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INFLUENCE OF REINFORCING POLYMETHYL METHACRYLATE BY CARBON FIBRES ON FRICTION AND WEAR

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ABSTRACT
The present work aims to investigate the influence of reinforcing polymethyl methacrylate (PMMA) by continuous carbon fibres (CF) on the friction coefficient and wear resistance. Experiments have been carried to investigate the effect of earthing CF reinforced PMMA composites on the friction and wear behaviour of the tested composites by grounding them to have specific information about the effect of the electrostatic charge generated on the friction process.

It was found that reinforcing PMMA by carbon fibres increased friction coefficient. PMMA free of CF displayed relatively lower friction values than that observed for composites reinforced by 7.5 wt. % CF. It seems that presence of CF homogeneously distributes the generated electrostatic charge on the friction surface so that worn layer of PMMA composites was strongly adhered to the steel disc in a manner that the contact had become PMMA/PMMA and consequently friction coefficient displayed relatively higher values. When composites were grounded to the earth, friction coefficient showed lower values than that observed for ungrounded composites due to the leakage of the electrostatic charge outside the friction surface.

CF significantly enhanced the wear resistance by impeding the removal of material from the worn surface. Besides, the high CF stiffness combined with the good adhesion between fibres and PMMA matrix may develop the high wear resistance of the tested composites. Grounded composites displayed lower wear than ungrounded ones. This trend may be attributed to the ability of grounded composites to leak the electrostatic charge outside the friction surface due to good electrical conductivity of CF so that the worn the electrostatic charge gained by PMMA surface would be minimum. Based on that assumption, PMMA transfer into steel surface decreased.

KEYWORDS
Friction, wear, polymethyl methacrylate, carbon fibres, reinforcement.

INTRODUCTION
Carbon fiber reinforced epoxy composites provide the engineering materials in aeronautical industry relatively higher mechanical properties that enable them to be used to manufacture aileron, flaps, and landing-gear doors, [1 - 6]. The effect of

reinforcing epoxy matrix by carbon fibres (CF) on the friction and wear has been. Adhesion and abrasive tests have been carried out using short and continuous carbon fibres of different contents. Based on the experimental results it was found that, for adhesion test, friction coefficient of the tested composites slightly decreased with increasing CF content. As the load increased friction coefficient decreased. Slight decrease in friction coefficient was observed for the increase of the length ratio of CF. Besides, as the fibres content increased friction coefficient decreased. Wear drastically decreased with increasing fibres content, while increased with increasing applied load. The detached CF from the matrix might spread over the sliding surface and decrease the contact area between the tested composites and the counterface and hence friction and wear decreased. The results of the scratch tests revealed that friction coefficient of the scratched tested composites decreased with increasing fibres content, while it increased as the load increased. Wear drastically decreased with increasing fibres content. It is clearly shown that CF displayed relatively lower wear scar width compared to unreinforced epoxy composites due to the strength improvement of the fibres. Unreinforced epoxy exhibited the highest wear. As the length ratio of CF increased, wear slightly decreased, where continuous fibres displayed the lowest wear values.

Carbon fibers are extensively used in polymer matrix composites, where they provide higher strength and wear resistance, [6]. Studies have shown that the addition of nanoparticles into the matrix can enhance the tribological and mechanical properties, [7, 8]. Abrasive wear behavior of epoxy reinforced with carbon, glass and aramid fabrics was investigated, [9]. Addition of spherical TiO_2 nanoparticles reduced the friction coefficient and wear of carbon fibres reinforced epoxy composites, [10]. The rolling effect of TiO_2 protects the short carbon fibres from severe wear. The effect on the wear resistance of epoxy filled by short carbon fibre (CF), graphite, polytetrafluoroethylene (PTFE) and nano-TiO_2, have been investigated, [11]. The best wear resistant composition was obtained by nano-TiO_2 and CF.

