

Research Article

# Study of the Fracture Toughness Strength of Composites Made from Unsaturated Polyester with Pineapple Leaf Fiber Reinforcement

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## Abstract

The development of natural fibre composites is needed to replace synthetic composites which are difficult to decompose. However, natural fibre composites have many weaknesses that need to be studied, including being brittle and easily cracked. One of the things carried out in this research is a material derived from unsaturated polyester reinforced with natural fibres from pineapple leaves and used to reduce the percentage of synthetic materials from polyester which can form composites that are easily decomposed. With this research, engineering in the engineering field such as raw materials for fishing boat bodies, tourist boat bodies, and fishing boats is very helpful. This unsaturated polyester mixture with 20% pineapple leaf fibre has the highest critical stress intensity factor of  $K_{1c} = 1,733 \text{ MPa.m}^{0.5}$ , an increase from  $K_{1c} = 0,779 \text{ MPa.m}^{0.5}$  in pure unsaturated polyester. This material has the highest performance and can withstand good fracture strength, making it suitable for engineering applications. This research increased the toughness and crack resistance of the UP material treated with the addition of the SN mixture by 222.47%.

## Keywords

Synthetic-composite, Polyester-unsaturated, Pineapple-leaf Fiber-fiber, Factor-intensity-voltage

## 1. Introduction

Currently, polymer materials are starting to be widely used in the transportation sector, such as for vehicles, ships, airplanes and other engineering fields as a replacement for metal materials that have been used for a long time [1-3]. The reason is that polymers have a low specific gravity, are easy to shape, and can be strengthened by mixing with other materials in the form of composites [1, 3, 5]. The use of polymers in combination with reinforcement in composite materials has recently played a major role in the field of engineering. The advantage of composites is their mechanical strength which can exceed

the strength of the original polymer material according to the reinforcing element [2, 4, 5]. But besides that, polymers have several weaknesses, including having low tensile strength, being brittle and cracking easily, and not being able to withstand high temperatures [6, 7]. Efforts to strengthen polymers with natural fibres have been carried out, for example with carbon fibres, nylon fibres, hemp fibres, and other fibres [3, 8, 9].

Unsaturated polyester is a type of polymer widely used in the construction of transportation equipment and is produced

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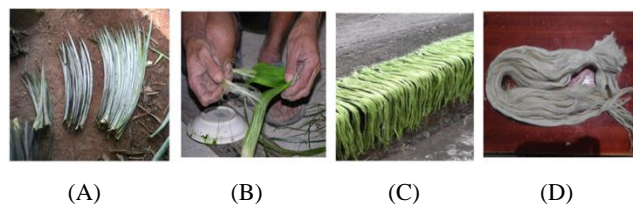
by breaking down the carbon and hydrogen chains of petroleum. Unsaturated polyester (UP) is a type of thermosetting polymer made from synthetic materials with a molecular structure that is cross-linked and closely related to each other, with mechanical characteristics that are a type of material that is brittle [6, 10]. For this reason, efforts need to be made to reduce the brittle nature of the material to make it ductile so that it does not easily fail, such as breaking or cracking, when subjected to loads that work under certain conditions and magnitudes [10]. One thing that has been done is to increase the crack resistance of unsaturated polyester reinforced with rice husk fibres, it was reported [11]. Furthermore, composite reinforcement with sugarcane bagasse fibre has been reported by [2, 13].

In this study, references will be made to several articles that have conducted research studies on pineapple leaf fibres with a brittle pine matrix with reported results of tensile strength of 2.4 MPa [14]. Furthermore, research on the morphology of pineapple leaf fibre composite structures has been reported by [15]. After referring to several previous studies, no one has reported on the study of the crack strength of pineapple fibre composites. To conduct a study on the crack resistance capability of composite materials from unsaturated polyester (UP) reinforced by pineapple leaf fibre (SN) refers to the crack test standard on the one-dimensional crack test standard with ASTM Standard D 5405 [1-2, 16].

