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FRICTION AND TRIBOELECTRIFICATION OF EPOXY FLOORINGS FILLED BY ALUMINIUM OXIDE NANOPARTICLES

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ABSTRACT
In the present experiments, friction coefficient and electrostatic charge of epoxy composites filled by nanoparticles of aluminium oxide (Al_2O_3) sliding against rubber were investigated to develop proper materials to be used as flooring materials of high friction coefficient and low electrostatic charge.

The experimental results showed that, at dry sliding, Al_2O_3 nanoparticles addition into epoxy matrix decreased friction coefficient and voltage with increasing Al_2O_3 content. Voltage showed the maximum values for epoxy free of filling materials. At water wetted surfaces, slight decrease in friction coefficient was observed. Epoxy free of Al_2O_3 showed relatively lower voltage than that observed for dry sliding. As Al_2O_3 content increased voltage significantly increased. At detergent wetted surfaces, friction coefficient and voltage slightly increased with increasing Al_2O_3. In the presence of sand particles on the sliding surfaces, slight increase in friction coefficient was observed with increasing Al_2O_3. Values of friction coefficient indicated that sand particles action was dominating either by rolling between epoxy matrix and rubber surface or by embedment in the sliding surfaces. Voltage slightly increased with increasing Al_2O_3, where the voltage displayed relatively low values. At water contaminated by sand, friction coefficient and voltage increased with increasing Al_2O_3. For surface covered by detergent contaminated by sand, friction coefficient increased with increasing Al_2O_3, while voltage drastically decreased with increasing Al_2O_3. At oil lubricated surfaces, friction coefficient drastically decreased with increasing Al_2O_3 when sliding against rubber lubricated by oil. As the load increased, friction coefficient decreased. Voltage drastically decreased with increasing Al_2O_3. At oil/water emulsion, friction coefficient significantly increased while voltage decreased with increasing Al_2O_3. At oil contaminated by sand, friction coefficient significantly increased while voltage decreased with increasing Al_2O_3. At water/oil emulsion contaminated by sand, friction coefficient slightly increased, while voltage drastically decreased with increasing Al_2O_3.

KEYWORDS
Friction, triboelectrification, electric static charge, epoxy, floorings, aluminium oxides nanoparticles.

INTRODUCTION
Friction coefficient and electrostatic charge of epoxy composites filled by nanoparticles of aluminium oxide (Al_2O_3) sliding against rubber were investigated to develop proper

materials to be used as flooring materials of high friction coefficient and low electrostatic charge, [1]. It was observed that at dry, water and detergent wetted surfaces, Al_2O_3 nanoparticles addition into epoxy matrix decreased friction coefficient with increasing Al_2O_3 content. When sand particles were covering the sliding surfaces, no change was observed for friction coefficient with increasing Al_2O_3 content. At water contaminated by sand, detergent, oil, water/oil emulsion, oil contaminated by sand and water/oil emulsion contaminated by sand wetted surfaces, friction coefficient increased with increasing Al_2O_3. As for voltage as a measure of the electrostatic charge generated from friction, it was observed that at dry sliding, voltage decreased with increasing Al_2O_3 content.

Friction coefficient and wear of polyester composites reinforced by nanoparticles of Al, copper, iron and aluminium oxide, dry sliding against steel were investigated to develop new engineering materials with low friction coefficient and high wear resistance which can be used as bearing materials, [2, 3]. Experiments were carried out at dry and oil lubricated surfaces. Pin on disc tribometer was used to perform friction and wear experiments under the application of electric voltage. Experiments showed that, friction coefficient increased with increasing electric voltage for composites filled by Al, while at no voltage, friction coefficient decreased with increasing Al content. As the electric voltage increased wear decreased.

The field of nanotechnology is extending the applications of engineering and technology. The polymer based nanoparticles/nanocomposites are the fast growing field of research for developing the materials, [4]. There is an increasing demand to develop materials based on thermosetting polymers due to the relatively high thermal stability and environmental resistance as well as the good tribological performance. Thermosetting polymer composites are used as substrate, coating, and plastic bearings as well as in the automotive, railway and transport industries, [5]. The major drawback is their relatively poor wear resistance. While many thermoplastic materials show self lubricating behaviour, [6], while the lubricating properties of thermosetting polymers need to be modified by solid lubricants or by the addition of nanoparticles of selected materials in particular ZnO nanoparticles.

Silica nanoparticle filled polypropylene (PP) and PP blends were studied. Mechanical property improvement was the major, [7 - 9]. It is well known that the intrinsic properties of semi-crystalline polymer material, including the mechanical properties, are determined by the microstructure of the final products, which is in turn dependent on the thermal or mechanical history that the material experiences during processing. There exists a great interest in the development of new polymer-clay nanocomposites in the expectation of improved physicochemical and mechanical properties with respect to the pure polymers and conventional composites, with the use of a relatively low filler proportion, [10 - 12]. Polycarbonate is an amorphous engineering thermoplastic which combines good thermal stability, transparency, impact resistance and the ability to be processed on conventional machinery. Thus, the surface properties are important for many applications such as medical, optics, automobile, etc., since problems related to scratching or wear on the surface are of interest in the case of this thermoplastic. New polycarbonate nanocomposites are being developed in order to improve the thermal, mechanical, electrical or optical properties of the base polymer.

The effect, of silane treatment of Fe_3O_4 on the magnetic and wear properties of Fe_3O_4/epoxy nanocomposites, was investigated, [13]. The results showed that the specific wear rate of surface-modified Fe_3O_4/epoxy nanocomposites was lower than that of unmodified Fe_3O_4/epoxy nanocomposites. The decrease in wear rate and the increase in magnetic properties of surface-modified Fe_3O_4/epoxy nanocomposites occurred due to the improved dispersion of Fe_3O_4 into the epoxy matrix. Many authors became interested in magnetic nanopowder reinforced polymer composites because magnetic nanoparticles have shown great potential for applications, including aircraft, spacecraft, magnetic hard disks, and the magnetic bars of credit card. These applications can take advantage of both the magnetic properties and wear properties of these compositions, [14]. Among the composites, one can produce magnetic nanopowder reinforced polymer nanocomposites that exhibit magnetic properties and wear properties superior to those of other composites. On the microscale of filling materials reinforcing polyester composites, several research works were carried out, [15]. Friction coefficients and wear rates of polyester composites reinforced by graphite fibres with different diameters and impregnated by vegetable oils (corn, olives, and sunflower oil) were measured to develop new engineering materials with low friction coefficients and high wear resistance which can be used in industrial applications as bearing materials. Corn and sunflower oil display good tribological behavior of the polyester composites.

Several works were carried out to develop polyester composites to be used as self lubricated bearing material in different engineering applications. Polyethylene and glass fibres were used to reinforce polyester in order to increase wear resistance of the tested composites. Paraffin, glycerin, almond, olives, cress, sesame and baraka oils were added to polyester during molding to produce self lubricated composites, [16 - 18]. It was found that increasing oil content and polyethylene fibres decreased friction content. The highest friction and wear were displayed by composites free of oil. Composites containing olive oil displayed higher friction and lower wear than that containing almond oil. Impregnating polyester matrix by paraffin and glycerin oils caused significant reduction in friction coefficient and wear.

Friction of polymers is accompanied by electrification. During frictional interaction chemical and physichemical transformations in polymers promote increases in the surface and bulk states density. Electrification in friction is a common feature, it can be observed with any mode of friction, and with any combination of contacting surfaces, [19]. The potential difference generated by the friction of polymeric coatings against steel counterface has been measured. The effect of sliding velocity and load on the generation of electric charge on the friction surface has been investigated, [20]. The results indicated that, at dry sliding condition the potential generated from friction increases rapidly with increasing both of sliding velocity and load at certain values then decreases due to the rise of temperature which causes molecular motion and reorientation of the dipole groups in the friction direction and leads to the relaxation of space changes injected during friction.