Friction coefficient displayed by epoxy composites reinforced by unidirectional carbon fibres was measured. It was found that, composites reinforced by fibres parallel to the sliding direction had a significantly lower friction coefficient, [12]. Composites reinforced by carbon fibres exhibited very high wear resistance, [13]. This behavior recommends that composite to be used as antifriction bearings and guide ways. Friction and wear unidirectional and woven carbon fiber/epoxy composites were investigated. Under abrasive conditions, unidirectional fiber composites with fibers parallel to the sliding direction were more wear resistant and lower friction coefficient, [14]. It was found that, [15], compared to dry sliding, friction and wear of the braided carbon fibre/epoxy composites at lubricated sliding was less dependent on fiber content, load, and velocity.

The present work investigates the influence of PMMA reinforced by continuous carbon fibres (CF) on the friction coefficient and wear resistance.

EXPERIMENTAL

Experiments were carried out using a pin-on-disc wear tester. It consists of a rotary horizontal steel disc driven by a variable speed motor. The details of the wear tester are shown in Fig. 1. The test specimen is held in the specimen holder fastened to the loading lever through load cell, where friction force can be measured. Friction coefficient was determined through the friction force measured by the deflection of the cell. The load is

applied by weights. The counterface in the form of a steel disc, of 100 mm outer diameter, was fastened to the rotating disc. Its surface roughness (Ra) was about 3.2 µm. Test specimens were prepared in the form of cylindrical pins of 8 mm diameter and 30 mm long. The test specimens were loaded against counterface of a carbon steel disc (1.16 wt. % C, 0.91 wt. % Si, 1.65 wt. % Mn, 0.52 wt. % Cr, and 95.5 wt. % Fe) of 2720 N/mm^2 hardness. Friction and wear tests were carried out under constant sliding velocity of 2.0 m/s and 5, 10, 15, 20 and 25 N applied load. Every experiment lasted for 900 s.

The material of the matrix of test specimens was PMMA. Test specimens were prepared by reinforcing PMMA by CF. Then they were left to cure under standard atmospheric conditions. Test specimens have been molded in cylindrical tubes of 8 mm diameter. Continuous CF were used as reinforcement of 7.5 wt. % content. One end of the tested composites was polished before the test by cotton textile. The surface roughness (Ra) of contact surfaces of the tested pins was approximately 3.2 µm. The CF extended from the second end of the tested composites were ungrounded and grounded to the earth during the experiments, Fig. 2. The diameter of the nanocarbon fibres was 0.45 µm.

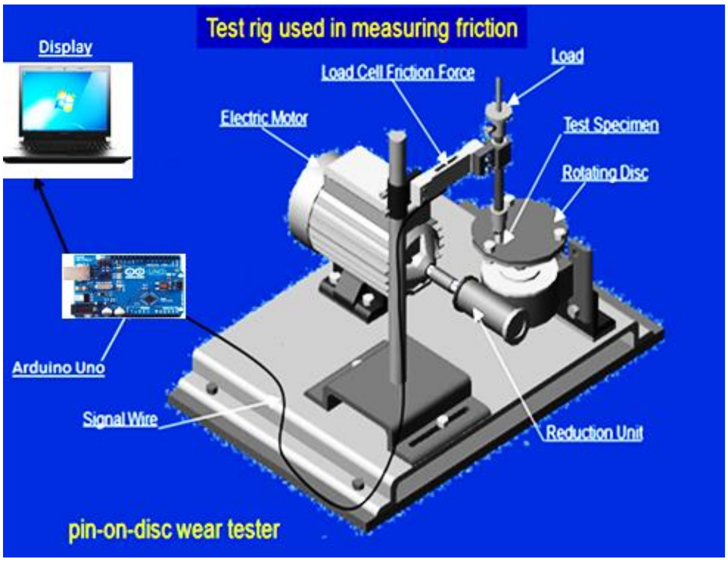
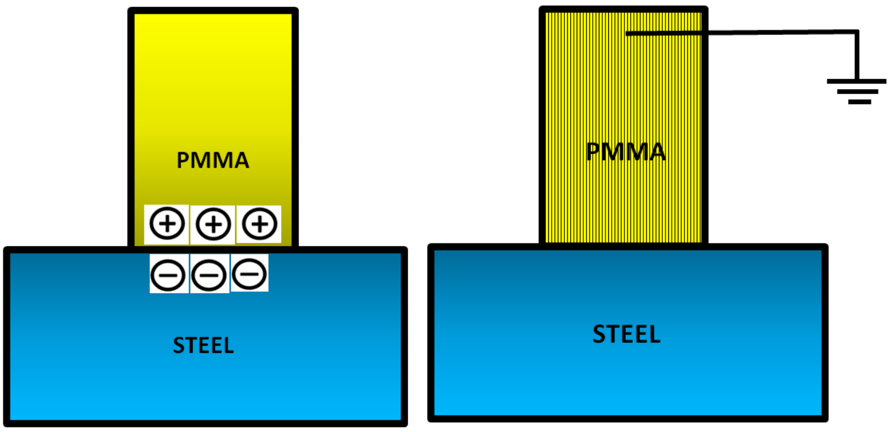


