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BIDIRECTIONAL DIRECT CURRENT TRIBOELECTRIC NANOGENERATOR FOR ELECTRONIC SKIN

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ABSTRACT

The present study discusses the testing of proper materials to be used as friction surface such as polymeric textiles and strings to be applied in the double-channel bidirectional direct current triboelectric nanogenerator (BDC-TENG). The BDC-TENG will be used as self-powered sensor in the application of electronic skin (e-skin). Textiles and strings of polymethyl methacrylate (PMMA) and polyamide (PA) as well as aluminium (Al) and copper (Cu) films were chosen as friction surfaces sliding on polytetrafluoroethylene (PTFE) film in order to generate feedback signal by triboelectrification.

Based on the experimental results, it was observed that fibrous PMMA textile of 0.8 mm thickness recorded the highest voltage values when slid on PTFE film that adhered to an elastic substrate. While PA textile of 0.4 mm thick showed reasonable voltage values. Voltage increased with increasing the applied load. PMMA strings displayed lower values than that observed for textiles. Besides, Al and Cu film showed the lowest voltage values. It was found that the thickness of the textile affects the value of the generated voltage. It can be recommended that the values of voltage produced by the proposed BDC-TENG can be developed by applying fibrous PMMA textile sliding on PTFE films adhered to soft substrate.

KEYWORSD

Bidirectional direct current triboelectric nanogenerator, textiles, strings, copper, aluminium film, feedback signal, electronic skin.

INTRODUCTION

The triboelectric nanogenerator (TENG) is used to convert sliding motion of different dielectrics on each other into electric energy. The design of electronic skin (e-skin) may be developed by applying the electrostatic charge (ESC) generated from friction of objects on e-skin as feedback signal to control the gripping force. TENG was developed to produce DC current by using two charge-collecting electrodes (CCE) on the two sides of the friction surface (FC), [1, 2]. That TENG generates bidirectional

voltage of positive and negative signs according to the sliding direction, [3]. It is called direct current triboelectric nanogenerator (DC-TENG), [4 – 8]. Soft foamy polyurethane sponge substrate under the friction surface was applied in order to increase the contact area. It was observed that copper electrodes displayed higher voltage than aluminium ones, [9]. BDC-TENG was modified by inserting permanent magnet wrapped by copper coil under the friction surface to strengthen the magnetic induction in the sliding area, [10]. The modified BDC-TENG can be used to feed current into the control system in application of e-skin.

The design of e-skin to control the handling of the objects necessitates DC current to work as feedback signal, [11]. The performance of e-skin was modified by using sensors where their functions are based on resistive and capacitive performance in addition to triboelectrification and electrostatic induction, [12 - 23]. Besides, e-skin was developed to detect finger touch, [24 - 26]. The safe objects grasp depends on developing the mechanism of gripper to control the gripping force. An e-skin consists of outer layer of latex to guarantee safe grasping due to the relative high friction was proposed, [27]. It was observed that PTFE and Kapton as friction surfaces showed the highest ESC values.

In the present work, BDC-TENG is proposed to generate direct current as feedback signal in the e-skin. Different materials in form of textiles and strings as well Al and Cu films are tested as friction surfaces sliding on PTFE film in order to get the highest voltage output.

EXPERIMENTAL

The materials tested as friction surfaces of the BDC-TENG contained PA textiles of thickness ranged from 0.2 mm 0.4 mm, Figs. 1 - 3. Polymethyl methacrylate (PMMA) and polyamide (PA) strings of diameter of 2.0 and 0.32 mm respectively were used. Besides, Cu and Al film of 20 µm thickness was adhered to PMMA cube of 30 × 30 × 30 mm^3 working as the sliding friction surface.

The BDC-TENG consisted of two charge-collecting **electrodes made of copper sheet. The stationary friction dielectric was PTFE of 25 µm thickness adhered to polyurethane (PU) foam of 5 mm thickness. The photographs of the tested materials of the friction surface are shown in Fig. 4. The two friction surfaces were loaded by weights of 2, 4, 6, 8 and 10 N, and slid on each 10 mm. The voltage between the two electrodes was measured by DC voltmeter.**

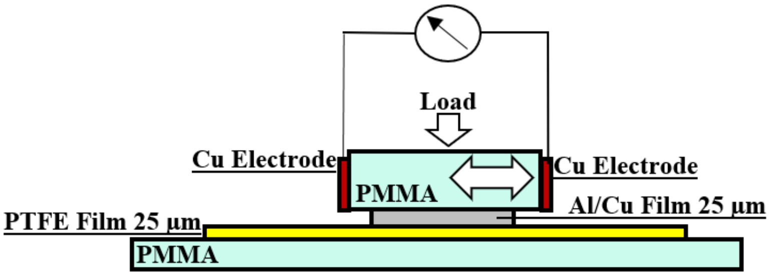

Fig. 1 Sketch of the BDC-TENG when PTFE was adhered to PMMA sheet.

