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FRICTION REDUCTION AND WEAR RESISTANCE ENHANCEMENT OF ALUMINUM/EPOXY COMPOSITES

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Abstract:

In this study, the effect of surface modification of aluminum powders on wear and the fracture mechanics behaviors of aluminum/epoxy composites was investigated. Aluminum powders were surface-modified with 3-aminopropyltriethoxysilane. Aluminum/epoxy composites were fabricated by the cast molding method using 10% wt. untreated and silane-treated aluminum powders. Tensile, Mode I fracture and wear tests were performed on both composites. The results showed that the tensile modulus and strength of silane-treated aluminum/epoxy composites were 20% and 30% greater, respectively than those of untreated aluminum/epoxy composites. The results also showed that the fracture toughness and wear resistance of silane-treated aluminum/epoxy composites were ~25% and ~75% greater than that of untreated aluminum/epoxy composites. The scanning electron microscope (SEM) examination showed that the improvement of tensile and fracture properties of silane-treated aluminum/epoxy composites were attributed to the improved dispersion and bonding of aluminum particles in the epoxy, due to the silanization of aluminum powders.

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KEYWORDS

composite, fracture toughness, wear, surface modification, functionalization

1. INTRODUCTION

The aluminum/polymer composites are very attractive materials for a wide range of industrial applications due to the combination of properties such as low density, corrosion resistance, thermal stability, and ease of fabrication. Accordingly, many studies have been made to investigate the mechanical, thermal, and electrical properties of aluminum powder reinforced polymer composites [1-4].

One of the main issues in fabrication of the aluminum/polymer composites is to achieve a good dispersion and interfacial strength between aluminum powders and the polymer. To address this issue, some studies have been performed for the surface treatment of aluminum powders. Jallo et al. [3] reported the effect of surface modification on aluminum powder on its flowability, combustion and reactivity. Silanization provides lower surface energy values and such materials are expected to flow better after the surface treatment. Chen et al. [4] described modification of aluminum particles surface applying methyltrichlorosilane. The basic procedure involved mixing of aluminum powder with silane solution in hexane. Crouse et al. [5] demonstrated functionalization of oxide-passivated aluminum nanoparticles using 3-methacryloxypropyltrimethosilane (MPS), to provide the chemical compatibility within various solvent and polymeric systems. In this study, the effect of silane treatment of aluminum powders on the tensile, fracture, and wear behaviors of aluminum/epoxy composites was investigated.

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The aluminum/epoxy composites were fabricated by cast molding method using 10% wt unmodified and silanized aluminum powders. The FTIR analysis was conducted on the untreated and silanized aluminum powders to determine the chemical change on the surface of aluminum powders due the surface treatment. The tensile, Mode I fracture and wear tests were performed on both composites, Table 1. After the fracture tests, the scanning electron microscopy (SEM) examination was done on the fracture surfaces of both composites to determine the fracture mechanism, depending on the silane treatment of aluminum powders.

2. RESULTS AND DISCUSSION

The friction coefficient of the untreated and silane-treated aluminum/epoxy composites are in the ranges of 0.34-0.42 and 0.04-0.06, respectively. The worn surfaces of the untreated and silane-treated aluminum/epoxy composites were examined using the optical microscope and the surface profiler to determine the wear mechanism and wear loss [6].

