

The Effect of Fiber Orientation on Polypropylene Composites Reinforced with Ramie Fiber on Impact Resistance as a Dashboard Material

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Abstract

The increasing demand for lightweight and high-strength materials in the automotive industry has encouraged the development of natural fiber-reinforced polymer composites. However, studies specifically investigating the effect of ramie fiber orientation in polypropylene (PP) composites fabricated using a hot press remain limited. This study investigates the effect of ramie fiber orientation on the impact toughness of PP composites for potential dashboard applications. Composite specimens were fabricated using a hot press with a composition of 85% PP and 15% ramie fiber in a three-layer configuration (PP: fiber: PP). Fiber orientations of 15°, 30°, and 45° were investigated. Impact testing was conducted using the Charpy method according to ASTM D5942, followed by macroscopic observation of the fracture surfaces. The highest impact toughness was obtained at 15°, with an average value of 0.0265 J/mm² and absorbed energy of 0.777 J. The impact toughness decreased to 0.0248 J/mm² at 30° and 0.0221 J/mm² at 45°, with absorbed energies of 0.715 J and 0.696 J, respectively. The fracture surfaces showed matrix cracking, voids, and fiber pull-out, indicating variations in stress transfer and interfacial bonding. Among the investigated orientations, the 15° orientation provided the highest impact toughness, demonstrating the influence of fiber orientation on the impact energy absorption behavior of ramie fiber-reinforced PP composites.

Keywords: composite; dashboard; fiber orientation; impact; ramie

Abstrak

Meningkatnya kebutuhan industri otomotif terhadap material yang ringan dan berkekuatan tinggi mendorong pengembangan komposit polimer berpenguat serat alam. Namun, penelitian yang secara khusus mengkaji pengaruh orientasi serat rami pada komposit polipropilena (PP) yang difabrikasi menggunakan metode hot press masih terbatas. Penelitian ini bertujuan untuk mengetahui pengaruh orientasi serat rami terhadap ketangguhan impak komposit PP untuk potensi aplikasi sebagai material dashboard. Spesimen komposit dibuat menggunakan mesin hot press dengan komposisi 85% PP dan 15% serat rami dalam konfigurasi tiga lapis (PP: serat: PP). Orientasi serat yang digunakan adalah 15°, 30°, dan 45°. Pengujian impak dilakukan menggunakan metode Charpy sesuai standar ASTM D5942, kemudian dilanjutkan dengan pengamatan makro pada permukaan patahan. Ketangguhan impak tertinggi diperoleh pada orientasi 15°, yaitu sebesar 0.0265 J/mm² dengan energi serap sebesar 0.777 J. Ketangguhan impak menurun menjadi 0.0248 J/mm² pada orientasi 30° dan 0.0221 J/mm² pada orientasi 45°, dengan energi serap masing-masing sebesar 0.715 J dan 0.696 J. Permukaan patahan menunjukkan adanya matrix cracking, void, dan fiber pull-out yang mengindikasikan adanya perbedaan transfer tegangan dan ikatan antarmuka. Dari orientasi yang diteliti, orientasi 15° menghasilkan ketangguhan impak tertinggi, yang menunjukkan adanya pengaruh orientasi serat terhadap kemampuan penyerapan energi impak komposit PP berpenguat serat rami.

Kata kunci: dashboard; impak; komposit; orientasi serat; rami

1. Introduction

The industrial demand for lightweight, high-strength materials with superior characteristics continues to increase along with the development of the automotive, transportation, and manufacturing sectors. Natural fiber-reinforced polymer composites have emerged as an alternative to replace metal-based materials and synthetic fibers [1]. These materials not only offer good mechanical properties but are also considered more environmentally friendly and cost-effective compared to synthetic fiber-based composites. Polypropylene is one of the most widely used thermoplastic

matrices due to its lightweight nature, corrosion resistance, and ease of processing at low cost [2]. Ramie fiber is a type of natural fiber with a high cellulose content ($\pm 68\text{--}76\%$), excellent mechanical strength, and resistance to fungal attack, making it a promising reinforcement material for composites [3]. The combination of these two materials has the potential to significantly enhance mechanical properties, including impact toughness, which is a critical factor for automotive applications such as vehicle dashboards [4].

