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FRICTION AND WEAR OF RUBBER FILLED EPOXY COMPOSITES

Dina N., El-Sharkawy M., Rabie M. and Youssef M. M.

Automotive and Tractors Department, Faculty of Engineering, Minia University, P. N. 61111, El-Minia, EGYPT.

ABSTRACT
Friction and wear of epoxy based composites filled by different contents of rubber is experimentally investigated in the present work. Styrene butadiene rubber in form in granulates is added as friction modifier into epoxy matrix of the composites. Besides, copper particles and silica nanoparticles are used as constituents of the proposed composites.

The experimental results showed that friction coefficient displayed by epoxy composites filled by rubber, copper and sand showed the highest values among the tested composites due to the presence of sand. The increase in friction may be due to the ability of sand particles to remove the burnt bonding material and rubber from the friction surface, so that the influence of the carbon film covered the surface of the contact area causing reduction in friction coefficient would diminished. Besides, it seems that sand particles was responsible for the reduction of the fade. Wear values were the lowest among the tested composites. It seems that sand particles were responsible for preventing the worn material from the tested composites to be adhered to the counterface, providing rolling elements separating the two sliding surrfaces and protecting them from excessive wear.

KEYWORDS
Friction, wear, epoxy composites, styrene butadiene rubber granulates, copper particles and sand nanoparticles.

INTRODUCTION
Friction materials have been formulated for about 100 years, [1], where asbestos fiber was chosen as a friction material for use in all kinds of vehicles. Nowadays however non-asbestos (NAO) formula becomes main stream to overcome the negative effect of asbestos on human respiratory system. A typical brake lining formula includes phenolic resin mixed with metal powder, inorganic fillers and fibers. The use of phenolic resin compound with rubber prevails over the rare use of pure phenolic resin. The most commonly used rubbers in friction materials are SBR and NBR. Rubbers can be applied in two forms, i.e. rubber block and rubber powder. Generally speaking, application of rubber block in friction material production is complicated and less efficient, while application of rubber powder is much simpler. Properties of rubber component can be better retained, and will have direct influence on the properties of cured phenolic resin binder and hence the properties of final products. While the industry has put substantial

investment in new friction materials to improve the performance of brake pads, researches on the optimization of commercial disc brake pads for better performance are also reported, [2]. Powdered rubber product with nano-scale particle size was introduced for the first time in friction material application, [3 - 8]. Since its industrialization, the novel rubber product has been already successfully applied to areas such as thermoplastics and thermosets toughening, thermoplastic preparation.

Styrene butadiene nano powdered rubber and nitrile-butadiene nano powdered rubber were used for manufacturing clutch facings, disc brake pads and brake linings to replace conventional styrene butadiene rubber and nitrile-butadiene rubber, [9]. The results of constant speed friction test and dynamometer test showed that nano powdered rubber can substantially improve properties of friction materials. The friction coefficient of friction materials modified with nano powdered rubber varies steadily with the change of temperature, and the wearing rate of friction materials is relatively low by using nano powdered rubber. These results indicate that nano powdered rubber has ideal application effect in various friction materials and is a kind of novel rubber modifier for friction materials.

Metallic, ceramic, glass, acrylic reinforced fibers are used for automotive brake friction materials, [10 - 14]. Usually, commercial friction materials contain 5 - 25 vol. % of fibrous ingredients and the types and the relative amounts of the fibers affect many characteristics of brake accomplishment and wear life. In the middle of many investigations about the role of reinforcing fibers on tribological characteristics, aramid pulp, in particular, has drawn much attention since the aramid pulp shows good filler retention and presents well as a processing aid supplying sufficient strength.

The possibility of replacing the asbestos based friction materials by proposed friction materials free of asbestos to eliminate the health hazards caused by asbestos fibers which may cause asbestosis, mesothelioma, and lung cancer was discussed, [15]. The performance of the proposed friction materials consisting of fibrous reinforced organic and natural fibres such as date palm leaves, banana, coconut and sugar cane was investigated. Besides, the proposed composites contain barium sulphate, oxide, copper, iron, sand and phenolic resin. The friction and wear of the proposed composites have been investigated at different values of applied loads. The experiments revealed that friction coefficient displayed by composites filled by rubber nanoparticles and reinforced by palm fibres (PF) displayed the highest values of friction coefficient. Minimum wear values were observed for composites reinforced by PF. The lowest wear was exhibited by composites reinforced by 40 wt. % PF.

It was observed that, nanopowdered rubber can substantially improve properties of friction materials, [16], where the friction coefficient varied steadily with the change of temperature, and the wearing rate of friction materials was relatively low by using nanopowdered rubber. Friction composites were reinforced by agricultural fibres of corn, palm, and sugar bars, [17]. It was found that, addition of agriculture fibres increased friction coefficient and decreased wear. Friction coefficient slightly increased, while wear drastically decreased with increasing fibres content.

Natural fibres are used as reinforcement in friction composites to replace asbestos due to the health hazards caused by asbestos fibres which may cause asbestosis, mesothelioma, and lung cancer. Natural fibres such as corn, palm and sugar bars gave relatively high

friction coefficient suitable for friction materials. It is necessary to investigate the variation of friction coefficient with temperature. The fade of composites reinforced by corn, palm and sugar bar fibres was discussed, [18 - 19]. Experiments were carried out to determine friction coefficient and temperature rise for the tested composites. The results of the tested composites were compared to that observed from three types of conventional friction brake linings. The experimental results show that composites containing 25 % palm fibres and 10 % iron powder gave the minimum fade among the conventional brake linings, while friction composites containing sugar bare fibres displayed the highest fade. Besides, addition of aluminium and copper into the matrix of the composites displayed relatively lower fade value due to their high thermal conductivity.

Friction behavior is a critical factor in brake system design and performance. For up-front design and system modeling it is desirable to describe the frictional behavior of a brake lining as a function of the local conditions such as contact pressure, temperature, and sliding speed, [20 - 23]. Friction coefficient depends on applied load and metallic content in the tested composites.

Styrene butadiene nano powdered rubber and nitrile-butadiene nano powdered rubber were used for manufacturing clutch facings, disc brake pads and brake linings to replace conventional styrene butadiene rubber and nitrile-butadiene rubber, [24 - 27]. The results showed that nano powdered rubber can substantially improve properties of friction materials. The friction coefficient of friction materials modified with nanopowdered rubber varies steadily with the change of temperature, and the wearing rate of friction materials is relatively low by using nano powdered rubber.

Recently, brake friction materials comprising of varying proportions of lapinus and wollastonite fibres are investigated for their tribological properties, [28]. Tribological performance evaluation in terms of performance coefficient of friction, friction–fade, friction–recovery, disc temperature rise and wear is carried out. The increase in wollastonite fibre led to an increase in density and hardness whereas void content, heat swelling, water absorption and compressibility increased with the increased in lapinus fibre. The performance coefficient of friction, friction–fade behaviour and friction stability have been observed to be highly dependent on the fibre combination ratio i.e. coefficient of friction, fade and friction–stability follow a consistent decrease with a decrease in the lapinus fibre content.

