Advance Sustainable Science, Engineering and Technology (ASSET)
Vol. 8, No.4, October 2026, pp. 02604015-01 ~ 02604015-09
ISSN: 2715-4211 DOI: https://doi.org/10.26877/asset.v8i4.3086

Sustainable Utilization of Jute Sack Waste in Jute/Epoxy Laminate: Effect of Fiber Orientation for Bumper Applications

Heri Yudiono[1*], Hadromi[1], Deni Fajar Fitriyana[1], Januar Parlaungan Siregar[2], Tezara Cionita[3], Much Rizky Ubaidillah[1], Ayyub Ridananda[1], Rahmat Hidayat [1]

[1]Faculty of Engineering, Universitas Negeri Semarang, Semarang 50229, Indonesia

[2]Faculty of Mechanical & Automotive Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, Pekan 26600, Pahang, Malaysia

[3]Faculty of Engineering, Built Environment & Information Technology, SEGi University, Petaling Jaya, Selangor, Malaysia

* heri_yudiono@mail.unnes.ac.id

Abstract. Fiber orientation plays a major role in controlling the mechanical properties of natural fiber bio composites. An investigation into the impact of fiber direction variations on the toughness and tensile strength of burlap waste composites for automobile bumpers was carried out. This research was designed as a controlled experimental investigation. The factors evaluated were fiber orientation, while the tensile strength and impact toughness were. Bio composites were manufactured utilizing the hand lay-up procedure, and mechanical testing included tensile (ASTM D638) and impact (ASTM 4812). The number of test replications was fixed at three specimens for each variable. By improving interfacial adhesion, the 0°/+90°/0°/+90°/0° fiber orientation produces a tensile strength of 21.087 N/mm² and an impact toughness of 0.0482 J/mm², which is higher than a car bumper. These research show proof that burlap sack waste-based composites can be used as an alternative material for environmentally acceptable and sustainable bumpers. These findings complement SDG 12, which focuses on responsible production and consumption.

Keywords: Epoxy, fiber orientation, automotive bumper application, circular economy, impact resistance

(Received 2025-12-05, Revised 2026-05-12, Accepted 2026-07-14, Available Online by 2026-09-08)

1. Introduction

The problem of garbage accumulation and solid waste is becoming an increasingly severe environmental concern in Indonesia. According to the Kementerian Lingkungan Hidup Waste Management Information System, food waste would account for 41.07% of national rubbish in 2022, followed by plastic (18.08%), wood/twigs (13.44%), and paper/cardboard (11.05%) [1]. Burlap sack waste is a sort of solid waste that is abundant but underutilized. To date, burlap sack trash has only been utilized in the form of low-cost handicraft products, thus technological innovation is needed to boost its added value and contribute to environmental sustainability.

In the context of developing environmentally friendly materials (eco-materials), using natural fiber-based waste as a reinforcing material in composites is a possible solution [2,3]. Jute fiber has excellent tensile strength, is abundantly available, decomposes naturally, and has comparatively cheap production costs [4-6]. Jute fiber can be converted into biocomposite materials with outstanding mechanical qualities and a low environmental impact using green technology. A laminate composite is a type of material development in which numerous layers of natural fibers and a polymer matrix are stacked in a certain orientation to obtain an optimal combination of mechanical qualities [7,8].

Laminate composites are known to have a high Young's modulus to density ratio, making them lighter and stronger than traditional metal materials [9]. Laminate composites have low shear modulus values, leaving them vulnerable to shear stress [10]. As a result, modifying factors such as layer thickness, fiber orientation, number of laminae, and fiber weight percentage are essential aspects in boosting the material's toughness and strength [11,12]. The automobile industry is spending a lot of work into researching alternative materials for car components in order to improve energy efficiency and sustainability [13-15].

Car bumpers, being a structural component that absorbs impact energy, require materials with high mechanical qualities, as well as being lightweight and environmentally friendly [16,17]. Although the impact of fiber orientation on natural fiber composites has been extensively studied, there are still limited studies on the utilization of gunny sack waste with specific shape factors, its processing path into laminated composites, and its performance evaluation based on the needs of vehicle bumper applications. The utilization of waste jute bags as reinforcement in laminated composites has a high potential to achieve these criteria. In addition to enhancing waste's economic worth, this innovation also promotes waste reduction efforts and the application of green manufacturing principles and Sustainable Development Goals (SDGs), particularly in the areas of sustainable consumption and production. Based on these issues, the purpose of this research is to investigate the effect of fiber orientation on the tensile strength and toughness of laminated composites made from jute sack waste, as well as to expand their potential for structural applications such as automobile bumpers.

