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REDUCING THE TRIBOELECTRIFICATION OF POLYMERIC STRINGS

Ali A. S.[1], Mohamed M. K.[2], Youssef M. M.[3], Ali W. Y.[2] and Abdu H. M.[2]

[1]Mechanical Engineering Dept., Faculty of Engineering, Suez Canal University, EGYPT,
[2]Production Engineering and Mechanical Design Department,
[3]Automotive Engineering and Tractors Department,
Faculty of Engineering, Minia University, P. N. 61111, El-Minia, EGYPT.

ABSTRACT
The surface properties of the strings control the comfort and quality of textiles. The measure of the smoothness and slipperiness of textiles are evaluated by the friction coefficient displayed by sliding of textiles against human skins or other textiles. The extensive use of polymeric fibers such polyester (PET) in textile industry increased the need to investigate their triboelectrification during contact/separation and sliding on cotton as well as human skin. The electrostatic charge (ESC) generated from the friction of PET strings against cotton was tested.

The present study showed that among the tested strings, PE generated the highest negative voltage followed by PET, while wool recorded the highest positive voltage followed by PMMA. Besides, the blend of wool/PET and wool/PE strings reduced ESC generated after contact/separation and sliding on cotton, where ESC decreased with the increase of the PMMA content. It was observed that, inserting Cu wires and CF in the core of polymeric strings showed drastic ESC decrease. The effect of Cu wires was more effective than CF to reduce ESC. Finally, blending the polymeric strings as well as inserting Cu wires or CF in the polymeric strings are recommended to decrease the generated ESC.

KEYWORDS
Triboelectrification, polymeric strings, polyester, contact/separation, sliding, cotton.

INTRODUCTION
The extensive application of polymeric strings in textiles raised the necessity of reducing their triboelectrification. Electrostatic charge (ESC) generated from sliding of the polymeric textiles against cotton and human body should be reduced to avoid serious health problems. Recently, ESC generated from the contact/separation and sliding of polymeric textiles on cotton and wool was tested, [1 - 8], by blending polymeric strings of dissimilar electrostatic properties or by filling by carbon fibers (CF). ESC of specimens of PET blended by polyamide (PA), rayon strings were

investigated by sliding on cotton and wool textiles. It was observed that ESC decreased with increasing PA content. The lowest values of ESC at sliding were detected at 93 wt. % PA. Blending cotton and wool with polymeric fibers decreased ESC generated from their friction with each other, [9 - 11]. Therefore, blending of fibers was recommended. Besides, it was observed that addition of carbon fibers (CF) into the polymeric strings drastically decreased ESC compared to that observed in strings free of CF due to the good electrical conductivity of CF.

It was found that use of textiles with conductive earthed threads can decrease the friction-induced injuries of skin like blistering in sport, [12 – 14]. Further researches were recommended to study the friction as well as the contact between foot, sock and shoe during walking and running. In automotive application, the contact of the covers of car seat against the clothes can generate ESC of values depended on their electrostatic properties, [15 - 17]. The friction as well as the contact of hair and head scarf of textiles materials were studied, [18 - 23]. The contact/separation and sliding of cotton, PET and PA were tested against hair, where sliding displayed higher ESC than contact/separation. PA showed the lowest friction. Human hair generated ESC when rubbed human skin, polymers and textiles, [24 - 26].

The purpose of the present study is to decrease ESC generated from the contact/separation and sliding of PMMA and PET strings against cotton. Two procedures are proposed, the first is to blend the polymeric strings by others of different triboelectric properties as well as inserting Cu wires or CF in the polymeric strings to decrease the generated ESC.

EXPERIMENTAL

ESC was measured by the electrostatic fields (voltage) measuring device. The tested strings were adhered into the one surface of the moving polymethyl methacrylate (PMMA) cube of 50 × 50 × 50 mm^3. The stationary surface was PMMA sheet of 5 mm thickness and 200 mm length, where the cotton textile was adhered. Test specimens consisted of polyethylene (PE), PET, PMMA and wool strings of 2.0 mm diameter, Fig. 1. Tests were carried out at room temperature under 2, 4, 6, 8 and 10 N normal loads. Tests were carried out by contact/separation as well as sliding the test specimens against cotton for 100 mm distance. PET strings of 2.0 mm were filled by copper (Cu) wires and carbon fibers (CF) 0.2 mm diameter, Fig. 2.

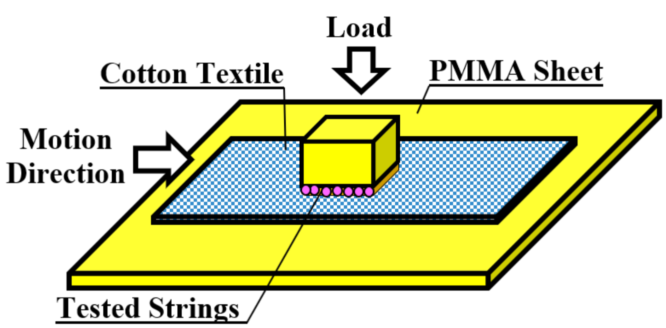


Fig. 1 Details of test procedure.

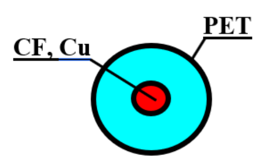


Fig. 2 Details of the tested string filled by Cu or CF.

