International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Revue des Composites et des Matériaux Avancés-Journal of Composite and Advanced Materials
Vol. 35, No. 5, October, 2025, pp. 981-986
Journal homepage: http://iieta.org/journals/rcma

Enhanced Flexural and Impact Properties of a Prosthetic Pylon Using Ramie and Carbon/Glass Hybrid Composites

Hassanein A. Hashim[1*], Ahmed H. Oleiwi[2]

[1] Prosthetics and Orthotics Engineering Department, College of Engineering, University of Kerbala, Kerbala 56001, Iraq
[2] College of Engineering, Wasit University, Al Kut 52001, Iraq

Corresponding Author Email: hassanain.a@uokerbala.edu.iq

https://doi.org/10.18280/rcma.350517

Received: 28 August 2025
Revised: 29 September 2025
Accepted: 29 October 2025
Available online: 31 October 2025

Keywords:
composite materials, natural fibers, prosthetic pylon, mechanical properties, synthetic fibers

ABSTRACT

Prosthetic pylons are the columns that connect the prosthesis to the person's body and play a vital role in providing stability, comfort, and functional performance to prosthetic users. Improving the properties of these columns contributes significantly to enhancing the user experience. The research aims to develop prosthetic pylons' mechanical properties using natural and synthetic fibers. We could achieve these objectives by utilizing composite prosthetic pylon materials that replace conventional materials made of titanium, aluminum, or stainless steel. The vacuum method was used to produce specimens with polyester as the matrix and varying numbers of synthetic hybrid (carbon and glass) and natural (Ramie) fiber layers as reinforcing materials. The findings showed that the mechanical characteristics of laminated composites were significantly impacted by the kind and number of reinforcing layers. The results indicated that the samples made of two layers of synthetic hybrid (glass & carbon) fibers gave better properties in terms of flexural strength, flexural modulus, maximum shear stress, impact strength, and fracture toughness, which were 160 MPa, 7 GPa, 6.5 MPa, 35 kJ/m², and 15 MPa·m$^{1/2}$, respectively, compared to the samples made of three layers of ramie natural fiber, which were 86 MPa, 4 GPa, 5.5 MPa, 19 kJ/m², and 9 MPa·m$^{1/2}$, respectively. The effects of both materials yielded acceptable results and demonstrated their suitability for use as alternatives to certain metal materials that can cause fatigue, exhaustion, and discomfort to users.

1. INTRODUCTION

Lower limb amputation can occur at several levels, such as partial foot, ankle, transtibial, knee, transfemoral, and hip disarticulation. The lower limb an artificial external device called a prosthesis can replace all or a portion of the lower extremities. The purpose of a prosthesis is to enable a person with an amputated limb to carry out functional activities, especially walking, which might not be possible without the limb. A prosthesis should ideally be lightweight, long-lasting, pleasant to wear, easy to put on and take off, and aesthetically beautiful. A prosthesis must also have high mechanical performance and require very little care. Last but not least, the usage of a prosthesis is mostly determined by the patient's motivation, as none of the aforementioned traits are significant if the patient does not wear the prosthesis [1]. The foot-ankle assembly, pylon, socket, and adapter are the fundamental parts of lower limb prostheses that are below the knee. The pylons are laminated using composite materials (perlon, ramie, carbon and glass fiber and polyester resin) with different layers under vacuum conditions [2]. From the 1950s to now, the materials used in pylons have evolved significantly, ranging from wood, low-carbon steel, aluminum, titanium, plastic, and composite [3, 4]. Aluminum, although widely used in prosthetics because it offers a good balance between weight and durability, can be prone to buckling or deformation under high stresses and needs to be replaced more quickly than other materials like plastics [5, 6]. Thermoplastic and thermosetting plastics are presently being developed in a variety of ways. Thermosetting may be utilized with a broad variety of reinforcement and composite materials. In the last few years, people have become more aware of new materials made from natural fibers and how well they work for a reasonable price [7]. Natural fibers have unique properties and also environmental and health benefits, which make them an excellent substitute for synthetic fibers such as carbon fiber and glass fiber. They can be used to make renewable, affordable, and environmentally friendly composites. Because of its many advantages, including ease of availability, inexpensive production costs, and appropriate mechanical properties in comparison to many other fibers, ramie is regarded as one of the most attractive natural fibers. Reinforcing materials for polymer composites. Hybrid fibers, which consist of natural fibers, synthetic fibers, or a combination of both, demonstrate superior load-bearing capabilities in various directions when compared to single-fiber reinforcements [8, 9]. The surrounding matrix plays a crucial role by maintaining the optimal positioning and orientation of the fibers, thereby enhancing load transfer efficiency between them [9, 10].