2. Methods

2.1 Materials

Jute suck waste

The jute sacks utilized in this investigation came from Semarang, Indonesia. The jute bags are 90 cm × 100 cm and have a capacity of 70 kg. They are used for coffee powder/bean containers. Jute fiber is eco-friendly, renewable, lightweight, has great thermal properties, is non-corrosive, cheaper than other natural fibers, biodegradable, and non-abrasive [18]. Jute fiber is strong, thermally conductive, lightweight, and inexpensive. Jute fiber has 3.5-4.5% elongation, a tensile strength of 393-723 MPa, and a density of 1.3 g/cm^3 [19,20]. We used standard jute sacks. Plain weave has a distinct and basic diagonal pattern, distributes weight more evenly, is easier to create and maintain, and is stronger. Jute bags come in a variety of weave configurations, most often a 1/1 plain weave [21].

Epoxy Resin

Colorchem epoxy resin from a chemical source in Semarang, Indonesia, was employed in this experiment. This substance, with a resin-hardener composition of 1:1, serves as a matrix to attach the fibers to the burlap sacks. Epoxy resin is a thermoset substance utilized in aerospace, automotive, marine, coating, composite, biomedical, and electronics sectors [22]. Epoxy resin has the ability to increase toughness, decrease shrinkage, and resist corrosion and heat [23]. Tensile strength is 85 MPa, elongation is 5%, and density is between 1.11-1.23 g/cm³ [24].

Creating laminate composites.

The biocomposite was created using a hand lay-up method. Alkalized hemp fibers with a thickness of 0.6 mm were cut to the mold size, which was established by weighing and adjusting the thickness five times for each variable. The molding process begins by combining epoxy resin and hardener in a 1:1 proportion. The fibers were inserted in orientation patterns of 0°/0°/0°/0°/0°, 0°/+30°/0°/+30°/0°, 0°/+45°/0°/+45°/0°, 0°/+60°/0°/+60°/0°, and 0°/+90°/0°/+90°/0°, following the approach employed in prior research [25]. A brush is used to evenly wet each fiber layer with resin and hardener, creating a smooth surface and preventing delamination. The mold is closed and a 5 kg load is given to a 200 x 200 mm mold for 24 hours. Aluminum foil is used as a protective coating for the mold, assisting in the composite removal process. The pressing process is carried out for a full day at room temperature until the composite has fully solidified.

2.2 Mechanical Properties

Impact test

Impact testing is done to determine how much energy a laminated composite made of used jute bags and car bumpers absorbs. The severity of material damage increases with the amount of energy absorbed [26]. The toughness test was carried out at the Mechanical Engineering Laboratory of Universitas Negeri Semarang utilizing a GOTECH GT-7405-MDH impact testing equipment. This equipment has a swing speed of 3.46 m/s and an impact energy capacity of 25 Joules. Impact test specimens utilizing the ASTM D4812 standard without notches [27]. Impact testing was conducted on each research variable using three specimens (n = 3). The impact strength is determined by Equation 1.

$$IS = \frac{E}{A} \tag{1}$$

IS = Impact strength (J/mm^2)

E = Energy absorption (J)

A = Cross-sectional area (mm^2)

Tensile test

Tensile testing was carried out to determine the maximum tensile strength of a laminated composite manufactured from recycled jute sacks and automotive bumpers. The maximum tensile strength test was used to determine how much force was required to hold the material until it broke [28]. The tensile test was performed in the Universitas Muhammadiyah Semarang Mechanical Engineering Laboratory using a Universal Testing Machine brand GOTECH model GT-TCS-2000 with a capacity of 2.000 kg. The maximum load is the result of machine testing. The ASTM D638 standard [29] defines specimen dimensions for tensile testing. Tensile testing was conducted with three specimens (n = 3) for each variable. Equation (2) is used to determine the composite's maximum strength by comparing the maximum load per unit area.

$$\sigma_u = \frac{P_u}{A}. \tag{2}$$

σ_u = Tensile strength (N/mm^2)

P_u = Ultimate load (N)

A = Cross-sectional area (mm^2)

