**EGTRIB Journal**
**JOURNAL OF**
**THE EGYPTIAN SOCIETY OF TRIBOLOGY**
*VOLUME 11, NO. 1, JANUARY 2014, 12 – 23,* **ISSN 2090 - 5882**

# TRIBOELECTRIFICATION OF ENGINEERING MATERIALS

**Alahmadi A.**

**Faculty of Engineering, Taif University, Al –Taif, SAUDI ARABIA.**

## ABSTRACT
**Electric static charges generated from friction of engineering materials have a negative effect in technological applications. The increased use of polymeric materials raised the importance of studying that effect. The present study investigates the voltage generated from the dry sliding of aluminium oxide ($Al_2 O_3$), copper (Cu), aluminium (Al), iron (Fe), silicon oxide ($Si O_2$), polymethyl methacrylate (PMMA), high density polyethylene (HDPE) and low density polyethylene (LDPE) against synthetic rubber, HDPE, polypropylene (PP) and polytetrafluoroethylene (PTFE).**

**It was found that voltage generated from the sliding of aluminium oxide, copper, aluminium, iron and silicon oxide against rubber generated the lowest voltage, while PTFE showed the highest one. Generally, voltage decreased with increasing load due to heating process which increased the temperature of the friction surfaces and consequently the relaxation of the electric charge proceeded. Besides, it was observed that the maximum level of the voltage generated from the materials is dependent on their position in the triboelectric series relative to the counterface. The triboelectric series can be used to determine the charge polarity of the materials. This series can be used to evaluate the relative charging capacity of many polymeric materials.**

## KEYWORDS
**Triboelectrification, friction, engineering materials.**

## INTRODUCTION
**It is necessary to study the electrification of engineering materials. It is well known that when two different materials contact each other, they may get charged. This tribocharging phenomenon is also known as triboelectrification when materials rub against each other, [1 - 3]. The mechanism of charge transfer in tribocharging can be explained by three mechanisms: electron transfer, ion transfer, and material transfer, [4 – 6]. The electric static charge generated from the friction of different polymeric textiles sliding against cotton textiles, which used as a reference material, was discussed, [7]. Experiments were carried out to measure the electric static charge generated from the friction of different polymeric textiles sliding against cotton under varying sliding distance and velocity as well the load. It was found that increase of cotton content decreased the generated voltage. Besides, as the load increased voltage generated from**

**rubbing of 100 % spun polyester specimens increased. Besides, mixing polyester with rayon (viscose) showed the same behavior of mixing it with cotton. Generally, increasing velocity increased the voltage. The voltage increase with increasing velocity may be attributed to the increase of the mobility of the free electrons to one of the rubbed surfaces. The fineness of the fibres much influences the movement of the free electrons.**

**The electrostatic charge generated from the friction of polytetrafluoroethylene (PTFE) textiles was tested to propose developed textile materials with low or neutral electrostatic charge which can be used for industrial application especially as textile materials, [8]. Test specimens of composites containing PTFE and different types of common textile fibers such as cotton, wool and nylon, in a percentage up to 50 vol. % were prepared and tested by sliding under different loads against house and car padding textiles. Ultra surface DC Voltmeter was used to measure the electrostatic charge of the tested textile composites. The results showed that addition of wool, cotton and nylon fibers remarkably decreases the electrostatic discharge and consequently the proposed composites will become environmentally safe textile materials.**

**Research on electrostatic discharge (ESD) ignition hazards of textiles is important for the safety of astronauts. The likelihood of ESD ignitions depends on the environment and different models used to simulate ESD events, [9]. Materials can be assessed for risks from static electricity by measurement of charge decay and by measurement of capacitance loading, [10]. Tribology is the science and technology of two interacting surfaces in relative motion and of related subjects and practices. The popular equivalent is friction, wear, and lubrication, [11]. Tribological behavior of polymers is reviewed since the mid-20th century to the present day. Surface energy of different coatings is determined with contact adhesion meter. Adhesion and deformation components of friction were discussed. It was shown how load, sliding velocity, and temperature affect friction. Different modes of wear of polymers and friction transfer were considered, [12]. The ability to engineer a product's tactile character to produce favorable sensory perceptions has the potential to revolutionize product design. Another major consideration is the potential for products to produce friction-induced injuries to skin such as blistering, [13, 14]. Sports activities may cause different types of injuries induced by friction between the skin and sport textiles. Focusing on runners who are often bothered with blisters, the textile–foot skin interface was studied in order to measure and predict friction. The characteristics of mechanical contacts between foot, sock and shoe during running were determined. It was found that textiles with conductive threads did not give ignitions provided they were adequately earthed, [15]. When isolated, all textiles were capable of causing ignitions regardless of the anti-static strategy employed.**

**Friction coefficient displayed by clothes sliding against car seat covers was discussed, [39]. The frictional performance of two groups of covers, the first contained five different types of synthetic leather and the second contained nine different types of synthetic textiles, was measured. Measurement of friction coefficient is, therefore, of critical importance in assessing the proper friction properties of car seat covers and their suitability to be used in application to enhance the safety and stability of the driver. Less attention was considered for the triboelectrification of the textiles. Friction**

coefficient and electrostatic charge generated from the friction of hair and head scarf of different textiles materials were measured, [16]. Test specimens of head scarf of common textile fibres such as cotton, nylon and polyester were tested by sliding under different loads against African and Asian hair. The results showed that friction coefficient generated from the sliding of the cotton head scarf against hair displayed higher values than that showed by polyester head scarf. The nylon head scarf when sliding against hair showed relatively lower friction coefficient than that observed for polyester and cotton scarf. Electric static charge measured in voltage represented relatively lower values. This behaviour may be attributed to the ranking of the rubbing materials in the triboelectric series where the gap between human hair and nylon is smaller than the gap between hair and cotton as well as hair and polyester. Generally, at higher loads, the difference in friction values was insignificant. African hair displayed relatively higher voltage. Nylon displayed relatively higher friction coefficient than polyester when slid against human hair, while cotton proposed the highest friction coefficient especially at lower loads. The nylon head scarf showed slight decrease in friction coefficient compared to scarf. The decrease might be from the difference in the weave form although the both two textiles are made of nylon. The weaves form has significant effect on friction coefficient and voltage generated.