Several researchers have conducted different studies on this topic. These researchers [11, 12] used hemp, carbon, glass, and Kevlar fibers as reinforced materials and acrylic as matrix materials for prosthetic sockets. The findings demonstrated that the quantity and kind of reinforcing layers used in the study affected the mechanical properties of laminated composites. Abdalikhwa et al. [13] used carbon and glass fibers as reinforcing materials and polymethyl methacrylate (PMMA) as a matrix. The results indicated that Young's modulus, tensile strength, and buckling load increased with the increasing number of composite fiber layers. Improving the properties of the pylons in terms of tensile and stiffness increases their ability to withstand weight and various mechanical stresses. These improvements ensure that the prosthetic pylons last longer without frequent maintenance or replacement, enhancing the prosthetics' sustainability and providing users with a long-term solution. The current research aims to improve the properties of the materials used in the manufacture of the pylons in terms of resistance to buckling or fracture to increase safety and help distribute pressure evenly on the prosthesis, which protects the user from injuries resulting from excessive concentration of pressure in certain areas. To achieve this goal, a composite material was manufactured using two types of reinforcement, natural (ramie) and artificial (hybrid fibers of carbon and glass) fibers and with different numbers of layers to know their effect on the properties and obtain the best lamination, which gives us the best mechanical properties for the prosthetic pylons.

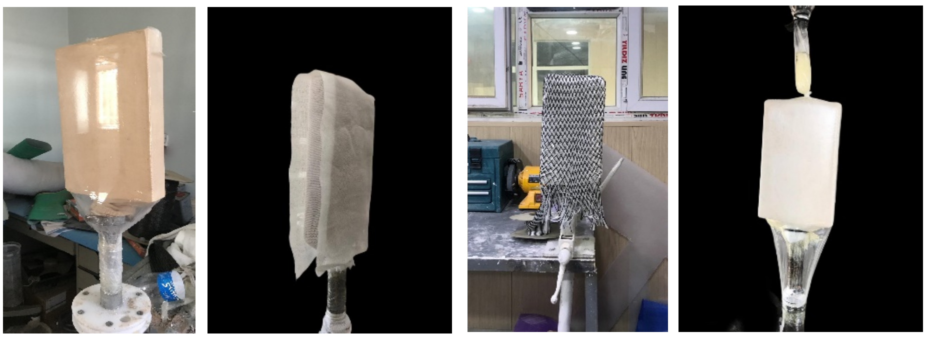
2. EXPERIMENTAL PART

2.1 Materials and equipment

The prosthetic pylon utilized in this investigation was made of isophthalic polyester produced by the B-Chem firm, Methyl Ethyl Ketone Peroxide haedener, twill carbon glassfiber stockinette (616G14), perlon elastic stockinette (623T5) manufactured by the Ottobock company, and plain ramie fibers. The manufacturing of the prosthetic pylons also requires the use of molds of plaster of Paris and polyvinyl alcohol (PVA) bags. A rectangular Jepson positive mold with dimensions of 35 cm × 20 cm × 15 cm was used. Additionally, a vacuum system and a platform are required to secure the Jepson pipe in position.

Table 1. Categories of laminated composite materials for prosthetic pylons

Lamination Title	Layer Configuration	Sum Layers
Laminate 1	3 perlon - 1 Ramie - 3 perlon	7
Laminate 2	3 perlon - 2 Ramie - 3 perlon	8
Laminate 3	3 perlon - 3 Ramie - 3 perlon	9
Laminate 4	3 perlon - 1hybrid (carbon & glass fiber) - 3 perlon	10
Laminate 5	3 perlon - 2hybrid (carbon & glass fiber) - 3 perlon	11



(a) **(b)** **(c)** **(d)**

Figure 1. Experimental results involved in the manufacturing of the composite specimens: (a) layer of PVA, (b) layers of ramie fiber, (c) layers of carbon glass fiber, and (d) casting of resin.

