

TRIBOLOGICAL PROPERTIES OF EPOXY COMPOSITES

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ABSTRACT

The present work investigates the influence of the addition of nanoparticles to epoxy on the tribological properties, such as friction coefficient and wear resistance. The nanoparticles such as carbon (C) and aluminum oxide (Al_2O_3), as well as microparticles of bronze (Bz) and aluminum (Al) of 1, 2, 3 and 4 wt. % content are added to epoxy matrix.

Based on the experimental results, it was found that increasing filling materials content caused friction coefficient increase. Besides, as the load increased, friction coefficient increased. This behavior is attributed to the increase of contact area due to the increase of the depth of insert in the matrix of the tested composites. Bz and Al particles show the lowest values of friction coefficient compared to Al_2O_3 and C particles because of their ductility and lubricity. Also it is observed that as the filling material increased the wear decreased. This behavior is attributed to the increase of wear resistance of composites. In addition, it seems that both C nanoparticles and Bz particles work as solid lubricants where the insert would be less abrasive.

KEYWORDS

Scratch, epoxy matrix, friction coefficient, wear resistance, C, aluminum oxide, Bz, nanoparticles.

INTRODUCTION

Wear generally originates from damage induced by rubbing bodies due to repeated applications of mechanical, impact and other kinds of forces [1–5]. Therefore, the surface loses mechanical cohesion and debris is formed that is dislodged from the contact zone. Many wear mechanisms have been proposed, [2, 4, 6 - 9], e.g., abrasive, adhesive, fatigue, corrosive, erosive and delamination, which show the complexity of the wear phenomena. Wear debris can also be generated by material transfer from one surface to another. Wear of polymers is affected by many intrinsic and extrinsic factors, such as surface roughness, contact kinematics, material nature, mechanical, physical and chemical properties of interacting bodies, testing environment, etc. In general, depending on the molecular and internal structural organizations, polymers have lower multiple transition temperatures and thermal conductivity than metals.

Hence, the energy consumed in the processes of friction and wear can lead to softening, melting, oxidation or pyrolysis on the surface of the polymer and its relevant wear debris significantly affects the wear and friction performance, [10]. It is necessary to understand the interaction between two mating surfaces so as to demonstrate completely the tribological performance.

Scratching is an alternative to conventional wear testing to evaluate the tribological properties of polymers. In the scratch test, a hard indenter is pressed onto the material under load and moves relative to the material; and scratch resistance is given by its ability to withstand mechanically induced surface damage under those conditions. Unlike an indentation process where the normal load is uniformly distributed beneath the indenter, scratching involves a high-friction-induced sliding process, [11]. The indenter is fully supported by the specimen in the front and only partially by recovered material in the rear-half. The extent of recovery again depends on the stress-relaxation characteristics of the material in the contact zone. The scratch process is also divided into two stages where the first stage involves indenting the specimen until a specified load (which is a dynamic process) and then the second stage involves the sliding of the indenter on the sample surface (which is a quasi-static process).

Different types of testing methods are developed over the last few decades to measure the resistance to scratching in polymers and these include: Ford five finger test, Taber scratch tester, instrumented indentation test, DIN abrasion, and recently, depth-sensing instruments capable of scratching at nano-level on different materials. Wong et al., [12] have reviewed currently available scratch testing techniques for polymers and noted that a scratch test employing a linear load increase method provides sufficient repeatability of the test data. Scratch performance of polymers is determined by the material properties, test environment, and the stress field due to the scratching process.

The most common types of material damage during scratching for (a) ductile, (b) ductile and brittle, (c) brittle and (d) elastomeric responses, [13]. In addition, the surface tension of polymers has also been shown to play a role in influencing the scratch resistance. Brostow et al., [14] related surface tension, residual scratch depth, penetration depth, static and dynamic friction for epoxy when fluoropolymer was added. They demonstrated that increasing the surface tension, friction, penetration and residual depths were also increased.

In the present work, the effect of the addition of nanoparticles to epoxy on friction coefficient and wear resistance is investigated. The nanoparticles such as C (C) and aluminum oxide (Al_2O_3), as well as microparticles of Bronze (Bz) and aluminum (Al) of 1, 2, 3 and 4 wt. % content are added to epoxy matrix.

