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Effect of Alumina Particles on the Mechanical and Physical Properties of Polypropylene Whisker Reinforced Lamination 80:20 Resin Composite

Ali Faraj Hammadi*, Ahmed H. Oleiwi, Abdalameer Tariq Abbas, Anwer J. Al-Obaidi

Department of Mechanical Engineering, Engineering Faculty, Wasit University, Kut,Wasit 52001, Iraq

Corresponding Author Email: alifaraj@uowasit.edu.iq

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ABSTRACT

The low cost, relatively high fibre strength, and low density of polypropylene (PP) fibres make them an attractive candidate for reinforcing low-cost composite materials for various applications. The use of particles in fibre-reinforced composite structures usually improves the strength of the basic material. Alumina (Al_2O_3), with its unique properties, has been used to improve the composite material's properties. It is crucial to determine the appropriate concentration of Al_2O_3 particles that can be added to Polypropylene whisker/epoxy composites to get the required mechanical and physical properties. In this study lamination 80:20 resin was used as a matrix material to prepare a Polypropylene whisker (3 %wt.) reinforced lamination 80:20 resin (PP/resin) composite. The composite materials were manufactured by hand lay-up method. Different concentrations (1, 3, 5, 7 & 10 wt. %) of alumina (Al_2O_3) particles, were used to reinforce the composite. The composite materials are prepared with standard sizes according to the tests, the tests include mechanical tests (tensile, impact, and hardness test) and physical tests (water absorption and density). The tests results showed an improvement in tensile strength, elongation, toughness, fracture toughness, hardness and density, while the water absorption diminishes concerning an increase in the concentration of the Al_2O_3 particles. The tensile strength, elongation, elastic modulus, hardness and density improved from (17 MPa, 1.3%, 1.13GPa, 70 Shore D and 0.93gm/cm^3) respectively for neat lamina and reach the maximum value (34.5 MPa, 3.1%, 1.47 GPa, 83 Shore D and 1.01 gm/cm^3) respectively at (3%wt. PP and 10%wt. Al_2O_3), while the toughness and fracture toughness improved from (3.8 KJ/m^2 and 0.06 MPa.m$^{1/2}$) respectively for neat lamina and reach the maximum value (23.1 KJ/m^2 and 0.19 MPa.m$^{1/2}$) respectively at (3 %wt. PP and 7% wt. Al_2O_3).

1. INTRODUCTION

Polypropylene is in high demand in many industries, which is why global propylene consumption is high. It is impossible to find another plastic with such a broad range of applications as PP. One of the things that makes PP unique is that it can be used for an unlimited number of applications. For example, in vehicles, polypropylene is widely used [1]. Polypropylene (fiber and whisker) as a reinforcement material has been used with resin matrix to make up composite materials for different applications. This is because the Poly propylene is economical synthetic fibers and characterized by good mechanical, chemical and physical properties that can improve the ductility of hard phase of the composite [2-4]. Singh et al. [5] used PP fiber to reinforce the glass fiber reinforced polymer composite. The results showed that present of polypropylene fibers improved the impact strength of composites by 44%. Prabhu et al. [6] found that polypropylene fibers improve the thermal stability of fiber reinforced resin composites. Dutra et al. [7] reported that polypropylene fiber reinforcement to the resin matrix results in considerable improvement in impact strength of PP/resin composite. Orthocryl lamination is versatile resin has been using for fabricating fiber reinforced polymer composites. lamination resin 80:20 PRO characterized by low viscosity vs. high strength. The low viscosity enhances the homogeneity mixing with additives, the resin penetration of the fibers and the air bubbles evacuation. Prosthetic sockets lamination is one of recent applications for the fiber reinforced lamination resin 80:20 composite. This is because the fabricated laminate is light due to the low proportion of resin to fiber of a composite [8, 9].