RESULTS AND DISCUSSION

The Voltage generated from the contact/separation of PE, PET, PMMA and wool strings is illustrated in Fig. 3. It is revealed that PE generated the highest negative voltage followed by PET, where the voltage remarkably increased as the load increased due to the increased contact area. Wool displayed the highest voltage followed by PMMA. The generation of the positive and negative voltage depends on the rank of the materials in the triboelectric series. The contact and friction of dissimilar materials generates ESC. This behavior is known as triboelectrification, [27]. The transfer of ESC can be in form of electron transfer and ion transfer as well as material transfer, [28, 29]. The sliding of the tested strings generated higher voltage values than that observed for contact/separation, Fig. 4. PE displayed the highest negative voltage up to 8200 volts. According to the triboelectric series, because PE lies in the lower part of the series and cotton lies in the middle the friction between the two surfaces causes the cotton to be positively charged and PE to be negatively charged. Besides the long distance between the two materials in the series increases the chance to exchange more electrons between PE and cotton, Fig. 5.

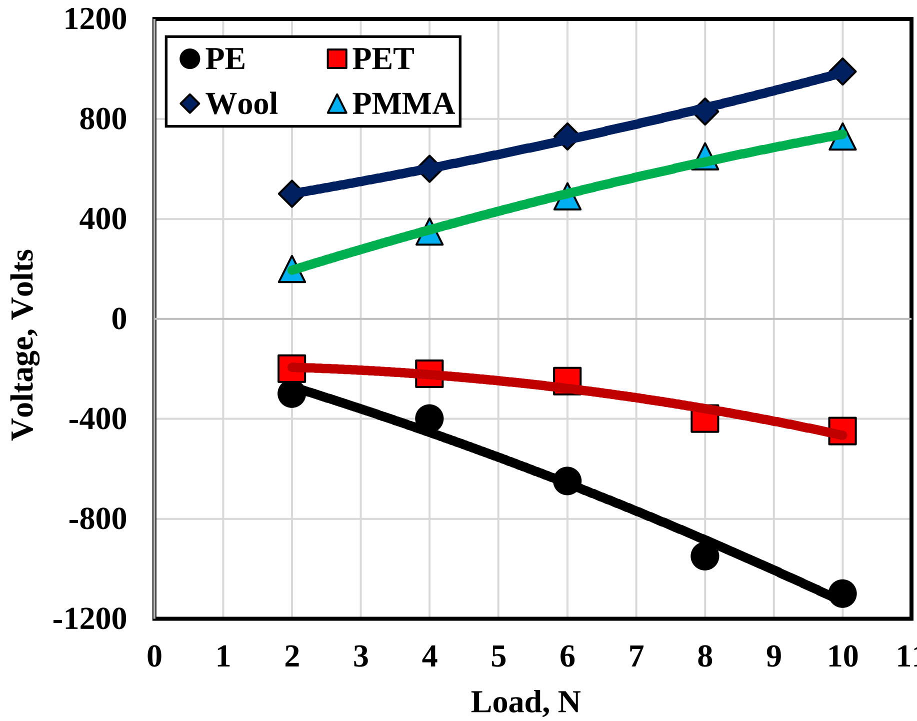


Fig. 3 Voltage generated from the contact/separation of the tested strings with cotton.

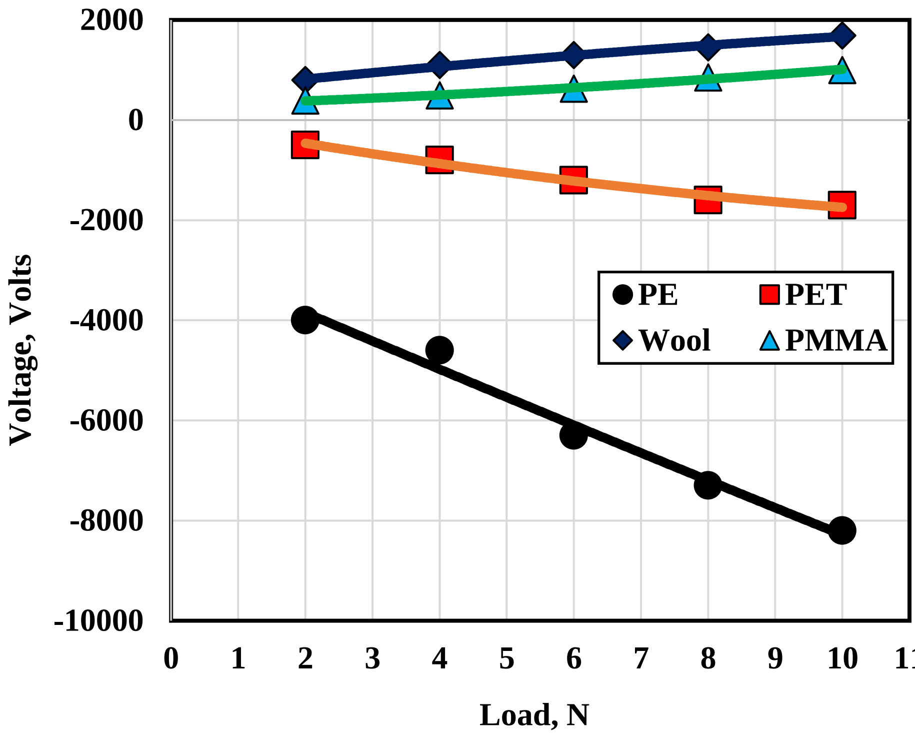


Fig. 4 Voltage generated from the sliding of the tested strings on cotton.

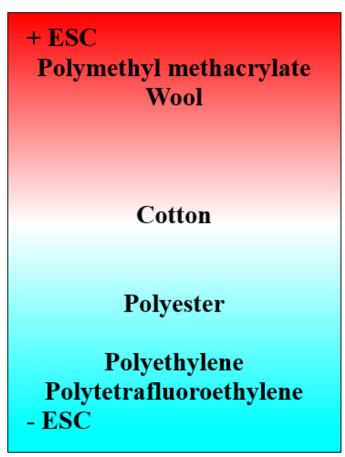


Fig. 5 Triboelectric series of the tested materials.