Usually, a typical friction material formulation contains many ingredients (sometimes more than 10). The ingredients used can be mainly classified into four prime classes as fibres, space filler, friction modifiers (abrasives, lubricant) and binder. The role of fibres, space filler, friction modifier and binder in the friction material has been extensively studied for improving the tribological performance and new ingredients are still being developed to attain higher triboperformance, [29 – 35]. Among the many ingredients currently available for friction materials, the fibrous reinforcement: such as organic fibre, inorganic fibre, ceramic fibre, metallic fibre and their combinations have been found to play a crucial role as they reinforce the composites during fabrication and also help in the formation of topographical features which enhance the tribo performance. The role of Kevlar fibre has been well reported to aid wear minimizationand friction stabilization. Lapinus fibres inherently comprising metallic-silicates, when combined synergistically with other fibres that improved the tribo-

performance and suppress the unwanted phenomenon like noise, vibration, judder over wide range of driving conditions. Wollastonite fibres having high thermal resilience and inherent hardness have been found to stabilize the coefficient of friction and maximize recovery performance.

In the present work, the tribological performance of epoxy filled by rubber granulates, copper particles and silica nanoparticles is experimentally investigated.

EXPERIMENTAL

Experiments were carried out using pin-on-disc wear tester, Fig. 1. It consists of a rotary horizontal steel disc driven by variable speed motor. The test specimen is held in the specimen holder that fastened to the loading lever. Through two thin spring steel sheets, where strain gauges are adhered, friction force can be measured. Friction coefficient was determined through the friction force measured by the deflection of the spring steel sheets by strain gauges. The load is applied by weights. The test specimens are epoxy based composites. Test specimens were prepared in the form of a cylindrical pin of 6 mm diameter and 30 mm length. Three types of composites are proposed. The first composites contained rubber granulates of 100 - 300 µm particle size in 20, 33, 43, 50, 56 wt. % content, while the second contained 20, 33, 43, 50, 56 wt. % rubber and 22 wt. % copper particles of 30 – 50 µm size. The third contained 22 wt. % copper, 20, 33, 43, 50, 56 wt. % rubber and 0.5, 1.0, 1.5, 2.0 and 2.5 wt. % silica of 50 – 100 ηm particle size.

The friction tests have been carried out at different load values of 7, 9, 11, 13, 15 and 17 N representing stress values of 0.2, 0.25, 0.31, 0.36, 0.42 and 0.47 N/mm^2 respectively. The sliding velocity was 0.5 m/s for four minutes. The material loss of the test specimens during sliding was measured by weighing the specimen before and after test, using electronic balance of ±1 mg accuracy. The test specimens were loaded against counterface of grey cast iron disc (3.60 % C, 2.30 % Si, 0.50 % Mn, 0.12 % S, 0.75 % P), of 150 mm outer diameter, fastened to the rotating disc. Before the test, the friction surfaces of the test specimens and the cast iron discs were ground by 320 grid sand paper.

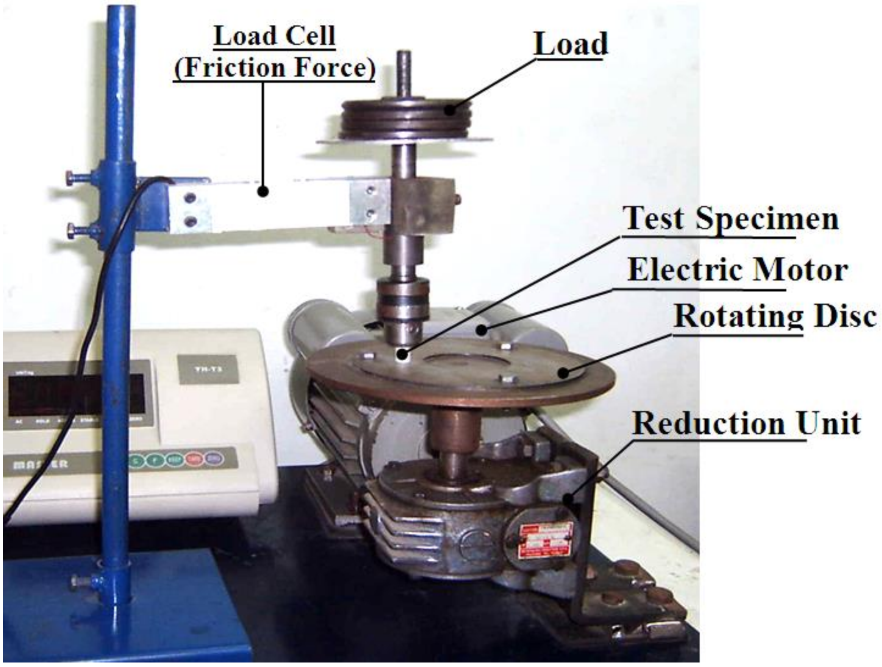

Fig. 1 Test rig used in measuring friction and wear.

RESULTS AND DISCUSSION

The variation of friction coefficient of epoxy composites filled by rubber particles with time is shown in Figs. 2 and 3. Friction coefficient increased with increasing applied load. The variation of friction coefficient with time was relatively high due to the presence of rubber in the matrix of the tested composites. The values of friction coefficient are ranged between 0.22 and 0.58, Fig. 2. The lower friction value is not recommended for applications. It is known that the critical factor of performance of friction materials is their stablity to give adequate kinetic friction coefficient and minimize their sensitivity to the brake operating parameters in order to produce low fade and high recovery characteristics. It should be no significant deterioration in the function of the binder nor the other constituents of the composites when the brake is operated under diverse conditions. However, when excessive frictional heat is generated, changes in the resin and the fillers can deteriorate performance. The friction decrease during brake application is called fade, and resistance to fade at high temperatures is a critical requirement for commercial friction materials. The friction coefficient depends on the temperature rise since adhesion and deformation resistance of the materials change as a function of temperature. Maximum temperature rise was measured at the end of the sliding time. The relatively high reduction in friction coefficient (fade) may be attributed to the high ratio of rubber. At high temperature epoxy will be burned and a layer of carbon will be formed on the contact surface causing reduction in friction coefficient. This means that friction coefficient can drop and loose its value during performance.