The incorporation of particulate fillers into fiber reinforced resin composites is a process has employed by many researchers to enhance the composite properties [10-13]. Although, Aluminum oxide (Al_2O_3) was used for property improvement and life-extending of composite materials in different applications, because of its unique properties [14]. In the field of Al_2O_3/PP nanocomposite, little research has been conducted. The available information on the effects of adding Al_2O_3 particles on the mechanical and physical properties of the Polypropylene whisker reinforced lamination resin 80:20 (PP/resin) composite is limited and needs further investigations. Thus, in this study, in order to fill this research gap, the effect of different concentrations (1, 3, 5, 7 and 10 wt.%) of Al_2O_3 addition on the mechanical (Tensile strength, impact resistance and hardness) and physical (water absorption and density) properties of (PP/resin) composite was investigated. In addition, the morphology of the fracture surface of the composite was examined by Scanning Electron Microscopy (SEM). Figure 1 shows whole structure or the paper's layout. According to the results, the composite with a 7 wt.% Al_2O_3 concentration exhibited the highest strength and elongation, elastic modulus, toughness, and fracture toughness. Despite exceeding the specified concentration (7 wt.% Al_2O_3), hardness and density continue to increase. As Al_2O_3 concentration increased, water absorption decreased due to alumina's hydrophobicity.

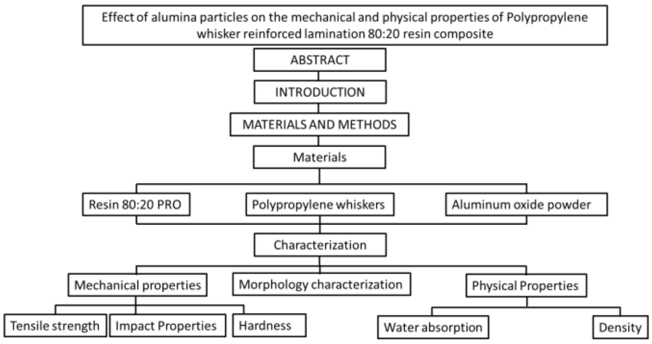

Figure 1. Whole structure or the paper's layout

2. MATERIALS AND METHODS

2.1 Materials

In this research, composite material composed from orthocryl lamination resin 80:20 PRO was used as a matrix phase and supplied by Ottobock company, Germany with properties illustrated in Table 1. Polypropylene whiskers (silvery white fiber) of 12 mm in length with 25 µm diameter were supplied by Emirates Chemicals LLC, UAE and Aluminum oxide powder (White cooler and 10^4 nm size) was supplied by Renfert GmbH company, Germany) as reinforcement phase.

Table 1. Properties of lamination resin 80:20

Properties	Value
Appearance	Denes and transparent color liquid
Density	0.88-0.91 gm/cm^3
Ultimate Strength	16-18 MPa
Total Elongation	1.3%
Modules of elasticity	1.1-1.2 GPa
Poisson's ratio	0.35

2.2 Methods

The PP/Resin composite prepared by mixing 3wt.% PP fibers (whisker) into lamination resin. PP/resin composite modified by different concentrations (1, 3, 5, 7 and 10 wt.%) of alumina particles. An ultrasound bath was used for 30 min to achieve a homogenous dispersion of particles within the PP/Resin mixture and drive out the trapped air bubbles in the mixture. The hardener (617P37) was mixed handily, at 2% concentration, with the PP/Resin mixture for five minutes. Finally, the prepared mixture was poured into plastic moulds. The shapes of the moulds were accordioning to the standards of the tests. An anti-adhesive agent was applied on the surface of the moulds before pouring the mixture into the moulds to prevent adhesion and ease the removal sample. A PP/Resin composite sample with and without aluminum oxide is shown in Figure 2.

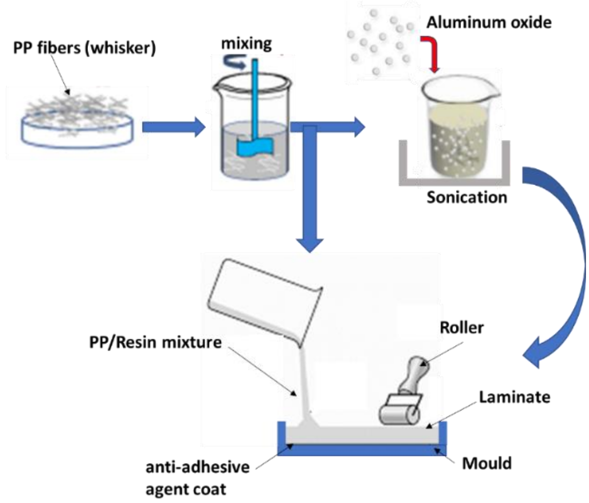

Figure 2. Schematic diagram of the preparation process of the PP/Resin composite with and without aluminum oxide samples

3. CHARACTERIZATION

The tensile strength test was performed, in the university of technology/material engineering department, according to ASTM D695 by Ghent Hamburg hydraulic universal material tester (50 KN).

