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DEVELOPMENT OF ELECTRONIC SKIN BASED ON BIDIRECTIONAL DIRECT CURRENT TRIBOELECTRIC NANOGENERATOR

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ABSTRACT

The present paper studies the development of the design of electronic skin by introducing bidirectional direct current triboelectric nanogenerator (BDC-TENG) to work as self-powered sensor. The feedback signal generated from the BDC-TENG due to the sliding of polytetrafluoroethylene (PTFE) on polyamide (PA) is tested. It is aimed that BDC-TENG generates electric current from the sliding of PTFE on PA, where the polarity depends on the motion direction. The generated DC current works as feedback signal to control the sliding of the object surface on e-skin.

It was observed that the proposed DC-TENG generated bidirectional voltage of signal depends on the sliding direction. When the thickness of PU sponge substrate increased, voltage slightly increased due to the soft contact between PTFE and PA provided by PU foam layer that increased the contact area. Besides, as the load increased, voltage increased. Copper electrodes displayed higher voltage than aluminium ones, where the voltage increased with increasing the width and length of the electrode due to the increase of the contact area of electrode that collects ESC from both the sliding surfaces. In addition, when PA was replaced by PMMA strings, voltage increased up to maximum then decreased with the increase of the electrode width, while voltage slightly increased as electrode length increased. The sliding of PTFE directly on the PU foam significantly increased the voltage. During sliding, DC-TENG generates direct current in two directions.

KEYWORSD

Electronic skin, triboelectric nanogenerator, polyamide, polytetrafluoroethylene, polyurethane.

INTRODUCTION

TENG can be used to covert the sliding of different dielectrics on each other into electric current. That performance can be utilized in the design of e-skin by transferring the sliding of objects on e-skin into electric current to be applied as feedback signal to control the grasping of objects. The traditional triboelectric nanogenerator (TENG) was developed by adding extra charge-collecting electrode (CCE) on the opposite end of the friction surface (FC), [1, 2]. The modified TENG gave bidirectional and double-channel output.

The objective of the direct current triboelectric nanogenerator (DC-TENG) is to be used in the electronic skin. It was found that the DC-TENG can do that subject, [3 – 7]. During sliding, the friction surface induced electrostatic field because of the increase of the ESC density that generates direct current.

In the design of e-skin, it is essential to generate electric current to work as feedback signal during sliding on the surface of the objects to be handled, [8]. Design of e-skin was developed by capacitive, resistive sensors, triboelectrification and electrostatic induction, [9 - 20]. In addition to that, e-skin was developed to detect finger touch, [21, 22]. A gripper mechanism was modified to secure safe objects grasp through the control of the sliding to adapt the gripping force. The feedback signal of the previously mentioned gripper depended on the triboelectrification making use of the ESC double layers generated at the two sliding surfaces, [23]. It was concluded that voltage measured can be applied as feedback signal, [33]. The proposed e-skin included coil of carbon fibers on aluminium film as the electrode in PMMA core. The counterface was kapton film.

Recently, it was proposed to design e-skin consisted of latex as outer layer to guarantee safe grasping of the objects, [34]. It was found that the highest voltage values were observed for PTFE and Kapton as friction surface. To increase the voltage in the external circuit, two charge collecting electrodes were used. It was proposed to apply the DC-TENG to generate DC current to be applied in e-skin.

The present work develops an e-skin based on BDC-TENG to induce direct current as feedback signal.

EXPERIMENTAL

The TENG, proposed in the present work to generate the feedback signal, consisted of two dielectrics, the first was PTFE of 25 µm thickness adhered to wooden block representing the sliding surface. Copper film of 20 µm thickness was used as output electrodes adhered to the both sides of the wooden block to collect ESC generated from sliding of PTFE on the other dielectric. The other sliding surface was polyamide (PA) of 20 µm thickness adhered to the polyurethane (PU) foam, followed by 0.5 mm PMMA sheet as substrate of 30 mm length and 20 mm width. The PU thickness was 2, 5, 8 and 10 mm adhered to the PMMA sheet to provide soft contact layer to increase the contact area between the two sliding surfaces. Then the whole proposed

construction was wrapped by latex, as external layer due to the relative high friction values when sliding with other surfaces. The details of the proposed TENG are shown in Fig. 1. Load was applied by weights up to 10.25 N. The sliding distance was 20 mm.