3. Results and Discussion

3.1 Tensile Test Results

Figure 1 depicts the results of tensile strength tests, which indicate how fiber orientation effects the mechanical properties of jute fiber-based laminate composites as an alternative material for automobile bumpers. The interaction of fiber orientation and matrix interface characteristics affects tensile strength values, which in turn affects load transmission between layers. The tensile strength of specimens with a fiber orientation of 0°/0°/0°/0°/0° was 16.997 N/mm², a 25.38% drop from the reference bumper tensile strength of 22.777 N/mm². Laminate composites with an orientation of 0°/+30°/0°/+30°/0° increased tensile strength to 19.31 N/mm², which was still 15.22% lower than the standard. Furthermore, the 0°/+45°/0°/+45°/0° orientation resulted in a tensile strength of 12.96 N/mm², therefore the loss was minimal, accounting for only 43.10% of the reference value. When the fiber orientation was altered to 0°/+60°/0°/+60°/0°, the tensile strength dropped to 15.057 N/mm², a 7.42% decrease from the bumper tensile strength result. In comparison, the specimen with a fiber orientation of 0°/+90°/0°/+90°/0° demonstrated a rise in tensile strength of 21.087 N/mm², or an increase of 5.40% compared to the bumper reference value, making this configuration the most optimal orientation in this study.

Overall, research findings show that fiber orientation is very important in determining the mechanical performance of composites [30,31]. Fiber orientation is essential because the direction of fiber arrangement in the matrix effects stress distribution and deformation patterns when the material is loaded. The strength, stiffness, and toughness of the composite are increased by optimal fiber organization, which facilitates more effective load transfer and resistance [32]. Conversely, improper fiber orientation may lead to an uneven distribution of stress among layers, which could impair structural performance and reduce mechanical load resistance. Among the several configurations examined, the parallel fiber orientation of 0°/+90°/0°/+90°/0° was proven to have the best load transmission performance. Meanwhile, intermediate orientations such as 0°/+30°/0°/+30°/0° and 0°/+60°/0°/+60°/0° tended to diminish stress distribution efficiency, resulting in less than optimal mechanical performance.

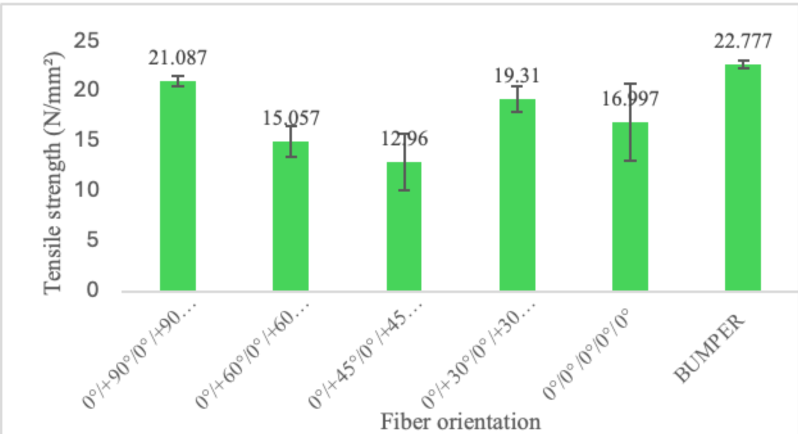
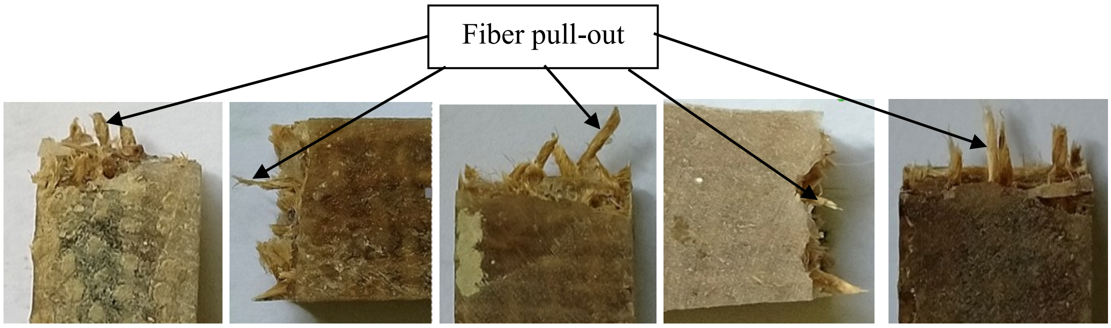