The hardness test was carried out on dorumeter hardness test, type Shore D, according to ASTM D2240 [15]. The applied load was 50N for 15sec depressing time. This test was repeated seven times at different positions on the sample surface to determine the average value.

The impact resistance of the composite was determined by the Izod Impact strength test. In this test, an un-notched sample is used with length (55mm) and rectangular cross-section (10 mm x 10 mm) according to ASTM D256 [16]. Impact strength (G_c) was calculated from Eq. (1):

$$G_c = \frac{V_c}{A} \quad (1)$$

where, V_c is the fracture energy (Joule), and A is the cross section area of the sample. And the fracture toughness (K_c) was calculated according to:

$$K_c = \sqrt{G_c \times E} \quad (2)$$

where, E is the modulus of elasticity (MPa) was determined from tensile test.

INSPECT S50 was used to characterize the water absorption and true density by a sensitive balance for specimens, according to ASTM D570 [17]. Cylindrical specimens, with a diameter (40 mm) and thickness (10 mm), were used to perform the tests. Eq. (3) was used to calculate the water absorption where the dry specimens were weighted firstly and then these samples were weighted again after being immersed in water for seven days.

$$M(\%) = \frac{W_d - W_a}{W_a} \times 100 \quad (3)$$

where, M is Water absorption percentage, W_a is Mass of sample before immersion (gm) and W_d is Mass of sample after immersion for seven days (gm). While the true density was calculated using the following Eq. (4):

$$\rho_t = \frac{W_a}{W_c - W_b} \times D \quad (4)$$

where, ρ_t is the true density (gm/cm^3), D is the density of the distill water (1 gm/cm^3), W_a is the mass of the sample before immersion in the water (gm), W_b is the mass of the sample when submerged with water (gm) and W_c is the mass of the sample after immersion in the water for one day (gm).

4. RESULT AND DISCUSSION

4.1 Mechanical properties

4.1.1 Tensile strength

Figure 3 shows the stress/strain curves of PP/resin composite composites without and with different Al_2O_3 concentration. This figure shows that an increase in the Al_2O_3 concentration corresponds to an improve in the mechanical properties of the PP/resin composite. A linear-elastic behaviors can be observed in the stress-strain curves. The samples initially withstand stress, but when they reach the peak of their stress-strain curve, they change sharply, which leads to catastrophic failure. The composite (with 7wt.% Al_2O_3) showed change for the better mechanical properties compared with the other concentrations. The composite (with 7wt.% Al_2O_3) showed a preferable change in the mechanical properties compared with the other concentrations. In contrast, the mechanical properties devalue with the particle concentration increase to 10 wt.%.

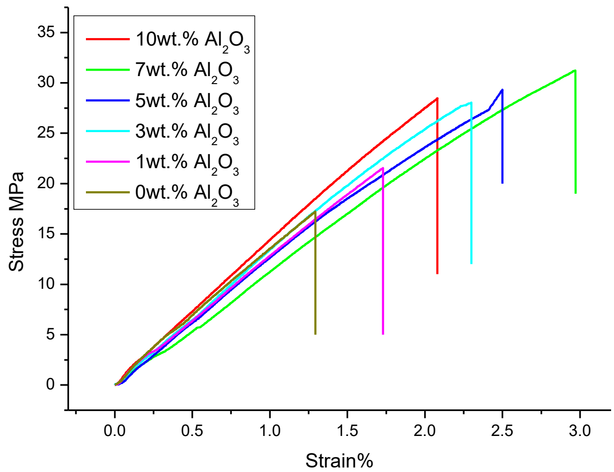

Figure 3. Stress-strain curves PP/resin composite modified by different concentrations of Al_2O_3 particles.

The results of the tensile strength, strain at break and Elastic modulus for lamination 80:20 resin with different concentration of Al_2O_3 particles are illustrated in Figure 4a-c. The tensile strength (a), strain (b) and Elastic modulus (c) of the PP/resin composite without Al_2O_3 particles were 17MPa, 1.29% and 1.13GPa, respectively. These values increase with the increase of Al_2O_3 particles contact into the composite. The Highest tensile strength and strain were achieved for the PP/resin composite having 7wt.% of Al_2O_3 particles. Where, the tensile strength and strain increased about 80% and 130%, respectively, compared with the PP/resin composite without Al_2O_3 particles. The increase can be attributed to the sufficient Al_2O_3 concentration that strengthens the interfacial bonding between the PP fiber, Al_2O_3 particles and resin, resulting in increased mechanical properties.

