Influence of Alumina and Zinc Oxide Nanoparticles on The Tensile, Impact and Hardness Properties of Epoxy Nanocomposites

Raad Obaid. Al-Mansoori 1,3, Abbas Ali Diwan*1,2, Ahmed A. Taher1

1 Mechanical Engineering Department – Faculty of Engineering, University of Kufa, Najaf, Iraq;
2 Nanotechnology and Advance Material Research Unit, Faculty of Engineering, University of Kufa.
3 Directorate of Executing rivers Dredging Work, Ministry of Water Resources, Iraq;

Raad_obeid@yahoo.com, abbas.albosalih@uokufa.edu.iq, Ahmed.abosabeeh@uokufa.edu.iq

ABSTRACT The present work investigates the effect of addition different concentration of nano Alumina (Al₂O₃) and nano zinc oxide (Zno) by (1%, 3%, 5%) weight fraction with epoxy as the matrix on the tensile, impact and hardness properties. Preparing the samples by using hand lay-up technique, magnetic sterrier, vacuum chamber and ultra-sonication method. The results show that there are increases in tensile strength and impact toughness at 3% Al₂O₃ nanoparticles (21%) and (189%) respectively compare to pure epoxy. Due to adding 3% Zno nanoparticles there are increase in tensile strength by (21%) and increase impact strength (28%) compare to pure epoxy. In addition, the hardness improved slightly when increase nanoparticles materials of both components.

Keywords: Alumina nanoparticles; Zinc oxide nanoparticles; Epoxy nanocomposites;

1. Introduction

Nowadays, polymeric materials are widely used in variety of applications. It offers unique properties and can be adjusted to suit our daily technology needs such as marine applications, aircraft applications, electronic devices, energy applications, medical applications[1-3] Depending on the type of application used in daily life and the required mechanical properties, the polymer is chosen. The symmetric dispersion of nanofillers within a polymeric matrix is the primary step to get the enhanced properties of nanocomposites. Nowadays, nanotechnology has become one of the most important ways to improve the mechanical properties of polymers[4-6]. Ramesh K. Nayak et al studied the effects of addition (alumina, Silica and Titanium dioxide) on mechanical properties of fibre reinforced polymer
The result showed that the hardness of Al₂O₃ epoxy composite is more compared to SiO₂ and TiO₂ type, and they observed the impact strength maximum for Al₂O₃ hybrid composite compare to silica and Titania[7]. Nur Suraya Anis Ahmad Bakhtiar et al. used in this investigation epoxy resin (DGEBA), nano particles such as carbon nanotubes and clay. The tensile strength and microhardness of epoxy/CNT–MUS HYB nano composites are improvement compared to neat epoxy, this improvement are mainly attributed due to the good dispersion of CNT/MUSCOVITE hybrid in the epoxy composites[8]. Minjie Wu et al. used the nano-alumina (Al₂O₃, 30 nm) particles to reinforce epoxy resin and its effect on the mechanical properties of the epoxy nano. The results showed that addition 3%wt Al₂O₃ increase the tensile strength 82.6% also The impact strength increased by 63.58% compared with that of pure epoxy [9]. Devaraju A et al. studies the mechanical properties of hybrid composites reinforced by Coconut Bunch Fiber (CBF) and Al₂O₃ nanoparticles, the result showed that improve Impact and Hardness strengths of Nano-alumina with Coconut Bunch fiber composites compared to the Coconut Bunch Fiber composites[10]. Yasmine N. Baghdadi et al. found that the addition of zinc oxide nanoparticles ZnO to Epoxy resins improve the mechanical properties of composite[11]. Mohan AC et al. Studied the effects of addition zinc oxide (ZnO) nanoparticles on the mechanical properties of a polymer composite materials. The result showed that increase The tensile strength of the nano polymer composites to doubled compared to pure epoxy at 2%wt ZnO nanoparticles [12]. These Nano composites material can be used in many mechanical applications such as Dashboards and hull of marine ships, fuselages and wings of aircraft and prosthetics.

Therefore, in this paper the mechanical properties of epoxy such as tensile, impact and hardness would be improved by adding nano Alumina (Al₂O₃) and nano zinc oxide (ZnO) to make composites with different weight fraction of them.

2. Experimental work
   2.1 Materials used
   Epoxy clear coat (Ren floor HT2000) was produced by Renksan Ltd company, Turkey, with specific density 1.1 kg/L and curing agent for HT2000 with mixing ratio (2:1) used as matrix. Aluminum dioxide Nanoparticles type α with average particle size (50-100 nm) were provided from Company Briture Co., Ltd, China and zinc oxide nano particles size (30-40) nm were provided from U.S research of nanomaterials Inc.