The triboemission characteristics of both negatively and positively charged particles from various materials such as metals, ceramics and glass were studied, [21]. The results obtained during scratching the tested materials showed increasing emission intensity with increasing electrical resistance of the materials, [22]. Mechanisms of polarization and relaxation of dielectrics were used to provide explanation of the friction and wear behaviour of insulators. Unfilled and filled PA6 coatings by metal powders as well as

high density PE, PA6, polypropylene coatings, reinforced by copper wire, were tested. Increasing the concentration of metal powder can reduce the effect of the applied voltage on friction and wear. Reinforcing PA6 and polypropylene coatings by copper wires increased the wear resistance and reduced the friction, [23]. The application of an electric field, however, is considered to promote the breakdown of EHL film formed, [24]. The influence of applying electric field on the tribological behaviour of steel in a vertical magnetic field produced by an AC or DC electric current was investigated. The effect of a magnetic field on both oxidation and concentrations of dislocations on the surface is presented, [25]. Experiments showed that a magnetic field applied through the sliding contact decreased wear rate.

Voltage generated as a result of the friction caused by the sliding of the tested polymers against each other as well as steel surface was measured, [26]. The test results showed that friction coefficient displayed by the sliding in salt water represented maximum values due to the relatively high value of voltage generated as a result of friction. Triboelectrification of metallic and polymeric surfaces was investigated at dry and lubricated sliding conditions. The effect of sodium chloride (NaCl), gasoline, diesel fuel, and hydrochloric acid (HCl) as contaminants in the lubricant on voltage and friction was discussed, [27]. The test results showed that relatively high voltage generated due to sliding of metallic surfaces against each other in salt water and oil dispersed by ethylene glycol while sliding of PA6 against steel surface produced the highest values of voltage at oil lubricated condition. In the presence of NaCl in water, relatively high value of voltage due to friction was observed accompanied by high value of friction coefficient. It was found that a correlation between friction coefficient and voltage generated was found for polymers sliding against themselves and against steel in water and salt water lubricated conditions, [28]. Wear of the tested polymers decreased with increase of sand particle size down to minimum because of the sand embedment in the polymeric surface. Further increase in sand particle size increased wear due to the removal of sand from the polymeric surface.

The aim of the present work is to investigate the influence of the addition of Al_2O_3 nanoparticles to epoxy composites on the friction coefficient and electric static charge generated from friction. The proposed epoxy composites are aimed to be used as flooring materials.

EXPERIMENTAL

The test rig used in the present work, was designed and manufactured to measure the friction force displayed by the sliding of the tested epoxy composites filled with nanoparticles specimens against the rubber surface through measuring the friction force and applied normal force. The rubber surface in form of a sheet was placed in a base supported by two load cells to measure the horizontal force (friction force) and the vertical force (applied load). A digital screen was attached to the load cells to detect the friction and vertical forces. Friction coefficient was determined by the ratio between the friction force and the normal load. Voltage was measured after sliding of the tested composites against the rubber surface by the electrostatic field measuring device. The arrangement of the test rig is shown in Fig. 1.

The test specimens prepared from epoxy filled by Al_2O_3 nanoparticles are shown in Figs. 2 and 3. The specimens were poured in form of a cuboid of 50 × 50 mm and 6 mm

thickness adhered on a steel sheet fixed to wooden block. Al_2O_3 nanoparticles (100 nm) were added to epoxy composites in contents of 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 wt. %.

Measurements of friction coefficient as well as voltage generated from friction were carried out at different values of normal load. Test specimens were loaded against rubber counterface of 3 mm thickness which simulated the footwear surface. The load values were 20, 40, 60 and 80 N. The sliding surfaces were lubricated by water, sand, water contaminated by sand, water + 2.0 vol. % detergent, water + 2.0 vol. % detergent contaminated by sand, oil, oil contaminated by sand, water + 2.0 vol. % oil and water + 2.0 vol. % oil contaminated by sand. Sand particles of silicon oxide (SiO_2) of 0 – 999 µm size were used, while paraffin oil was used.

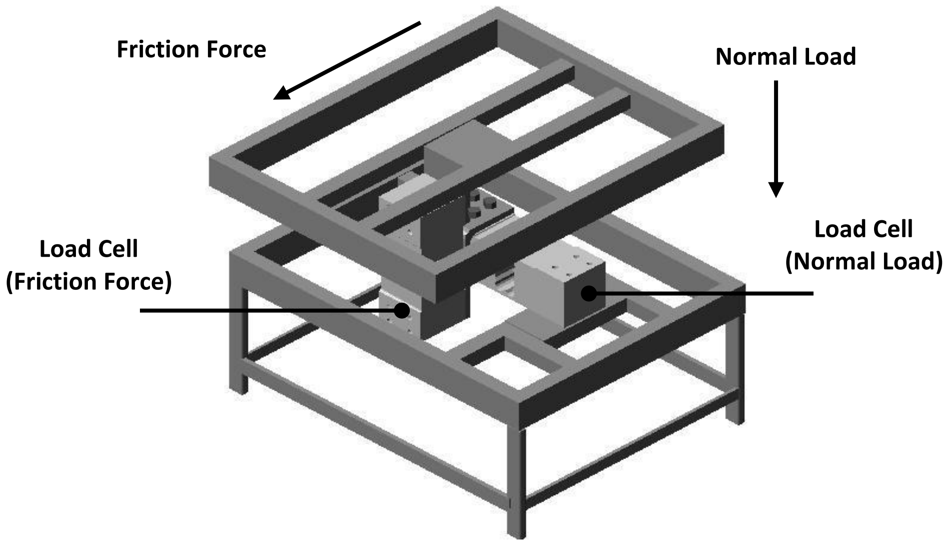

Fig. 1 Details of the test rig.

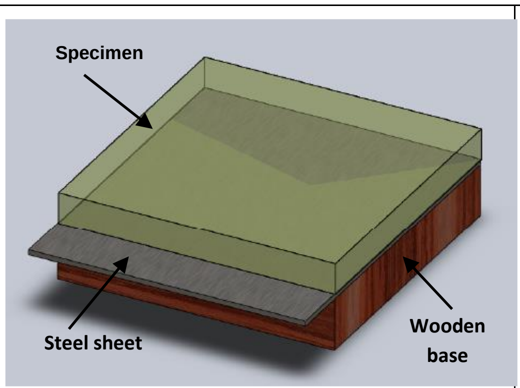

Fig. 2 Epoxy free of aluminium.

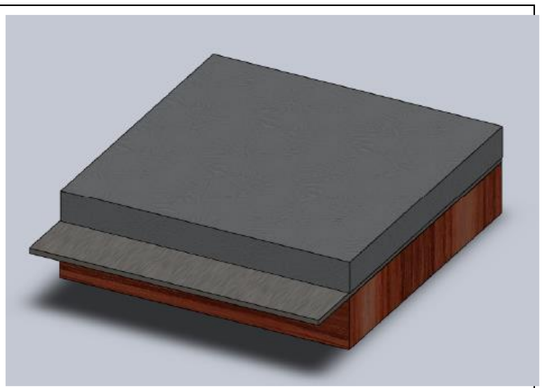

Fig. 3 Epoxy composites filled with aluminium nanoparticles.

Fig. 4 Electrostatic field measuring device.

The electrostatic fields (voltage) measuring device (Ultra Stable Surface DC Voltmeter) was used to measure the electrostatic charge (electrostatic field) for test specimens, Fig. 4. It measures down to 1/10 volt on a surface, and up to 20 000 volts (20 kV). Readings are normally done with the sensor 25 mm apart from the surface being tested.

RESULTS AND DISCUSSION

Friction of epoxy against rubber is accompanied by electrification. Based on that theory, one of the sliding surface gains positive electrostatic charge, while the other gains negative charge. As a result of that, an electrostatic force is generated and this force influences the applied normal load. The magnitude of the electrostatic force is proportional to the electrostatic charge which depends on the rank of the rubbing surfaces in the triboelectric series.

