Springer Proceedings in Materials

Amel Babay
Rim Cheriaa
Riadh Zouari *Editors*

Proceedings of the 10th International Conference of Applied Research on Textile and Materials

CIRATM-10

Springer

Springer Proceedings in Materials 49

Series Editors

Springer Proceedings in Materials publishes the latest research in Materials Science and Engineering presented at high standard academic conferences and scientific meetings. It provides a platform for researchers, professionals and students to present their scientific findings and stay up-to-date with the development in Materials Science and Engineering. The scope is multidisciplinary and ranges from fundamental to applied research, including, but not limited to:

- Structural Materials
- Metallic Materials
- Magnetic, Optical and Electronic Materials
- Ceramics, Glass, Composites, Natural Materials
- Biomaterials
- Nanotechnology
- Characterization and Evaluation of Materials
- Energy Materials
- Materials Processing

To submit a proposal or request further information, please contact one of the following Springer Publishing Editors according to your affiliation location:

European countries: **Mayra Castro** (mayra.castro@springer.com)
India, South Asia and Middle East: **Priya Vyas** (priya.vyas@springer.com)
South Korea: **Smith Chae** (smith.chae@springer.com)
Southeast Asia, Australia and New Zealand: **Ramesh Nath Premnath** (ramesh.premnath@springer.com)
The Americas: **Michael Luby** (michael.luby@springer.com)
China and all the other countries or regions, as well as topics in materials chemistry: **Maggie Guo** (maggie.guo@cn.springernature.com)

This book series is indexed in **SCOPUS** and EI Compendex database.

Amel Babay · Rim Cheriaa · Riadh Zouari
Editors

Proceedings of the 10th International Conference of Applied Research on Textile and Materials

CIRATM-10

Springer

Editors
Amel Babay
Textile Engineering Laboratory
ISET Ksar Hellal
Ksar Helal, Tunisia

Rim Cheriaa
Textile Engineering Laboratory
ISET Ksar Hellal
Ksar Helal, Tunisia

Riadh Zouari
Textile Engineering Laboratory
ISET Ksar Hellal
Ksar Helal, Tunisia

ISSN 2662-3161 ISSN 2662-317X (electronic)
Springer Proceedings in Materials
ISBN 978-3-031-63611-0 ISBN 978-3-031-63612-7 (eBook)
https://doi.org/10.1007/978-3-031-63612-7

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Organization

Organizing Committee of CIRATM-10

Chairwoman

Amel Babay	LGTex-Ksar Hellal, Tunisia

Co-chairwomens and Co-chairmans

Narjes Rjiba	ATCTex–Ksar Hellal, Tunisia
Paulette Kaci	Vestechpro–Montreal, Canada
Laurence Jeanmichel	CETELOR–Lorraine, France
Frederic Heim	LPMT–Mulhouse, France

President of the Organizing Committee

Riadh Zouari	LGTex-Ksar Hellal, Tunisia

Vice President

Sondes Gargoubi	LGTex-Ksar Hellal, Tunisia

Finance and Sponsoring

Soufien Dhouib	LGTex-Ksar Hellal, Tunisia
Bassem Kordoghli	ATCTex, LGTex-Ksar Hellal Tunisia
Imene El Ghezal	LGTex-Ksar Hellal, Tunisia
Imed Ben Marzoug	LGTex-Ksar Hellal, Tunisia

Reviewing and the Editing of Papers

Mouna Gazzah	LGTex-Ksar Hellal, Tunisia

Planning

Rim Cheriaa	LGTex-Ksar Hellal, Tunisia

Documentation

Yosr Ben Mlik	LGTex-Ksar Hellal, Tunisia
Houda Helali	LGTex-Ksar Hellal, Tunisia

Logistics

Arwa Turki	LGTex-Ksar Hellal, Tunisia

Registration, Media and Event Planning

Helmi Khlif	LGTex-Ksar Hellal, Tunisia
Wael Rmili	Tunisia

Design and Graphics

Kaies Debbabi, Tunisia
Leila Meddeb, Tunisia

Promotion

Mehdi Sahnoun	LGTex-Ksar Hellal, Tunisia

International Relationships

Foued Khoffi	LGTex-Ksar Hellal, Tunisia

Scientific Committee of CIRATM-10

Amar Boukerrou, Algeria
Ahmed Elsayed Elnashar, Egypt
Aida Baffoun, Tunisia
Amel Babay, Tunisia
Amine Haj Taib, Tunisia
Aminoddine Haji, Iran
Arzu Marmarali, Turkey
Demsar Andrej, Slovenia
Emilia Visileanu, Romania
Ennouri Triki, Canada
Faouzi Sakly, Tunisia
Fatma Göktepe, Turkey

Fatma Kalaoglu, Turkey
François Boussu, France
Ilda Kazani, Albania
Ivan Medeiros, Brazil
Karima Horchani, Tunisia
Kiril Lisichkov, Macedonia
Lubos Hes, Czech Republic
Mahdi Sahnoun, Tunisia
Mirela Blaga, Romania
Mohamed Ben Hassen, Tunisia
Neji Laadhari, Tunisia
Nizar Meksi, Tunisia
Omar Cherkaoui, Morocco
Ziya Özek, Turkey
Paul Kiekens, Belgium
Raja Ben Amar, Tunisia
Raul Fangueiro, Portugal
Rosace Guiseppe, Italy
Saber Ben Abdessalem, Tunisia
Slah Msahli, Tunisia
Sonia Dridi Dhaouadi, Tunisia
Soufien Dhouib, Tunisia
Thomas Bechtold, Austria
Antonita Tomljenović, Croatia
Vassiliadis Savvas, Greece
Zakaria Sarani, Malizia