The dashboard is an interior panel that functions as a housing for various essential features, such as the instrument panel, storage compartment, head unit, and air-conditioning controls. Conventional dashboards made from pure plastic materials often experience mechanical degradation due to heat exposure and repeated impact loading. One approach to address this issue is combining ramie fiber, which has good mechanical strength, with polypropylene as an alternative material. The application of polymer composites in automotive components has been proven effective in reducing vehicle weight while maintaining passenger safety [5]. Fiber orientation can influence stress distribution and fracture behavior when materials are subjected to shock or impact loads [6]. According to Mulyoaji et al. [16], fiber orientation arrangement significantly affects the mechanical strength of composites. Research conducted by Atikoh et al. [7] reported that bamboo fiber composites with a 0° orientation exhibited an impact toughness of 0.031 J/mm^2 , which was higher than that of the 45° orientation at 0.024 J/mm^2 . In producing composites with superior mechanical strength, appropriate fiber volume fraction and fiber content are also required. A study by Athilah et al. [17] on fiber orientation and volume fraction in sugarcane fiber composites with an epoxy resin matrix showed that the highest impact value was obtained at a 15% volume fraction and a 0° fiber orientation, reaching 0.085 J/mm^2 with an absorbed energy of 8.5 J/mm^2 . Fibers oriented perpendicular to the loading direction tend to exhibit higher impact toughness [7].

Based on the studies above, most previous research has focused on fibers other than ramie or employed different fabrication methods, such as hand lay-up techniques or thermoset resins. Experimental studies that specifically evaluate the effect of ramie fiber orientation in polypropylene-matrix composites fabricated using the hot press method and tested according to the ASTM D5942 standard for automotive dashboard applications remain relatively limited. Therefore, this study focuses on examining the effect of fiber orientation variations on the mechanical properties of ramie fiber-reinforced polypropylene composites. This research aims to analyze impact toughness at fiber orientations of 15° , 30° , and 45° . The analysis is further supported by observations of fracture cross-sections from impact test specimens to identify the material failure mechanisms involved.

2. Material and Method

In this study, the materials used were woven ramie fiber and a polypropylene matrix. The ramie fibers were cleaned using running water to minimize impurities. The drying process of the ramie fibers was carried out by sun-drying until completely dry. Polypropylene pellets were ground to reduce the possibility of defects during the manufacturing process. Subsequently, both materials were molded using a mold with dimensions of $260 \text{ mm} \times 90 \text{ mm} \times 3 \text{ mm}$. Based on these dimensions, the material composition consisted of 85% polypropylene and 15% ramie fiber. The composite was then fabricated using a hot press machine under a pressure of 70 kgf and a temperature of 190°C for 20 minutes.

2.1 Tools and Materials

Figure 1 shows the materials and equipment used in this study, including plain-woven ramie fiber cut according to the predetermined orientation angles and polypropylene as the composite matrix. The equipment consisted of an aluminum mold, digital scale, grinder for pulverizing polypropylene, and impact testing machine.

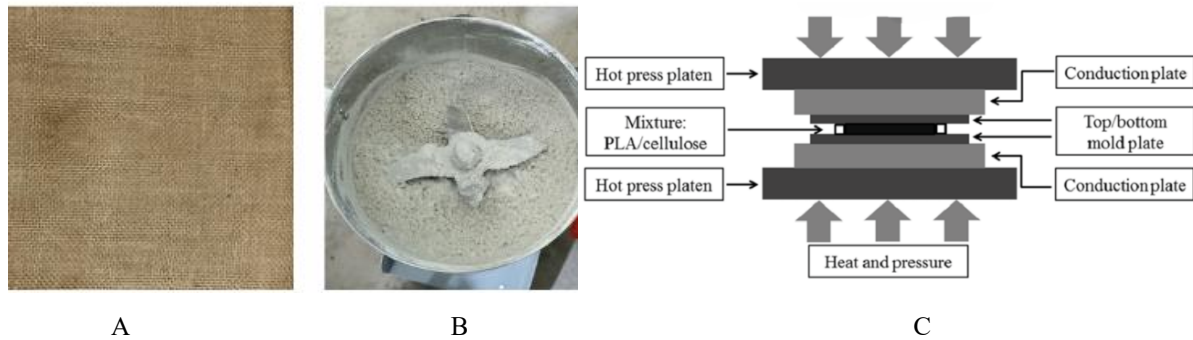


Figure 1. Materials and Equipment Fabrication: (A) Ramie Fibers, (B) Polypropylene, (C) Hot Press