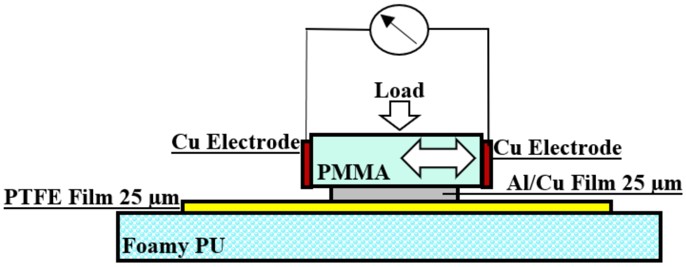

Fig. 2 Sketch of the BDC-TENG when PTFE was adhered to foamy PU.

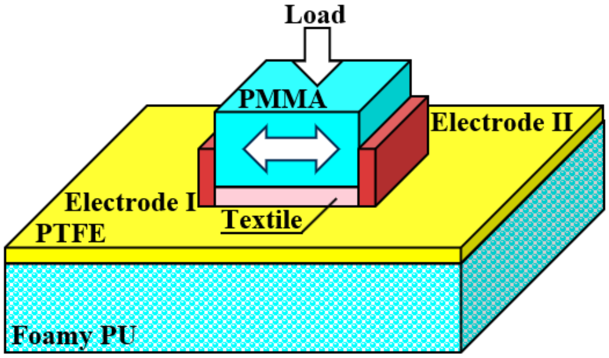

Fig. 3 Sketch of the proposed BDC-TENG.

PA thin textile (0.2 mm).

PMMA textile (0.4 mm). Fibrous surface.

PMMA textile (0.4 mm). Back surface.

PMMA strings.

PA strings.

Copper film.

Fig. 4 Photographs of the tested materials of the friction surface.

RESULTS AND DISCUSSION

In the present work the development of the proposed BDC-TENG depends on testing different materials like PA and PMMA textiles and strings as friction surfaces sliding on PTFE film to generate positive and negative voltage, where signal depends on the sliding direction, Fig. 3. PA textiles of different thicknesses slid on PTFE adhered to PMMA substrate, Fig. 5, where the voltage difference between the two electrodes increased up to maximum then decreased with increasing the thickness. The highest voltage values were observed at 0.4 mm thickness. As the load increased the voltage increased. The highest voltage value was 950 mV at 10.2 N load. When the PTFE film was adhered to foamy PU, the highest voltage recorded 750 mV, Fig. 6. The voltage values were measured when the friction surface moves to the right and left. The electrodes I and II collect ESC from PTFE friction surface in different signs, Fig. 3.

When PA was replaced by fibrous PMMA textiles, voltage recorded relatively higher values, Fig. 7, where the highest voltage value was 1300 mV at 0.8 mm thickness of the PMMA textiles. The voltage increase was attributed to the PMMA fibers that increased the electrons transfer on the surfaces of the fibers. When PTFE film was adhered to foamy PU, voltage showed significant increase up to 1870 mV, Fig. 8. It seems that the hyper elastic behavior of foamy PU increased the contact area between the two friction surfaces leading to the increase of the generated ESC. Voltage measured for the back surface displayed lower values than that observed for fibrous surface. Based on the results, it can be recommended to apply fibrous textile as friction surface. Figures 9 and 10 illustrate the voltage difference displayed by the back and fibrous surfaces of PMMA textile slid on PTFE adhered to PMMA (I) and foamy PU (II) substrates respectively. The thickness of the textile was 0.4 mm. The two surfaces showed increasing attitude with increasing the applied load, where the effect of the substrate of PTFE was insignificant.