Contents

Study of Absolute Humidity on a Textile Triboelectric Generator

Galata F. Sotiria[1](✉), Repoulias Aristeidis[1], Ertekin Mustafa[2], Pesez Julien[3], Anicaux Cyril[3], Vassiliadis Savvas[1], and Marmarali Arzu[2]

[1] Department of Electrical and Electronic Engineering, University of West Attica, Athens, Greece
sgalata@uniwa.gr
[2] Textile Engineering Department, Ege University, Izmir, Turkey
[3] Ecole Nationale Supérieure des Arts et Industries Textiles, Roubaix, France

Abstract. Triboelectricity is a phenomenon that has been discovered almost 2500 years ago with limited applications. However, over the last decades has gained great attention due to the development of Tribo Electric Generators (TEGs) which harvest the electrical energy that is produced when mechanical energy is converted to electrical energy by combing the triboelectric effect and the electrostatic induction. Textile based Tribo Electric Generator offer many options for energy harvesting, since there is an enormous variety of textiles consisting of various structural patterns and structural units making them easily compatible with TEGs. At the present work we investigate the effect of the absolute humidity (AH) at the performance of a textile based TEG device. Five sets of samples were examined under our textile based TEG prototype varying the external absolute humidity. These samples had the same structural characteristics and were the same in size but they had developed from different raw materials such as acrylic, polyester (PES), cotton, wool and modal. It was observed that absolute humidity affects significantly the outcome voltage and in particular the outcome voltage is decreasing when the absolute humidity is increasing for all set of samples.

Keyword: Triboelectricity · Textiles · Triboelectric Generator · Humidity

1 Introduction

Triboelectricity is a phenomenon when two uncharged surfaces are brought into contact or they are rubbed and then separated, they become charged (Lin et al., 2016). It was discovered almost 2500 years ago by ancient Greek philosopher Thales of Miletus. Therefore, he appointed the original name from the words ‘Tribo’, meaning to rub and ‘Electro’, meaning amber; in other words, rubbing amber created electrostatic charging (Iversen, Lacks, 2012). This charging can be created not only by rubbing but also by simple non-frictional contact between two surfaces. The charges that are created at these two contacting surfaces are equal in magnitude and opposite in sign (Molnar et al., 2018). The intensity of the phenomenon is related to the electron affinities on their surfaces (Lin et al., 2016) and external factors such as the humidity of the medium, the temperature of

A. Babay et al. (Eds.): CIRATM 2023, SPM 49, pp. 1–7, 2024.
https://doi.org/10.1007/978-3-031-63612-7_1

the surrounding area and the roughness of the contacting surfaces (Molnar et al., 2018). Based on the triboelectricity effect, a lot of research has been carried out over the last decades to harvest electrical energy by developing novel devices named as Tribo Electric Generators (TEGs) and lately as Tribo Elecrtic Nano Generators (TENGs). A TEG is a device that mainly harvests energy that converts the external mechanical energy into electricity, combining the triboelectric effect and the electrostatic induction, by making use of various set-up modes (Lin et al., 2016; Chacko et al., 2017).

Energy harvesting of a TEG using triboelectricity has gained great attention over the last years, because of the increasing demand for power that is needed for the wearable electronics, e-textiles and sensors in order to operate (Fan et al., 2012). In addition, energy harvesting from TEGs could be offered from every day human activities, such as walking or even from mechanical vibration having numerous applications in self-powered systems, monitoring medical data in humans or environmental data or even powering large scale electronics.

Textile based TEGs are advantageous due to their large contact areas and the fact that the wearer can be in continuous movement and in contact to the textile garment, which is desired for having continuous mechanical motion for the operation of the TEGs (Chacko et al., 2017).

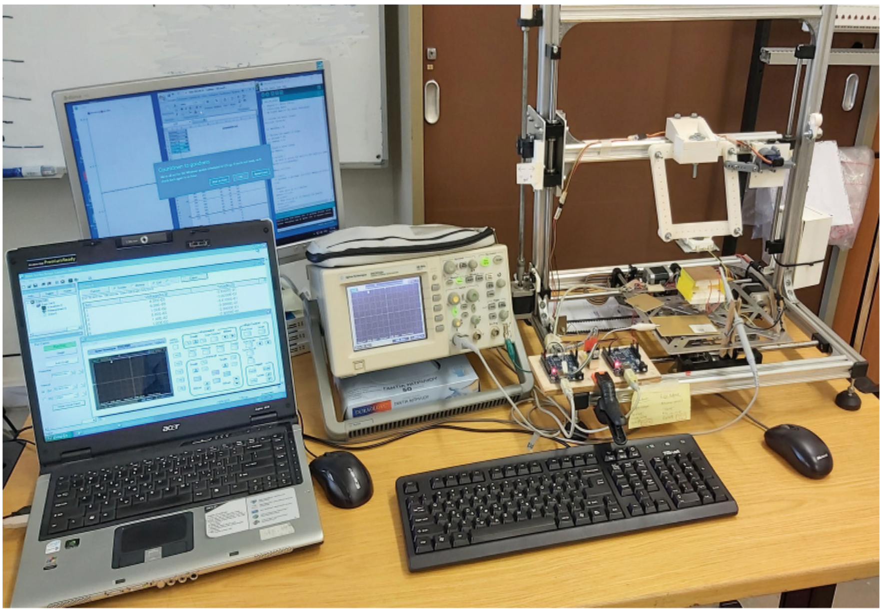

Fig. 1. Experimental setup

The contacting surfaces of the textiles could be quite rough due to their fibrous nature, therefore providing higher electrical outcome when combined to a TEG (Dudem et al., 2019). Also, there is a wide variety of textiles which have various structural patterns such as woven or nonwoven, embroided, knitted or they consist of various structural units such as conductive yarns, multi-layered yarns, natural or synthetic yarns, which allows the combination and therefore the creation of even more variety of structures, eg multilayer textile TEGs (Hu & Zheng, 2019). Another important point about textiles is that they have a huge variety of properties such as elasticity, flexibility, conductivity, breathability and washability that make them easily compatible with TEGs and therefore more prone to product energy (Li et al., 2018). At the present work we investigate the effect of the absolute humidity (AH) at the performance of a textile based TEG device which combines vertical and sliding modes, similar to a part of a wearable garment.

