Exp. Theo. NANOTECHNOLOGY 9 (2025) 247-258 https://doi.org/10.56053/9.S.247

Aluminum particles effect of mechanical properties on fiberglass-reinforced polymer

Sura Hameed Ahmed Ali[1], *Sarah Abdulsalam Hattab*[2], *Wafaa Mahdi Salih*[3,*], *Sanaa Mahdi Salih*[4]

[1]Ministry of Higher Education and Scientific Research, Baghdad, Iraq
[2]Chemical Engineering Department, University of Technology, Baghdad, Iraq
[3]Materials Engineering Department, University of Technology, Baghdad, Iraq
[4]Department of Electromechanical Engineering, University of Technology, Baghdad, Iraq
[*]) Email: wafaa.m.salih@uotechnology.edu.iq

Received 21/1/2025, *Received in revised form* 29/1/2025, *Accepted* 19/2/2025, *Published* 15/3/2025

This study investigates the behavior of epoxy resin reinforced by aluminum particles to study some mechanical properties of metal-reinforced polymer composites (PMCs). Firstly, preparation of an epoxy sample, then the reinforcement of the matrix by 5% weight fraction of glass-fiber, then preparation of hybrid samples with 5% weight fiber glass + different concentrations of aluminum, and finally testing tensile, flexural, hardness, and impact properties of the samples in order to test the mechanical properties of the samples. The main reason for selecting this study is as a practical application of plastic natural gas (CNG) cylinders, which consist of epoxy and glass fibers. Reinforced these materials with aluminum powder to improve their properties and to study the effect of the weight fraction of aluminum on some mechanical properties. The results showed that the mechanical properties (tensile strength, modulus of elasticity, flexural strength, flexural modulus, hardness, impact strength, and flexural toughness) increased when increasing the concentrations of reinforcing. The composite materials have the highest value of these properties (EP+5% Eglass+0.98% Al) compared with other percentages.

Keywords: Epoxy resin; Metal-reinforced polymer; E-glass fibers; Aluminum particles.

1. INTRODUCTION

Composite materials can be categorized in a variety of ways. For instance, there are diffusion-enhanced composite materials, particle-enhanced composite materials, and fiber-reinforced composite materials, all of which follow the reinforcing principle. Composite materials can be classified as structural or functional, based on the specific needs of the application. Lastly, there is the categorization based on matrix material type: polymer matrix composites (PMCs), inorganic non-metallic (ceramic) matrix composite materials (CMCs), and metal matrix composites (MMCs). We already know that there is a large variety of composite materials based on the grouping of composite materials. It goes without saying that various composite material types have various performance attributes.

On the other hand, composite materials also possess certain characteristics. Polymer matrix composites are the most popular and rapidly expanding composite materials due to their intrinsic qualities. The following features of polymer matrix composites set them apart from more conventional materials like metals: 1) Excellent modulus and specific strength; 2) Sufficient fatigue resistance and damage tolerance; 3) Sufficient damping properties; 4) Multifunctional performance; 5) Robust processing techniques; and 6) Anisotropic in and characteristics design-ability [1]. Saini and Asser [2] have studied thermally conductive polymeric composites is expanding, wherein polymers containing thermally conductive fillers efficiently disperse heat produced by electronic components. In this work, epoxy composites with weight percentages of 1, 2.5, and 5.5 are created by adjusting the copper/aluminum ratio. It is looked at how adding copper/aluminum particles affected the composite material's thermal conductivity. Additionally, Ansys is used to analyze the thermal conductivity of composites using the finite element approach. The findings showed that the use of metallic filler increased the epoxy composite's heat conductivity. There is a correlation between the theoretical model and the experimental data. When compared to the experimental value, the thermal conductivity derived from the series conduction model produced better findings [2]. Bello et al. [3] have investigated 1,3-diethanamine benzene hardener is used to cure the diglycidyl ether of bisphenol A (DGEBA) after aluminum particles from aluminum can waste are added. The created epoxy composites are subjected to tensile, flexural, impact toughness, and microhardness tests as part of mechanical property testing. The epoxy system and the aluminum particles are shown to be involved in a chemical reaction by the XRD measurements. Within the produced epoxy framework, the second-phase particles are distributed pretty uniformly. The epoxy/10% aluminum nanoparticle composite (E/10%Alnp) is tested for mechanical characteristics, and the findings indicated that its microhardness value is 12.03 HV, its tensile strength is 18.58 Nmm2, and its flexural strength is 130.87 Nmm2. The impact energy is 16.30 J. The E/10% AlnP nanocomposite's mechanical property values are published in [3]. Verma and Srivastava [4] have researched the current to investigate how metallic additives affected the mechanical properties of a commercial epoxide resin (PL-411). As a result, we reinforced filler particles made of copper and aluminum that are smaller than 100 m. We assessed and contrasted Vickers's hardness, compressive strength, and tensile strength. The addition of ductile fillers steadily decreased the tensile strength. As the filler content rose, so did the hardness and compressive strength [4]. Gong [5] has researched the mechanical and electrical properties of hybrid Al/epoxy composites that contain three different kinds of hybrid aluminum (Al) particles that vary in size. We specifically prepared the composites with an Al/Ws ratio of 1:15, an Al/Ws ratio of 18 mm/45 mm, and an Al/Ws ratio of 1:15. We kept the filler content of the hybrid Al/epoxy composites at 50%. We have discovered that the hybrid filler type and the Ws significantly influence the mechanical and electrical characteristics of the hybrid Al/epoxy composites, and we can adjust the Ws. At an ideal Ws, the composites' maximal tensile strength and elongation at break are seen. Also, the dielectric permittivity, dielectric breakdown strength, and volume resistivity of the hybrid Al/epoxy composites change in ways that are similar to how their mechanical properties change with Ws [5]. Bello [6] has studied the aluminum microparticles and nanoparticles created from aluminum cans using ball milling, sand casting, and lathe machine spinning processes. mixed both kinds of aluminum particles with a combination of epoxy resin and diglycidyl ether of bisphenol A (DGEBA) and cured them using amine base hardener (ABH). The XRD results showed that there are aluminum phases and/or compounds because the aluminum particles and the DGEBA/ABH system did chemical things with each other.