Little attention has been devoted so far to the electrostatic properties of hair although these properties are very sensitive to the friction between hair and head scarf textiles. Hair has a tendency to develop static charge when rubbed with dissimilar materials like human skin, plastic and textiles. Human hair is a good insulator with an extremely high electrical resistance. Due to this high resistance, charge on hair is not easily dissipated, especially in dry environments. Many macroscale studies have looked at the static charging of human hair, [17 - 19]. Most of these studies include rubbing hair bundles with various materials like plastic combs, teflon, latex balloons, nylon, and metals like gold, stainless steel and aluminum. Hair in these cases is charged by a macroscale triboelectric interaction between the surface and the rubbing element. The kinetics of the charging process and the resulting charge are then measured using modified electrometers.

In the present work, the voltage generated from the dry sliding of $Al_2O_3$, copper, aluminium, iron, silicon oxide, PMMA, LDPE and HDPE against synthetic rubber, HDPE, PP and PTFE is measured.

## EXPERIMENTAL

The test specimens were $Al_2O_3$, copper, aluminium, iron, silicon oxide, PMMA, LDPE and HDPE in form of particles adhered into the surface steel strip of 100 × 30 × 1 mm fastened on wooden table. The particle size ranged from 30 – 50 µm. The counterface was a steel disc of 25 mm diameter covered by sheets of synthetic rubber, HDPE, PP and PTFE of 2 mm thickness. The counterface was driven by a reciprocating motion of 50 mm stroke and velocity of one stroke/second. Loads of 2, 4, 6, 8 and 10 N were applied by weights. Experiments were carried out under dry sliding condition. The electrostatic fields (voltage) measuring device (Ultra Stable Surface DC Voltmeter) was used to measure the electrostatic charge (electrostatic field) for test specimens, Fig. 1. It measures down to 1/10 volt on a surface, and up to 20 000 volts (20 kV). Readings were normally done with the sensor 25 mm apart from the surface being tested.


**Fig. 1 Electrostatic field measuring device.**

## RESULTS AND DISCUSSION

**Triboelectrification was investigated for metals and was attributed to the transfer of electrons from the metal to the accompanying material. As for polymers it is not as easily explained and it needs more research to understand. Engineering materials including polymers can be arranged in a ‘‘triboelectric series’’ which lists the materials in the order of their relative polarity. In the triboelectric series the higher positioned materials will acquire a positive charge when contacted with a material at a lower position along the series, [20]. The triboelectric series can be used to estimate the relative charge polarity of the materials.**

**Table 1 Triboelectric series of the materials used in the present work.**

| Material | Polarity |
|---|---|
| Polymethyl methacrylate<br>Aluminum | positive |
| Steel | Neutral |
| Copper<br>Synthetic Rubber<br>Polyethylene<br>Polypropylene<br>Polyester<br>Polyvinyl Chloride<br>Polytetrafluoroethylene | Negative |

**The results of experiments carried out in the present work are shown in Fig. 2 – 11. Voltage generated from the sliding of aluminium oxide against the tested materials is illustrated in Fig. 2. Rubber generated the lowest voltage, while PTFE showed the highest one. Generally, voltage decreased with increasing load. It is interesting to note that the ranking of the voltage values strongly depends on the triboelectric series. The polarity and amount of charge transferred when two materials sliding against each**

**other depend on the amount of energy required by each to lose electrons, this property is called their relative work functions, [21]. The material with the higher work function will gain electrons from the other and thus acquire a negative charge. The amount of charge transferred can be affected by friction between the sliding surfaces. It was found that the maximum level of the voltage generated from the materials is dependent on their position in the triboelectric series relative to the surface material.**