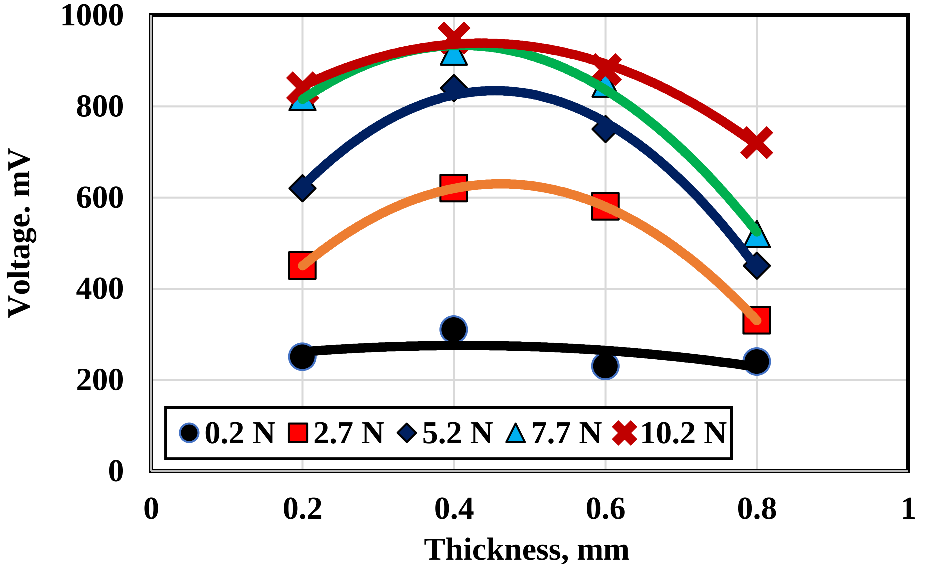

Fig. 5 Voltage difference between the two electrodes versus the thickness of PA textile slid on PTFE adhered to PMMA substrate.

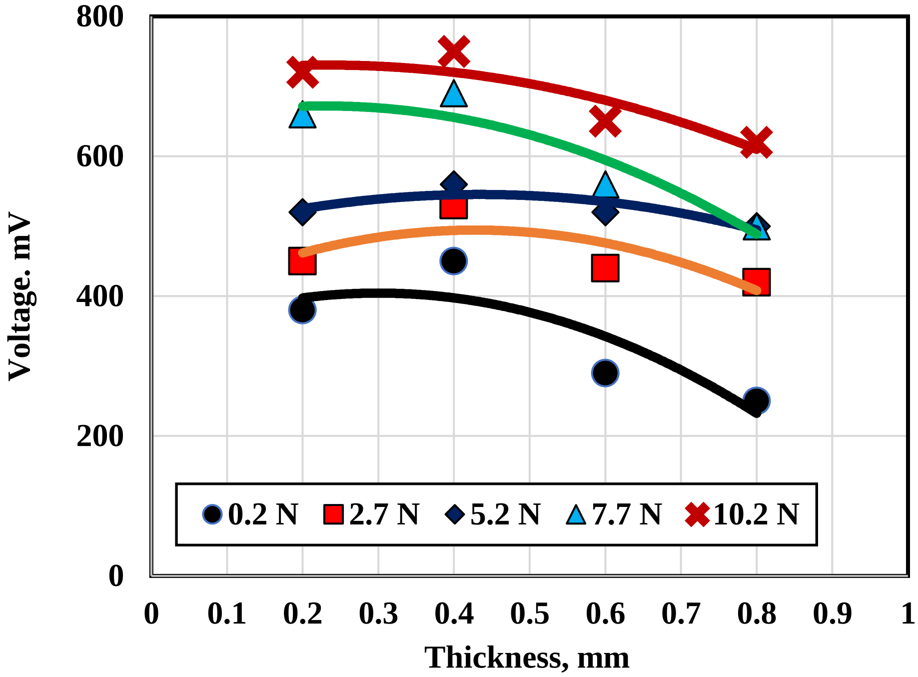

Fig. 6 Voltage difference between the two electrodes versus the thickness of PA textile slid on PTFE adhered to foamy PU substrate.