EXPERIMENTAL

The epoxy used in experiments was kemapoxy 150 of $\rho = 1.11 \text{ Kg/ liter}$. The epoxy matrix was filled by nano C particles of 100 nm particles, nano Al_2O_3 particles of 20 nm, Bz particles of 300 μm and Al particles of 150 μm , of 1, 2, 3 and 4 %weight content. The test specimens were molded in a die shown in Fig. 1.

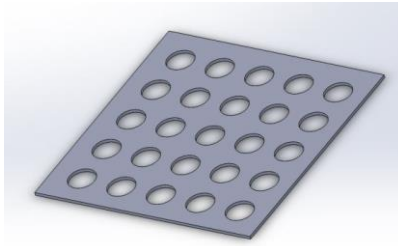


Fig. 1 The molding die.

The scratch test was carried out by the test rig shown in Fig. 2. It consists of rigid stylus mount, where a steel stylus of 90° apex angle and hemispherical tip. The stylus was mounted to the loading lever through three jaw chuck. A counter weight was used to balance the loading lever before loading. Vertical load was applied by weight of 2, 4, 6, 8 and 10 N. Scratch resistance force was measured using a load cell mounted to the loading lever and connected to display digital monitor. The test specimen was held in the specimen holder which mounted in a horizontal base with a manual driving mechanism to move specimen in a straight direction. The test specimens were scratched by an indenter. The test was conducted under dry conditions at room temperature. The test specimen under scratch action is shown in Fig. 3.

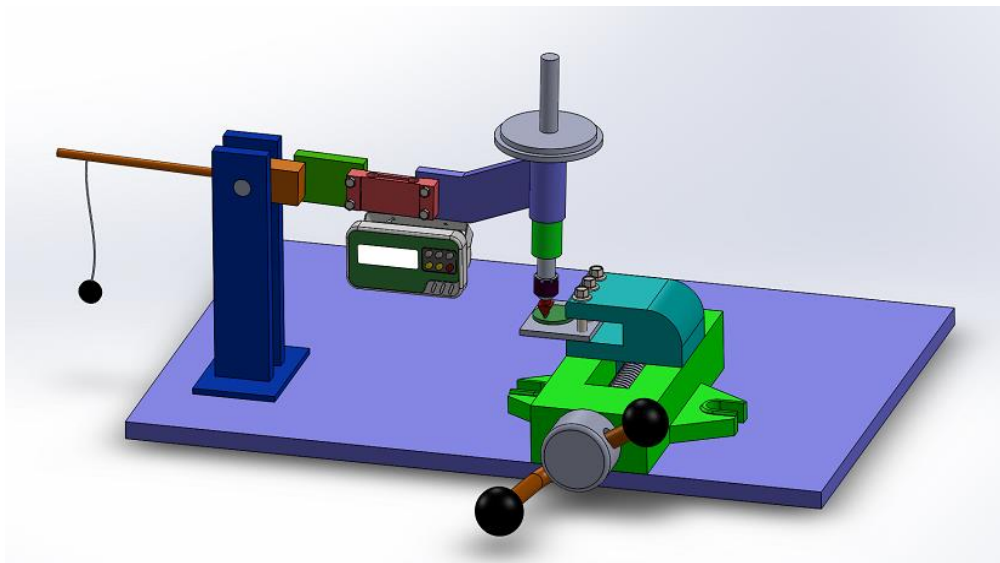


Fig. 2 Arrangement of scratch test rig.

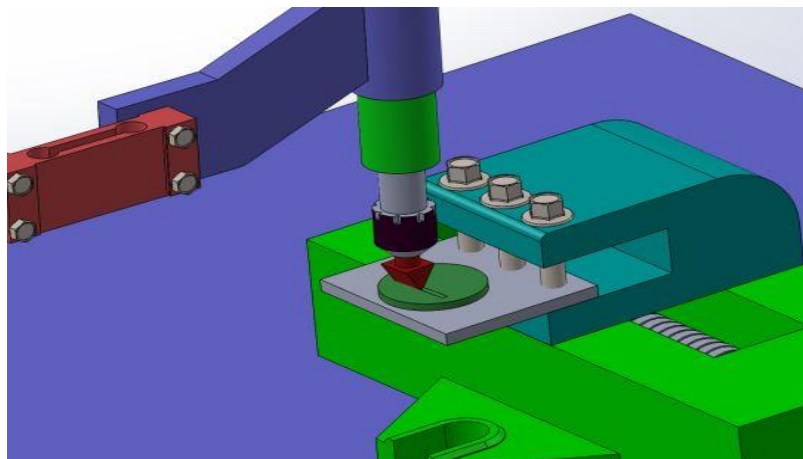


Fig. 3 The specimen under scratch action.

