Terbit *online* pada laman web jurnal : http://metal.ft.unand.ac.id

METAL: Jurnal Sistem Mekanik dan Termal

| ISSN (Print) 2598-1137 | ISSN (Online) 2597-4483 |

Research Article

Study of Improving Fracture Toughness of Un-Saturated Polyester with Addition of Mixing Percentage of CPO Oils

N. Nusyirwan [a*], *S. Ilham* [b]

[a,b] *Mechanical Engineering Department, Andalas University, Kampus Limau Manis, Padang, 25163, Indonesia*

ARTICLE INFORMATION

Article History:
Received:31 August 2022
Revised: 18 October 2022
Accepted: 31 October 2022

KEYWORDS

Stress-intensity-factor
un-saturated-polyester
fracture-toughness
crude-palm-oil

CORRESPONDENCE

E-mail: nusyirwan1802@gmail.com

A B S T R A C T

Unsaturated polyester is a polymer that is widely used as a basic matrix to form strong composites for engineering applications such as for cars, ships and aeroplanes. The advantages of using this material are owing to have a fairly high tensile strength when reinforced with appropriate reinforcing fibers, light and easy to shape. However, due to its brittle nature, this material cannot withstand shock loads. Therefore, it is necessary to overcome that weakness. Crude Palm Oil (CPO) can give benefits as a strengthening agent. However, its proper mixture to polyester need to be figured out so that it would help in improving crack resistance properties of this polyester. This can be done by determining of fracture resistance value of the mixture polymer. A crack resistance testing was carried out and crthe itical stress intensity factor was calculated based on ASTM D 5005. The composition of the CPO mixture was varied from 100%: 0%, 10%: 20%, 30%: 40%. From the test results, it can be identified that the greatest critical stress intensity factor is K_{1c} = 15.787 MPa.m$^{1/2}$. This is found out in composition of 30% CPO. Meanwhile the critical intensity factor of pure Unsaturated Polyester (UP) is only 2,023 MPa.m$^{1/2}$. There is approximately 700% improvement that can be gained in mixing with CPO.

1. INTRODUCTION

Nowadays, polymer materials are widely used in transportation, such as for vehicles, ships, and aircraft, to substitute metal materials[1][2]. This is owing to have low specific gravity, easy to form, and able to be modified by mixing with other materials in the form of composites[3][4]. The advantage of composites is that their mechanical strength can exceed the strength of the polymer matrix material depending on the reinforcing elements[1][4][5][6]. But besides that, polymers have several weaknesses, including low tensile strength, easy to crack, and not able to withstand high temperatures[7][9]. Efforts to strengthen polymers with natural fibers have been carried out, for example reinforcing with carbon fiber, nylon fiber, hemp fiber, and other fibers[1][10][11]. Unsaturated polyester is a polymer produced from the process of breaking the carbon and hydrogen chains of petroleum. This polymer is a type of thermosetting polymer made from synthetic materials that have a tightly cross-linked molecular structure and are closely related to each other, with the mechanical characteristics of this material being brittle[12][13][14]. Accordingly, it is necessary to make efforts to improve the brittle nature of the material so that it is able to withstand crack loads within a certain load range[15][16].

One thing that will be developed in this research is to strengthen the crack resistance of un-saturated

https://doi.org/ 10.25077/metal.6.2.132-137.2022 Attribution-NonCommercial 4.0 International. Some rights reserved

polyester polymer by mixing with Crude Palm Oil (CPO) from palm oil[17][18]. A test will be carried out to determine the crack resistance ability of the un-saturated polyester material due to the addition of a mixture of CPO oil in carrying out crack loading [19]. Crack test standards and test sample dimensions refer to crack test standards based on ASTM D5405.

2. METHODOLOGY

In this study, testing was carried out on the material that was given an initial crack. Afterward, testing materials were given a gradually increased tensile load until the maximum load that material fails to withstand. In this stage, material would experience a total crack called fracture toughness. The amount of energy is required to make the material withstand of the cracks due to called "Fracture Energy." In addition, the magnitude of the stress distribution that occurs at the crack tip of the material that is given the initial defect is called the Stress Intensity Factor. The stress intensity factor of the material is indicating ability of the material to sustain a total crack called the fracture threshold. The Critical Stress Intensity Factor symbolized by (K_{Ic}) can define the level of material thoughness.