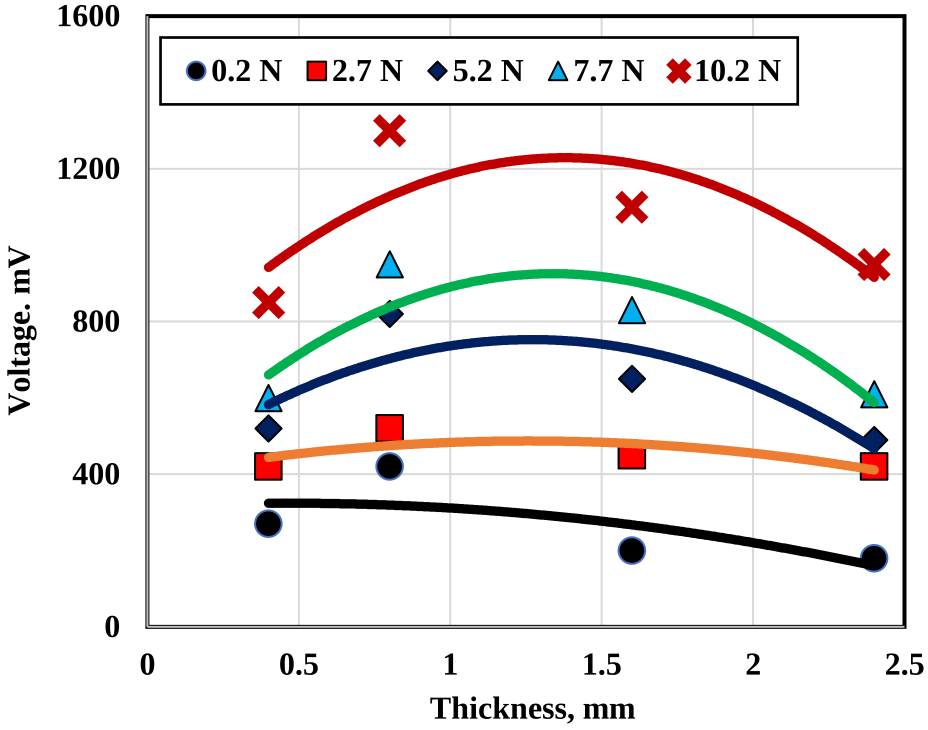

Fig. 7 Voltage difference between the two electrodes versus the thickness of PMMA textile slid on PTFE adhered to PMMA substrate.

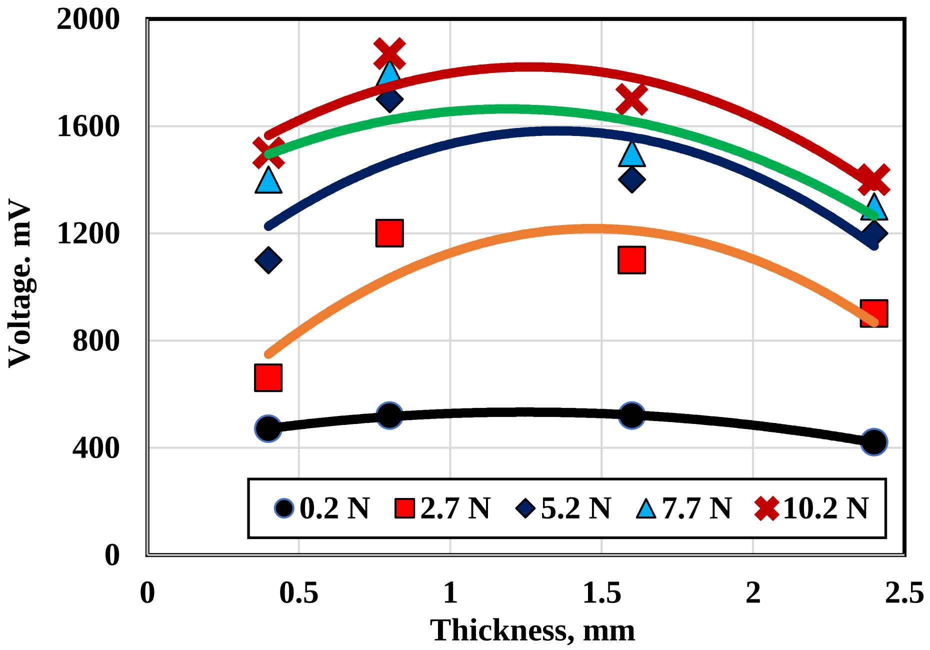

Fig. 8 Voltage difference between the two electrodes versus the thickness of PMMA textile slid on PTFE adhered to foamy PU substrate.