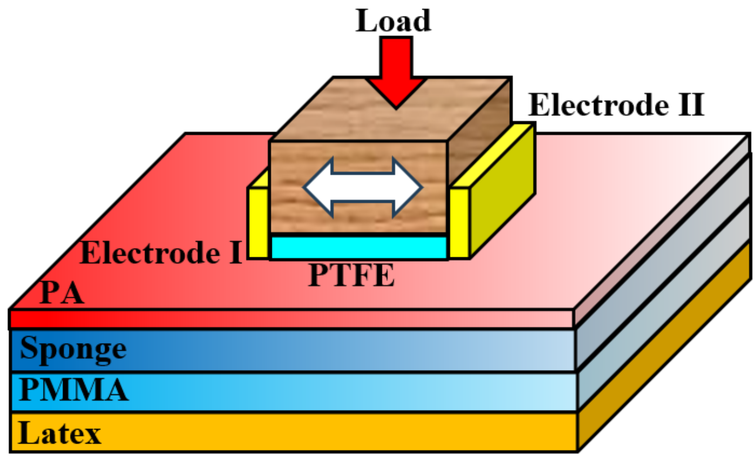


Fig. 1 Details of the DC-TENG proposed to be inserted in the e-skin.

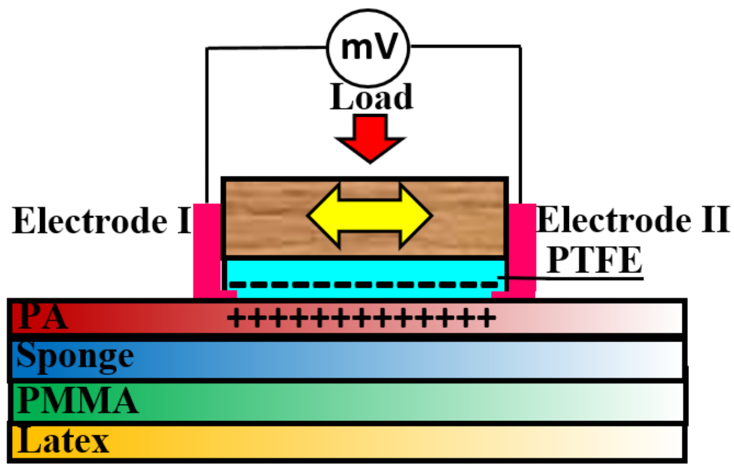
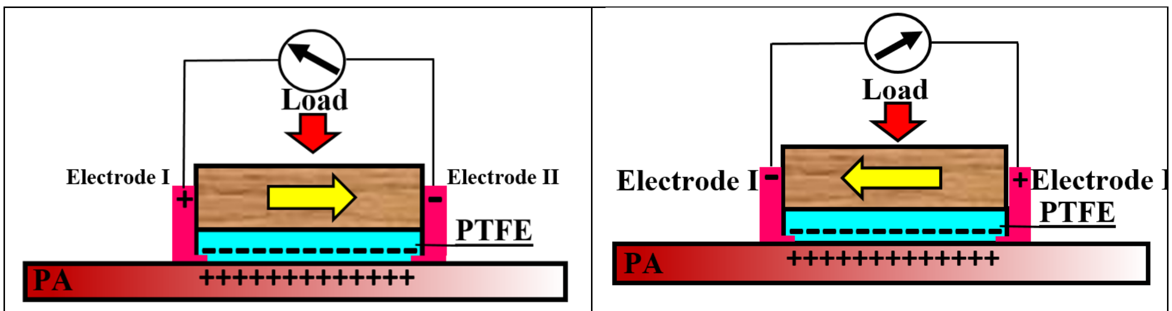
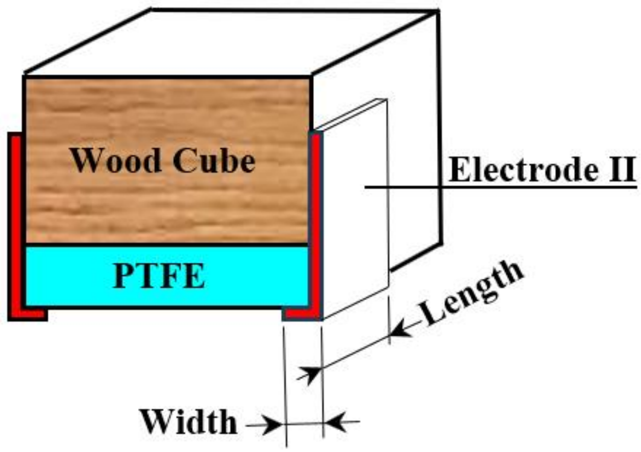


Fig. 2 Generation of ESC on the sliding surfaces.



a.Voltage generated due to the sliding of PTFE to the right.	b. Voltage generated due to the sliding of PTFE to the left.

Fig. 3 Generation of the bidirectional direct current according to the sliding direction.



RESULTS AND DISCUSSION

When PTFE film moved to the right, electrode I collected the positive ESC from PA surface, Fig. 3, a. While the movement of PTFE to the left caused that electrode II collected the positive ESC, Fig. 3, b. The addition of the second electrode, a bidirectional output could be obtained according to the sliding direction. The function of the proposed TENG is to generate double simultaneous ESC, where the current direction is tunable by adjusting the PTFE sliding direction.

