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TRIBOELECTRIC NANOGENERATOR BASED ON CONTACT AND SEPARATION AS WELL AS SLIDING OF POLYAMIDE ON POLYTETRAFLUOROETHELENE

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ABSTRACT

Triboelectric nanogenerators (TENGs) have been proposed to harvest the mechanical energy because of their low cost and simplicity of manufacturing. This work discusses the possibility of designing a TENG operated by the contact and separation as well sliding of two dissimilar materials such as polytetrafluoroethylene (PTFE) and polyamide (PA).

The experimental observation revealed that adhering insulated copper wires in PTFE surface sliding on PA increased the voltage generated from the electrostatic charge (ESC). Copper wires of 0.1 mm diameter generated the highest voltage values, then the voltage decreased with increasing the diameter of the wires. It seems that copper wires induced an electric field that induced an electric current. Besides, as the number of copper wires turns increased, voltage difference of the open circuit increased. Generally, contact and separation recorded relatively lower voltage than sliding, while sliding in the transverse direction showed the highest values. It seems that the double layer of ESC generated due to the friction on the contact surfaces of PTFE and PA generated an electric field, while the electric current induced by the copper wires generated extra electric field on the sliding surfaces leading to the voltage increase. It can be concluded that the efficiency of the triboelectric nanogenerators can be enhanced by inserting copper coil under one of the contacting surfaces.

KEYWORDS

Polyamide, polytetrafluoroethylene, contact and separation, sliding, triboelectric nanogenerator.

INTRODUCTION

Clean and renewable energy has become of great significance due to the fast growing demand of energy, [1–3]. There is an increasing demand to reduce the dependency on fossil fuels to decrease global warming and climate change. Renewable and clean energy should be urgently implemented. TENG can be suitable alternative by harvesting mechanical energy. Contact and separation between two dissimilar materials generates ESC. It was assumed that the charged regions on each surface led to ESC between identical materials due to their transfer, [4, 5]. The TENGs based on contact–separation mode are assembled by adhering two different polarity dielectrics such as nylon, polytetrafluoroethylene (PTFE) on acrylic board.

The intensity and sign of ESC on the surface of the two contacting materials due to the triboelectric effect is achieved using the triboelectric effect, [6 - 8], based on the triboelectric series that may rank materials by the likelihood of induction of a positive or negative charge on the surface of the material. PTFE has a high likelihood of obtaining a negative charge upon contact with another material, [9], while PA is one of the materials that are located near the top of the triboelectric series and acquires a positive charge, [10]. When PA and PTFE contact each other, PTFE will gain relatively high value of negative charge, while PA will gain relatively high value of positive charge.

The TENG is made of two dielectric materials that are on the opposite sides of the triboelectric series and then they are connected to electrodes. After contact and separation as well as sliding, the two dielectric surfaces induce equal and opposite charges on their surface. This potential difference produces an electric current. The two main uses are energy harvesters, [11-14], and self-powered sensor, [15 - 18]. It was proved that the output open circuit voltage of the TENG can be predicted using the V-Q-x equation, [19], while other TENG characteristics can be predicted using different models, [20 - 21]. TENGs are be classified into contact and separation type TENGs, [22 - 23] and sliding type TENGs, [24 - 25]. Contact and separation type TENGs contained two dielectric surfaces separated by an elastic spacer.

The effect of induction on the generation of ESC on the surfaces of polymers slid against PTFE, polypropylene (PP), and PA has been investigated, [26 - 29]. Carbon fibers and metallic wires reinforcing PE and sliding against PA showed relatively higher values of ESC, where steel displayed the highest ESC. That observation was explained on the basis of generation of an E-field inside the PE matrix.

In the present work, TENG that can harvest mechanical energy by combining contact-electrification and electrostatic induction was proposed.

EXPERIMENTAL

The test specimens were prepared from wooden cube of $40 \times 40 \times 40$ mm^3, covered by aluminium film (Al) of 0.25 mm thickness to work as the first terminal. PTFE film of 0.25 mm thickness wrapped on the Al film representing the first dielectric surface. The tested PA was in form of textile adhered on Al film (second terminal) that covered the wooden block representing the second dielectric surface.

The load was applied by weights (0, 2, 4, 6, 8 and 10 N). The sliding distance was 200 mm. The details of the test specimens and the test rig are shown in Fig. 1. The wooden cube was wrapped by insulated copper wires of 0.1 and 0.2 mm to investigate the effect of induction on the generated ESC. The experiments were repeated for each weight to measure the voltage difference. The test procedure contained contact and separation, where the load is applied for 5 seconds followed by the measurement of the voltage, as well as sliding in two direction the first in the direction of the wires (longitudinal sliding) and the second normal to the wires direction (transverse sliding), Fig. 2. In contact and separation, Sliding is carried by loading PTFE on PA textile by the tested weights and sliding for 200 mm.