Figures 6 and 7 shows the voltage generated from the contact/separation and sliding respectively of the blend of wool/PET and wool/PE strings on cotton. The wool content was 50 wt. %. According to the fact that PET and PE get negatively charged while wool gaines positive ESC when they rub cottton, the resultant ESC accumulated on the two contacting surfaces showed relative decrease. The triboelctric series informs that the magnitude of ESC depends on the contact materials rank where the gap between cotton and PET is smaller than the gap between PE and cotton. The friction between wool and cotton causes the wool in the

upper position of the series to be positively charged and cotton that relatively in the lower position to be negatively charge. PET and PE gain negative ESC when rub cotton that gains positive ESC.

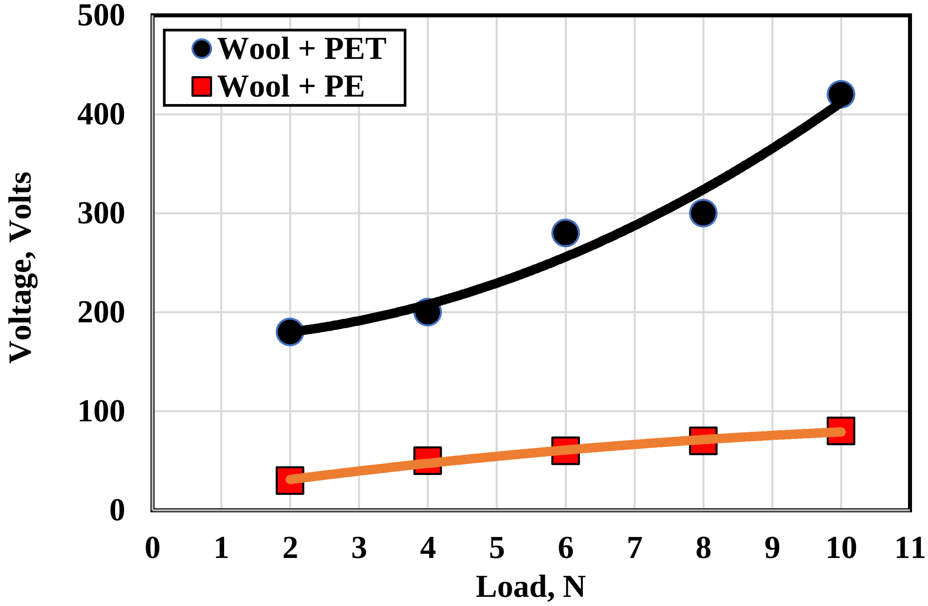


Fig. 6 Voltage generated from the contact/separation of the blend of wool/PET and wool/PE strings with cotton.

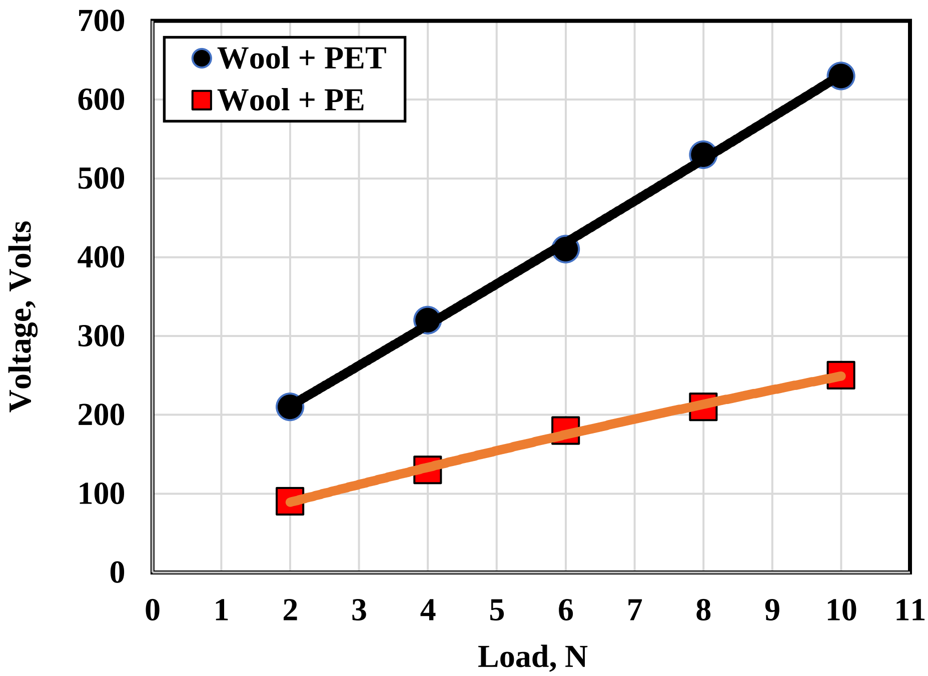


Fig. 7 Voltage generated from the sliding of the blend of wool/PET and wool/PE strings on cotton.