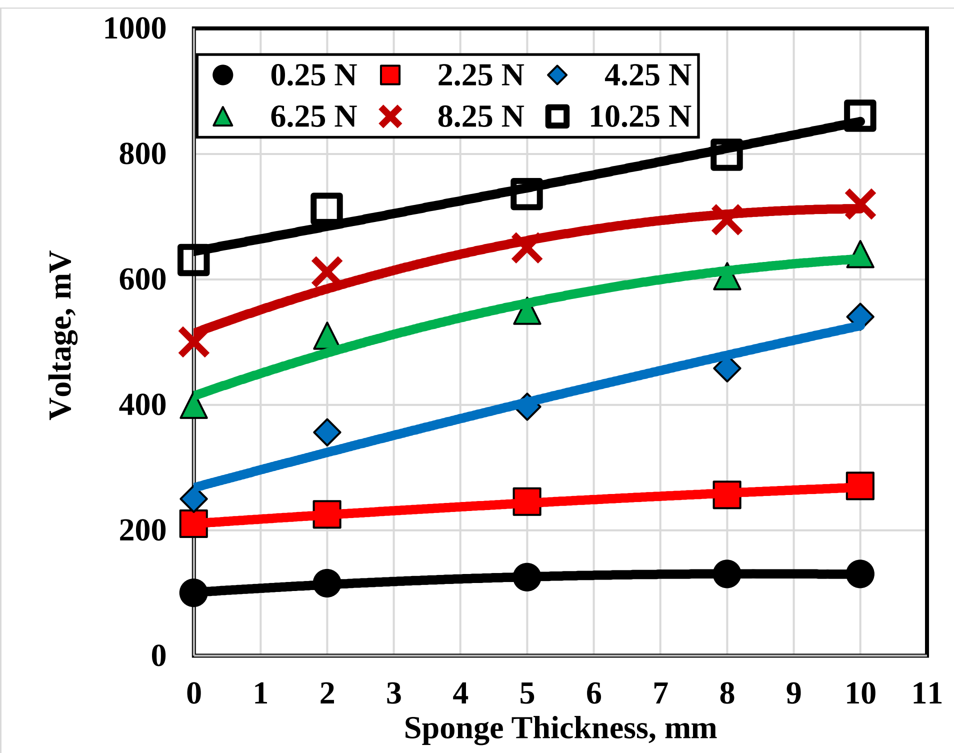


Fig. 4 Voltage difference between the two electrodes versus thickness of sponge. Length 18 mm, 5 mm width of electrode.

The relationship between the generated voltage and the thickness of the sponge is illustrated in Fig. 4. Voltage slightly increased with increasing sponge thickness. Besides, as the load increased, voltage increased. The length and width of electrode were 18 mm, 5 mm respectively. The effect of the type of materials of electrodes on the generated voltage is shown in Fig. 5, where the two copper electrodes (Cu/Cu) displayed relatively higher voltage than that measured for copper and aluminium electrodes (Al/Cu). The length and width of the electrodes were 18 and 4 mm respectively. The highest voltage values were 1590 and 1344 mV for Cu/Cu and Cu/Al electrodes respectively at 18 N load. That behavior recommends to use copper electrodes. Figure 6 shows the voltage difference between the two electrodes versus width of the two electrodes of 18 mm length. As the electrode width increased voltage increased. It seems that the increase of the area of electrode that collects ESC from both of PTFE and PA surfaces was responsible for increase of the voltage. The highest voltage value reached 800 mV at 10 mm sponge thickness and 10.25 N load.

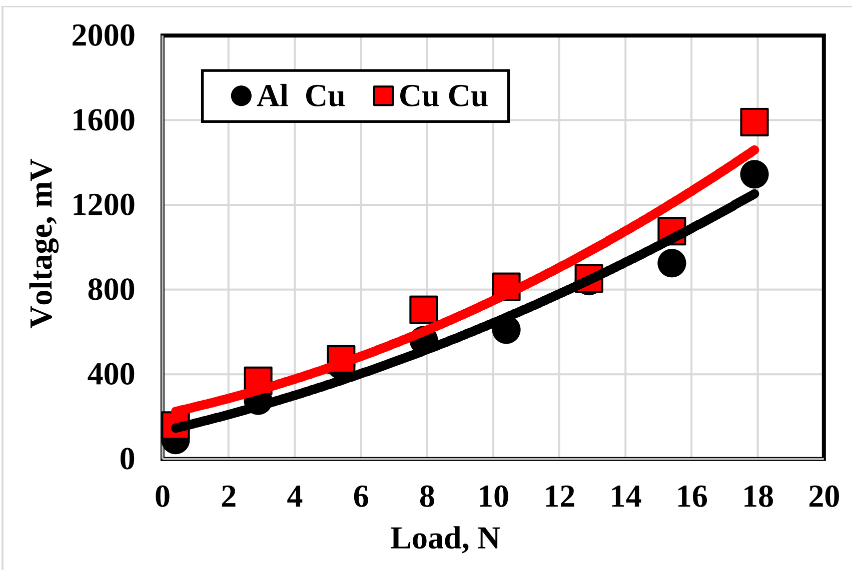


Fig. 5 Voltage difference between the two electrodes I (Cu) and II (Al).

