**TEKSTİL VE MÜHENDİS**

**(Journal of Textiles and Engineer)**


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# KIZAKLI VE DİKEY MODU BİRLEŞTİREN BİR TEG İLE TEKSTİL YAPILARINDA TRİBOELEKTRİĞİN İNCELENMESİ

# INVESTIGATION OF TRIBOELECTRICITY ON TEXTILE STRUCTURES THROUGH A TEG WHICH COMBINES SLIDING AND VERTICAL MODE


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Online Erişime Açıldığı Tarih (Available online):30 Aralık 2022 (30 December 2022)



**Bu makaleye atıf yapmak için (To cite this article):**

Aristeidis REPOULIAS, Mustafa ERTEKİN, Sotiria F GALATA, Savvas VASSILIADIS, Arzu MARMARALI (2022): Investigation Of Triboelectricity on Textile Structures Through A Teg Which Combines Sliding and Vertical Mode, Tekstil ve Mühendis, 29:128, 291-296.

**For online version of the article:** https://doi.org/10.7216/teksmuh.1222522

***Araştırma Makalesi / Research Article***

# INVESTIGATION OF TRIBOELECTRICITY ON TEXTILE STRUCTURES THROUGH A TEG WHICH COMBINES SLIDING AND VERTICAL MODE

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*Gönderilme Tarihi / Received: 01.09.2022*
*Kabul Tarihi / Accepted: 01.12.2022*

***ABSTRACT:*** The use of textile materials and structures to build textile-based TEGs is of particular interest as they can also offer unique textile properties. In this work, the initial goal is to present a prototype TEG measuring device and its experimental results for comparing the open circuit voltages coming from various pairs of knitted samples which may constitute part of a textile TEG. We focus on representing realistic testing conditions as on a wearable garment, by introducing a friction stage between the contact and separation stages which is applied under a lightweight load. A second goal is to explore the possibilities of some environmentally friendly textile materials to provide electric energy, again under realistic conditions. From the carried tests, it was seen that even conventional natural knitted textiles structures like single jersey, without expensive and complex nano-treatments, can provide considerable voltages if they are part of a wearable garment. Moreover, it was found that even low friction under a weight load of 20grf is adequate to give the above results. The hereby presented measuring TEG device can be used in the comparison or improvement of textile or even non-textile based TEGs, in order to find optimal combinations of materials and designs to be used on clothing TEGs.

***Keywords:*** *Textile, Fabric, Triboelectricity, Triboelectric Generator*

## KIZAKLI VE DİKEY MODU BİRLEŞTİREN BİR TEG İLE TEKSTİL YAPILARINDA TRİBOELEKTRİĞİN İNCELENMESİ

***ÖZ:*** Tekstil malzemelerinin ve yapılarının tekstil bazlı triboelektrik üreteçleri (TEG) oluşturmak için kullanılması, benzersiz tekstil özellikleri de sunabildikleri için özellikle ilgi çekicidir. Bu çalışmada, ilk amaç, tekstil TEG'inin bir parçasını oluşturabilecek çeşitli örme numune çiftlerinden gelen açık devre gerilimlerini karşılaştırmak için bir prototip TEG ölçüm cihazı ve deneysel sonuçlarını sunmaktır. Hafif bir yük altında uygulanan temas ve ayrılma aşamaları arasında bir sürtünme aşaması getirerek, giyilebilir bir giysi üzerinde olduğu gibi gerçekçi test koşullarının temsil edilmesine odaklanılmıştır. İkinci hedef, yine gerçekçi koşullar altında, bazı çevre dostu tekstil malzemelerinin elektrik enerjisi sağlama olanaklarını keşfetmektir. Yürütülen testlerden, pahalı ve karmaşık nano-işlemler olmaksızın süprem gibi geleneksel doğal örme tekstil yapılarının bile giyilebilir bir giysinin parçası olmaları durumunda önemli voltajlar sağlayabildiği görülmüştür. Ayrıca, 20grf'lik bir yük altında düşük sürtünmenin bile yukarıdaki sonuçları vermeye yeterli olduğu bulunmuştur. Burada sunulan TEG cihazı ölçümleri, giyim TEG'lerinde kullanılacak optimum malzeme ve tasarım kombinasyonlarını bulmak için tekstil ve hatta tekstil bazlı olmayan TEG'lerin karşılaştırılması veya geliştirilmesinde kullanılabilir.