SEM confirms that the phases of the epoxy matrix are spread out evenly and that the epoxy matrix and the aluminum particles stick together strongly. Based on a correlation between their mechanical characteristics and the purchased bumper materials, researchers found the produced nanocomposites to be somewhat suitable for use in automotive applications [6]. Misiura et al. [7] has looked for the mechanical properties, electrical conductivity, and thermal conductivity of epoxy polymer (EP)-filled composites with copper (Cu) and nickel (Ni) particles that are spread out. The electrical conductivity of the composites is revealed to exhibit percolation behavior; the EP-Cu and EP-Ni composites' percolation threshold values are found to be 9.9 and 4.0 vol.%, respectively. The thermal conductivity of the distributed metal phase in the composites, kf, is calculated using the Lichtenecker model and is found to be 35 W/mK for Cu powder and 13 W/mK for Ni powder [7]. Bandpatte et al. [8] have used to model the cylinder in three dimensions. We then use Finite Element Analysis to analyze the performance of the composite material cylinder and compare it with a steel cylinder. The results show that while each cylinder generates similar tension, composite cylinders save weight, resist corrosion, and reduce shipping costs [8]. Moketla and Shukla [9] have studied LPG cylinder with composite HDPE plastic, vinylester resin, and E-glass fiber underwent design and finite element analysis (FEA). Continuous fiber E-glass composite with a vinyl-ester polymer matrix weaves the cylinder's liner, while HDPE plastic (blow molding grade) constructs the structure. The cylinder cover also employs HDPE plastic. The intended and tested burst pressure for the LPG cylinder is 3 MPa. We determined the cylinder's thickness to be 3.5 mm using FEA based on Abaqus software, which includes 1.5 mm of liner and 2 mm of FRP composite layer. We developed a number of design options and conducted a financial viability study. In this article, the design goal is to create a robust, lightweight, rust-proof, and semi-transparent LPG cylinder with an emphasis on South African usage [9]. Aly et al. [10] have researchers examined the wear and friction of polymer composites loaded with nanoparticles. Researchers discovered that the composites' resistance to wear and friction increased as the filler content increased. Additionally, researchers discovered that multifunctional fillers could potentially create high-performance composites, a feat that single fillers cannot achieve [10].,to Fabricate the composite material (polymer reinforced two types of reinforced (fiber –glass & metal in different weight fraction), and to Studying the effect of The Mechanical Behavior of Polymeric Composite Materials Reinforced by fiber –glass and Aluminum Particles.

3. EXPERIMENTAL

3.1. Materials

The Materials Used in This Project They can be divided into three types; the first is the epoxy resin and hardener, while the other is the reinforcing material, which are glass- fiber and aluminum particles. The following materials are used for preparation of specimens: -

Matrix material (Epoxy resin): the Egyptian Swiss Chemical Industries Company produced the epoxy resin under the trademark (Euxit 50 KI). This low viscosity resin is liquid, but it may be made solid by adding a hardener at a 1:3 ratio. Table 1 displays the characteristics of the epoxy resin utilized in this project based on the product company's attributes.

Glass Fiber: The E-glass fiber used in this study is made by (Mowding LTD. UK Company); this type of fiber is the most common used for commercial fiber reinforced materials, which are immersed in matrix (epoxy) and in polymer Nano composite as laminate arrangement. Table (2) depicts the physical and mechanical properties of the (E-Glass) fibers used in the present work.