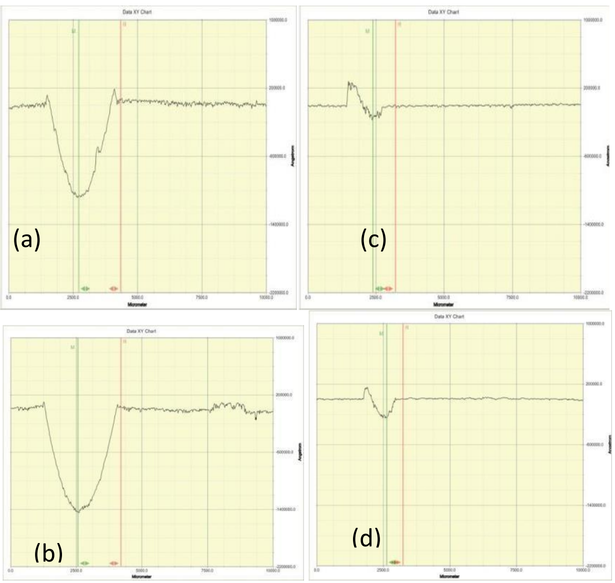


Fig. 1. Surface profile after the wear test of the unmodified a, b, and the silane surface modified c, d, aluminum powder-epoxy composite. The worn surface is deeper and wider in unmodified Al- epoxy composite.

Figure 1 shows the wear trace and depth profile of the untreated and silane-treated aluminum/epoxy composites, respectively. The mean depth profile was obtained according to several points taken from the cross-section in the worn area. It can be seen in the figure that the wear trace of untreated the aluminum/epoxy composites is wider and deeper than that of silane-treated aluminum/epoxy composites.

Table 1. Fracture results of unmodified and silane surface modified aluminum powder epoxy composites

	Fracture Load [N]	Displa-cement [mm]	Fracture Toughness [$MPa*m^{1/2}$]
Unmodified	408	3.00	1.53
Modified	538	5.55	2.07

Figure 2 shows the comparison of wear rate from sliding distance for both composites.

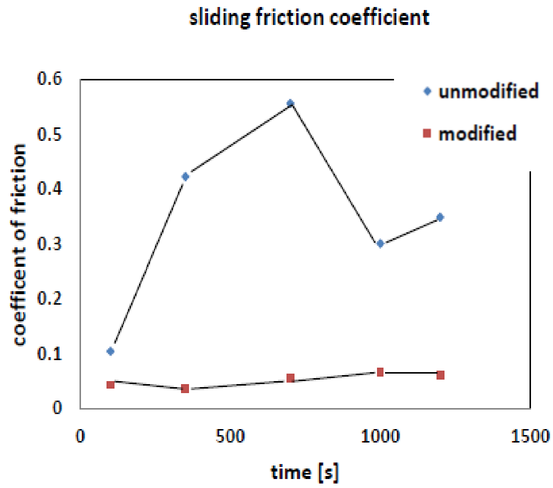


Fig. 2. Coefficient of friction versus sliding time, average is ~0.348 in unmodified aluminum powder/epoxy composite and ~ 0.061 for silane surface modified aluminum powder/epoxy composite

The wear rate, *K* was determined by the following equation (1):

$$k = \frac{V_m}{Nvt'} - \frac{Z\pi A_m}{2Nvt'} \qquad (1)$$

In the above equation, V_m is the wear volume loss, *N* is the applied load, *v* is the sliding velocity, and *t'* is the test duration. A_m is the average cross-sectional area of the wear trace obtained from its depth profile and R_m is the average radius of the wear trace. As shown in the figure, the wear rate of aluminum/epoxy composites decreased by the silane treatment of aluminum powders.

Specifically, the wear rate of silane- treated aluminum/epoxy composites was ~ 75% smaller than that of the untreated aluminum/epoxy composites.

The FTIR spectral analysis was performed to determine the chemical change on the surface of aluminum powder due to the silane treatment. Figure 3 shows the FTIR spectra of the untreated and silane-treated aluminum powders. For the untreated aluminum powder, the peaks at 3440 and 1048 cm^{-1} were caused by hydroxyl groups (Al-OH) on the surface of aluminum powder due to the presence of atmospheric moisture on the surface of aluminum powder. For the silane-treated aluminum powder, the characteristic absorption peak at ~ 1070 cm^{-1} is attributed to formation of networked system of (Si-O-AL) in groups following extensive cross-linking through silanization of Al-OH group. This confirms the reaction of 3- aminopropyltriethoxysilane organic coating film on aluminum powder surface.

