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FRICTION AND WEAR OF CARBON FIBRES REINFORCED EPOXY COMPOSITES

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ABSTRACT
The present study investigates the effect of reinforcing epoxy matrix by carbon fibres (CF) on the friction and wear. Adhesion and abrasive tests have been carried out using short and continuous carbon fibres of different contents.

Based on the experimental results it is 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.

KEYWORDS
Friction, wear, carbon fibres, epoxy composites.

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 - 4]. Carbon fibers are extensively used in polymer matrix composites, where they provide higher strength and wear resistance, [5]. Studies have shown that the addition of nanoparticles into the matrix can enhance the tribological and mechanical properties, [6, 7]. Abrasive wear

behavior of epoxy reinforced with carbon, glass and aramid fabrics was investigated, [8]. Addition of spherical TiO_2 nanoparticles reduced the friction coefficient and wear of carbon fibres reinforced epoxy composites, [9]. 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, [10]. The best wear resistant composition was obtained by nano-TiO_2 and short (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, [11]. Composites reinforced by carbon fibres exhibited very high wear resistance, [12]. 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, [13]. It was found that, [14], 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 tribological properties of composites reinforced by polymeric fibres and metallic wires were enhanced relative to the unreinforced ones, [15 – 18]. It seems that reinforcing epoxy coating by the fibres and wires increased the tensile strength of the coating.

In the present work, the effect of reinforcing epoxy matrix by carbon fibres (CF) on the friction and wear is investigated.

EXPERIMENTAL

Test specimens were prepared by reinforcing epoxy resins by CF. Then they were left to cure under standard atmospheric conditions. Test specimens have been prepared in block form of $20 \times 10 \times 8$ mm^3, Fig. 1, where the circular specimens were turned from the blocks, Fig. 2. Short and continuous CF were used as reinforcement in length ratio of 25, 50, 75 and 100 %, Fig. 3.

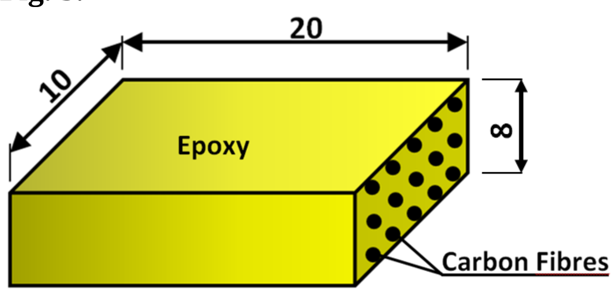

Fig. 1 Test specimens of scratch test.

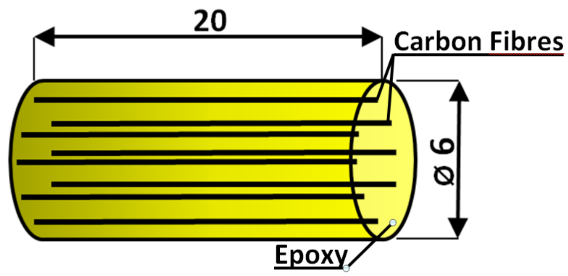

Fig. 2 Test specimens of adhesion test.

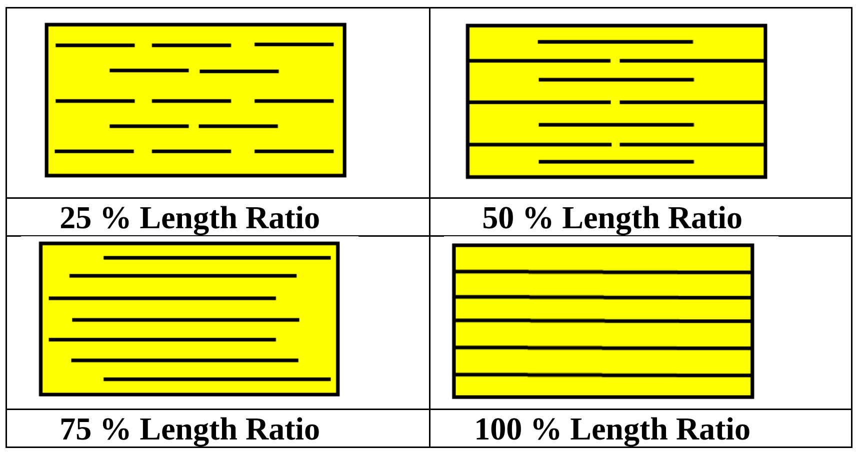

Fig. 3 Distribution of CF in the epoxy resin.

Adhesion wear was carried out using pin-on-disc wear tester. The details of the wear tester are shown elsewhere, [15]. The test specimens are held in the specimen holder and loaded to the rotating disc of 3.2 µm, R_a surface roughness. Tests were carried out under constant sliding velocity of 2.0 m/s and 12, 24 and 36 N load and lasted for 300 seconds. The test specimens, in the form of cylinders, were 6 mm diameter and 20 mm height.

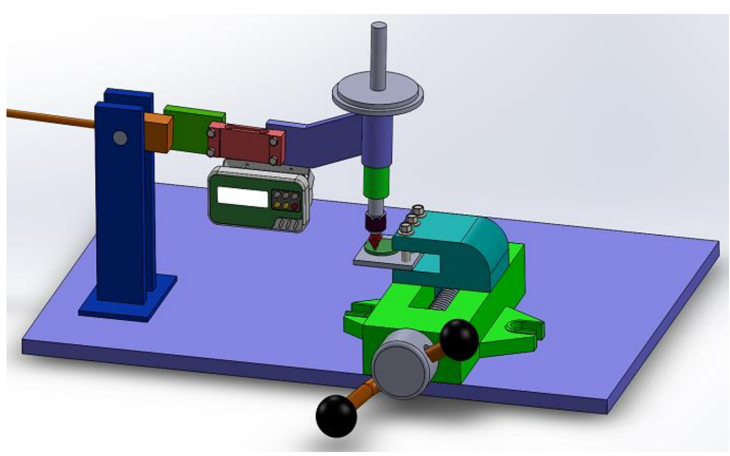

Fig. 4 Arrangement of scratch test rig.

The scratch test was carried out by the test rig shown in Fig. 4. It consists of rigid stylus mount, where a steel stylus of 90º 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. Vertical load was applied by weight of 4, 8, 12, 16 and 20 N. Scratch resistance force was measured using a load cell mounted to the loading lever and connected to a digital monitor. The test specimen was held in the specimen holder which was 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.