Aluminum particles is imported from Choice-Chem is a specialty chemicals company in China. Table (3) depicts some properties of aluminum. Figure (1) shows the results of the particle size analyzer of aluminum particles.

Exp. Theo. NANOTECHNOLOGY 9 (2025) 247-258

Table 1 The mechanical and physical properties of epoxy used according to the properties of Product Company

Properties	Value
The density (gm/cm^3)	1.05
Thermal conductivity (w/m.k)	0.18-.195
Compression strength (MPa)	70
Flexural Strength (MPa)	63
Tensile Strength (MPa)	27
Modulus of elasticity (GPa)	163.3

Table 2 Some Mechanical and Physical Properties of the (E-Glass) Fibers used in this Study according to the properties of Product Company

Properties	Value
Tensile Strength (MPa)	3.4
Young modulus (MPa)	72.5
Density (gm/cm^3)	2.58
Thermal conductivity	1.3
Poisson ratio	0.22

Table 3 Some Mechanical and Physical Properties of the aluminum particle used in this Study according to the properties of Product Company

Properties	Value
Shear modulus (GPa)	26
Young Modulus (GPa)	70
Density (gm/cm^3)	2.70
Poisson ratio	0.35
Specific Heat (jol/mol.k)	24.200

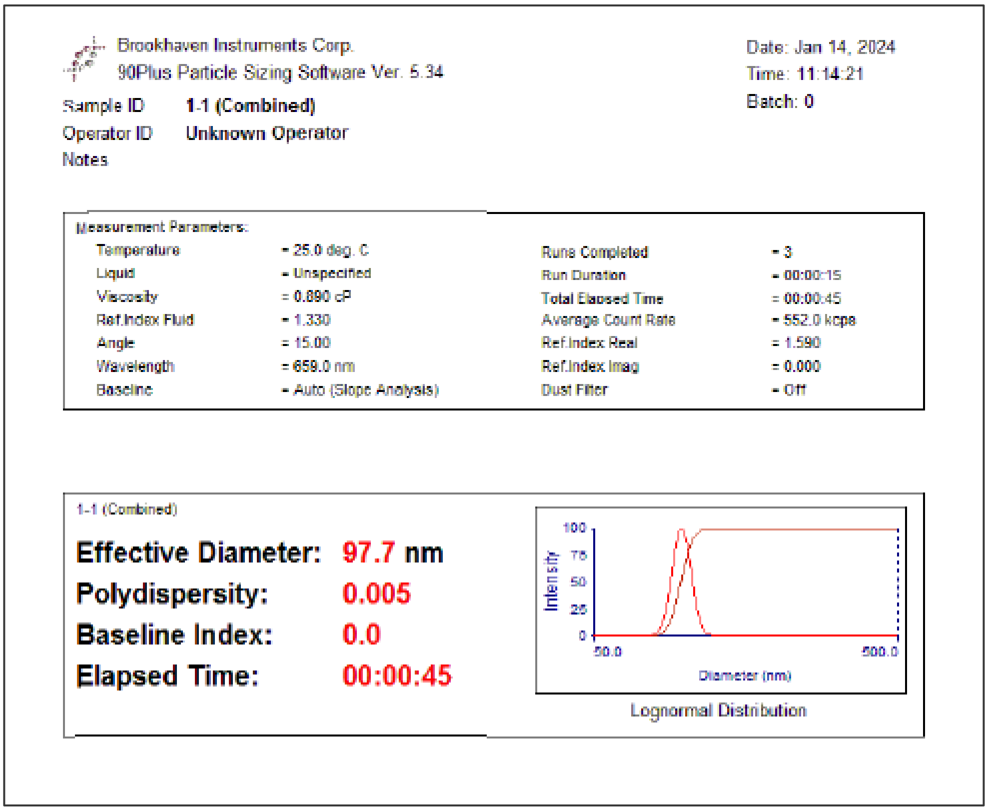

Figure 1 Shows the results of the particle size analyzer of aluminum particles.

3.2 Methods

These procedures are followed in order to produce each sample utilized in the current study using the hand lay-up technique.

1. Preparing pure epoxy: The manufacturing company specifies a weight ratio of three parts epoxy to one part hardener for the normal mixing ratio of epoxy resin to hardener. You need to do the mixing process gradually to prevent bubbles.

2. The Composite Preparation Process: Two Steps the first one required long mixing to avoid bubble formation since it reinforced epoxy with a five percent weight fraction of glass fiber. In the second step, mixture theory is used to make the composite stronger by adding different amounts of aluminum particles to the epoxy and 5% weight glass fiber. Table (4) illustrates the numerous sample types and material weight ratios. We introduced the particles to the polymer gradually and manually mixed them for five minutes to ensure a proper dispersion of particles throughout the matrix. The process of preparing composite materials is depicted in Figure (2).