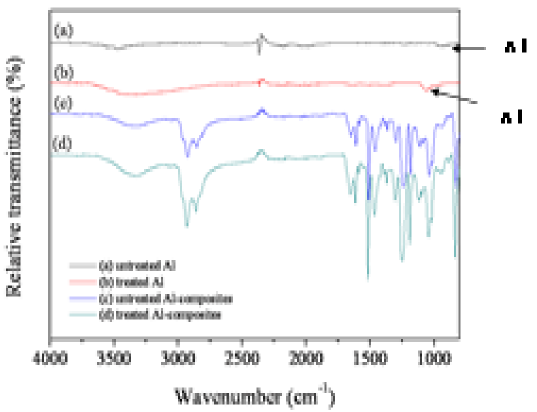
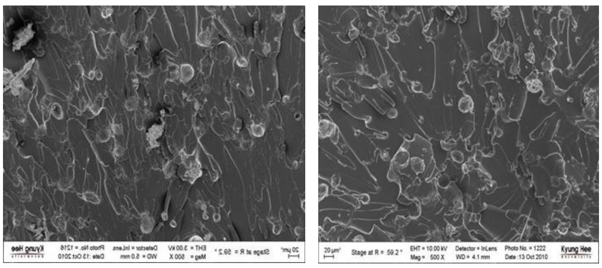


Fig. 3. FT-IR peak vibrations bands in unmodified and silane surface modified aluminum powder. Si-O-Al show the silanization of aluminum powder at ~ 1070 cm^{-1}.

2.1. The FESEM analysis

In order to investigate the fracture mechanism, the FESEM analysis was performed on the fracture surfaces of the untreated and silane-treated aluminum/epoxy composites after fracture test. Figure 4 shows the fracture surfaces of the untreated and silane-treated aluminum/ epoxy composites. For the untreated aluminum/ epoxy composites, as shown in figure, debonding occurs in unmodified aluminum powder epoxy, the better is dispersion and strong link between the aluminum filler and the polymer matrix in the silane surface modified aluminum powder epoxy composite. In addition, the fracture path shows that the unidirectional fracture occurs in unmodified aluminum polymer composite due to the weaker interfacial adhesion between the aluminum and polymer. The SEM images in Figure 5 show that several micro cracks appeared in the silane surface modified aluminum powder epoxy composite; that indicates the stronger interfacial adhesion and that more energy is needed to break this interlink and start the fracture. The fracture toughness values are ~ 2.07 in the silane surface modified aluminum powder compared to 1.57 in the unmodified aluminum powder in polymer matrix composites, as shown in Table 1 and Figure 8.



a) b)

Fig 4. The FESEM images of the fracture surface after the fracture test of unmodified (a) and the silane surface modified aluminum powder composite (b), dispersion and adhesion is better in the surface modified aluminum powder epoxy composite

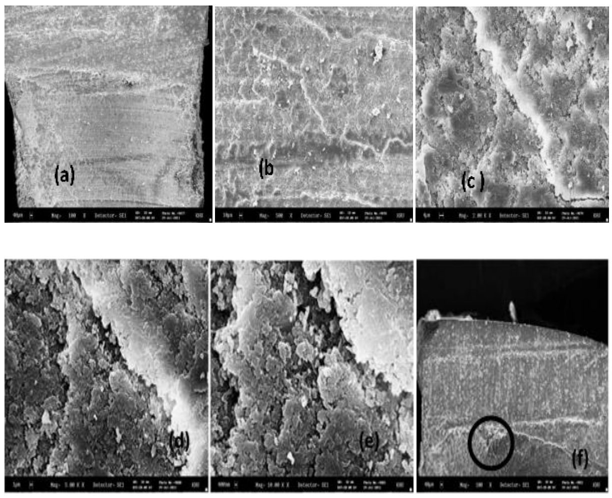


Fig. 5 a. SEM images a, b, c, d, e, on the worn surface of silane surface modified aluminum powder/ epoxy composite. The behavior is mostly abrasive and mild wear; image f shows the border of the quantity of material removed and wear debris transferred by the zirconia counter face. Micro parallel scratching indicates the abrasion and wear loss process.