RESULTS AND DISCUSSION

The Effect of CF content on the hardness of the tested composites is shown in Fig. 5. It is clearly shown as CF content increases, hardness of the tested composites proportionally increases due to the extra strength provided by CF.

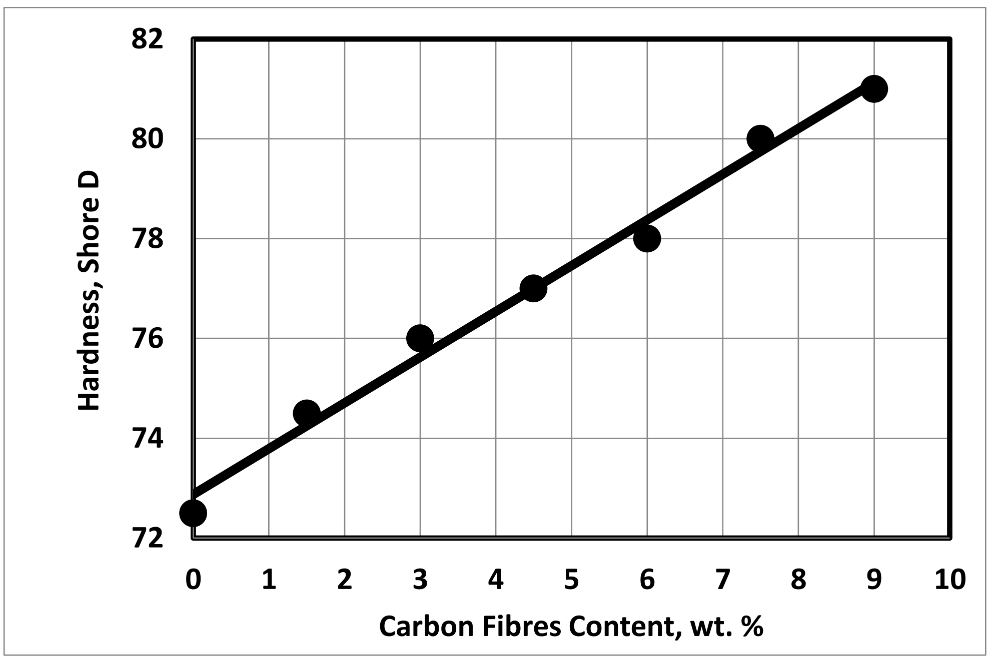

Fig. 5 Effect of CF content on hardness of the tested composites.

The results of the adhesion tests of the tested composites are shown in Figs. 6 – 12. Friction coefficient of the tested composites slightly decreased with increasing CF content, Fig. 6. As the load increased, friction coefficient decreased. In consequence, the stresses exceeded the interfacial strength between fibres and epoxy matrix. 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.

It is common known that the highest mechanical properties are obtained with continuous fiber composites. As for short fibre composites, it is difficult in practice to maintain good alignment inside the matrix of the composite. Short fibre composites are used where cost should be low. The relationship between friction coefficient and the length ratio of CF is illustrated in Figs. 7, 8 and 9 for 1.5, 4.5 and 7.5 wt. % fibres content respectively. 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. Theis behavior may be from the wear debris that removed from the tested composites and formed layer that consists of epoxy and CF covering the sliding surfaces and consequently they reduce friction. Increasing applied load caused significant friction decrease due to the heating effect that decreases the shear strength of epoxy matrix.

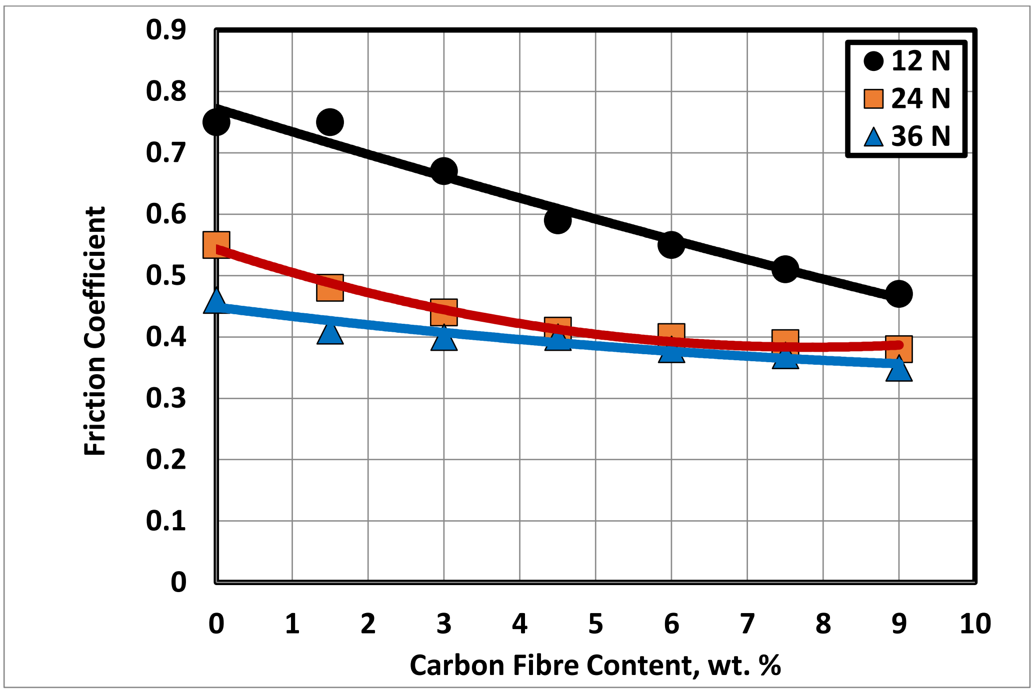

Fig. 6. Effect of CF content on friction coefficient of the tested composites.

The results of wear of the tested composites are shown in Figs. 10 – 13. Wear drastically decreased with increasing CF content, while increased with increasing applied load, Fig. 10. The enhancement in wear resistance is attributed to the extra strength provided by CF that improve mechanical properties. CF are able to reduce wear of epoxy due to their high load carrying capacity. The role of CF is to share supporting the applied load. The reduction in friction coefficient and wear may be attributed to the formation of transfer film formed from the detached CF, where continuous CF displayed the lowest wear values, Figs. 11 - 13. Breaking and peeling of short CF are easier than of continuous ones, so that fibres detaching from the sliding surface can control the wear rate.