2 Material and Methods

The experimental setup is shown in Fig. 1. It is a prototype TEG that is developed to measure the triboelectric effect on a variety of textile samples. It consists of a tapping unit which brings the samples into contact, two flat electrodes where the samples are attached on them, and a force sensor that measures the applied load among the samples during the contact. Due to a special designed 3D arm, the movement of the upper sample towards the lower one follows an elliptical motion, which corresponds to the contact between the samples, their sliding and finally their separation. Therefore, it is similar to the motion of a textile based TEG which could be embedded in the moving parts of a real-life wearable garment. An Arduino microcontroller was used to activate the moving parts and to control their movements (direction and duration of movement) via an actuator.

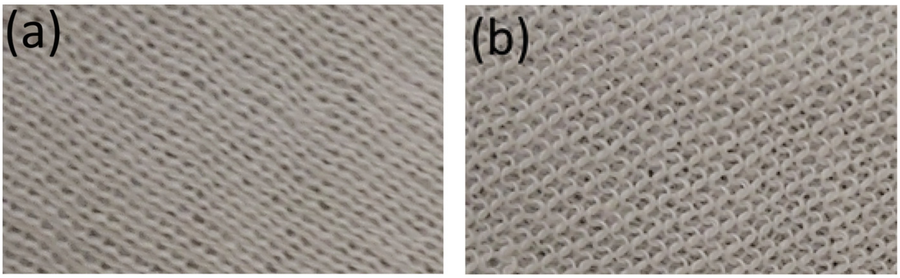

Fig. 2. (a) Front side and (b) back side of polyester (PES) yarn knitted sample

The conductive parts of the two electrodes were connected to an oscilloscope, so that the output voltage (V_{pp}) coming from the contact and the sliding of the electrodes to be measured. The lower electrode was kept steady and underneath from it was placed a weight load sensor which is used to measure the weight load between the two samples under testing during their contact and sliding. 20 grf load was applied when the two samples were sliding at each other. Another Arduino microcontroller was used to collect the measured values of the load. The measured voltage output (V_{pp}) data were directed and collected to a laptop. (Repoulias et al., 2021, Repoulias et al., 2022).

External conditions such as temperature and the relative humidity were controlled via an air-conditioning system. Relative humidity and temperature were measured by two calibrated high precision sensor hydrometers. Temperature ranged from 18 °C up to

28 °C, whereas relative humidity ranged from 20% up to 55%. Absolute humidity was calculated indirectly via the relative humidity and the ambient temperature.

A set of textile samples were prepared for triboelectric measurements. All of them were cut at the same size (5 cm × 5 cm). Para-aramid was attached at the lower electrode and used as a reference sample. At the upper electrode, 5 different samples were attached which had the same structural characteristics such as linear density and jersey pattern and also the same wale density and course density. However, they consisted of different raw material such as acrylic, polyester (PES), cotton, wool and modal.

In Fig. 2 (a) and (b) are illustrated the front and back side of a polyester (PES) yarn knitted sample. The knitting pattern is the same for all set of samples at the front side and the same at the back side.

A typical electrical measurement which is the outcome of the triboelectric effect and includes the contact of the samples, their sliding and finally their separation, is shown in Fig. 3, as appeared on the screen of the oscilloscope. The first peak on the left-hand side of Fig. 3 corresponds to the contact of the two textile surfaces, the last peak on the right hand side of the picture corresponds to the separation of the two textile surfaces and the line in between the two peaks corresponds to the sliding between the two textile surfaces.

Fig. 3. Typical electrical measurement (voltage) as an outcome of a measurement loop which includes the contact between the samples, their sliding and finally their separation.

3 Results and Discussions

In Fig. 4 is presented the measured output Voltage (peak to peak, V_{pp}) values versus the change at the absolute humidity (AH) for two set of samples, polyester (PES) and para-Aramid and wool and para-Aramid. Absolute humidity was calculated using Eq. (1) via the measured relative humidity RH in % (Vaisala, 2013, Shi et al., 2020, Nottmeyer, Sera, 2021), where T is in °C.

$$AH = \frac{13.253 \times RH \times 10^{\left(\frac{7.591T}{T+240.726}\right)}}{T + 273.15}\left(\mathrm{g/m^3}\right) \quad (1)$$

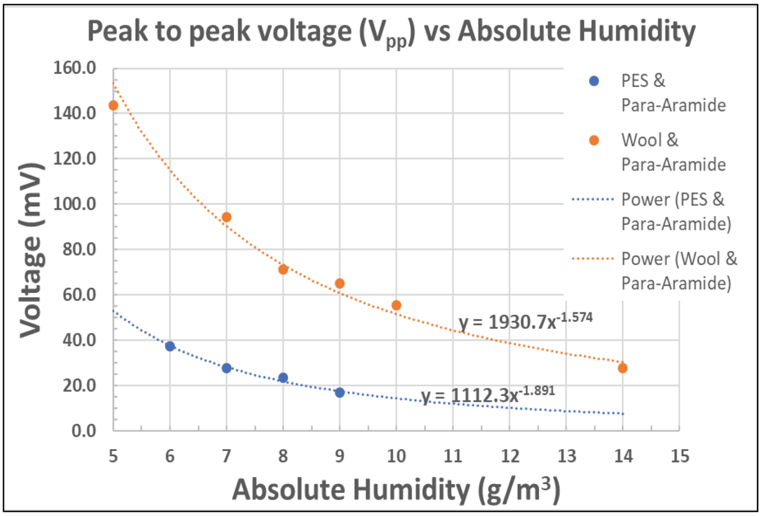

Fig. 4. Average peak to peak outcome voltage (V_{pp}) over the absolute humidity for two sets of samples. (The dots correspond to the measured values and the doted lines correspond to the power-law trendline applied).