   2.2 Mold Preparation
   Acrylic plastic sheet is used to Preparation molds of tensile and impact test by using a Computer Numerical Control (CNC) milling machine. Tensile test mold is prepared with the dimension (180 * 230) mm and the thickness of 5mm in two layers According to the standard tensile specimen ASTM (D638-14)[13] see fig (1), impact test mold is prepared with the dimension (120 * 150) mm and the thickness of 5mm in two layers According to the standard impact specimen ASTM (D256-04)[14] see fig (2).
2.3 Preparation of epoxy nano composite

Three weight fractions (1%, 3% and 5%) with epoxy of each AL₂O₃NPs and ZnONPs were used in this work. Mixing epoxy with different weight percentage of nano filler for 20 minutes by mechanical mixer, then use ultrasonic homogenizer (MTI Corporation 1200w) to dispersing nanoparticles in epoxy for 30 minutes. after that, the hardener is addition and use mechanical mixing for 10 minutes to obtain homogeneity [15]. The vacuum oven for 15 minutes under (-80 kpa) and 40 °C, then cast in the molds and cured for 48h.

3. Mechanical tests

3.1 Tensile test

It is the ability of the material to resist fracture under tensile forces applying through both ends of samples. it test was done by using (WDW-5E) Electronic Universal Testing Machine of Time Group Inc / China , Maxcapcity 5KN . The test was carried out at room temperature and cross head speed 5mm/min according to ASTM (D638-14). Three samples were testing for each composition and mean value is taken. Figure (3) shows tensile test specimens after test.
3.2 The impact Test

It is used to measure the strength of a material when exposed to a sudden force. The test was carried out using a device (WP 400 Impact test, 25Nm) pendulum impact tester of gunt Hamburg CO / Germany. According to the standard impact specimen ASTM (D256-04). Three samples were testing and the average was calculated for each composite. The test was performed at room temperature. Figure (4) shows impact specimens after test. Impact strength (I.S) is calculated by applying the equation

\[ I.S = \frac{U_c}{A} \text{ (KJ/m2)} \]

Where

- \( U_c \): is the fracture impact energy (kJoule) which is determined from charpy impact test device.
- \( A \): is the cross-sectional area of the samples.
3.3 The hardness Test

Hardness is the parameter expressing the value for deformation of the materials with concentrated force on the surface [16]. The test were carried out by using Digital Shore D Hardness Tester TIME®5431 of TIME Group Inc \ Beijing - China. was carried out by considering the average of five measurements for each specimen at different locations at the surface of specimens according to the (ASTM D 2240) [17].

4. Results and Discussions

Figures (6 and 7) show the stress-strain curves of epoxy with weight fractions (1, 3 and 5) %wt. of AL₂O₃NPs and ZnONPs respectively. The results show that increase tensile strength due to addition nanoparticles up to 3%wt then decreas at 5%wt compare to pure epoxy. The best ultimate tensile reach to 34MPa with improvement percentage (21.43%) at 3% for both Al₂O₃NPs and ZnONPs as indicated in figure 8.

The addition nanoparticles to pure epoxy caused very large contact surface area between them lead to increase interfacial bonding created by the inclusion of nano particlesand good dispersion of nano filler with polymer matrix [18-20 ] .

The best young modulus of elasticity were 3.7GPa and 3.5GPa with improvement percentages 94.74% and 84.21% at 3% for Al₂O₃NPs and ZnONPs respectively as indicated in figure 9.

Figure 4. composites specimens after impact test

Figure 5. specimen of composites after hardness test
At high concentration the nano particles filler congregate with each other forming agglomeration and develop the cracking [21]. Finally plastic deformation appear and the occurrence of a remarkable decrease as the nanomaterial increased [22].

**Figure 6.** Stress- Strain Curve of AL₂O₃ Nps With Epoxy

**Figure 7.** Stress- Strain Curve of ZnONps With Epoxy
Figure 8. Ultimate tensile stress of ZnONPs and AL₂O₃NPs With Epoxy

Figure 9. Young Modulus of ZnONPs and AL₂O₃NPs With Epoxy
Figure 10. shows the impact energy of epoxy/Al$_2$O$_3$ and epoxy/Zno nanocomposites. The maximum impact energy were 20J and 8.33J occured at 3%wt. of both epoxy/Al$_2$O$_3$ and epoxy/Zno nanoparticles respectively. The best improvement percentages in impact energy are 189.86% and 28% for epoxy/Al$_2$O$_3$ and epoxy/Zno nanoparticles respectively. The improvement the impact energy due to the nanoparticles have a high Absorption energy compared to the matrix[23] . These particles effectively hindering the formation and propagation of small cracks in the matrix[24].