Fig. 1 Arrangement of the test rig.



a. Ungrounded. b. Grounded

Fig. 2 Test specimens.

RESULTS AND DISCUSSION

The effect of earthing on the friction and wear behaviour of the tested composites is discussed, where friction coefficient of PMMA composites sliding against dry steel disc is shown in Fig. 3. It is clearly shown that friction coefficient depends on the applied normal load. As the load increases friction coefficient increases up to maximum then decreases with further load increase. It seems that friction increase may be due to contact area increase, while friction decrease can be from the heating accompanied to friction which causes plastic softening that is responsible for decrease of shear strength. Relatively high friction fluctuations are observed during friction process. That behaviour may be from the transfer of PMMA into steel and transfer back to the composite surface.

The effect of reinforcing PMMA by carbon fibres on friction coefficient is shown in Fig. 4. PMMA free of CF displayed relatively lower friction values than that observed for PMMA reinforced by 7.5 wt. % CF. That behavior can be interpreted on the fact that during friction steel disc gained negative charge, while PMMA composites surface gained positive charge. The presence of CF homogeneously distribute the electrostatic charge on the friction surface so that worn layer of PMMA composites was strongly adhered to the steel disc in a manner that the contact had become PMMA/PMMA and consequently friction coefficient displayed relatively higher values.