3. The sample is cured for 24 hours at room temperature, and then it is placed in an oven set at 50 °C for two hours, exactly like in the creation of pure epoxy. 4-The samples are taken out of the silicone mold cavities once the curing process is complete, and they are now prepared for the necessary testing. The mechanical test samples are displayed in Figure (3).

Exp. Theo. NANOTECHNOLOGY 9 (2025) 247-258

Table 4 Shows the types of samples and the weight ratios of materials.

Samples	
S1	100% pure EP
S2	95%EP+5%E-glass
S3	94.005%EP+5%E-glass+0.995%Al
S4	94.01%EP+5%E-glass+0.99%Al
S5	94.015%EP+5%E-glass+0.985%Al
S6	94.02%EP+5%E-glass+0.98%Al

Figure 2 Prepare composite material.

Exp. Theo. NANOTECHNOLOGY 9 (2025) 247-258

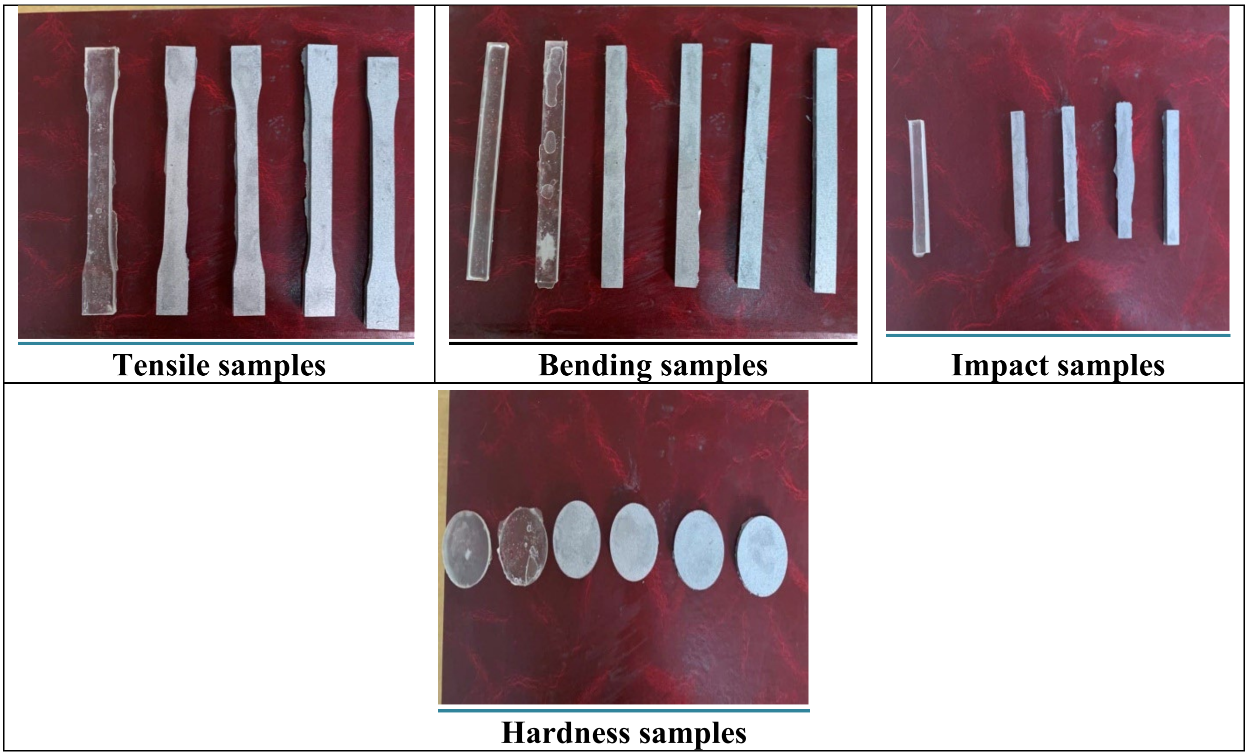

Figure 3 Shows the samples of mechanical tests.

