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Enhancing the Crack Resistance of Polyester Resin Composites with Rice Husk Fiber Reinforcement

Nusyirwan Nusyirwana*, Yul Hijar, and Adam Malik
Department of Mechanical Engineering, Universitas Andalas, Padang, Indonesia, 0751-72564/Fax: 0751-72566
*Corresponding Author: nusyirwan1802@gmail.com

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ABSTRACT

Polymers have been widely developed as alternative materials to replace metal materials due to various advantages such as low density and an easy manufacturing process. Still, polymers have many disadvantages, including not having high mechanical strength, easy to crack when hit by impact. One of the materials studied is an unsaturated polyester polymer widely used for composite matrices in vehicle structural components, aircraft and ship bodies, and vehicle components. One of the studied fibers is rice husk particle fiber. The study of cracks is crucial because it causes the material to no longer be able to support the load according to the previous plan and causes failure to occur more quickly. One way to overcome material failure due to cracks in the composite material is to prevent crack propagation by adding reinforcing material. In this study, a composite material was made using rice husk fiber to increase the crack resistance of the polyester composite matrix. From the results of crack testing, there is a tendency to increase the percentage of rice husks by 5%, 10%, 15%, and 20%. The value expected to be obtained for determining the crack resistance of the material is the value of the stress intensity factor (K_1). The largest K_1 value was obtained at the variable percentage of rice husk 15% with MMA as much as 10% and MEKP 4% obtained a stress intensity factor of 1,558 MPa.m$^{0.5}$; this value can increase the value of the stress intensity factor of pure polyester K1 by 0.667 MPa.m$^{0.5}$ which shows an increase of 233.58%.

Keywords: Stress-Intensity, Polyester, Rice-Husk-Particle-Fiber

ABSTRAK

Bahan polimer telah banyak dikembangkan sebagai bahan alternatif untuk menggantikan bahan logam berbagai keunggulan seperti memiliki kepadatan yang rendah, dan proses pembuatannya yang mudah. Polimer memiliki banyak kelemahan diantaranya tidak memiliki kekuatan mekanik yang tinggi, mudah retak saat terkena benturan. Salah satu bahan yang diteliti adalah polimer poliester tak jenuh yang banyak digunakan untuk matriks komposit pada komponen struktural kendaraan, badan pesawat dan kapal, serta komponen kendaraan. Salah satu serat yang diteliti adalah serat partikel sekam padi. Kajian retakan penting karena menyebabkan material tidak lagi dapat menopang beban sesuai rencana sebelumnya dan menyebabkan kegagalan terjadi lebih cepat. Salah satu cara mengatasi kegagalan material akibat retakan pada material komposit adalah dengan mencegah perambatan retak dengan menambahkan bahan penguat. Pada penelitian ini, dibuat bahan komposit menggunakan serat sekam padi untuk meningkatkan ketahanan retak matriks komposit poliester. Dari hasil crack testing, terdapat kecenderungan peningkatan persentase sekam padi sebesar 5%, 10%, 15%, dan 20%. Nilai yang diharapkan diperoleh untuk menentukan ketahanan retak material adalah nilai faktor intensitas tegangan (K_1). Nilai K_1 terbesar diperoleh pada persentase sekam padi 15% dengan MMA sebanyak 10% dan MEKP 4% diperoleh faktor intensitas tegangan sebesar 1.558 MPa.m$^{0.5}$, nilai ini dapat meningkatkan nilai faktor intensitas tegangan polimer murni K1 sebesar 0,667 MPa.m^{0,5} yang menunjukkan peningkatan sebesar 233,58%.