RESULTS AND DISCUSSION

The effect of Al_2O_3 and C particles contents on the friction coefficient is shown in Figs. 4 and 6 respectively. As for Al_2O_3 , the relationship between friction coefficient and normal load is shown in Fig. 4. Slight increase in friction coefficient was observed as the normal load increased. This behavior is attributed to the increase of contact area due to the increase of the depth of insert in the matrix of the tested composites. In condition of scratching Al_2O_3 filled epoxy, the contact is divided into steel/epoxy and steel/ Al_2O_3 . It seems that friction of steel against Al_2O_3 was higher than that observed for steel against epoxy. As a result, friction coefficient increased as the Al_2O_3 content increased.

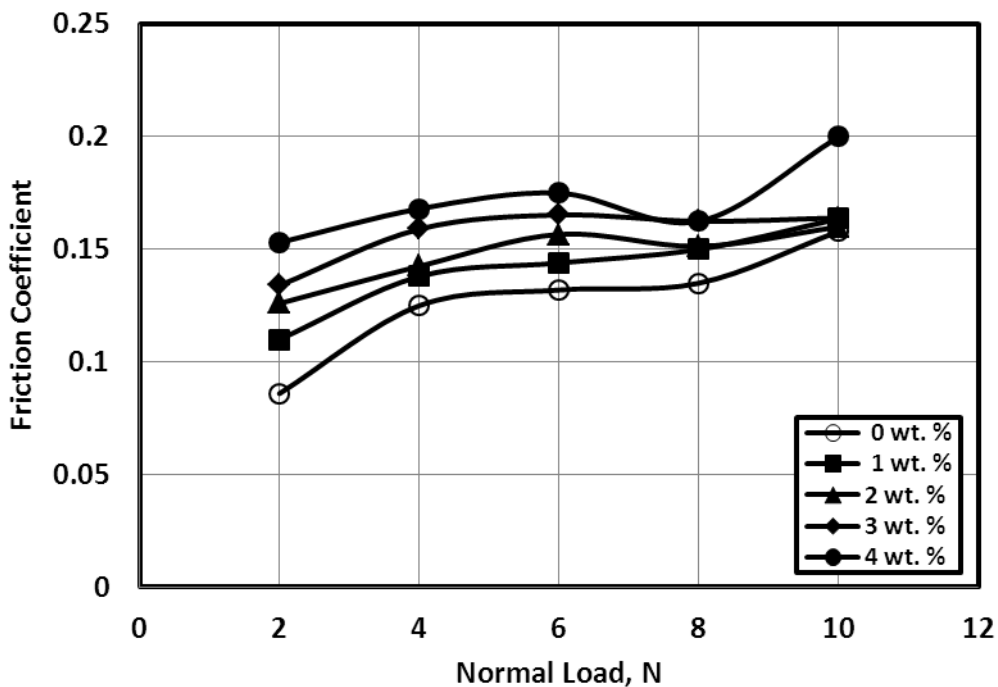


Fig. 4 Friction coefficient of composites filled by nanoparticles of Al_2O_3 .

A slight increase in friction coefficient was observed with increasing normal load. Furthermore, slight increase in friction coefficient with increasing C particles content was observed. This may be regarded to the increase of the cohesion of the matrix of the tested composites based on increasing C particles content. As follows from the Fig. 5, the maximum value of friction coefficient was 0.21 at 10 N normal load for 4 wt. % C content.

Figure 6 illustrates that friction coefficient increased with increasing both of the normal load and the content of Bz particles. This may be referred to the increase of the resistance to insert movement inside the specimen. As observed from Fig. 6, the maximum value of friction coefficient was approximately 0.17 at 10 N for particles content of 4 wt. %. This value is lower than that observed for Al_2O_3 filled composites because of the ductility and lubricity of Bz particles, that deformed during scratching.