***Anahtar Kelimeler:*** *Tekstil, Kumaş, Triboelektrik, Triboelektrik Üreteci*

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***DOI:** https://doi.org/10.7216/teksmuh.1222522   www.tekstilvemuhendis.org.tr*

*This study was presented at "3rd International Congress of Innovative Textiles (ICONTEX2022)", May 18-19, 2022 Çorlu, Turkey. Peer review procedure of the Journal was also carried out for the selected papers before publication.*

## 1. INTRODUCTION

One decade ago, the introduction of the first triboelectric generators (TEGs) made the first steps to harvest energy which exists in the environment thanks to various forms of motion and which is lost without utilization [1]. This would be used for low power consumption electronics. Perhaps no one imagined that so soon, today in 2022, the issue of energy crisis [2] would overwhelm the whole world. Now, the search for methods to use sustainable energy sources (green energy, blue energy) are urgent more than ever at a worldwide level [3,4]. By definition, triboelectric generators are structures whose function is based on the natural phenomenon of triboelectricity. In their simplest form, they consist of two separate surfaces which come in contact, being attached to two separate electrodes, driving the outcoming electric power to storage or consumption.

Among them are the textile-based TEGs, which use textile materials and structures (eg core filaments, yarns, woven, knitted and non-woven fabrics) and are embedded in clothes, shoes etc as part of them, in order to supply small wearable electronics with electric power [5–7]. Textile based TEGs are of great interest because they can combine the unique textile properties of flexibility [8], washability [9,10], long-lasting [11], breathability [12,13], bacterial resistance [14], elasticity [15], softness and comfort [16], as part of clothing with the benefits of a TEG, making them ideal for wearable electronics [14,17]. Moreover, textile-based TEGs may have the advantage of being eco-friendly when using natural or recycled fiber materials like Cotton, Tencel or Chitosan fibers, giving considerable voltage outputs [14,18,19].

An example of such a TEG application can be seen in Figure 1, where a TEG is embedded in a garment's inner side of the sleeve (red color) and aside from the body part (blue color). This can harvest energy which otherwise would be lost and left unused like e.g. through the motion of arms when walking [20,21].

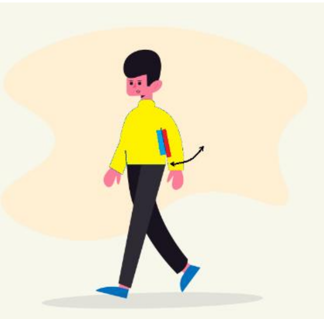

**Figure 1**. Example of the contact, friction and separation motion executed by two triboelectric surfaces in the inner side of the sleeve (red color) and aside of the body (blue color) while walking.

The motion of the two triboelectric surfaces of a TEG can be based on four operational modes: contact separation mode, single-electrode mode, linear sliding mode and free-standing mode [3,14]. Most of the TEGs reported in the literature apply the contact separation mode, which is the simplest [14]. However, from a practical point of view, we must mention that most TEGs (i) apply big weight loads contrary to the real conditions of wearing a garment, (ii) they do not introduce friction between contact and separation of the TEGs surfaces, and (iii) they are not designed to hold and compare various material structures.

In this work, the initial goal is to present a prototype TEG which we have built and used as a measuring device to compare knitted samples in terms of their ability to provide electricity through triboelectricity under realistic conditions on a wearable garment. Its special features are that (i) it does not apply big weight loads, (ii) it takes into account friction by adding it between the contact and separation stages and (iii) it is more versatile as for the attachment of various structures samples to test their triboelectric performance.

This is achieved by making the two triboelectric surfaces to move by combining the contact-separation mode and the sliding mode. As presented in Figure 2, the upper triboelectric surface (red color) moves towards the lower surface (blue color) following an elliptical orbit (steps i-ii). At step (iii) the upper surface touches the lower surface, and it continues moving. From that point, between steps (iii) and (v), we have a sliding of the upper surface on the lower surface under a weight load. Finally, at step (v) the two surfaces begin to separate again till they reach a final position at step (vii).