In general, research was performed in several stages, including the material supply stage, the casting stage of the crack test specimen sample, and crack testing by crack loading in the vertical direction of two sides of the specimen.

2.1 *Materials*

Un-saturated polyester is a polymer that is commonly used as a matrix in composite manufacturing. Unsaturated polyester used in the study as a polymer matrix was Yukalac 1560 BL-EX [13][20]. The composition between UP and CPO was arranged according to Table 1.

Furthermore, in order to reduce the viscosity of the UP, Methyl methacrylate (MMA) was used to improved its mechanical properties. Then, CPO used in this study was supplied by PT. Pelita Agung Agro Industry. After UP and CPO were mixed up, it is required to put a catalyst to accelerate drying rate of composite samples. The catalyst used in this research was the Mepoxe catalyst produced by PT. Justus Kimiaraya that composes 4% of mixture composition.

Tabel 1. Mixture composition variation of UP and CPO

Material	UP (% wt)	CPO (% wt)	MMA (%wt)
UP/CPO 100	100	0	10
UP/CPO 90	90	10	10
UP/CPO 80	80	20	10
UP/CPO 70	70	30	10
UP/CPO 60	60	40	10

The material in the form of mixing un-saturated Polyester, CPO oil, Methyl Methacrylate (MMA), and a catalyst was prepared according to the determination of the mixture ratio. The mixture composition was then got casting using a mold that has a size referring to ASTM D 5405. There were four specimens casted for each mixture composition according to several references as shown in Figure 1.

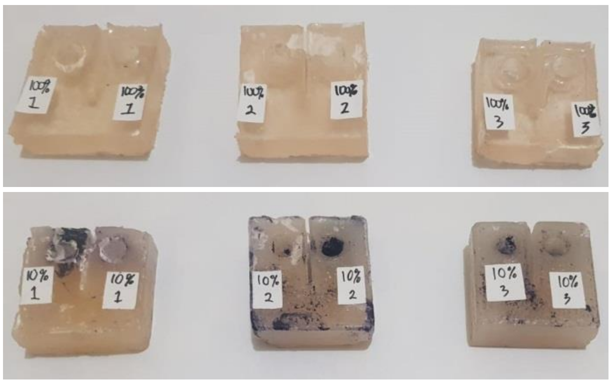

Figure 1. Freezing crack test specimens at room temperature

2.2 *Testing Equipments*

This study utilized some equipment to help achieving the objective as follows;

1. A crack test mold was used to casting test specimens.
2. Universal Testing Machine COM-TEN testing machine 95T series was used for crack testing.

The specimen was got drawn in two-way vertical movement of the test machine as can be seen in Figure 2. The machine can move as the load increases automatically when the material resists.

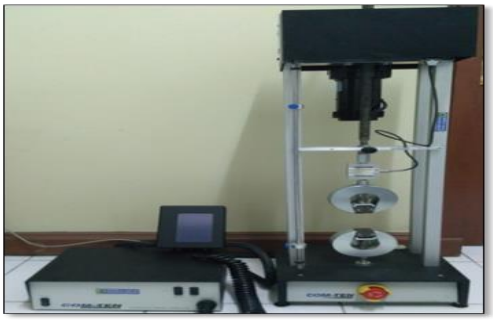

Figure 2. Crack testing machine with brand of COM-TEN series 95T

3. A hot plate typed magnetic stirrer was used to stir the mixture composition to make it homogeneous.

2.3 Methods

The crack testing performed by drawing the material as can be seen in Figure 3 so that the given load will cause an initial crack on the specimen. The initial crack will cause cracks propagated until the material hold the given load longer. The length of the crack propagated was read directly on the machine display. This reading magnitude will then use to determine mathematical equation as in Equation 1. The crack testing refers to the ASTM D 5045 standard. The ASTM D 5045 standard can be seen in the cracks.