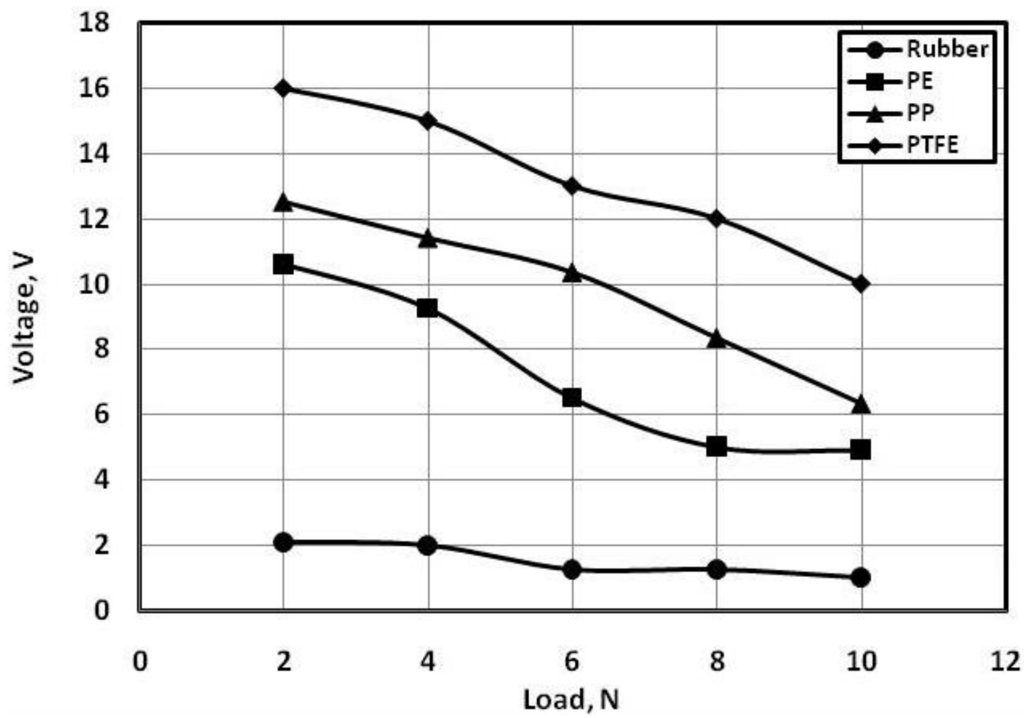


**Fig. 2 Voltage generated from the sliding of aluminium oxide against the tested materials.**

**Voltage generated from the sliding of copper against the tested materials is shown in Fig. 3. Rubber displayed the lowest voltage followed by PE, PP and PTFE. Values of voltage were relatively higher than that displayed by aluminium oxide. Voltage decreased with increasing load due to heating process accompanied by the load increase which increased the temperature of the friction surfaces and consequently the relaxation of the electric charge proceeded. Sliding of aluminium against the tested materials showed the same trend observed for $Al_2O_3$, Fig. 4. The values of generated voltage were ranked as their positions in the triboelectric series. It is noticed that the difference between the valued generated from rubber and thermoplastic polymers (PE, PP and PTFE) was relatively high. Voltage generated from the sliding of iron against the tested materials is shown in Fig. 5. PTFE showed the highest voltage, while rubber displayed the lowest one. The ranking of the materials based on the values of the generated voltage depended on the triboelectric series. In the triboelectric series the higher positioned materials will acquire a positive charge when contacted with a material at a lower position along the series. Thus, the triboelectric series can be used to estimate the**

relative charge polarity of the materials. This series can be used to estimate the relative charging capacity of many polymeric materials.