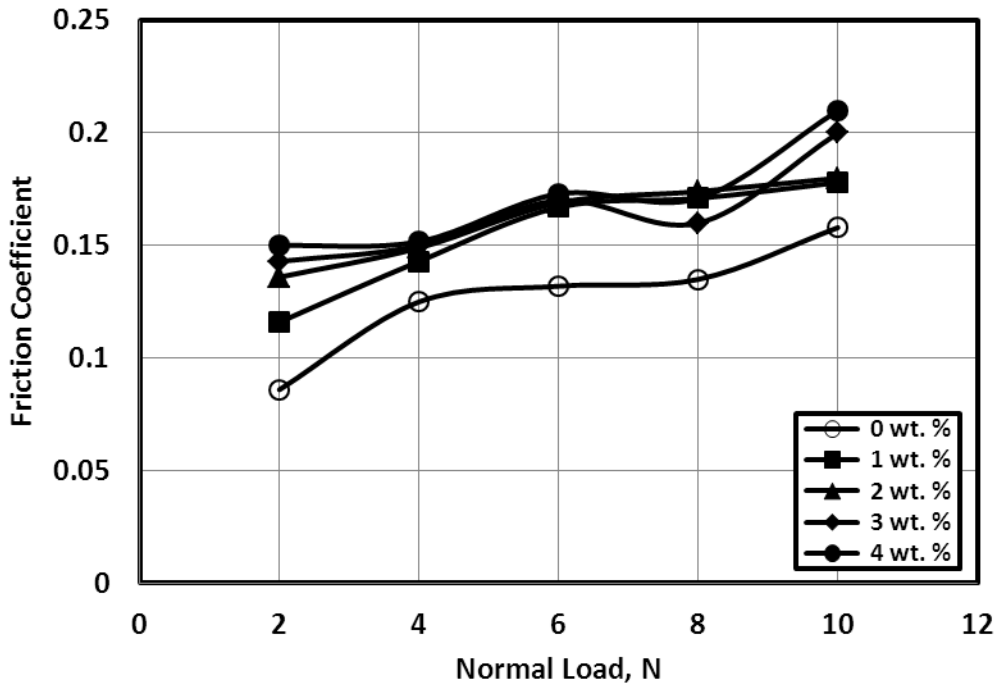


Fig. 5 Friction coefficient of composites filled by C nanoparticles.

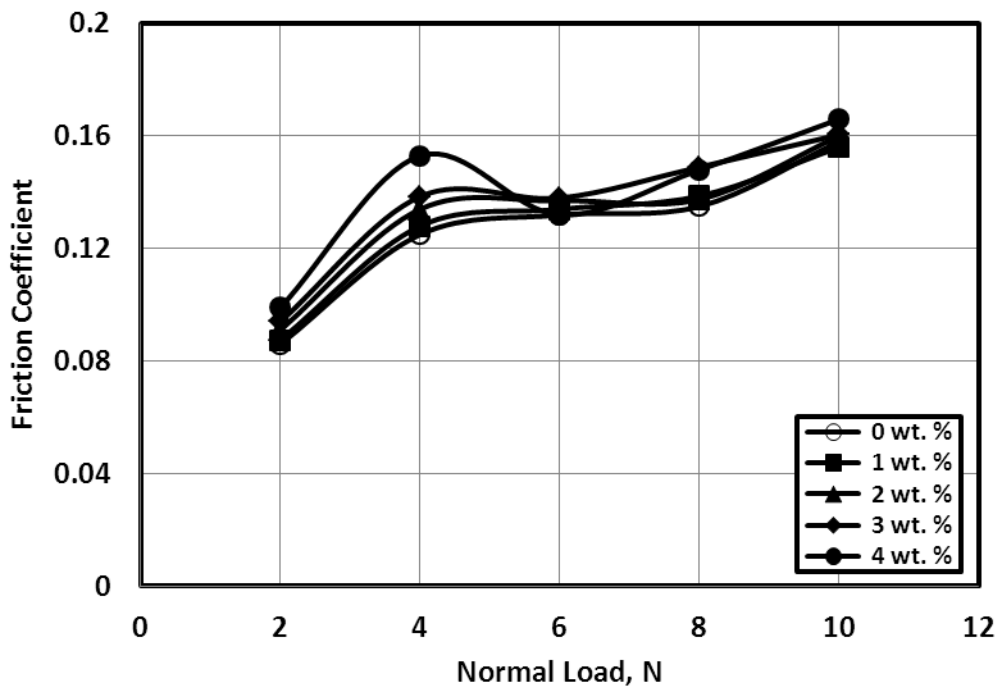


Fig. 5 Friction coefficient of composites filled by Bz nanoparticles.