Figure 1. Average tensile strength

Another study that studied the effect of fiber orientation on the tensile characteristics of jute-epoxy laminate composites revealed that the 0°/90° orientation combination gave the maximum tensile strength, 39.10 MPa [33]. This research demonstrates that appropriate fiber orientation is crucial for improving the tensile strength and structural performance of flax fiber-based laminated composites. This invention has the potential to serve as an environmentally friendly alternative automobile bumper material.



a. Orientation 0° b. Orientation 30° c. Orientation 45° d. Orientation 60° e. Orientation 90°

Figure 2. Tensile test fracture cross-section

Figures 2(a)-2(e) depict the fracture cross-sectional morphology of jute fiber-based laminated composites with varying fiber orientations. The fracture surfaces of all specimens show a failure mechanism in the form of fiber pull-out, which is a condition where the fiber is dragged out of the matrix when the composite is subjected to loading, notably tensile loading [34]. This mechanism develops as a result of poor interfacial connections between the fiber and the matrix, resulting in an inefficient load transfer process. This sort of fracture typically suggests poor fiber-matrix bonds, which are distinguished by the appearance of several pulled out fibers and the absence of plastic deformation in the composite. High shear forces acting on the fiber-matrix layer cause the fibers to pull out, both during the debonding stage and after the delamination process occurs [35].

3.2 Impact Test Results

Variations in fiber orientation have a substantial effect on the impact strength of jute fiber biocomposites, as shown in Figure 3. At the fiber orientation of 0°/0°/0°/0°/0°, the impact strength fell by 30.74% to 0.0365 J/mm², compared to the bumper's initial value of 0.0527 J/mm². The orientation of 0°/+30°/0°/+30°/0° decreased by 35.48% to 0.0340 J/mm², whereas the orientation of 0°/+45°/0°/+45°/0° decreased by 25.05% to 0.0395 J/mm². At a direction of 0°/+60°/0°/+60°/0°, the impact strength fell by 30.36% to 0.0367 J/mm². The 0°/+90°/0°/+90°/0° orientation outperforms the original bumper, increasing impact strength by 8.54% to 0.0482 J/mm².

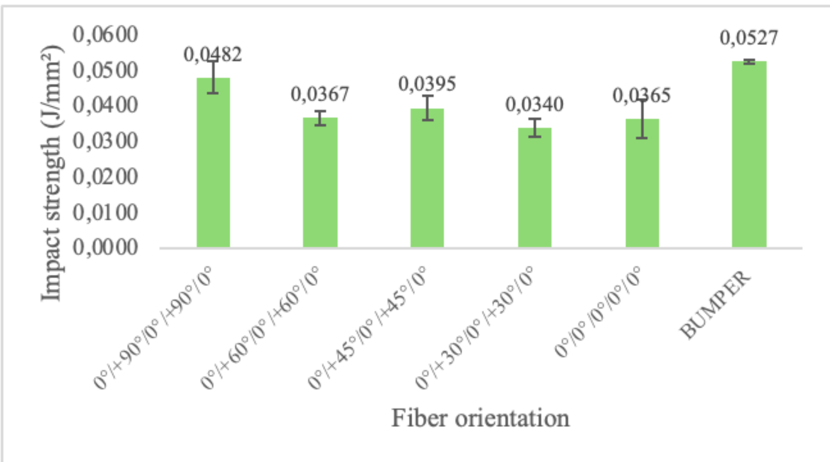


Figure 3. Average impact strength

These findings suggest that fiber orientation has a major impact on the material's ability to absorb impact energy. When exposed to impact loads, fiber arrangements at low angles (0°-60°) provide less equal stress distribution, resulting in simpler crack formation and faster damage propagation. A 90° orientation, on the other hand, allows for a more efficient crack-resistance mechanism as well as a more uniform load distribution across layers [36], resulting in better impact absorption. As a result, the

0°/+90°/0°/+90°/0° design is the most promising orientation for car bumper component applications that need strong impact toughness.