2.2 Research Flowchart

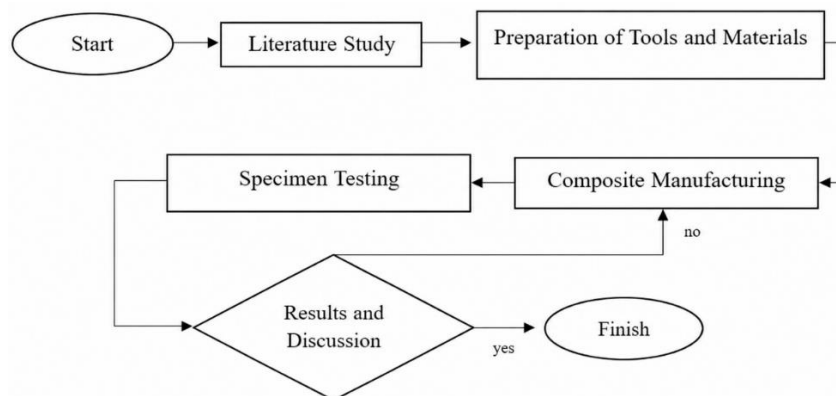


Figure 2. Research Flowchart

Figure 2 illustrates the research procedure used in this study. The research began with the preparation of ramie fiber and polypropylene as the reinforcement and matrix materials, respectively. The ramie fibers were cleaned and dried, while the polypropylene pellets were ground before composite fabrication. The materials were then arranged according to the predetermined fiber orientations of 15° , 30° , and 45° and fabricated using a hot press. The resulting composite plates were cut into impact test specimens according to ASTM D5942. Impact testing was subsequently performed for each fiber orientation, followed by calculation of absorbed energy and impact toughness. Finally, macroscopic observations were conducted on the fracture surfaces to identify the failure mechanisms associated with each fiber orientation.

Impact test specimens were made according to the ASTM D5942 standard. In making composite specimens, there are 3 layers, namely polypropylene: fiber: polypropylene. The fibers are arranged with orientations of 15° , 30° , and 45° , as shown in Figure 3.

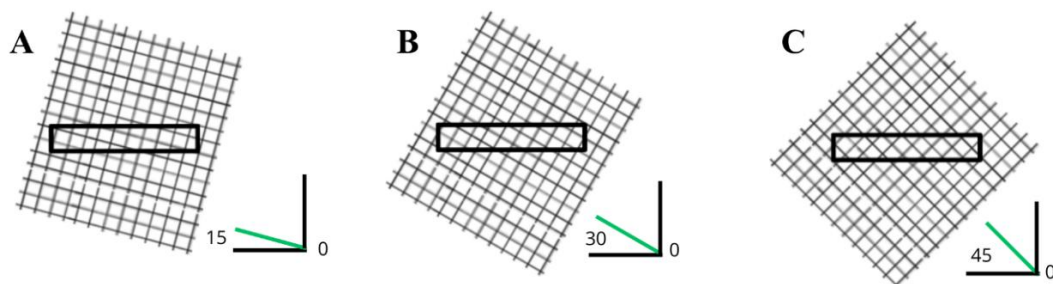


Figure Error! No text of specified style in document.3. Orientation Fiber Direction (A) 15° , (B) 30° , (C) 45°

The impact test was selected because impact toughness indicates the ability of a material to absorb energy under sudden loading before fracture. This property is relevant to automotive interior components such as dashboards, which may experience sudden impact during service [4,5,7]. Therefore, this study focuses on impact toughness to evaluate the effect of ramie fiber orientation on the energy absorption behavior of polypropylene composites.