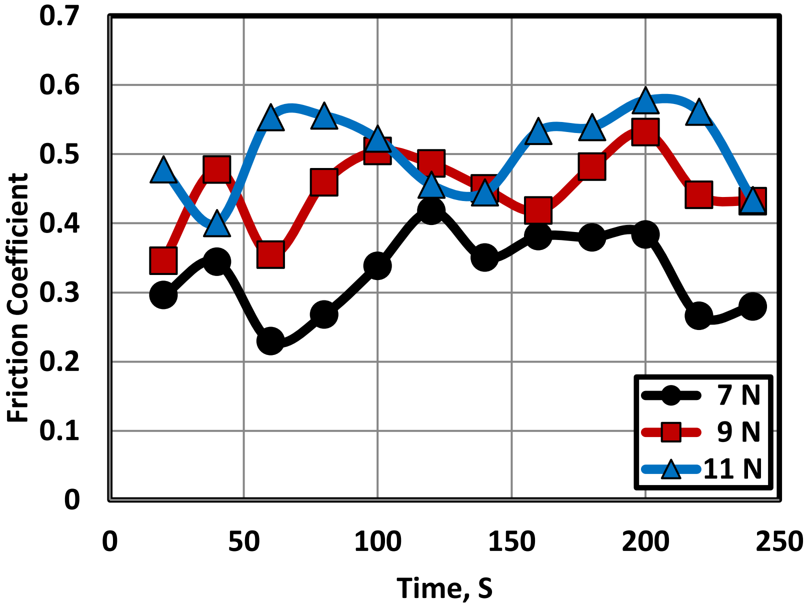

Fig. 2 Friction coefficient displayed by epoxy composites filled by rubber.

At relatively higher values of load, the fade decreased, Fig. 3, while the values of friction coefficient increased, where the maximum value reached 0.69 and lower value was 0.43. It seems that at higher load, the transferred epoxy layer was removed and rubber interacted the counterface effectively. In this condition, friction values were suitable for engineering application.

Friction coefficient displayed by epoxy composites filled by rubber slightly increased with increasing rubber content and applied load, Fig. 4. The highest friction values were 0.58 at 56 wt. % rubber content. It seems that presence of rubber in the contact surface is responsible for the relatively high values. As the load increased friction slightly increased, where the highest values were displayed by the highest load, Fig. 5. Composites containing 56 wt. % rubber still have the highest friction values. Friction coefficient showed a value of 0.65 for composites free of rubber at 17 N load.

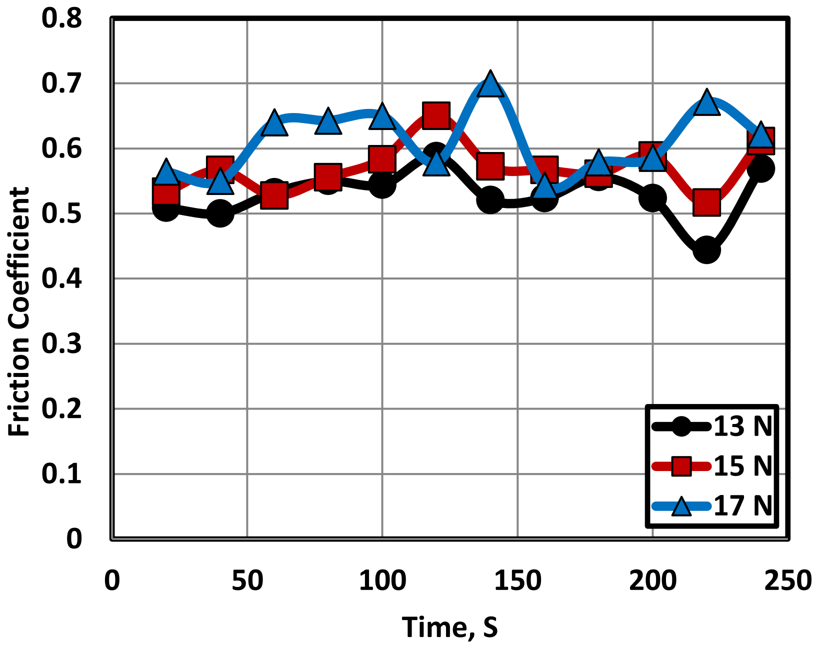

Fig. 3 Friction coefficient displayed by epoxy composites filled by 56 wt. % rubber.

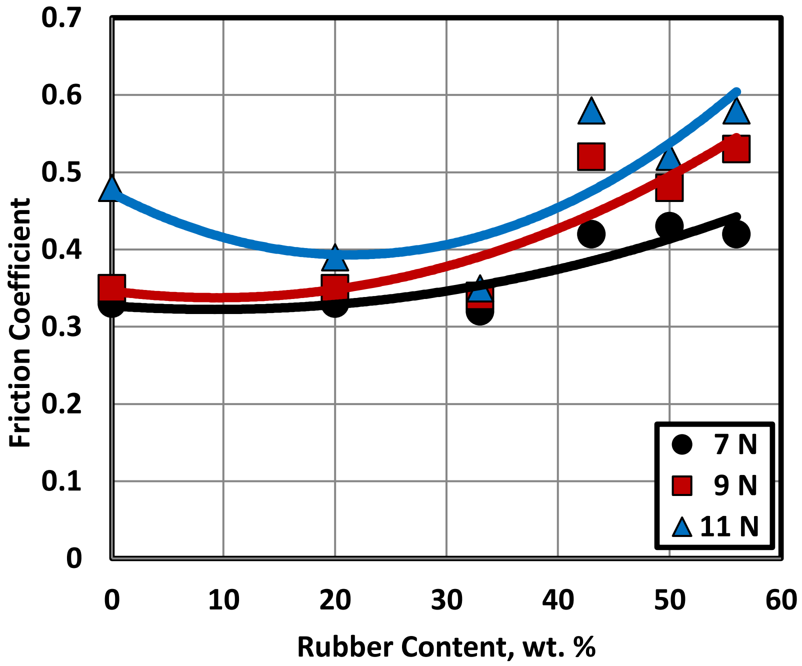

Fig. 4 Friction coefficient displayed by epoxy composites filled by rubber.

Wear of test specimens was much influenced by the rubber, where it remarkably increased with increasing rubber content, Fig. 6. The mechanism of wear could be explained on the basis that as the rubber content increased, epoxy as binding material could not withstand the shear process during friction so that rubber can be easily removed from the sliding surface. Besides, the epoxy layer was removed by rubber. Kowing that epoxy layer is responsible for preventing rubber from the tested composites to be adhered on the counterface and provide a relatively low shear strength film separating the tested composites and the counterface. In addition to that, wear significantly increased with increasing applied load, Fig. 7, where the recorded values were 23 and 27 mg at 11 and 17 N respectively.