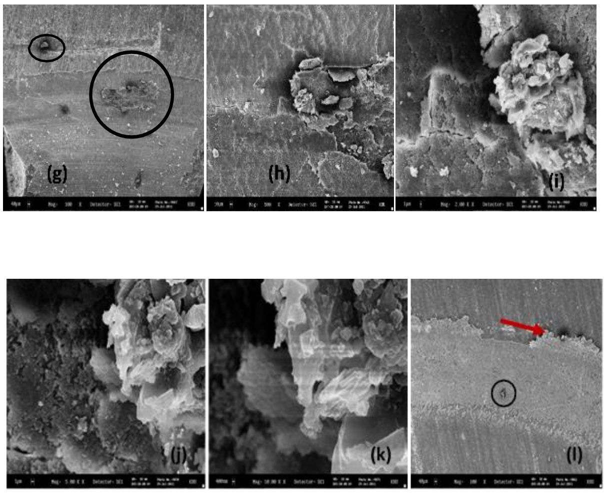


Fig. 5 b. The SEM images g, h, i, j, k of unmodified aluminum powder/epoxy composite. The behavior is mostly adhesive wear due to the plasticity of the material. Image l shows the wear debris and the quantity of material removed; the wear loss is high - considered as severe wear

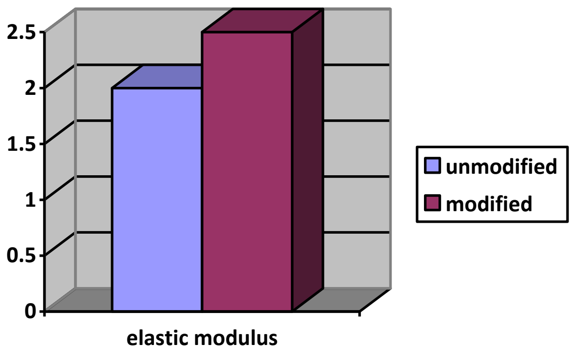


Fig. 6. Elastic modulus of Al-epoxy composite is about 20-25% greater in the modified aluminum powder

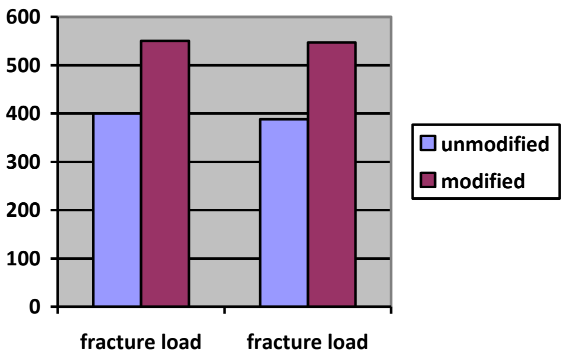


Fig. 7. The fracture Load (N) is about 25 % greater in the silane surface modified aluminum powder polymer composite

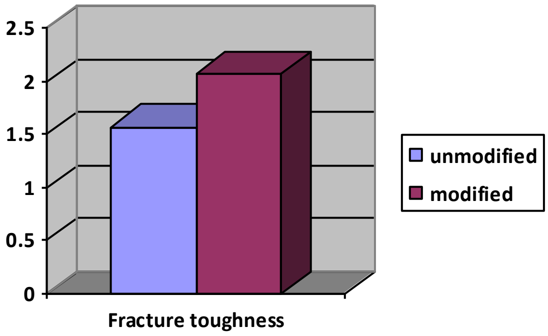


Fig. 8. The fracture Toughness of unmodified (1.53) and the silane surface modified (2.07) aluminum powder polymer composites