Kata kunci: Stres-intensitas, faktor; Poliester, Sekam padi- partikel- serat

1. Introduction

One of the aims of technological developments in polymers is to find alternative materials to replace metal materials for the construction components of vehicles, ships, and airplanes [1][2]. This is done because metal materials have a high specific gravity, so they require a large amount of driving energy when used for this purpose[1] [3][4]. One of the materials chosen is polymer because polymers have a low specific gravity. However, not all construction components can be replaced by polymers[2][5][6]. The problem is that polymers have many weaknesses, including low mechanical strength, easy to crack, and cannot withstand high temperatures[4][7]. One of the polymers that is widely used as a matrix in composites is polyester and vinyl ester[5][8]. However, polyester has a relatively low price compared to vinyl ester. Efforts to increase the mechanical strength of polymers have been carried out, including reinforcing with synthetic fibers or natural fibers [4][9][10]. This material has good mechanical properties when combined with fiber as reinforcement to form a composite material [11][12].

Another method to strengthen polymers is to combine two polymers that have almost similar properties, for example, mixing polyester with vinyl ester [9][13][14]. In its application, composite materials still have many weaknesses, including not being resistant to impacts, which can result in cracks, which are the main triggers for failure[15][16]. One of the things studied in this study is how to increase the crack resistance of unsaturated polyester polymers against various mixtures of rice husk fiber (SP) added reinforcements. Previous studies have discussed the improvement of the mechanical properties of polyester against tensile loads, impact loads, and bending loads[3][8][9]. In previous research, rice husk composite material was cracking with a content of 20% with an epoxy matrix, and the crack strength was 2.5 MPa. m0.5 was obtained[17]. However, no information discusses the increase in crack resistance of this unsaturated polyester polymer against rice husk fiber reinforcement against the crack resistance of composites with an unsaturated polyester matrix[10][18][19]. Therefore, this research will aim to increase the crack resistance of polyester material by reinforcing it with rice husk fiber particles for various specific mixture percentages [9][14]. One of the aspects examined in this study is the enhancement of crack resistance in unsaturated polyester polymers through various reinforcing mixtures incorporating rice husk fiber. The selection of rice husks for this purpose is based on their availability as agricultural waste, making them a sustainable and environmentally friendly composite material. In previous studies, the particle dimensions of the rice husk used have not been explained, and the material used is epoxy resin instead of unsaturated polyester.

2. Materials and Methods

2.1. Materials

In this study, the crack resistance of polyester polymers was strengthened with rice husk particle reinforcement to obtain a composite material that has good crack resistance properties from polyester polymers with the addition of reinforcement[6][9][20]. The materials used in this study include:

a. Polyester is commonly used as a matrix in composite materials, particularly when combined with rice husk fiber particles, to enhance crack resistance. It is known for its good mechanical properties and affordability [4][5]. In this study, the type of polyester used is unsaturated polyester, specifically the Yukalac 1560 BL-EX product. The mechanical properties of polyester are presented in Table 1;

Table 1. Mechanical Properties of Polyester[9]

Item	Unit	Value
Tensile strength	MPa	20-100
Tensile modulus	GPa	2.1-4.1
Ultimate strain	%	1-6
Poisson's ratio	-	-
Density	g/cm^3	1.0-1.45
T_g	˚C	100-140
CTE	10^{-6}/˚C	55-100
Cure Shrinkage	%	5-12

b. The rice husk is the outermost part of rice grains, a by-product of rice milling. One of this study's objectives is to use rice husk to increase the crack resistance of polyester composite materials. The chemical composition of rice husk consists of active silica (SiO_2) with a reasonably high content, namely 94-96% of rice husk ash, other components, CaO, MgO, Al_2O_3, and NaO_2, so from the chemical composition of rice husk, it can be used as one source of raw materials for silica-based materials (Table 2). In this study, rice husks were finely ground with a grinding machine and then filtered with a better sieve with a sieve hole of 300 micrometers.

Figure 1. Fiber from rice husk particles.