2.2 The method for fabricating specimens

The vacuum process was employed to fabricate laminated composite specimens using the lamination configuration depicted in Table 1. The mold was initially attached to the vacuum's jaw and connected to a pressure system via pipelines to create specimens. Subsequently, the vacuum pressure was held to -0.7 bar, and a PVA film was incorporated into the positive mold at an ambient temperature of 25℃. After that, as illustrated in Figure 1, layers of perlon stockinet, ramie fibers, and carbon glass fiber stockinet were placed on top of each other in accordance with Table 1's lamination lay-up. Afterward, a film of PVA was placed on the layers of composite material. The resin "polyester" is blended with the hardener using the standard ratio (2% by weight of resin) until the mixture is homogenous, this resin is poured into a PVA bag and distributed homogeneously to get a uniform layer. Finally, the vacuum device was kept working until the laminating composite material became rigid during the one-hour cure time, at which point the lamination was extracted from the gypsum mold. This process was performed on all the laminated composite specimens.

2.3 Mechanical tests

2.3.1 Flexural tests

A flexural test is carried out in accordance with ASTM standard (D790-07) using a universal test machine, and the test is carried out at room temperature (25°C) and relative humidity of 59%. The specimens were loaded from the center (by three-point bending) with a strain rate of 2 mm/min. Five specimens were tested for flexural testing as shown in Figure 2, and the average value was mentioned. Flexural strength and flexural modulus are deviations from the flexural test.

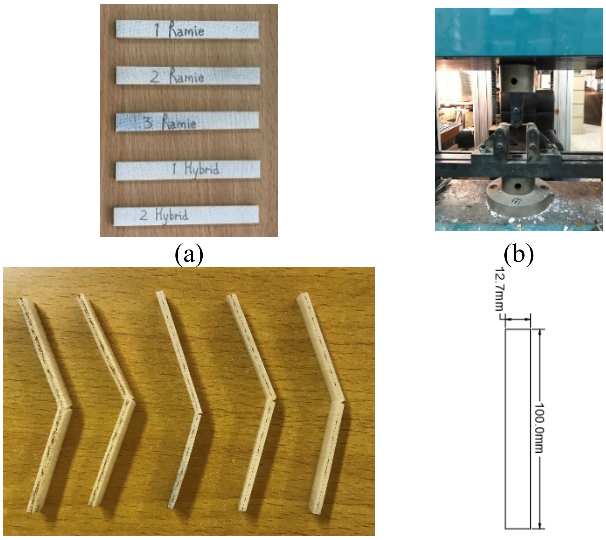


Figure 2. (a) The specimens previous to the test, (b) flexural apparatus, (c) the specimen's post-test, and (d) sample dimensions

2.3.2 Maximum shear stress test

A shear load is a force that attempts to deform a material by causing it to slide across one or more planes parallel to the applied force. The max. shear stress test is carried out in accordance with the ASTM standard (D2344) at room temperature (25°C) and a relative humidity of 59% [14]. Five specimens were tested and the average value was mentioned for the maximum shear stress testing.

2.3.3 Impact test

An Izod impact test is used to conduct an impact test in compliance with ISO 180 [15]. The test is conducted with a relative humidity of 59% and a room temperature of 25°C. Each laminated composite was evaluated on five specimens, and the average value was reported. Impact test variations include fracture toughness and impact strength.

2.4 Characterization test

2.4.1 Scanning electron microscopy (SEM)

The scanning electron microscope (SEM) model (TESCAN MIRA) was used to cut and examine the flexural specimens on the fracture surface. The morphology of the polymer composite was examined using a scanning electron microscope. samples that were made using a 400x magnification.