The outer surface of the e-skin was latex of 0.06 mm thickness. Latex was selected because of its relatively higher value of friction coefficient. It is well known that the friction coefficient (μ) between latex and PMMA sheet should be high to facilitate the sliding of PTFE on the PA, [1]. Application of latex enhanced the secure grasp of the objects. The easy sliding of PTFE on PA can be developed by using suitable lubricant that will be discussed in the future research.

Voltage difference between the two electrodes versus length of electrode of 9 mm width during sliding is shown in Fig. 7. It is clearly noticed that voltage significantly increased with increasing the length of electrode due to the increase of the contact area between the electrode and the sliding surface. The highest voltage value

increased from 610 to 800 mV as the electrode length increased from 4 to 18 mm respectively.

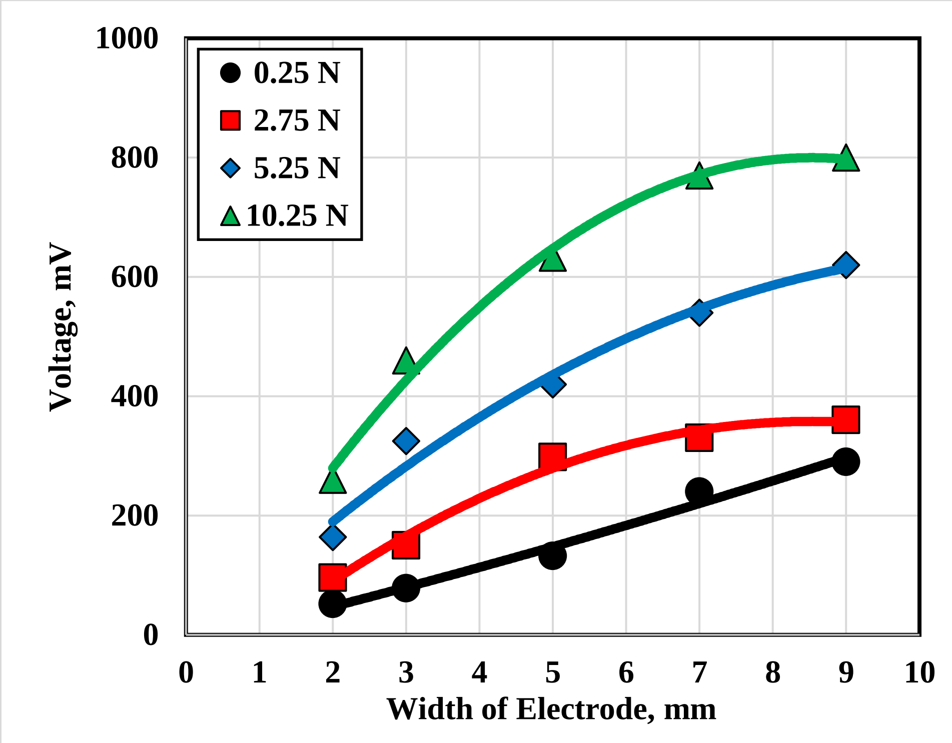


Fig. 6 Voltage difference between the two electrodes versus width of electrode.