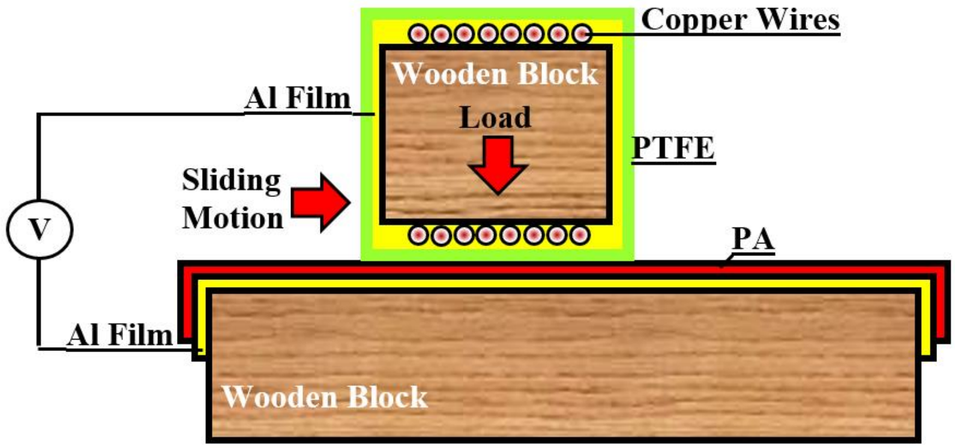

Fig. 1 The arrangement of the test rig.

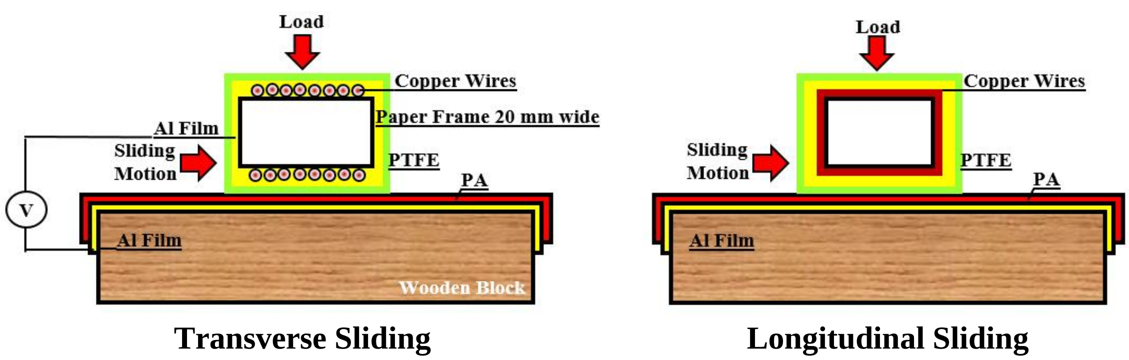

Fig. 2 The direction of sliding relative to the wire direction.

RESULTS AND DISCUSSION

ESC generated and measured in mV after contact and separation as well as sliding of PTFE on PA is shown in Fig. 3. As the applied load increased, voltage increased due to the increase of the contact area. The highest value of ESC was observed at 10.3 N load. This experiment was carried out using PTFE surface without copper wires, where voltage difference reached 1000 mV after sliding, while that recorded for contact and separation was 210 mV. It seems that the charges during motion can be trapped on the surface leading to the increase of voltage difference.