Table 2. Composition of rice husk

No	Component	Percentage Content(%)
1	Water content	9.02
2	Crude protein	3.03
3	Fat	1.18
4	Crude fiber	35.68
5	Ash	17.71

c. Methyl methacrylate, often called MMA, is a polymer material with biocompatible properties, making MMA a research material in biomedical material literature studies[21]. MMA molecules that are combined in the bond chain lead to the distance between bonds in the polyester bonds, reducing the stiffness of the polyester network structure [7]. MMA is a colorless polymer material with a relatively low cost[5]. The advantages of adding MMA to an alloy are that it produces a non-toxic material, has relatively lower costs, is easy to process, is compatible, and can be used to process materials with high fracture resistance[22]. Mixing MMA with thermosetting resins can reduce the viscosity of the polymer blend[23]. Adding MMA here is expected to make the polyester network structure homogeneous. Previous studies found an impact value increase by adding 10% MMA[3]. MMA is a diluent material in the form of a liquid that functions so that polyester can bond well with rice husk fibers. MEKP is in the form of a liquid and functions as a catalyst to accelerate the coagulation of polyester.

d. The catalyst used is the methyl ethyl ketone peroxide (MKEP) produced by PT. Justus Kimiaraya. The function of the catalyst is to accelerate the drying rate of polyester. The use of a catalyst is 4% of the polyester blend[3].

2.2. Methods

In this study, a crack test was conducted on polyester composite material reinforced with rice husk fiber by providing notch grooves and initial cracks. The test material will be subjected to vertical tensile loading on both sides, gradually increasing until the maximum load the material can withstand is reached until it experiences total cracking or maximum material fracture toughness, according to ASTM Standard D5405[24]. The stress intensity factor is the magnitude of the stress distribution that occurs at the crack tip for a material that is given an initial defect. The magnitude of the stress intensity factor of a material with specific dimensions against the load given until the material experiences total cracking is called the critical stress intensity factor; this term is known as fracture toughness, symbolized by (K_{1C}).

In this study, composite materials were made from a polyester matrix with rice husk particle reinforcement with the ratio of polyester to rice husk particles as follows: 100%: 0%, 95%: 5%, 90%: 10%, 85%: 15% and 80%: 20% each mixture will be compared fracture toughness against all percentages of the mixture made and will be compared with pure polyester without reinforcement. This section explains the steps for making rice husk particle polyester composite specimens. The procedure for preparing the composite specimen begins with preparing the rice husk, polyester, and MMA. The mixture consists of 5% rice husk, 95% polyester, and 10% MMA as a catalyst, with variations in rice husk content at 10%, 15%, and 20%. The components are dissolved using a hot plate magnetic stirrer at 600 rpm and 60°C for 90 minutes, followed by a cooling period of 60 minutes. The mixture is then stirred again using a hot plate magnetic stirrer for 3 minutes before being poured into the crack test specimen mold. Finally, the specimens are left to dry at room temperature for 24 hours.

2.3. Testing Procedure

The crack testing was conducted by applying a two-sided vertical tensile load at a pulling speed of 4 mm/min, as this speed aligns with the standard for crack research based on previous studies. Exceeding this speed may introduce dynamic effects, potentially affecting the accuracy of the results.

A hot plate magnetic stirrer was utilized to ensure uniform mixing of the matrix and reinforcement, with adjustable temperature settings to optimize composite formation. The specifications of the hot plate magnetic stirrer used in this study are as follows: Daihan Scientific Brand, Model MS-H280-Pro, working temperature range of 25–280°C, and rotation speed of 0–1500 rpm.

The crack testing machine was employed to evaluate the crack resistance of the composite samples, following the ASTM D5405 standard. The dimensions of the test specimens are shown in Figure 2. The crack strength properties of the composite materials were analyzed by inputting the necessary material specification data into the testing system. The specifications of the crack testing machine are as follows: COM-TEN Testing Machine 95T Series 5K, 5000-pound capacity, Load Cell Model TSB0050, equipped with a touch screen display monitor (Figure 3).