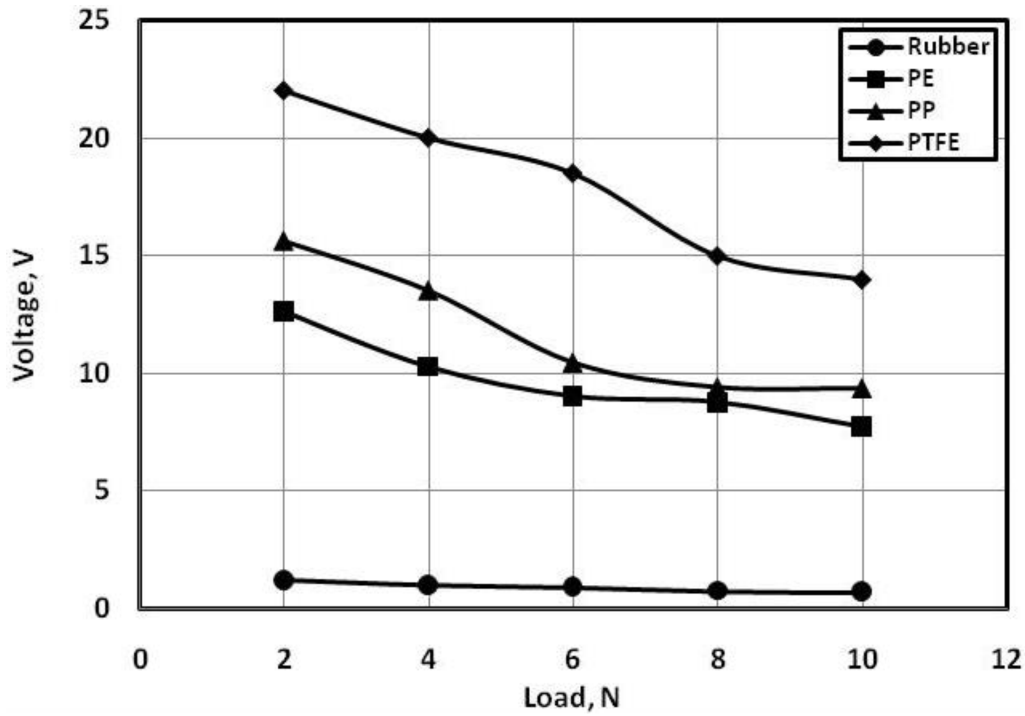


**Fig. 3 Voltage generated from the sliding of copper against the tested materials.**

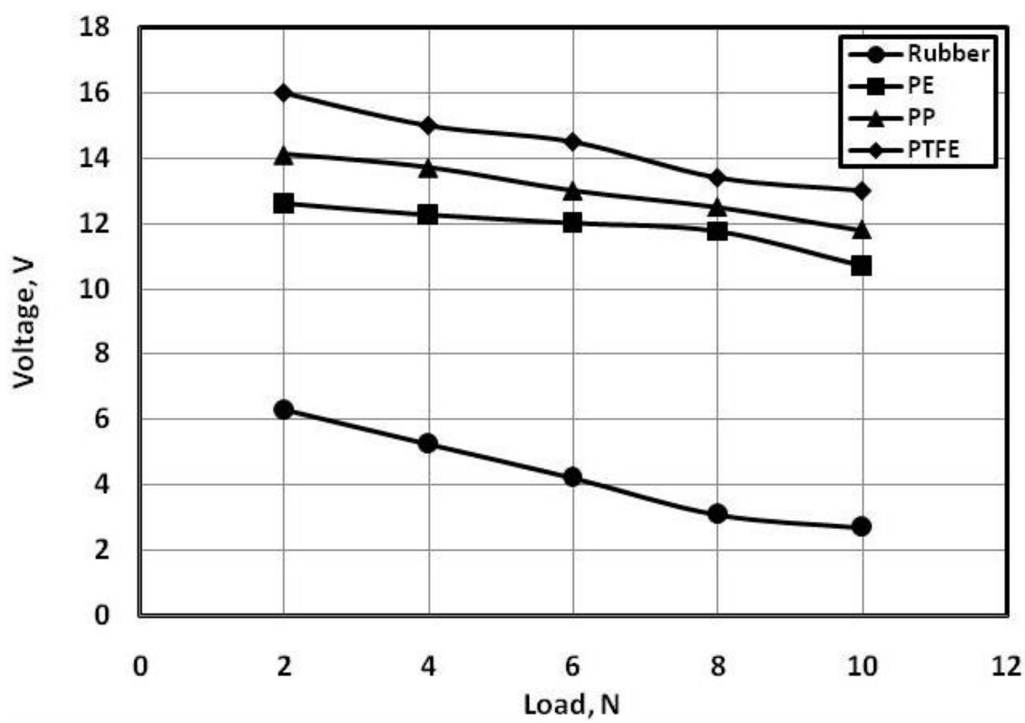


**Fig. 4 Voltage generated from the sliding of aluminium against the tested materials.**

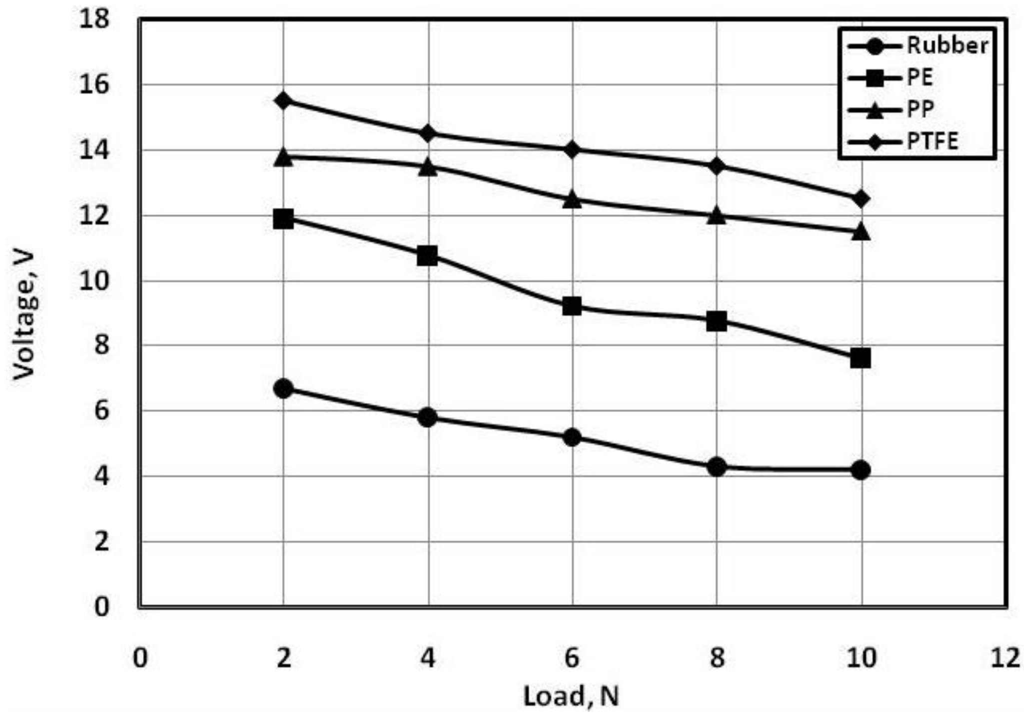


**Fig. 5 Voltage generated from the sliding of iron against the tested materials.**

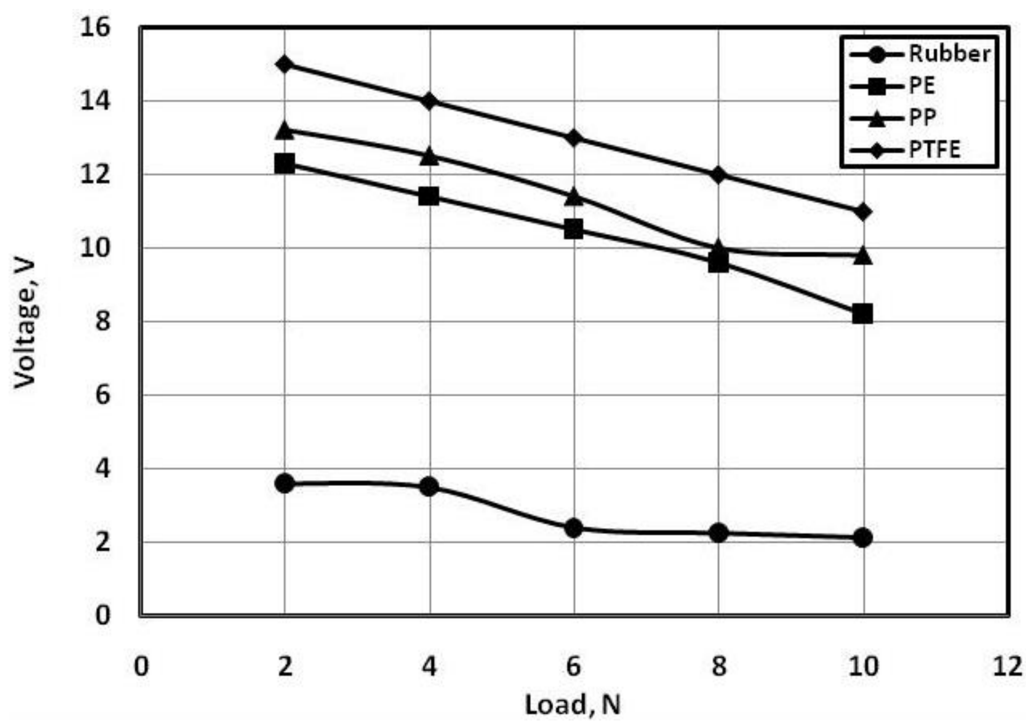


**Fig. 6 Voltage generated from the sliding of silicon carbide against the tested materials.**

**Voltage generated from the sliding of Si C against the tested materials is illustrated in Fig. 6. Synthetic rubber displayed the lowest values, where the difference in voltage values among rubber and the thermoplastic polymers PTFE, PP and PE was significant. Si C is electrically semiconducting. The friction and wear behaviour of silicon carbide based materials may be influenced by electric potentials applied to the tribological system, [22 – 25]. Also, it was found that the surface state of Si C ceramics can be influenced by electric potentials.