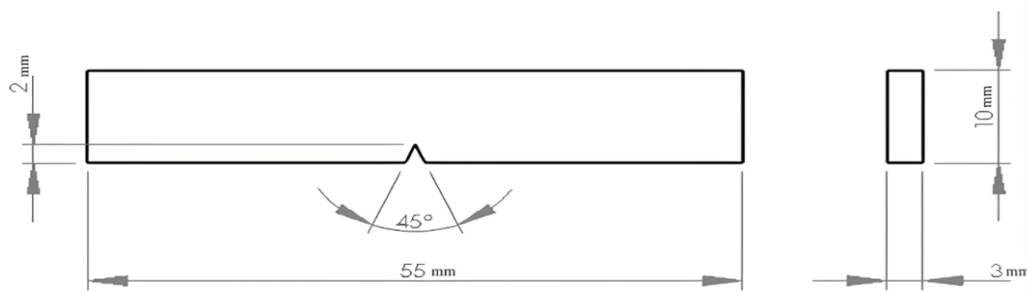


Figure 4. Impact Test Specimen (ASTM D5942)

$$\text{Energy absorption} = m \cdot g \cdot R (\cos \beta - \cos \alpha) \quad (1)$$

$$\text{Impact Toughness (HI)} = \frac{E}{A} \quad (2)$$

$$A = t (l - b) \quad (3)$$

Where t = Thickness of the specimen (mm), l = Width of the specimen (mm), b = Depth of the notch (mm), A = Cross-sectional area of the specimen under the notch (mm^2), β = Final angle after impact ($^\circ$), α = Initial angle of the pendulum ($^\circ$), R = Length of the pendulum arm (m), g = Acceleration due to gravity (m/s^2), m = Pendulum mass (kg)

3. Results and Discussion

3.1. Impact Test Results

The test was conducted using a Charpy impact testing machine. Composite specimens for impact testing were prepared in accordance with ASTM D5942 standards. Examples of impact test specimens with fiber orientation of 15° , 30° , and 45° can be seen in Figure 5.

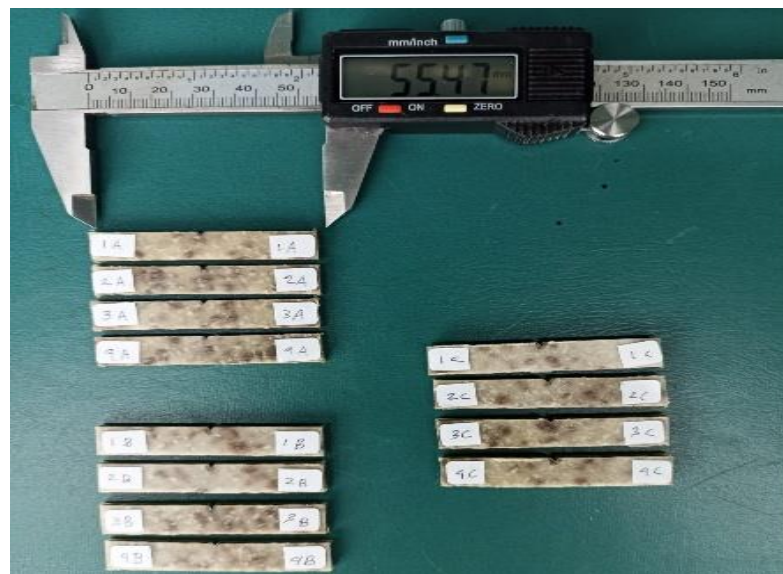


Figure 5. Impact Test Specimens

For each variation, four tests were conducted. From these four tests, three data points were selected for each variation, and the average values of absorbed energy and impact toughness were then calculated. The impact test results are presented in Table 1.

Table 1. Impact Test Results

No.	Fiber Direction Orientation (°)	E _{abs} (J)	HI (J/mm ²)
1.	15	0.777	0.0265
2.	30	0.715	0.0248
3.	45	0.696	0.0221

The average values of absorbed energy and impact toughness for fiber orientations of 15°, 30°, and 45° are subsequently presented in graphical form. The graphs of the average absorbed energy and impact toughness are shown in Figure 6.