The set of samples between wool and para-Aramid revealed the best results from all other set of samples, in terms of highest values of the output voltage; one the other hand polyester (PES) and para-Aramid revealed the lowest values of the output voltage (V_{pp}). This is due to the structural characteristics of wool and more specifically, wool has a rougher surface than polyester (PES). Therefore, the effective area of friction between wool and para-Aramid is higher than the one between polyester and para-Aramid. Therefore, this higher effective area of friction results to higher electrical output. (Molnar et al., 2018, Fan, Lin et al., 2012). The rest of the set of samples were in between these two graphs. Para-Aramid is located at the negative edge of the charge densities table for fabrics and materials, thus it attracts more electrons, so it was selected as a reference (Liu et al., 2018). Moreover, the difference of the charge densities between para-Aramid and wool as they are located at the charge densities table for fabrics and materials is higher than the one between para-Aramid and polyester therefore the resulted output voltages are expected to be higher for the set of para-Aramid and wool than para-Aramid and polyester (Liu et al., 2018), (Molnar et al., 2018); this is also confirmed by our experiments.

In addition, regarding the set of wool and para-Aramid, an increase of absolute humidity from 5 up to 14 g/m^3 resulted in a decrease of output voltage from 145 up to 30 mV respectively. The set of polyester and para-Aramid revealed a similar behaviour; at an increase of absolute humidity from 6 up to 9 g/m^3 there was a decrease of the output voltage from 38 mV up to 18 mV, as it can be also observed from Fig. 4. Therefore, the outcome V_{pp} is decreasing as the absolute humidity is increasing for both set of samples and also for the rest of samples (not shown here). The decrease is more abrupt at lower absolute humidity values and smoother for higher absolute humidity values. In addition, a power-law dependence was applied on the data revealing a similar trend between PES and para-Aramid and wool and para-Aramid samples. So, for the set of wool and para-Aramid the dependence between absolute humidity (AH) and output voltage V_{pp} is the following:

$$V_{pp} = 1937.30 \times (AH)^{-1.574} \tag{2}$$

And for the set of polyester and para-Aramid the dependence between V_{pp} and AH is the following:

$$V_{pp} = 1112.3 \times (AH)^{-1.981} \tag{3}$$

The precision of the trends is quite high for both cases, i.e. $R^2 = 0.984$ and $R^2 = 0.982$ for wool and para-Aramid and polyester and para-Aramid, respectively. Therefore, absolute humidity affects dramatically the energy output of a textile triboelectric generator.

4 Conclusion

The effect of absolute humidity with respect to the triboelectric phenomenon via a textile prototype Tribo Electric Generator (TEG) was investigated. Textiles can be created with various structural patterns and units which allows the combination and therefore the creation of even more variety of structures. Also, they have a huge variety of properties and the fact that they can offer large contact areas make them easily compatible with TEGs and therefore more prone to product energy. In addition, the fact that the wearer can be in continuous movement and in contact to the textile garment is also desired for having continuous mechanical motion for the operation of the TEGs. Five sets of samples were studied which had the same structural characteristics such as linear density and jersey pattern and also the same wale density and course density. They consisted of different raw material such as acrylic, polyester (PES), cotton, wool and modal. Para-Aramid was used as a reference sample for all sets of samples due to its position at the charge densities table for fabrics and materials. These common textiles could be embedded in a textile wearable TEG. These samples were tested at a prototype textile based TEG which included the stages of contact, sliding and the separation between them. The electrical output out due to the triboelectric effect was measured when the absolute humidity and temperature conditions were varied. Absolute humidity was measured indirectly via the relative humidity and the ambient temperature. It is concluded that by increasing the absolute humidity, the outcome energy in terms of voltage (V_{pp}) is decreasing for all set of samples, as expected. The behaviour was similar for all set of samples and they all exhibited a power law. Therefore, humidity plays a vital role and should be taken into great account when designing a textile based TEG that could be a wearable garment.

Acknowledgments. The publication of the article was fully funded by the University of West Attica.

References

Chacko, P., Kapildas, K.S., Jarin, T.: Nano generator intended for energy harvesting. Asian J. Appl. Sci. Technol. **1**(9), 88–91 (2017)

Dudem, B., Mule, A.R., Patnam, H.R., Yu, J.S.: Wearable and durable triboelectric nanogenerators via polyaniline coated cotton textiles as a movement sensor and self-powered system. Nano Energy **55**, 305–315 (2019). https://doi.org/10.1016/j.nanoen.2018.10.074

Fan, F., Tian, Z.-Q., Wang, Z.: Flexible triboelectric generator. Nano Energy **1**(2), 328–334 (2012). https://doi.org/10.1016/j.nanoen.2012

Hu, Y., Zheng, Z.: Progress in textile-based triboelectric nanogenerators for smart fabrics. Nano Energy **56**, 16–24 (2019). https://doi.org/10.1016/j.nanoen.2018.11.025