3. RESULTS AND DISCUSSION

3.1 Flexural test

3.1.1 Flexural strength

The prosthetic pylon must have flexural strength to support the user's body weight and withstand the extreme movements that can occur during walking and other dynamic activities. The average flexural strength values for each laminated composite are displayed in Figure 3. This figure shows that increasing the number of ramie layers while maintaining the perlon (6 layers) increased the flexural strength for three ramie layers to 86 MPa. The incorporation of synthetic fiber hybrids (glass and carbon) with consistent perlon layers enhanced flexural strength, achieving 160 MPa for the two hybrids. This improvement is because of the high mechanical properties of glass and carbon fibers [16].

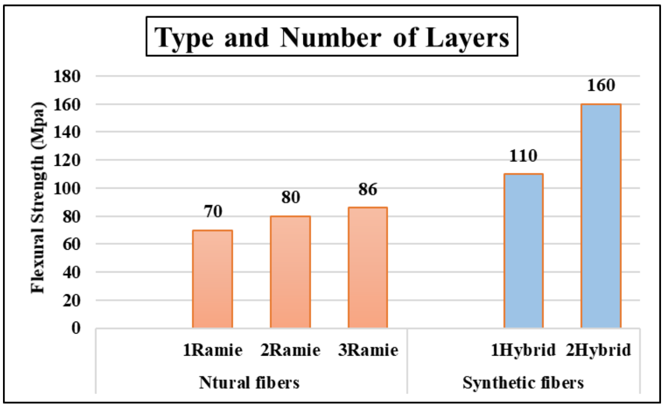


Figure 3. Flexural strength of composites with hybrid laminations and varying reinforcement layers

3.1.2 Flexural modulus

The relationship between stress and strain within the elastic region is known as a material's flexural modulus. Stiff materials exhibit a high modulus, whereas flexible materials show a low modulus. The average flexural modulus values for each laminated composite are shown in Figure 4. According to the research, while maintaining the perlon at six layers, increasing the number of reinforcing layers to 4 GPa for three layers of ramie may improve the flexural modulus. The fibers, exhibiting greater rigidity and strength compared to the matrix, bear a substantial portion of the composite's loads. The maximum flexural modulus observed for two hybrid laminations is 7 GPa. This results from the improved interaction between the matrix and fiber, along with the exceptional mechanical properties of carbon fiber [17].

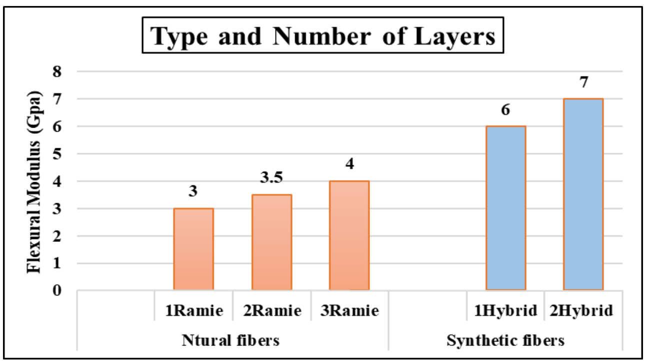


Figure 4. Flexural modulus of composites with hybrid laminations and varying reinforcement layers

3.2 Maximum shear stress

A rectangular beam experiences a shear force, and the bending moment resulting from normal stress is utilized to determine the shear stress. The average shear stress values for each laminated composite are displayed in Figure 5. This figure shows that adding more ramie layers while maintaining the same number of perlon layers (6 layers) increased the shear stress by up to 5.5 MPa. According to the "strengthening mechanism," these fibers can prevent cracks from spreading throughout the matrix because they form a strong link with it. For synthetic fibers made of two glass and carbon fiber hybrids, the maximum shear stress is 6.5 MPa.

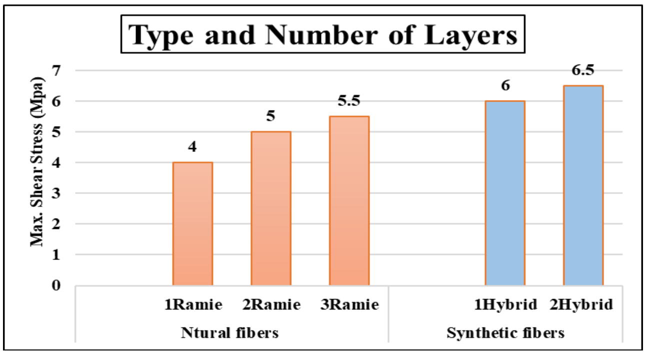


Figure 5. Maximum shear stress of composites with hybrid laminations and varying reinforcement layers

