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Effect Of Post-Curing Treatment Temperature On The Tensile Strength And Impact Resistance Of Coconut Fiber-Reinforced Polyester Composites

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Abstract:
Composite material is an engineered material created by combining two or more materials to produce enhanced mechanical properties compared to its constituent materials. This study focuses on natural fiber composites using coconut fiber as reinforcement with a polyester matrix. Post-curing treatment is applied to improve the mechanical strength of the composite. Post-curing is a heating process at a specific temperature aimed at enhancing the properties of the composite. The purpose of this research is to determine the effect of post-curing temperature on the impact strength of polyester-coconut fiber composites. The specimens were fabricated using the mixing method for material blending and hand lay-up for composite formation, following the standards of ASTM D638-02 Type I and ASTM D256 for impact testing. The specimens were heated in an oven at various temperatures: non-post curing, 110°C, 120°C, and 130°C, each for one hour. Impact testing was conducted using a Mory Testing Machine. The results showed that the composite with a post-curing temperature of 120°C achieved optimum tensile strength of 9.2 N/mm² and impact strength of 0.1663 J/mm². Based on these findings, the polyester-coconut fiber composite can be used as material for particleboard type 100 and meets the SNI 03-2105-1996 standards for tensile and impact strength. Additionally, this composite has the potential to be used as an alternative material for manufacturing SNI-standard helmet.

Keywords: *Coconut Fiber Composite; Post Curing; Tensile Strength; Impact Strength; Polyester; Temperature.*

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I. Introduction

The development of material technology has advanced significantly, with natural fibers emerging as strong candidates for reinforcing materials to produce composites that are lightweight, strong, environmentally friendly, and cost-effective [1]. This has led to natural fiber composites gradually replacing glass fiber and metal composites [2]. Recent research focuses heavily on sustainability principles, global environmental efficiency, and green chemistry, requiring integration across materials, process development, and products [3]. The use of metal materials in various product components is declining [4], largely due to the heavy weight of metal components, the difficulty in shaping them, their susceptibility to corrosion, and the high production costs [5]. Consequently, alternative materials with properties similar to metal are being explored, one of which is composite materials.

Composites are a combination of two or more materials that merge into a unified whole, offering improved properties over their individual components [6]. Composite materials have introduced numerous innovations in engineering, including enhanced durability, longer service life, higher strength, lower weight, corrosion resistance, and ease of maintenance [7]. These characteristics have made composites highly attractive in engineering applications, particularly in the transportation sector, where they contribute to significant reductions in energy consumption and are environmentally friendly [4], [5], [8]. The production of composites involves two key components: fiber and matrix [6], [9]. The fiber serves as the reinforcing element, transmitting the load carried by the matrix and thereby determining the mechanical properties of the composite [10]. Fibers can be categorized into synthetic fibers and natural fibers [9] with the industry predominantly using fiberglass (synthetic fibers) as the main reinforcing material for composites [11], [12],[13]. However, fiberglass is costly, non-degradable, and requires complex chemical processing [6]. In contrast, natural fiber-reinforced composites offer numerous advantages, such as renewability, recyclability, environmental safety, and lower cost [14].

Indonesia has an abundance of natural fibers, one of which is coconut coir fiber [15], [10], [16]–[18]. Coconut fiber offers several advantages, such as strength, elasticity, resistance to microbes, and biodegradability [19], [20] The mechanical strength of composites is influenced by factors such as fiber distribution, interaction with the matrix, fiber size, and shape. Coconut fiber, rich in lignin, exhibits unique and beneficial properties [21], [22]. To assess the mechanical properties of composites, tensile testing and impact testing will be conducted following ASTM D638 and D256 standards, respectively [23]. These standards are commonly used to evaluate the tensile and impact strength of thermoplastic-based composites, including polyester composites (Kumaraswamy et al., 2020), ensuring the results can be validly compared with other studies [24], [25]. Previous research has consistently shown that curing temperature and fiber length play key roles in enhancing composite quality [26]. Found that oven curing at 100°C produced the highest tensile strength, likely due to the complete evaporation of water, improving adhesion between the fiber and matrix [27].