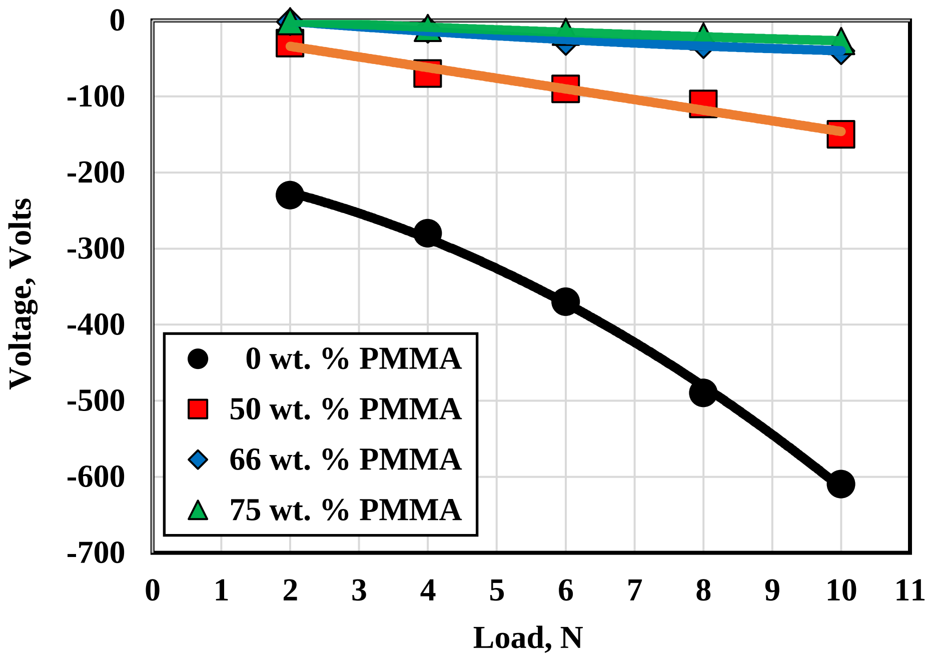


Fig. 8 Voltage generated from the contact/separation of the blend PMMA/PET strings with cotton.

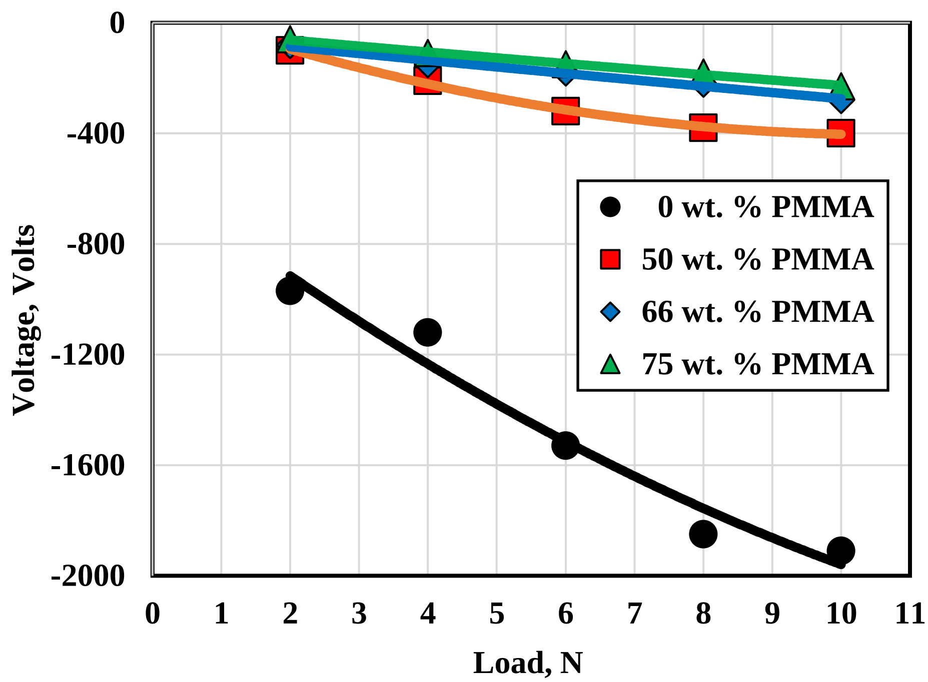
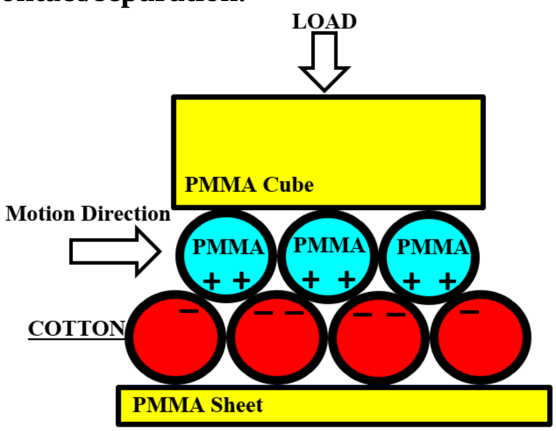
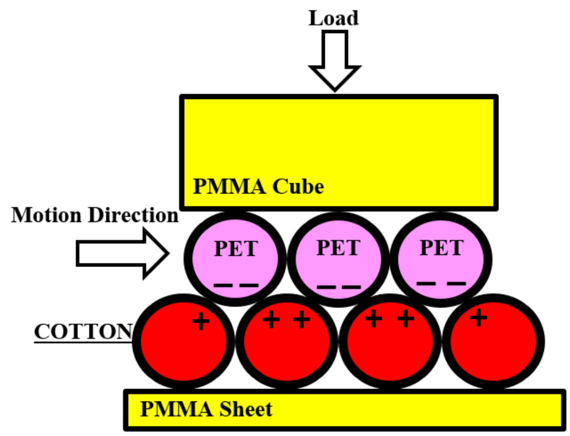


Fig. 9 Voltage generated from the sliding of the blend PMMA/PET strings on cotton.