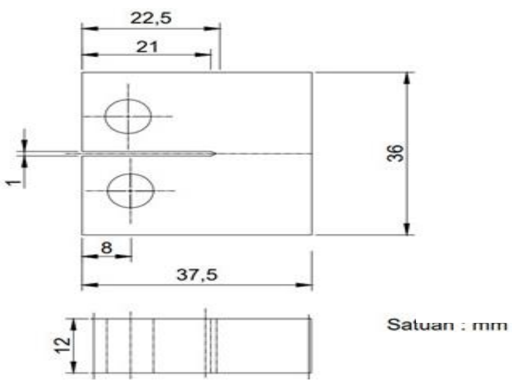

Figure 3. Crack testing specimen according to ASTM D 5405 standard

Meanwhile stress intensity factor calculated by using Equation 1 and Equation 2.

$$K_{Ic} = \frac{P}{BW^{1/2}} \cdot f\left(\frac{a}{w}\right) \tag{1}$$

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

3. RESULTS AND DISCUSSION

Before the crack test was carried out, each specimen dimension was measured and the results is given in Table 2.

Tabel 2. Data of crack test specimen dimension

CPO (%)	Spesimen	*a* (cm)	a/W	F(a/W)
	1	1.53	0.42	7.604
0	2	1.51	0.41	7.517
	3	1.49	0.41	7.391
	1	1.52	0.42	7.571
10	2	1.58	0.44	8.952
	3	1.45	0.39	6.126
	1	1.48	0.40	7.321
20	2	1.52	0.42	7.543
	3	1.51	0.41	7.464
	1	1.53	0.43	7.701
30	2	1.49	0.41	7.373
	3	1.51	0.41	7.485
	1	1.54	0.42	7.670
40	2	1.56	0.43	7.829
	3	1.48	0.41	7.352

Afterward the crack test was performed to obtain the value of Tensile Toughness and the displacement (strain). The result is depicted in Table 3. In Table 3 is also given the calculation result of critical stress intensity factor.

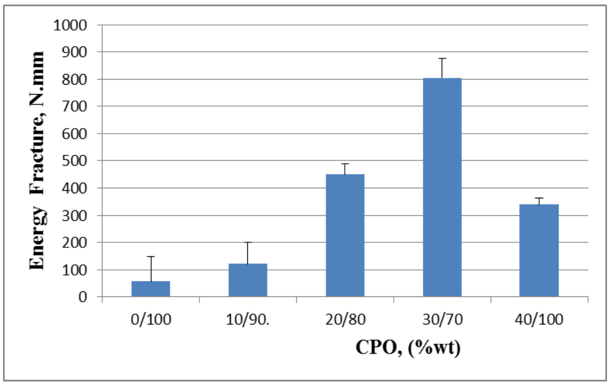

Figure 4. Effect of CPO addition on energy fracture

https://doi.org/ 10.25077/metal.6.2.132-137.2022

Data provided in Table 3, further is proceeded to quantify the effect of CPO addition on energy fracture and the result is given in Figure 4.

Tabel 3. Fracture toughness of test specimen

CPO (%)	**Specimen**	***Force*** (kN)	**K_{Ic}** (MPa/mm$^{1/2}$)	
	1	0.62	1.990	
0	2	0.34	1.083	2.023
	3	0.101	2.966	
	1	0.226	7.387	
10	2	0.194	6.628	6.620
	3	0.193	5.845	
	1	0.312	9.654	
20	2	0.325	10.463	9.866
	3	0.301	9.483	
	1	0.486	16.015	
30	2	0.440	13.820	15.787
	3	0.530	17.528	
	1	0.120	3.904	
40	2	0.138	4.672	4.201
	3	0.126	4.029	

Energy fracture can be defined as the energy necessary to alter one unit of fracture surface area from the initial no-load state to the complete separation state. From Figure 4, it can be discovered that CPO addition would enhance fracture energy of the composed material.

Nevertheless, only addition of 30% of CPO would provide the maximum benefit to CPO-UP mixture. It implies that CPO is responsible to retain crack propagation.

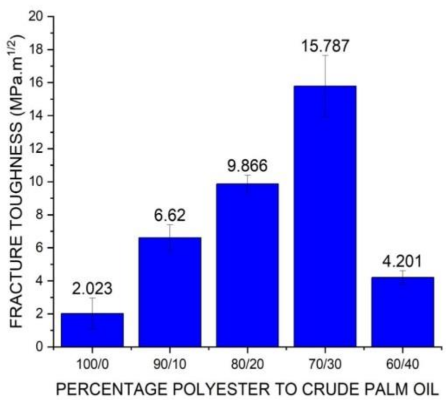

Figure 5. Facture Toughness curve to the Percentage of Mixed CPO against UP.

