JURNAL TEKNIK MESIN (JOURNAL OF MECHANICAL ENGINEERING)

VOL. 15, NO. 01, February 2026
https://publikasi.mercubuana.ac.id/index.php/jtm/index
DOI :10.22441/jtm.v15i1.23591

Study on the Flexural Strength of Polyester Composite Beams and Coconut Husk Charcoal Powder

Nusyirwan[1], Hayatul Fikri[1]
[1]Department of Mechanical Engineering, Faculty of Engineering, Andalas University, Padang, 25163, Indonesia

E-mail: nusyirwan1802@gmail.com

Abstract-- *Polymer materials are being rapidly researched because they have the potential to replace metal materials, offering advantages such as low mass, ease of shaping, and moisture resistance. However, this material still has many disadvantages, including low mechanical strength and easy cracking under impact. Unsaturated polyester is a widely used matrix material for composite materials in the engineering field, such as for vehicle bodies and ship hulls. In this study, the flexural strength of polyester composites reinforced by coconut shell charcoal was studied. From flexural strength testing according to ASTM D 390-92, a tendency to increase flexural strength with the addition of a coconut shell charcoal mixture from 10% to 20% was observed; beyond 20%, the flexural stress decreased. The maximum flexural stress value obtained at a percentage of 20% coconut shell charcoal was 132.43 N/mm². This value can increase the maximum flexural stress of pure polyester, which was only 52.10 N/mm², by 253.35%.*

Article History:
Received: October 12, 2023
Revised: November 04, 2025
Accepted: January 14, 2026
Published: January 28, 2026

Keywords: *Polyester, coconut-shell-charcoal, bending tension*

1. INTRODUCTION

The use of composite materials made from polymers reinforced with natural fibers has been widely developed as a substitute for metal materials in the construction industry. These materials are used in transportation equipment such as car bodies and yachts, light vehicles, and other engineering applications [1][2][3]. Replacing metal materials with lighter composite materials can reduce vehicle propulsion energy requirements and significantly lower fuel consumption [4][5][1][3]. Coconut shell charcoal is a byproduct of abundant coconut plantations, but its use has been limited to burning for boiler energy and as a heating source. As raw materials for wooden boat construction become increasingly scarce for fishermen in Indonesia, the manufacture of composites from coconut shell charcoal is an alternative to wood [6][7][8]. Two factors that determine the quality of a composite are its tensile strength and its ability to withstand cracks under load. One advantage of polymer composite materials is their low density and ease of shaping [2][9][10][11]. Several requirements must be met: the polymer must not be prone to cracking [5][12][7]. Polyester resin is one of the materials widely used for the manufacture of composite matrices [9][13]. To strengthen composite materials, synthetic or natural fibers must be added to achieve the desired mechanical strength [14][5][15]. The desired composite material has good mechanical strength and does not cause environmental pollution, i.e., it is easily recyclable and biodegradable [16][17].

Polyester reinforced with synthetic fibers, such as carbon fiber, has seen rapid adoption across luxury cars, airplanes, and other transportation components. [18][14][19]. Composites with synthetic fibers are derived from petroleum, so their use needs to be reduced because they cause side effects that can damage the environment through the waste they produce [20][21].

Several studies have been conducted to develop easily degradable composite materials, one of which involves mixing polyester resin with natural materials derived from empty palm fruit bunches to reduce mass. Another composite material is made by substituting natural materials for synthetic materials, such as hemp fiber, knaff fiber, rice husk fiber, and other natural fibers. Several previous studies have reported that adding CPO oil increases the toughness of polyester, enhancing crack resistance, tensile load, and flexural load [13][4][14][22]. Complete information has been obtained on the improvement of the crack resistance of polyester resin with the addition of rice husk fiber and palm fiber [15][19][23][24].

In this study, the crack resistance properties of polyester resin (unsaturated polyester), denoted as

(UP), were improved by adding coconut shell charcoal (AT) as a reinforcing material to enhance the crack resistance properties of the composite formed from these two materials with various specific mixing percentages.

2. METHODOLOGY

This study uses a monofiber composite consisting of a single type of natural material, uniformly mixed coconut shell charcoal fiber. The method used in this study is the hand-layup method. This manufacturing process involves pouring polyester resin by hand into a mold containing fiber, then applying pressure while smoothing it with a press wheel or a brush. This process is repeated until the required thickness is achieved. The specimen mold is shown in Figure 1.