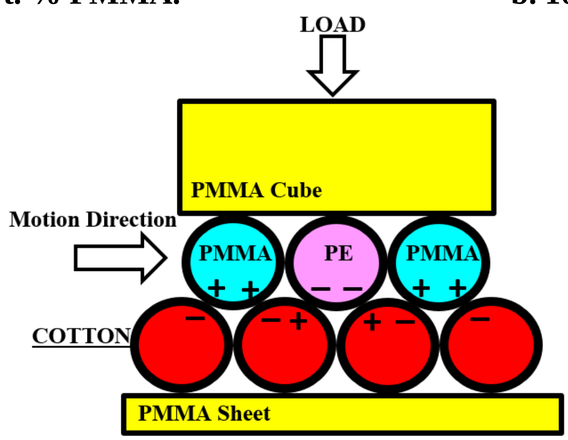
Experiments were carried out to investigate the influence of blending polymeric strings of different electrostatic properties such as PMMA and PET after contact/separation and sliding on cotton, where the results are illustrated in Figs. 8 and 9. Based on the triboelectric series, PET gaines negative ESC and PMMA gaines positive one when they rub cottton. Then the resultant generated ESC on the two blend and cotton surfaces depends on the relative content of PET and PMMA, Fig. 10. It was found that as the content of PMMA increased, ESC generated decreased. Sliding of PMMA/PET on cotton recorded higher ESC values than that measured for contact/separation.



a. 100 wt. % PMMA.



b. 100 wt. % PET.



c. Blend of PMMA and PET.

Fig. 10 Illustration of the ESC distribution on the surfaces of the tested strings.

The effect of inserting CF in PMMA strings during contact/separation and sliding on cotton textile is shown in Figs. 11 and 12 respectively, where the highest ESC values were displayed by PMMA free of CF. As CF content increased the voltage decreased. It seems that the ESC decrease may be from the charge transfer offered by CF. ESC generated on the surface of PMMA strings blended by 10 wt. % CF displayed very low voltage values that did not exceed 60 volts at 10 N load confirming the effect of CF was significant in reducing ESC. It can be mentioned that CF conduct ESC from

one surface to the other.

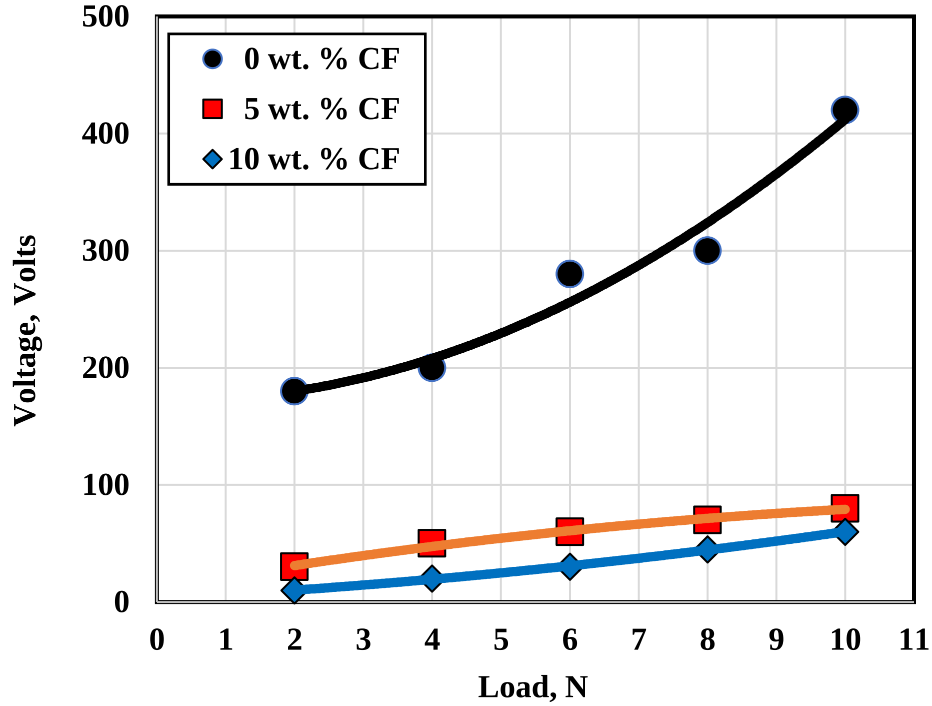


Fig. 11 Voltage generated from the contact/separation of PMMA strings filled by CF with cotton.

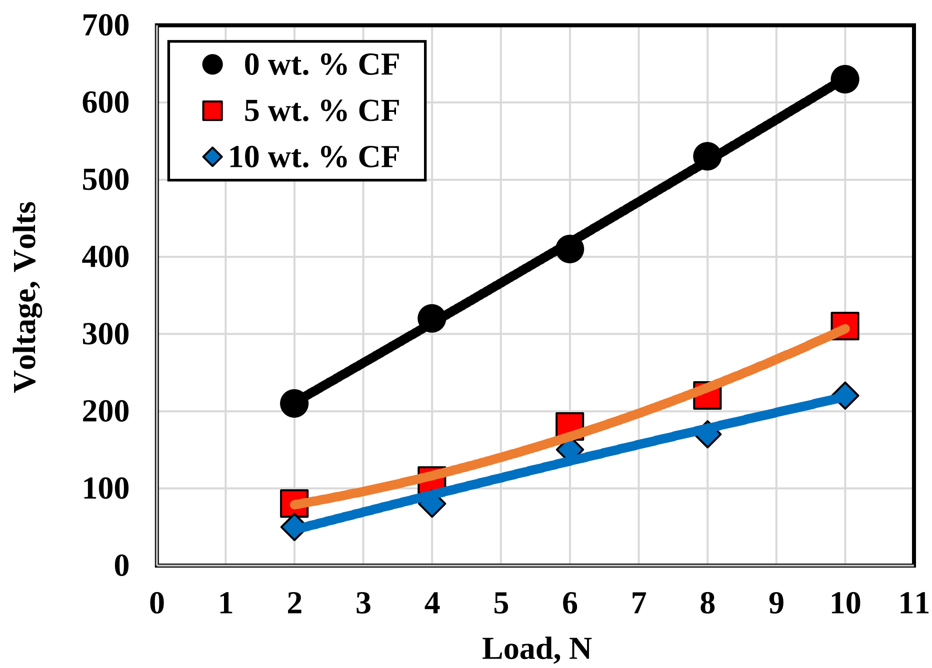


Fig. 12 Voltage generated from the sliding of PMMA strings filled by CF on cotton.