## 2. Research Methods

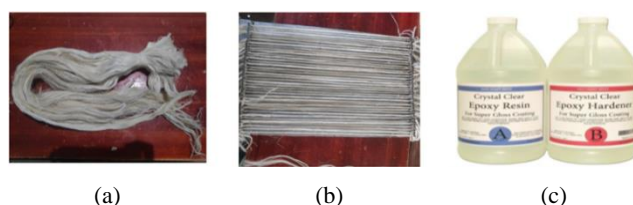
In this study, an evaluation will be carried out on the ability of a material to withstand maximum cracking loads until the material experiences a total cracking load, known as fracture toughness. The magnitude of the stress intensity factor of the material that the fracture toughness material can withstand can be described as the critical stress intensity factor (SIF) symbolized by  $K_{IC}$ . In this study, several materials were used, including matrix material and reinforcing material, namely pineapple leaf fibre mixed with polyester uniformly. The type of polyester used in this study is unsaturated polyester from the Yukalac 1560 BL-EX product with the following properties and characteristics; has the property of easily binding fibers, moisture resistance and has quite good mechanical strength, high density and dries quickly [16, 2].

The process of extracting pineapple fiber (SN) from pineapple leaves is first the pineapple leaf fiber is separated from lignin by combing after that the pineapple leaf fiber is washed with water to clean the pineapple leaf fiber from its binding material after the fiber is cleaned the fibre is dried in the sun. after being dried the pineapple fiber is sorted by the same size and is ready to be made into composite material. The fiber extraction process can be seen in Figure 1.



**Figure 1.** Pineapple fiber processing process. A). Pineapple leaves, B). Fiber separation from pineapple leaves, C). Drying pineapple fiber, D). Dried pineapple fibre.

The process is done by pouring resin into a mould containing glass, and then applying pressure while smoothing it with a roller or brush. This process is repeated until the required thickness is achieved. Process To form a composite material, two types of materials are needed, namely the matrix material used to bind the fibre material, and the reinforcing material derived from pineapple fibre. To make composite material test objects, the mixture is moulded by pouring it into a mould and drying it in the open air (room temperature) for 48 hours. To carry out the research, the material is planned with a composition that is by the literature that has been reviewed previously [1, 4, 13, 17]. Distribution of pineapple fibres, one type of fibre that is woven and mixed with polyester evenly. The manufacturing process is done by evenly distributing the dough into the mould and then pressed evenly with a roller or brush. This process is repeated until the standard thickness is achieved. The material made for the composite can be seen in Figure 2.



**Figure 2.** Pineapple fiber composite manufacturing process. A). Pineapple leaves, B). Woven fibers, C). Unsaturated polyester.

The composition of the mixture of materials to be made into composite materials has been designed with a composition that is hypothesized to produce crack-resistant materials as in Table 1 below;

**Table 1.** The composition of the mixture of Polyester (UP) and Pineapple Fiber (SN).

Material No	UP Composition (% Volume)	SN Composition (% Volume)
1	100	0
2	90	10

Material No	UP Composition (% Volume)	SN Composition (% Volume)
3	80	20
4	70	30

### Crack Testing

The crack tester is used for crack testing of composite samples that have been made, according to the referenced standard, namely ASTM D 5405, its dimensions can be seen in Figure 2. On this tool, the material specification data required for the analysis of the crack strength properties of composite material samples can be input. The specifications of the crack tester are as follows; COM-TEN testing machine 95T Series 5K brand, 5000 Pound Capacity, Load Cell Model TSB0050, with a touch screen display monitor or com-touch screen.