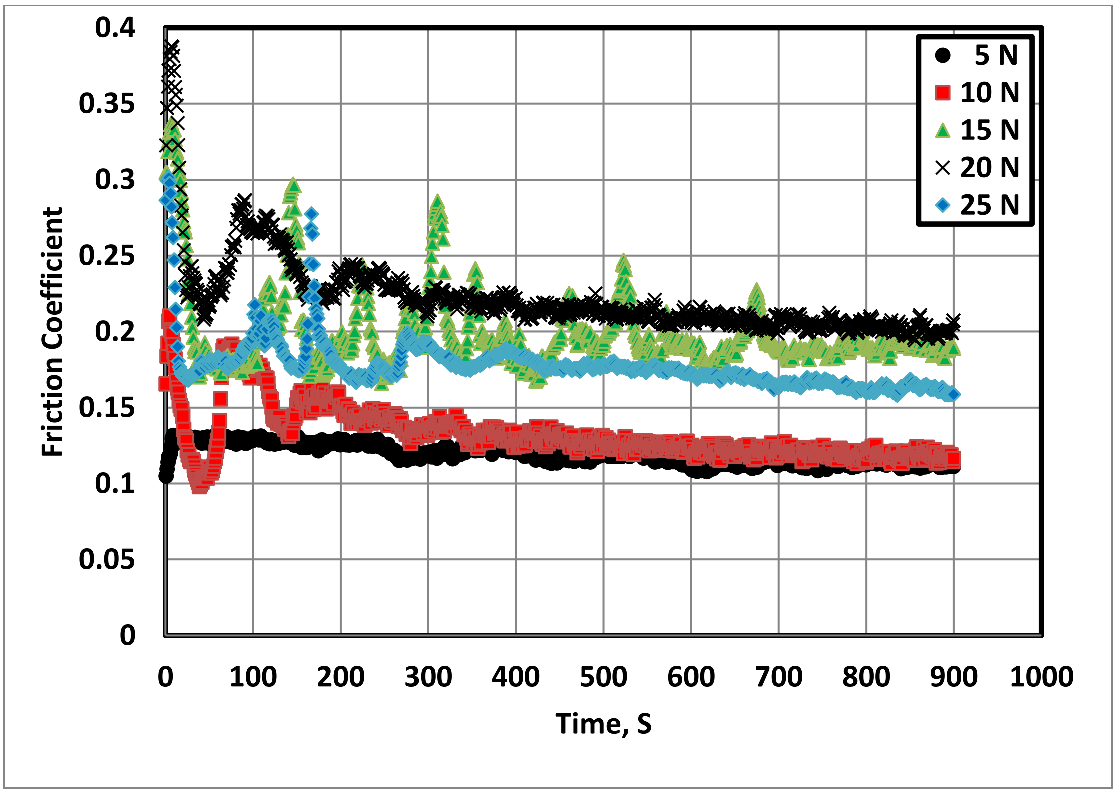


Fig. 3 Friction coefficient displayed by PMMA specimens sliding against steel.

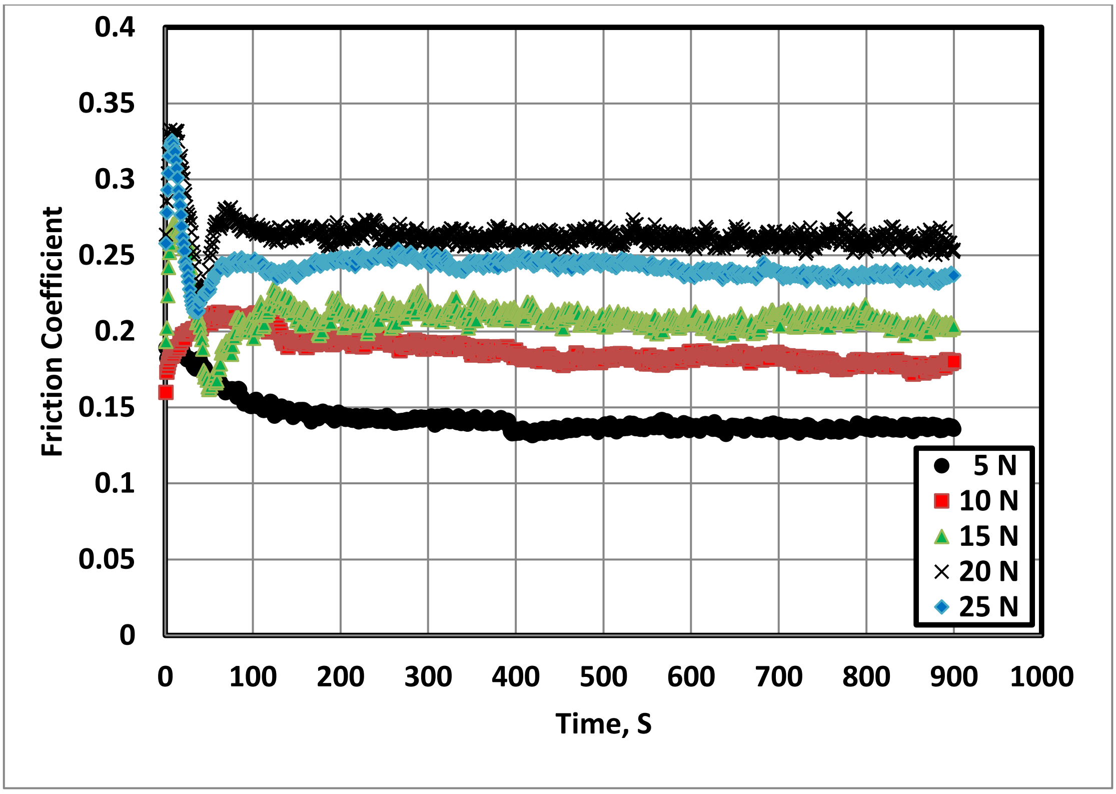


Fig. 4 Friction coefficient displayed by ungrounded CF reinforced PMMA specimens sliding against steel.