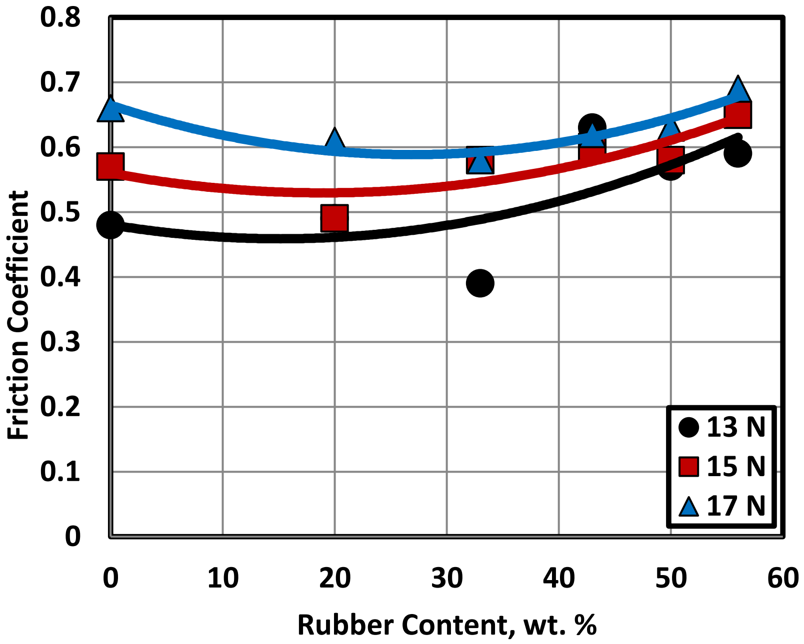

Fig. 5 Friction coefficient displayed by epoxy composites filled by rubber.

The second type of the tested composites is filled by 22 wt. % copper and 20, 33, 43, 50, 56 wt. % rubber. These composites showed friction coefficient reduction (fade) higher than that displayed by composites containing rubber, Figs. 8 and 9. The low reduction in friction may be due to the relatively high thermal conductivity of copper as well as the formation of copper oxides at the friction interface, which was responsible of the high fluctuation of friction coefficient. Friction coefficient decreased from 0.5 to 0.3 at 11 N load. The high fade may be attributed to the burning of the bonding material, so that a layer of carbon as well copper oxide covered the contact area causing reduction in friction.

Composites filled by copper particles showed the lowest friction values, Figs. 10 and 11. The decrease of friction may be attributed to the ability of copper particles to abrade the materials transferred from the test specimens into the counterface. The constituents of the transferred material are rubber, epoxy and copper. Friction coefficient showed a value of 0.34, 0.35 and 0.48 for composites free of rubber at 7, 9 and 11 N load respectively, Fig. 10. This behaviour was discussed on the basis of lubrication of metallic film, where the worn copper particles are pressed between the composites and the

couneterface forming copper film. The relative sliding is facilitated by the shear of the copper film and the sliding resistance cannot exceed the shear strength of the copper causing significant reduction in friction coefficient. Friction coefficient showed slight decrease with increasing rubber content. The highest value of friction coefficient was 0.5 displayed by composites containing 56 wt. % rubber content.

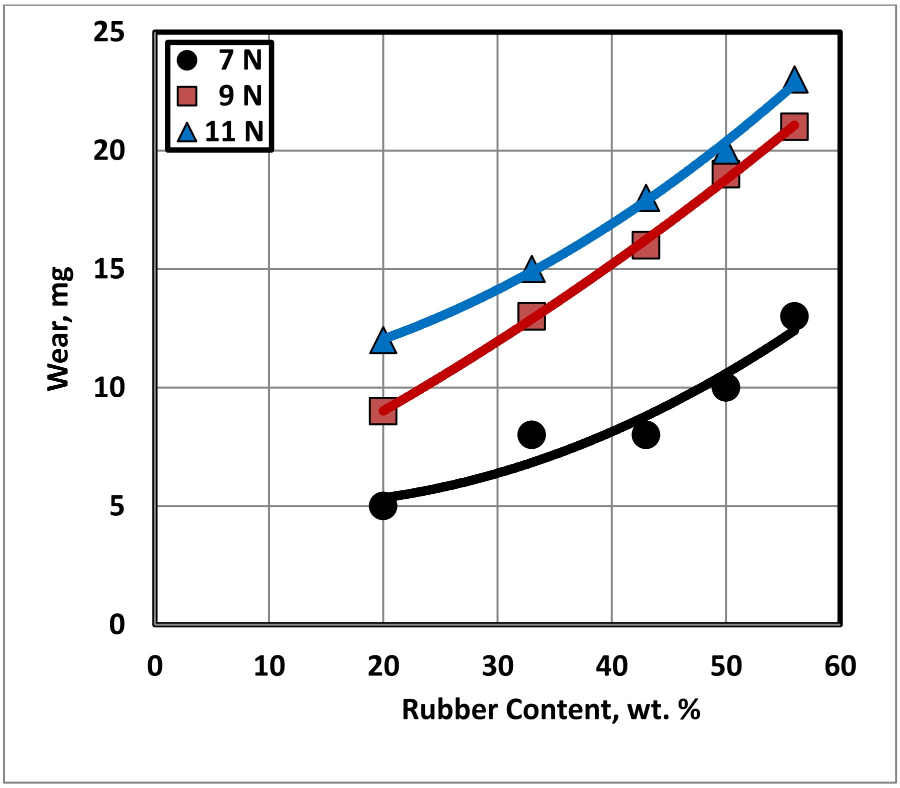

Fig. 6 Wear displayed by epoxy composites filled by rubber.

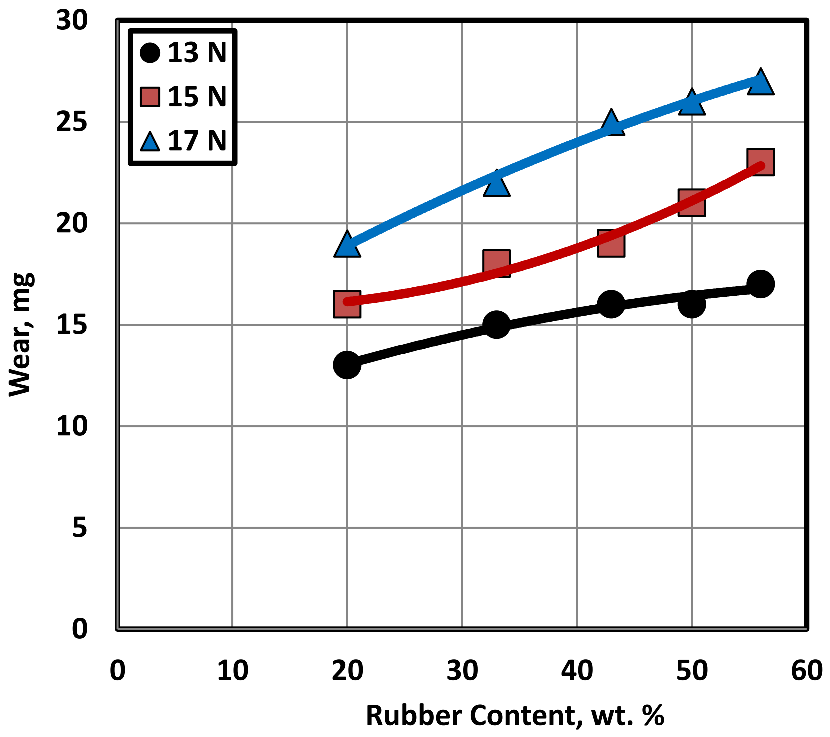

Fig. 7 Wear displayed by epoxy composites filled by rubber.