3.3 Impact test

3.3.1 Impact strength

The ability of a material to bear a quick load or force is known as the material's impact strength. Figure 6 shows a comparison of the average impact strength values for each laminated composite [18]. It was discovered that the impact strength could be improved by increasing the number of ramie layers to a maximum of 19 kJ/m^2 for three ramie layers while maintaining the perlon at a fixed level of six layers simultaneously. One possible explanation for this enhancement is that the addition of additional layers leads to an increase in the amount of kinetic energy that is dissipated, which in turn leads to a higher degree of impact strength [19]. The synthetic fibers that are formed of two hybrids of glass and carbon fibers have the highest impact strength (35.5 kJ/m^2) of any synthetic fiber. The ability of prosthetic pylon to withstand a high impact force is necessary in order to guarantee people's safety and prevent any damage from occurring.

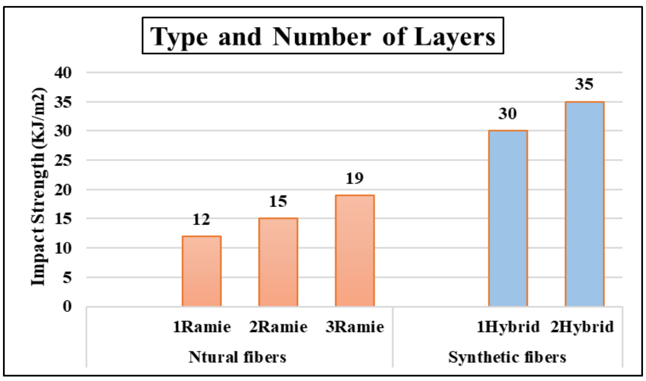


Figure 6. Impact strength of composites with hybrid laminations and varying reinforcement layers

3.3.2 Fracture toughness

The ability of a material to withstand fracture when a crack is present is referred to as "fracture toughness." Figure 7 illustrates the mean fracture toughness values for all laminated composites. The data presented indicates that augmenting the number of ramie layers, while maintaining a constant perlon layer count of six, led to an enhancement in fracture toughness, reaching a value of 9 $MPa \cdot m^{1/2}$ with three ramie layers. The increase in the impact strength and flexural modulus of ramie correlates positively with the number of layers present. The results indicate that an increase in the number of layers leads to enhanced ductility in the material. Consequently, enhanced fracture toughness leads to a decrease in crack propagation [20]. The maximum fracture toughness recorded is 15 $MPa \cdot m^{1/2}$ for synthetic fibers made from a hybrid of glass and carbon fibers.

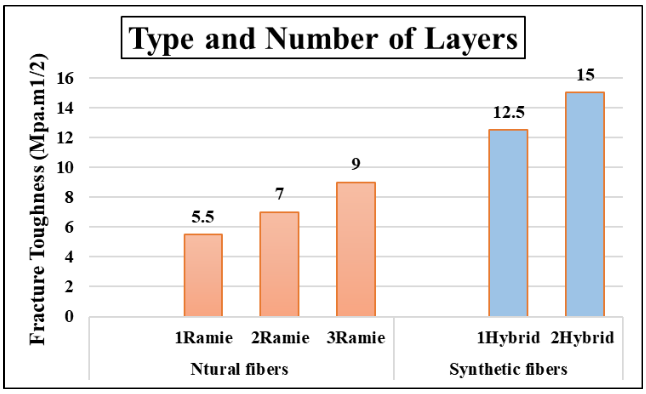
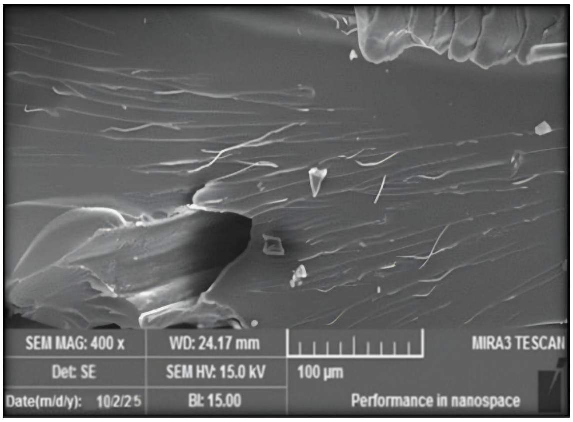