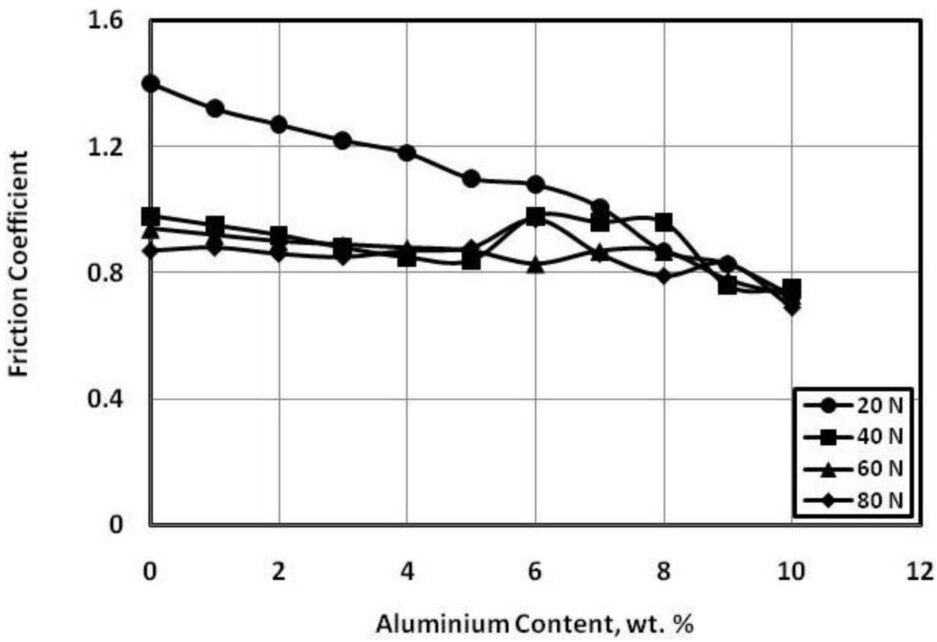

Fig. 5 Friction coefficient of dry sliding of epoxy composites against rubber.

The effect of filling epoxy by Al_2O_3 nanoparticles on friction coefficient is shown in Fig. 5. Friction coefficient showed slight decrease with increasing Al_2O_3 content. Epoxy free of Al_2O_3 displayed the highest friction coefficient. Friction coefficient decreased from 1.4 to 0.72 as Al_2O_3 increased to 10 wt. %. The presence of Al_2O_3 in the epoxy matrix decreased epoxy/rubber contact, where the contact was partially Al_2O_3/rubber. Besides, Al_2O_3 asperities abraded the epoxy transferred into the rubber surface. The effect of Al_2O_3 on the voltage generated from dry sliding of epoxy against rubber is shown in Fig. 6. Voltage drastically decreased with increasing Al_2O_3 content. Value of voltage for epoxy free of aluminum oxide was 800 volts at 20 N normal load, while the value reached to 20 volts for epoxy filled by 10 wt. % Al_2O_3.

At water wetted sliding surfaces, friction coefficient of epoxy filled with nanoparticles of Al_2O_3 sliding against rubber is shown in Fig. 7. Friction coefficient values showed slight decrease with increasing Al_2O_3. It seems that water decreased epoxy transfer into the rubber surface and the contact was partially epoxy/rubber. Voltage generated from test specimens sliding against water lubricated rubber is shown in Fig. 8. Epoxy free of Al_2O_3 showed relatively lower voltage than that observed for dry sliding. As Al_2O_3 content significantly increased voltage increased.

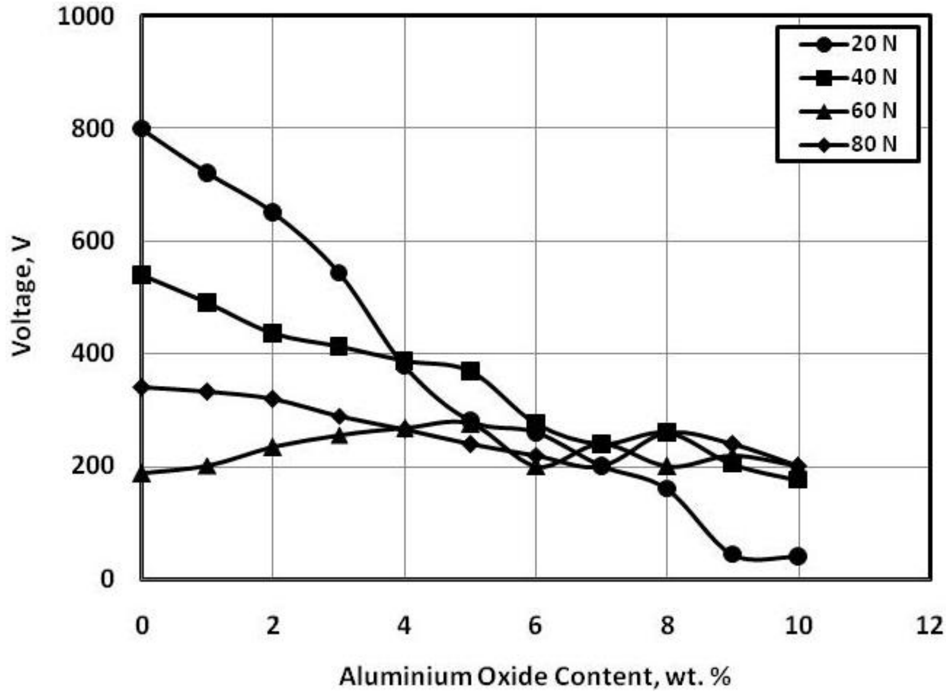

Fig. 6 Voltage generated from dry sliding of epoxy composites against rubber.

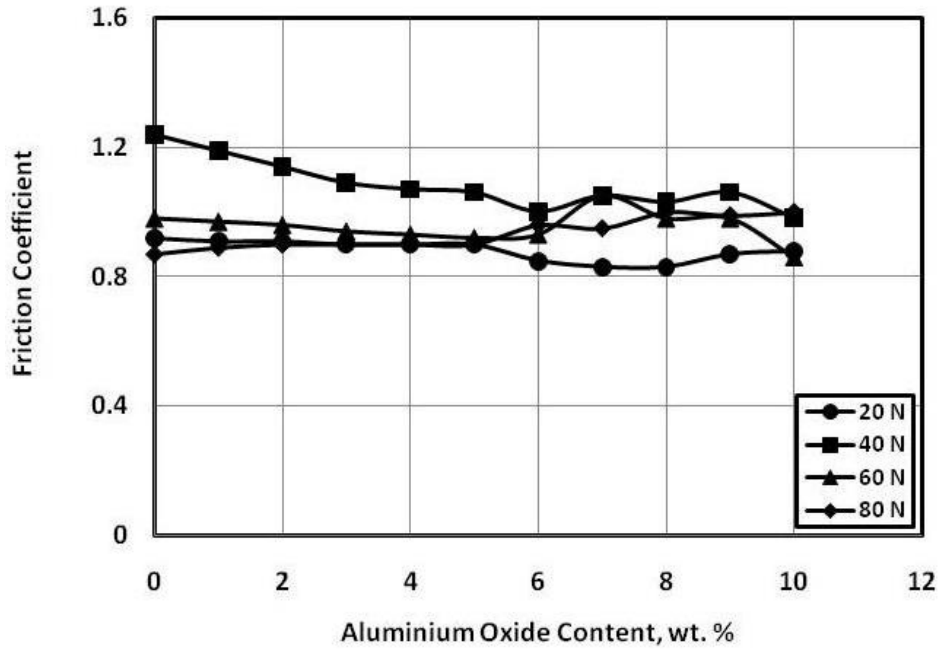

Fig. 7 Friction coefficient of epoxy composites sliding against water wetted rubber.

The results of experiments carried out at detergent wetted sliding are shown in Figs. 9 and 10. Friction coefficient displayed by epoxy composites slightly increased with increasing Al_2O_3 content. Voltage showed slight increase with increasing Al_2O_3 content, Fig. 10. This behaviour could be explained on the basis of the electric properties of detergents.