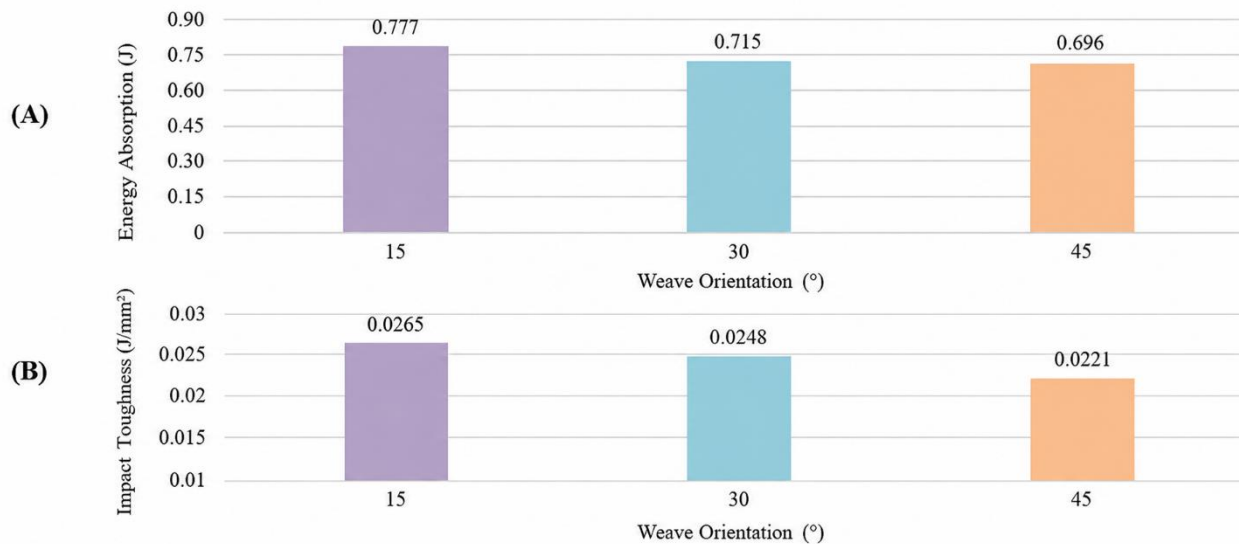


Figure 6. (A) Energy Absorption Graph, (B) Impact toughness Graph

Based on Figure 6, the results of the Charpy impact test indicate that ramie fiber orientation has a significant effect on the ability of the composite to absorb impact energy. The highest impact toughness was obtained at a fiber orientation angle of 15°, with a value of 0.0265 J/mm² and the highest average absorbed energy of 0.777 J, while the lowest values occurred at a 45° orientation, with an impact toughness of 0.0221 J/mm² and an absorbed energy of 0.696 J. The increase in toughness at the 15° orientation indicates that the fibers are positioned more effectively to transfer stress from the matrix to the fibers when subjected to impact loading. At smaller orientation angles, stress distribution becomes more uniform, allowing plastic deformation of the matrix and fiber-bridging mechanisms to contribute more optimally [9]. This occurs because, at a 15° orientation, the fibers tend to be more perpendicular to the loading direction, enabling better load distribution and more effective fiber reinforcement [8].

These results are consistent with the findings of Atiqoh et al. [7], who reported a decrease of approximately 22% in impact values from a 0° to a 45° orientation. This trend reflects a similar pattern observed in the present study, where increasing the fiber orientation angle leads to a reduction in energy absorption capability [10]. This reduction is associated

with the dominance of interlaminar shear mechanisms and an increase in fiber pull-out phenomena at higher orientation angles, causing the specimens to fail more easily. At a 30° orientation, the absorbed energy decreased to 0.715 J with an impact toughness of 0.0248 J/mm². The decrease in impact toughness from 15° to 45° reached 16.6%, indicating that changes in fiber orientation significantly influence the energy absorption mechanisms. This reduction correlates with increased shear forces acting parallel to the fiber direction, leading to earlier interfacial failure. Therefore, fiber orientation significantly affects the impact toughness of ramie fiber-reinforced polypropylene composites, where smaller fiber orientation angles provide higher impact toughness, while larger angles reduce the composite's ability to absorb impact energy [11].