However, when the content of the Al_2O_3 particles is 10wt%, the tensile strength and strain values decrease by 9.7% compared with the PP/resin composite having 7wt.% of Al_2O_3 particles. This is maybe due to non-homogeneous dispersion, and voids and agglomerate particles which result in a poor load transfer mechanism between composite components [18, 19]. The modulus of elasticity of PP/resin composite increase gradually as the content of the Al_2O_3 particles increases. Since the Al_2O_3 particles are strong, rigid, and brittle, increasing additives percentage restricts the matrix chain's mobility due to high rigidity [20]. Briefly, the PP/resin composite modified by 7wt.% of Al_2O_3 particles has the highest mechanical properties.

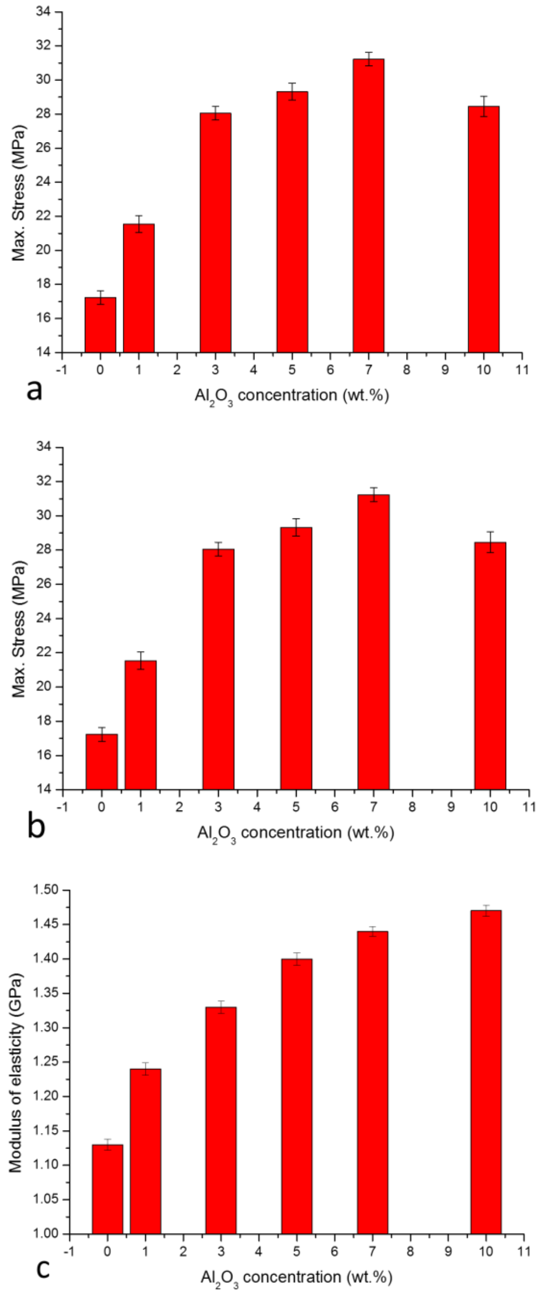

Figure 4. (a) Tensile strength, (b) Strain and (c) Elastic modulus for PP/resin composite modified by different concentrations of Al_2O_3 particles

4.1.2 Impact properties

The impact resistance of a material is a measurement to its toughness. Figure 5 shows the toughness and fracture toughness values of PP/resin composite without and with different Al_2O_3 concentration. These values increase with the increase in the concentration of Al_2O_3 particles up to 7wt.% and then start to decrease with further increase. The toughness and fracture toughness values of the PP/resin composite without Al_2O_3 particles are 3.8 Kj/m^2 and 0.06 $Mpa.m^{1/2}$, respectively. The addition 1, 3, 5, 7 and 10 wt.% of Al_2O_3 particles enhances the toughness and fracture toughness values by 150, 194, 410, 500 and 195%, respectively. The toughness and fracture toughness changes are quite similar and 7wt.% of Al_2O_3 particles concentration is proper to achieve maximum value. This behviour is agree with Duan et al. [18]. The particles can be work as barriers, in the composite structure, impeding the cracks initiating and growth, where the primary cracks tend to tilt and twist between the barriers forming secondary cracks resulting in high resistance to impact loads before fracture (increasing the fracture energy) [21, 22]. Increasing the concentration of Al_2O_3 particles more than 7wt.% cause reduction in the toughness and fracture toughness. This can be attributed to the presence of initiated micro-cracks and porosities due to non-homogeneous dispersion and agglomeration, of the Al_2O_3 particles, which reduce the ability to absorb impact energy [23].