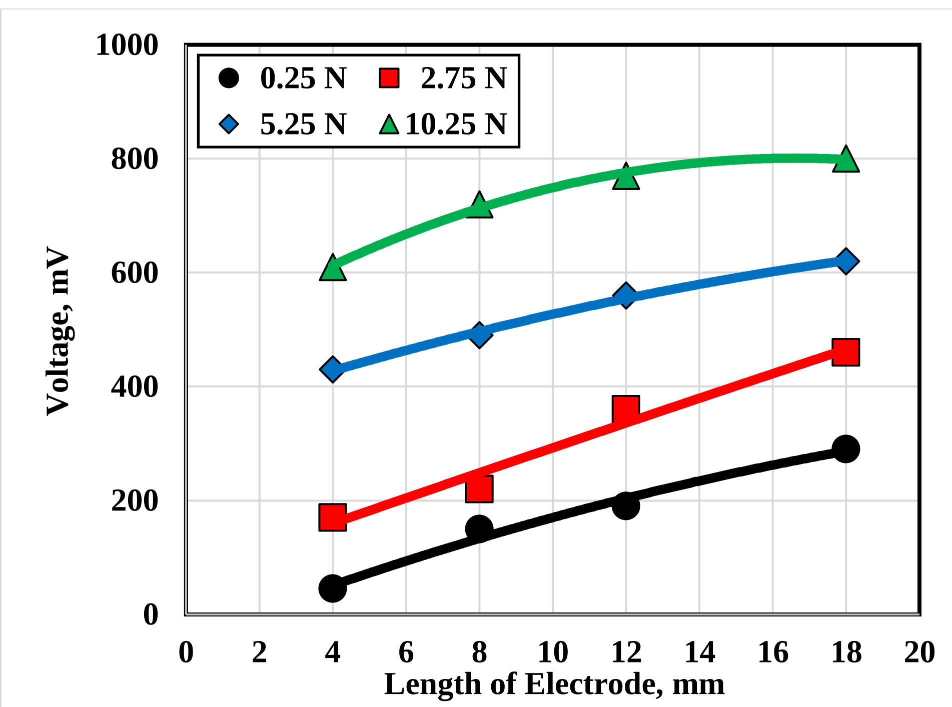


Fig. 7 Voltage difference between the two electrodes versus length of electrode.

When PA surface was replaced by PMMA strings of 2 mm diameter, voltage difference versus width of electrode increased up to maximum then decreased with increasing electrode width, Fig. 8. The highest voltage values were observed at 6 mm electrode width. The increase might be from the increase of the contact area between electrode and sliding surface, while the decrease could be from the decrease of the area of both PTFE and PMMA subjected to friction. The relationship between voltage and length of electrode is shown in Fig. 9. The electrode width was 8 mm. Voltage difference showed slight increase as electrode length increased, where the values showed relatively lower values than that observed for PA surface. The highest voltage value reached 620 mV at 18 mm electrode length and 10.25 N load.

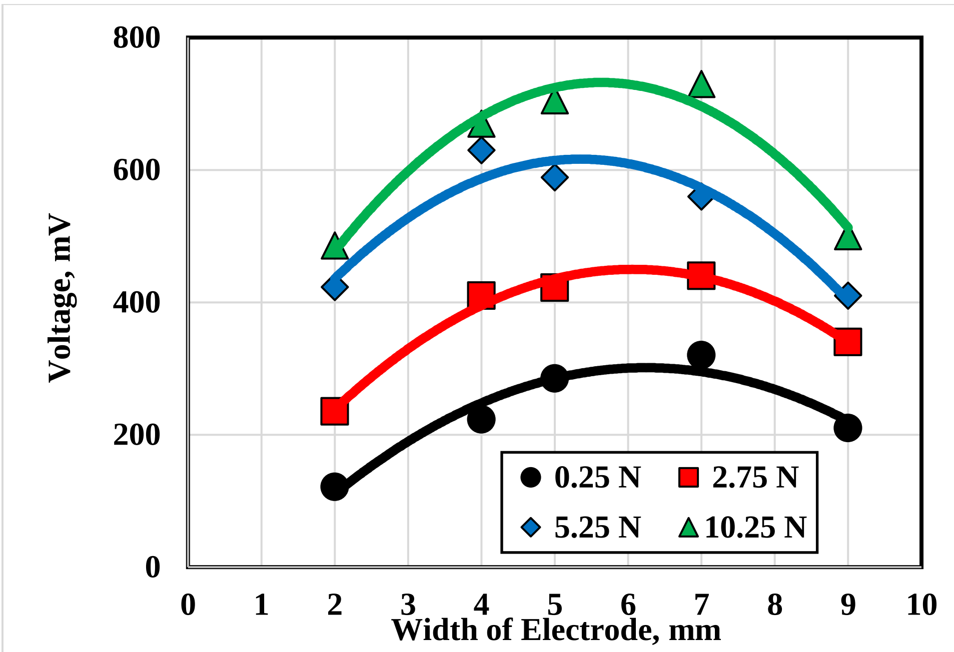


Fig. 8 Voltage difference between the two electrodes versus width of electrode.

Figure 10 illustrates the relation between voltage and electrode width when PA surface was backed by 10 mm thick PU foam, where the electrode length was 18 mm. It is clearly seen that the voltage showed the same trend observed in Fig. 8 for PMMA strings. The voltage values were much higher than that displayed by PMMA surface. It seems that soft contact between PTFE and PA provided by PU foam layer increased the contact area and consequently voltage increased. The optimal electrode width was ranging between 5 and 6 mm for 18 mm electrode length.

The sliding pf PTFE on the surface of PU foam showed significant voltage increase, Fig. 11. The highest voltage value was 1080 mV for 9 mm electrode width and 10.25 N load. It is noticed that replacing PA surface by foamy PU substrate showed increased voltage with increasing electrode width to 9 mm. That behavior was pronounced for the relatively higher loads.