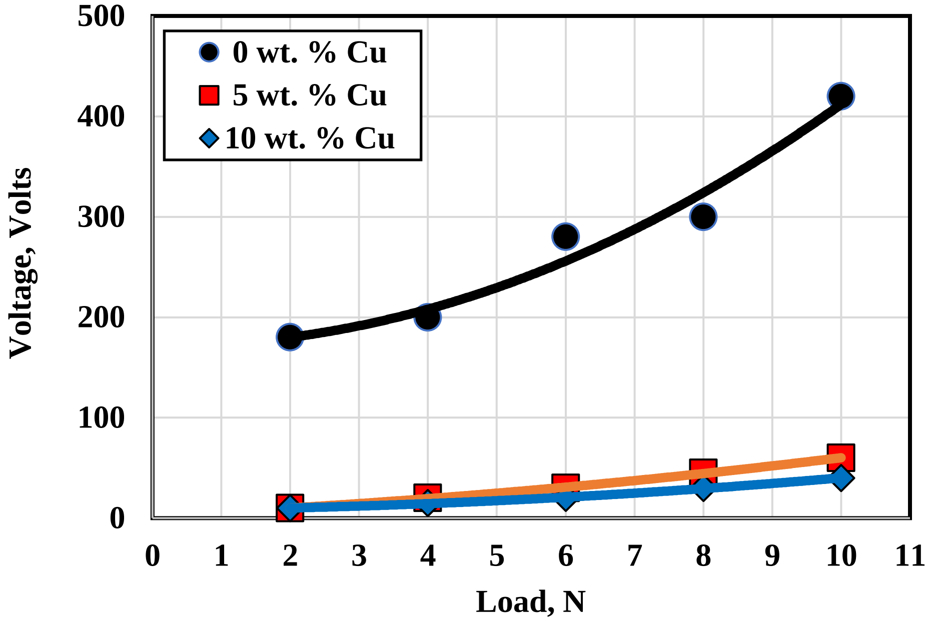


Fig. 13 Voltage generated from the contact/separation of the blend wool/PET strings filled by Cu with cotton.

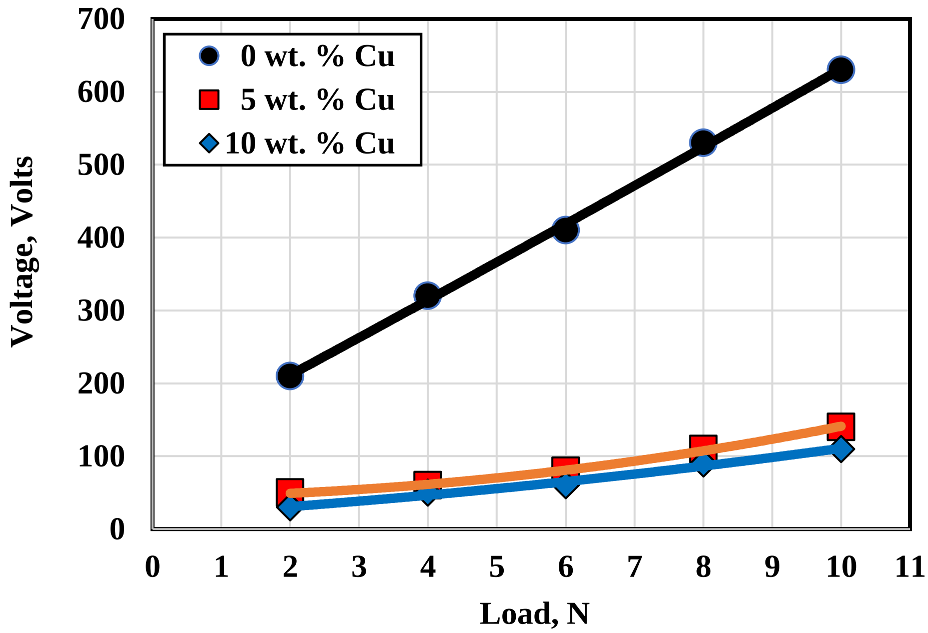


Fig. 14 Voltage generated from the sliding of the blend wool/PET strings filled by Cu on cotton.