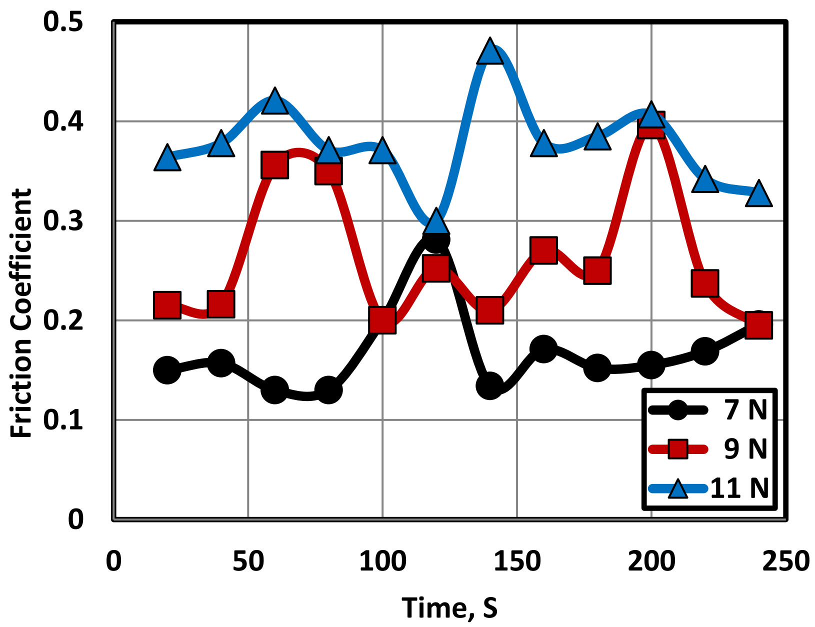

Fig. 8 Friction coefficient displayed by epoxy composites filled by rubber and copper.

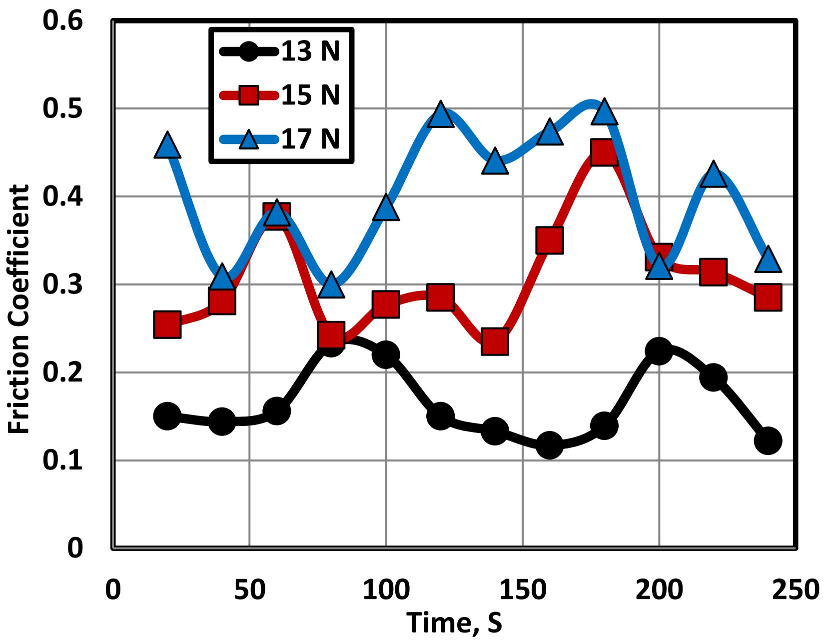

Fig. 9 Friction coefficient displayed by epoxy composites filled by rubber and copper.

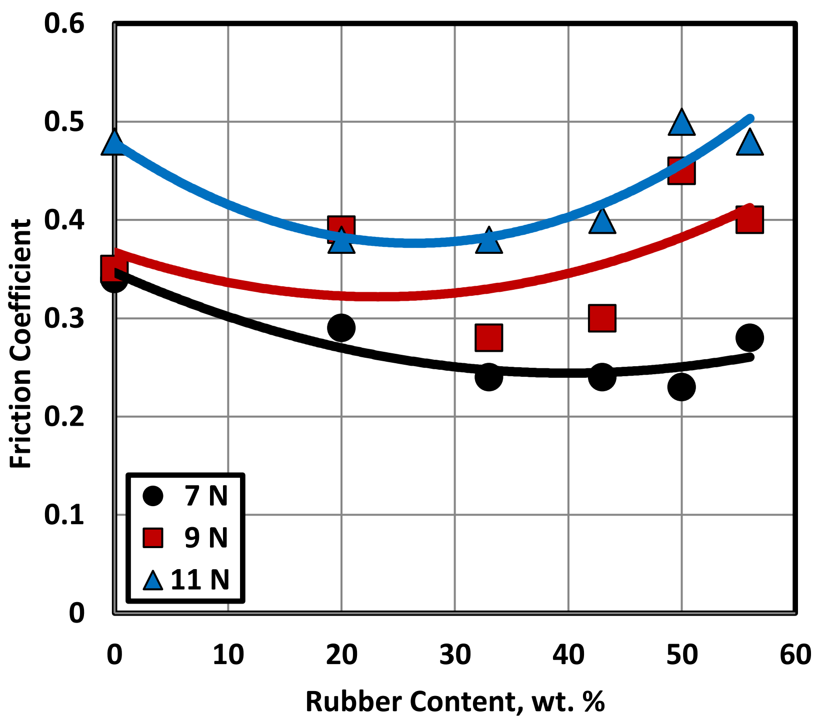

Fig. 10 Friction coefficient displayed by epoxy composites filled by rubber and copper.