4. CHARACTERIZATION AND TEST METHODS

Tensile Test: This test is done by using a universal tensile device with a 10 mm/min speed of crosshead in the department of materials engineering/ university of technology. Tensile properties of the specimens are determined depending on ASTM D638 [11].
The flexural test: Using the same apparatus as the tensile test, the samples for the flexural test are constructed at the Materials Engineering Department of the University of Technology, Iraq, in accordance with (ASTM D790) standards [12]. The three-point flexural technique is employed on a universal testing equipment to ascertain the samples' flexural strength.
Hardness (Shore A) Test: is employed to evaluate the nanocomposites hardness based on the (ASTM D-2240). The prepared specimens with (40mm) diameter and (4mm) thickness are used to perform the hardness test in the university of technology / materials engineering department [13].
The impact test: Using a pendulum Izod machine, the impact samples are designed in accordance with the (ISO-180) standard [14]. We used the impact test to determine the impact strength and fracture toughness of the composite specimens. An impact device with high energy (5.5 J) and high velocity (3.5 m/s) broke the samples.
Scanning Electron Microscopy (SEM) with EDX Test: The SEM test is utilized to examine the fracture surface morphology of the polymer composite (94.02%EP+5%E-glass+0.98%Al) at different magnifications during the ˝EM investigation, which is conducted using an electrophotography beam. The apparatus sputter-coated the samples with gold to enhance their electrical conductivity. Next, we conducted a fracture surface scan of the material. The gadget is available at the Tehran Petrochemical Institute.

Exp. Theo. NANOTECHNOLOGY 9 (2025) 247-258

5. RESULTS AND DISCUSSION

5.1 Tensile test

The (tensile strength T_S, and modulus of elasticity E, for (EP+5% E-glass) when the expansion different proportions (X%) from Aluminum form showed up in Figures 4 (a and b). It is found that the addition of aluminum particles to the polymer matrix increased the polymer's tensile strength and elastic modulus arbitrarily with increasing aluminum particle weight %. The efficient and uniform dispersion of the particles may explain this behavior, reducing the likelihood of particle clumping. This could lead to a decrease in the internal stress concentration in composite materials near nanoparticle clustering. Despite the fact that there are some minor internal tensions, they are not strong enough to disrupt the interactions at the interface [15]. It can be observed that has the highest value of tensile strength at (94.02%EP+5%E-glass+0.98%Al) compared with other percentages.

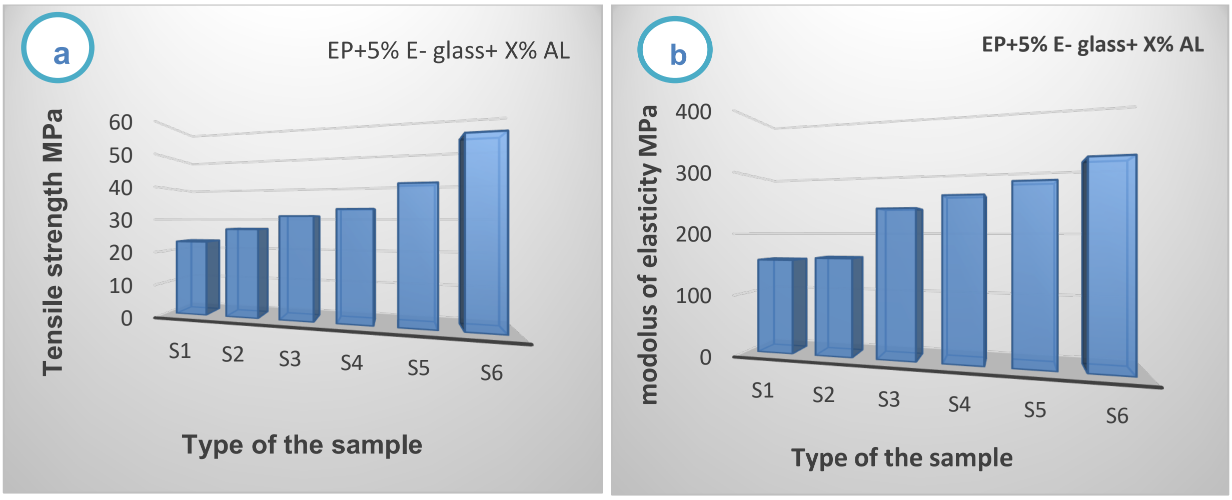

Figure 4 Tensile Properties where (a): Tensile Strength, and (b): Modulus of Elasticity with weight fraction for PMC samples.

5.2 Flexural test

Figures 5(a and b) show the effect of adding aluminum particles at varying ratios on the flexural characteristics of the samples (EP+5% E-glass). As the weight percentage of aluminum particles increased, the flexural strength ($\sigma_{bend.}$) and flexural modulus (E_f) of polymer materials also rose. Strong bonding between the polymer matrix and the particles causes the high compatibility between the elements of the polymer matrix and the nanoparticles, which in turn restricts fracture development inside polymer composites [16]. Thus, the flexural strength and flexural modulus values increase from (60 MPa and 145 MPa) for (95% EP +5% E-glass) to (107 MPa and 265 MPa) for (94.02%EP+5%E-glass+0.98%Al).