3.2. Stereo Microscope Observation

Macro photographic observation was conducted on the fracture surfaces to identify the failure modes occurring on the composite fracture cross-sections [12]. The fractured specimens after impact testing of ramie fiber-reinforced polypropylene composites exhibited several material failure mechanisms. Macro images of the fracture surfaces obtained from the impact test for the three fiber orientation angles (A) 15° , (B) 30° , and (C) 45° can be seen in Figure 7.

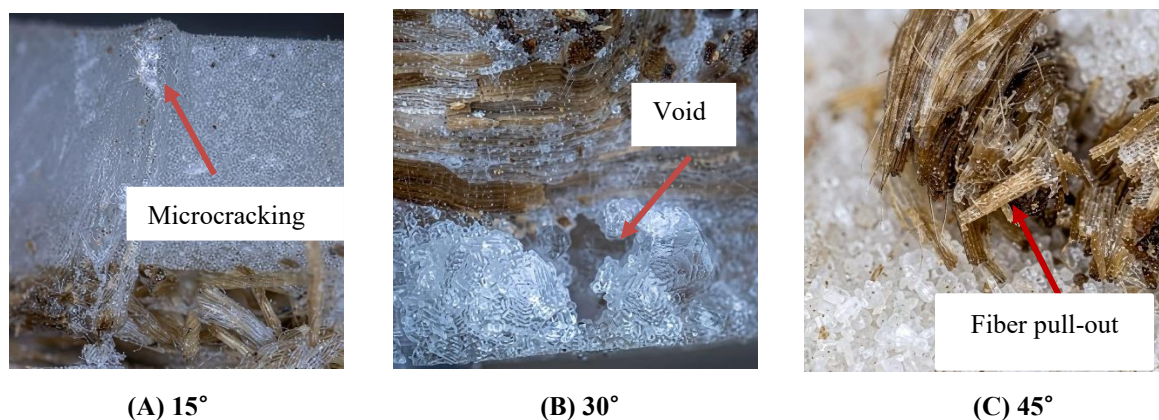


Figure 7. Macro Photographs of Fractures Resulting from Fiber Orientation Impact Tests (A) 15° , (B) 30° , (C) 45°

Figure 7 shows the fracture surfaces of the composite specimens after impact testing. At the 15° fiber orientation, matrix cracking was observed as the dominant visible failure characteristic, while the fibers remained embedded in the matrix and could contribute to crack propagation resistance [13]. At the 30° orientation, voids were observed on the fracture surface. These voids can act as stress concentration sites and may facilitate crack initiation and propagation during impact loading [14]. At the 45° orientation, fiber pull-out was clearly observed, indicating insufficient interfacial bonding between the ramie fibers and polypropylene matrix. Fiber pull-out reduces the effectiveness of stress transfer between the matrix and reinforcement and can contribute to lower impact energy absorption [15].

4. Conclusion

This study demonstrates that fiber orientation significantly affects the mechanical properties of ramie fiber-reinforced polypropylene composites. The highest impact toughness was obtained at a fiber orientation of 15° , with a value of 0.0265 J/mm². In contrast, the lowest impact toughness was observed at a 45° fiber orientation, with an average value of 0.0221 J/mm². These results indicate that the more perpendicular the fiber orientation angle is to the direction of impact loading, the higher the impact toughness achieved. Macro-photographic observations of the impact fracture surfaces revealed

several structural failure mechanisms, primarily characterized by fiber pull-out, where composite fibers were extracted from the matrix during impact loading.