2.1 Preparation of Research Materials

To form composite materials, two types of materials are needed: a matrix material to form a binder, and natural fibers to strengthen the composite.

2.2 Matrix Materials

The material used in this study is intended to serve as a binding matrix for composite materials made from coconut shell charcoal-derived natural fibers. Polyester and coconut shell charcoal fibers are mixed and stirred to evenly distribute the fibers and improve the composite's flexural strength. The good fiber-binding properties of polyester make this material widely used in engineering construction, and, in terms of price, polyester binding material is inexpensive [5][4]. Some properties of polyester include: easy fiber bonding, moisture resistance, fairly good mechanical strength, high density, and quick drying. The type of polyester used in this study is unsaturated polyester resin (UP), specifically the Yukalac 1560 BL-EX product. The mechanical properties of polyester are shown in Table 1.

Table 1. Physical Properties of Polyester

Item	Unit	Price
Maximum Tensile Strength	MPa	20-100
Modulus of Elasticity	GPa	2.1- 4.1
Ultimate Strain	%	1- 6
Poisson's Ratio	-	-
Density	g/cm^3	1.0 – 1.45
T_g	^oC	100 – 140
CTE	$10^{-6}/^oC$	55 -100
Cure Shrinkage	%	5-12

2.3 Reinforcing Material

To obtain a composite material, a reinforcing fiber is needed. The natural fiber used in this study is derived from coconut shell charcoal (AT) and undergoes a refining process by pounding until it reaches a fineness of 50 microns. The reason for choosing these fibers is that they have not been optimally utilized as coconut agricultural waste, and the excess fibers can be processed into fibers with uniform fineness and sufficient particle density. The charcoal is quite complicated and does not contain bound wax or lignin, so not much purifying material, such as NaOH, is needed. Based on the above reasons, it is expected that the bond strength between the matrix and fiber materials will be well established and uniform, thereby improving the flexural strength of the composite material [22][25][6][10][6].

Figure 2. Finely ground coconut shell charcoal.

$$\sigma = \frac{3PL}{2bh^2} \quad (1)$$

For the processing of flexural test data, standard dimensions are used in accordance with Figure 4 and calculated using Equation (1).

2.4 Research Equipment

Magnetic stirrers with heating plates are devices used to mix matrix and reinforcing materials at controlled temperatures to ensure proper formation of composite materials. The specifications of the magnetic stirrer with heating plate are as follows: Specifications of Daihan Scientific magnetic stirrer with heating plate, Model MS-H280-Pro, Working Temperature 25–280 °C, Rotation Speed 0–1500 rpm.

Figure 3. Hot plate type material mixer

To make composite materials, a mold is needed that produces materials with dimensions that comply with ASTM D 790–92, as shown in Figure 4.

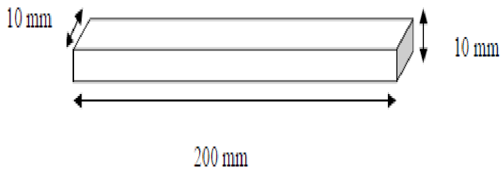

Figure 4. Dimensions of the flexural test specimen in accordance with ASTM D 790-92.

The materials for this study were planned with compositions consistent with the literature reviewed previously [3][10][26]. The composition of the materials used in this study, consisting of coconut shell charcoal, is shown in Table 2.

Table 2. Composition of Test Specimen Mixtures

Material	Polyester (% wt)	Charcoal (% wt)
UP/AT 100	100	0
UP/AT 90	90	10
UP/AT 80	80	20
UP/AT 75	70	30

Figure 5. Flexural testing of specimens in accordance with ASTM D 790-92.

Flexure Testing Machines are used to perform flexural load tests by moving downward to press the material, with the load automatically increasing as the material withstands it. GALDABINI 32559 series Universal Testing Machines are used for flexural testing of specimens.

Figure 6. GALDABINI 32559 Series Flexure Testing Machine.