4. Conclusion

Several studies on the toughness and tensile strength of used jute sack laminated composites as an alternative material show that composites with fiber orientations of 0°/+90°/0°/+90°/0° have a maximum tensile strength of 21.087 N/mm², an increase of 5.40% compared to car bumpers, which have a tensile strength of 22.777 N/mm². Composites with the same fiber arrangement have an impact strength of 0.0482 J/mm², which is 8,54% higher than the automobile bumper's value of 0.0527 J/mm². The increased tensile and impact strengths imply that fiber orientation is significant in increasing interfacial adhesion between the fiber and the epoxy matrix, directly affecting the composite's mechanical performance. Therefore, jute sack waste-based composites can be considered a viable substitute material for sustainable and eco-friendly car bumpers. These discoveries also provide an important contribution to the development of green technology and sustainable composite materials by utilizing natural fiber waste. By maximizing waste into value-added commodities, reducing reliance on new raw materials, and minimizing waste, this approach is consistent with the objectives of the Sustainable Development Goals (SDGs), especially SDG 12 on responsible production and consumption.

Declaration of AI and AI assisted technologies in the writing process
The author claims that ChatGPT was used to improve several areas of the grammar during the writing of this article. Subsequently, the work was personally modified to meet the content criteria.

Declaration of Competing Interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Acknowledgements
This research was financed by Universitas Negeri Semarang under the Research Implementation Agreement for 2026.

References
[1] Sistem Informasi Pengolahan Sampah Nasional KLHK 2022 https://sipsn.menlhk.go.id/sipsn/public/data/komposisi.
[2] M. S. Haque, M.A. Islam, "Waste natural fibers for polymer toughening and biodegradability of epoxy-based polymer composite through toughness and thermal analysis," *Heliyon*, vol. 10, e28110, 2024, doi: https://doi.org/10.1016/j.heliyon.2024.e28110.
[3] X. Huang, R. Ye and L. Zhao, "Research progresses of composites with natural fibers recycled from textiles waste," *Journal of Engineered Fibers and Fabrics*, vol. 20, pp. 1–12, 2025, doi: https://doi.org/10.1177/15589250251338265.
[4] T. Cionita, M. H. M. Hamdan, J. P. Siregar, D. F. Fitriyana, R. Junid, W. L. Shing, J. Jaafar, A. P. Irawan, T. Rihayat, R. Ismail, A. P. Bayuseno, E. Jehadus, "Overview of Jute Fibre as Thermoplastic Matrix Polymer Reinforcement," *Journal of Renewable Materials*, vol. 12, issue 3, pp. 457-483, 2024, doi: https://doi.org/10.32604/jrm. 2024.045814.
[5] A. A. Musa, A. P. Onwualu, "Potential of lignocellulosic fiber reinforced polymer composites for automobile parts production: Current knowledge, research needs, and future direction," *Heliyon*, vol. 10, p. e24683, 2024, doi: https://doi.org/10.1016/j. heliyon.2024.e24683.
[6] S. Maiti, Md. R. Islam, M. A. Uddin, S. Afroj, S. J. Eichhorn, and N. Karim, "Sustainable fiber-reinforced composites: a review," *Adv. Sustainable Syst.* Vol. 6, p. 220025, 2022, doi: https://doi.org/10.1002/adsu.202200258.

[7] M. Kamruzzaman, S. Alam, "Influence of stacking sequence on the mechanical properties of banana-glass fiber hybrid laminates for automotive shells," *Heliyon*, vol. 10, p. e40130, 2024, doi: https://doi.org/10.1016/j.heliyon.2024.e40130.

[8] A. D. Castro-Franco, M. Siqueiros-Hernández, V. García-Angel, I. Mendoza-Muñoz, Benjamín González-Vizcarra, Hernán D. Magaña-Almaguer and Lidia E. Vargas-Osuna, "Hybrid laminates reinforced with natural and synthetic fibers: experimental characterization and preliminary finite element assessment for prosthetic applications," *Fibers*, vol. 13, p. 107, 2025: doi: https://www.mdpi.com/2079-6439/13/8/107.

[9] B. Cetinkaya, E. Yilmaz, ˙I. Özkol, ˙I. ¸Sen and T. Saracyakupoglu, "Development of Structural Model of Fiber Metal Laminate Subjected to Low-Velocity Impact and Validation by Tests," *J. Compos. Sci*. vol. 9, p. 322, 2025, doi: https://www.mdpi.com/2504-477X/9/7/322.

[10] D. P. Islami, A. F. Muzaqih, R. Adiputra, A. R. Prabowo, N. Firdaus, S. Ehlers, M. Braun, M. Jurkoviˇc, D. F. Smaradhana, H. Carvalho, "Structural design parameters of laminated composites for marine applications: Milestone study and extended review on current technology and engineering," *Results in Engineering*, vol. 24, p.103195, 2024, doi: https://doi.org/10.1016/j.rineng.2024.103195.