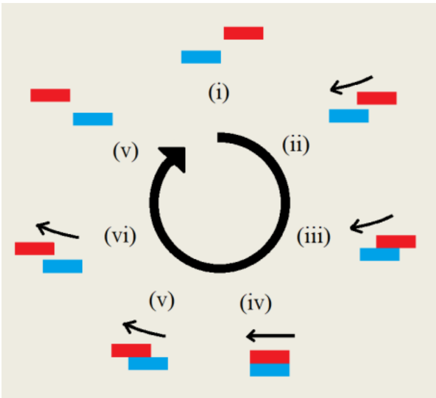


**Figure 2**. The relative motion of the upper triboelectric surface (red color) over the lower triboelectric surface (blue color).

In addition, a second goal is to explore the possibilities of some environmentally friendly textile materials (Cotton, Modal and Wool) to provide electric energy, under conditions which simulating the physiological motions of the human body.

The hereby thoroughly presented testing device was firstly used for proof of concept to compare the different triboelectric outcomes of three cotton woven patterns (twill, plain and honeycomb) in combination with a PE film [22].

## 2. MATERIAL AND METHOD

To compare textile materials in terms of their ability to provide electric power through triboelectricity under realistic loading conditions, a device has been designed, built and used to measure the triboelectric properties of the textile fabrics (Figure 3).

Its particular feature is that through a specially designed and 3D-printed mechanism, it receives and moves the upper sample over the lower sample performing an elliptical orbit motion, which translates to a contact, a sliding and a separation stage (Figure 2). The sliding stage is done under the low load of 20gr . Proposing this new approach of a contact-sliding-separation motion, the present device simulates more realistically a textile-based TEG which is embedded in the moving parts of a wearable garment [18,23–25], than most experimental TEGs which rely solely on the contact-separation motion of the two triboelectric surfaces and in fact under less realistic and considerable load of several Newtons.

Significant advantages of the measuring device are its ability: (i) to accept samples regardless of thickness or structure, (ii) to accept minor adjustments to the applied load, (iii) to accept fine adjustments for precise contact of the specimens on the X-Y-Z axes, and (iv) to accept settings for the number, duration or frequency of contact-sliding-separation cycles of the samples.

The samples which were produced and used in the experiments were knitted textiles, made on the same knitting machine, with the same settings and a single jersey knitting pattern. The used yarns had the same linear density 20x2 Tex (Ne30/2) but they were made of six different materials: Cotton, Modal, PES, Wool, Acrylic and Para-Aramide. Five different specimens of dimensions 5cm x 5cm were cut from each textile sample (S1-S5). These were measured on different days so that it was ensured that there is repeatability in the coming results.

Each measurement test examined a pair of knitted fabrics samples, which consisted of one permanent reference specimen (Para-Aramide) combined with any of the rest of five specimens (Cotton, Modal, PES, Wool, Acrylic). The knitted fabrics specimens were cut and positioned on the sample holders following a rule of keeping steady the orientation of the knitting pattern.

The applied load from the upper to the lower sample was 20grf, while the exposed surface of the textile samples was 25cm2 (dimensions 5x5cm). Before starting any type of measurement the textile samples were grounded so that they do not have significant accumulated electric loads. The laboratory's temperature was 23±1oC and relative humidity 40±2%.