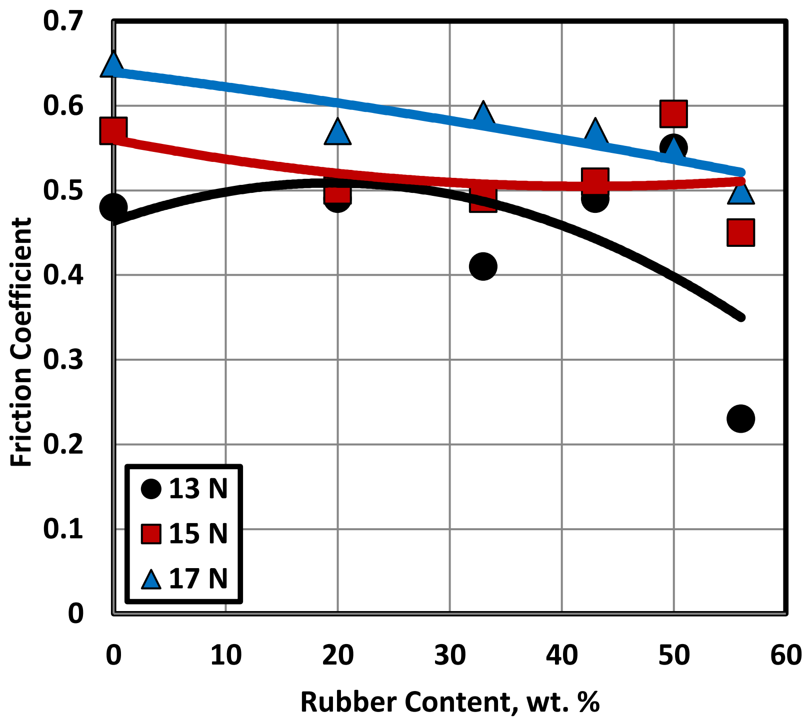

Fig. 11 Friction coefficient displayed by epoxy composites filled by rubber and copper.

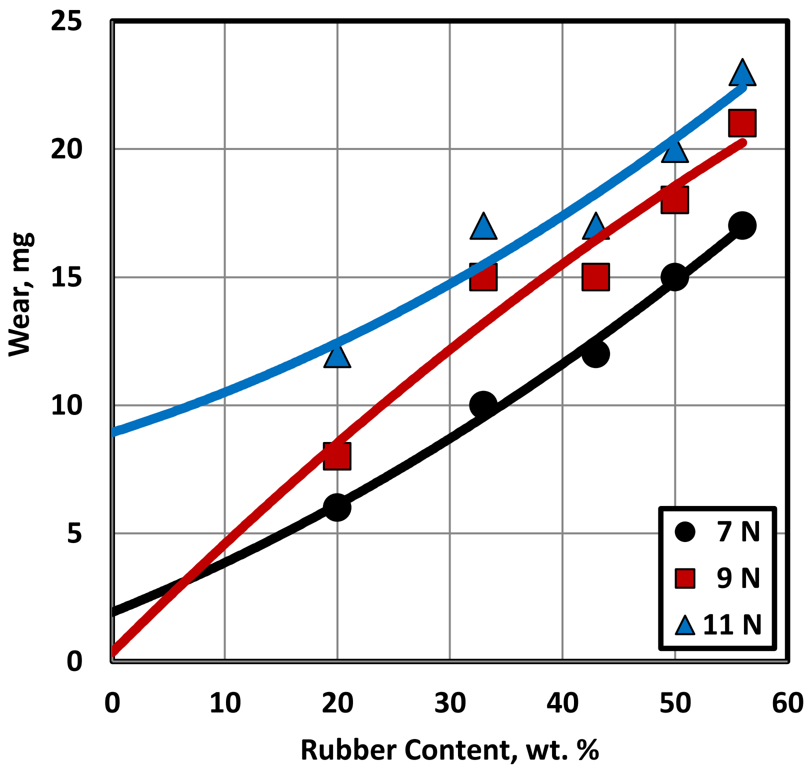

Fig. 12 Wear displayed by epoxy composites filled by rubber and copper.

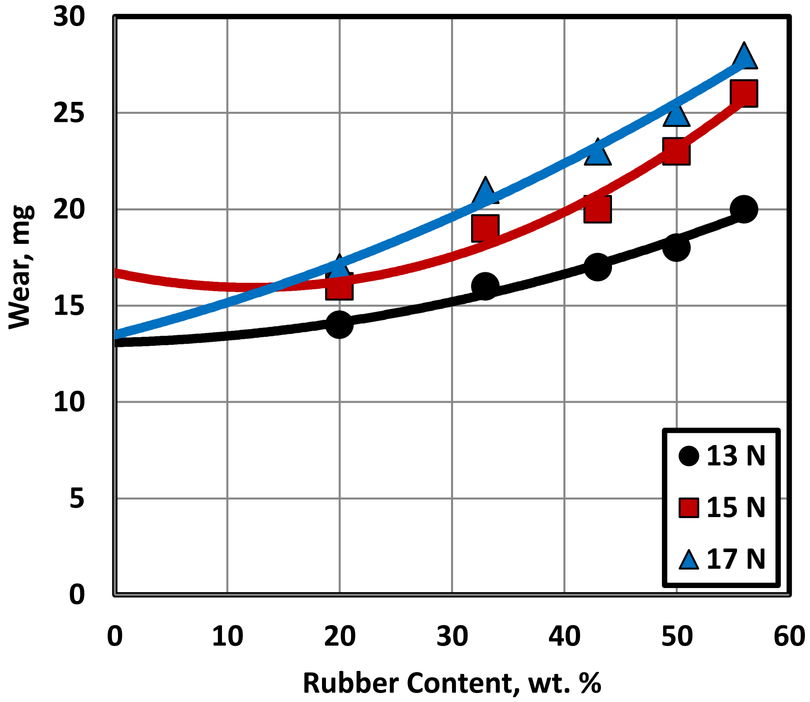

Fig. 13 Wear displayed by epoxy composites filled by rubber and copper.

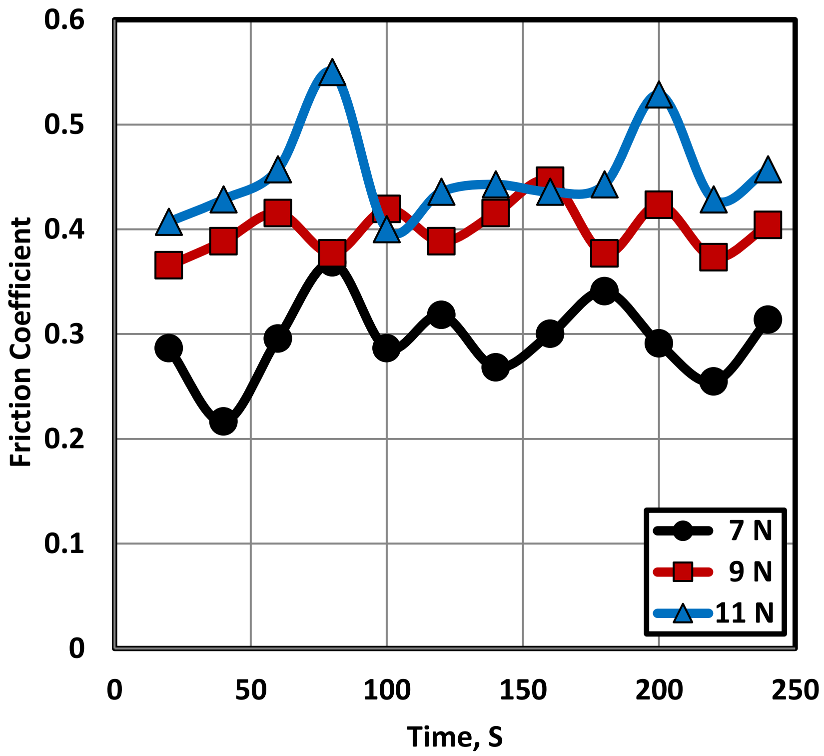

Fig. 14 Friction coefficient of epoxy composites filled by 22 wt. % copper, 56 wt. % rubber and 2.0 wt. sand.