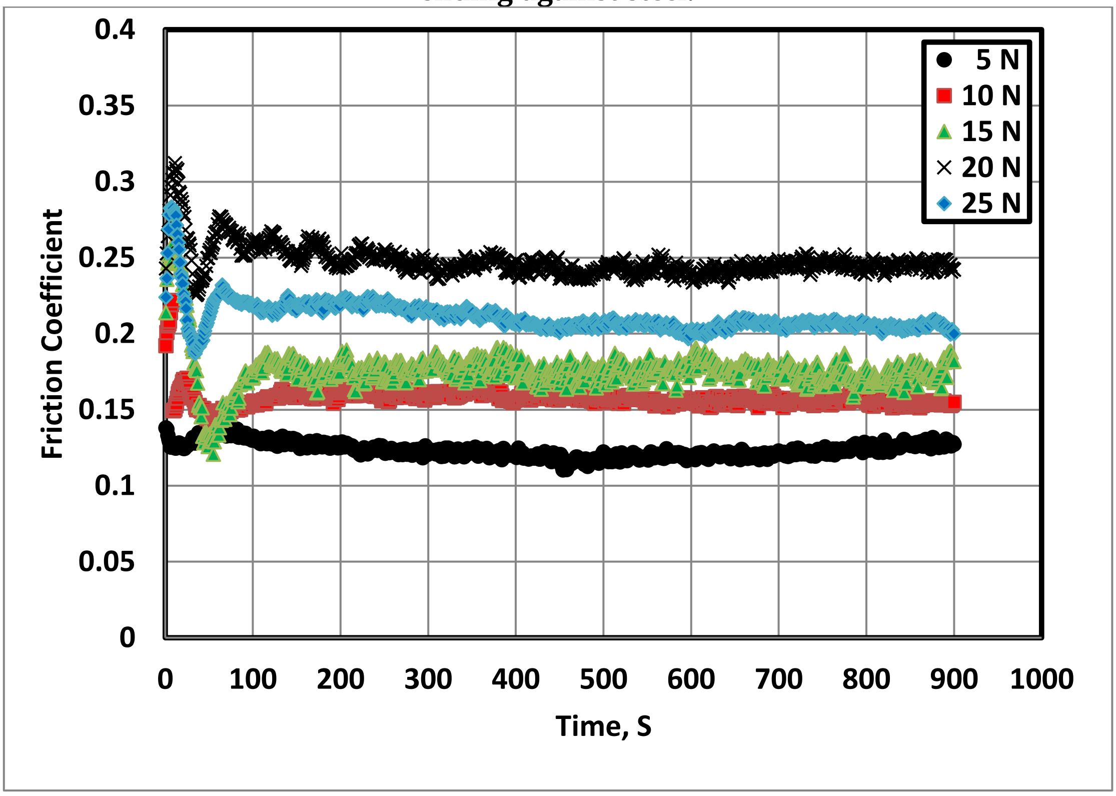


Fig. 5 Friction coefficient displayed by grounded CF reinforced PMMA specimens sliding against steel.