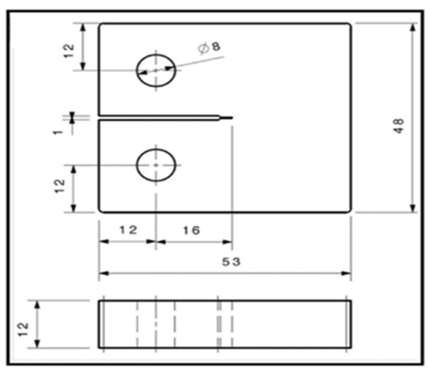

Figure 2. Dimensions of test specimens according to ASTM D5405 standard.

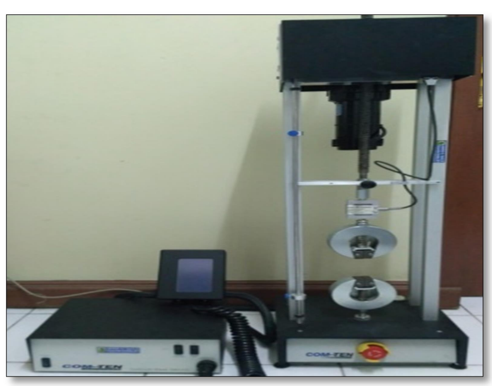

Figure 3. COM-TEN 95T series 5K crack testing machine.

Following the completion of the crack testing process, the obtained measurement data were analyzed using Equations (1) and (2).

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

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

Symbol description:
K_{1c} = Stress intensity factor (MPa.m $^{0.5}$)
P = Maximum load (kN)
B = Specimen thickness (cm)
W = Specimen width (cm)
a = Crack length (cm)

3. Results and Discussion

3.1. Mechanical Properties of Polyester Mixture with Rice Husk

The main work in this study was to produce a mixture of polyester composite (UP) with rice husk particles (RS) and MKEP and MMA catalysts according to the percentage of each mixture and freeze the material at room temperature according to the composition of the mixture shown in Table 1. The composite mixture was molded and dried for 3 days to produce a transparent, dense, hard, stiff material, as shown in Figure 4. from the cured mixture. The drying time increased with the increase in the vinyl ester composition in the mixture. The main work in this study was to produce a mixture of polyester composite (UP) with rice husk particles (RS) and MKEP and MMA catalysts according to the percentage of each mixture and freeze the material at room temperature according to the composition of the mixture shown in Table 3. The composite mixture was molded and dried for 3 days to produce a transparent, dense, hard, stiff material, as shown in Figure 4. from the cured mixture. The drying time increased with the increase in the vinyl ester composition in the mixture.

Table 3. Composition of the mixture.

Sample No.	UP (wt %)	RS (wt %)	MMA (wt %)	MEKP (wt %)
1	100	0	10	4
2	95	5	10	4
3	90	10	10	4
4	85	15	10	4
5	80	20	10	4

Figure 4. Molded polyester composite material.