**

**Because PMMA falls at the positive end of each series and polytetrafluoroethylene at the negative end significant increase in voltage generated from the sliding of polymythyl methacrylate against the tested materials, Fig. 7. Voltage difference arises from excess charge. It is well known that charge generation on some polymers increased with increasing metal work function, suggesting an electron transfer mechanism. Material transfer and charge transfer occur in electrification and they responsible for the ions transfer.**

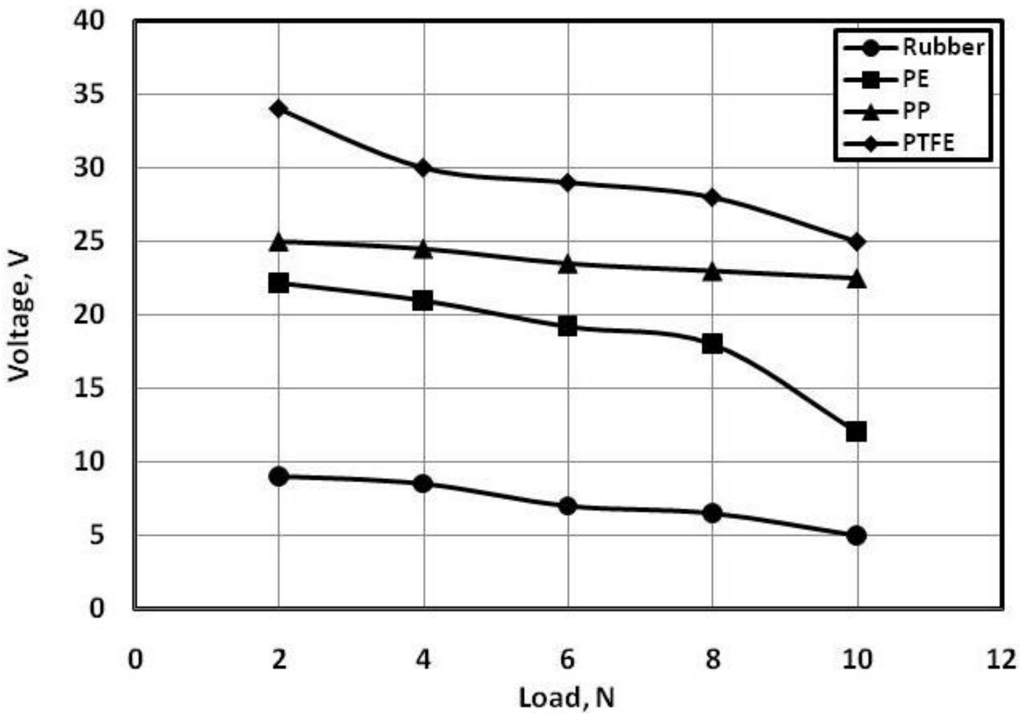


**Fig. 7 Voltage generated from the sliding of polymythyl methacrylate against the tested materials.**

**Slight decrease in the values of voltage generated from the sliding of polyester against the tested materials was observed, Fig. 8. This behaviour may be attributed to position of polyester in the triboelectric series. Based on the triboelectric series, it is known that the generated voltage increased when the ranking distance between the rubbed two surfaces increased. Polyester is relatively close to PTFE, PP and PE, so the values of generated voltage were relatively low.**