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References

- [1] Masdani, M., & Dharta, Y. Potensi Pengembangan Komposit Berpenguat Serat Kulit Gaharu Sebagai Material Pengganti Fiberglass Pada Pembuatan Dashboard. *Manutech: Jurnal Teknologi Manufaktur*. 2018; 10(01): p. 33-38.
- [2] Ramesh, M., Palanikumar, K., & Reddy, K.H. Mechanical property evaluation of sisal–hemp–ramie fiber reinforced polyester composites. *Journal of Natural Fibers*. 2020; 17(09): p. 1256–1268.
- [3] Sanjay, M.R., Arpitha, G.R., Naik, L.L., Gopalakrishna, B., & Yogesha, B. Applications of natural fibers and its composites: An overview. *Natural Resources*. 2018; 9(01): p. 1-16.
- [4] Asim M, Jawaid M, Saba N, et al. A review on pineapple leaf fibers and their composites for automotive applications. *Compos Part B Eng*. 2018;110:152–173.
- [5] Latief, A.E., Anggraeni, N.D., & Hernady, D. Karakterisasi Mekanik Komposit Matriks Polipropilena High Impact Dengan Serat Alam Acak Dengan Metode Hand Lay Up Untuk Komponen Automotive. *Jurnal Rekayasa Hijau*. 2020; 3(03): p. 241–247.
- [6] Huda MS, Drzal LT, Mohanty AK, Misra M. Natural fiber reinforced composites for automotive applications. *Polym Compos*. 2006;27(5):637–648.
- [7] Atiqoh, N., Wulandari, D., Ryandadari, D., & Ganda, A.N.F. Pengaruh Variasi Arah Serat Bambu terhadap Kekuatan Impak Komposit sebagai Material Bumper Mobil. *Jurnal Rekayasa Mesin*. 2023; 8(02): p. 114–119.
- [8] Amonrattanasud M, Tuchinda K. Experimental Study of Fiber Orientation Effect on Frictional Material Properties and Tribology Performance. *Solid State Phenomena*. 2020;304:25-32.
- [9] Azhari NJ, et al. Pengaruh Orientasi Arah Serat Terhadap Ketangguhan Impact Komposit Serat Daun Lidah Mertua dengan Metode Hand Lay-Up. *Malikussaleh Journal of Mechanical Science and Technology*. 2024;8(1):183-187.
- [10] Rendy R, Syahrizal S. Pengaruh Variasi Arah dan Massa Serat TKKS terhadap Kekuatan Material Komposit Termoset. *JTRM (Jurnal Teknologi dan Rekayasa Manufaktur)*. 2022;4(1):1-10.
- [11] Radhakrishnan G, Mathialagan S. Effect of fiber orientation on mechanical behavior of glass fiber reinforced polyethylene terephthalate foam sandwich composite. *Materials Today: Proceedings*. 2022;62:624-628.
- [12] Priyanto K, Purwono AH, Cristanto DA. Ketangguhan impak dan kekuatan tarik komposit fiberglass/clay filler bermatriks unsaturated polyester Bqtn-ex 157. *Teknika*. 2019;6(2):45-53.
- [13] Lokantara IP. Analisis Kekuatan Impact Komposit Polyester-Serat Tapis Kelapa Dengan Variasi Panjang Dan Fraksi Volume Serat Yang Diberi Perlakuan NaOH. *Dinamika Teknik Mesin*. 2012;2(1).
- [14] Syarief A, et al. Pengaruh fraksi volume dan orientasi sudut serat komposit polyester-serbuk kayu ulin (eusideroxylon zwageri)-kawat kasa terhadap kekuatan bending. *Turbo: Jurnal Program Studi Teknik Mesin*. 2022;11(2).

- [15] Firiya B, Marizal M, Waskitho BM, Sosiati H. Karakterisasi Sifat Tarik Komposit Hibrid Karbon/Abaka/Pmma Sebagai Bahan Alternatif Prosthesis. *Media Mesin: Majalah Teknik Mesin*. 2019;21(1):1-8.
- [16] Mulyoaji, A., & Wulandari, D. Pengaruh Variasi Susunan Arah Serat Komposit Berpenguat Serat Bambu Terhadap Kekuatan Tarik dan Bending. *Jurnal Teknik Mesin*. 2024; 13(01): p. 1–6.
- [17] Athilah, M. R. N., & Widjanarko. Pengaruh Arah Serat dan Fraksi Volume Terhadap Kekuatan Impact Komposit Serat Tebu (Sugar Cane Fiber) Epoxy. *Mars: Jurnal Teknik Mesin, Industri, Elektro dan Ilmu Komputer*. 2025; 3(03): p. 260–270.