Moreover, if fracture toughness (i.e. critical intensity factor magnitude) is taken into account, CPO addition would improve fracture toughness as CPO is added to the mixture materials. Fracture toughness is a brittle material characteristic in resisting defect propagation due to stress loading.

Similar trend as energy fracture, for fracture toughness as shown in Figure 5, the mixture of UP and CPO with percentages of 70% and 30% respectively, had posed the highest fracture toughness. It indicates that the material has high fracture toughness would be hard to get crack kept growing. So that, a specific percentage of CPO in UP would yield a material that can withstand off crack.

In addition, Figure 6 shows effect of material deflection on load. In Figure 6, it also can be seen the maximum force that make material failed to withstand at deflection length.

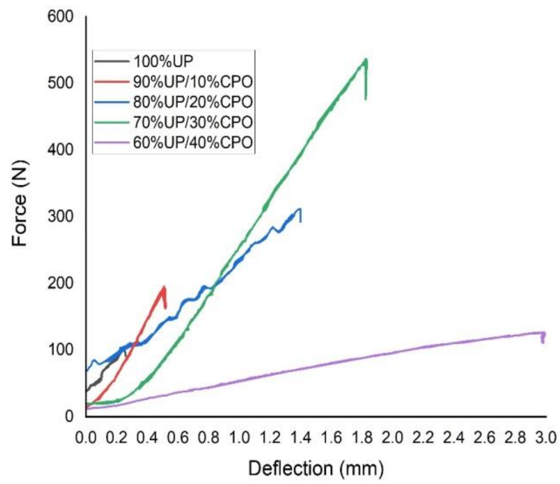

Figure 6. The magnitude of load crack according to the level of material deflection of CPO and Un-saturated Polyester mixture

4. CONCLUSIONS

Based on the research that has been done, it had identified that CPO addition to UP with particular percentage would improve crack resistance of the mixture material. In this study, it is found that composition of 30% UP and 70% CPO requires above 440 N of force on average to get crack.

Meanwhile, the Stress Intensity Factor K_{1c} can reach to 15.787 MPa.m $^{1/2}$. Eventually, there is approximately 700% improvement can be attained as CPO introduced into UP with maximum percentage of 30%.

ACKNOWLEDGMENTS

This research was funded by the 2021 Mechanical Engineering Department Research Grant Fund to the Head of the Mechanical Engineering Department, Faculty of Engineering who provided funding for this research.

REFERENCE:

[1] S. Jeyanthi and J. Janci Rani, "Improving mechanical properties by KENAF natural long fiber reinforced composite for automotive structures," *J. Appl. Sci. Eng.*, vol. 15, no. 3, pp. 275–280, 2012, doi: 10.6180/jase.2012.15.3.08.

[2] Z. Othman, M. P. Saiman, M. F. A. Hamid, and M. N. Talibin, "The application of 2D woven kenaf reinforced unsaturated polyester composite in automotive interiors," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 368, no. 1, 2018, doi: 10.1088/1757-899X/368/1/012032.

[3] M. T. Islam *et al.*, "Effect of Coconut Shell Powder as Filler on the Mechanical Properties of Coir-polyester Composites," *Chem. Mater. Eng.*, vol. 5, no. 4, pp. 75–82, 2017, doi: 10.13189/cme.2017.050401.

[4] A. Balaji, R. Purushothaman, R. Udhayasankar, S. Vijayaraj, and B. Karthikeyan, "Study on Mechanical, Thermal and Morphological Properties of Banana Fiber-Reinforced Epoxy Composites," *J. Bio- Tribo-Corrosion*, vol. 6, no. 2, 2020, doi: 10.1007/s40735-020-00357-8.

[5] Nusyirwan, H. Abral, M. Hakim, and R. Vadia, "The potential of rising husk fiber/native sago starch reinforced biocomposite to automotive component," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 602, no. 1, 2019, doi: 10.1088/1757-899X/602/1/012085.

[6] H. Oliver-Ortega, F. Julian, F. X. Espinach, Q. Tarrés, M. Ardanuy, and P. Mutjé, "Research on the use of lignocellulosic fibers reinforced bio-polyamide 11 with composites for automotive parts: Car door handle case study," *J. Clean. Prod.*, vol. 226, pp. 64–73, 2019, doi: 10.1016/j.jclepro.2019.04.047.