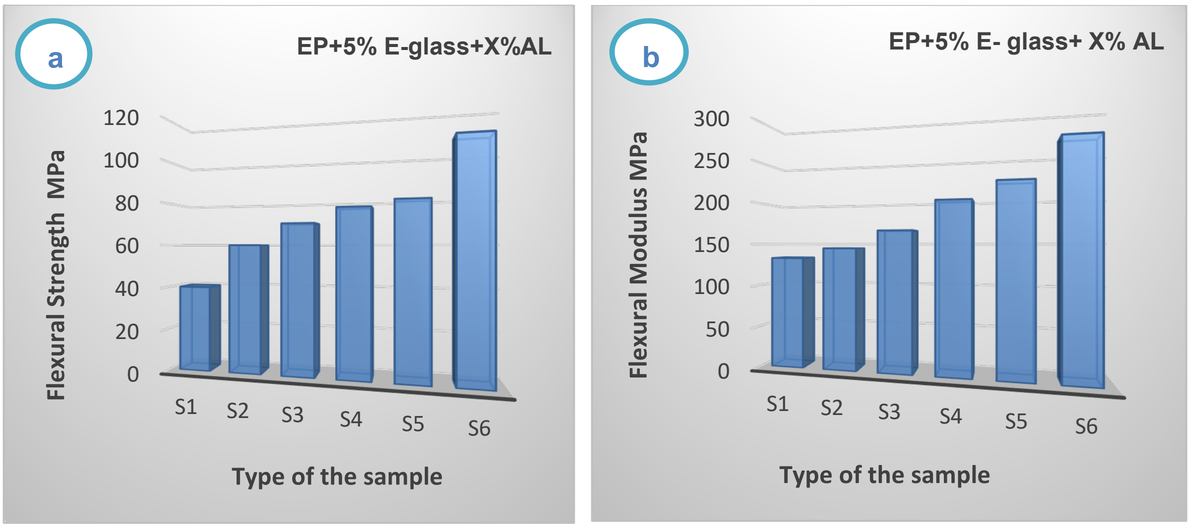

Figure 5 Flexural Properties where (a) Flexural Strength, and (b) Flexural Modulus with weight fraction for PMC samples.

5.3 Hardness test

Figure (6) illustrates the correlation between the weight fraction of PMC and the hardness (shore D). the hardness increases when increasing the constrictions of reinforcing materials and there observed that the hardness increase the range of hardness when reinforced between (76 – 80) shore D. For such systems containing aluminum particles as reinforcement, the previous results have noticed the effect on hardness values done by the particles. It is easy to recognize how effective it is; adding the particles as reinforcement to composite behavior. and hence this led to increasing the inter connections between the matrix (epoxy) and the glass fiber, making the entire system harder to penetrate.

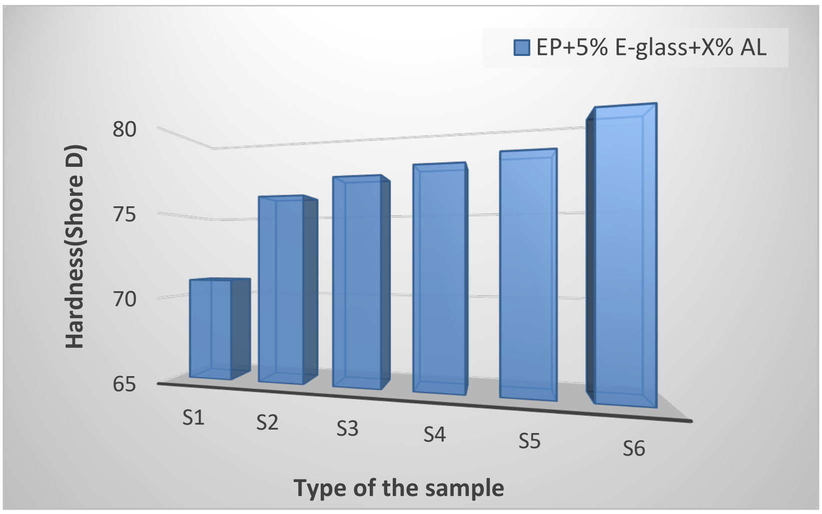

Figure 6 Comparison of hardness shore D with weight fraction for PMC samples.

5.4 Impact test

The impact test is different compared to other mechanical tests in that it happens quickly and subjects the sample to high stress, which alters the material's behavior. Figures 7(a and b) depict the relationship between the PMC weight percentage and the impact parameters (impact strength and flexural toughness). When compared to other percentages, it is evident that (94.02%EP+5%E-glass+0.98%Al) has the greatest value of (I.S). This indicates that the material behaved like a tough material since it could absorb more energy before breaking. Epoxy is a brittle substance that exhibits brittle behavior under impact loading; however, when combined with reinforced materials, it transforms into a ductile material. Put differently, glass fiber and aluminum particles are epoxy property modifiers [17].