3. RESULT AND DISCUSSION

3.1 Flexibility Test

The test results for each flexural test specimen can be displayed on the flexural testing machine, and the recorded load value can be displayed until the material undergoes flexural failure. The maximum flexural load values recorded on the flexural testing machine are shown in Table 3 and in the graphs in Figures 8 and 9. The maximum flexural load values show an increase with the addition of 10% to 20% coconut shell charcoal, but decrease above 20%. It is estimated that above 20% coconut shell charcoal does not adhere well to the polyester material.

Figure 7. Results of testing specimens that have undergone flexural testing.

Table 3. Flexural Test Results of Test Sample Mixtures

Material	*Material Maximum Flexural Load, F (N)*	Maximum Flexural Stress, σ_b (N/mm²)
UP/AT 100	220,34	52,10
UP/AT 90	432,76	80,57
UP/AT 80	623,23	132,43
UP/AT 75	310,65	58,35

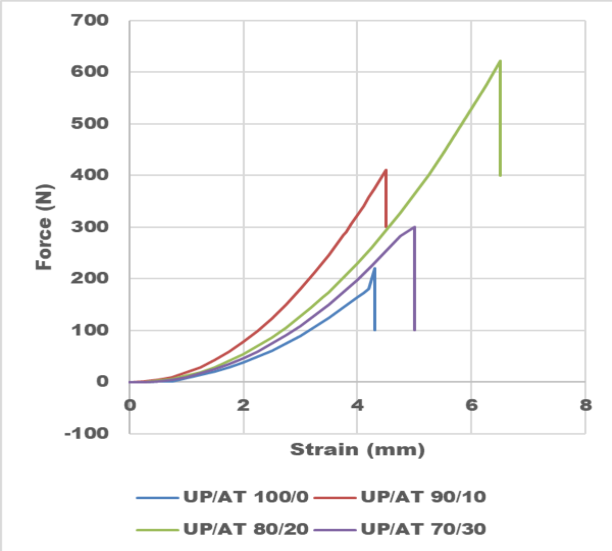

Figure 8. Graph of Flexural Strength Test Results for test specimen mixtures.

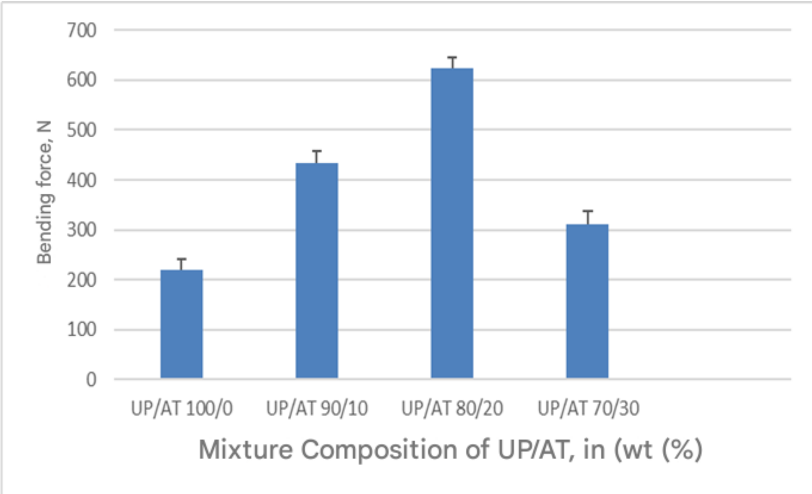

Figure 8. Graph of Flexural Strength Test Results for test specimen mixtures.

Next, the flexural stress is presented in Table 3 and graphed in Figure 10. After the load value is displayed on the flexural testing machine monitor, the flexural stress value is then calculated using Equation (1). The flexural stress value increases with the addition of coconut shell charcoal from 10% to 20%, but the flexural stress value decreases with the addition of coconut shell charcoal of more than 20%. It is estimated that adding more than 20% coconut shell charcoal is not well bound to the polyester material.

To obtain the maximum flexural stress, the flexural test was continued until the specimen fractured in flexure. The test results showed that in a mixture of polyester and 80% coconut shell charcoal: 20%, the maximum flexural stress value obtained was σ_b = 132.43 N/mm².