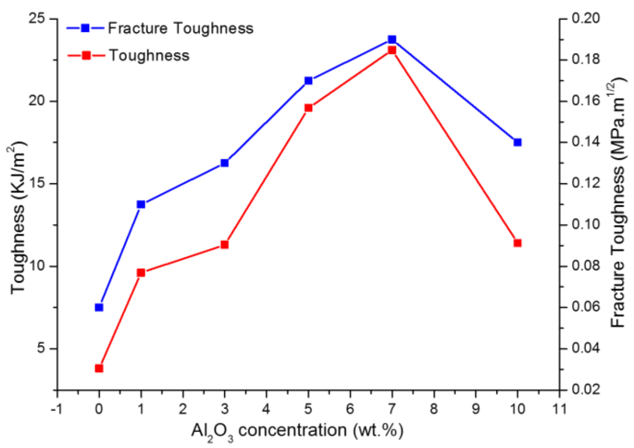

Figure 5. Toughness and fracture toughness for PP/resin composite modified by different concentrations of Al_2O_3 particles

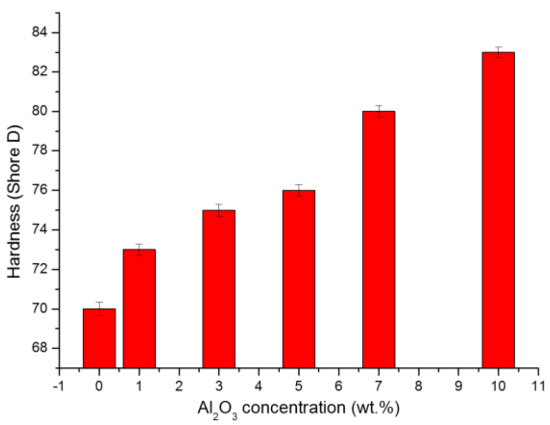

Figure 6. Hardness for PP/resin composite modified by different concentrations of Al_2O_3 particles.

4.1.3 Hardness

Figure 6 illustrate the hardness of the PP/resin composite modified by different concentrations of Al_2O_3 particles. The hardness rate of the PP/resin composite increase with increasing Al_2O_3 particles concentration. The addition 1, 3, 5, 7 and 10 wt.% of Al_2O_3 particles increase the hardness rate by 4.2, 7, 8.5, 14.2 and 18.5%, respectively. Since the Al_2O_3 particles are characterized by high hardness and brittleness compared to PP fibre and resin matrix of the composite, that leads to composites with a harder surface and resistance to deformation, scratching, and indention. This result agrees with the previous results [13, 24].

4.2 Morphology characterization

Figure 7 illustrate the PP whiskers pulled out from the composite after fracture. The dimeter of the fiber is around $22{\times}10^3$ nm. Furthermore, it can be noted that very little quantity of resin sticking on the single fibers. That indicates a weak interface bonding between the fibers and surrounding matrix. On the contrary, the quantity of sticking resin increased in the case of the PP/resin composite reinforced by 7wt.% of Al_2O_3 particles (Figure 8). Figure 8 shows the fibers on the fracture surface of the composite, it can be distinguished interlocking fibers coated by the matrix, fibers pull out and fibers breakage. Strong interface bonding between the fibers and matrix indicates improvement in mechanical performance.

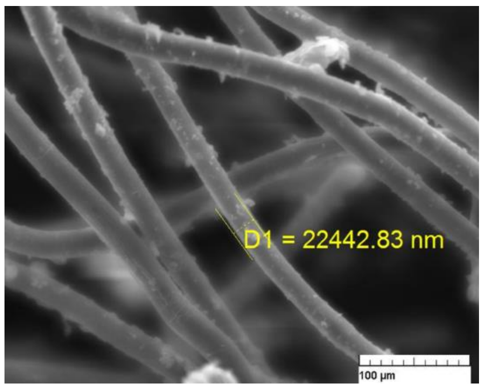

Figure 7. SEM image of polypropylene whiskers pulled out of from the fracture surface of the PP/resin (without Al_2O_3 particles) composite.