Iversen, P., Lacks, D.J.: A life of its own: the tenuous connection between Thales of Miletus and the study of electrostatic charging. J. Electrostat. **2012**, 309–311 (2012). https://doi.org/10.1016/j.elstat.2012.03.002

Li, C., Cao, R., Zhang, X.: Breathable materials for triboelectric effect-based wearable electronics. Appl. Sci. **8**(12), 2485 (2018). https://doi.org/10.3390/app8122485

Lin, Z., Chen, J., Yang, J.: Recent progress in triboelectric nanogenerators as a renewable and sustainable power source. J. Nanomater. **2016**, 1–24 (2016). https://doi.org/10.1155/2016/5651613

Liu, S., Zheng, W., Yang, B., Tao, X.: Triboelectric charge density of porous and deformable fabrics made from polymer fibers. Nano Energy **53**, 383–390 (2018). https://doi.org/10.1016/j.nanoen.2018.08.071

Molnar, O., Gerasimov, V., Kurytnik, I.P.: Triboelectricity and construction of power generators based on it. Przegląd Elektrotechniczny **R.94**(1), 167–171 (2018). https://doi.org/10.15199/48.2018.01.41

Nottmeyer, L.N., Sera, F.: **(2021):** Influence of temperature, and of relative and absolute humidity on COVID-19 incidence in England – A multi-city time-series study. Environ. Res. **196**(110977), 1–8 (2021). https://doi.org/10.1016/j.envres.2021.110977

Repoulias, A., Vassiliadis, S., Galata, S.F.: Triboelectricity and textile structures. J. Text. Inst. **112**(10), 1580–1587 (2021). https://doi.org/10.1080/00405000.2020.1829331

Repoulias, A., Ertekin, M., Galata, S.F., Vassiliadis, S., Marmarali, A.: Investigation of triboelectricity on textile structures through a TEG which combines sliding and vertical mode. Tekstil ve Mühendis **29**(128), 291–296 (2022). https://doi.org/10.7216/teksmuh.1222522

Shi, P., et al.: The impact of temperature and absolute humidity on the coronavirus disease 2019 (COVID-19) outbreak – evidence from China. medRxiv (2020). https://doi.org/10.1101/2020.03.22.20038919

Vaisala, O.: Humidity Conversion Formulas (2013)

Stent Grafts from Polymeric Material: A Novel Design to Improve the Implant Durability

Abdul Rahman Asaad(✉), Frédéric Heim, Corinne Jung, and Christian Pidancier

Laboratory of Physics and Mechanical Textiles, University of Haute-Alsace, Mulhouse, France
abdul-rahman.asaad@uha.fr

Abstract. Stent grafts have become a solution of choice to treat aneurysm diseases over the last 2 decades. As these devices are implanted in a mini-invasive way, the patients comfort related to the procedure is largely improved compared to open heart surgery. The long experience acquired in the clinic shows that a large range of thoracic as well as abdominal pathologies can be treated with a large range of devices varying in diameter and design. However, stent grafts being composed of a polymeric textile membrane and metallic stent segments, their durability depends largely on the interactions that occur between these 2 materials. Metallic segments are very abrasive and tend to degrade the textile cover through apex indentation or relative friction, when the stent graft undergoes cyclic loading.

This work investigates a strategy to replace the metallic stent segments with less abrasive polymeric segments obtained from monofilament material. An additional goal is to integrate the polymeric stent segments directly into the textile membrane using the embroidery technique for secure assembling purpose. Limited relative movement between the composing elements is expected to improve the lifetime of the device. However, the mechanical properties of the embroidered assembly must match the deformability and elasticity required by the aneurysm treatment application. This was tested in the frame of this study.

Keywords: CVD · Stenosis · Aneurysm · Stent Grafts · Vascular Surgery · Polymer · Compliance

1 Introduction

Cardiovascular diseases (CVD) affect the heart and blood vessels, creating disruptions similar to traffic jams in our body's pathways. CVD can slow or block blood flow, affecting the delivery of oxygen and nutrients. There are major issues related to CVD, including 'Atherosclerosis,' which narrows arteries and can cause heart attacks and strokes. 'Stenosis' narrows vessels like lanes on a road (Fig. 1).

While 'Aneurysms' are weak spots that may rupture blood vessels. Addressing CVD involves lifestyle changes, medication for blood pressure and cholesterol, and procedures such as medical devices or surgery. Medical devices like stents, grafts, and stent grafts are essential for keeping vessels open, repairing damage with grafts, and reinforcing weak areas with stent grafts (Fig. 2).

A. Babay et al. (Eds.): CIRATM 2023, SPM 49, pp. 8–17, 2024.
https://doi.org/10.1007/978-3-031-63612-7_2

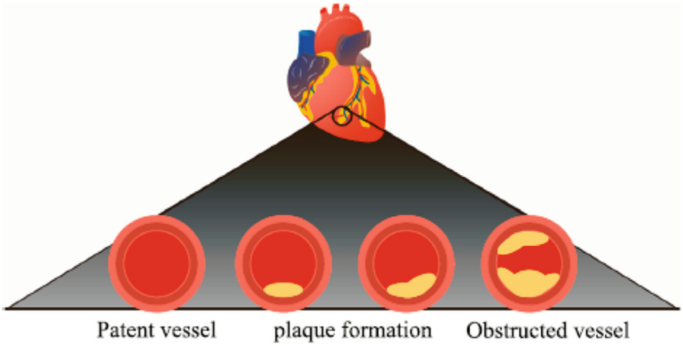

Fig. 1. Visual representation of stenosis formation [1]