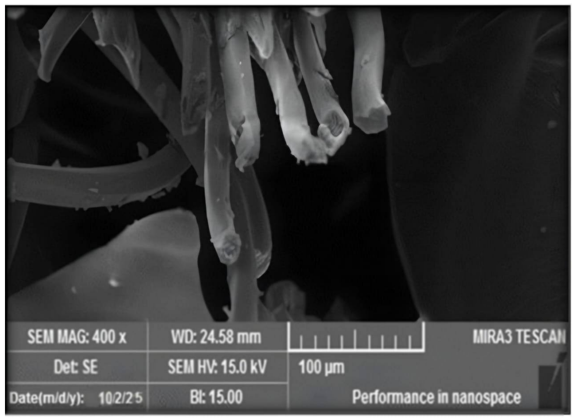
Figure 7. Fracture toughness of composites with hybrid laminations and varying reinforcement layers

3.4 Scanning electron microscope

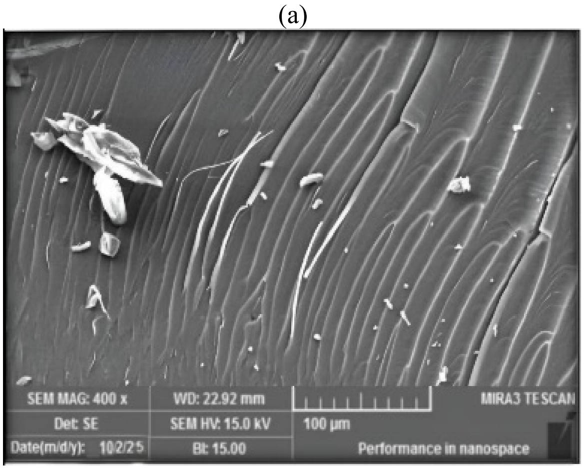
The purpose of SEM was to compare the mechanical characteristics and behavior of polyester polymeric composite samples with their fracture surface morphology, based on the quantity of layers in the carbon fiber glass and ramie. Samples from a flexural test were examined for this test. After a composite with a different composition ruptured mechanically, the morphological data of a composite was examined using SEM micrographs at 400x magnification. In Figures 8(a)-(d), the outcomes are displayed. The kind of polymeric material, The percentage of materials used for reinforcement, the moisture content, manufacturing conditions, and the melting viscosity of the components are some of the many variables that influence the SEM micrographs of fracture surfaces for polymeric composites [21]. Figure 8(a) shows the fracture morphology of composite reinforced with a one layer of ramie. The SEM microscopic imaging reveals a brittle failure and displays the rough fracture surface shape. The fibers' orientation, alignment, and homogeneous appearance are all visible. One common way to observe the interface effect is to do a fiber pull-out research, which involves a debonding process followed by a pull-out operation. Because the composite comprises fibers and fiber pieces, pull-out testing is possible. The morphology of polyester composites reinforced with three ramie fiber layers is shown in Figure 8(b). The polyester matrix's fibers are uniformly spaced, and the morphology seems to be semi-continuous. Three layers of ramie fibers in a polyester composite give it a semi-ductile appearance and enhance the connection between the fibers and the polyester. It was discovered that the resin was evenly dispersed throughout the fabric and that there was excellent interfacial adhesion between the fiber and matrix. The enhanced mechanical properties of ramie-polyester composites are a direct result of their superior morphological characteristics. Figures 8(c) and 8(d) display the fracture surface morphology of the carbon glassfiber hybrid polyester composites. The morphology seems to be semi-continuous. It is observed that the majority of the carbon glassfiber hybrid becomes entrenched in the polyester matrix material and exhibits smoother fracture surface morphology in the SEM microscopic imaging. Furthermore, it demonstrates the highest interfacial adhesion among fiber materials and composite material components due to the strong link between the fibers and polyester material. Thus, the addition of carbon glassfiber to the composite material improves its mechanical properties.