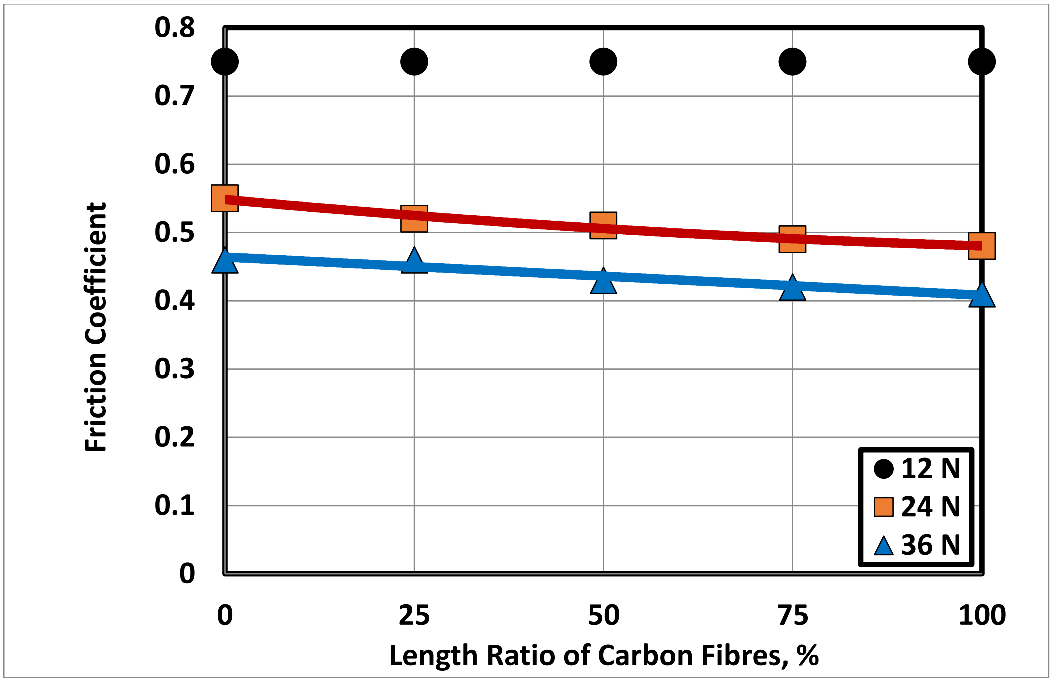

Fig. 7 Friction coefficient displayed by composites reinforced by 1.5 wt. % CF versus length ratio.

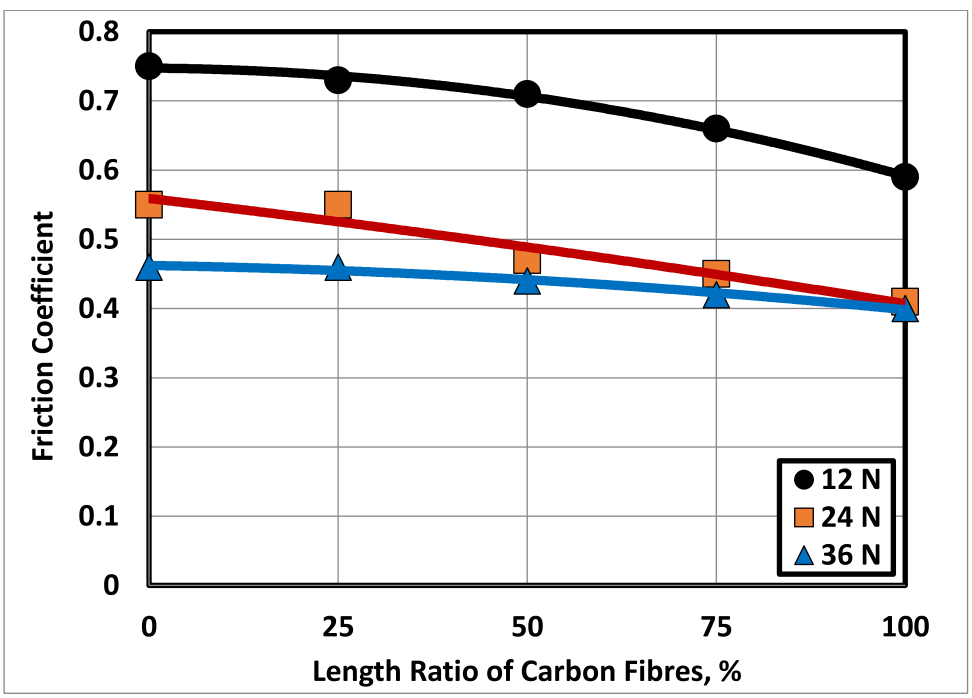

Fig. 8 Friction coefficient displayed by composites reinforced by 4.5 wt. % CF versus length ratio.

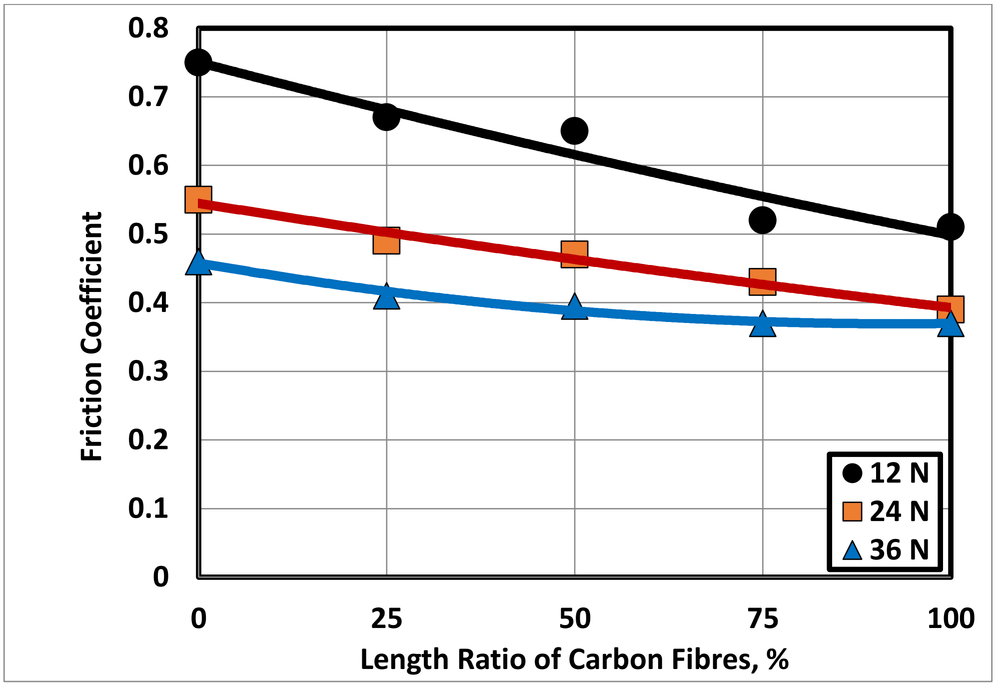

Fig. 9 Friction coefficient displayed by composites reinforced by 7.5 wt. % CF versus length ratio.