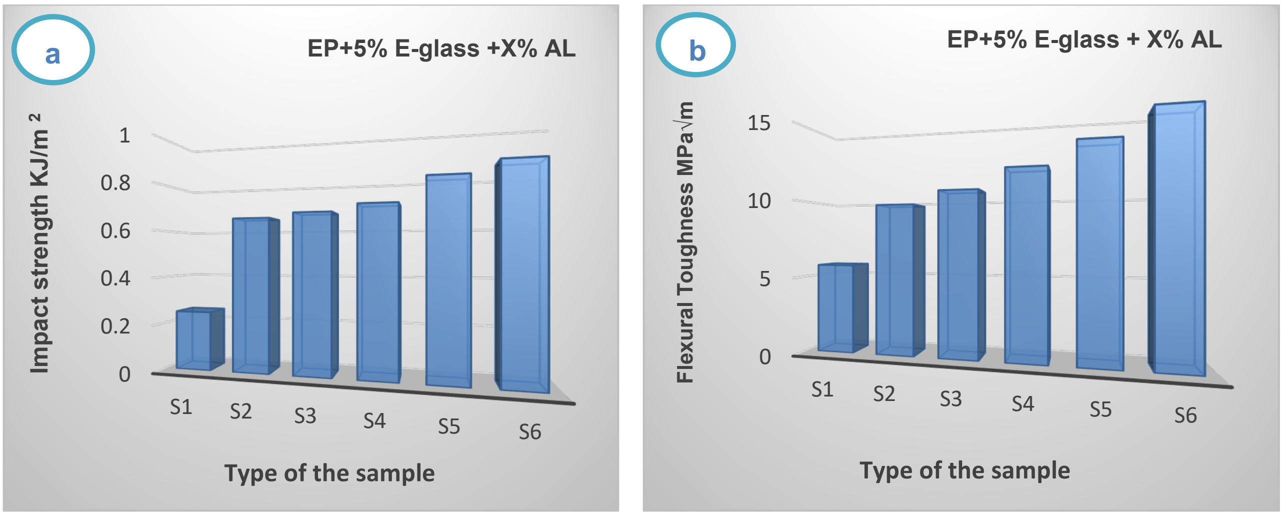

Figure 7 Impact Properties where (a): Impact Strength, and (b): Flexural toughness with weight fraction for PMC samples.

5.5 SEM Morphology for PMC

The number of nanoparticles added to the matrix materials changed the structure of the polymer composites (SEM) so that it is the same for all types. This morphology also revealed that the fracture is semi-smooth and exhibited characteristics of a semi-brittle fracture. On the other hand, the nanoparticles are well dispersed and have integrated themselves into the matrix, becoming a part of it. The matrix and nanoparticles in the composite specimens have a strong physical connection and a large interfacial distance. This means that the nanoparticles are spread out evenly across the whole matrix. The results show that the compatibility of the reinforcing materials (nanoparticles) with the matrix makes it less likely that cracks will start and spread, and the mechanical properties are better [18-22].

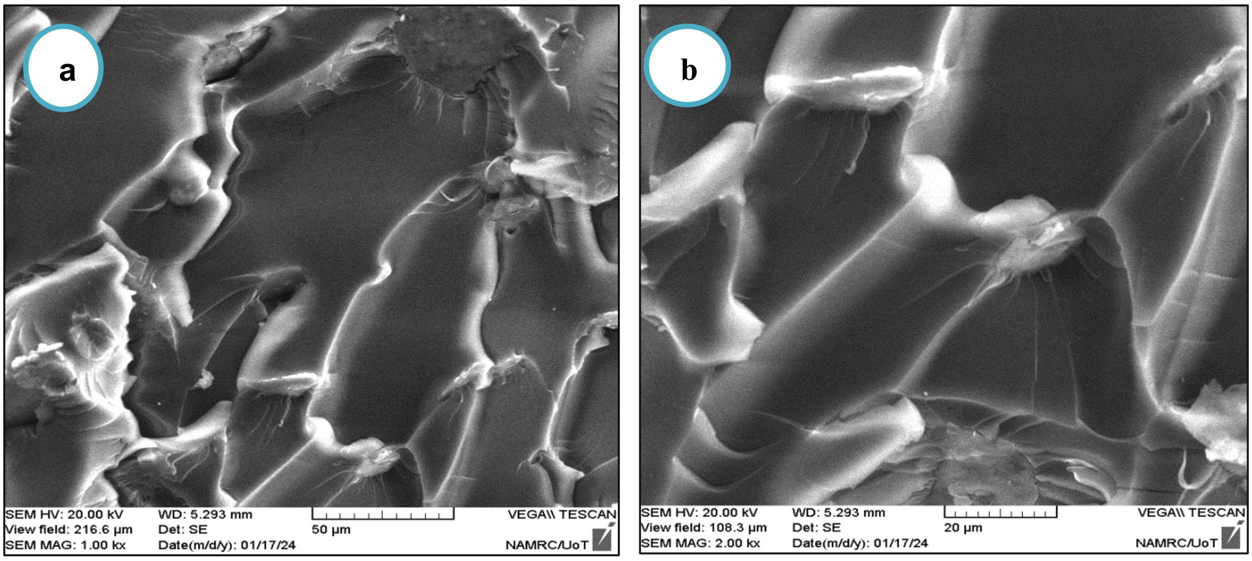

Figure 8 SEM Fractured Surface for PMC, (a and b) Represent, Where (a) Represent the Fraction at (1000X) Magnification and (b) Represent the Fraction at (5000X) Magnification.