After the composite material crack testing process has been carried out, the measurement results will then be entered into the following equations (1) and (2);

$$K_{1c} = \frac{P}{BW^{\frac{3}{2}}} \cdot f\left(\frac{a}{w}\right) \quad (1)$$

$$f\left(\frac{a}{w}\right) = \frac{\left(2 + \frac{a}{w}\right) \left\{ 0.886 + 4.64\left(\frac{a}{w}\right) - 13.32\left(\frac{a}{w}\right)^2 + 14.72\left(\frac{a}{w}\right)^3 - 5.6\left(\frac{a}{w}\right)^4 \right\}}{\left(1 - \frac{a}{w}\right)^{\frac{3}{2}}} \quad (2)$$

$$\epsilon = \frac{\Delta L}{L} \quad (3)$$

The amount of fracture energy from the tensile test machine absorbed by the composite material is derived by the following equation;

$$W = \int_0^u P \cdot dl \quad (4)$$

Symbol description:

$K_{1c}$  = Stress intensity factor (MPa.m<sup>0.5</sup>)

P = Maximum load (kN)

B = Specimen thickness (cm)

W = Specimen width (cm)

a = Crack length (cm)

ε = strain (.)

E = flexural modulus (N/mm<sup>2</sup>)

I = moment of inertia area (mm<sup>4</sup>)

L = specimen length (mm)

Δl = increment length (mm)

Crack testing is a material test by giving a pull to the material so that the load given will cause an initial crack to occur on the specimen. The initial crack produced will cause a crack that spreads on the specimen until the material cannot withstand the load given [17]. The length of the crack obtained from the measuring instrument that is read on the machine display will be calculated using the mathematical

equation in equation (2) as discussed [18, 17]. In this study, the dimensions of the test samples refer to the ASTM D 5045 standard which is shown in Figure 3.

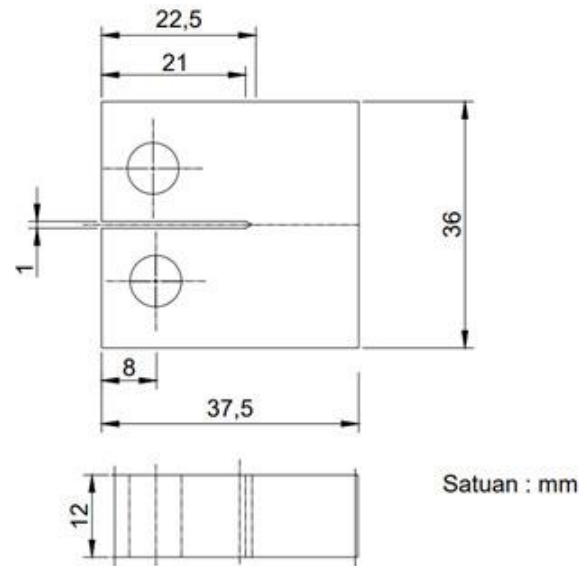


Figure 3. Dimensions of Crack Test Specimens based on ASTM Standard D 5405 [1-2].

The crack test specimen mould used in this study is rectangular and has a notch groove and is equipped with a 1 mm long incision groove for the crack path guide (initial crack). The shape of the crack test specimen mould can be seen in Figure 4.



Figure 4. Crack test Specimen mold.



Figure 5. Crack Test Specimen.

The crack test specimen used in this study Where on both ends of the specimen are given holes for pulling the specimen

by the crack test machine. The shape of the crack test specimen can be seen in Figure 5.

#### Crack Testing Machine

COM-TEN testing machine 95T series is used for mechanical study of the samples made, the testing standard for this tool refers to ASTM D 5405 with the appearance as seen in Figure 5. This tool has the following specifications:

- 1) Merk: COM-TEN testing machine 95T series 5K as seen in Figure 6.
- 2) Maximum capacity: 5000 pounds
- 3) Load cell: TSB0050
- 4) Test control: Automatic with com-touch total control



Figure 6. Composite Crack Testing Machine COM-TEN testing machine 95T series.

### 3. Results and Discussion

In the following sub-chapter, the results of crack testing of composite materials will be shown with the following details.

The test results of each crack test specimen can be shown directly automatically on the crack test machine monitor. The test results show that the maximum crack load price for each material test sample can be seen in Table 2.

Table 2. Test Results of Crack Test Specimens.