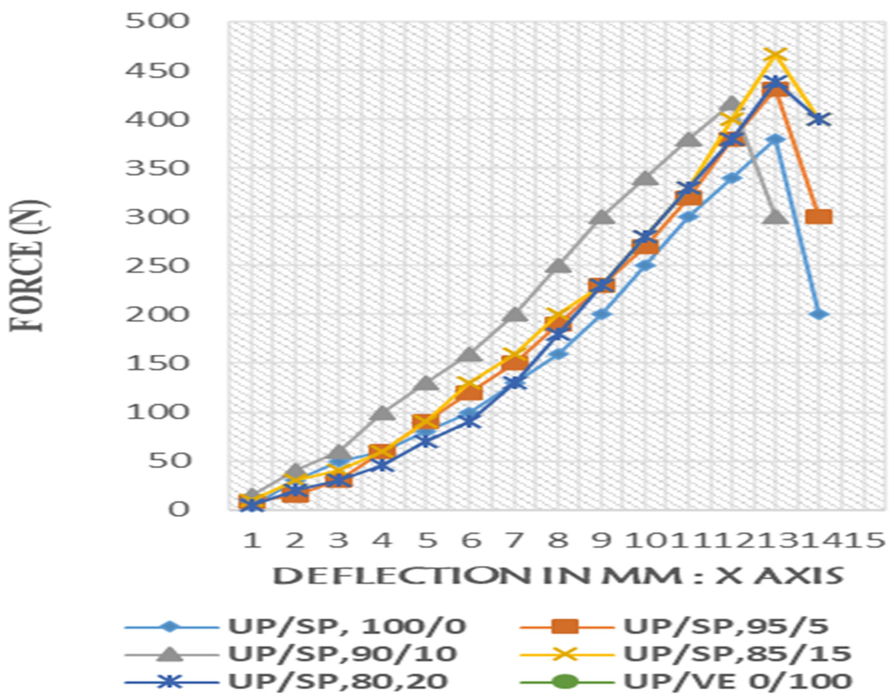

Figure 5. Load vs. crack opening displacement (COD) curves.

The stress intensity factor ($K_{1}c$) of molded polyester (UP) blended with rice husk (RS) was evaluated using a compact stress (CT) configuration. The CT specimens were prepared following the ASTM D5045 standard, as illustrated in Figure 2. Based on prior studies, the loading rate was set to 4 mm/min to prevent dynamic effects that could influence the accuracy of the measurements. The relationship used to calculate $K_{1}c$ is shown in Equation (1). Figure 5 presents the fracture load versus displacement curves obtained from the crack testing machine (CT) for various RS and MMA blend compositions. The results indicate that pure polyester (UP) is brittle, forming straight-line cracks upon failure, whereas blended polyester mixtures containing vinyl ester exhibited different cracking behaviors. The crack propagation behavior observed in the load-crack curve was influenced by the mixture proportion. Before reaching the maximum load, the curve exhibited a linear trend, as shown in Figure 5. Also, based on the results, unsaturated polyester/vinyl ester (UP/VE) (0/100) serves as a benchmark material, demonstrating superior crack resistance and mechanical strength compared to UP/SP composites, indicating that while rice husk reinforcement enhances polyester performance, it does not fully match the toughness and structural integrity of pure vinyl ester.

Table 4. Maximum cracking load of composites with rice husk.

No	Composition of Material (%)	Load (N)
1	UP/RS,100/0	379 ± 11.136
2	UP/RS,95/5	431 ± 15.036
3	UP/RS,90/10	417 ± 11.136
4	UP/RS,85/15	466 ± 7.603
5	UP/RS,80/20	438 ± 13.219

Table 4 presents the maximum cracking load for different composite formulations. The table illustrates how different ratios of UP to RS influence the material's ability to withstand cracking loads before failure. The values are reported in Newtons (N) along with their respective standard deviations, which indicate the variability in the measured cracking load. The incorporation of RS up to 15% enhances the crack resistance of UP composites, with UP/RS, 85/15 showing the best performance. However, increasing RS content beyond 15% slightly reduces the cracking resistance, likely due to fiber saturation or imperfect bonding.

These results indicate that a balanced RS-to-UP ratio is crucial for achieving optimal mechanical performance in the composite material.

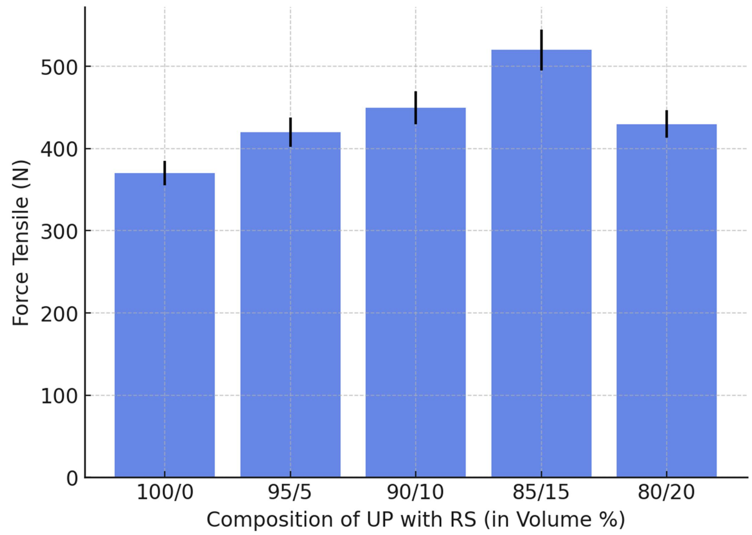

Figure 6. Crack-causing load of polyester mixture with rice husk.