6. CONCLUSIONS

1. When the number of (AL) particles in the polymer expanded, the tensile strength and elastic modulus of the polymer composite (EP+5% E-glass) also increased. The composite at (94.02%EP+5%E-glass+0.98%Al) has the highest estimated tensile strength (53 MPa) and modulus (310 MPa), respectively.
2. The polymer composite (EP+5% E-glass) exhibited an increase in flexural strength and flexural modulus when the expansion of (AL) particles within the polymer increased. The most elevated estimation flexural strength and flexural modulus composite at (94.02%EP+5%E-glass+0.98%Al) is (107MPa) and (265 MPa) respectively.
3. It can be realized that adding glass fiber as a woven and aluminum particles are added, which means that the material has slightly increased has enhanced hardness.it is increasing at the range of hardness when reinforced between (76 – 80) shore D.
4. increasing the weight fraction of fibers and particles the impact strength increase. indicates that the material behaved like a tough material because of its improved capacity to absorb energy before breaking. In other words, glass fiber and aluminum particles as modifiers of epoxy properties.
5. The results of the SEM test indicated that the polymer composite's structural morphology was similar to that of the polymer material, indicating that the polymer composite's morphology is constant. Every form of polymer composite has a homogenous structure, as seen by the fractured surface SEM.

References

[1] R. M. Wang, S. R. Zheng, Y. P. Zheng, Polymer matrix composites and technology. 2011
[2] A. Saini and J. R. Aseer, J. Mater. Sci. Mech. Eng. 2 (2015) 2393
[3] S. A. Bello, J. O. Agunsoye, J. A. Adebisi, R. G. Adeyemo, S. B. Hassan, J. King Saud Univ. - Sci. 32 (2020) 402
[4] A. Verma and V. K. Srivastava, Int. J. Mech. Prod. Eng. 3 (2015) 77
[5] Y. Gong et al., High Perform. Polym. 31 (2019) 124

Exp. Theo. NANOTECHNOLOGY 9 (2025) 247-258
[6] S. A. Bello, J. O. Agunsoye, J. A. Adebisi, S. B. Hassan, Acta Period. Technol. APTEFF 48 (2017) 25
[7] A. I. Misiura, Y. P. Mamunya, M. P. Kulish, J. Macromol. Sci. 2 (2019) 2348
[8] S. Bandpatte, K. Shede, R. Chavan, N. Katkar, B. Kamanna, B. Jose, Glob. J. Enterp. Inf. Syst. 9 (2017) 54
[9] M. B. MOKETLA M. SHUKLA, Int. J. Instrum. Control Autom. 11 (2012) 44
[10] A. A. Aly, E.-S. B. Zeidan, A. A. Alshennawy, A. A. El-Masry, W. A. Wasel, World J. Nano Sci. Eng. 2 (2012) 32
[11] "Standard Test Method for Tensile Properties of Plastics," in Annual Book Of ASTM Standard, 1988.
[12] Salih, W.M., Ahmed, S.H. AIP Conference Proceedings, 2660 (2022) 020033
[13] A. B. O. A. Standard, Standard Test Method For Rubber Property-Durometer Hardness D2240-00. New York, 2000
[14] A. B. O. A. Standard, Standard test Method For Izod Impact (Unnotched) ASTM D4812, ISO180. 2014
[15] M. A. Ahmed and M. I. Ebrahim, World J. Nano Sci. Eng. 4 (2014) 50
[16] S. H. Ahmed, Salih, W.M., AIP Conference Proceedings 2437 (2022) 020001
[17] A. M. Hameed and M. Sabah Mahdi, Eng. Technol. J. 34 (2016) 451
[18] C. K. R. Y. Huang, D. L. Hunston, A. J. Kinloch, Toughened Plast. 55 (1993) 1
[19] Abu Bakar and Rohani, J. Chem. Chem. Eng. 6 (2012) 962
[20] Abraham George, Exp. Theo. NANOTECHNOLOGY 8 (2024) 1
[21] M. Tadres, Exp. Theo. NANOTECHNOLOGY 8 (2024) 11
[22] J. G. Kim, P. Tan, Exp. Theo. NANOTECHNOLOGY 8 (2024) 17