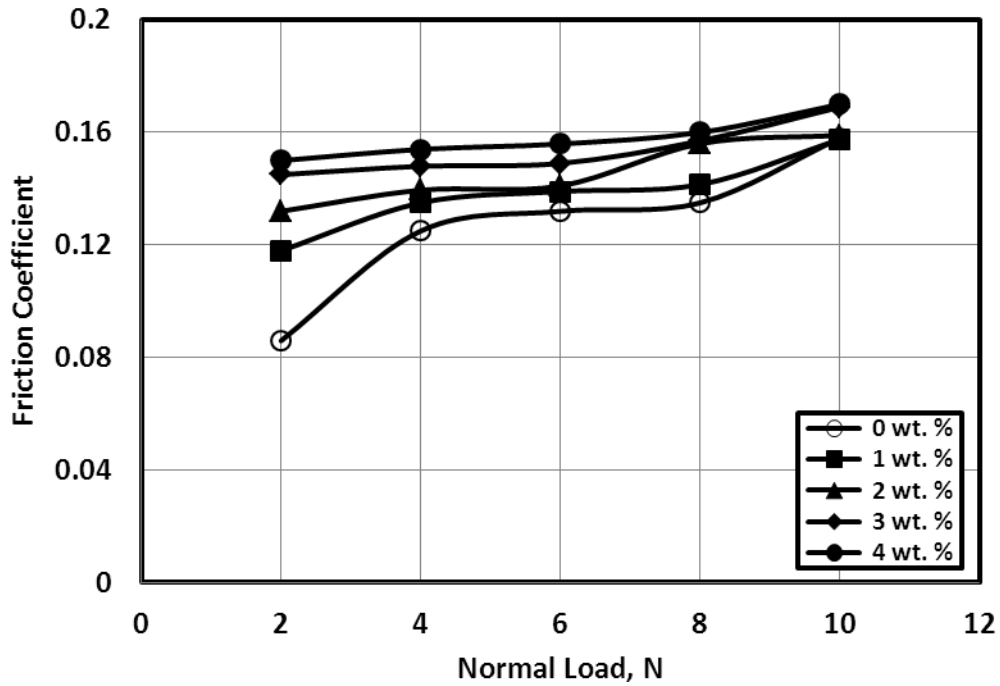


Fig. 7 Friction coefficient of composites filled by Al powder.

The same trend was observed compared to the previous figures, where the friction coefficient increased by increasing both the normal load and Al particles content in the epoxy matrix, Fig. 7. This may be attributed to the same reason as the particles content increased, wear resistance increased. In the same way the friction coefficient values are nearly similar to that plotted for Bz particles.

Evidence of scratch test

Photomicrographs were made by an optical microscope. The wear track was photographed to measure the scratch width of $\pm 1 \mu\text{m}$. The wear track morphology is shown in Fig. 8.