Highlighted the importance of fiber volume fraction and fiber length, with a higher fiber volume providing more uniform load distribution and improving bending strength [28], [29]. Longer fibers allow for more effective load transfer between the matrix and fibers, reducing material fractures[30]. Thus, optimizing curing temperature, fiber volume fraction, and fiber length can significantly enhance both tensile and bending strength of composites. This combination of factors indicates that proper manufacturing processes can yield optimal composite performance, meeting industry demands for strong, durable materials. Future research should explore other curing temperature variations and further investigate fiber length and matrix interactions. Against this background, the author is interested in investigating further in the thesis titled "The Effect of Post-Curing Treatment Temperature on the Tensile Strength and Impact Strength of Coconut Coir Fiber-Reinforced Polyester Composites." This study aims to explore the influence of post-curing temperature on the tensile strength of composites using coconut coir fiber, as well as to provide deeper insights into the potential use of natural fibers in developing sustainable composite materials.

II. Material And Methods

When developing, manufacturing, and printing composites, as well as testing tensile and impact strength, these activities were conducted at PT Pupuk Sriwijaya Tbk and the Department of Mechanical Engineering, Master's Program, Faculty of Engineering, Sriwijaya University, South Sumatra, Indonesia. The materials used during the tests were polyester resin reinforced with coconut fiber with four variations of post-curing temperatures, namely non-post-curing, 110°C, 120°C, and 130°C. Additionally, the solvent used was 5% NaOH solution, with MEKPO catalyst and Aquades. The heating process was carried out in an oven for 1 hour to ensure the solidification of the composite. The method involved mixing materials to produce a homogeneous composite. In this study, the mixing process was conducted for an unspecified duration to ensure uniformity, after which the composite was cast before tensile and impact strength testing was performed. The results of this study are expected to provide a better understanding of the effect of post-curing temperature on the mechanical properties of polyester composites reinforced with coconut fiber.

Figure 1 Coconut Coir Fiber.

After the forming process is completed, the polyester resin produced in the form of flat sheets is shaped into samples according to the planned tests. In this study, three types of tests were conducted: tensile testing, impact testing, and results documentation..

Tensile test:

Tensile test was conducted to determine the mechanical properties of the polyester resin. Before testing the membrane, the test samples were measured according to the standard. The testing equipment used is the ASTM D638-02 type 01 tensile testing machine. The samples used in this tensile test consist of 9 samples. There are three samples for each temperature concentration, namely non-post curing, 110°C, 120°C, and 130°C, each with three samples. Each sample is made from a mixture of resin with a composition of 30 percent and polyester 70 percent. The dimensions of the ASTM D 638-02 Type I tensile test specimen can be seen in the figure below.

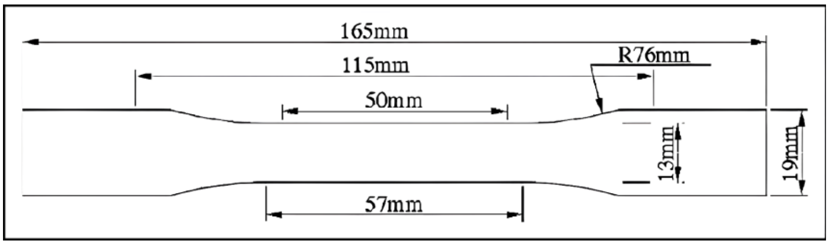


Figure 2. Dimensions of ASTM D 638-02 Type I Tensile Test Specimen (ASTM Book)

Impact Test:

Impact test is conducted to determine the mechanical properties of the polyester resin. This test aims to measure the material's resistance to sudden loads and to assess how well the material can absorb energy before failure occurs. Before testing the membrane, the test samples are measured according to the standard. The testing equipment used is the ASTM D256 impact testing machine. The samples used in this impact test consist of 9 samples. There are three samples for each temperature concentration, namely non-post curing, 110°C, 120°C, and 130°C, each with three samples. Each sample is made from a mixture of resin with a composition of 30 percent and polyester 70 percent. The dimensions of the ASTM D 256 impact test specimen can be seen in the figure below.