UP/SN (%)	Specimens	Force (kN)	$K_{1c}$ (MPa.mm <sup>0.5</sup> )
100/0	1	632	0,790
	2	545	0,783
	3	617	0,766
90/10	1	1363	1,287
	2	1283	1,168
	3	1336	1,167
80/20	1	1612	1,754
	2	1525	1,763
	3	1681	1,683
70/30	1	1486	1,435

UP/SN (%)	Specimens	Force (kN)	$K_{1c}$ (MPa.mm <sup>0.5</sup> )
	2	1436	1,230
	3	1530	1,348

The magnitude of the cracking force from Table 2 above for the test specimens of each mixture of UP and SN materials and from the test shows that in pure UP it ranges from 545 N to 617 N. If the mixture of unsaturated polyester and pineapple leaf fibre is added starting from 10% in the UP material, the cracking force price increases from 1283 to 1363 N. In the mixture of UP and SN, it is increased to 20% The cracking force increases ranging from 1525 N to 1681 N. Furthermore, if the mixture of UP and SN is increased to 30% the cracking force decreases ranging from 1436 N to 1530 N. In Table 2 it is shown that the saturation of the mixture has occurred at the limit of the SN mixture in UP exceeding 20% the material strength begins to decrease. The shape of this cracking force curve can also be seen in Figure 6. The magnitude of the cracking force from Table 2 above for the test specimens of each mixture of UP and SN materials and from the test shows that in pure UP it ranges from 545 N to 617 N. If the mixture of unsaturated polyester and pineapple leaf fibre is added starting from 10% in the UP material, the cracking force price increases from 1283 to 1363 N. In the mixture of UP and SN, it is increased to 20% The cracking force increases ranging from 1525 N to 1681 N. Furthermore, if the mixture of UP and SN is increased to 30% the cracking force decreases ranging from 1436 N to 1530 N. In Table 2 it is shown that the saturation of the mixture has occurred at the limit of the SN mixture in UP exceeding 20% the material strength begins to decrease. The shape of this cracking force curve can also be seen in Figure 7.

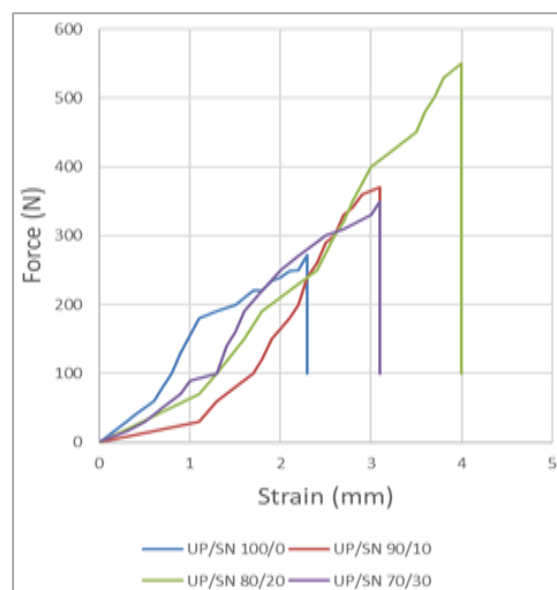
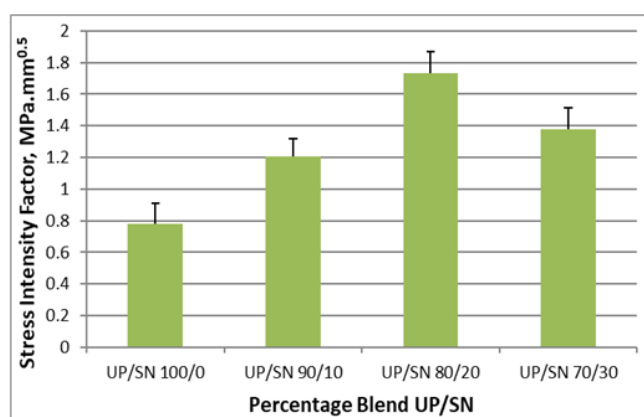


Figure 7. Cracking Force Value from Crack Test Results for UP/SN Composites.