[11] J. Jefferson Andrew, H.N. Dhakal, "Sustainable biobased composites for advanced applications: recent trends and future opportunities – A critical review," *Composites Part C: Open Access*, vol. 7, p.100220, 2022, doi: https://doi.org/10.1016/j.jcomc.2021.100220.

[12] S. Huang, Q. Fu, L. Yan, B. Kasal, "Characterization of interfacial properties between fibre and polymer matrix in composite materials e A critical review," *Journal of Materials Research and Technology*, vol. 13, pp. 1441-1484, 2021,doi: https://doi.org/10.1016/j.jmrt.2021.05.076.

[13] L. Yan, H. Xu, "Lightweight composite materials in automotive engineering: State-of-the-art and future trends," *Alexandria Engineering Journal*, vol. 118, pp. 1-10, 2025, doi: https://doi.org/10.1016/j.aej.2024.12.002.

[14] W. Wellbrock, D. Ludin, L. Röhrle and W. Gerstlberger, "Sustainability in the automotive industry, importance of and impact on automobile interior – insights from an empirical survey," *Wellbrock et al. International Journal of Corporate Social Responsibility*, vol. 5, no. 10, 2020, doi: https://doi.org/10.1186/s40991-020-00057-z.

[15] Q. Yang, W. Ming, "Review: application of green manufacturing processes in precision machining of automotive components," *Green Manuf. Open*, vol. 3, no. 2, pp. 1-134, 2025, doi: https://dx.doi.org/10.20517/gmo.2024.120501.

[16] F. Khan, N. Hossain, J. J. Mim, SM. M. Rahman, Md. J. Iqbal, M. Billah, M. A. Chowdhury, "Advances of composite materials in automobile applications – A review," *Journal of Engineering Research*, vol. 13, pp. 1001–1023, 2025, doi: https://doi.org/10.1016/j.jer.2024.02.017.

[17] D. Jan, M. S. Khan, I. U. Din, K. A. Khan, S. A. Shah, A. Jan, "A review of design, materials, and manufacturing techniques in bumper beam system," *Composites Part C: Open Access*, vol. 14, p. 100496, 2024, doi: https://doi.org/10.1016/j.jcomc.2024.100496.

[18] M. M. Hasan, Md. A. Islam, T. Hassan, Analysis of jute-glass fiber reinforced epoxy hybrid composite," *Heliyon* 10, e40924, 2024, doi: https://doi.org/10.1016/j.heliyon.2024.e40924.

[19] I. D. S. Silva, J. J. P. Barros, A. Albuquerque, N. G. Jaques, M. V. L. Fook, and R. M. R. Wellen, "Insights into the curing kinetics of epoxy/PLA: Implications of the networking structure," *Express Polym Lett*, vol. 14, no. 12, pp. 1180–1196, 2020, doi: https://doi.org/10.3144/expresspolymlett.2020.96

[20] H. Yudiono, J. P. Siregar, S. Asri, H. Hidayat, D. B. Chikam, J. A. Aprilian, T. A. Supriyadi, T. Cionita, D. F. Fitriyana, "Effect of alkalization time on the toughness and strength of jute sack waste lamina composite as an alternative car bumper material," International Journal of Automotive and Mechanical Engineering, vol. 21, no. 4, pp. 11809 – 11820, 2024: doi: https://doi.org/10.15282/ijame.21.4.2024.6.0909.

[21] R. V. Patel, A. Yadav and J. Winczek, “Physical, mechanical, and thermal properties of natural fiber-reinforced epoxy composites for construction and automotive applications,” *Applied Sciences*, vol. 13, no. 8, p. 5126, 2023, doi: https://doi.org/10.3390/app13085126.

[22] C. Verma, L. O. Olasunkanmi, E. D. Akpan, M.A. Quraishi, O. Dagdag, M. E. Gouri, E. M. Sherif , E. E. Ebenso, “Epoxy resins as anticorrosive polymeric materials: A review,” *React Funct Polym*, vol. 156, p. 104741, 2020, doi: https://doi.org/10.1016/j.reactfunctpolym.2020.104741.

[23] B. Biswas, N. R. Bandyopadhyay, G. Mandal, and A. Sinha, “Effect of alkaline treatment on mechanical properties of composites: Unsaturated polyester reinforced ZrO2/jute and sisal,” *Polymers and Polymer Composites*, vol. 29, no. 9_suppl, pp. S1000–S1008, 2021, doi: 10.1177/09673911211033949.