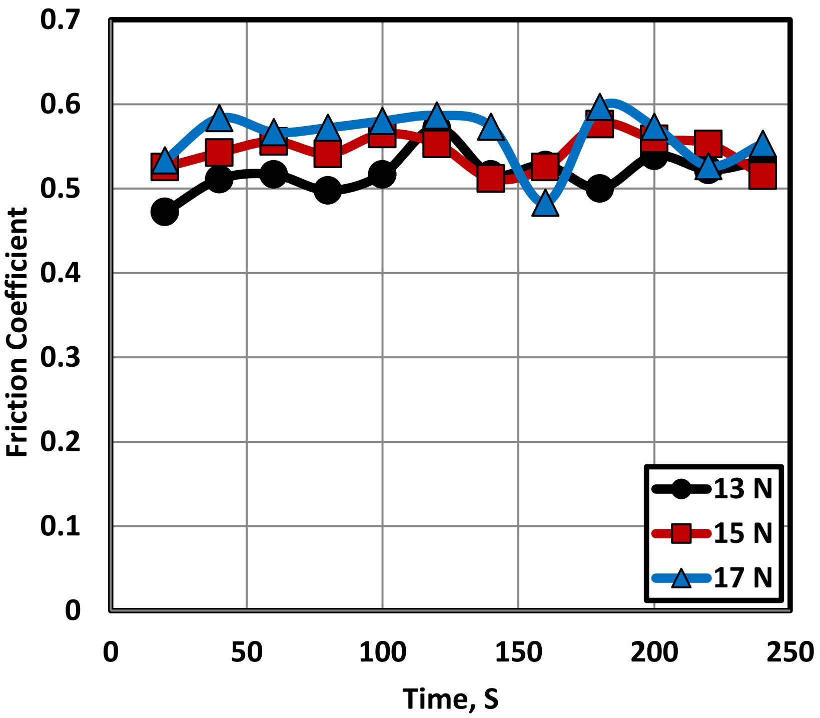

Fig. 15 Friction coefficient of epoxy composites filled by 22 wt. % copper, 56 wt. % rubber, 2 wt. % sand.

Wear displayed by epoxy composites filled by rubber and copper is shown in Figs. 12, 13. Wear was influenced by the copper, where it significantly increased. Wear increased as the rubber content increased due to the wear resistance of rubber.

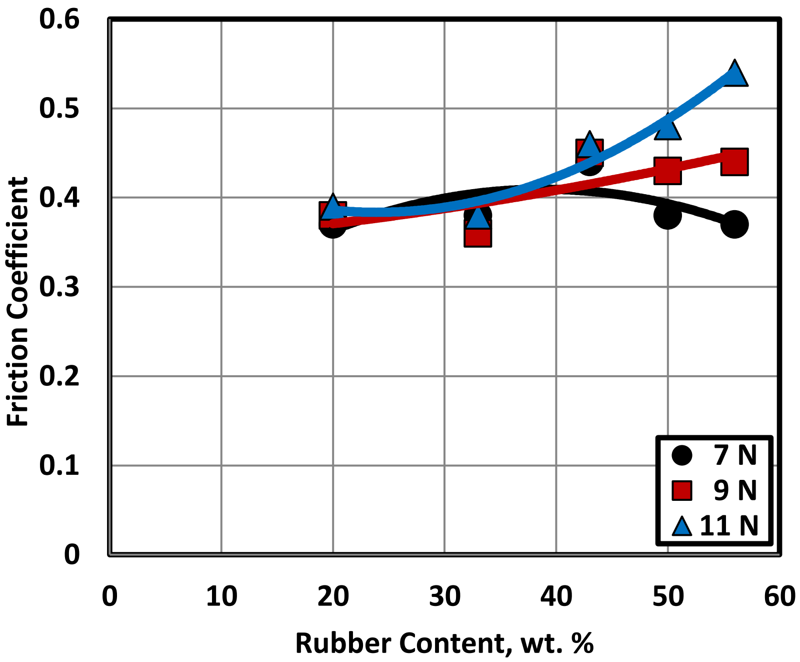

Fig. 16 Friction coefficient displayed by epoxy composites filled by rubber, copper and sand.

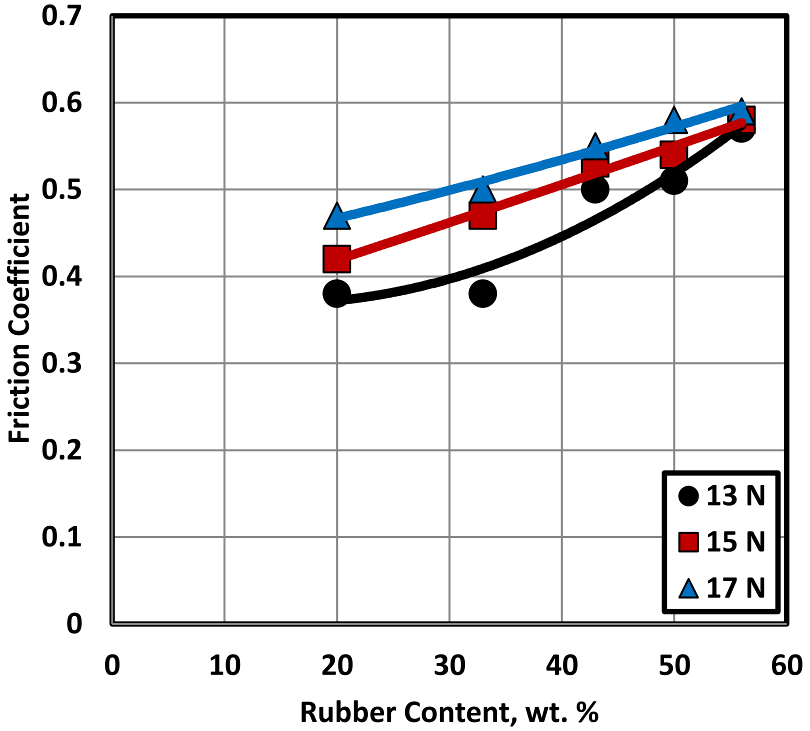

Fig. 17 Friction coefficient displayed by epoxy composites filled by rubber, copper and sand.