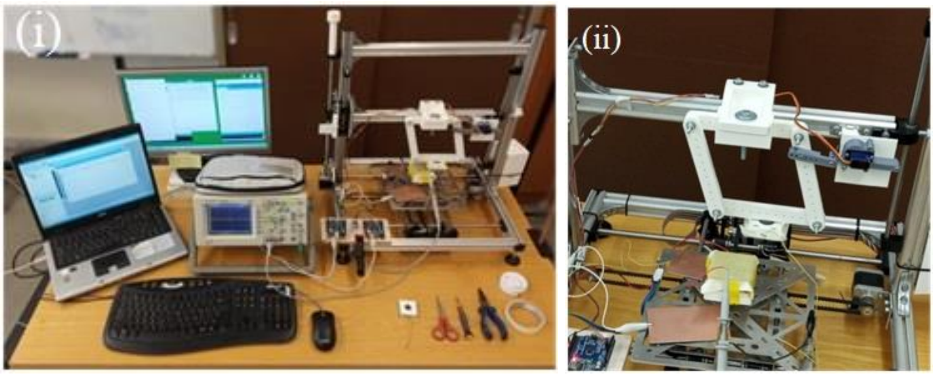


**Figure 3**. (i) View of the measuring device and its peripherals (ii) View of the white 3D printed arms moving the upper sample, the 3D printed grey motion actuator, the upper sample and the lower sample.

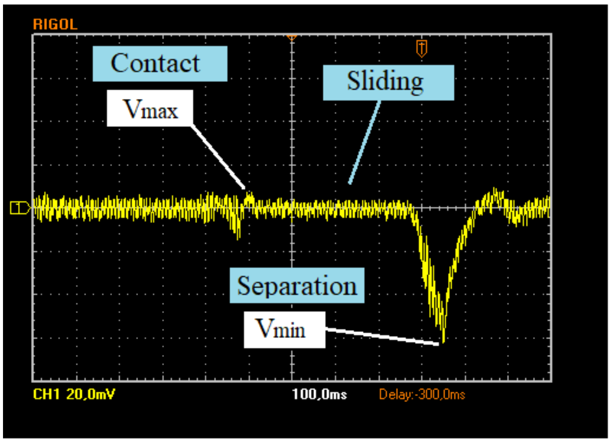


**Figure 4.** The $V_{max}$ and $V_{min}$ voltage peaks as seen on the oscilloscope's display at the moment of the contact and separation respectively. Between these two exists the sliding phase.

## 3. RESULTS AND DISCUSSION

During the tests, the open-circuit voltage which is produced by a single contact-sliding-separation motion cycle was measured. An oscilloscope was used for this, by connecting its probes to the electrodes which hold each of the two triboelectric surfaces. Upon the execution of a test, the oscilloscope's display (Figure 4) shows that at the moment of contact we get a voltage peak which is the Vmax (positive value), then follows the friction of the samples, and finally, at the moment of separation, we get the second voltage peak which is the Vmin (negative value).

The samples were tested paired with Para-Aramide using the TEG device under one cycle of contact-sliding-separation, load 20grf. The values of open circuit Vmax, Vmin and Vpp were recorded, and their average values were calculated.

From the applied measurements it was found that the combination of Para-Aramide with Cotton gave average Vmax=7.9mV (Table 1), with Modal Vmax=11.0mV (Table 2), with PES Vmax=6.3mV (Table 3), with Wool Vmax=12.6mV (Table 4), and with Acrylic Vmax=10.6mV (Table 5).

**Table 1.** Average values of open circuit $V_{max}$, $V_{min}$ and $V_{pp}$ for the combination of Cotton & Para-Aramide.

| | Sample | $V_{max}$ | $V_{min}$ | $V_{pp}$ |
|---|---|---|---|---|
| Cotton & Para- Aramide | S1 | 8,9 | -34,1 | 43,0 |
| | S2 | 9,8 | -36,3 | 46,1 |
| | S3 | 9,1 | -34,0 | 43,1 |
| | S4 | 6,0 | -36,8 | 42,7 |
| | S5 | 6,0 | -39,9 | 45,9 |
| | **AVE** | **7,9** | **-36,2** | **44,1** |

**Table 2.** Average values of open circuit Vmax, Vmin and Vpp for the combination of Modal & Para-Aramide.

| | Sample | $V_{max}$ | $V_{min}$ | $V_{pp}$ |
|---|---|---|---|---|
| Modal & Para- Aramide | S1 | 14,0 | -63,5 | 77,5 |
| | S2 | 11,8 | -54,8 | 66,6 |
| | S3 | 14,1 | -59,0 | 73,1 |
| | S4 | 11,1 | -57,0 | 68,2 |
| | S5 | 13,2 | -63,4 | 76,6 |
| | **AVE** | **12,8** | **-59,5** | **72,4** |