[24] M. Arryyanto, H. Yudiono, J. P. Siregar, T. Cionita, D. F. Fitriyana, A. I. Imran, “The effect of weaving patterns on the impact and bending strength of *eichhornia crassipes* composites for car bumper applications,” *International Journal of Automotive and Mechanical Engineering*, vol. 22, no. 3, pp. 12640 – 12653, 2025: doi: https://doi.org/10.15282/ijame.22.3.2025.7.0964.

[25] I. Zahrotin, A. L. Juwono, and S. Roseno, “Water content and nail head pulled-through strength of epoxy/Sumberejo kenaf fiber composite with fiber orientation 0°/0°/0°/0° and 0°/90°/0°/90°,” in *AIP Conference Proceedings*, AIP Publishing, 2023, doi: https://doi.org/10.1063/5.0115062.

[26] Z. Huang, N. Tang, Y. Jiang, Q. Zhang, “Effect of repeated impacts on the mechanical properties of nickel foam composite plate/AA5052 self-piercing riveted joints,” *Journal of Materials Research and Technology*, vol. 23, pp. 4691–4701, 2023, doi: https://doi.org/10.1016/j.jmrt.2023.02.095.

[27] “ASTM D4812-19e1. Standard Test Method for Unnotched Cantilever Beam Impact Resistance of Plastics. ASTM International,”.

[28] T. Mauseth, M. L. Dunzik-Gougar, S. Meher, and I. J. van Rooyen, “Determining the tensile strength of fuel surrogate TRISO-coated particle buffer, IPyC, and buffer-IPyC interlayer regions,” *Journal of Nuclear Materials*, vol. 583, p. 154540, 2023, doi: https://doi.org/10.1016/j.jnucmat.2023.154540 .

[29] “ASTM D638-14. Standard Test Method for Tensile Properties of Plastics. ASTM International,”.

[30] U. S. Gupta, A. Dharkar, M. Dhamarikar, A. Choudhary, D. Wasnik, P. Chouhan, S. Tiwari, R. Namdeo, “Study on the effects of fiber orientation on the mechanical properties of natural fiber reinforced epoxy composite by finite element method,” *Materials Today: Proceedings*, vol. 45, pp. 7885–7893, 2021, doi: https://doi.org/10.1016/j.matpr.2020.12.614.

[31] R. Iquilio, J. L. Valín, K. Villalobos, S. Núñez, Á. González and M. Valin, “Influence of fiber orientation on mechanical response of jute fiber-reinforced polymer composites,” *Polymers*, vol. 16, p. 2573, 2024, doi: https://doi.org/10.3390/polym16182573.

[32] M. M. Alzahrani, K. A. Alamry, M. A. Hussein, “Recent advances of Fiber-reinforced polymer composites for defense innovations,” *Results in Chemistry*, vol. 15, p. 102199, 2025, doi: https://doi.org/10.1016/j.rechem.2025.102199.

[33] M. R. Hossain, M. A. Islam, A. V. Vuurea, and I. Verpoest, “Effect of Fiber Orientation on the Tensile Properties of Jute Epoxy Laminated Composite,” *J. Sci. Res*, vol. 5, no. 1, pp. 43-54, 2013, doi: http://dx.doi.org/10.3329/jsr.v5i1.10519

[34] O. H. Figueroa, H. Varum, M. I. Prieto, R. J. G. Amaya, A. C. Escamilla, “Effect of fiber-matrix interaction and embedment length on the pullout behavior of rice straw fibers embedded in clay matrix,” *Results in Engineering* 27, 106144, 2025, doi: https://doi.org/10.1016/j.rineng.2025.106144

[35] M. J. Suriani, H. Z. Rapi, R. A. Ilyas, M. Petru, and S. M. Sapuan, Delamination and manufacturing defects in natural fiber-reinforced hybrid composite: A review,” *Polymers*, 13, 1323, 2021, doi: https://doi.org/10.3390/polym13081323

[36] M. R. Islam, M. F. Hossain, M. S. Rana, M. S. Ferdous, "Effect of fiber orientation on mechanical properties of JUCO fiber reinforced epoxy composites," Hybrid Advances 8, 100386, 2025: https://doi.org/10.1016/j.hybadv.2025.100386