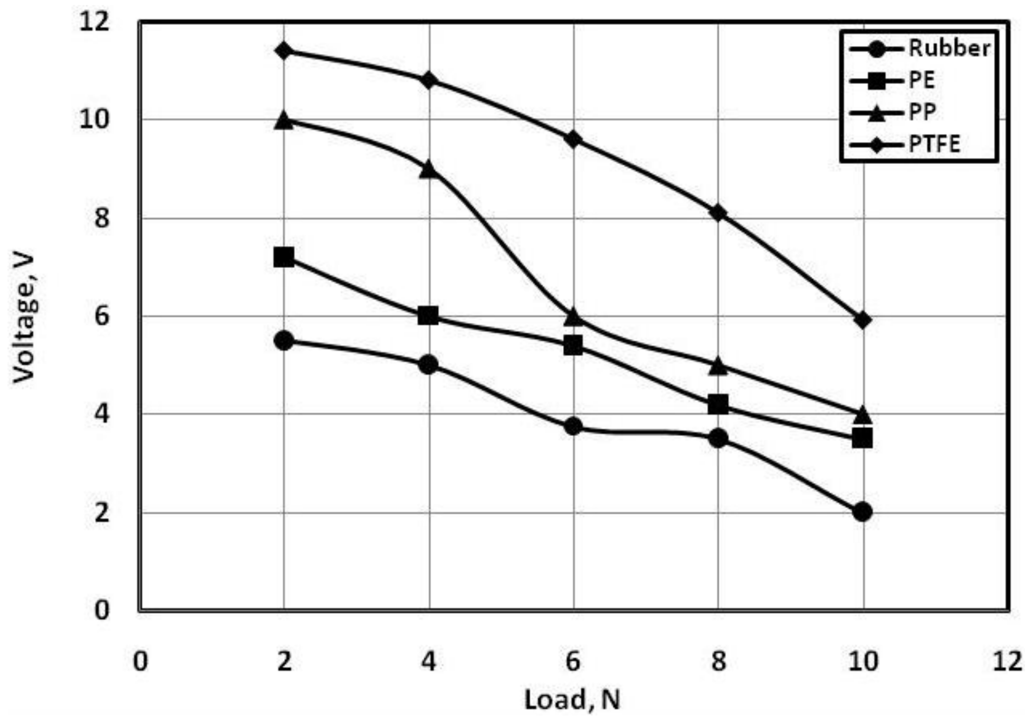


**Fig. 8 Voltage generated from the sliding of polyester against the tested materials.**

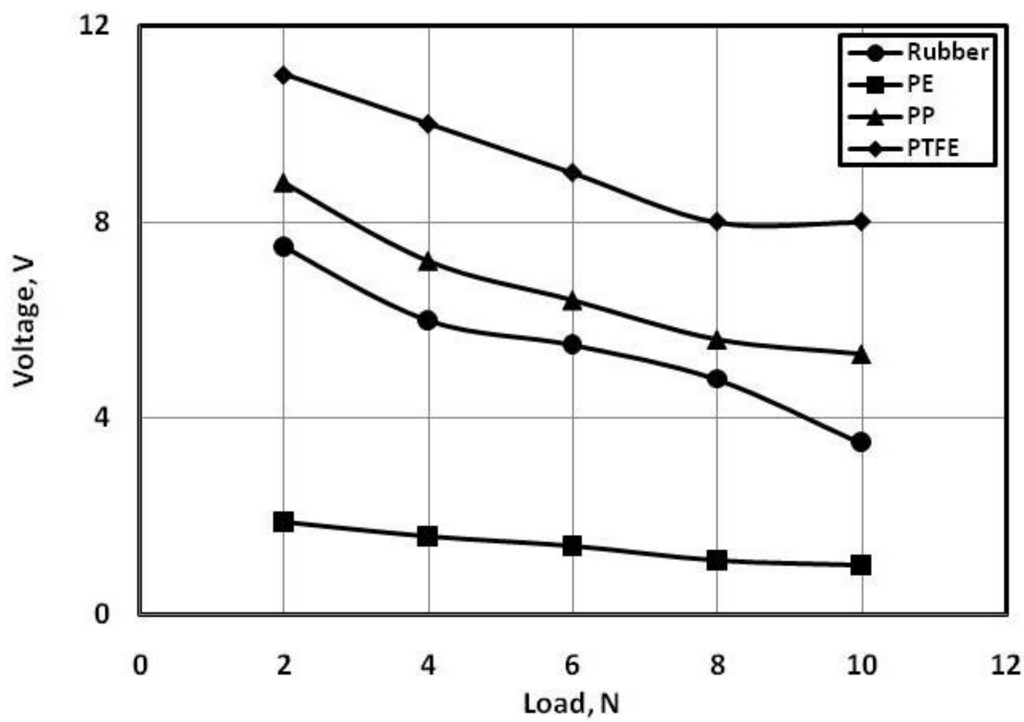


**Fig. 9 Voltage generated from the sliding of high density polyethylene against the tested materials.**

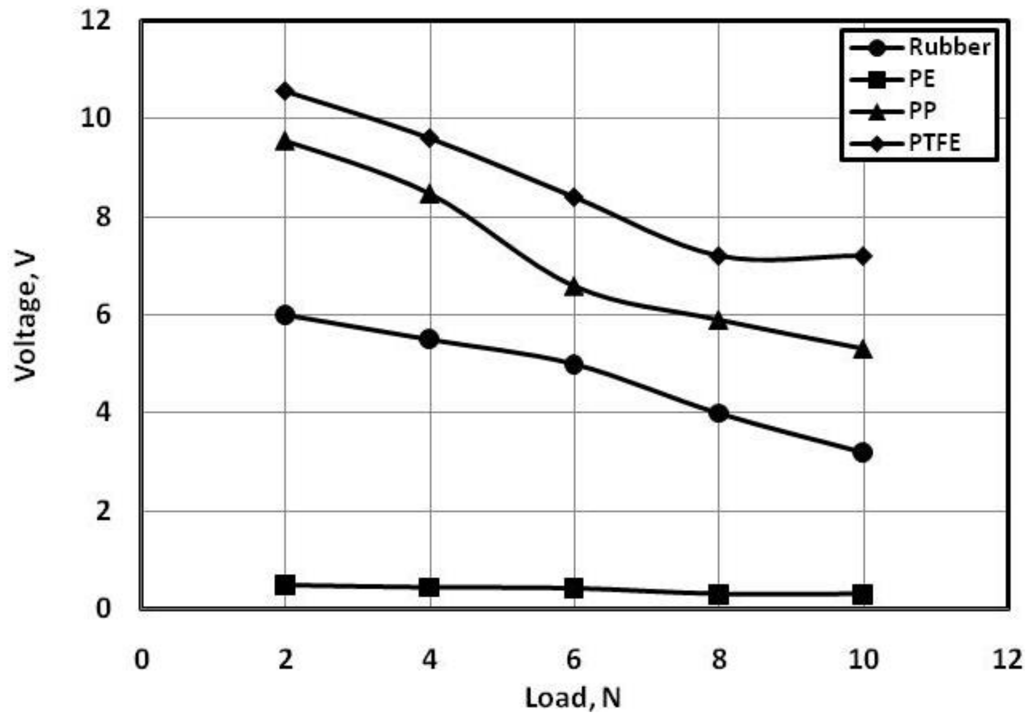


**Fig. 10 Voltage generated from the sliding of low density polyamide against the tested materials.**

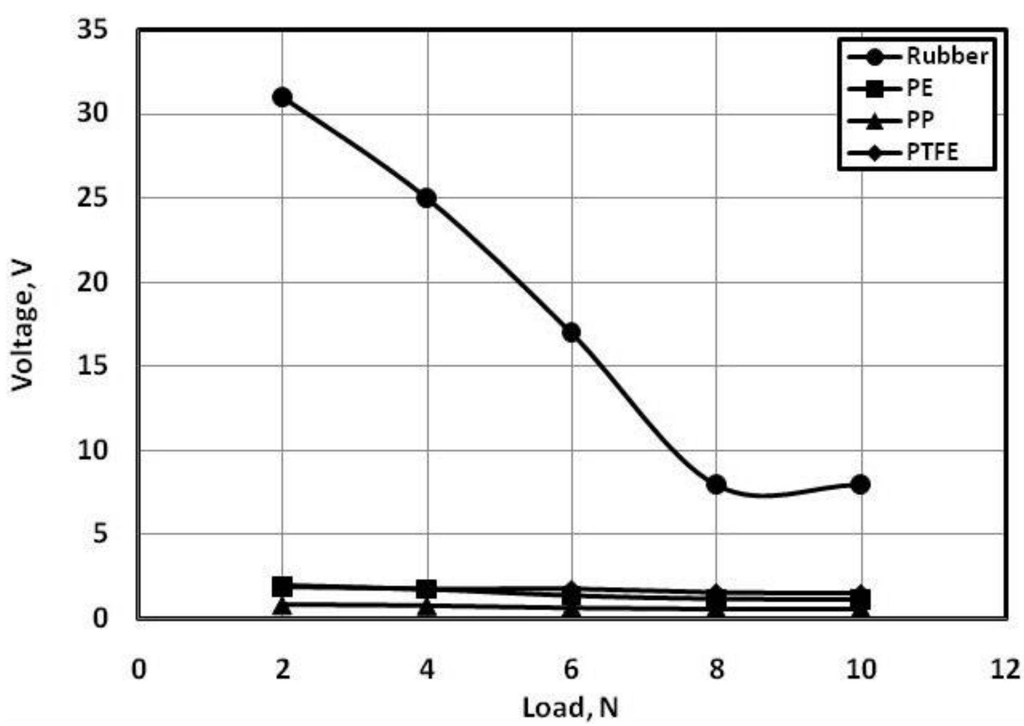


**Fig. 11 Voltage generated from the sliding of polypropylene against the tested materials.**

**The same trend was observed for HDPE and LDPE, Figs. 9 and 10, where the generated voltage was low, where the recorded values were 11, 9, and 7.5 volts for PTFE, PP and PE respectively, Fig. 9. Voltage generated from sliding of PE against HDPE represented the lowest values whwre the highest was 1.8 volts. Voltage generated from the sliding of polypropylene against the tested materials is shown in Fig. 11. As expected, rubber displayed significant increase in the generated voltage due to the ranking in the triboelectric series, Table 1, while PE, PP and PTFE showed very low voltage values.**

## CONCLUSIONS

**1. Voltage generated from the sliding of aluminium oxide, copper, aluminium, iron and silicon oxide against rubber generated the lowest voltage, while PTFE showed the highest one.**
**2. Voltage decreased with increasing load.**
**3. The ranking of the voltage values strongly depends on the order of the tested materials in triboelectric series.**
**4. Voltage generated from the sliding of Si C showed significant difference in voltage values among rubber and the thermoplastic polymers PTFE, PP and PE.**
**5. Significant increase in voltage generated from the sliding of PMMA against the tested materials.**
**6. Slight decrease in the values of voltage generated from the sliding of PET, LDPE and HDPE against the tested materials was observed.**
**7. Rubber displayed significant voltage increase when slid against PP.**