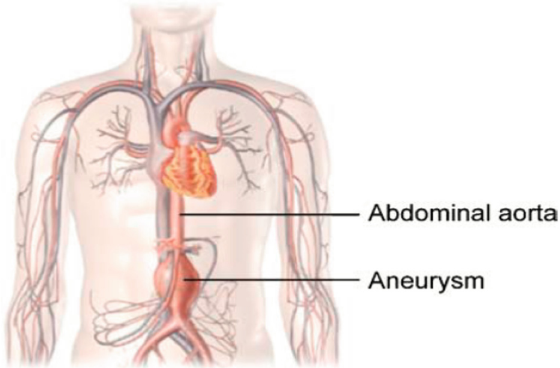

Fig. 2. Visual representation of aneurysm formation [2]

2 Materials and Methods

In light of these considerations, we are currently investigating the utility of polymers as potential substitutes. Polymers offer smoother surfaces and compatibility with biological systems. Our primary objective is to replace a problematic metallic component in stent grafts, aiming to enhance compliance and elasticity while minimizing abrasion caused by the metallic segments.

The technical process we employ can be termed "functionalization", this process is executed using an embroidery machine, which blends the polymer with textiles to create our biocompatible elastic device. We will begin by crafting the device on a flat textile, akin to the operation of a 2D printer. Afterward, the flat device will undergo a subsequent process to seal it and transform it into a vascular tube (Fig. 3).

2.1 Parameters

Certainly, there is parameters that has influence upon the prototype.

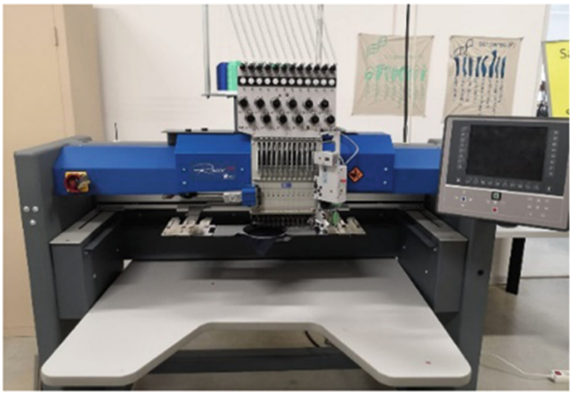

Fig. 3. Image of the ZSK embroidery machine.

1. Stitch Tension: This parameter pertains to the tightness of stitches and is dependent on the machine's settings.
2. Stent Design: We will analyze the specific pattern utilized in our stent, as it holds significant importance.
3. Stent Material: The material composition of the stent is a critical factor.
4. Filament Diameter: The thickness of the material used for the stent is a significant consideration.
5. Textile Material: The type of fabric employed is of utmost importance.
6. Textile Design: We will evaluate the manner in which the fabric is woven or assembled.
7. Material Placement: We will determine the optimal positioning of materials within the machine, taking into account the orientation of the threads.

2.2 Idea

The way we're putting things together is different from what's typically done in commercial settings. Instead of weaving the material horizontally like a classic fabric, we're tilting it at a 45-degree angle. This makes the textile deformable, as shown in the picture, and turns the flat textile into a tubular structure for blood vessels. Also, it's important to mention that the spring is gonne be the one helping the graft to recover (Fig. 4).

2.3 Specifications

We started our testing with a commercial type of monofilament called polyamide 6,6, which is also known as Nylon. It's important to note that Nylon is not the final material choice for our desired prototype; it's solely used for testing purposes at this stage. We utilized Nitinol to draw comparisons with the concept of implanting it into the existing framework (Fig. 5).

When it comes to the spring design, we've developed two different designs. The first design, shown in Fig. 6, consists of two zigzags and has a spring with an inner diameter of 1cm and a total of 2 spiral loops. The second design, shown in Fig. 7, is called "3zigzag" because it's made up of 3 spiral loops.

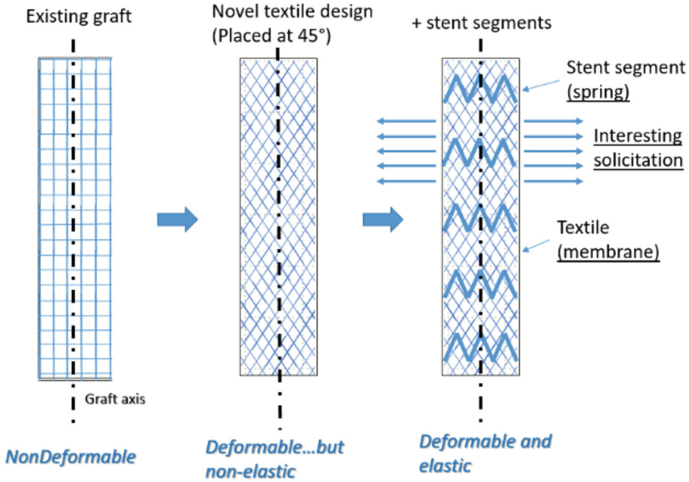

Fig. 4. Visual process of the fabrication of the vascular tube

Filaments	N(spiral number)	D (mm)	d (mm)	G (Gpa)
Polyamide 6,6	2	10	300	3
Polyamide 6,6	2	10	450	3
Polyamide 6,6	2	10	600	3
Nitinol	2&3	7&10	200	30

Fig. 5. Specification about the material used

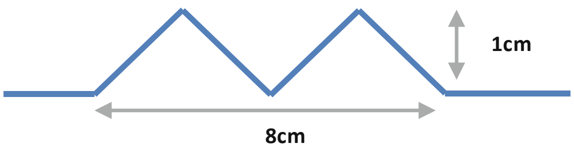

Fig. 6. Illustration of first design

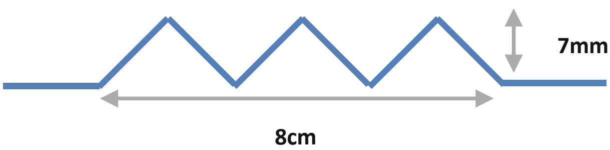

Fig. 7. Illustration of second design

2.4 Equations

The classical equation of the stiffness of the spring is the following.

$$k = (G * d^4)/(8 * D^3 * n)$$

3 Results and Discussion

3.1 Testing the Textile

We began our testing by first analyzing the textile on its own to understand how much recovery we needed from that specific segment. Afterward, we examined each filament separately. All the samples were tested for 30 cycles.