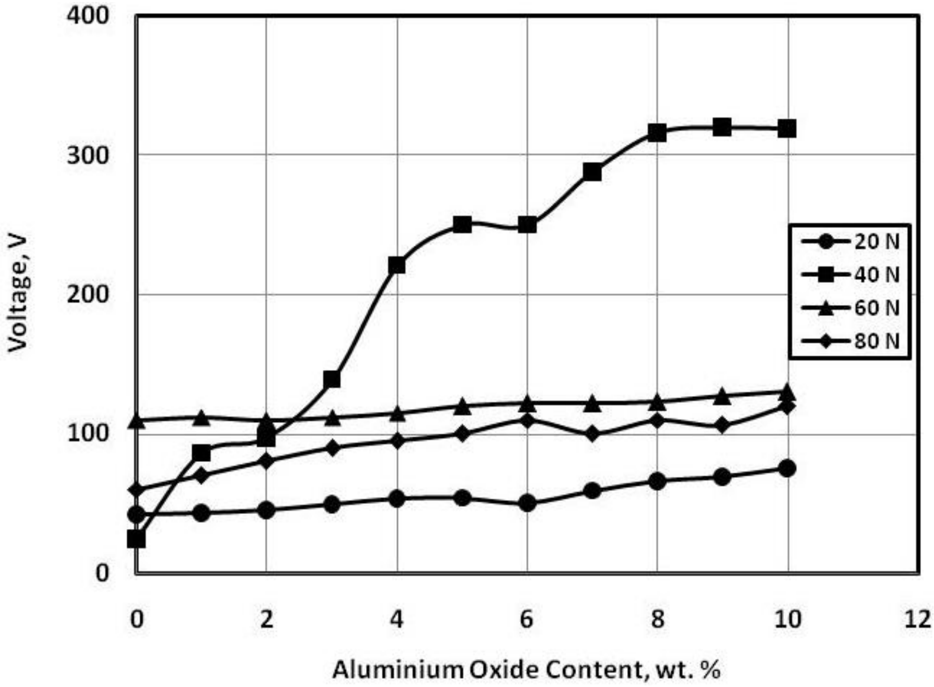

Fig. 8 Voltage generated from epoxy composites sliding against water wetted rubber.

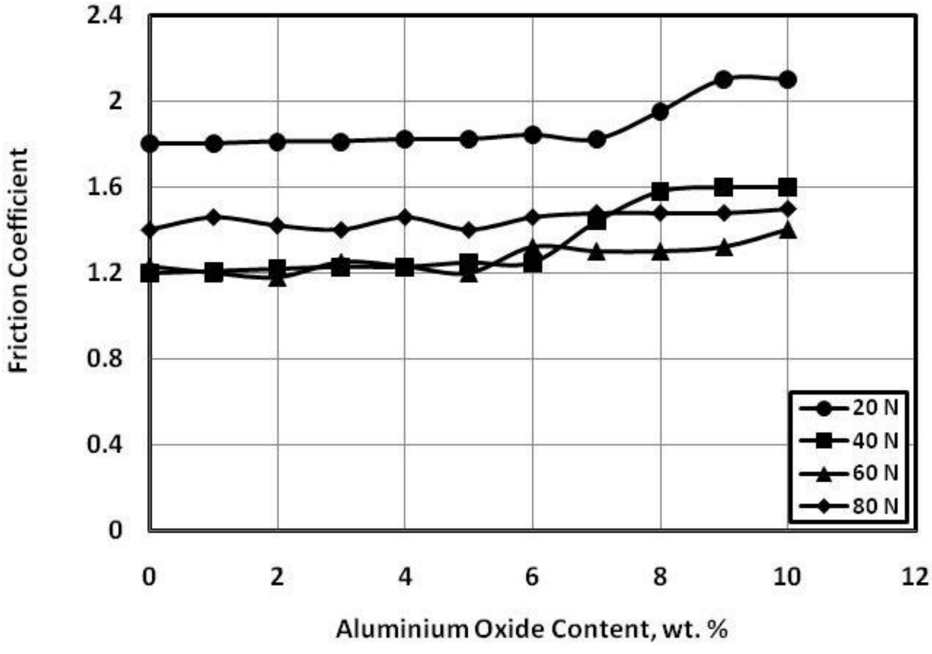

Fig. 9 Friction coefficient of epoxy composites sliding against detergent wetted rubber.

It was noticed that friction coefficient drastically decreased with increasing Al_2O_3 content when sliding against rubber lubricated by oil, Fig. 11. At 10 wt. % Al_2O_3

content, the highest friction coefficient (1.1) was displayed by 20 N load. As the load increased, friction coefficient decreased. Voltage drastically decreased with increasing Al_2O_3 content, Fig. 12. Epoxy free of Al_2O_3 displayed the maximum value of voltage (190 volts) at 80 N normal load.

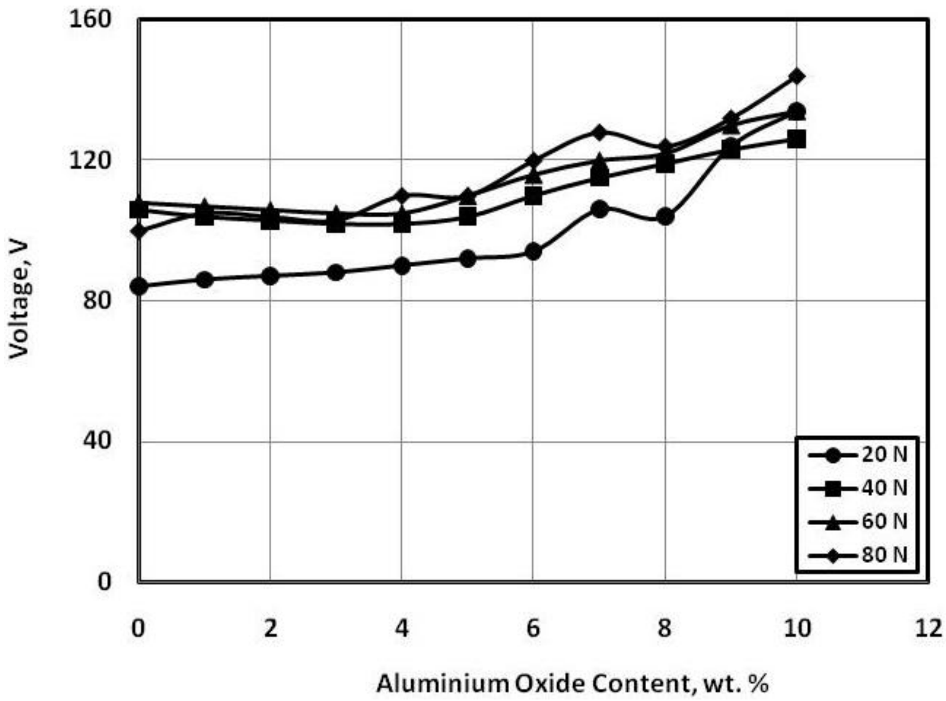

Fig. 10 Voltage generated from epoxy composites sliding against detergent wetted rubber.

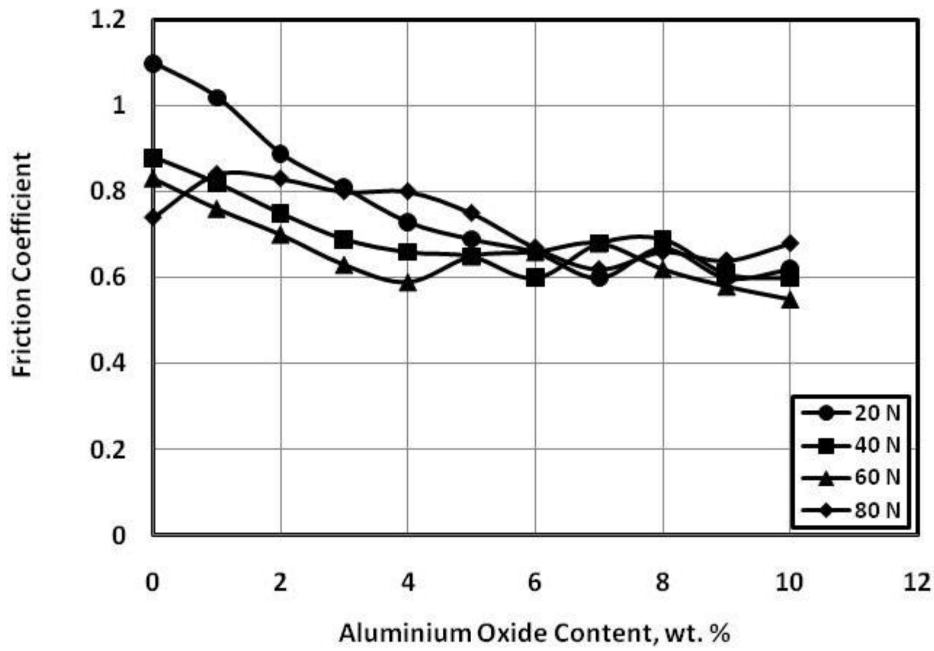

Fig. 11 Friction coefficient of epoxy composites sliding against oil lubricated rubber.