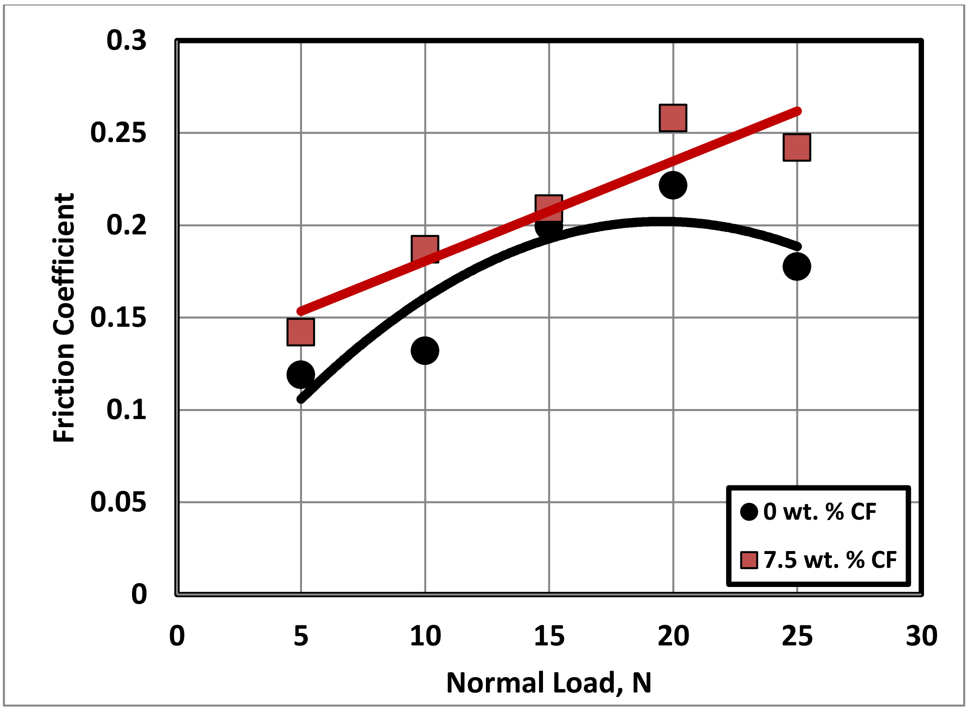


Fig. 6 Effect of normal load on friction coefficient displayed by ungrounded PMMA composites sliding against steel.

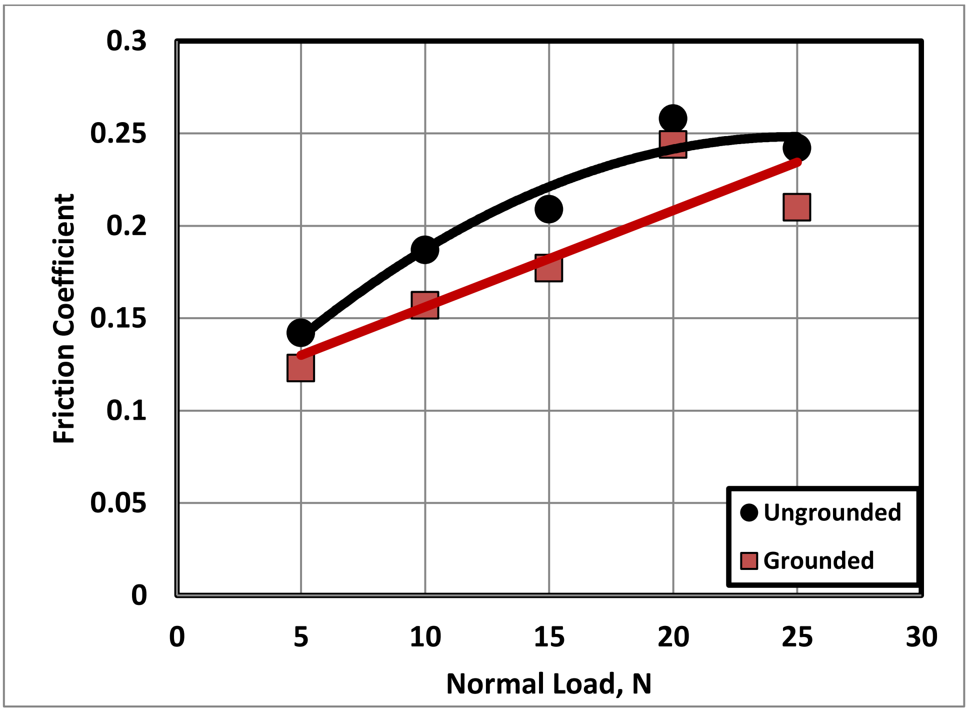


Fig. 7 Effect of earthing on friction coefficient displayed by CF reinforced PMMA composites sliding against steel.