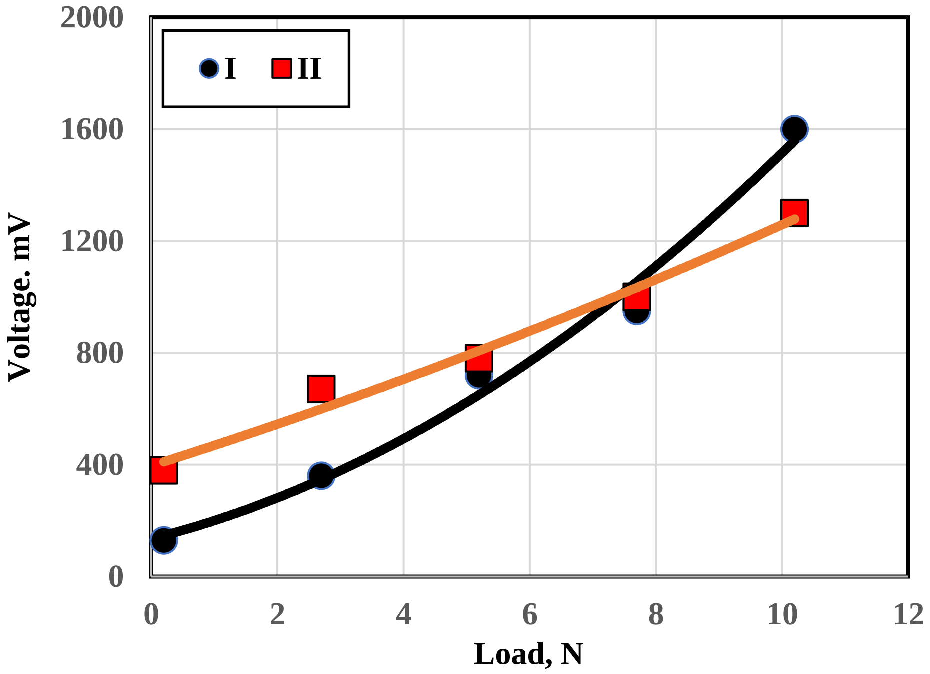

Fig. 9 Voltage difference between the two electrodes when the back surface of PMMA textile slid on PTFE adhered to PMMA (I) and foamy PU (II) substrates.

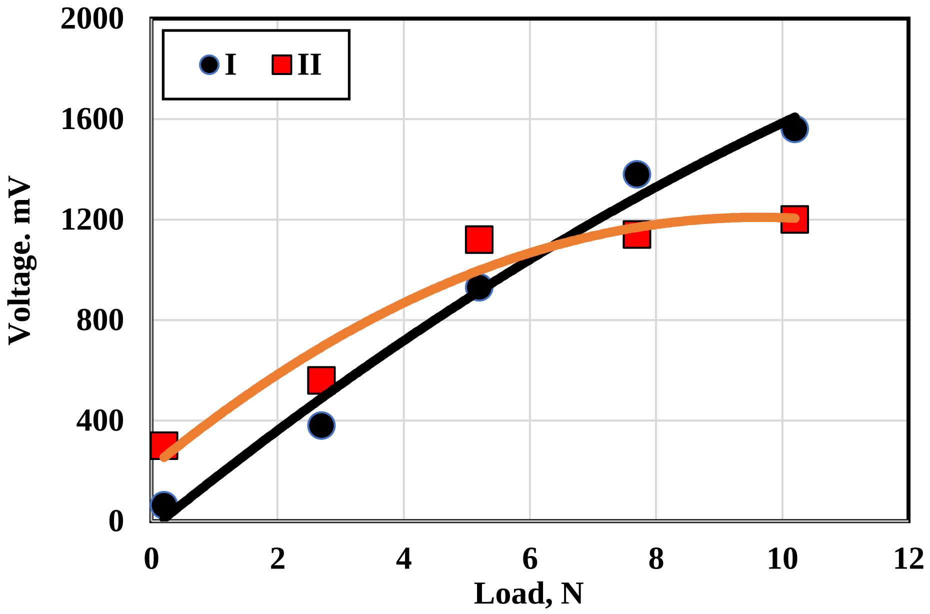

Fig. 10 Voltage difference between the two electrodes when the fibrous surface of PMMA textile slid on PTFE adhered to PMMA (I) and foamy PU (II) substrates.