It was noticed that friction coefficient significantly increased with increasing Al_2O_3 content. As the load increased friction coefficient decreased at low content of Al_2O_3. The

highest value of friction coefficient (0.18) was displayed by epoxy filled by 10 wt. % Al_2O_3 and 80 N load. The effect of Al_2O_3 on voltage generated from sliding of epoxy composites against rubber lubricated by oil and water is shown in Fig. 14. Voltage decreased with increasing Al_2O_3 content. Epoxy free of Al_2O_3 displayed the maximum voltage value of (11 volts) at 20 N normal loads. At Al_2O_3 content of 10 wt. %, the lowest voltage (2.2 volts) was displayed by 40 N load.

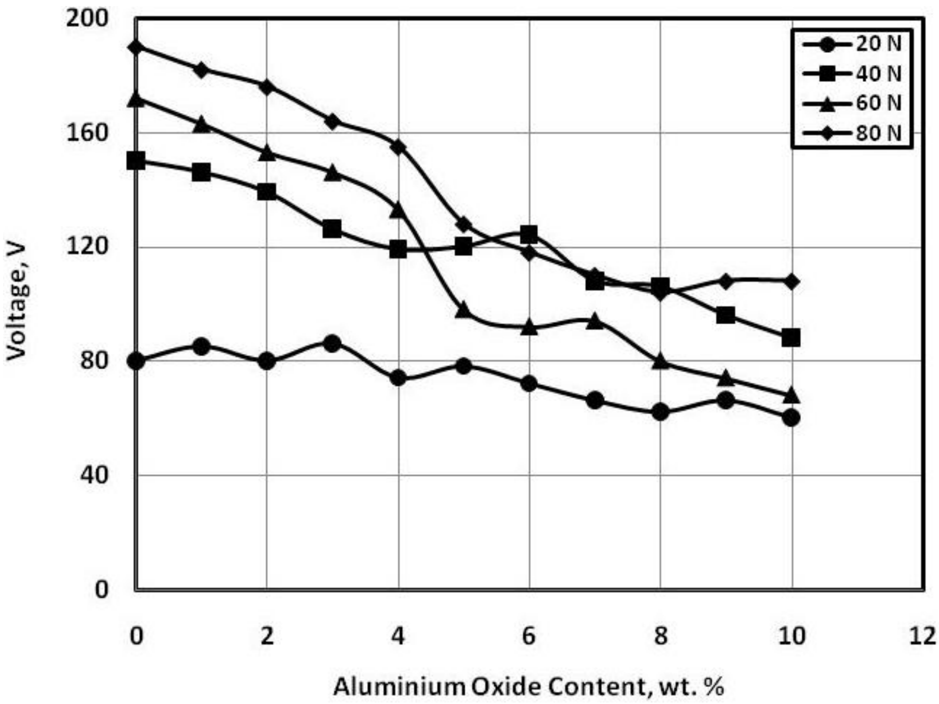

Fig. 12 Voltage generated from epoxy composites sliding against oil lubricated rubber.

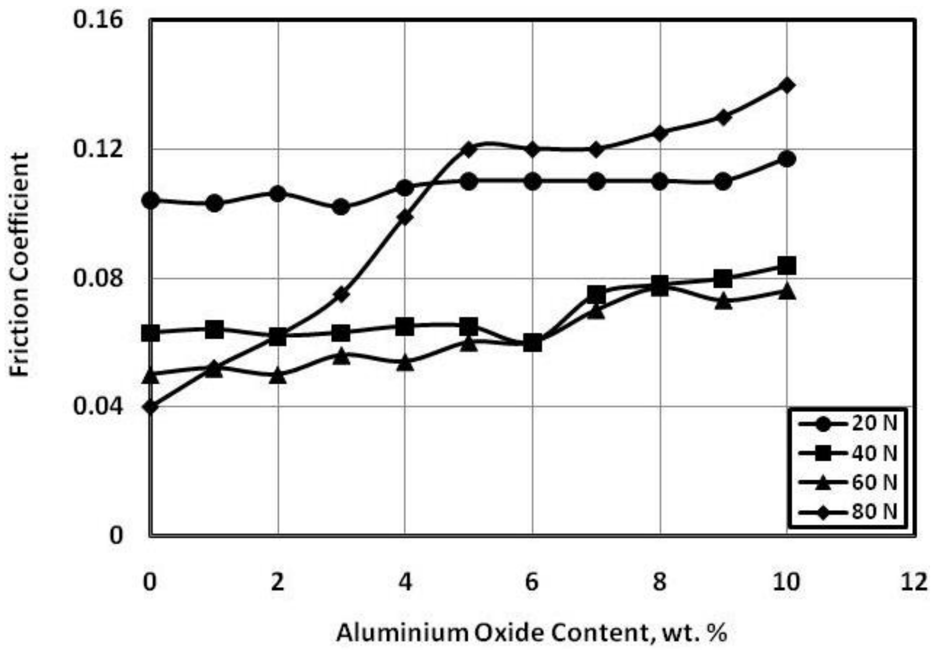

Fig. 13 Friction coefficient of epoxy composites sliding against water/oil emulsion lubricated rubber.

Friction coefficient of epoxy filled by Al_2O_3 and sliding against rubber contaminated by sand is shown in Fig. 15. Slight increase in friction coefficient was observed with increasing Al_2O_3 content. Values of friction coefficient indicated that sand particles action was dominating either by rolling between epoxy matrix and rubber surface or by embedment in the sliding surfaces. Voltage slightly increased with increasing Al_2O_3 content, Fig. 16. The highest value of voltage (13.3 volts) was observed at 10 wt. % Al_2O_3 and 80 N load. The relatively lower voltage values confirmed the mechanism of action of sand particles which completely separated the two sliding surfaces. It can be noted that the values of friction and voltage indicated that sand particles formed a layer on the sliding surfaces.

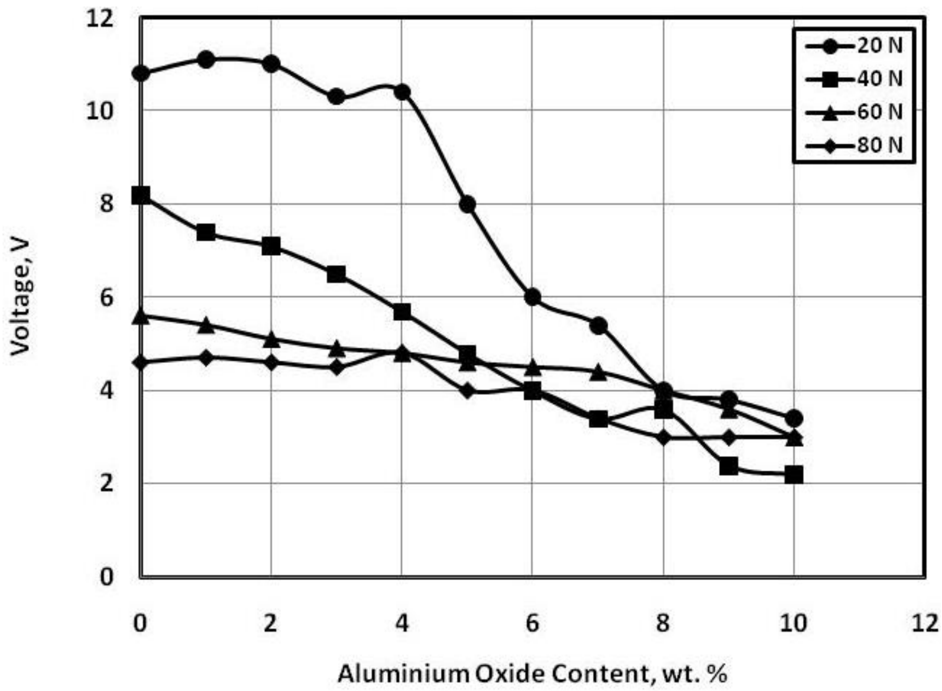

Fig. 14 Voltage generated from epoxy composites sliding against water/oil emulsion lubricated rubber.