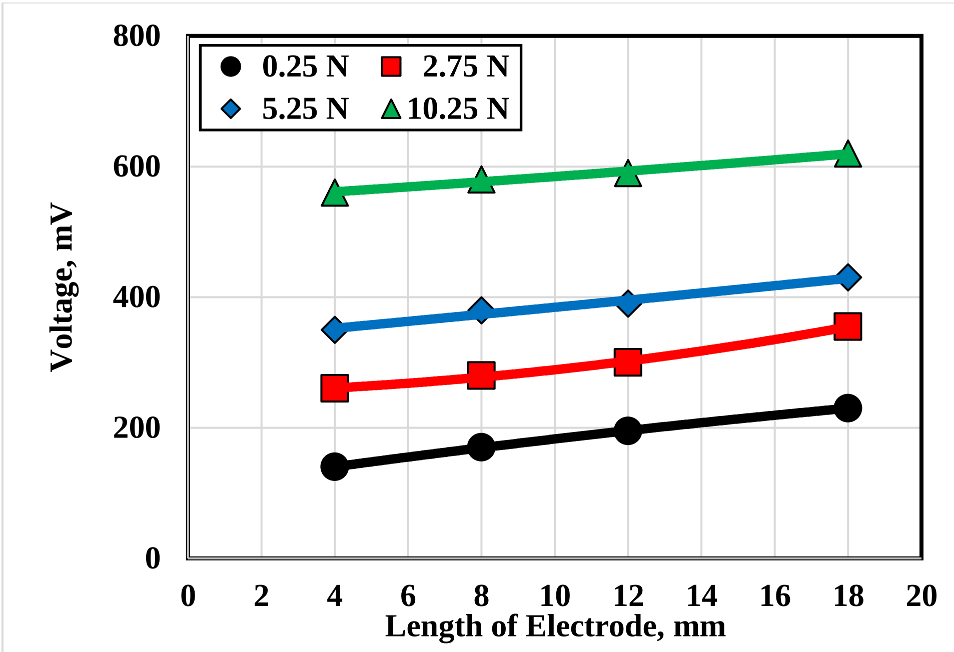


Fig. 9 Voltage difference between the two electrodes versus length of electrode.

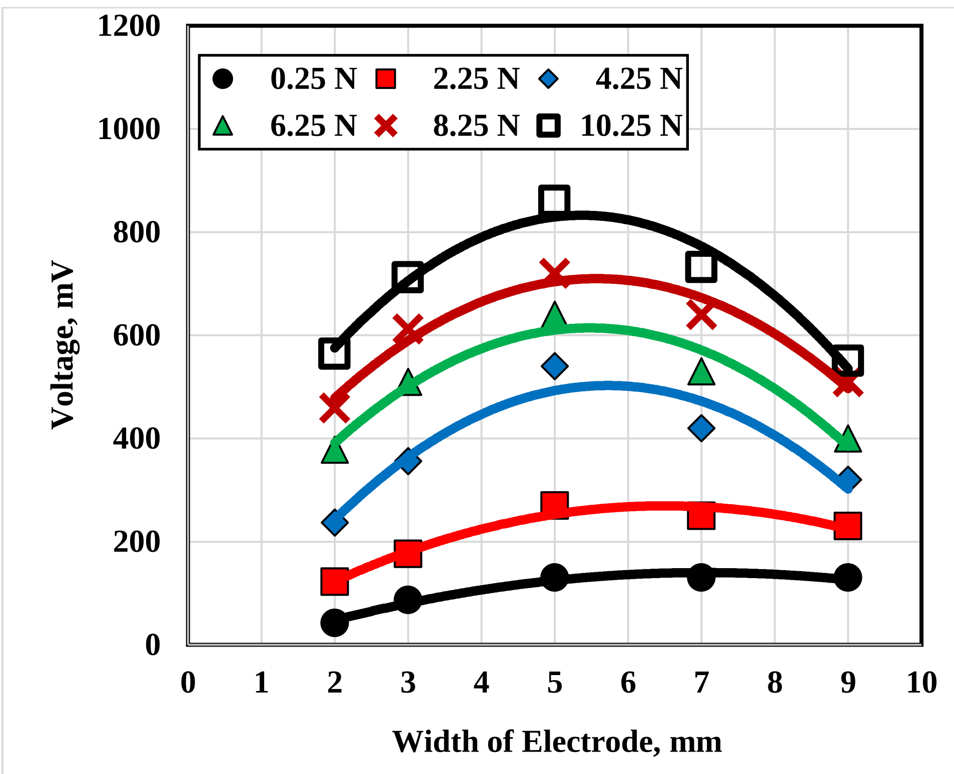


Fig. 10 Voltage difference between the two electrodes versus width of electrode in the presence of PU foam of 10 mm thickness.