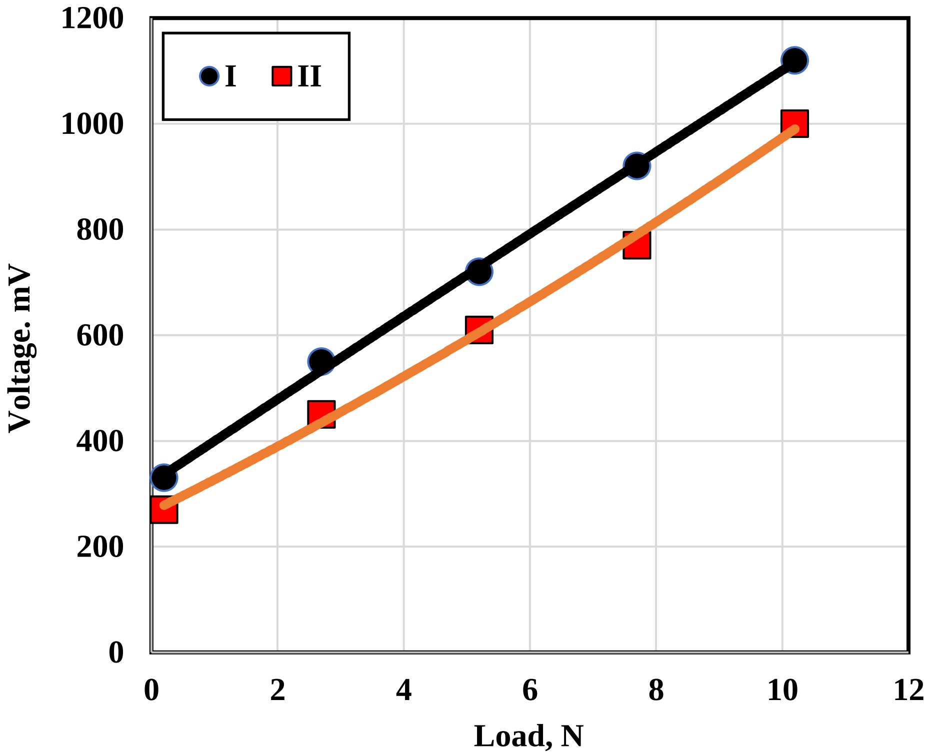

Fig. 11 Voltage difference between the two electrodes when PMMA strings slid on PTFE adhered to foamy PU (I) and PMMA (II) substrates.

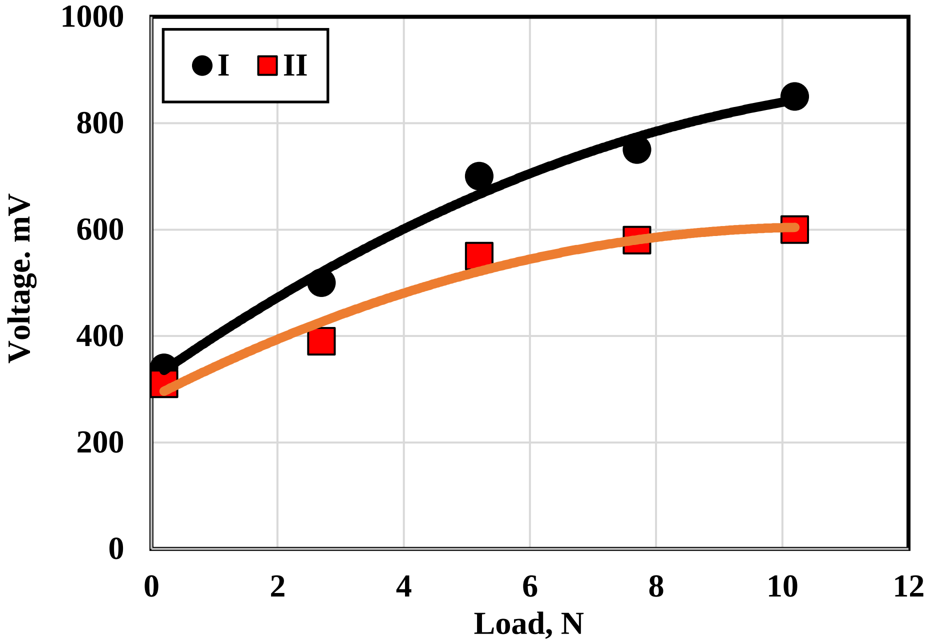

Fig. 12 Voltage difference between the two electrodes when PA strings slid on PTFE adhered to foamy PU (I) and PMMA (II) substrates.