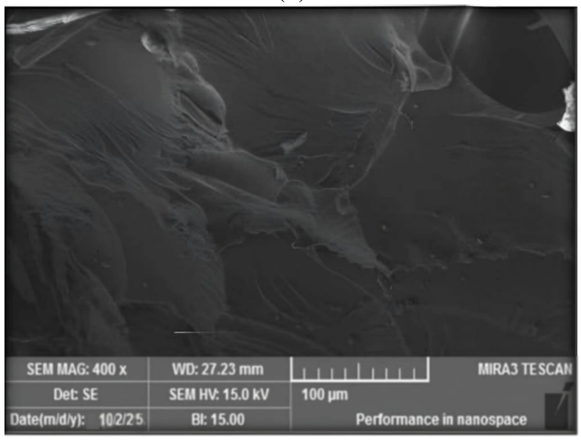
(a)



(b)



(c)



(d)

Figure 8. SEM pictures showing the fractured surface morphology of polyester with (a) single layer of ramie fiber, (b) three layers of ramie fiber, (c) single layer of carbon glass fiber, and (d) double layers of carbon glass fiber

4. CONCLUSIONS

Three ramie natural and two synthetic hybrid (glass and carbon) layers are the good hybrid laminated composite materials for manufacturing prosthetic pylons because they have a higher flexural strength and modulus than other hybrid laminated composites. These laminated composites are lighter and more cost-effective than conventional metals used for pylons, and this is very important for patients.

The values of shear stress increased when the layers of both synthetic and natural fibers increased. This plays a very important role in the design and function of prosthetic pylons, leading to improved durability, comfort, functionality, and enhanced user experience.

The impact strength and fracture toughness must be high to sustain sudden forces or impacts such as trips or falls. A prosthetic with excellent impact strength can protect the patient from injury; these depend on the material used in manufacturing the prosthetic pylon.

A limitation of this study is the lack of long-term fatigue testing. Future work should focus on dynamic fatigue testing, environmental aging studies, and the fabrication of full-scale pylon prototypes for real-world validation.

ACKNOWLEDGMENT

The authors are thankful to University of Technology/College of Materials Engineering.

REFERENCES

[1] Rashad, B.J., Bdaiwi, W. (2024). Study of mechanical, physical, and thermal properties of polyester-polyethylene composite materials reinforced with rubber granules. Annales de Chimie Science des Matériaux, 48(6): 767-784. https://doi.org/10.18280/acsm.480603

[2] Chiad, J.S. (2014). Study the impact behavior of the prosthetic lower limb lamination materials due to low velocity impactor. Engineering Systems Design and Analysis, 45844: V002T07A001.

https://doi.org/10.1115/ESDA2014-20007

[3] Oleiwi, A.H., Hasan, M.T., Hashim, H.A. (2024). Investigation of the hybridization effect of glass fibers and diboron trioxide epoxy composites on some mechanical properties. Journal of Physics: Conference Series, 2857(1): 012045. https://doi.org/10.1088/1742-6596/2857/1/012045

[4] Oleiwi, A.H., Abdualraman, S.A., Salman, H.A. (2025). Effect of zirconia-alumina additives on some mechanical and physical properties of epoxy resin for industrial applications. Revue des Composites et des Matériaux Avancés, 35(1): 21-26. https://doi.org/10.18280/rcma.350103

[5] Mahmood, N.Y., Zainulabdeen, A.A., Mohmmed, J.H., Abd Oun, H. (2020). Effect of cyclic heat treatment on microstructure and mechanical properties of AA 6061-T6 aluminum alloy. Al-Nahrain Journal for Engineering Sciences, 23(4): 383-387. http://doi.org/10.29194/NJES.23040383

[6] Mohmmed, J.H., Mahmood, N.Y., Ali, M., Zainulabdeen, A.A. (2020). Buckling and bending properties of aluminium plate with multiple cracks. Archives of Materials Science and Engineering, 106(2): 49-58. https://orcid.org/0000-0003-3785-6104

[7] Mohammed, R.A., Attallah, M.S., Al-Zubidi, A.B., Al-Gebory, L. (2023). Investigation of the effect of waste materials on the properties of the composite polymer prosthetics limbs. Revue des Composites et des Matériaux Avancés, 32(4): 191-197. https://doi.org/10.18280/rcma.320404

[8] Ali, M., Hashim, H.A., Oleiwi, A.H., Mohmmed, J.H. (2025). Study of tensile, hardness, and compressive properties of prosthetic pylon made of ramie and carbon/glass hybrid composite materials. Archives of Materials Science Engineering, 132(1): 21-28.