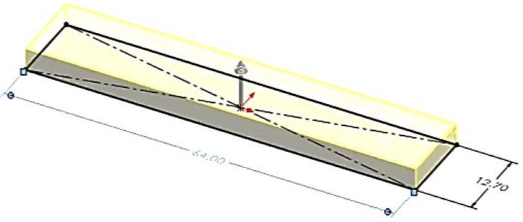


Figure 3. Dimensions of ASTM D 256 Impact Test Specimen (ASTM Book)

Photomacro Test:

Macro photos taken during both tests, namely the tensile test and the impact test, provide a high-resolution view of the surface structure of the polyester resin samples after testing. In the tensile test, the macro photos illustrate how the fibers within the resin interact under load and highlight potential cracks that emerge due to deformation. Meanwhile, in the impact test, the macro photos reveal the damage area that occurs on the sample as a result of the impact, offering insights into the material's resistance to sudden pressure. Visual analysis through high-resolution macro photography using a smartphone is essential for understanding the mechanical behavior of materials and can aid in the development of better composites in the future.uses 1 sample for each polymer concentration of polyethersulfone and silver nitrate. The macro photos of the polyester resin samples after testing provide detailed insights into their structural integrity. The first photo shows the surface of the sample post-tensile test, highlighting deformations and the emergence of small cracks due to applied load. The second photo captures the damage area on the sample after the impact test, revealing deep dents and cracks originating from the impact point, indicating how well the material absorbs energy. Comparing these figures enhances our understanding of the mechanical behavior of the material under different testing conditions.

Figure 4. Photmacro of Specimen

III. Result

Tensile and impact tests were conducted to evaluate the mechanical properties of polyester resin with variations in post-curing temperatures. In the tensile test, the samples exhibited variations in mechanical strength depending on the applied temperature, with some samples showing the highest strength. Meanwhile, the impact test revealed that the resin's resistance to sudden loads was also influenced by the post-curing temperature, with some samples demonstrating the best energy absorption capabilities. Thus, the post-curing process plays a crucial role in enhancing the interaction between the fibers and the resin matrix, resulting in stronger and more durable materials. he results of the tensile test, impact test, and macro photos are as follows:

Tensile Test

The table below presents the results of the tensile test for all post-curing temperatures:

Table 1 Tensile Test of All Temperature

Temperature (ºC)	Stress (σ)	F_{max} (N)	A_0 (mm^2)	L_0 (mm)	T (mm)
Non Post Curing	6	900	150	50	3
	6,13333333	920	150	50	3
	6,53333333	980	150	50	3
110 ºC	7,33333333	1100	150	50	3
	7,86666667	1180	150	50	3
	7,33333333	1100	150	50	3
120 ºC	9,26666667	1300	150	50	3
	9,26666667	1290	150	50	3
	9,06666667	1290	150	50	3
130 ºC	8,66666667	1390	150	50	3
	8,6	1390	150	50	3
	8,6	1360	150	50	3

Table above illustrates the relationship between post-curing temperature and the stress experienced by the polyester resin samples. Generally, increasing the post-curing temperature tends to enhance the maximum stress achieved by the samples. The samples tested at 120°C exhibited the highest stress, reaching 9.27 MPa, while those at non-post-curing temperatures showed lower maximum stress compared to the higher temperatures. This indicates that the post-curing process positively influences the mechanical strength of the polyester resin. and the graph can be seen in the figure below:

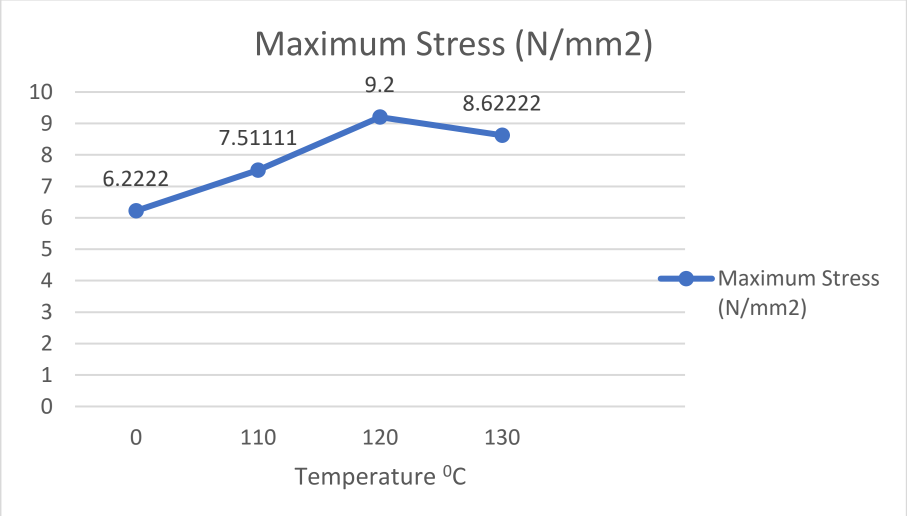


Figure 5. Graph of Tensile Stress of All Temperature

The graph above illustrates the relationship between post-curing temperature (in degrees Celsius) and maximum stress (in N/mm²) of the polyester resin. The graph shows that maximum stress tends to increase with rising post-curing temperatures, reaching a peak of 9.2 N/mm² at 120°C. However, after 120°C, there is a decline in maximum stress, indicating that there is an optimal threshold in the post-curing process that affects the mechanical strength of the polyester resin.