![Impact Energy of ZnONPs and AL$_2$O$_3$NPs With Epoxy](image)

Figure 10. Impact Energy of ZnONPs and AL$_2$O$_3$NPs With Epoxy

Figure 11. shows the hardness ( shore – D) of various epoxy nano composites . The results showed small improvement in hardness when increase nano particles concentration . On the other hand, the hardness of alumina nano composites higher than zinc oxide nano composites. The best improvements percentages were 5% and 4.29% at weight fraction of 5% for both AL2O3 and ZnONPs nanocomposites . The small enhancement in hardness because there are little amount of nanoparticles in upper and lower surface of samples due to dispertion of nanomaterials in epoxy.[25]
Figure (11) : Hardness of Nanocomposites for Al₂O₃ and ZnO with epoxy

Comparison of mechanical properties in present work with the earlier work literature. The tensile properties of present research that used epoxy with (1%, 3%, 5%) wt of Al₂O₃ NPs and ZnO NPs. The maximum ultimate tensile 34MPa with improvement percentage (21.43%) at 3% for both Al₂O₃ NPs and ZnO NPs. The maximum young modulus of elasticity were 3.7GPa and 3.5GPa with improvement percentages 94.74% and 84.21% at 3% for Al₂O₃ NPs and ZnO NPs respectively. Mohan AC et al. [12]. Used epoxy with (1%, 3%, 5%) wt of ZnO NPs. The maximum ultimate tensile 16.3MPa with improvement percentage (13.9%) at 1% NPs. Yasmine N. Baghdadi et al. [11]. Used epoxy matrix (1%, 2.5%, 5%) wt of ZnO NPs. The maximum ultimate tensile 50.7MPa with improvement percentage (32%) at 2.5% NPs but decrease the elastic modulus of the composite to 8.4%. Reyam sabah et al. [26]. used epoxy matrix reinforced by polymide fiber and (0.02%, 0.03%) Nano Alumina. Redused the tensile strength from 22mpa to 21 mpa when increase the nanoparticles.

Impact strength of present work maximum at 3% wt for both Al₂O₃ NPs and ZnO NPs. Impact strength of Al₂O₃ high better ZnO Nnoparticles. Ramesh k. Nayak et al. [7]. showed the impact strength of epoxy modified by Al₂O₃ NPs higher compare to SiO2 and TiO2.

5. CONCLUSIONS

The obtained experimental results showed that addition Al₂O₃ and ZnO nanoparticles to the epoxy polymer composite improves its mechanical properties and makes it suitable for many engineering applications that require high mechanical properties.

- addition of nano Al₂O₃ to epoxy matrix increase the tensile, impact and hardness. The highest improvement value at 3% wt for tensile and impact While the highest improvement hardness at 5% wt.
addition of nano Zno to epoxy matrix increase the tensile, impact and hardness. The highest improvement value at 3% wt. for tensile and impact. While the highest improvement hardness at 5% wt.

- The results showed that the impact strength and hardness values of Alumina nano particles epoxy composites were higher than Zinc nano particles epoxy composites, while the tensile strength values of both were equal.

- Mechanical properties depend on types of nano particles, weight fraction of particles and Mixing method etc.

References

[1] Koo, J. H. (2016). Fundamentals, properties, and applications of polymer nanocomposites. Cambridge University Press.

[2] Taher, A.A., Mohammed, A., Al-Hatemmi, M.H., Jabber, H.J. Study rheometric, physic-mechanical properties of nitrile butadiene rubber blended with hydrogenated nitrile butadiene rubber as a model of sustainable energy, Journal of Green Engineering, 2021, 11(1), pp. 29–38

[3] Dhiaa, A.H., Taher, A.A., Diwan, A.A., Thahab, S.M. Azez, R.J., Study the thermal properties of PVP/CuNPs composite prepared by different concentrations, IOP Conference Series: Materials Science and Engineering, 2020, 870(1), 012153

[4] Naito, M., Yokoyama, T., Hosokawa, K., & Nogi, K. (2018). Nanoparticle technology handbook. Elsevier.