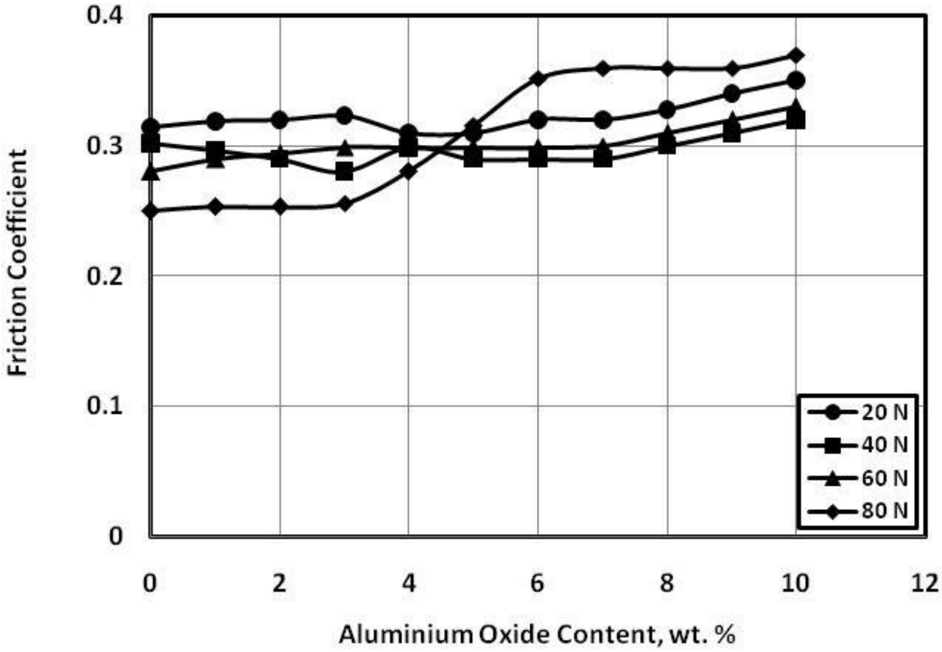

Fig. 15 Friction coefficient of epoxy composites sliding against sand contaminated rubber.

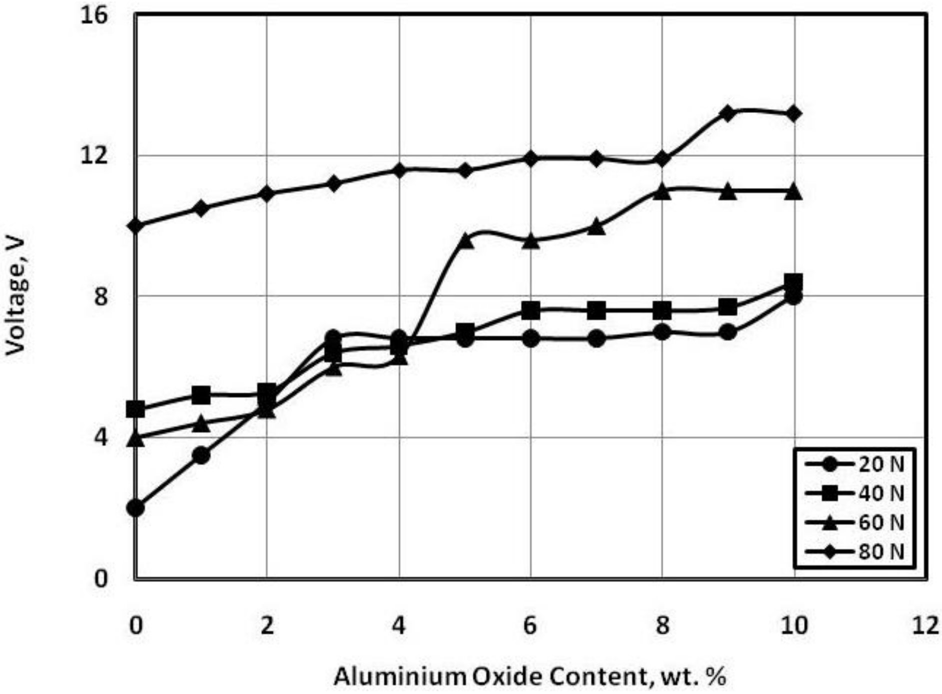

Fig. 16 Voltage generated from epoxy composites sliding against sand contaminated rubber.

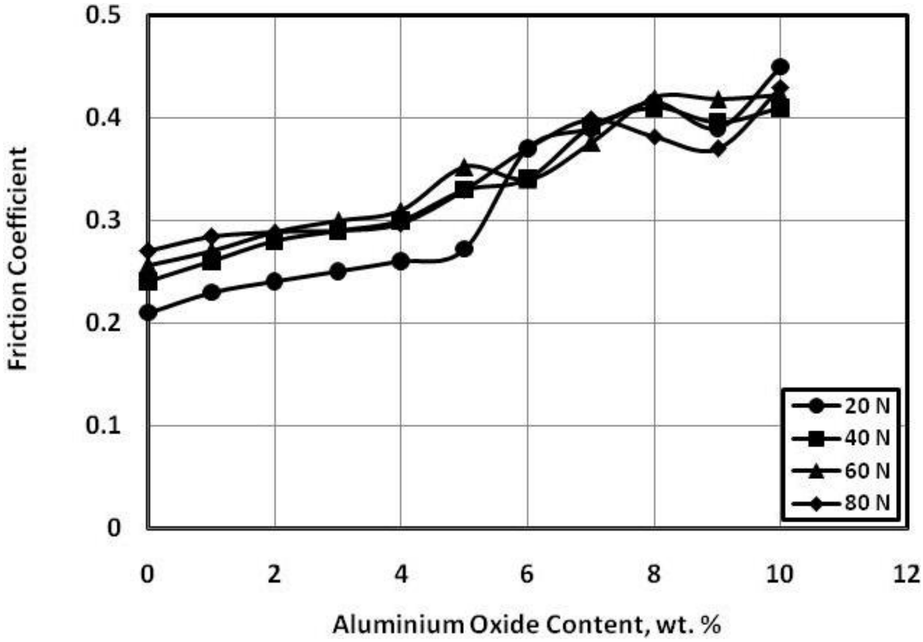

Fig. 17 Friction coefficient of epoxy composites sliding against sand contaminating water wetted rubber.

The friction coefficient displayed by epoxy composites sliding against rubber wetted by water and contaminated by sand is shown in Fig. 17. Friction coefficient significantly increased with increasing Al_2O_3 content up to 10 wt. %, where the highest friction coefficient (0.43) was displayed at 20 N load. The effect of Al_2O_3 on voltage is shown in Fig. 18. Voltage increased with increasing Al_2O_3 content. Friction coefficient displayed by composites filled by Al_2O_3 is shown in Fig. 19. It was noticed that the friction coefficient slightly increased with increasing Al_2O_3 content. At 10 wt. % Al_2O_3 content, the highest friction coefficient (0.45) was displayed by 20 N load. Epoxy free of Al oxide displayed the lowest friction coefficient (0.21) by 20 N load. Voltage displayed by the sliding of epoxy specimens filled by Al_2O_3 is shown in Fig. 20. Voltage drastically decreased with increasing Al_2O_3 content. The voltage reached the maximum (32 volts) at 0 wt. % Al, while the lowest value (4 volts) was observed at 20 N load and 10 wt. % Al_2O_3 content.

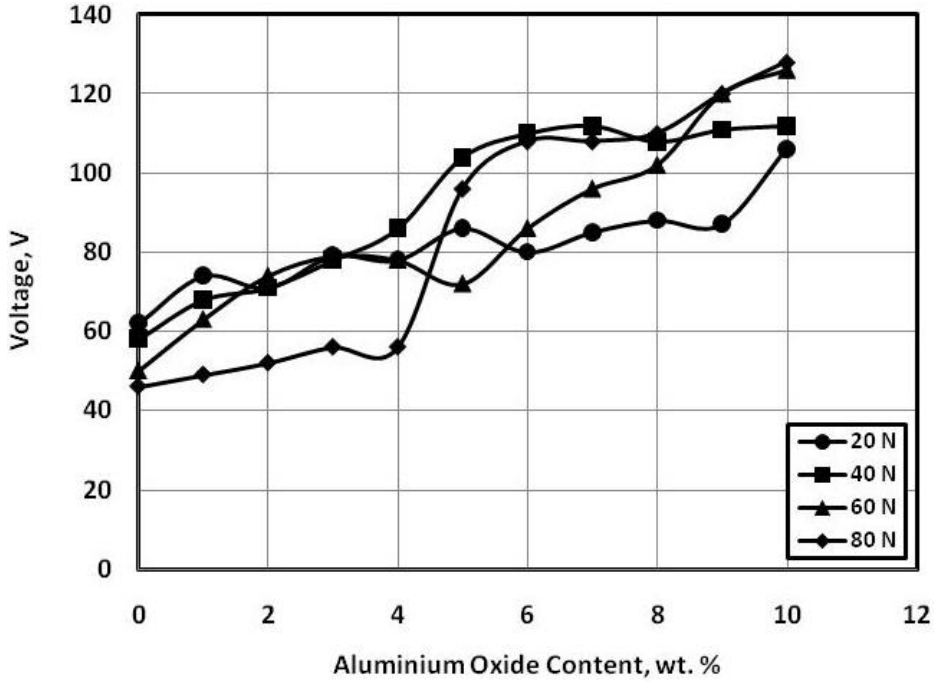

Fig. 18 Voltage generated from epoxy composites sliding against sand contaminating water wetted rubber.