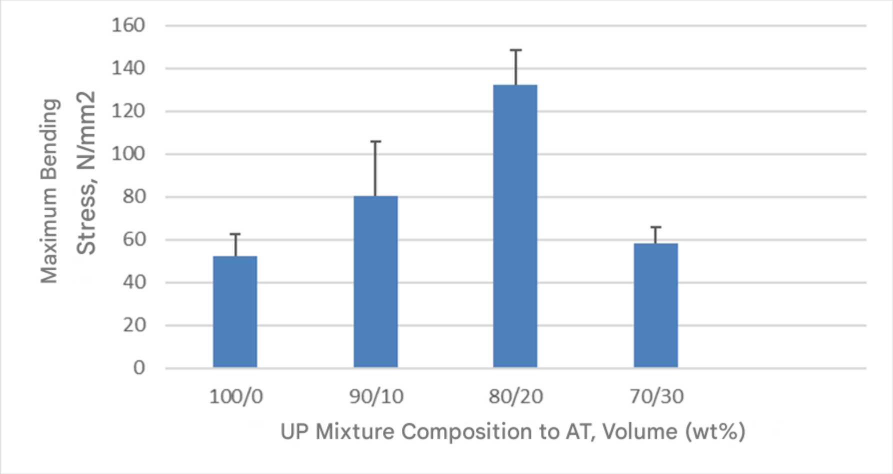

Figure 10. Graph of Flexural Strength Test Results for UP and AT Mixtures.

4. CONCLUSION

The test results show that the breaking strength of each mixture of polyester fiber (UP) and coconut shell charcoal fiber (AT) can increase the flexural strength of pure polyester (without mixture) by up to 220.34 N. In addition, adding up to 20% coconut shell charcoal fiber can increase the material's flexural strength. The maximum flexural strength was achieved in a mixture of 80% UP and 20% AT, with an average of 623.23 N, an increase of 282.84%. Furthermore, the test results show that the maximum flexural stress of each polyester (UP)-coconut shell charcoal fiber (AT) mixture can increase the maximum flexural stress of pure polyester (without mixture) to a maximum of $σ_b = 52.10$ N/mm². In addition, adding up to 20% coconut shell charcoal can increase the material's flexural stress. The flexural strength value occurred in the UP 80% and AT 20% mixture, with an average $σ_b = 132.43$ N/mm², an increase of (254.18%).
The results of this study indicate that polyester can bond well with coconut shell charcoal to form composite materials at coconut shell charcoal contents of up to 20%, and molecular bonding decreases above 20%. This study aligns with previous Research trends [3][10][26].

REFERENCES

[1] 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.

[2] M. Davallo, H. Pasdar, and M. Mohseni, “Mechanical properties of unsaturated polyester resin,” *Int. J. ChemTech Res.*, vol. 2, no. 4, pp. 2113–2117, 2010.

[3] N. Nusyirwan *et al.*, “Methods for increasing fracture toughness of thermosetting polyester polymers with vinyl ester mixtures as raw materials for automotive components,” *Indian J. Eng.*, vol. 20, no. 53, pp. 1–10, 2023, doi: 10.54905/disssi/v20i53/e20ije1648.

[4] and D. H. H. Abral, R. Fajrul, M. Mahardika, “Improving impact, tensile and thermal properties of thermoset unsaturated polyester via mixing with methyl merhacrylate and thermoset vinyl ester,” 2019.

[5] D. Frómeta *et al.*, “Identification of fracture toughness parameters to understand the fracture resistance of advanced high strength sheet steels,” *Eng. Fract. Mech.*, vol. 229, no. February, p. 106949, 2020, doi: 10.1016/j.engfracmech.2020.106949.

[6] N. Nusyirwan, P. Abiema, and A. Malik, “Methods Increased Fracture Toughness Thermosetting Polyester Mixture with Vi- nyl Ester for Raw Materials in Ship Bodies,” vol. 1, no. 1, pp. 43–50, 2023.

[7] N. Nusyirwan and S. Ilham, “Study of Improving Fracture Toughness of Un-Saturated Polyester with Addition of Mixing Percentage of CPO Oils,” vol. 2, pp. 132–137, 2022.

[8] H. Adam, “Carbon fibre in automotive applications,” *Mater. Des.*, vol. 18, no. 4–6, pp. 349–355, 1997, doi: 10.1016/s0261-3069(97)00076-9.