## REFERENCES


**1. Wu G., Li J., Xu Z., "Triboelectrostatic separation for granular plastic waste recycling: A review", Waste Management 33, pp. 585 - 597, (2013).**
**2. Lowell J., Rose-Innes A. C., "Contact electrification", Adv. Phys. 29, pp. 947 - 1023, (1980).**
**3. Matsusaka S., Maruyama H., Matsuyama T., Ghadiri M., "Triboelectric charging of powders: a review", Chem. Eng. Sci. 65, pp. 5781 - 5807, (2010).**
**4. Lee L. H., "Dual mechanism for metal–polymer contact electrification", J. Electrostat. 32, 1 - 29, (1994).**
**5. Matsusaka S., Masuda H., "Electrostatics of particles" Adv. Powder Technol. 14, pp. 143 - 166, (2003).**
**6. Saurenbach F., Wollmann D., Terris B., Diaz A., "Force microscopy of ioncontaining polymer surfaces: morphology and charge structure" Langmuir 8, pp. 1199 - 1203, (1992).**
**7. Al-Qaham Y., Mohamed M. K. and Ali W. Y., "Electric Static Charge Generated From the Friction of Textiles", Journal of the Egyptian Society of Tribology Vol. 10, No. 2, April 2013, pp. 45 – 56, (2013).**
**8. Ibrahim R. A., Khashaba M. I. and Ali W. Y., "Reducing the Electrostatic Discharge Generated from the Friction of Polymeric Textiles", Proceedings of The Third Seminar of the Environmental Contaminants and their Reduction Methods, September, 26 – 28, 2011, AlMadina AlMonawwara, Saudi Arabia, (2011).**
**9. Zhancheng W., Chen Y., and Xiaofeng L., Shanghe, "Research on ESD ignition hazards of textiles". J. of Electrostatics 57, pp. 203 – 207, (2003).**

**10. Chubb J., New approaches for electrostatic testing of materials, J. of Electrostatics 54, pp. 233 – 244, (2002).**

**11. Bhushan B., "Introduction - measurement techniques and applications", Handbook of Micro/Nanotribology, pp. 3 - 4, Boca Raton: CRC Press LLC, (1999).**

**12. Myshkin N. K., Petrokovets M. I., Kovalev A. V., "Tribology of polymers: Adhesion, friction, wear, and mass-transfer", Tribology International, Vol. 38, pp. 910 - 921, (2005).**

**13. Matthew D. A., Christian S. J., "Investigation of skin tribology and its effects on the tactile attributes of polymer fabrics", Wear, Vol. 267, pp. 1289 - 1294, (2009).**

**14. Derler S., Schrade U., Gerhardt L. C., "Tribology of human skin and mechanical skin equivalents in contact with textiles", Wear, Vol. 263, pp. 1112 - 1116, (2007).**

**15. Poopathy K., Michael T. J., Juk H., Paul H., Jan L., Gabriele S. L., "Measurements of incendivity of electrostatic discharges from textiles used in personal protective clothing", Journal of Electrostatics, Vol. 49, pp. 51 - 70, (2000).**

**16. Sulaimany A. A., AlGethami A. A. and Ali W. Y., "Friction Coefficient Between Clothes and Car Seat Covers", Journal of the Egyptian Society of Tribology Vol. 8, No. 4, October 2011, pp. 35 – 46, (2011).**

**17. Al-Osaimy A. S., Mohamed M. K. and Ali W. Y., "Friction Coefficient and Electric Static Charge of Head Scarf Textiles", Journal of the Egyptian Society of Tribology Vol. 9, No. 3, July 2012, pp. 24 – 39, (2012).**

**18. Morioka K., "Hair Follicle-Differentiation Under the Electron Microscope, Springer-Verlag, Tokyo, (2005).**

**19. Bhushan B., LaTorre C., "in: B. Bhushan (Ed.), Nanotribology and Nanomechanics - An Introduction", second ed., Springer, Berlin, (2008).**

**20. Diaz A.F., Felix-Navarro R.M., "A semi-quantitative tribo-electric series for polymeric materials: the influence of chemical structure and properties", Journal of Electrostatics 62, pp. 277 - 290, (2004).**

**21. Greason W.D., "Investigation of a test methodology for triboelectrification", J. Electrostatics 49, pp. 245 – 256, (2000).**

**22. Kailer A., Amann T., Krummhauer O., Herrmann M., Sydow U., Schneider M., "Wear Influence of electric potentials on the tribological behaviour of silicon carbide", Wear 271, pp. 1922– 1927, (2011).**

**23. Meng Y., Hu B., Chang Q., "Control of friction of metal/ceramic contacts in aqueous solutions with an electrochemical method", Wear 260, pp. 305 - 309, (2006).**

**24. Sydow U., Schneider M., Herrmann M., Kleebe H.-J., Michaelis A., "Electrochemical corrosion of silicon carbide ceramics", Mater. Corros. 61 (8) (2010).**

**25. Celis J.-P., Ponthiaux P., Wenger F., "Tribo-corrosion of materials: interplay between chemical, electrochemical, and mechanical reactivity of surfaces", Wear 261 (9), pp. 939 - 946, (2006).**