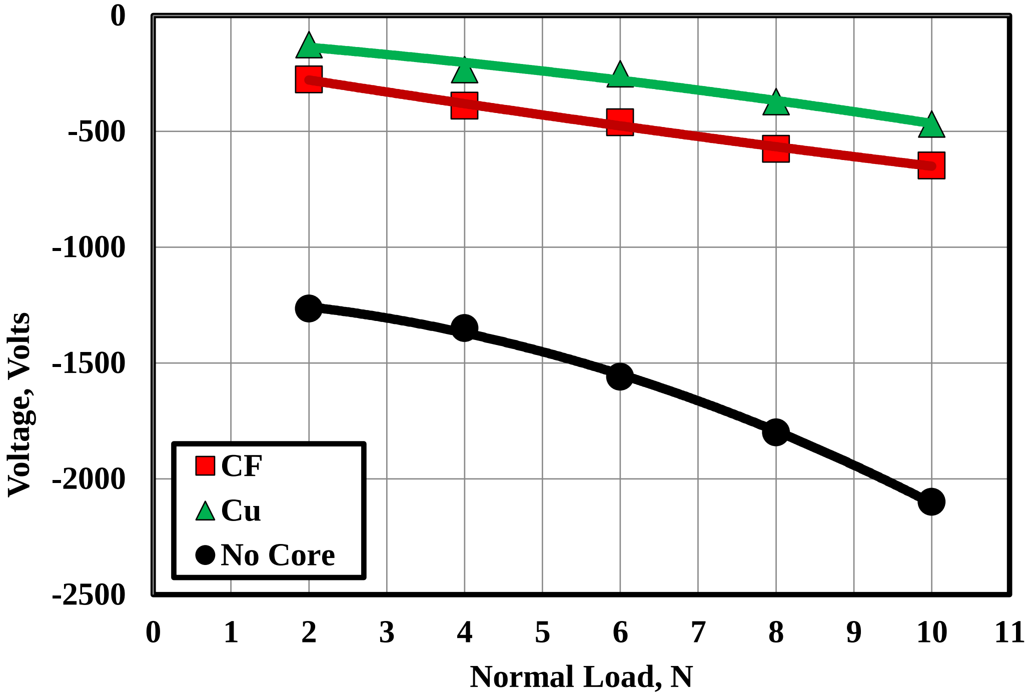


Fig. 15 Voltage generated from the contact/separation of PET strings filled by Cu and CF with cotton.

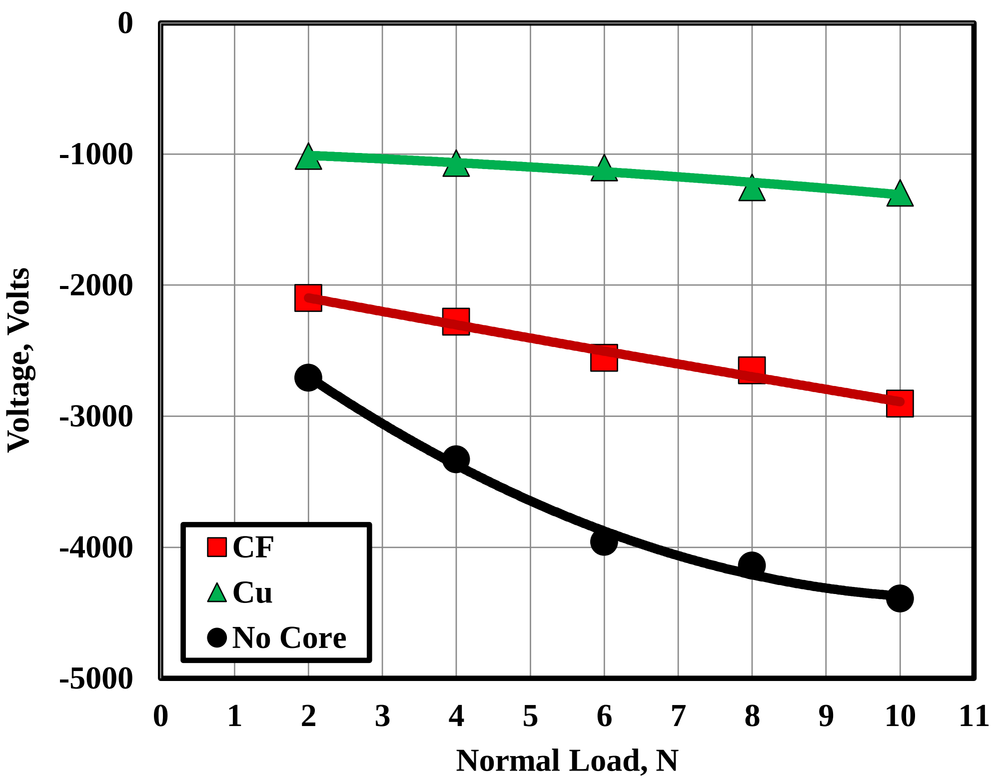


Fig. 16 Voltage generated from the sliding of PET strings filled by Cu and CF with cotton.

Voltage generated from the contact/separation and sliding of PMMA strings blended by Cu wires is displayed in Figs. 13 and 14 respectively. It is shown that the voltage drastically decreased with increasing applied load, while it drastically decreased with increasing Cu wires content. The lowest voltage values were observed for 10 wt. % Cu wire content. AT 10 N load the voltage value was 40 volts. PMMA gained positive ESC while cotton gained negative one, then Cu wires facilitated the conduction of negative ESC from cotton to PMMA and the positive ESC from PMMA to the cotton. Consequently, the resultant ESC drastically decreased. Based on the results plotted in Figs. 11 – 14, it can be concluded that the effect of Cu wires was more pronounced that CF in the reduction of ESC.

The results of the strings filled by electrically conductive materials such as Cu wires and CF were inserted in PET strings to release ESC from the surface are shown in Figs. 15 and 16 for contact/separation and sliding respectively. Cu wires proved the effective voltage reduction followed by CF. That behavior confirmed that voltage can be easily reduced by reinforcing PET strings by Cu or CF. Because PET is an insulator that trap ESC on the surface of its fibers, ESC cannot transfer from the surface, but when the conductor contacts the surface can remove ESC. Inserting of conducting wires or fibers inside PET allows electrons to leave the surface. Because polymers are insulators they can trap the generated ESC on their surfaces. It is known that ESC cannot transfer along the surface, but it can be released from the surface by the conductor that contacts the surface. The presence of Cu or CF cores inside PET strings allows electrons to leave the surface.

CONCLUSIONS

1. PE generated the highest negative voltage followed by PET.
2. Wool displayed the highest positive voltage followed by PMMA.
3. Blend of wool/PET and wool/PE strings after contact/separation and sliding on cotton showed relative decrease in the resultant ESC accumulated on the two contacting surfaces. ESC decreased as the content of PMMA increased.
4. Sliding of PMMA/PET on cotton displayed higher ESC values than that observed for contact/separation.
5. When CF content inserted in PMMA strings increased ESC decreased.
6. Influence of Cu wires was more pronounced than CF to reduce the magnitude of ESC.
7. It can be recommended to insert Cu wires or CF in the core of polymeric strings to reduce the their triboelectrification.