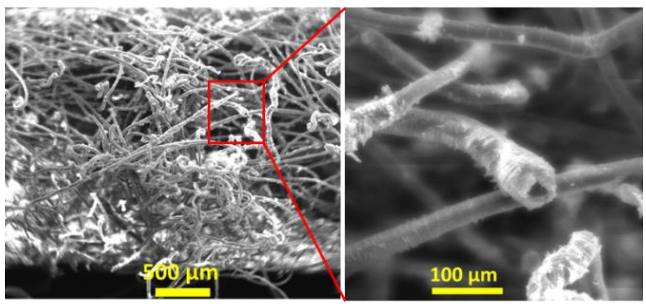

Figure 8. SEM images of polypropylene whiskers pulled out of from the fracture surface of the PP/resin composite, reinforced by 7wt.% of Al_2O_3.

Figure 9 presents different magnification SEM images to illustrate the dispersion of Al_2O_3 particles into the PP/resin (with 7% wt. Al_2O_3 particles) composite. It can be notes the particles can reduce the cavity size by filling in them and working as bridge to reduce and change the direction of crack propagation, thus enhance the mechanical properties of the composite [25].

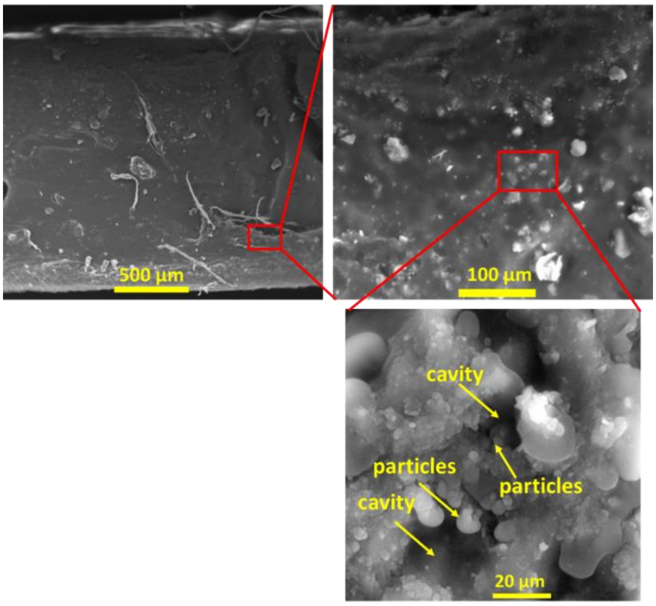

Figure 9. SEM images illustrate the dispersion of AL_2O_3 particles on fracture surface of the PP/resin composite, reinforced by Al_2O_3.

4.3 Physical properties

Figure 10 presents the change in water absorption and density according to additive alumina concentrations in the composite. The water absorption rate decreases by about 10, 20, 40, and 100% with increasing Al_2O_3 particle concentration, this is due to the increasing permeation resistance of the composite. The increase in permeation resistance is because of the high degree of intermolecular crosslinking and the accumulated tighter molecular chains that increase as Al_2O_3 particle concentration increases. In addition, the figure also illustrates that the density of the PP/resin composite increase by about 1, 2, 4.3, 4.3 and 8.6% for Al_2O_3 particle concentration of 1, 3, 5, 7 and 10 wt.%, since the Al_2O_3 particles have a density more that the matrix and fiber material. This result agrees with the previous results [19, 26].

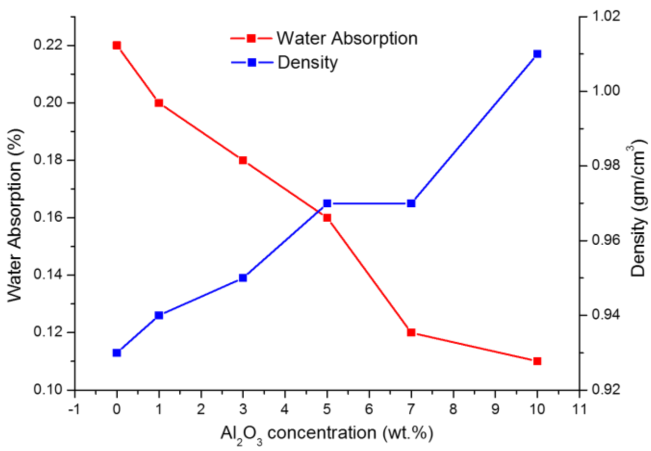

Figure 10. Water absorption and density for PP/resin composite modified by different concentrations of Al_2O_3 particles.