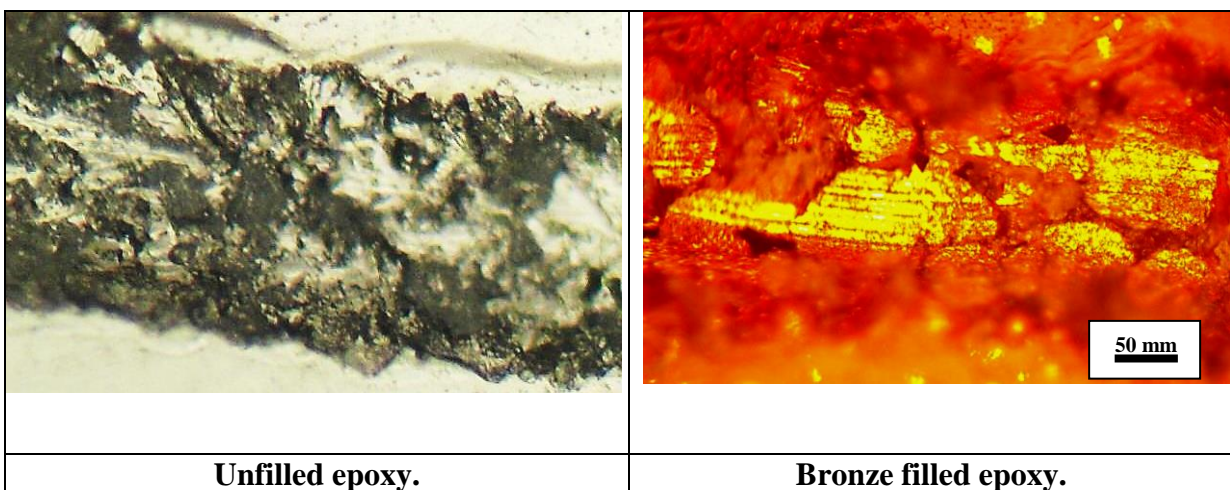


Fig. 8 Evidence of the scratch test in the surfaces of the tested composites.

Wear in the present work is represented by wear scar width. The relationship between wear scar width and content of Al_2O_3 nanoparticles for different values of loads is shown in Fig. 9. Slight decrease in wear was observed as Al_2O_3 content increased. The behavior is attributed to the increase of wear resistance of composites due to Al_2O_3 nanoparticles. It is observed that at 3 wt. % of Al_2O_3 minimum wear for several loading conditions is presented. Finally, it is observed that increasing Al_2O_3 content above 3 wt. % wear increased due to decreasing the cohesion of epoxy and Al_2O_3 particles.

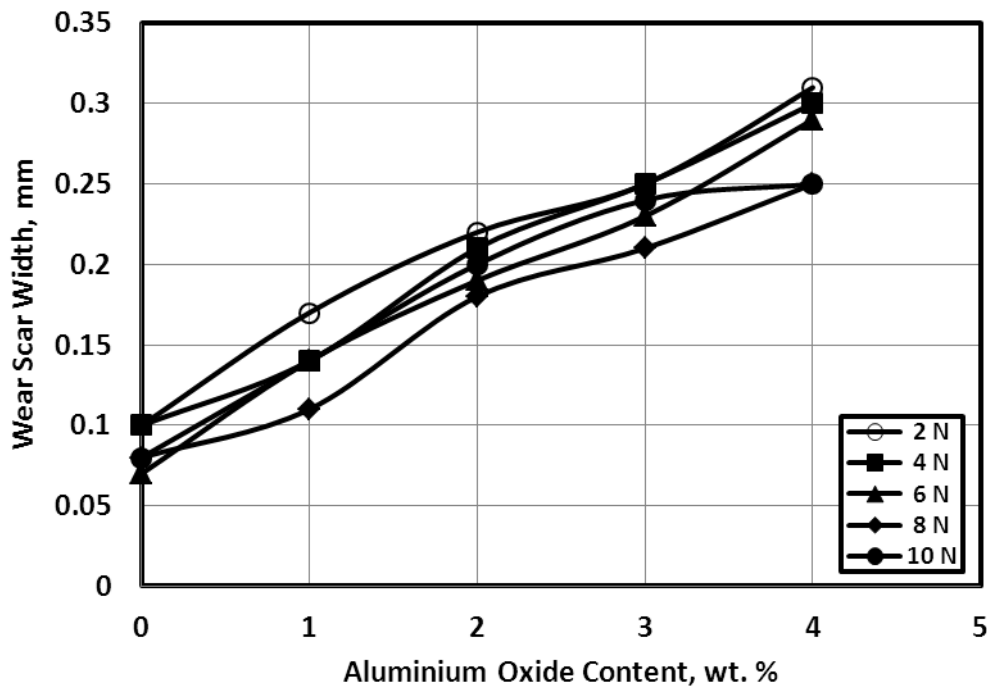


Fig.9 Wear scar width of composites filled by Al_2O_3 nanoparticles.

Slight decrease in wear with increasing C particles content and the normal load was observed, Fig. 10. This behavior may be due to action mechanism of C particles. It seems that C nano particles work as solid lubricant where the insert is less abrasive. In addition, it can be noticed that the wear was approximately 0.26 mm at 10 N normal load and 4 wt. % C content. In addition to that, it can be found that 4 wt. % C content gives minimum values.