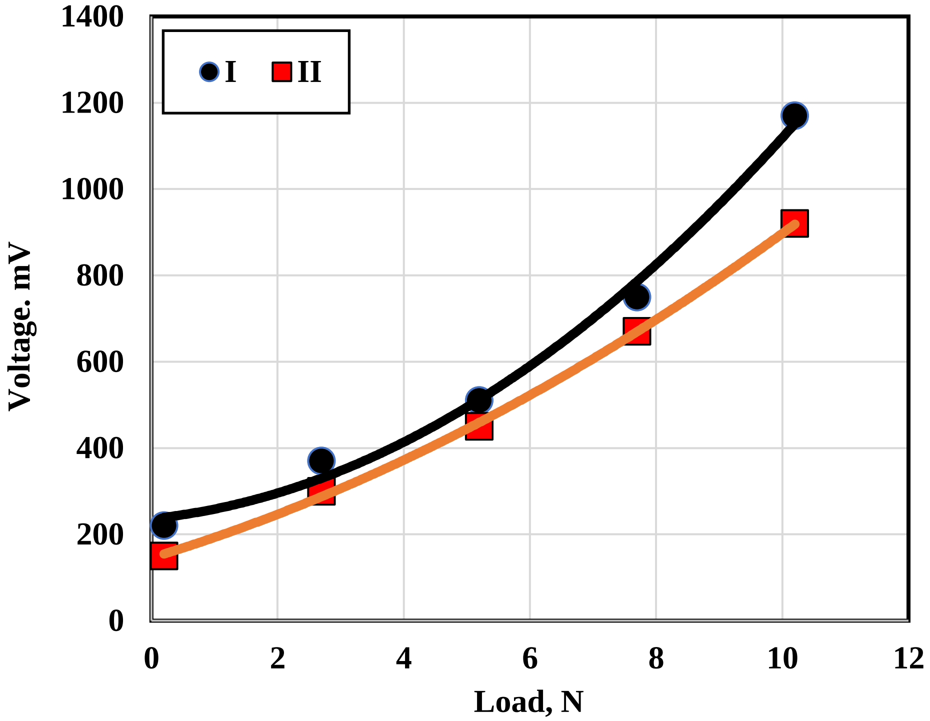

Fig. 13 Voltage difference between the two electrodes when rabbit fur slid on PTFE adhered to foamy PU (I) and PMMA (II) substrates.

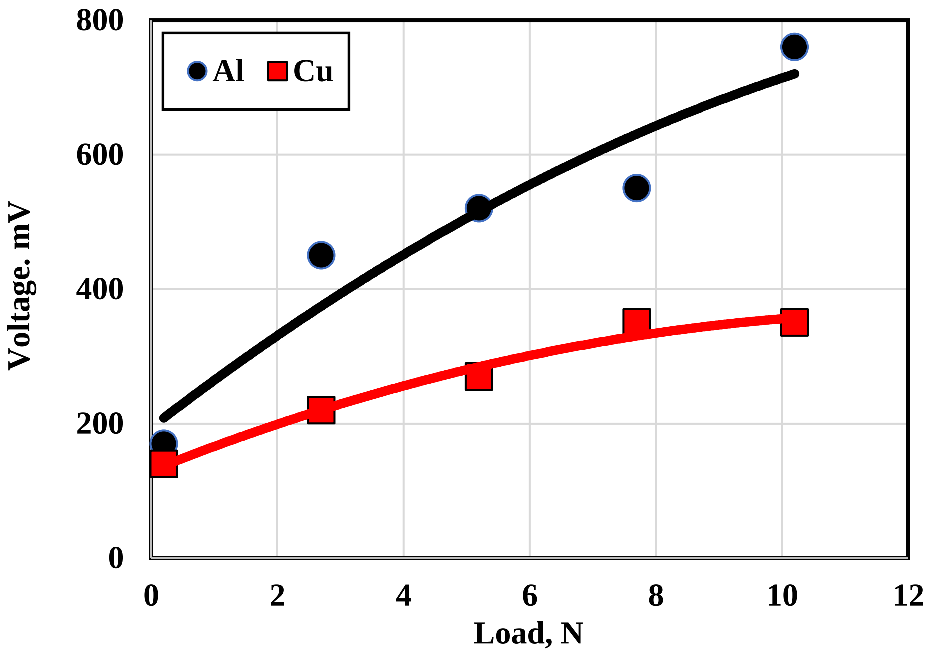

Fig. 14 Voltage difference between the two electrodes when Al (I) and Cu (II) slid on PTFE adhered to PMMA substrate.