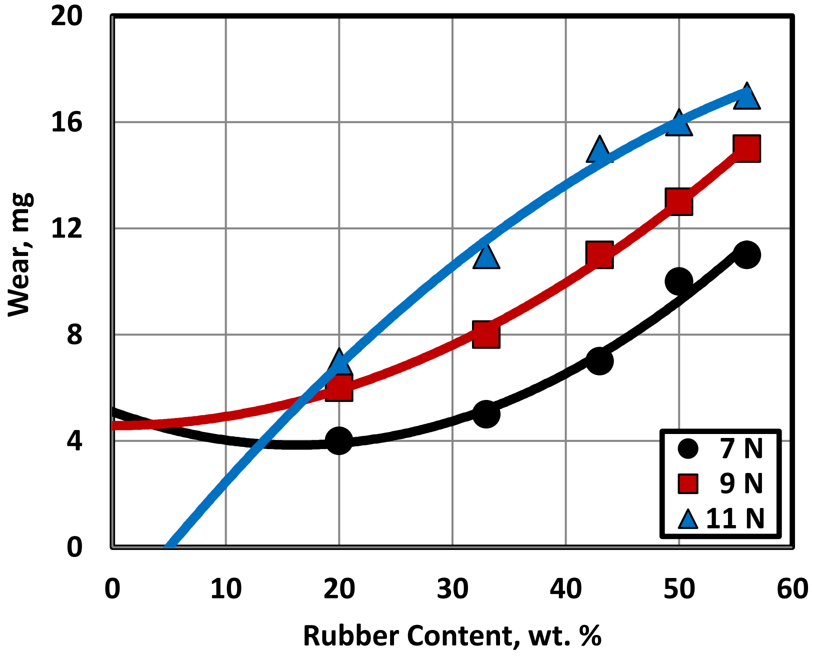

Fig. 18 Wear displayed by epoxy composites filled by rubber, copper and sand.

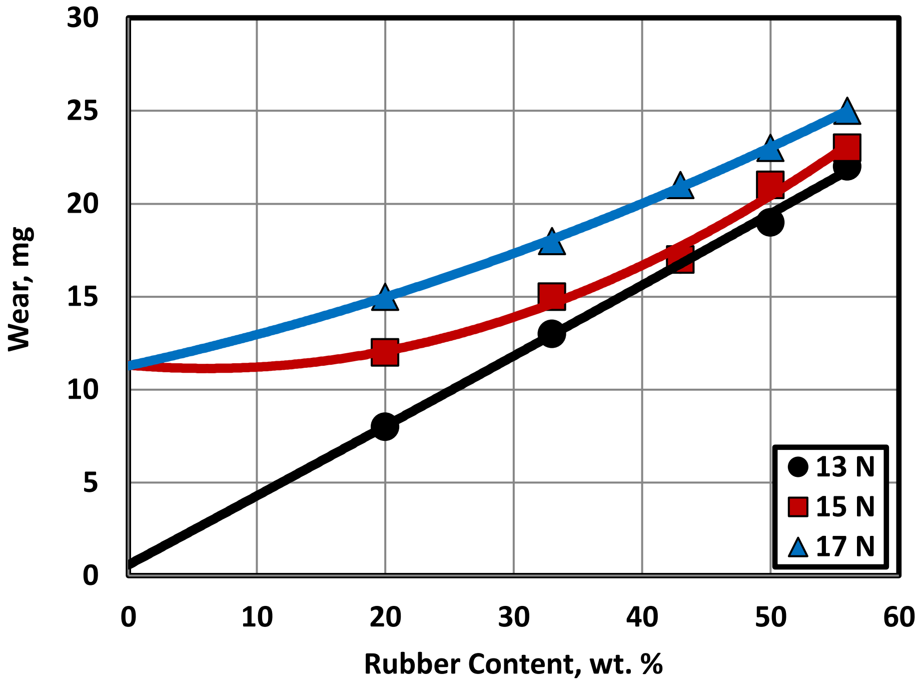

Fig. 19 Wear displayed by epoxy composites filled by rubber, copper and sand.

The third tested composites are filled by 22 wt. % copper, 20, 33, 43, 50, 56 wt. % rubber and 2.0 wt. sand. Friction coefficient of composites containing 22 wt. % copper, 56 wt. % rubber granulates and 2.0 wt. % sand showed relatively high fade at 7, 9 and 13 N load. This behavior may be from the carbon film formed on the contact area, causing reduction in friction, Figs. 14 and 15. Friction coefficient decreased from 0.55 to 0.4 at 11 N load, Fig. 14. Those composites showed friction coefficient reduction (fade) at higher load (13 – 17 N) less than that displayed at lower load.

Friction coefficient displayed by epoxy composites filled by rubber, copper and sand increased with increasing rubber content, Figs. 16 and 17. Those composites displayed friction coefficient higher than that displayed for composites filled by copper and rubber due to the presence of sand. The increase in friction may be due to the ability of sand particles to remove the burnt epoxy and rubber from the friction surface, so that the influence of the carbon film covered the surface of the contact area causing reduction in friction coefficient would diminish. Besides, it seems that sand particles was responsible for the reduction of the fade.

Wear displayed by epoxy composites filled by rubber, copper and sand, Figs. 18 and 19, showed the lowest values among the tested composites. It seems that sand particles were responsible for the lowest wear. The mechanism of wear could be explained on the basis that sand particles were responsible for preventing the worn material removed from the tested composites to be adhered into the counterface, providing rolling elements separating the tested composites and the counterface and protecting the friction surfaces from excessive wear. Sand particles existed between the two friction surfaces acted as rolling elements, therefore they reduced wear to a much lower level. This model is a further application of the principle that in dry sliding there should be a "third body" presented between the sliding surfaces to minimize friction and wear.

CONCLUSIONS

1. Friction coefficient displayed by epoxy composites filled by rubber slightly increased with increasing rubber content and applied load. The variation of friction coefficient with time was relatively high due to the presence of rubber. At relatively higher values of load, the fade decreased. Wear of test specimens was much influenced by the rubber, where it remarkably increased with increasing rubber content and applied load.

2. Composites filled by copper and rubber showed friction coefficient reduction (fade) higher than that displayed by composites containing rubber. The relative reduction in friction may be due to formation of copper oxides at the friction interface, which was responsible of the high fluctuation of friction coefficient. Composites filled by copper particles showed the lowest friction values. Wear increased in the presence of copper. Besides, wear increased as the rubber content increased.

3. Composites containing copper, rubber and sand showed relatively high fade at lower loads, while fade decreased at higher loads. Those composites showed friction coefficient higher than that displayed for composites filled by copper and rubber due to the presence of sand. Besides, it seems that sand particles was responsible for the reduction of the fade. Wear values were the lowest among the tested composites.

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