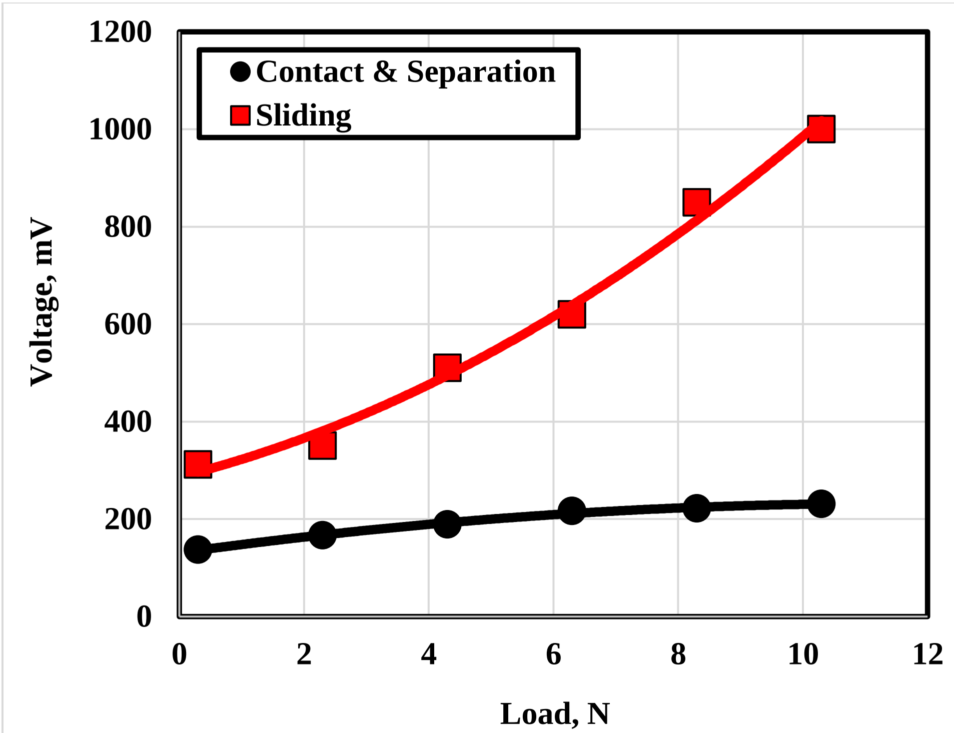

Fig. 3 ESC generated from the contact and separation as well as sliding of PTFE on PA.

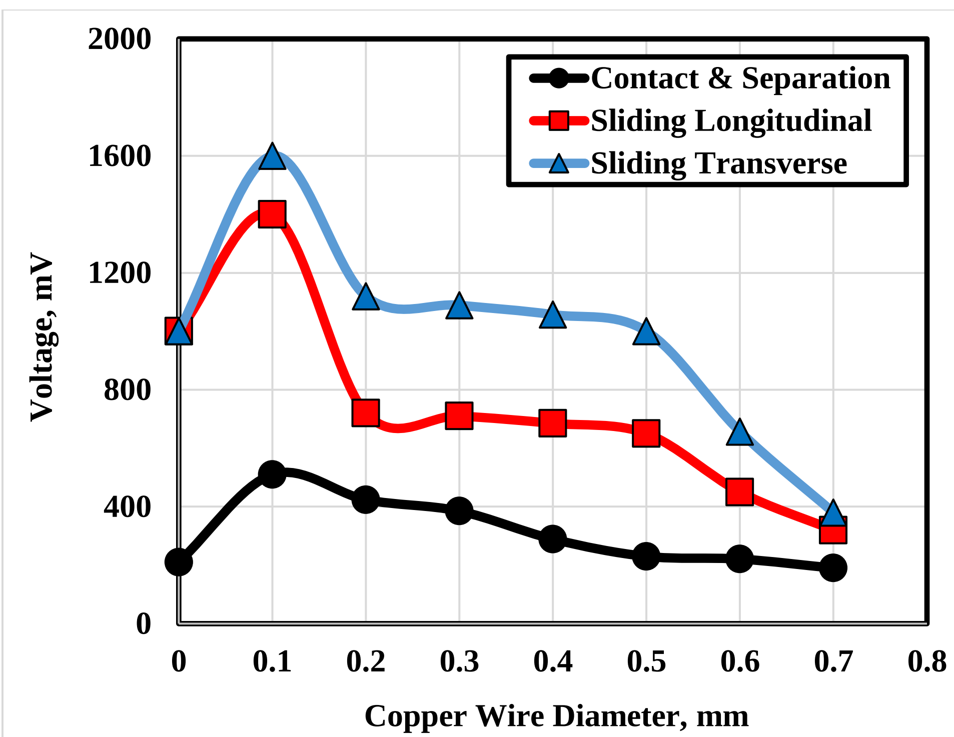

Fig. 5 ESC generated from the contact and separation as well as sliding of PTFE on PA as function of copper wire diameter.

Triboelectrification is defined as the gain or loss of ESC due to friction. Electron carries the charge that is transferred from one of the contacting surface to the other during friction of polymeric materials. Voltage difference between PA and PTFE is represented in Fig. 4, where inserting the copper wires coil of different diameters under PTFE showed significant increase. Copper wires of 0.1 mm diameter generated the highest voltage values. As the diameter of the wires increased, voltage decreased.