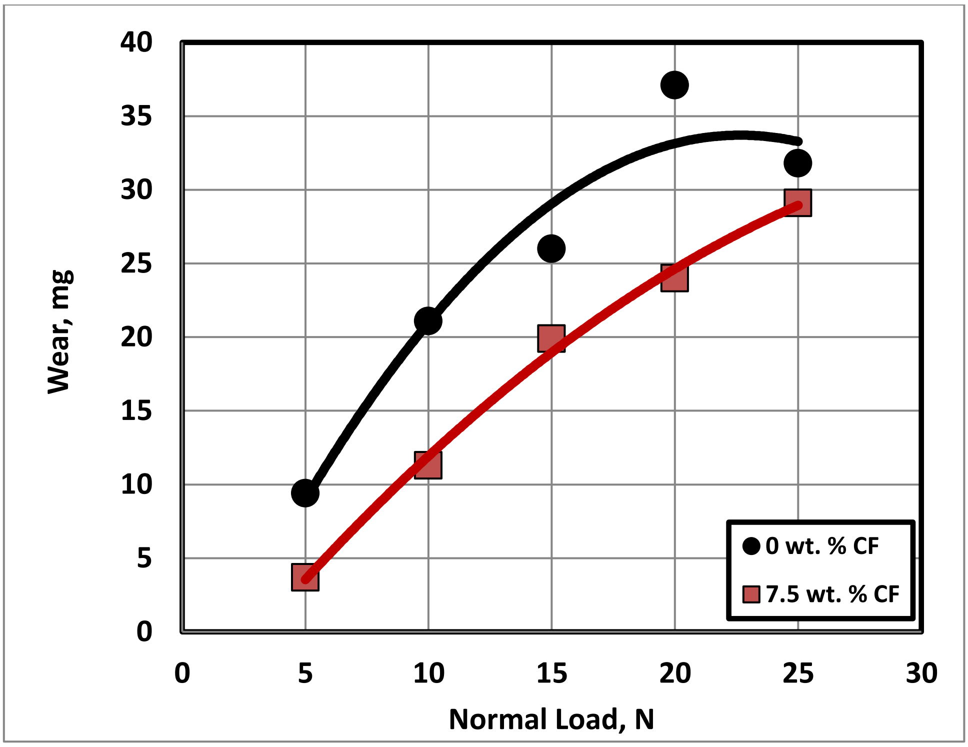


Fig. 8 Wear of ungrounded CF reinforced PMMA composites.