**Table 3.** Average values of open circuit Vmax, Vmin and Vpp for the combination of PES & Para-Aramide.

| | Sample | $V_{max}$ | $V_{min}$ | $V_{pp}$ |
|---|---|---|---|---|
| PES & Para- Aramide | S1 | 6,0 | -16,2 | 22,2 |
| | S2 | 7,2 | -10,8 | 18,0 |
| | S3 | 6,0 | -13,0 | 19,0 |
| | S4 | 7,1 | -13,7 | 20,8 |
| | S5 | 4,9 | -11,9 | 16,8 |
| | **AVE** | **6,3** | **-13,1** | **18,0** |

Moreover, it was found that the combinations of Para-Aramide with Cotton gave average Vmin= -36.2mV, with Modal Vmin= -54.3mV, with PES Vmin= -13.1mV, with Wool Vmin= -71.5mV, and with Acrylic Vmin= -41mV.

The average Vpp values of Para-Aramide with Cotton was Vpp=44.1 mV, with Modal Vpp=65.4mV, with PES Vpp=18.0mV, with Wool Vpp=84.1mV and with Acrylic Vpp=51.6mV. To better display and compare the three different voltage measures, we present Vmin in the following graph (Figure 5) as an absolute value.

At the beginning the test, when the two samples' surfaces come in contact, the value of the coming voltage (Vmax) is similar for all the samples regardless of their combinations, and it has relatively low values in the area of 6-13mV (Figure 5). That means that all samples enter the phase of the measurement tests from almost the same initial state of a very low electric charge. The surfaces of all the samples were initially left grounded for 24h before they were used in the tests.

**Table 4.** Average values of open circuit Vmax, Vmin and Vpp for the combination of Wool & Para-Aramide.

| | Sample | $V_{max}$ | $V_{min}$ | $V_{pp}$ |
|---|---|---|---|---|
| Wool & Para- Aramide | S1 | 11,6 | -67,5 | 79,1 |
| | S2 | 11,0 | -74,6 | 85,6 |
| | S3 | 16,5 | -64,6 | 81,1 |
| | S4 | 12,2 | -71,8 | 84,0 |
| | S5 | 11,7 | -79,2 | 90,9 |
| | **AVE** | **12,6** | **-71,5** | **84,1** |

**Table 5.** Average values of open circuit Vmax, Vmin and Vpp for the combination of Acrylic & Para-Aramide.

| | Sample | $V_{max}$ | $V_{min}$ | $V_{pp}$ |
|---|---|---|---|---|
| Acrylic & Para- Aramide | S1 | 11,5 | -41,4 | 53,0 |
| | S2 | 9,8 | -44,7 | 54,6 |
| | S3 | 12,6 | -44,4 | 57,1 |
| | S4 | 11,0 | -37,5 | 48,5 |
| | S5 | 7,9 | -36,7 | 44,7 |
| | **AVE** | **10,6** | **-41,0** | **51,6** |

On the other hand, at the moment of the separation of the two samples (after the sliding phase), the coming voltage peak (Vmin) is within a range of -13 to -72mV depending on the materials combination (Figure 5). As an absolute value, Vmin is much higher than the initial Vmax, a clear phenomenon of triboelectricity causing an increase in electrical charge, which is hereby measured as an increase in voltage.

Thus the five selected textile samples, when paired with the Para-Aramide reference sample, even under a low load of 20grf, provided considerably different voltage outputs. Wool with Para-Aramide was the most efficient pair of materials when rubbed.

A representation of the Vpp in the form of dispersed clouds, can be seen in Figure 6 for each material against Para-Aramide. It can be seen that the measurements of each pairing, cover a limited area of voltage (mV). Cotton and PES combined with Para-Aramide seem to had the highest precision.