It is clear from the results that copper wires were able to induce relatively higher electric field. Then if an electric conductor (copper wire) is moved through an electric field, or an electric field moves through the conductor, an electric current will be induced and flow into the conductor. The induced current creates an induced electric field then significant voltage increase in the presence of copper wires is observed. Figure 5 illustrates the generation of relatively higher voltage due the effect of the copper wires, where the double layer of ESC generated from friction supplies the system by an electric field, while the induced electric current produces extra electric field that is responsible for the increase of the voltage difference.

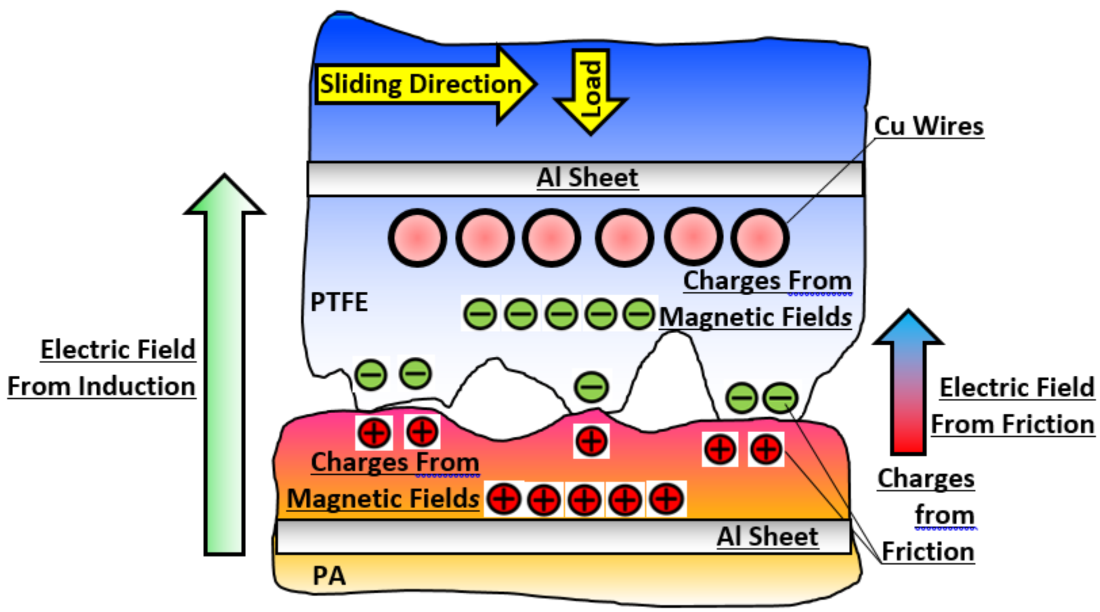

Fig. 5 Explanation of the generation of relatively higher voltage due the effect of the copper wires.