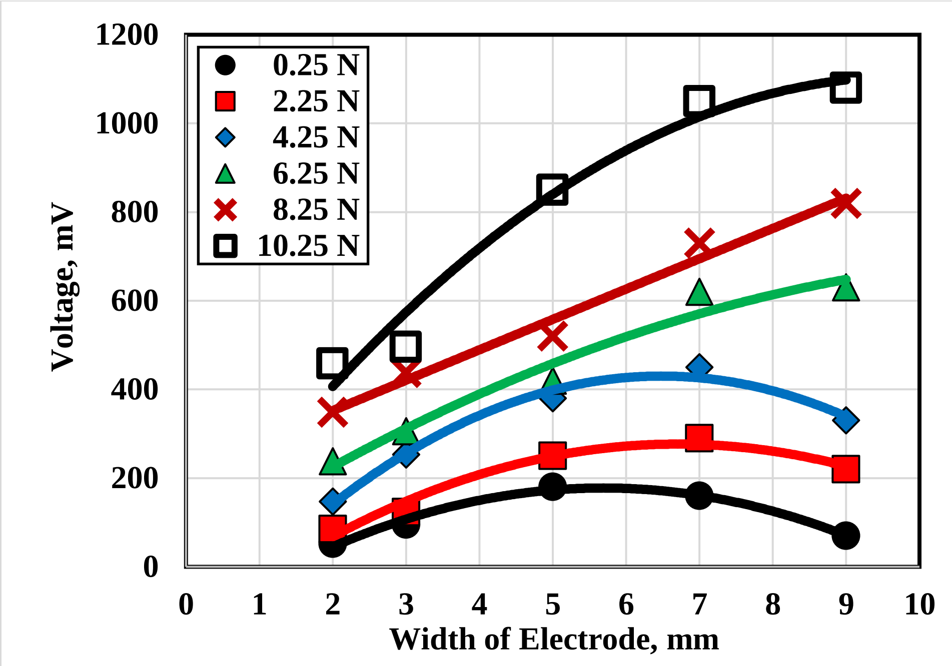


Fig. 11 Voltage difference between the two electrodes versus width of electrode.

The proposed DC-TENG generated bidirectional voltage difference. During sliding, direct current flew in the external circuit in two directions. The sign of ESC depended on the direction of the motion. Consequently, the application of the proposed DC-TENG can be applicable in e-skin design. It is favorable to develop modern methods to control the compactness, performance and stability to be used as a self-powered sensor in the design of the e-skin. It is necessary to carry out further research to enhance the performance by using lubricant between the two sliding surfaces of the proposed TENG

CONCLUSIONS

1. The proposed DC-TENG generated bidirectional voltage according to the sliding direction.
2. Increasing sponge thickness slightly increased voltage, while as the load increased, voltage increased.
3. Copper electrodes showed higher voltage output than aluminium electrodes.
4. Voltage increased as the width and length of the electrode increased.
5. Replacing PA by PMMA strings showed an increase in voltage difference up to maximum then slightly decreased with increasing electrode width. Voltage slightly increased as electrode length increased.
6. As the thickness of PU foam increased, voltage slightly increased.
7. The direct sliding of PTFE on the PU foam increased the voltage.

REFERENCES

1. Massoud M. A., Ali A. S., Al-Kabbany A. M., Ali W. Y., and. El-Shazly M. H., "Electronic Skin Based on Direct Current Triboelectric Nanogenerator", Journal of the Egyptian Society of Tribology, Vol. 20, No. 4, October 2023, pp. 44 – 53, (2023).