The tensile strength of the polyester-rice husk (UP/RS) composites was evaluated to determine the effect of rice husk reinforcement on mechanical properties. Figure 6 shows that pure polyester (UP/RS 100/0) exhibits the lowest tensile force, indicating its brittle nature. Adding rice husk improves the tensile strength, reaching the highest value at 85/15 composition, suggesting optimal reinforcement and load distribution within the composite. However, a slight decrease in tensile force is observed at 80/20, likely due to fiber agglomeration or weak interfacial bonding between the rice husk and the polyester matrix. These results indicate that adding up to 15% of rice husk enhances the mechanical properties of polyester, making it a viable reinforcement material for improving composite strength.

3.2. Crack Testing and Mechanical Strength

The crack test was performed using a COM-TEN 95T Series 5K crack testing machine (Figure 3). The specimens were subjected to a two-sided vertical tensile load with a pulling speed of 4 mm/min, following ASTM D5045. The tensile strength and crack resistance of polyester composites were analyzed based on their load-bearing capacity and fracture toughness ($K_{1}c$).

The addition of RS composition up to 15% increased the tensile strength of the UP/RS composite. However, beyond 20% RS composition, the cracking strength decreased due to the saturation of polyester with rice husk fiber reinforcement, as shown in Table 4.

3.3. Effect of Rice Husk on Fracture Toughness

Table 4. Maximum cracking load of composites with rice husk.

No	Material	Fracture toughness $MPa.m^{0.5}$	Standard deviation
1	UP/RS,100/0	0.667	± 0.036
2	UP/RS, 95/5	1.227	± 0.089
3	UP/RS,90/10	1.260	± 0,173
4	UP/RS,85/15	1.558	± 0,242
5	UP/RS,80/20	1.270	± 0,224

Table 5 presents the critical stress intensity factor ($K_{1}c$) values for polyester composites with different RS contents. The highest $K_{1}c$ value (1.558 $MPa.m^{0.5}$) was obtained at 15% RS and 10% MMA, indicating optimal reinforcement. However, increasing RS content to 20% led to a slight reduction in $K_{I}c$, suggesting that excessive RS loading may hinder the bonding between polyester molecules and rice husk fibers.

4. Conclusion

This study successfully determined the optimal composition of a polymer blend using an unsaturated polyester (UP) matrix reinforced with rice husk (RS) fiber and methyl methacrylate (MMA) to enhance the fracture toughness and crack resistance of pure polyester materials. The addition of 15% RS and 10% MMA resulted in the highest critical stress intensity factor ($K_{I}c$ = 1.558 MPa.m$^{0.5}$), significantly improving the toughness of the polymer blend compared to pure polyester ($K_{I}c$ = 0.667 MPa.m$^{0.5}$). The improved fracture toughness of this composite makes it a promising material for engineering applications, particularly in vehicle components, tourist boat bodies, and fishing boats, where high crack resistance is crucial. Compared to previous studies, the use of unsaturated polyester as the matrix material led to a slight deviation in $K_{I}c$, achieving 1.558 MPa.m$^{0.5}$ instead of 2.5 MPa.m$^{0.5}$ reported in the literature. This difference of only 0.56% suggests that the selected formulation effectively enhances the material's mechanical properties while maintaining comparable toughness. This research demonstrates that combining RS and MMA as reinforcements significantly increases the toughness and crack resistance of unsaturated polyester, making it a viable alternative for high-performance composite applications.

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