The results of the cyclic loading tests on the textile alone has given the following.

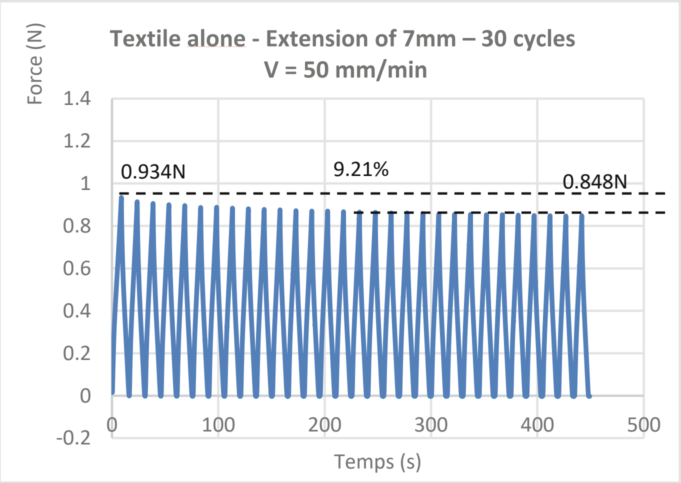

Fig. 8. Results of the cyclic loading tests on the textile alone

As shown in Fig. 8, the textile has experienced a 9.21% loss in its elasticity. However, our main focus is on the force value obtained from the initial cyclic loading test, which was 0.934N. From this, we can conclude that, in order to facilitate the recovery of the lost 9.21% elasticity in the textile, the spring needs to provide a force value close to 0.934N, or a second hypothesis could say that we only need to recover the lost 9.21%. We'll verify this during the future tests. With this in mind, we can proceed to test the filament.

3.2 Testing the Filament

To test the filament, we'll follow a process that involves securing the filament to a metallic support and subjecting it to heat treatment. We specifically chose aluminum to craft the support because it can withstand the high temperatures necessary for the essential heat treatment, which establishes the spring's memory shape. As depicted in the figure, we used clamps to secure the ends and angles of the spring (Fig. 9).

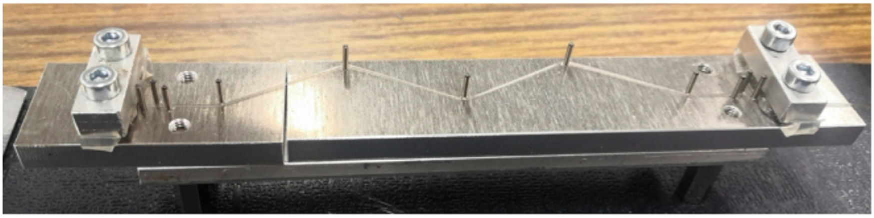

Fig. 9. Image showing the preparation phase of the filament

Next, the filament is secured while applying a specific tension to it, achieved by attaching a weight to the end of the filament. This process is applied uniformly to all samples, ensuring consistent testing conditions and minimizing any variations during the tests to enhance repeatability.

In the second phase, we proceed with the heat treatment of the samples. For each type of filament, such as polyamide and nitinol, we perform the heat treatment at the required glass transition temperature (Tg). However, nitinol requires a different treatment, involving two heat treatments with a quenching process in between.

Once all of this is done, the support will now fulfill its purpose, which is the placement phase of the filament be exactly the testing phase, that's why after the heat treatment of the samples, we put the support in the machine as shown in the Fig. 10.

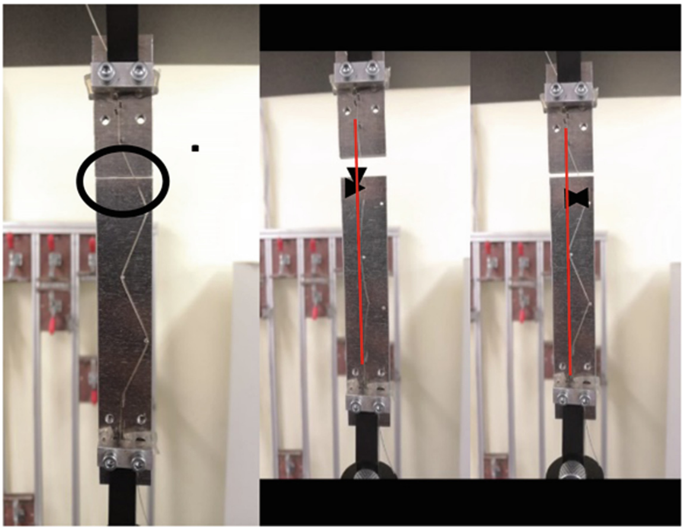

Fig. 10. Image of the placement phase in the machine

The initial results obtained with this method introduced additional friction, which led to the application of the following modification to the support. As illustrated in the figure below, you can see a cut made in the upper part of the piece (Fig. 11).

Fig. 11. Process of the support variations

This adjustment helps ensure that the filament can move freely in the air, and there will be no friction between the filament and the metal surface during the test, as depicted in the Figs. 12 and 13 below.