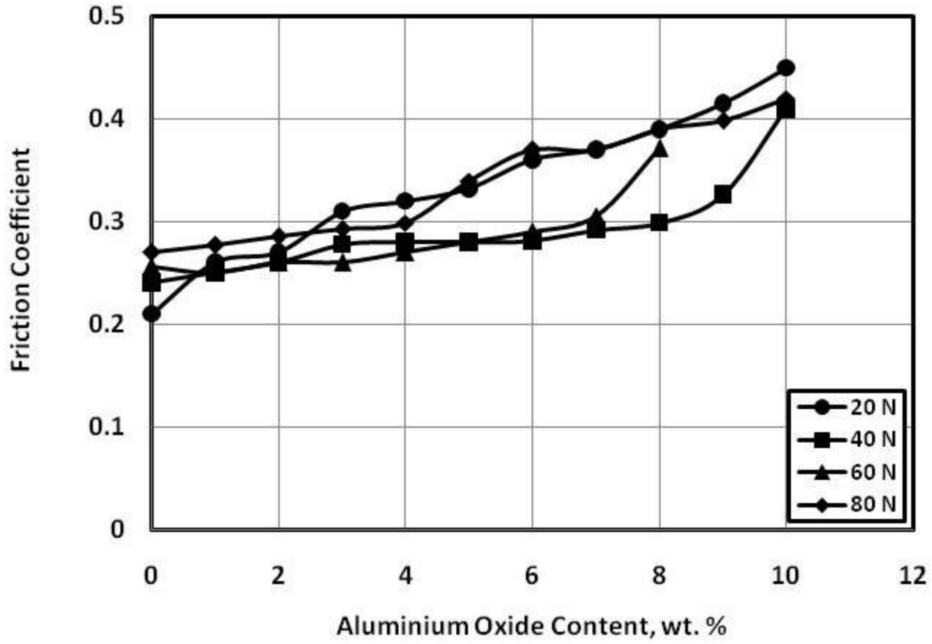

Fig. 19 Friction coefficient of epoxy composites sliding against sand contaminating oil lubricated rubber.

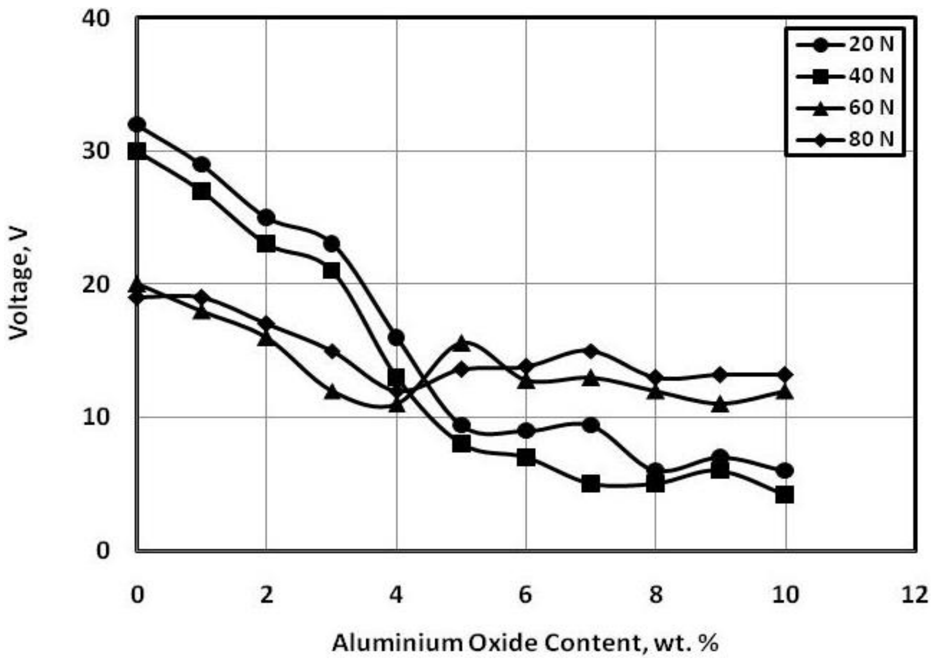

Fig. 20 Voltage generated from epoxy composites sliding against sand contaminating oil lubricated rubber.

Friction coefficient significantly increased with increasing Al_2O_3 content, Fig. 21. Epoxy free of Al_2O_3 displayed the lowest friction coefficient. The maximum value of friction coefficient (0.45) was observed at 20 N normal load and 10 wt. % Al_2O_3 content. Voltage generated from the sliding of epoxy specimens filled by Al_2O_3 is shown in Fig. 22. Voltage significantly increased with increasing Al_2O_3 content. At 10 wt. % Al_2O_3, the maximum value of voltage (16 volts) was displayed by 60 N load. Epoxy free of Al_2O_3 displayed the lowest voltage (4.6 volts) at 60 N loads.

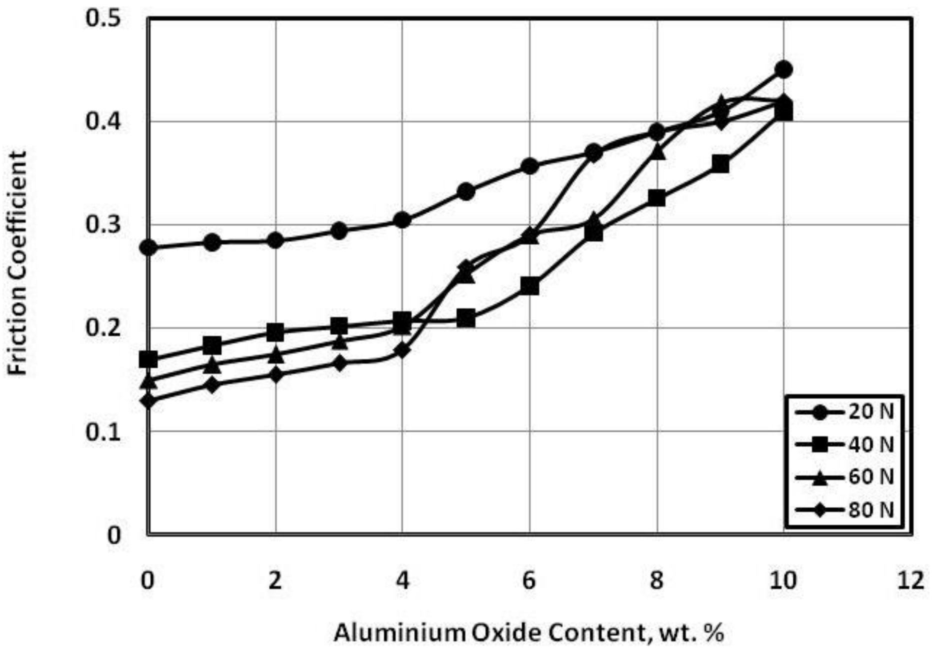

Fig. 21 Friction coefficient of epoxy composites sliding against sand contaminating water/oil emulsion lubricated rubber.