[7] H. Tuo, Z. Lu, X. Ma, J. Xing, and C. Zhang, "Damage and failure mechanism of thin composite laminates under low-velocity impact and compression-after-impact loading conditions," *Compos. Part B Eng.*, vol. 163, no. August 2018, pp. 642–654, 2019, doi: 10.1016/j.compositesb.2019.01.006.

[8] L. Prasad, V. Singh, R. V. Patel, A. Yadav, V. Kumar, and J. Winczek, "Physical and Mechanical Properties of Rambans (Agave) Fiber Reinforced with Polyester Composite Materials," *J. Nat. Fibers*, 2021, doi: 10.1080/15440478.2021.1904481.

[9] T. Gobikannan *et al.*, "Flexural properties and failure mechanisms of infusible thermoplastic- and thermosetting based composite materials for marine applications," *Compos. Struct.*, vol. 273, p. 114276, 2021, doi: 10.1016/j.compstruct.2021.114276.

[10] S. Wahono, A. Irwan, E. Syafri, and M. Asrofi, "Preparation and characterization of Ramie Cellulose Nanofibers/CaCO3 Unsaturated Polyester Resin composites," *ARPN J. Eng. Appl. Sci.*, vol. 13, no. 2, pp. 746–751, 2018.

[11] A. T. Seyhan, M. Tanoğlu, and K. Schulte, "Tensile mechanical behavior and fracture toughness of MWCNT and DWCNT modified vinyl-ester/polyester hybrid nanocomposites produced by 3-roll milling," *Mater. Sci. Eng. A*, vol. 523, no. 1–2, pp. 85–92, 2009, doi: 10.1016/j.msea.2009.05.035.

[12] H. Abral *et al.*, "Improving impact, tensile and thermal properties of thermoset unsaturated polyester via mixing with thermoset vinyl ester and methyl methacrylate," *Polym. Test.*, vol. 81, no. August 2019, p. 106193, 2020, doi: 10.1016/j.polymertesting.2019.106193.

[13] M. Mandhakini, S. Devaraju, M. R. Venkatesan, and M. Alagar, "Linseed vinyl ester fatty amide toughened unsaturated polyester- bismaleimide composites," *High Perform. Polym.*, vol. 24, no. 3, pp. 237–244, 2012, doi: 10.1177/0954008311436263.

[14] P. Hari Sankar, Y. V. Mohana Reddy, and K. Hemachandra Reddy, "Polyester/vinylester polymer hybrid blended nanocomposites:

Effect of nano on mechanical and thermal properties," *Fibers Polym.*, vol. 16, no. 2, pp. 443–448, 2015, doi: 10.1007/s12221-015-0443-9.

[15] H. Ardhyananta *et al.*, "Mechanical and Thermal Properties of Unsaturated Polyester/Vinyl Ester Blends Cured at Room Temperature," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 202, no. 1, 2017, doi: 10.1088/1757-899X/202/1/012088.

[16] J. Njuguna, P. Wambua, and K. Pielichowski, *Cellulose Fibers: Bio- and Nano-Polymer Composites*. 2011.

[17] J. S. Ullett and R. P. Chartoff, "Toughening of unsaturated polyester and vinyl ester resins with liquid rubbers," *Polym. Eng. Sci.*, vol. 35, no. 13, pp. 1086–1097, 1995, doi: 10.1002/pen.760351304.

[18] M. T. Albdiry and B. F. Yousif, "Toughening of brittle polyester with functionalized halloysite nanocomposites," *Compos. Part B Eng.*, vol. 160, no. October 2018, pp. 94–109, 2019, doi: 10.1016/j.compositesb.2018.10.032.

[19] H. N. Dhakal and S. O. Ismail, *Unsaturated polyester resins: Blends, interpenetrating polymer networks, composites, and nanocomposites*. Elsevier Inc., 2019.

[20] N. Hiremath, S. Young, H. Ghossein, D. Penumadu, U. Vaidya, and M. Theodore, "Low cost textile-grade carbon-fiber epoxy composites for automotive and wind energy applications," *Compos. Part B Eng.*, vol. 198, no. May, p. 108156, 2020, doi: 10.1016/j.compositesb.2020.108156.

NOMENCLATUR

a	initial crack	,mm
B	width specimen	,mm
f	Function	(-)
K_{1c}	Stress Intensity Factor	MPa.m$^{1/2}$
P	Loads	, N
(*%wt*)	weight fraction	(-)
W	width	,mm
x	a/W	(-)