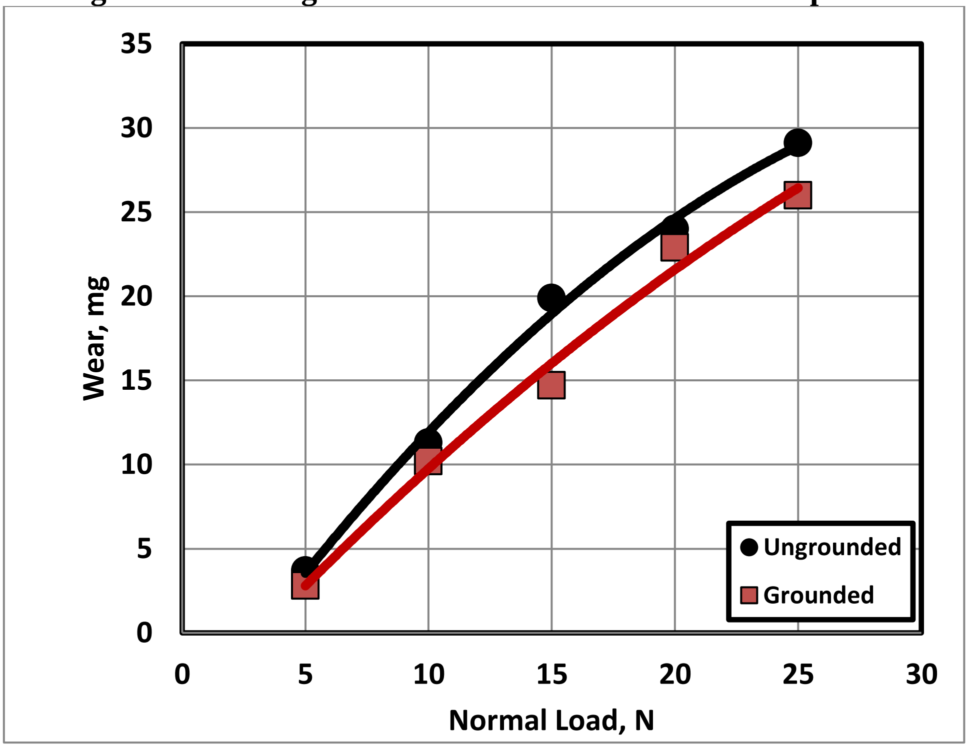


Fig. 9 Wear of grounded CF reinforced PMMA composites.

When PMMA composites were grounded to the earth, friction coefficient showed lower values than that observed for ungrounded composites due to leaking the electrostatic charge into the ground, Fig. 5. As a consequence the adherence of loose PMMA worn particles into steel surface became weaker. The contact surfaces were PMMA and steel. Besides, the fluctuations in friction values disappeared.

The comparative friction performance of PMMA free of CF and reinforced by CF at different values of normal load displayed by ungrounded PMMA composites sliding against steel is shown in Fig. 6. The average values of friction coefficient are plotted in the curve. PMMA reinforced by CF composites showed increasing friction trend with increasing normal load, while friction of PMMA increased up to maximum at 20 N load then decraesed with further load increase. It seems that CF incraesed the adherence of PMMA worn particles in the steel surface causing the friction increase.

The effect of earthing the tested composites on friction coefficient displayed by CF reinforced PMMA composites sliding against steel counterface is illustrated at Fig. 7, where ungrounded composites displayed relatively higher friction than grounded ones. That behavior can be explained on the basis that leakage of the electrostatic charge generated on the surface as a result of the friction decreased the adherence of PMMA particles into the steel surface.

Wear of ungrounded PMMA composites is shown in Fig. 8, where CF significantly enhanced the wear resistance that impedes the removal of material from the worn surface. It seems that high CF stiffness combined with the good adhesion between fibres and PMMA matrix may develop the high wear resistance of the tested composites. The comparison, of the grounded and ungrounded CF reinforced PMMA composites, is shown in Fig. 9, where grounded composites displayed lower wear than ungrounded ones. This trend may be attributed to the ability of grounded composites to leak the electrostatic charge outside the friction surface due to good electrical conductivity of CF so that the worn the charge gained by PMMA surface would be minimum. Based on that assumption PMMA transfer into steel surface would decrease.

CONCLUSIONS

1. The friction coefficient of PMMA composites sliding against dry steel disc depends on the applied normal load. As the load increases friction coefficient increases up to maximum then decreases with further load increase. Relatively high friction fluctuations are observed during friction process.

2. PMMA free of CF displayed relatively lower friction values than that observed for PMMA reinforced by 7.5 wt. % CF. When PMMA composites were grounded to the earth, friction coefficient showed lower values than that observed for ungrounded composites.

3. PMMA reinforced by CF composites showed increasing friction trend with increasing normal load, while friction of PMMA increased up to maximum then decraesed with further load increase. Ungrounded composites displayed relatively higher friction than grounded ones.

4. CF significantly enhanced the wear resistance that impedes the removal of material from the worn surface. Grounded composites displayed lower wear than ungrounded ones.

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