REFERENCES

1. Suaad H., Mohamed M. K. and Ali W. Y., “Reduction of Triboelectrification of Polymeric Textiles”, KGK Kautschuk Gummi Kunststoffe 77. Jahrgang, Nr 1/2024, pp. 66 – 70, (2024).
2. Suaad H., Mohamed M. K. and Ali W. Y., “Decreasing the Electrostatic Discharge Generated from Friction of Polyester and Polyamide Using Carbon Fiber”, Materialwiss. Werkstofftech., 55, pp. 1 - 6, (2024).
3. Suaad H., Mohamed M. K. and Ali W. Y., “Proper Selection of Textiles Based on

Electrostatic Charge Generated from their Contact-Separation and Sliding on Wool Fibers", Journal of the Egyptian Society of Tribology, Vol. 20, No. 3, July 2023, pp. 1 – 11, (2023).
4. Suaad H., Mohamed M. K. and Ali W. Y., "Electrostatic Charge Generated from the Contact-Separation and Sliding of Rayon/Polyester Textiles on Wool", Journal of the Egyptian Society of Tribology, Vol. 20, No. 3, July 2023, pp. 12 – 22, (2023).
5. Suaad H., Mohamed M. K. and Ali W. Y., "Enhancing the Performance and Comfort of Polymeric Textiles", Journal of the Egyptian Society of Tribology, Vol. 20, No. 2, April 2023, pp. 48 – 56, (2023).
6. Suaad H., Mohamed M. K. and Ali W. Y., "Electrostatic Charge Generated from the Contact-Separation and Sliding of Polyamide and Polyester Strings Blended by Carbon Fibers on Cotton", Journal of the Egyptian Society of Tribology, Vol. 20, No. 2, April 2023, pp. 66 – 76, (2023).
7. Suaad H., Mohamed M. K. and Ali W. Y., "Reducing the Electrostatic Discharge Generated from the Contact and Separation as well as Sliding of Polymeric Textiles on Cotton", Journal of the Egyptian Society of Tribology, Vol. 19, No. 4, October 2022, pp. 54 – 62, (2022).
8. Ali A. S., "Triboelectrification of Synthetic Strings", Journal of the Egyptian Society of Tribology, Vol. 16, No. 2, April 2019, pp. 26 – 36, (2019).
9. 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).
10. 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).
11. 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).
12. 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).
13. Shoush K. A., Mohamed M. K., Zaini H. and Ali W. Y., "Measurement of Static Electricity Generated from Contact and Separation of Clothes and Car Seat Covers", International Journal of Scientific & Engineering Research, Volume 4, Issue 10, October-2013 , pp. 1 – 6, (2013).
14. 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).
15. 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).
16. Ahmed Fouly, Badran A. H. and Ali W. Y., "A Study on the Electrostatic Charge Generated From the Friction of Wig Cap Textiles against Human Skin and Hair", International Journal of Engineering and Information Systems (IJEAIS), Vol. 2 Issue 7, July – 2018, pp. 25 – 33, (2018).
17. Mohamed R. A., Samy A. M., Ali W. Y., "Electric Static Charge and Friction Coefficient of Head Scarf Textiles Sliding Against Hair and Skin", International Journal of Advanced Materials Research, Vol.2, No. 3 (April), pp. 45 – 51, (2016).

18. Abdel-Mageed A. M.,Ibrahim R. A., Ali W. Y., "Friction Coefficient of Headscarf Textiles Sliding Against Hair and Skin", International Journal of Advanced Materials Research, Vol.2, N0. 3 (April), pp. 24 – 28, (2016).

19. Esraa S. S., Khansaa A. M., Rasha A. A., Sahar A. K., Sandra E. S., Ali W. Y., "Proper Selection of Foot Wearing Socks Textiles Based on Friction Coefficient Displayed by Sliding Against Indoor Floors", EGTRIB Journal, Vol. 13, No. 2, April 2016, pp. 15 – 24, (2016).

20. Mahmoud M. M., Ali W. Y., "Electric Static Charge Generated from the Sliding of Head Scarf Textiles Against Skin and Hair", International Journal of Scientific & Engineering Research, Volume 4, Issue 9, February - 2016, pp. 375 – 389, (2016).

21. Ali W. Y., AL-Ealy Y., AL-Otaibi A., AL-Zahrany N., AL-Harthy O. and Mohamed M. K., "Triboelectrification of Synthetic Textiles", 1st International Workshop on Mechatronics Education, March 8th -10th 2015, Taif, Saudi Arabia, pp. 264 – 277, (2015).

22. AlEili Y., Mohamed M. K. and Ali W. Y., "Triboelectrification of Polymeric Textiles", Journal of the Egyptian Society of Tribology, Vol. 12, No. 1, January 2015, pp. 26 - 35, (2015).

23. 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).

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

25. Bhushan B., La Torre C., "in: B. Bhushan (Ed.), Nanotribology and Nanomechanics - An Introduction", second ed., Springer, Berlin, (2008).

26. Schroder D. K., "Semiconductor Material and Device Characterization", third ed., Wiley, Hoboken, (2006).

27. Lowell J., Rose-Innes A. C., "Contact electrification", Adv. Phys. 29, pp. 947 - 1023, (1980).

28. Lee L. H., "Dual mechanism for metal–polymer contact electrification", J. Electrostat. 32, 1 - 29, (1994).

29. Sow M., Lacks D. J., Sankaran R. M., "Effects of material strain on triboelectric charging: Influence of material properties", Journal of Electrostatics 71 pp. 396 – 399, (2013).