3. CONCLUSION

The surface modification of aluminum powder due to the silane treatment was confirmed by the FTIR analysis, Figure 4, while improvement of the tensile and fracture of the modified Al/epoxy specimens is attributed to good dispersibility and strong interfacial bonding between the functionalized Aluminum powder and the epoxy matrix, the decreased values for unmodified aluminum powder/epoxy specimens were caused by the weakening of interfacial bonding of aluminum powder and epoxy matrix. The wear property of composite materials is characterized by the friction coefficient and wear rate. The effect of the silane treatment on the wear behavior of aluminum/epoxy composites was investigated by determining the change of the friction coefficient as a function of wear distance [6-11]. Figure 2 shows the change of the friction coefficient as a function of the wear distance for the untreated and silane-treated aluminum/ epoxy composites. As shown in the figure, the vibrational sliding friction behavior occurred in the untreated aluminum/epoxy composites, while the stable wear behavior occurred for the silane-treated aluminum/epoxy composites, which indicates that the silane-treated aluminum/epoxy composite is more compact and uniform. It can be seen in the figure that the average friction coefficient of the silane-treated aluminum/ epoxy composites is far lower than that of the untreated aluminum/epoxy composites. Specifically, the friction coefficient of untreated and silane-treated aluminum/ epoxy composites are in the ranges of 0.34-0.42 and 0.04-0.06, respectively.

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REFERENCES

[1] F. Deflorian, S. Rossi, L. Fedrizzi, Silane pretreatments on copper and aluminum. Electrochimica Acta, 51 (27), 2006: pp.6097-6103.

[2] N. Stevens, S. Tedeshi, K. Powers, H. El-Shall, Moudgil, Controlling unconfined yield strength in an humid environment through surface modification of powders. Powder technology, 191 (1-2), 2009: pp.170-175.

[3] L. Jallo, M. Schoenitz, E. Dreizin, C.E. Johnson, The effect of surface modification of aluminum powder on its flowability, combustion and reactivity. Powder Technology, 204 (1), 2010: pp63-70.

[4] Y. Chen, L. Jallo, M. A.S. Quintanilla, R. Dave, Characterization of particle and bulk level cohesion reduction of surface modified fine aluminum powders. Colloids and Surfaces A, 361 (1-3), 2010: pp.66-80.

[5] C.A. Crouse, C.J. Pierce, J.E. Spowart, Influencing solvent miscibility and aqueous stability of aluminum nanoparticles through surface functionalization with acrylic monomers. Applied Materials and Interface ACS, 2 (9), 2010: pp.2560-2569.

[6] G.W. Stachowiak, Wear, Materials, Mechanisms and Practice. John Wiley & Sons, Ltd, West Sussex, England, 2005.

[7] R.G. Bayer, Mechanical Wear Fundamentals and testing. Marcel Dekker Inc., New York, 2004.

[8] L.J. Yang, A test methodology for the determination of wear coefficient. Wear, 259 (7-12), 2005: pp.1453- 1461.

[9] J.H. Lee, J. Kathi, K.Y. Rhee, Lee, Wear properties of 3 aminopropyltriethoxysilane functionalized carbon nanotubes reinforced ultra-high molecular weight polyethylene nanocomposite. Polymer Engineering and Science, 50 (7), 2010: pp. 1433-1439.

[10] H.J. Kim, D.H. Jung, I.H. Jung, J.I. Cifuentes, K.Y. Rhee, D. Hui, Enhancement of mechanical properties of aluminium/epoxy composites with silane functionalization of aluminium powder. Composites Part B: Engineering, 43 (4), 2012: pp.1743-1748.

[11] J.I. Cifuentes, Improved Mechanical Properties of Aluminum Powder- Carbon Nanotubes and Epoxy Nano composites to Fabricate Blades for Wind Turbines and Different Components of Machines and Equipment. School of Mechanical Engineering, University of San Carlos of Guatemala, 2015.

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