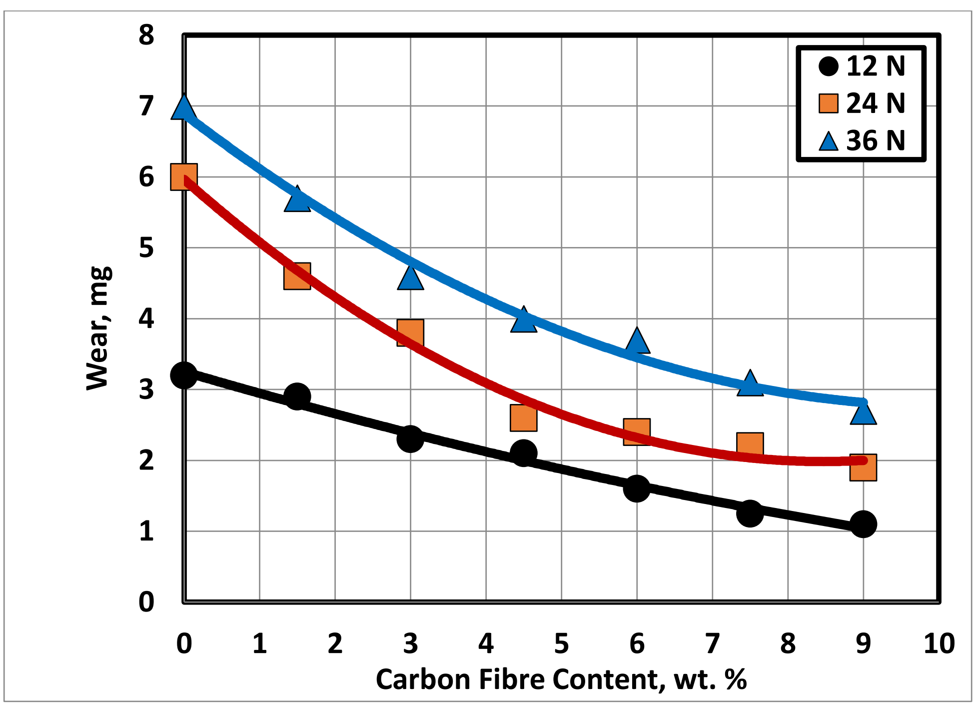

Fig. 10 Effect of CF content on adhesive wear of the tested composites.

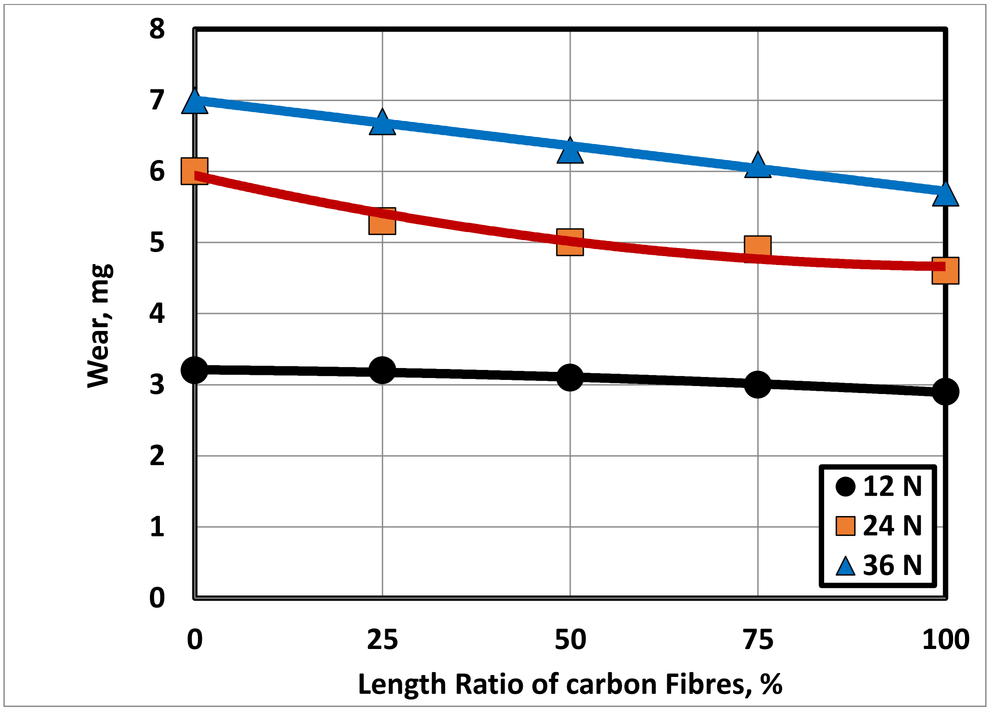

Fig. 11 Wear of composites reinforced by 1.5 wt. % CF versus length ratio.