5. CONCLUSIONS

The composite formation by combination of lamination 80:20 resin with two types of reinforcement materials (polypropylene whiskers and alumina particles) at different concentration were studied experimentally. The results displayed that the composite with 7 wt.% Al_2O_3 concentration, has the maximum strength and elongation, elastic modulus, toughness and fracture toughness. While the hardness and density values continue to increase even after exceeding the specified (7 wt.% Al_2O_3) concentration. The water absorption showed a reduction with increasing the Al_2O_3 concentration related to alumina hydrophobicity to water. The SEM images illustrate that the strong interface bonding between the fibers and matrix improve the mechanical performance of the composite.

REFERENCES

[1] Maddah, H.A. (2016). Polypropylene as a promising plastic: A review. American Journal of Polymer Science, 6(1): 1-11. https://doi.org/10.5923/j.ajps.20160601.01

[2] Tapiero, Y., Rivas, B.L., Sánchez, J. (2019). Activated polypropylene membranes with ion-exchange polymers to transport chromium ions in water. Journal of the Chilean Chemical Society, 64(4): 4597-4606. http://dx.doi.org/10.4067/S0717-97072019000404597

[3] Ali, B., Qureshi, L.A., Kurda, R. (2020). Environmental and economic benefits of steel, glass, and polypropylene fiber reinforced cement composite application in jointed plain concrete pavement. Composites Communications, 22: 100437. https://doi.org/10.1016/j.coco.2020.100437

[4] Liu, Y., Wang, L., Cao, K., Sun, L. (2021). Review on the durability of polypropylene fibre-reinforced concrete. Advances in Civil Engineering, 2021: 6652077. https://doi.org/10.1155/2021/6652077

[5] Singh, K., Nanda, T., Mehta, R. (2017). Compatibilization of polypropylene fibers in epoxy based GFRP/clay nanocomposites for improved impact strength. Composites Part A: Applied Science and Manufacturing, 98: 207-217. https://doi.org/10.1016/j.compositesa.2017.03.027

[6] Prabhu, T.N., Hemalatha, Y.J., Harish, V., Prashantha, K., Iyengar, P. (2007). Thermal degradation of epoxy resin reinforced with polypropylene fibers. Journal of Applied Polymer Science, 104(1): 500-503. https://doi.org/10.1002/app.25523

[7] Dutra, R.C., Soares, B.G., Campos, E.A., De Melo, J.D., Silva, J.L. (1999). Composite materials constituted by a modified polypropylene fiber and epoxy resin. Journal of Applied Polymer Science, 73(1): 69-73. https://doi.org/10.1002/(SICI)1097-4628(19990705)73:1<69::AID-APP8>3.0.CO;2-5

[8] Phillips, S.L., Craelius, W. (2005). Material properties of selected prosthetic laminates. JPO: Journal of Prosthetics and Orthotics, 17(1): 27-32. https://doi.org/10.1097/00008526-200501000-00007

[9] Abbas, E.N., Al-Waily, M., Hammza, T.M., Jweeg, M.J. (2020). An investigation to the effects of impact strength on laminated notched composites used in prosthetic sockets manufacturing. In IOP Conference Series: Materials Science and Engineering, 928(2): 022081. https://doi.org/10.1088/1757-899X/928/2/022081

[10] Hammadi, A.F., Rady, M.H., Abbas, A.T., Kale, S.A. (2022). Structural health monitoring of the carbon fiber reinforced epoxy/MWCNTS composites under vibration loading, using electrical resistance change method. In Materials Science Forum, 1068: 3-9. https://doi.org/10.4028/p-z9d35t

[11] Chethanbabu, H.M., Ramachandra, M. (2021). Evaluation of mechanical properties of polypropylene fibre reinforced epoxy composite filled with silicon carbide particulates. Materials Today: Proceedings, 46: 4400-4406. https://doi.org/10.1016/j.matpr.2020.09.669

[12] Singh, T., Gangil, B., Ranakoti, L., Joshi, A. (2021). Effect of silica nanoparticles on physical, mechanical, and wear properties of natural fiber reinforced polymer composites. Polymer Composites, 42(5): 2396-2407. https://doi.org/10.1002/pc.25986

[13] Ergün, Y.A. (2019). Mechanical properties of epoxy composite materials produced with different ceramic powders. Journal of Materials Science and Chemical Engineering, 7(12): 1-8. https://doi.org/10.4236/msce.2019.712001

[14] Ruys, A.J. (2018). Alumina ceramics: biomedical and clinical applications. Woodhead Publishing.