Impact Test

The table below presents the results of the Impact test for all post-curing temperatures:

Table 3 Impact Test of All Temperature

Temperature ^{0}C	***α*** **(^{0})**	***θ*** **(^{0})**
Non Post Curing	90	84,9
	90	84,8
	90	84,8
110^{0}C	90	84,4
	90	84,4
	90	84
120^{0}C	90	83
	90	83
	90	82,4
130 %	90	83,7
	90	83,8
	90	83,8

The table presents the results of angle measurements (α and θ) at various post-curing temperatures for the polyester resin. At non-post-curing conditions, the angles are consistently around 84.8 to 84.9 degrees. As the temperature increases to 110°C, the angles slightly decrease to around 84.0 to 84.4 degrees. At 120°C, the angles show a more significant reduction, ranging from 82.4 to 83.0 degrees. Finally, at 130°C, the angles stabilize between 83.7 and 83.8 degrees. This trend indicates that increasing post-curing temperatures may affect the orientation or arrangement of the resin, leading to variations in the measured angles.

Table 4 Average Impact Energy Value

Temperature	**E$_1$ (kg m)**	**E$_2$ (kg m)**	**E (E$_1$ – E$_2$) (Joule)**	**W (E/A$_0$) (J/mm^2)**	**E Average (J)**	**W Average (J/mm^2)**
Non Post Curing	171,317	156,089	15,228	0,1180	15,4271	0,1195
	171,317	155,791	15,526	0,1203		
	171,317	155,791	15,526	0,1203		
110^{0}C	171,317	154,600	16,717	0,1295	17,1135	0,1326
	171,317	154,600	16,717	0,1295		
	171,317	153,411	17,906	0,1387		
120^{0}C	171,317	150,441	20,876	0,1617	21,4701	0,1663
	171,317	150,441	20,876	0,1617		
	171,317	148,661	22,656	0,1755		
130^{0}C	171,317	152,519	18,798	0,1456	18,5999	0,1441
	171,317	152,817	18,500	0,1433		
	171,317	152,817	18,500	0,1433		

The table presents the energy values (E1 and E2) and calculated differences (E) for polyester resin samples at various post-curing temperatures. At non-post-curing conditions, the energy difference averages around 15.5 Joules, with an average stress value (W/A0) of approximately 15.43 J/mm². As the temperature increases to 110°C, the energy difference rises to an average of 16.7 Joules, with stress values averaging about 17.11 J/mm². At 120°C, the energy difference significantly increases to around 20.88 Joules, reflecting a higher average stress of approximately 21.47 J/mm². However, at 130°C, while the energy difference decreases to 18.80 Joules, the average stress remains relatively high at about 18.60 J/mm². This trend suggests that increasing post-curing temperatures generally enhance energy absorption and stress resistance in the polyester resin, up to an optimal temperature range. and the graph can be seen in the figure below:

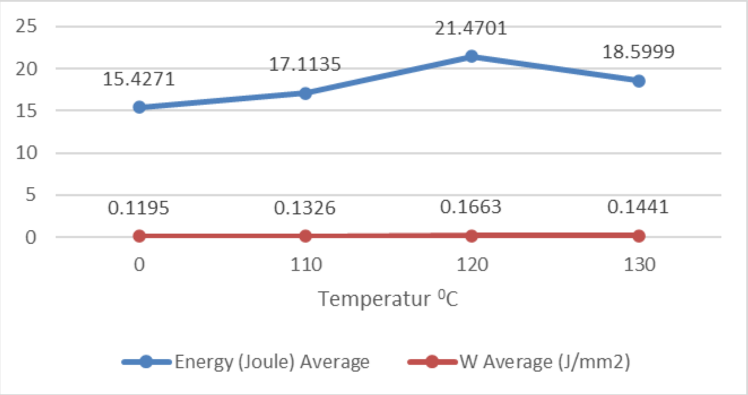


Figure 6. Graph of the Relationship Between Average Impact Energy (E), Impact Price (W), and Variations in Volume Fraction Comparison