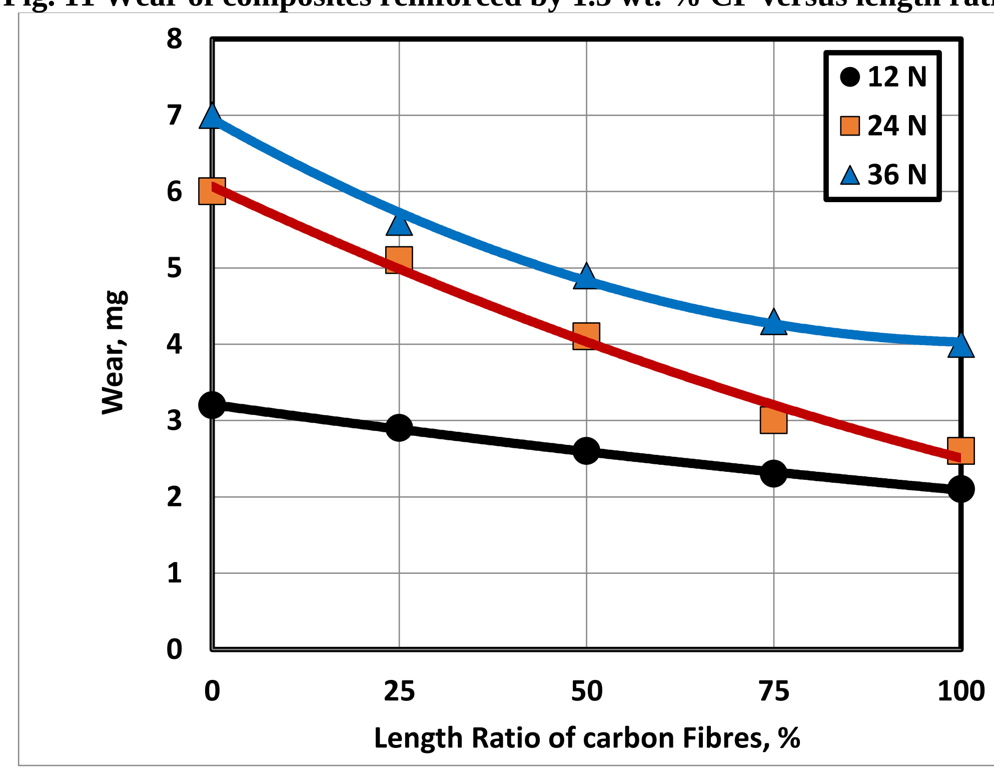

Fig. 12 Wear of composites reinforced by 4.5 wt. % CF versus length ratio.

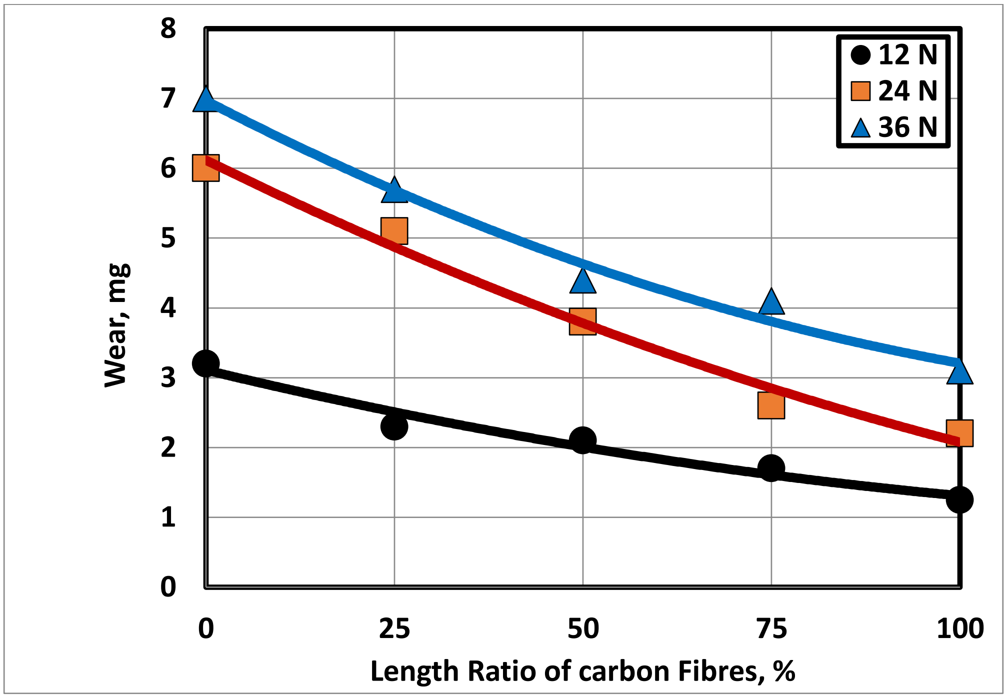

Fig. 13 Wear of composites reinforced by 7.5 wt. % CF versus length ratio.

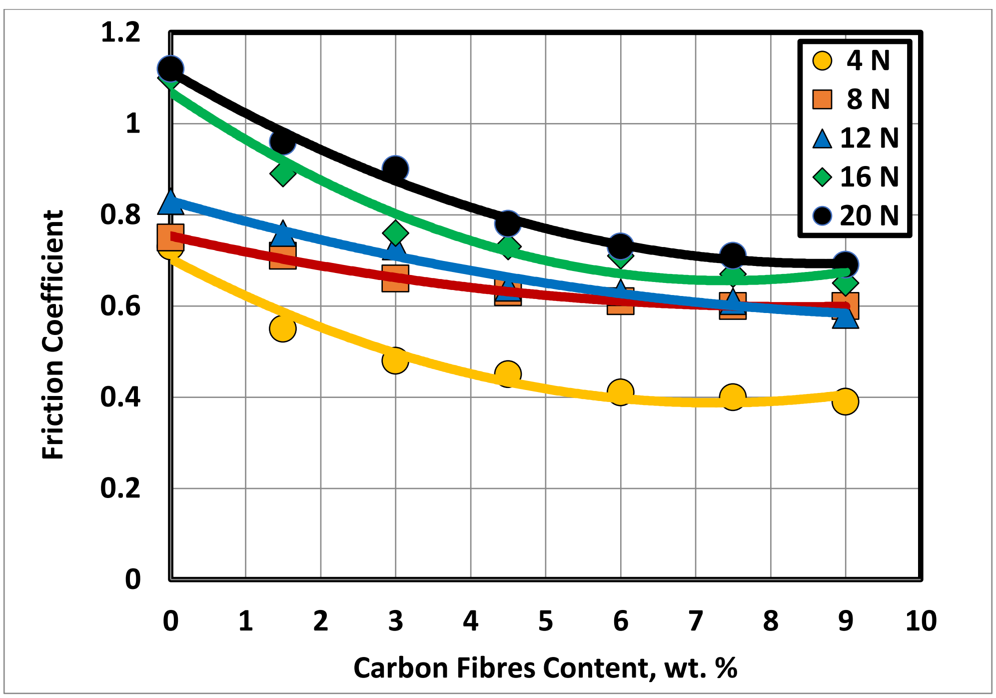

Fig. 14 Effect of CF content on friction coefficient of the scratched tested composites.