As Bz content increased, slight decrease in wear was observed, Fig. 11. This behavior is attributed to the increase of wear resistance of composites due to the action of Bz particles. Bz particles acted as solid lubricant and decreased the abrasion of insert in the epoxy matrix. It is observed that at high values of Bz particles content wear values relatively decreased, which confirms the role of Bz as solid lubricant.

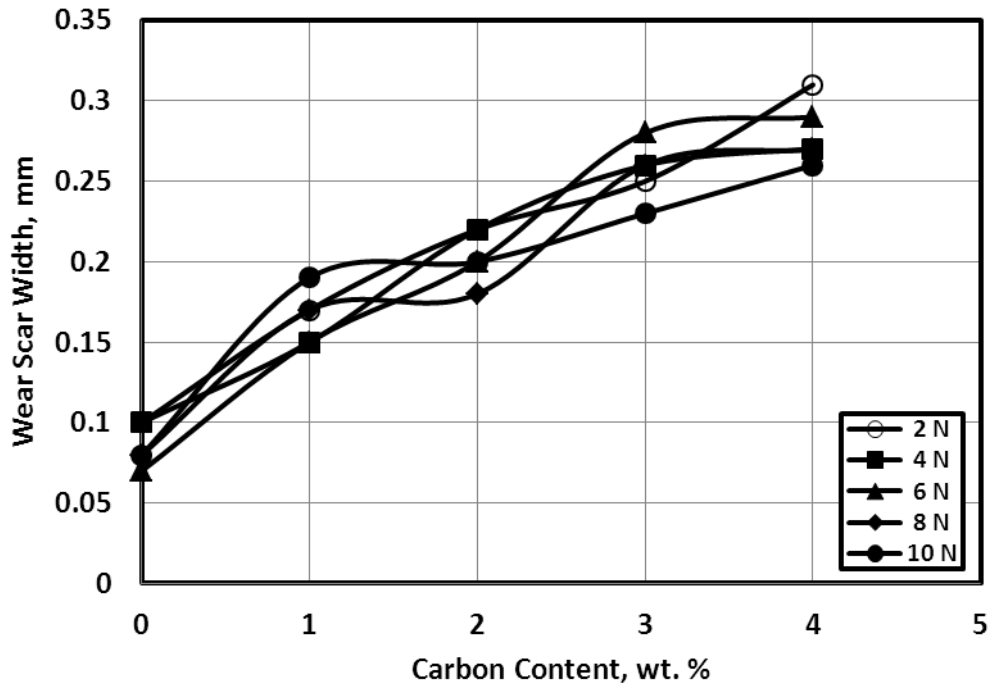


Fig. 10 Wear scar width of composites filled by carbon nano powder.