[9] Hammadi, A.F., Oleiwi, A.H., Abdalameer, T.A., Al-Obaidi, A.J. (2023). Effect of alumina particles on the mechanical and physical properties of polypropylene whisker reinforced lamination 80: 20 resin composite. Revue des Composites et des Matériaux Avancés, 33(1): 7-12. https://doi.org/10.18280/rcma.330102

[10] Oleiwi, A.H. (2022). Study some properties for UPS composites reinforced by sunflower husk ash. AIP Conference Proceedings, 2437(1): 020028. https://doi.org/10.1063/5.0092290

[11] Hashim, H.A., Hamad, Q.A., Oleiwi, J.K. (2024). Investigation of tensile and compressive properties of laminated composite materials for below-knee prosthetic socket. AIP Conference Proceedings, 3002(1): 080019. https://doi.org/10.1063/5.0206827

[12] Hashim, H.A., Oleiwi, J.K., Hamad, Q.A. (2023). Evaluation the impact and flexural properties for lower limbs prosthetic socket. In 4th International Scientific Conference of Engineering Sciences and Advances Technologies, 2830(1): 030012. https://doi.org/10.1063/5.0156849

[13] Abdalikhwa, H.Z., Al-Shammari, M.A., Hussein, E.Q. (2021). Characterization and buckling investigation of composite materials to be used in the prosthetic pylon manufacturing. IOP Conference Series: Materials Science and Engineering, 1094(1): 012170. https://doi.org/10.1088/1757-899X/1094/1/012170

[14] ASTM International. (2000). ASTM D2344/D2344M: Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates. https://doi.org/10.1520/D2344_D2344M-16

[15] International Organization for Standardization. (2019). Plastics—Determination of Izod Impact Strength (ISO 180:2019).

[16] Abbod, E.A., Challoob, S.H., Resan, K.K., Salman, A.A., Abdulrehman, M.A., Muhammad, A.K. (2025). Innovative carbon fiber-reinforced polypropylene for enhanced manufacturing of lower-limb prosthetic sockets. Annales de Chimie Science des Matériaux, 49(2): 139-144. https://doi.org/10.18280/acsm.490204

[17] Turla, P., Kumar, S.S., Reddy, P.H., Shekar, K.C. (2014). Processing and flexural strength of carbon fiber and glass fiber reinforced epoxy-matrix hybrid composite. International Journal of Engineering Research and Technology, 3(4): 394-398.

[18] Talla, H.K., Hassan, A.K.F., Oleiwi, J.K. (2022). An investigation into the effect of adding carbon and glass fibres to UHMWPE fibres on the mechanical characteristics of a sports prosthetic foot. Revue des Composites et des Matériaux Avancés, 32(2): 69-76. https://doi.org/10.18280/rcma.320203

[19] Oleiwi, J.K., Hamad, Q.A., Abdulrahman, S.A. (2022). Flexural, impact and max. shear stress properties of fibers composite for prosthetic socket. Materials Today: Proceedings, 56: 3121-3128. https://doi.org/10.1016/j.matpr.2021.12.368

[20] Rao, D.S., Reddy, P.R., Venkatesh, S. (2017). Determination of mode-I fracture toughness of epoxy-glass fibre composite laminate. Procedia Engineering, 173: 1678-1683. https://doi.org/10.1016/j.proeng.2016.12.193

[21] Ash, B.J., Rogers, D.F., Wiegand, C.J., Schadler, L.S., Siegel, R.W., Benicewicz, B.C., Apple, T. (2004). Mechanical properties of Al2O3/polymethylmethacrylate nanocomposites. Polymer Composites, 23(6): 1014-1025. https://doi.org/10.1002/pc.10497