The gap between the initial peak and the final peak in the cyclic loading tests represents the lost elasticity in this scenario. For all the filaments, the elasticity loss is approximately 10% for each of the 300, 450, and 600 cycles. However, in the case of nitinol, the loss is only about 3%.

Now the next step would be to adjust the design, and instead of doing tests on the 2zigzag we're gonna do it on the 3zigzag model illustrated earlier. The results were the following (Fig. 14).

The 3zigzag model showed even more ability of recovery since it has only lost 0.3% of elasticity between the first and last peak of the cyclic loading test.

3.3 Testing the Assembling

Now for the assembling, we've used our ZSK Racer 1WL embroidery machine (Fig. 15).

The textile assembled using 2zigzag PA6,6 (600 μm) experienced an 8% loss in elasticity, while the textile assembled with 2zigzag Nitinol had a 7.8% loss. The textile assembled with 3zigzag Nitinol showed a 3.67% loss in elasticity. In our future plans, we intend to test the 3zigzag configuration of PA6,6, and we will also explore the application of Dyneema in this project for further studies.

Fig. 12. Image showing the filament free in the air

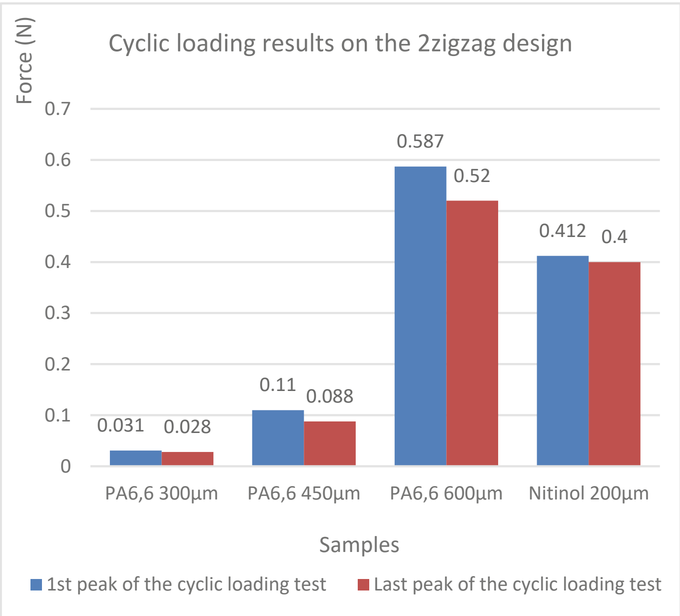

Fig. 13. Image showing the results of the 2zigzag design

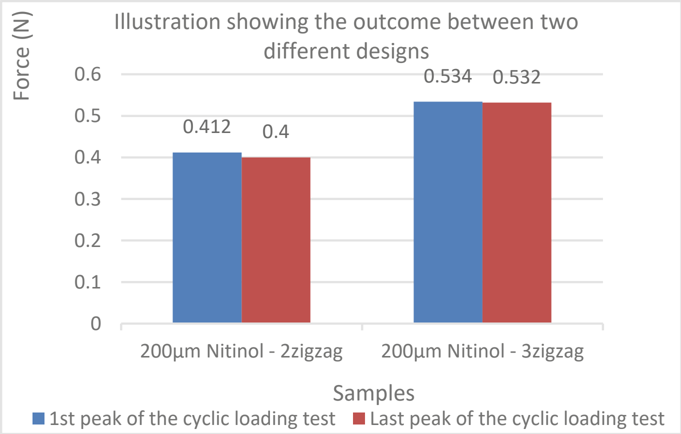

Fig. 14. Figure showing the difference in the outcome between the different designs

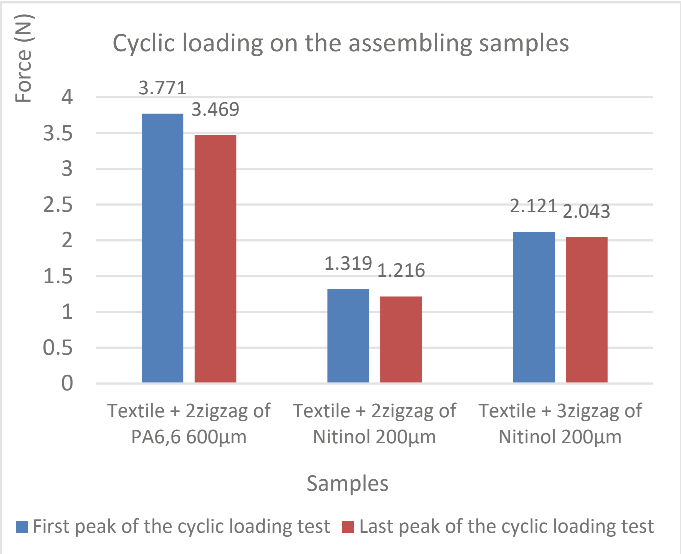

Fig. 15. Figure showing the difference in the outcome between the first cyclic loading and the last one

4 Conclusion

We've confirmed that attempting to improve elasticity in the medical device is a valid idea. First objective is to identify the ideal geometric pattern and the right polymer. Next one would be to perform extended tests to check our system's long-term performance. We can change the material is an option if we want to increase the elasticity and of course to have a better biocompatibility. And then create a vascular tube out of flat 45° textile.

References

1. Korei, N., Solouk, A., Nazarpak, M.H., Nouri, A.: A review on design characteristics and fabrication methods of metallic cardiovascular stents. Mater. Today Commun. **31**, 103467 (2022)
2. Lasheras, J.C.: The biomechanics of arterial aneurysms. Annu. Rev. Fluid Mech. **39**(1), 293–319 (2007). https://doi.org/10.1146/annurev.fluid.39.050905.110128