[9] N. Adnan, H. Abral, D. H, and E. Staria, “Identification of Mechanical Strength for Mixture of Thermoset Polyester with Thermoset Vinyl Ester due to Bending Load,” *JMPM (Jurnal Mater.*

dan Proses Manufaktur), vol. 6, no. 1, pp. 19–25, 2022, doi: 10.18196/jmpm.v6i1.14450.

[10] N. Adnand, R. Mutya, F. Ridwan, H. Abral, H. Dahlan, and E. Satria, "Pengaruh Variasi Persentase Campuran Polymer Polyester dan Vinyl Ester Terhadap Kekuatan Tegangan Lentur," *Met. J. Sist. Mek. dan Termal*, vol. 5, no. 2, p. 126, 2021, doi: 10.25077/metal.5.2.126-131.2021.

[11] Nusyirwan, F. Yande, H. Abral, Ihamdi, H. Dahlan, and E. Satria, "Effect of variations in load speed on fracture toughness of thermoset polyester/thermoset vinyl ester blend," *AIP Conf. Proc.*, vol. 2592, no. March 1996, 2023, doi: 10.1063/5.0115043.

[12] P. K. Naik, N. V. Londe, B. Yogesha, L. Laxmana Naik, and K. V. Pradeep, "Mode i Fracture Characterization of Banana Fibre Reinforced Polymer Composite," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 376, no. 1, 2018, doi: 10.1088/1757-899X/376/1/012041.

[13] 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.

[14] 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.

[15] 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.

[16] Z. Yang, H. Peng, W. Wang, and T. Liu, "Crystallization behavior of poly(ε-caprolactone)/layered double hydroxide nanocomposites," *J. Appl. Polym. Sci.*, vol. 116, no. 5, pp. 2658–2667, 2010, doi: 10.1002/app.

[17] 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.

[18] A. Budiman and S. Sugiman, "Karakteristik Sifat Mekanik Komposit Serat Bambu Resin Polyester Tak Jenuh Dengan Filler Partikel Sekam," *Din. Tek. Mesin*, vol. 6, no. 1, pp. 76–82, 2016, doi: 10.29303/d.v6i1.28.

[19] H. Abral *et al.*, "Nanovoids in fracture surface of unsaturated polyester/vinyl ester blends resulting from disruption of the cross-linking of the polymer chain networks," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1062, no. 1, 2021, doi: 10.1088/1757-899X/1062/1/012051.

[20] 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.

[21] Q. Meng and T. Wang, "An improved crack-bridging model for rigid particle-polymer composites," *Eng. Fract. Mech.*, vol. 211, no. January, pp. 291–302, 2019, doi: 10.1016/j.engfracmech.2019.02.028.

[22] N. Nusyirwan, A. Peronika, H. Abral, H. Dahlan, E. Satria, and A. Sutanto, "Unsaturated Polyester Fracture Toughness Mechanism With Blending To Vinyl Ester and Mma," *ARPN J. Eng. Appl. Sci.*, vol. 17, no. 23, pp. 1990–1996, 2022.

[23] H. N. Dhakal and S. O. Ismail, *Unsaturated polyester resins: Blends, interpenetrating polymer networks, composites, and nanocomposites*. Elsevier Inc., 2019. doi: 10.1016/B978-0-12-816129-6.00008-9.

[24] K. Liu, S. He, Y. Qian, Q. An, A. Stein, and C. W. Macosko, "Nanoparticles in Glass Fiber-Reinforced Polyester Composites: Comparing Toughening Effects of Modified Graphene Oxide and Core-Shell Rubber," *Polym. Compos.*, vol. 40, no. S2, pp. E1512–E1524, 2019, doi: 10.1002/pc.25065.

[25] N. Nusyirwan, M. Rani, and R. Pratama, "Identification of the fracture surface of thermoset polyester due to bending load," vol. 7, no. 1, pp. 51–58, 2022, doi: 10.22219/jemmme.v7i1.23086.

[26] M. A. Hakim and S. S. , Zaenal Muttaqien, Erik Heriana, "J URNAL T eknik M esin," *J. Tek. Mesin*, vol. 11, no. 1, pp. 22–27, 2018.