Next, the critical stress intensity factor ( $K_{1c}$ ) is calculated with the equation (2) for the test specimens of each mixture of UP and SN materials which are shown in Table 2. The results of the test show that for pure UP, a critical stress intensity factor of  $0,779 \text{ MPa.m}^{0.5}$  for the test specimens of each mixture of UP and SN materials and are shown in Table 2. The results of the test show that for pure UP, a critical stress intensity factor ( $K_{1c}$ ) of  $1,207 \text{ MPa.m}^{0.5}$ . Next, the addition of SN mixture to UP by 20%, the maximum critical stress intensity factor value obtained is  $K_{1c} = 1,733 \text{ MPa.m}^{0.5}$ . Furthermore, by increasing the pineapple fiber content to 30%, the critical stress intensity factor value was obtained which decreased by  $K_{1c} = 1,337 \text{ MPa.m}^{0.5}$ . This result can also be seen in Figure 8.



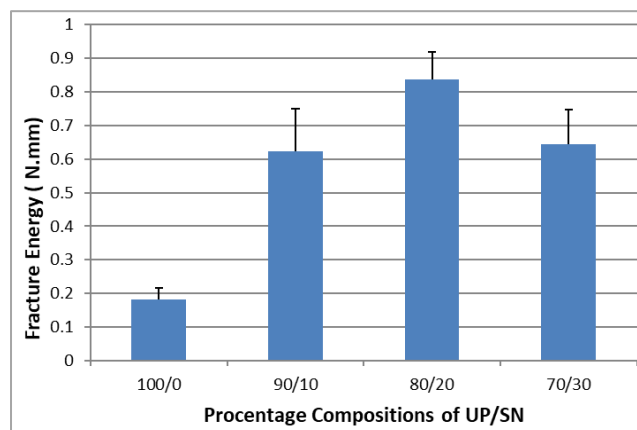
**Figure 8.** Stress Intensity Factor Value from Crack Test Results for UP/SN Composites.

**Table 3.** Fracture Energy Values of Composite Materials for UP and SN mixtures.

Material No.	Fracture Energy (N.mm)
UP/SN 100/0	0.182
UP/SN 90/10	0.624
UP/SN 80/20	0.837
UP/SN 70/30	0.645

The magnitude of the cracking energy is calculated using equation (3) and equation (4) for the cracking test specimens of each UP and SN material mixture and is shown in Table 3. The results of the test show that in pure UP, the cracking energy obtained is 0.182 N.mm. If the mixture of unsaturated polyester and pineapple leaf fibre starts to add SN mixture by 10%, the cracking energy price increases to 0.624 N.mm. With the addition of SN mixture to UP by 20%, the maximum cracking energy price is obtained at 0.837 N.mm. Furthermore, with the addition of pineapple fibre content to 30%, the cracking energy price is obtained which decreases by 0.645

N.mm, these results are also shown in Figure 8. This shows that the largest energy absorption capacity is only obtained in the UP and SN mixture up to 20% above that the energy absorption capacity decreases again, meaning that the material cannot withstand the cracking energy well.



**Figure 9.** Fracture Energy Value from Crack Test Results for Unsaturated Polyester Blend with Pineapple Leaf Fiber.

## 4. Conclusion

This study reports the success of determining the right composition of a composite material mixture made of an unsaturated polyester matrix with the addition of pineapple leaf fibre to increase the crack resistance of unsaturated polyester polymers into crack-resistant composite materials. With this study, engineering in the field of engineering such as raw materials for fishing boat bodies, tourist boat bodies, and fishing boats is very helpful. The unsaturated polyester blend with 20% pineapple leaf fibre has the highest critical stress intensity factor of  $K_{1c} = 1,733 \text{ MPa.m}^{0.5}$ , increasing from  $0,779 \text{ MPa.m}^{0.5}$  in pure unsaturated polyester. With the highest performance, this material can withstand good fracture strength, making it good and useful for engineering applications. This research increased the toughness and crack resistance of the UP material treated with the addition of an SN mixture by 222.47%.

## Abbreviations

UP	Unsaturated Polyester
SN	Pineapple Leaf Fibre

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## Conflicts of Interest

There is no conflict of interest in this research, the author is responsible for his written work.

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