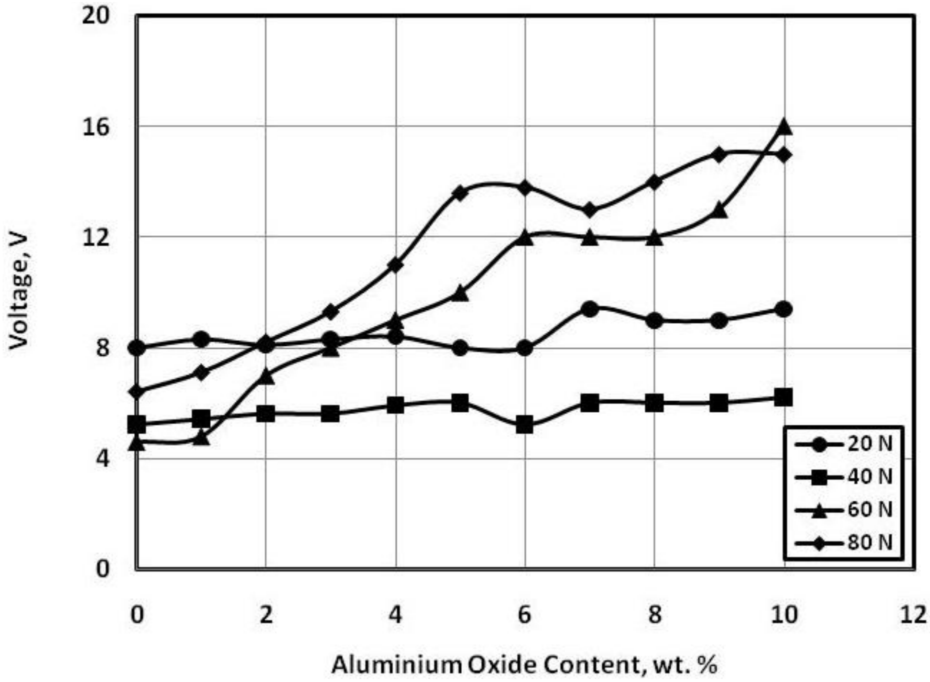

Fig. 22 Voltage generated from epoxy composites sliding against sand contaminating water/oil emulsion lubricated rubber.

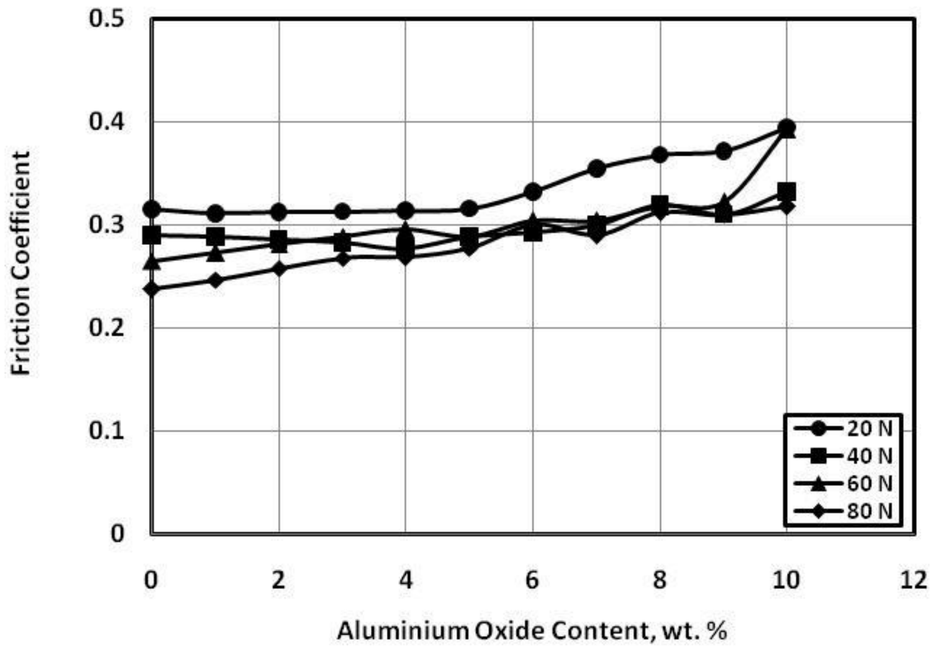

Fig. 23 Friction coefficient of epoxy composites sliding against sand contaminating detergent wetted rubber.

Friction coefficient showed slight increase with increasing Al_2O_3 when sliding against rubber wetted by detergent and contaminated by sand, Fig. 23. The maximum value of friction coefficient (0.4) was observed at 20 N normal load and 10 wt. % Al_2O_3. Voltage generated from the sliding of epoxy specimens filled by Al_2O_3 is shown in Fig. 24. Voltage drastically decreased with increasing Al_2O_3. The voltage approached maximum

value (54 volts) for epoxy free of Al_2O_3, while the lowest value (22 volts) was observed at 60 N load and 10 wt. % Al_2O_3.

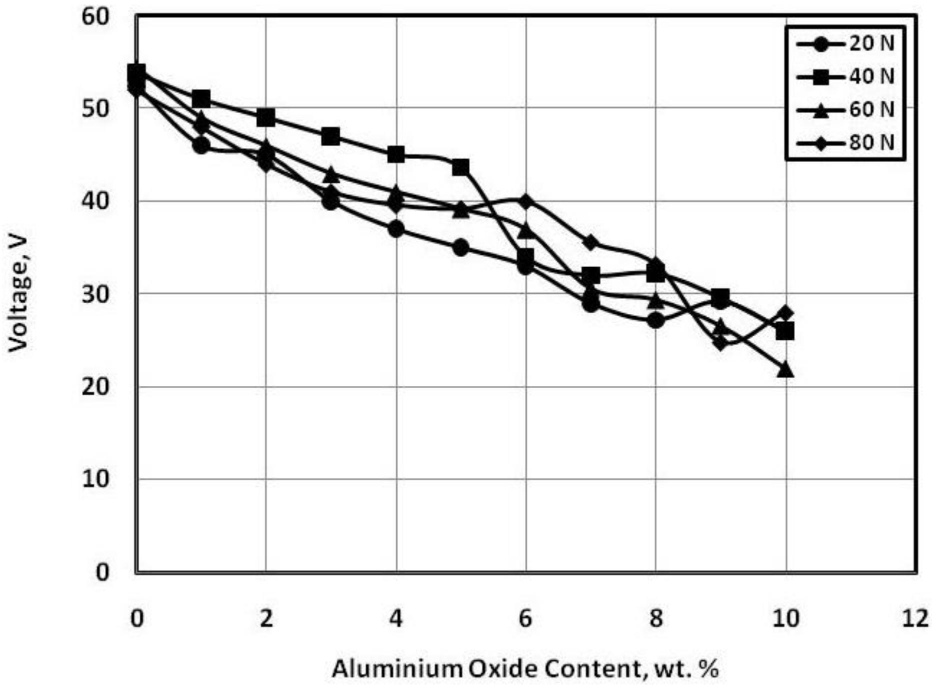

Fig. 24 Voltage generated from epoxy composites sliding against sand contaminating detergent wetted rubber.

CONCLUSIONS

1. At dry sliding, Al_2O_3 nanoparticles addition into epoxy matrix decreased friction coefficient with increasing Al_2O_3 content. Voltage drastically decreased with increasing Al_2O_3 content. Voltage showed the maximum values for epoxy free of filling materials.

2. At water wetted surfaces, slight friction coefficient decrease was observed. Epoxy free of Al_2O_3 showed relatively lower voltage than that observed for dry sliding. As Al_2O_3 content increased voltage significantly increased.

3. At detergent wetted surfaces, friction coefficient and voltage slightly increased with increasing Al_2O_3 content.

4. When sand particles were covering the sliding surfaces, Slight increase in friction coefficient was observed with increasing Al_2O_3 content. Values of friction coefficient indicated that sand particles action was dominating either by rolling between epoxy matrix and rubber surface or by embedment in the sliding surfaces. Voltage slightly increased with increasing Al_2O_3 content. The voltage displayed relatively low values.

5. In the presence of water contaminated by sand, friction coefficient and voltage increased with increasing Al_2O_3 content.

6. For detergent contaminated by sand wetted surface, friction coefficient increased with increasing Al_2O_3, while voltage drastically decreased with increasing Al_2O_3.

7. At oil lubricated surfaces, friction coefficient drastically decreased with increasing Al_2O_3 when sliding against rubber lubricated by oil. As the load increased, friction coefficient decreased. Voltage drastically decreased with increasing Al_2O_3.

8. At oil/water emulsion, significantly increased with increasing Al_2O_3. Voltage decreased with increasing Al_2O_3.

9. At oil contaminated by sand, friction coefficient and voltage significantly increased with increasing Al_2O_3, while voltage decreased with increasing Al_2O_3.

10. At water/oil emulsion contaminated by sand, friction coefficient slightly increased, while voltage drastically decreased with increasing Al_2O_3.

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