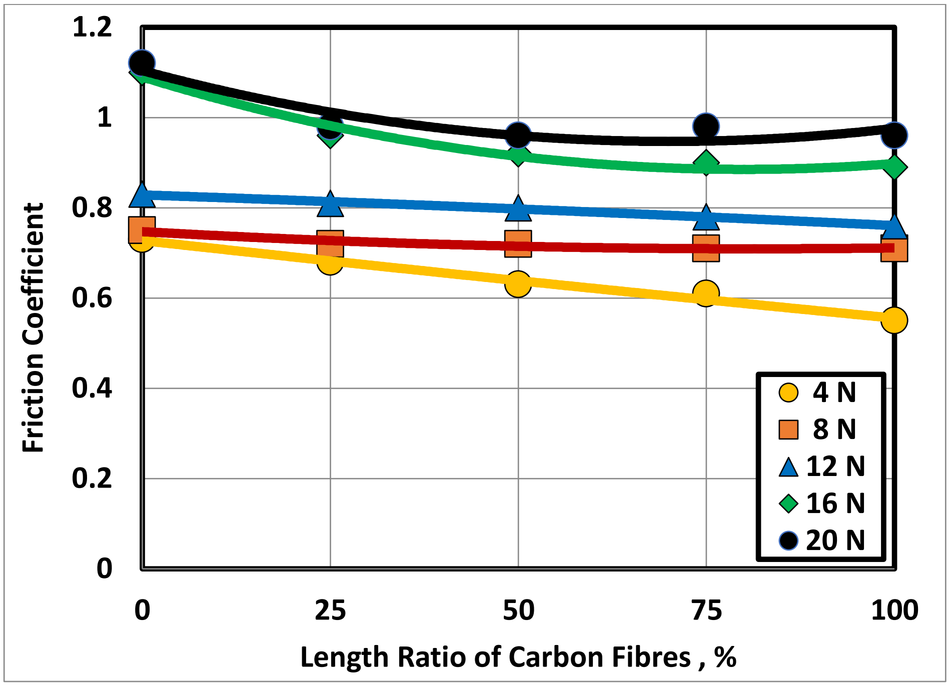

Fig. 15 Friction coefficient displayed by the scratched composites reinforced by 1.5 wt. % CF versus length ratio.

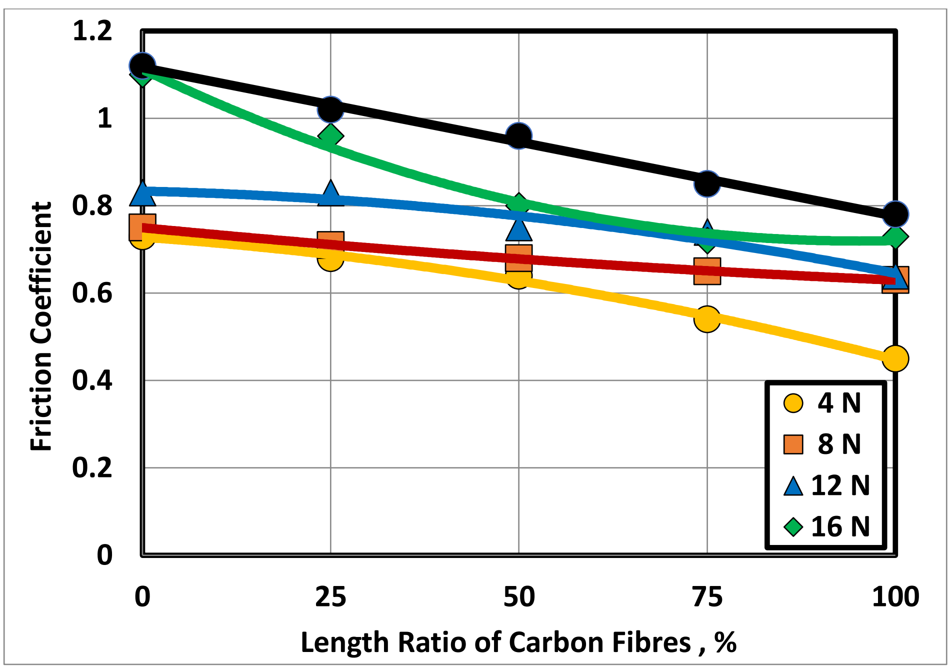

Fig. 16 Friction coefficient displayed by the scratched composites reinforced by 4.5 wt. % CF versus length ratio.

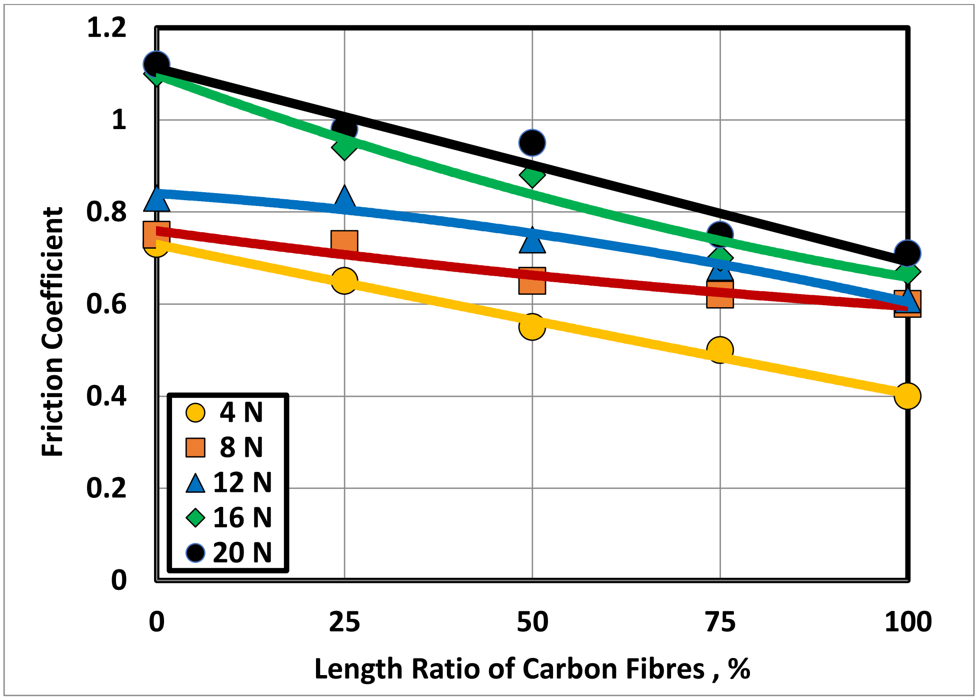

Fig. 17 Friction coefficient displayed by the scratched composites reinforced by 7.5 wt. % CF versus length ratio.