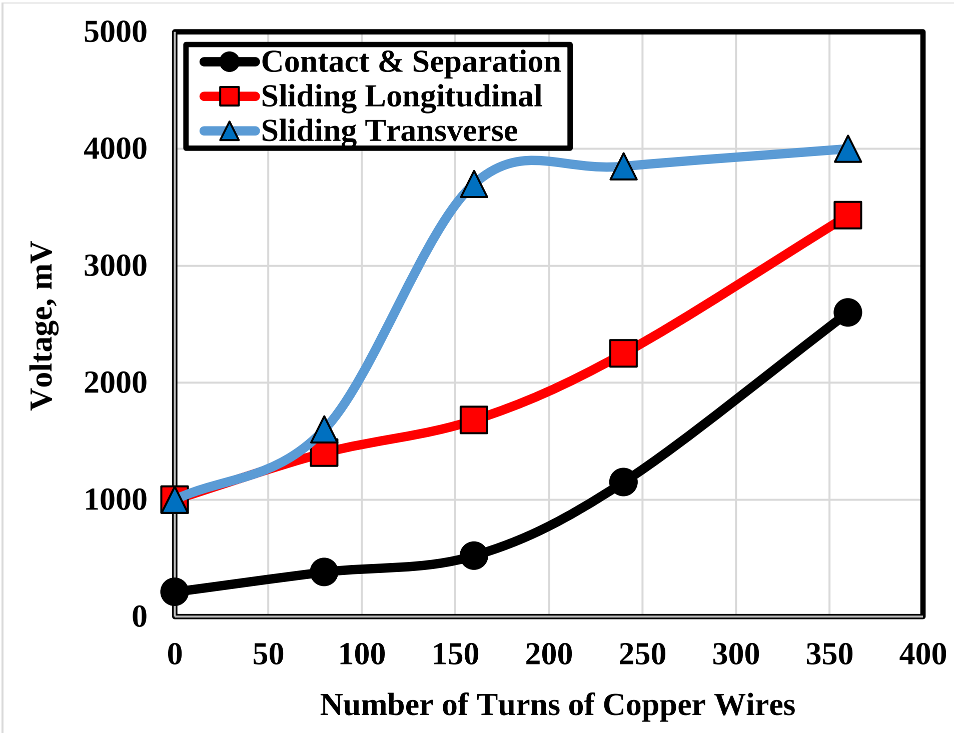

Fig. 6 ESC generated from the contact and separation as well as sliding of PTFE on PA as function of number of turns of copper wire of 0.1 mm diameter.

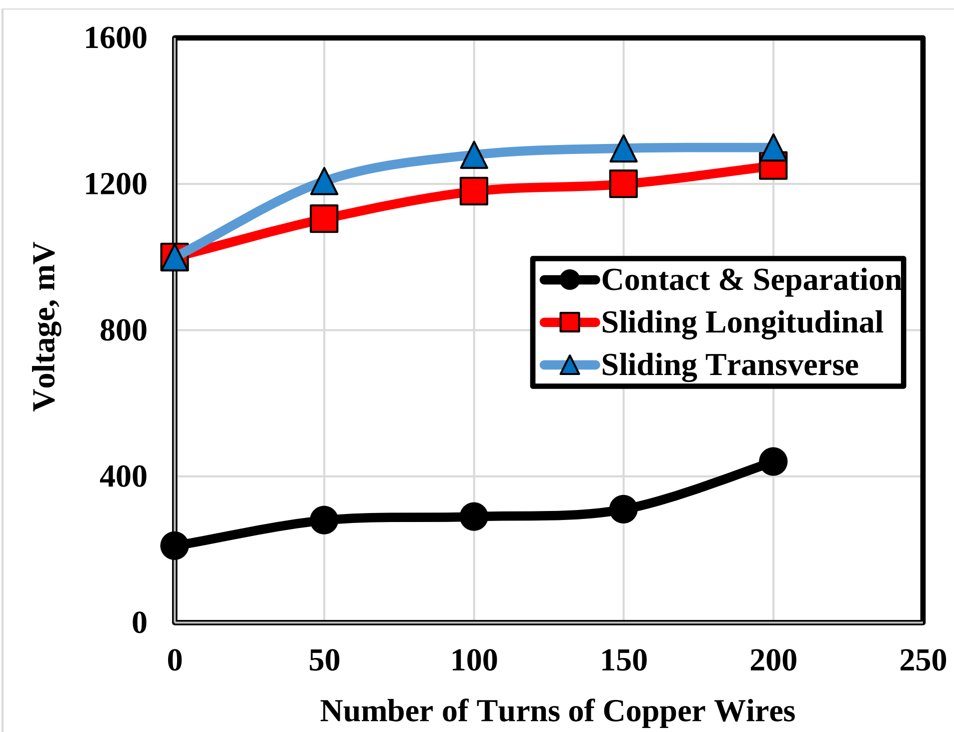

Fig. 7 ESC generated from the contact and separation as well as sliding of PTFE on PA as function of number of turns of copper wire of 0.2 mm diameter.

The influence of the number of turns of the copper wire of 0.1 mm diameter on the voltage difference between the two contact surfaces is shown in Fig. 6. It is observed that as the number of turns increased, voltage difference increased. Sliding recorded relatively higher voltage than contact and separation. Sliding in the transverse direction displayed the highest voltage. The highest values of voltage were 4000 and 3350 mV for transverse and longitudinal sliding respectively. It is observed that the voltage in the presence of copper wires showed higher values than that measured for surfaces free of wires. This behvior may be due to that the double layer of ESC generated on the contact surfaces of PTFE and PA induced an extra electric field on the sliding surfaces leading to the voltage increase. The same trend was observed for the copper wires of 0.2 mm, Fig. 6. The highest voltage values were 440, 1250 and 1300 mV at 200 turns of copper wires for contact and separation, longitudinal and transverse sliding respectively.

CONCLUSIONS

1. Inserting one of the contact surfaces (PTFE) by copper wires of different diameters showed significant increase in the measured voltage difference due to the induced electric field. As the diameter of the wires increased, voltage decreased.
2. Copper wires of 0.1 mm diameter generated the highest voltage values.
3. As the number of turns of the copper wires increased, voltage difference increased due to the increase of the induced electric field. Sliding displayed relatively higher voltage than contact and separation. Sliding in the transverse direction recorded the highest voltage.

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