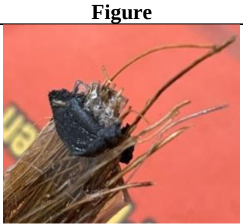
The graph above illustrates the relationship between average impact energy (in Joules) and impact price (W Average in J/mm²) against variations in post-curing temperature (in degrees Celsius). The graph shows that the average impact energy increases with rising temperatures, peaking at 21.47 Joules at 120°C. Meanwhile, the impact price (W Average) remains relatively stable, fluctuating between approximately 0.12 and 0.17 J/mm² across the tested temperature range. This indicates that the post-curing process influences the energy absorbed by the polyester resin, although its effect on the impact price does not show significant changes.

Photomacro View

The photomacro view of coconut fiber reveals its intricate structure, showcasing the unique properties that contribute to its performance in both impact and tensile tests. The fibrous texture and natural variations in diameter enhance the mechanical strength of the polyester resin composite, providing a robust reinforcement that is evident in the test results. Observing the fiber under magnification allows for a better understanding of how its physical characteristics influence the composite's overall performance.Photomacro Specimen test can seen in the figure below:

Figure 7. Specimen of Tensile and Impact Testing

Table 4 Photomacro of Testing

Temperature (^{0}C)	Figure
Non Post Curing	
10	
120	

130	

The tensile test results indicate that increasing the heating temperature affects the maximum tensile stress, which rises from non-post curing conditions up to 120°C. However, at 130°C, there is a decrease in tensile strength, likely due to weaker bonding among the components when using coconut fiber above 120°C. The relationship between tensile stress and volume fraction variations reveals that exceeding 120°C leads to reduced tensile strength in the specimens. While coconut fiber contributes significantly to the tensile strength of the polyester resin matrix, excessive heat may compromise these bonds. The detailed structure of the coconut fiber shown in the photomacro reinforces this finding, highlighting its relevance to the mechanical properties of the composite.

IV. Discussion

The tensile test results on composite materials based on a polyester resin matrix reinforced with coconut fiber indicate that increasing the temperature to 120°C can enhance the maximum tensile stress up to 9.2 N/mm². However, when the temperature is raised to 130°C, the tensile stress decreases to 8.62 N/mm². This suggests that temperatures above 120°C can weaken the bonding strength between composite materials, negatively impacting the material's performance. Although coconut fiber can strengthen the composite, using it at excessively high temperatures may lower the quality of the material.

Based on the impact test results, the average impact energy (W) values across varying volume fractions show a trend of increase. The impact energy value at non-post curing conditions was 0.1195 J/mm², increasing to 0.1326 J/mm² at 110°C, and reaching 0.1663 J/mm² at 120°C. However, at 130°C, there was a decrease to 0.1441 J/mm². A significant increase in impact energy values occurred up to 120°C, while the use of coconut fiber as a reinforcement at 130°C resulted in a decline in both energy and average impact values. Photomicrographs of the composite revealed the structural characteristics of the coconut fiber and its interaction with the polyester matrix, showcasing the effective reinforcement provided by the fibers.

From the research findings, the optimum tensile and impact strength obtained were 9.2 N/mm² and 0.1663 J/mm², respectively, at 120°C. With these values, the coconut fiber composite with a polyester matrix meets the minimum tensile strength requirement set for type 100 particleboard, which is 1.5 kg/cm², in accordance with the SNI 03-2105-1996 standard. Additionally, this composite has the potential to be an alternative material in the production of SNI helmets, as it closely approaches the required tensile strength of 10 N/mm² .

V. Conclusion

Based on the research conducted on composite materials with a polyester resin matrix reinforced with coconut coir fiber using the hand lay-up method, it was concluded that this composite exhibits good mechanical performance. With post-curing temperature variations of 110°C, 120°C, and 130°C, and random fiber orientation, tensile and impact testing were conducted according to ASTM D638-02 for tensile strength and ASTM D256 for impact. The optimal results were achieved at a temperature of 120°C, with a tensile strength of 9.2 N/mm² and an average impact value of 0.166 J/mm². Increasing the amount of coconut coir fiber improves mechanical strength up to the temperature limit of 120°C, after which performance decreases. The composite at 120°C meets the requirements of SNI 03-2105-1996 standards and can be used as an alternative material for type 100 particleboard, and it approaches the tensile strength specification for SNI helmets, which have a tensile strength of 10 N/mm².

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