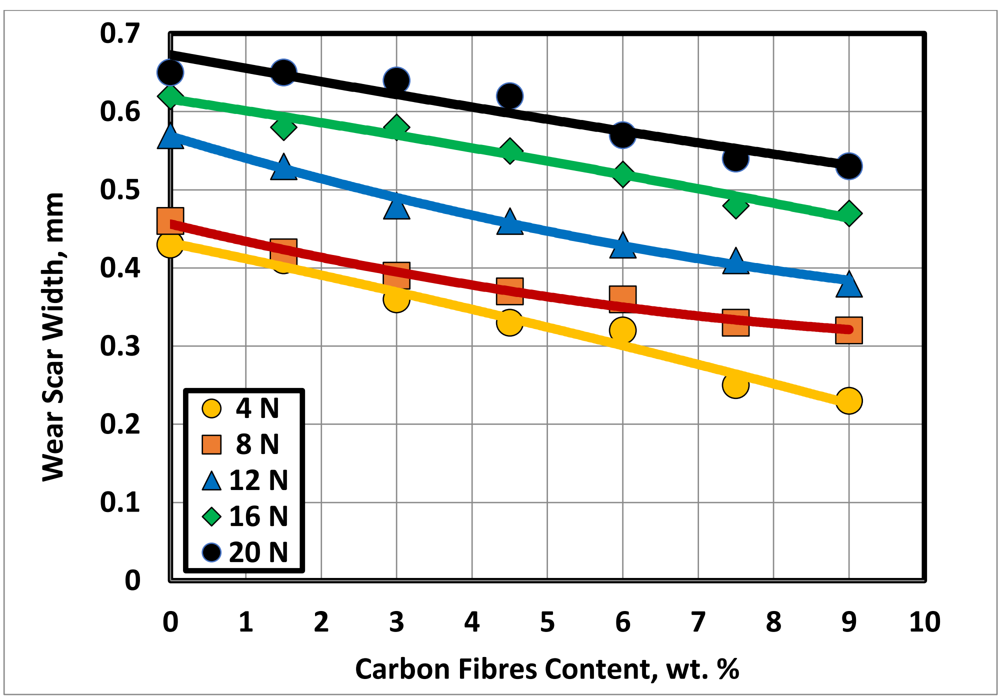

Fig. 18 Effect of CF content on wear of the scratched tested composites.

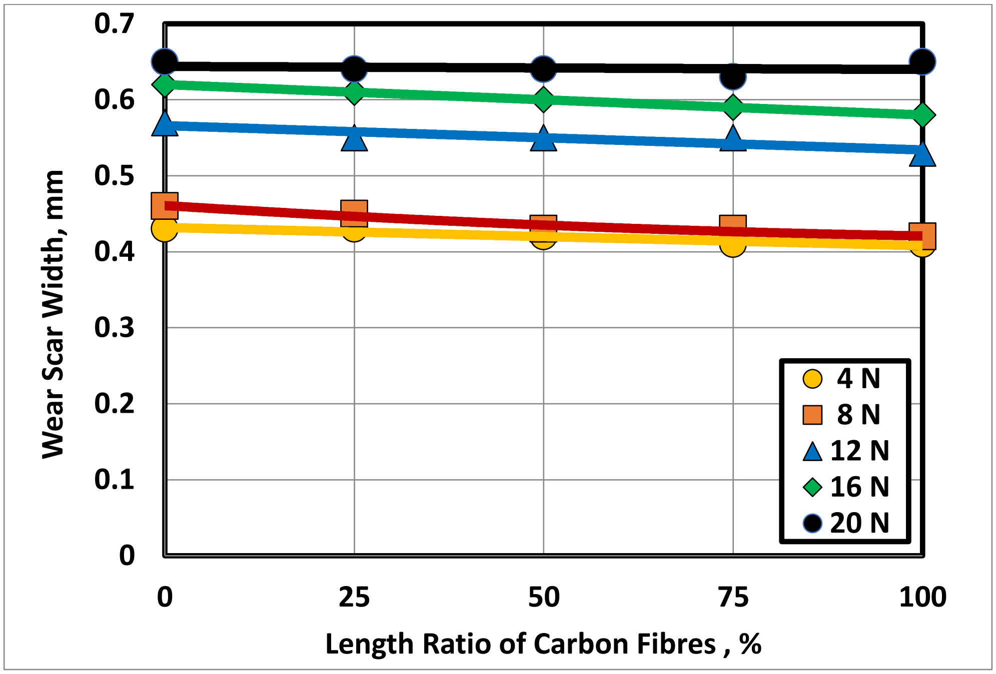

Fig. 19 Wear of the scratched composites reinforced by 1.5 wt. % CF versus length ratio.