[15] American Society for Testing and Materials. (2000). ASTM STANDARD D 2240-97: standard test method for rubber property-durometer hardness. West Conshohocken: ASTM.

[16] Gooch, J.W. (2010). Encyclopedic dictionary of polymers. Springer Science & Business Media.

[17] ASTM Standard 570. (2018). Test Method for Water Absorption of Plastics, American National Standards Institute (ANSI), United States.

[18] Duan, Z., He, H., Liang, W., Wang, Z., He, L., Zhang, X. (2018). Tensile, quasistatic and dynamic fracture properties of nano-Al_2O_3-modified epoxy resin. Materials, 11(6): 905. https://doi.org/10.3390/ma11060905

[19] Du, R., He, L., Li, P., Zhao, G. (2020). Polydopamine-modified Al_2O_3/polyurethane composites with largely improved thermal and mechanical properties. Materials, 13(7): 1772. https://doi.org/10.3390/ma13071772

[20] Wondu, E., Lule, Z., Kim, J. (2019). Thermal conductivity and mechanical properties of thermoplastic polyurethane-/silane-modified Al_2O_3 composite fabricated via melt compounding. Polymers, 11(7): 1103. https://doi.org/10.3390/polym11071103

[21] Spanoudakis, J., Young, R.J. (1984). Crack propagation in a glass particle-filled epoxy resin: Part 1 Effect of particle volume fraction and size. Journal of Materials Science, 19: 473-486. https://doi.org/10.1007/BF02403234

[22] Woldemariam, M.H., Belingardi, G., Koricho, E.G., Reda, D.T. (2019). Effects of nanomaterials and particles on mechanical properties and fracture toughness of composite materials: A short review. AIMS Materials Science, 6: 1191-1212. https://doi.org/10.3934/matersci.2019.6.1191

[23] Ghadami, F., Dadfar, M.R., Kazazi, M. (2016). Hot-cured epoxy-nanoparticulate-filled nanocomposites: Fracture toughness behavior. Engineering Fracture Mechanics, 162: 193-200. https://doi.org/10.1016/j.engfracmech.2016.05.016

[24] Hamad, Q.A. (2018). Study the effect of nano-Al_2O_3 and fiber glass on mechanical and physical properties of PMMA composites for prosthetic denture. Engineering and Technology Journal, 36: 715-722. https://doi.org/10.30684/etj.36.7A.3

[25] Dietsche, F., Thomann, Y., Thomann, R., Mülhaupt, R. (2000). Translucent acrylic nanocomposites containing anisotropic laminated nanoparticles derived from intercalated layered silicates. Journal of Applied Polymer Science, 75(3): 396-405. https://doi.org/10.1002/(SICI)1097-4628(20000118)75:3<396::AID-APP9>3.0.CO;2-E

[26] Duan, Z., He, H., Liang, W., Wang, Z., He, L., Zhang, X. (2018). Tensile, quasistatic and dynamic fracture properties of nano-Al_2O_3-modified epoxy resin. Materials, 11(6): 905. https://doi.org/10.3390/ma11060905

NOMENCLATURE

G_c	Impact strength (MPa)
V_c	Fracture energy (Joule)
A	Cross section area
E	Modulus of elasticity (MPa)
M	Water absorption percentage
W_d	Mass of sample after immersion for seven days (gm).
ρ_t	true density (gm/cm^3)
D	Density of the distill water (1 gm/cm^3)
W_a	Mass of sample before immersion (gm)
W_b	Mass of the sample when submerged with water (gm)
W_c	Mass of the sample after immersion in the water for one day (gm)

Subscripts

PP	Polypropylene whisker
Al_2O_3	Aluminum oxide
SEM	Scanning Electron Microscopy