2. Shan C., He W., H. Wu H., Fu S., Tang Q., Wang Z., Du Y., Wang J., Guo H. and Hu C., "A High-Performance Bidirectional Direct Current TENG by Triboelectrification of Two Dielectrics and Local Corona Discharge", Adv. Energy Mater. 2022, 12, 2200963 (1 of 9), Wiley-VCH GmbH, (2022).
3. Zhao Z., Liu D., Li Y., Wang Z. L. and Wang J., "Direct-current triboelectric nanogenerator based on electrostatic breakdown effect", Nano Energy 102, 107745, pp. 1 - 15, (2022).
4. Wang S., Xie Y., Niu S., Lin L., Liu C., Zhou Y. S., Wang Z. L., "Maximum surface charge density for triboelectric nanogenerators achieved by ionized-air injection: Methodology and theoretical understanding", Adv. Mater. 26 (39), pp. 6720 - 6728, (2014).
5. Li Y., Zhao Z., Liu L., Zhou L., Liu D., Li S., Chen S., Dai Y., Wang J. and Wang Z. L., "Improved output performance of triboelectric nanogenerator by fast accumulation process of surface charges", Adv. Energy Mater. 11, 2100050, (2021).
6. Zhang C., Zhou L., Cheng P., Yin X., Liu D., Li X., Guo H., Wang Z. L. and Wang J., "Surface charge density of triboelectric nanogenerators: Theoretical boundary and optimization methodology", Appl, Mater. Today 18, 100496, (2020).
7. Liu Y., Liu W., Wang Z., He W., Tang Q., Xi Y., Wang X., Guo H. and Hu C., "Quantifying contact status and the air-breakdown model of charge-excitation triboelectric nanogenerators to maximize charge density", Nat. Commun. 11 (1) 1599, (2020).
8. He H., Fu Y., Zang W., Wang Q., Xing L., Zhang Y., Xue X., "A flexible self-powered TZnO/PVDF/fabric electronic-skin with multifunctions of tactile-perception, atmosphere-detection and self-clean", Nano Energy 31, pp. 37 - 48, (2017).
9. Ma S., Ribeiro F., Powell K., Lutian J., Møller C., Large T., Holbery J., "Fabrication of novel transparent touch sensing device via drop-on-demand inkjet printing technique", ACS Appl. Mater. Interfaces 7, pp. 21628 - 21633, (2015).
10. Liao X., Zhang Z., Liang Q., Liao Q., Zhang Y., "Flexible, cuttable, and self-waterproof bending strain sensors using microcracked gold nanofilms@paper substrate", ACS Appl. Mater. Interfaces 9, pp. 4151 – 4158, (2017).
11. Yang W., Li N.-W., Zhao S., Yuan Z., Wang J., Du X., Wang B., Cao R., Li X., Xu W., Wang Z. L., Li C., "A breathable and screen-printed pressure sensor based on nanofiber membranes for electronic skins", Adv. Mater. Technol. 3 1700241, (2018).
12. Wang Q., Jian M., Wang C., Zhang Y., "Carbonized silk nanofiber membrane for transparent and sensitive electronic skin", Adv. Funct. Mater. 27, 1605657, (2017).
13. Wang Z.L., Jiang T., Xu L., "Toward the blue energy dream by triboelectric nanogenerator network", Nano Energy 39, pp. 9 - 23, (2017).
14. Fan F. R., Tang W., Wang Z. L., "Flexible nanogenerators for energy harvesting and self-powered electronics", Adv. Mater. 28, pp. 4283 - 4305, (2016).
15. Wu H., Huang Y., Xu F., Duan Y., Yin Z., "Energy harvesters for wearable and stretchable electronics: from flexibility to stretchability", Adv. Mater. 28, pp. 9881–9919, (2016).
16. Wang J., Wu C., Dai Y., Zhao Z., Wang A., Zhang T., Wang Z.L., "Achieving ultrahigh triboelectric charge density for efficient energy harvesting, Nat. Commun. 8, p. 88, (2017).

17. Chu H., Jang H., Lee Y., Chae Y., Ahn J.-H., "Conformal, graphene-based triboelectric nanogenerator for self-powered wearable electronics", Nano Energy 27, pp. 298 – 305, (2016).
18. Wu C., Kim T. W., Li F., Guo T., "Wearable electricity generators fabricated utilizing transparent electronic textiles based on polyester/Ag nanowires graphene core-shell nanocomposites", ACS Nano 10, pp. 6449 – 6457, (2016).
19. Wu C., Kim T. W., Sung S., Park J. H., Li F., "Ultrasoft and cuttable paper-based triboelectric nanogenerators for mechanical energy harvesting", Nano Energy 44, pp. 279 - 287, (2018).
20. Taghavi M., Mattoli V., Sadeghi A., Mazzolai B., Beccai L., "A novel soft metalpolymer composite for multidirectional pressure energy harvesting", Adv. Energy Mater. 4, 140002, (2014).
21. Dhakar L., Pitchappa P., Tay F. E. H., Lee C., "An intelligent skin based self-powered finger motion sensor integrated with triboelectric nanogenerator", Nano Energy 19, pp. 532 - 540, (2016).
22. Lai Y.-C., Deng J., Niu S., Peng W., Wu C., Liu R., Wen Z., Wang Z.L., "Electric e-skin inspired mechanically durable and super-Stretchable nanogenerator for deformable power source and fully autonomous conformable electronic-skin applications", Adv. Mater. 28, pp. 10024 – 10032, (2016).
23. Xu Z., Wu C., Li F., Chen W., Guo T., Kim T. W., "Triboelectric electronic-skin based on graphene quantum dots for application in self-powered, smart, artificial fingers", Nano Energy 49, pp. 274 - 282, (2018).
24. Massoud M. A., Ali W. Y. and Badran A. H., "Electronic Skin Based on Triboelectrification and Electrostatic Induction", Journal of the Egyptian Society of Tribology, Vol. 20, No. 2, April 2023, pp. 77 – 86, (2023).