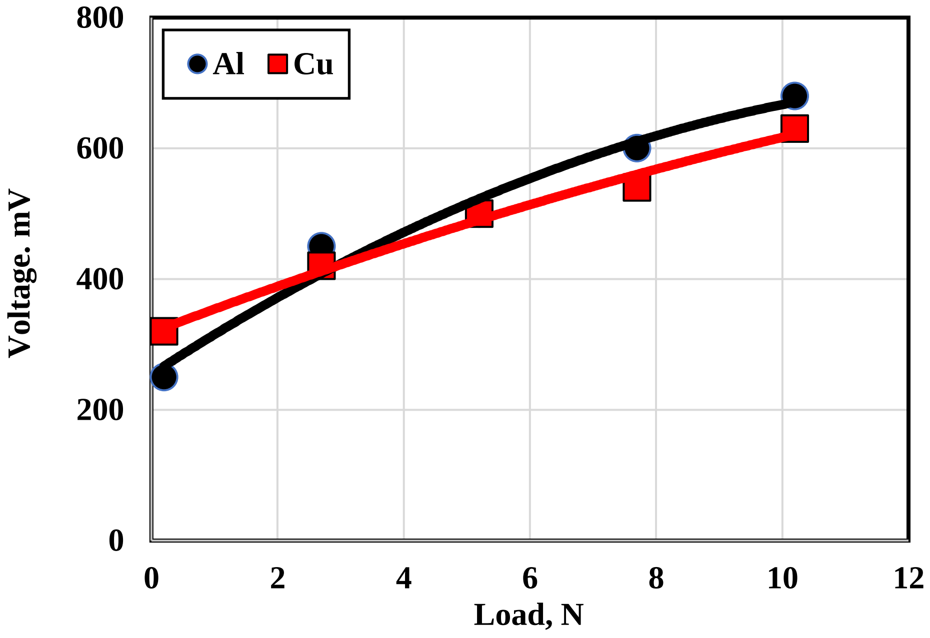

Fig. 14 Voltage difference between the two electrodes when Al (I) and Cu (II) slid on PTFE adhered to foamy PU substrates.

The results observed for experiments performed to measure the voltage generated from the sliding of PMMA strings on PTFE adhered to foamy PU (I) and PMMA (II) substrates are shown in Fig. 11. Voltage significantly increased with the increase of

the applied load. The highest voltage values were 1120 and 1000 mV at 10.2 N load for elastic and solid substrates respectively. Those results indicate that the elastic substrate should be applied for fibrous strings. Replacing PMMA by PA strings showed lower voltage values, Fig. 12, where the values dropped to 850 and 600 mV for elastic and solid substrates respectively at 10.2 N load. That observation confirms the influence of the fibers in increasing the magnitude of the generated ESC. Rabbit fur showed the same trend observed for fibrous PMMA strings, Fig. 13, where the highest voltage values were 1170 and 920 mV for elastic and solid substrates respectively.

Application of Al and Cu film of 0.025 mm thickness as friction surface showed relatively lower values than that observed for above mentioned tested materials, Fig. 14 and 15, where Al film recorded 680 and 760 mV when slid on PTFE adhered to foamy PU (I) and PMMA (II) substrates respectively. While Cu film displayed 630 and 350 mV at the same working conditions.

The selection of the materials used as friction surface depends on the triboelectric series that determine the polarity of ESC generated from the sliding of the two friction surfaces, [27]. The materials ranked in the upper part of the triboelectric series will be positively charged when slides on the materials lying in the lower part that will be negatively charged. The magnitude of ESC depends on the distance between the position of the two materials in the triboelectric series. Because PMMA and PA lies in the upper part of the triboelectric series while PTFE lies in the lower part of the series, while Al and Cu are lying in the middle, the voltage measured for the PMMA and PA displayed the highest values.

Based on the experiments, the performance of the proposed BDC-TENG can be enhanced by using fibrous PMMA textile sliding on PTFE films adhered to elastic substrate. The thickness of the textile has significant effect on the value of the generated voltage.

CONCLUSIONS

1. PA textiles of 0.4 mm thickness displayed the highest voltage values were observed when slid on PTFE.
2. As the load increased the voltage increased.
3. Fibrous PMMA textile of 0.8 mm thickness recorded the highest voltage values when PTFE film was adhered to elastic substrate.
4. Voltage generated from the sliding of PMMA strings on PTFE displayed lower values than that observed for PMMA textile.
5. Al and Cu film as friction surface showed the lowest voltage values.
6. It can be recommended to apply fibrous PMMA and PTFE films as friction surfaces.
7. The thickness of the textile significantly influences the value of the generated voltage.

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