[5] Taher, A.A., Takahk, A.M., Thahab, S.M., Experimental study of improvement shear strength and moisture effect PVP adhesive joints by addition PVA, IOP Conference Series: Materials Science and Engineering, 2018, 454(1), 012011

[6] Yamamoto, H., & Takahashi, C. (2018). Application of Polymeric Nanoparticles and Polymeric Micelles for Treatment of Biofilm Infection Disease. In Nanoparticle Technology Handbook (pp. 481–486). Elsevier.

[7] Nayak, R. K., Dash, A., & Ray, B. C. (2014). Effect of epoxy modifiers (Al2O3/SiO2/TiO2) on mechanical performance of epoxy/glass fiber hybrid composites. Procedia Materials Science, 6, 1359–1364.

[8] Bakhtiar, N. S. A. A., Akil, H. M., Zakaria, M. R., Kudus, M. H. A., & Othman, M. B. H. (2016). New generation of hybrid filler for producing epoxy nanocomposites with improved mechanical properties. Materials & Design, 91, 46–52.

[9] Wu, M., Lu, L., Yu, L., Yu, X., Naito, K., Qu, X., & Zhang, Q. (2019). Preparation and Characterization of Epoxy/Alumina Nanocomposites. Journal of Nanoscience and Nanotechnology, 20(5), 2964–2970.
[10] Devaraju, A., Babu, K., & Gnanavelbabu, A. (2018). Investigation on the Mechanical properties of Coconut Bunch fiber Reinforced Epoxy with Al2O3 Nano particles Composites for Structural Application. Materials Today: Proceedings, 5(6), 14252–14257.

[11] Baghdadi, Y. N., Youssef, L., Bouhadir, K., Harb, M., Mustapha, S., Patra, D., & Tehrani-Bagha, A. R. (2020). The effects of modified zinc oxide nanoparticles on the mechanical/thermal properties of epoxy resin. Journal of Applied Polymer Science, 137(43), 1–14.

[12] CA, M., & B, R. (2016). Effect of Zinc Oxide Nanoparticles on Mechanical Properties of Diglycidyl Ether of Bisphenol-A. Journal of Material Science & Engineering, 05(06).

[13] ASTM D638-14. (2016). Standard Practice for Preparation of Metallographic Specimens. ASTM International, 82(C), 1–15.

[14] ASTM. (2010). ASTM D 256 Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics. Annual Book of ASTM Standards, June, 1–20.

[15] Ayatollahi, M. R., Alishahi, E., Doagou-R, S., & Shadlou, S. (2012). Tribological and mechanical properties of low content nanodiamond/epoxy nanocomposites. Composites Part B: Engineering, 43(8), 3425–3430.

[16] Yokoyama, T. (2012). Nanoparticle technology handbook. Elsevier.

[17] Astm, D. (2010). ASTM D-2240.

[18] Shehata, F., Fathy, A., Megahed, M., & Morsy, D. (2019). Fabrication and Characterization of Nano-filled Polymer Composites. Egyptian Journal for Engineering Sciences and Technology, 28(1), 33–38.

[19] Kumar, V. K., Thakur, K. M., & Pappu, A. (2017). Hybrid Polymer Composite Materials properties and characterisation. Duxford, United Kingdom. Mathew Dean, 39–56.

[20] Young, R. J., & Lovell, P. A. (2011). Introduction to polymers. CRC press.

[21] Hofmann, H. (2009). Advanced nanomaterials, Course support. Powder Technology Laboratory, IMX, EPFL.

[22] Mohanty, S., Nayak, S. K., Kaith, B. S., & Kalia, S. (2015). Polymer nanocomposites based on inorganic and organic nanomaterials. John Wiley & Sons.

[23] Suresha, B., Varun, C. A., Indushekkara, N. M., Vishwanath, H. R., & Venkatesh. (2019). Effect of Nano Filler Reinforcement on Mechanical Properties of Epoxy Composites. IOP Conference Series: Materials Science and Engineering, 574(1).

[24] Megahed, M., Megahed, A. A., & Agwa, M. A. (2019). The influence of incorporation of silica and carbon nanoparticles on the mechanical properties of hybrid glass fiber reinforced epoxy. Journal of Industrial Textiles, 49(2), 181–199.

[25] Taher, A.A., Takhakh, A.M., Thahab, S.M. Study and optimization of the mechanical properties of PVP/PVA polymer nanocomposite as a low temperature adhesive in nano-joining, IOP Conference Series: Materials Science and Engineering, 2020, 671(1), 012145.

[26]Jabbar, Z., & Jawad, H. (2018). Mechanical Properties of Nanocomposites Reinforced by
Polyamide 66 Nanofibers. 7, 676–680.