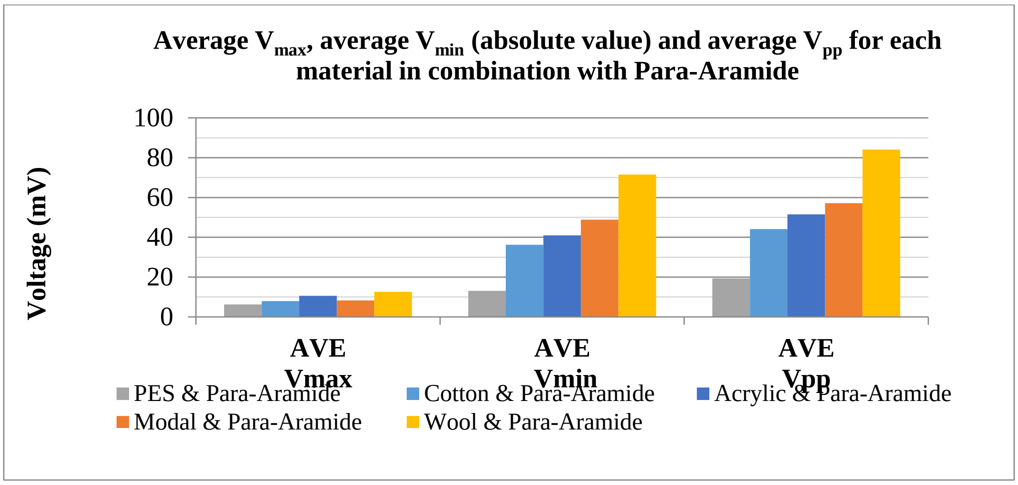


**Figure 5.** Graphical representation of the average open circuit $V_{max}$, average $V_{min}$ (absolute value) and average $V_{pp}$ for each material in combination with Para-Aramide, after they were cut and tested with our TEG device (one cycle of contact-sliding-separation, weight load 20grf).

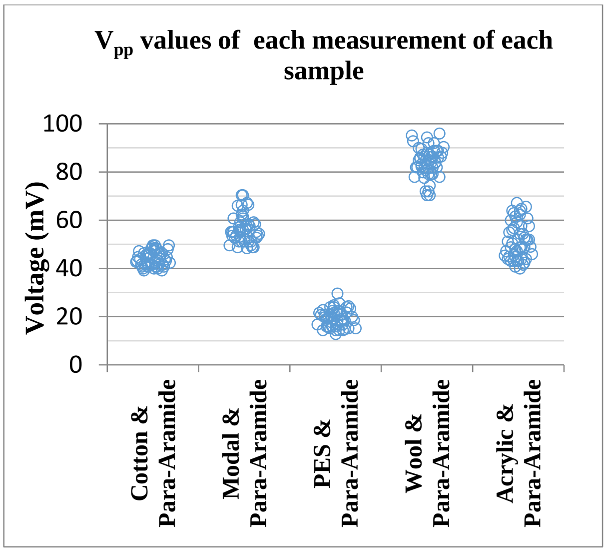


**Figure 6.** Graphical representation of the open circuit $V_{pp}$ values for each material in combination with Para-Aramide, after they were cut and tested with our TEG device (one cycle of contact-sliding-separation, weight load 20grf).

## 4. CONCLUSIONS

In the current work, a prototype TEG testing device has been presented. It applies a friction stage between the contact and separation stages and it does not apply big weight loads. Thus it simulates more realistically the movement of the two triboelectric surfaces of a textile-based TEG on a cloth's moving parts. This is technically achieved by moving one textile sample over the other in an elliptical orbit.

From the carried tests, it was seen that even conventional natural knitted textiles structures like single jersey, without expensive and complex nano-treatments, can provide considerable voltages if they are part of a TEG on the movable parts of a wearable garment.

Moreover, it was found that even low friction under a load of 20grf is adequate to give the above results. The chosen load corresponds to the realistic loads applied on clothing items during walking.

The hereby presented testing TEG device can be considered very useful to be used in the comparison or improvement of textile or even non-textile based TEGs, in order to find optimal combinations of materials and textile designs to be used on clothing TEGs.

### *ACKNOWLEDGEMENTS*

*The author would like to thank Mr. Dimitrios Apostolou (Industrial Designer), for his valuable 3D printing support.*

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