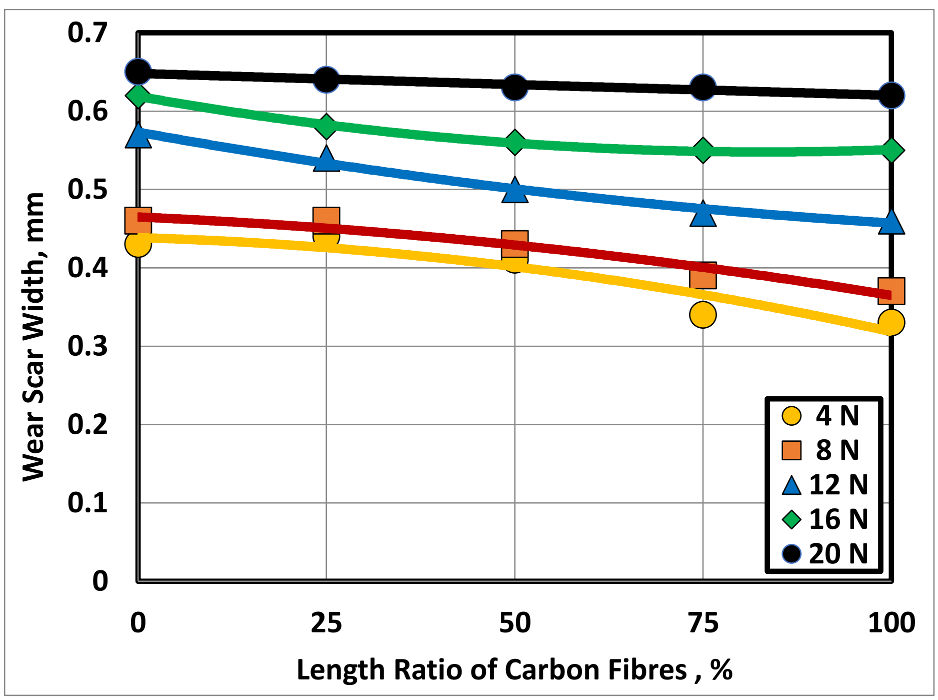

Fig. 20 Wear of the scratched composites reinforced by 4.5 wt. % CF versus length ratio.

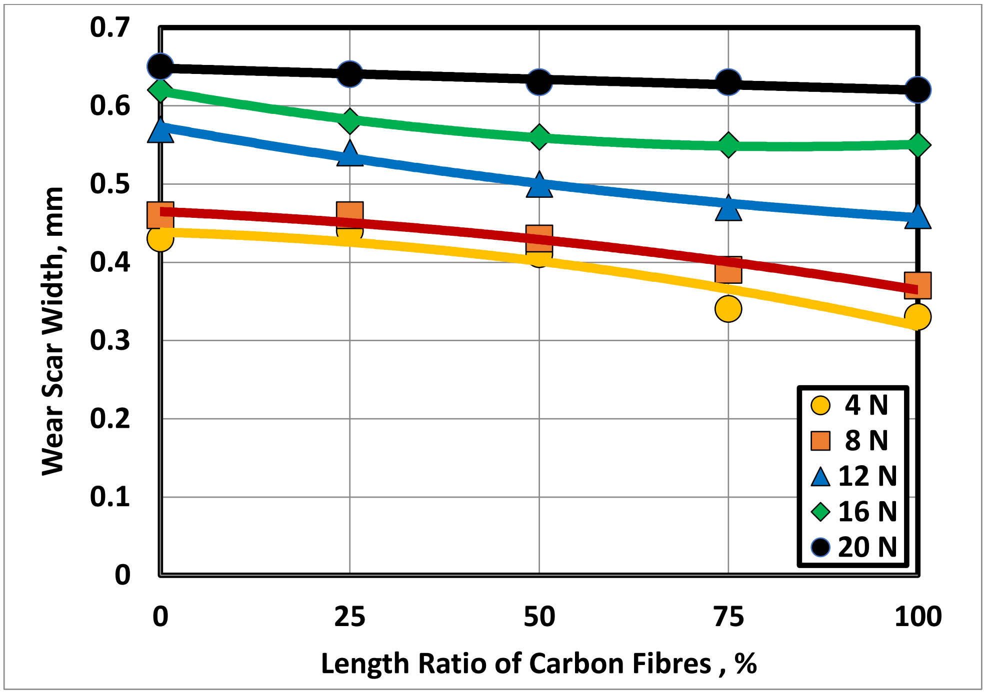

Fig. 21 Wear of the scratched composites reinforced by 7.5 wt. % CF versus length ratio.

The results of the scratch tests are illustrated in Figs. 14 – 21. Friction coefficient of the tested composites decreased with increasing CF content, while it increased as the load increased. CF are significantly harder than epoxy matrix, where they detached from epoxy and acted as hard rollers and consequently decreased friction. The friction increase with increasing load can be explained on the fact that the depth of the wear scar increases and hence the friction area between the indenter and the scratched surface increases. Unreinforced epoxy shows the highest friction coefficient, where continuous fibres displayed lower friction than short fibres, Figs. 14 – 17. CF composites show consistent values of friction coefficient accompanied by slight increase in friction as the fibres content increases. It is obvious that the high fibre stiffness, combined with the good adhesion between fibres and epoxy matrix, developed the friction of the tested composites.

Effect of CF content on wear of the scratched tested composites is shown in Fig. 18, where wear drastically decreased with increasing carbon content. It is clearly shown that CF displayed relatively lower wear scar width compared to unreinforced epoxy composites due to the strength improvement of CF. Two reasons can be the explanation of the observed tribological behavior; the first is the enhancement in the mechanical properties which impede the removal of material from the scratched surface. The second, as the load increases, wear increases due to the increase of the depth of cut of the indenter so that the volume of the removed material increases. Wear of the scratched composites reinforced by 1.5, 4.5 and 7.5 wt. % CF versus length ratio is shown in Figs. 19 – 21, where unreinforced epoxy exhibited the highest wear. As the length ratio of CF

increases, wear slightly decreased. Continuous fibres displayed the lowest wear values. This observation reveals that the high fibre stiffness combined with the good adhesion between fibres and epoxy matrix may develop the friction and wear of the tested composites.

CONCLUSIONS

1. As the CF content increase, hardness of the tested composites proportionally increases due to the extra strength provided by CF.
2. For adhesion tests, friction coefficient of the tested composites slightly decreased with increasing CF content. As the load increased friction coefficient decreased.
3. 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. Increasing applied load caused significant friction decrease due to the heating effect that decreases the shear strength of epoxy matrix.
4. Wear drastically decreased with increasing CF content, while increased with increasing applied load. The enhancement in wear resistance is attributed to the extra strength provided by carbon fibres that improve mechanical properties. CF are able to reduce wear of epoxy due to their high load carrying capacity. Continuous CF displayed the lowest wear values.
5. Friction coefficient of the scratched tested composites decreased with increasing CF content, while it increased as the load increased. Unreinforced epoxy shows the highest friction coefficient, where continuous fibres displayed lower friction than short fibres. Composites show consistent values of friction coefficient accompanied by slight increase in friction as the fibres content increases.
6. Wear drastically decreased with increasing carbon content. It is clearly shown that CF displayed relatively lower wear scar width compared to unreinforced epoxy composites due to the strength improvement of CF. Unreinforced epoxy exhibited the highest wear. As the length ratio of CF increases, wear slightly decreased. Continuous fibres displayed the lowest wear values.

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