientations and a 0/90º fiber orientation with the same initial crack lengths (a) 7mm initial crack, (b) initial crack 9 mm, (c) initial crack 11 mm, (d) initial crack 13 mm, (e) initial crack 15 mm. Whereas in orientation fiber 0/45° has a critical load greater than the critical load with fiber orientation 0/90° which is seen in the initial crack 7 mm, 9 mm and 11 mm. For an initial crack of 11 mm, the ratio of critical load and deflection experienced by both orientations was not very different i.e. 4.43 mm deflection and critical load 480.19 N for orientation of fiber 0/90° whereas at orientation fiber of 0/45° deflection experienced 4.25 mm and load critical 493 N. But at the initial crack 13 mm and 15 mm at orientation 0/90° the critical loads are likely to be greater than 0/45° fiber orientation with the same initial crack.

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 Crack (mm)	U (N.mm)	
	90°	45°
7	1049.58	1625.532
9	973.8294	1405.32
11	1042.012	1047.625
13	684.544	789.75
15	689.552	548.55

From Table 2 for orientation 0/90°, having the greatest elastic energy occurred in the initial 7 mm crack, which was 1049.58 N.mm, the elastic energy value tended to decrease at each addition of the initial crack length. The same is true of 0/45° fiber orientation.

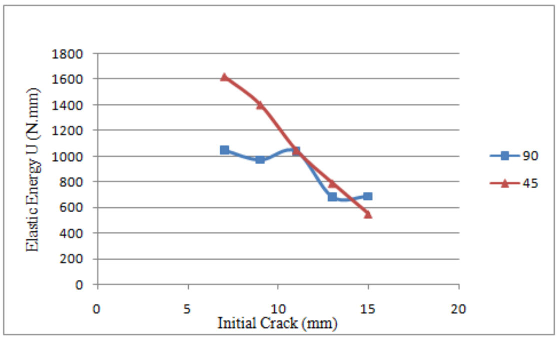


Figure 9. Elastic energy vs initial crack

Figure 9 shows that the elastic energy in test specimens tends to decrease especially in specimens with a fiber orientation of 0/45°. From a comparison of the value of elastic energy, the test specimen with 0/45° fiber orientation is higher than the specimen with a fiber orientation of 0/90°. This proves the energy theory introduced by Griffith is similar to the results of the test, where the amount of initial crack given to the test specimen will affect the stiffness and the elasticity value of the test specimen

To determine the value of crack resistance equivalent to the energy released, 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 10.

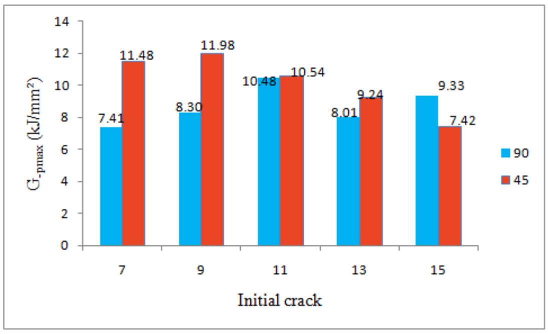
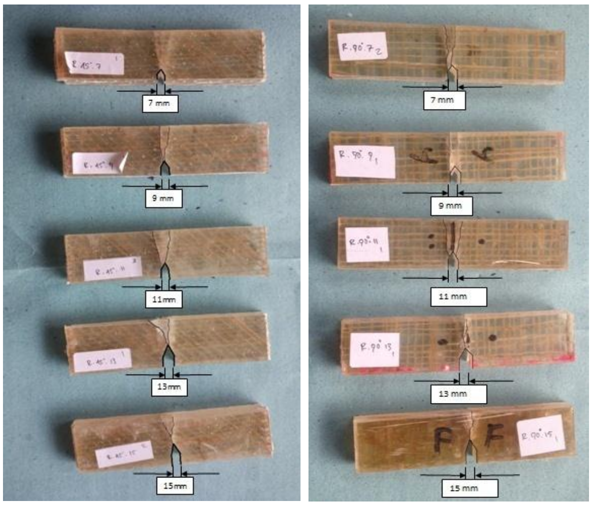


Figure 10. $G_{-p\ max}$ vs Initial crack

Figure 10 shows 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-p max 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 proves that the crack will be easily spread on composites with a fiber orientation of 0/90°.



(a) (b)

Figure 11. Fracture propagation at (a) orientation 0/45° and (b) orientation 0/90°

In Figure 11, it can be seen that the shape of crack propagation in test specimens is influenced by fiber orientation. Where crack propagation in specimens with orientation of fibers 0/90° tends to be straight and specimens with 0/45° fiber orientation tend to be branched. This is due to the fiber orientation to loading when the crack propagation takes place.

4. Conclusion

The conclusions of the study are Critical loading is inversely proportional to the initial crack length given, i.e the longer the initial crack is given, the smaller the critical load it has to break. Elastic energy of composites of 0/45° fiber orientation is larger than elastic energy of composite of 0/90° fiber orientation. And crack propagation rate in composite materials with fiber orientation 0/90° tends to be faster when compared to 0/45° fiber orientation.

References

[1] Paul. W, Jan. I, Ignaas, V. *Natural fibres: can they replace glass in fibre reinforced plastics*. Composites Science and Technology 63 (2003) 1259–1264]

[2] Budi, U.S., Hartati, S., Purwati, D.R., *2005, Biologi Tanaman Rami*, Monograf Balittas No.8,

[3] Maiti, R, 1997, *World Fiber Crop: Ramie (Boehmeria nivea)*, ch.4, pp.63-73, Science publ., USA

[4] Marsyahyo,E., Soekrisno,R., Rochardjo,H.S.B., Jamasri,. 2009, *Preliminary Investigation on Bulletproo Panels Made from Ramie Fiber Reinforced Composites for NIJ Level II, IIA, and IV*, Journal of Industrial Textiles,Vol. 39, No. 1.

[5] Mueller, D.H., Krobjilowski, A., 2003. *New Discovery in the Sifates of Composites Reinforced with Natural Fibers*. *Journal of industrial textiles*, vol. 33, no. 2—october 2003 1111528-0837/03/02 0111–20 $10.00/0 doi: 10.1177/152808303039248_2003 Sage Publications.

[6] Monteiro, SN., L., A., H., Terrones, J., R., M., and D'Almeida, 2008. *Mechanical Performance of Coir Fiber/Polyester Composites*, Polymer Testing 27. 591-595.

[7] Rusnoto . *Studi Ketangguhan Retak Pada Komposit Epoksi-Alumina*, Universitas Panca Sakti Tegal. (2014)

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

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

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

[11] 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.

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