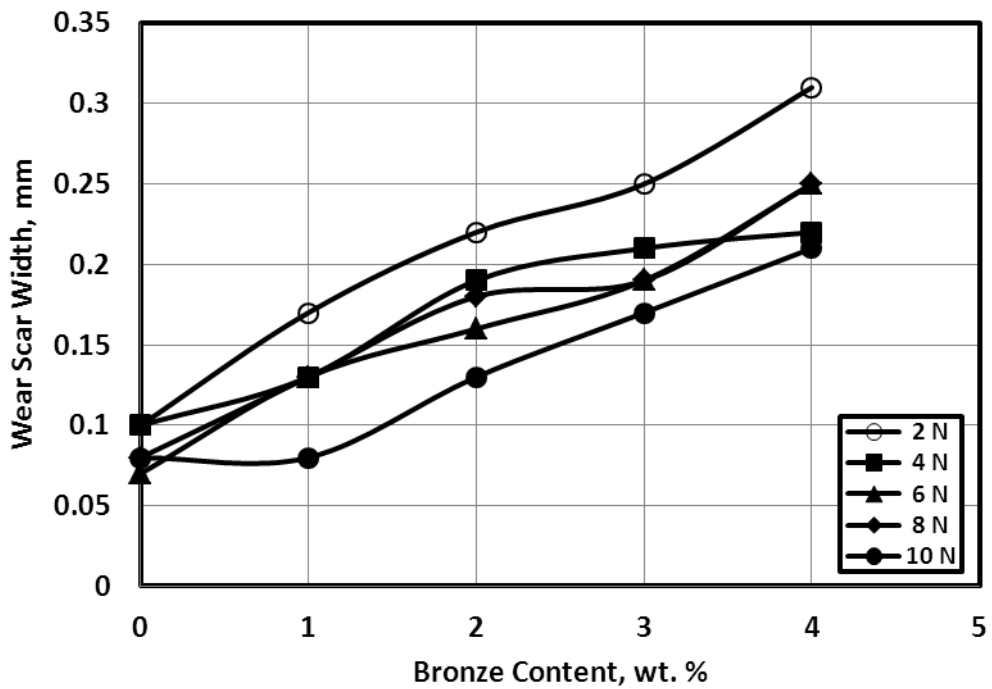


Fig. 11 Wear scar width of composites filled by bronze powder.

Figure 12 shows the relationship between wear and Al particles for different values of normal loads. It can be noted that a slight decrease in wear was observed as Al content increased. Besides, it can be seen that wear was 0.25 mm at 10 N normal load and 4 wt. % Al content.

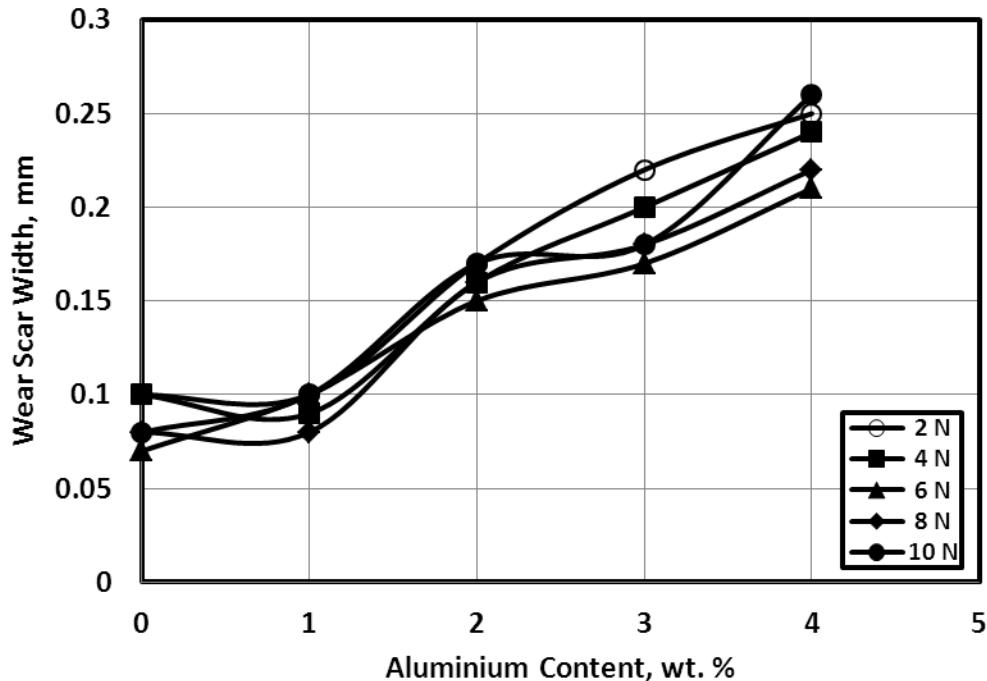


Fig. 12 Wear scar width of composites filled by Al powder.

CONCLUSIONS

From the experimental results, the following points can be concluded:

1. Slight increase in friction coefficient is observed for composites filled by Al_2O_3 as the normal load increased. Besides, friction coefficient increases as Al_2O_3 content increases.
2. The same trend is observed for C nano particles. The friction coefficient is relatively lower than that observed for Al_2O_3 .
3. The friction coefficient values observed for composites filled by Al particles are relatively lower than that observed for both Al_2O_3 and C nanoparticles.
4. Composites filled by Bz particles give minimum friction coefficient.
5. Slight decrease in wear is observed as Al_2O_3 content increased. It is observed that Al_2O_3 nanoparticles give minimum wear.
6. Slight decrease in wear is detected with increasing both C particles content and the normal load. In addition, it is found that 4 wt. % C content gives minimum values relatively.
7. Wear observed for composites filled by Bz particles shows relatively lowest values.

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