CHARACTERIZATION OF CARBON-NICKEL THERMOCOUPLES INTEGRATED IN TEXTILE FABRICS

Hardianto Hardianto[1,2], Gilbert De Mey[3], Benny Malengier[1], Carla Hertleer[1] and Lieva Van Langenhove[1]

[1] *Department of Materials, Textiles and Chemical Engineering, Ghent University, Technologiepark 70A, 9052 Zwijnaarde, Belgium; hardiant.hardianto@ugent.be*
[2] *Department of Textile Chemistry, Polytechnic of Textile Technology (Politeknik STTT Bandung), Jalan Jakarta 31, Bandung 40272, Indonesia*
[3] *Department of Electronics and Information Systems, Ghent University, Technologiepark 15, 9052 Zwijnaarde, Belgium; gilbert.demey@ugent.be*
E-mail of the Presenting Author: hardiant.hardianto@ugent.be

ABSTRACT

In this paper, the characterization of textile-based thermoelectric generators made of carbon fibers (C) and nickel-coated carbon fibers (Ni) integrated into polyester fabrics is reported. We used carbon yarns inserted into a fabric. The nickel was then deposited by an electrochemical reaction (electroplating) in order to form a series connection of C-Ni thermocouples (105 pairs). The electroplating process was done in such a way that all the hot junctions of the thermocouple chain were on one side of the fabric and all the cold junctions on the other side. A temperature difference across the fabric, which happens in all wearable garments due to the body heat, will then generate a voltage which can be used to power small electronic devices. Here, two electrical characterizations of the thermopile i.e. Seebeck coefficient and internal resistance are presented. All these measurements have been carried out on the C-Ni thermocouple chain formed on carbon yarn in the structure of the polyester fabric. The coefficient turned out to be 1219 µV/K or 11.61 µV/K for a single junction.

Key Words: Thermocouple**,** thermopile, thermoelectric generator, conductive textile yarn, fabric

1. INTRODUCTION

The topic of this paper is the integration of thermocouples from conductive textile yarn in wearable textiles. Due to the human body heat, there is always a temperature difference between the inner and outer part of a garment. By integrating thermocouples in the garment, a voltage can be generated which might be used to supply a small amount of electric power to wearable electronics.

Due to the flexibility aspect of textile fabrics, the principle of thermocouple has been adapted and integrated into fabrics by researchers for various purposes such as temperature sensors [1] and heat flux sensors [2–4]. Most of those research papers showed thermocouples made from metal wires. Ziegler and Frydrysiak [1] reported their preliminary research on using textile-based conductive materials to create textile thermocouple and using it as temperature sensors. The possibility of fabricating thermocouples from conductive textile yarns is also supported by the results of research conducted by Hardianto *et.al* [5–8].

A major problem in a thermocouple is that it delivers a low voltage (μV range). Moreover, the temperature differential across a garment is not so high. In order to obtain a sufficiently high voltage, many thermocouples have to be connected in series.

Normally, thermocouples are made of two different metals such as copper-constantan, iron-constantan, chromel-alumel, etc. Here, we present a textile-based thermopile made of a series of carbon fibers (C) and nickel-coated carbon fibers (Ni) thermocouples integrated into polyester fabrics.

In this contribution, open circuit voltage versus temperature difference and voltage versus delivered current will be presented. The measurement was carried out on sample with carbon-nickel thermocouples formed in series integrated into the polyester fabric.

2. SAMPLE PREPARATION

Carbon fiber used in this experiment is Tenax®-E HTA40 E13 3K 200 tex 15Z purchased from Toho Tenax Europe GmbH. Carbon fiber yarn was manually stitched in the polyester fabric with the help of a needle to get the patterns (105-pair junction) shown in Figure 1.

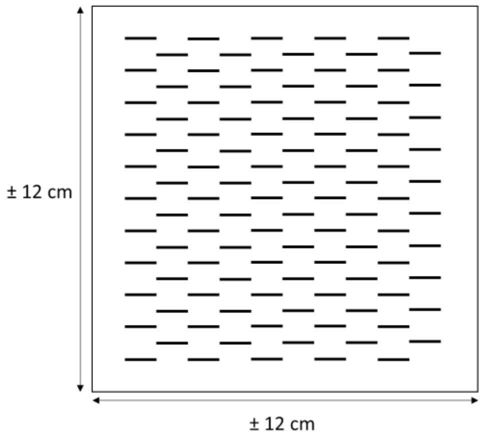

Figure 1 Stitching patterns of the thermopiles

The fabric containing the carbon fibers was then dipped in acetone prior to the electroplating process. Before electroplating, the carbon fiber was covered with acrylic dispersion dropwise on certain places to form a series of C-Ni junctions along the CF yarn where the hot junctions were on one side and the cold junctions were on the other side. The application of the polymer was done row by row. After each row was finished with the polymer then the drying process was carried out in an oven at 110°C for 2 minutes. Finally, the sample was put in the oven at 140°C for 15 minutes to carry out the polymerization. Then, it is ready to be electroplated.

Nickel electroplating process was performed in a glass beaker. Each sample was immersed in a 600 ml solution containing 200 g/L Nickel acetate, 0.3 g/L Sodium Dodecyl Sulfate and 30 g/L Boric acid. Two pieces of nickel anode electroplater (2.5 x 8 cm) was connected to the anode of the power supply and two Cu/Ag50 wires were connected to the cathode of the power supply through copper wire cable with clamps. The temperature was kept at 50°C. Initial voltage was 2.00 volts and the current was 0.080 ampere. The electroplating process was performed in 2 x 30 minutes. Then the sample was washed under running water and dried at room temperature.

3. ELECTRIC MEASUREMENTS

The sample has been tested using the circuit shown in Figure 2. V is voltage meter to measure the voltage generated from the thermopile at each load resistance R_L. ΔT is the temperature differential between the hot and cold side of the thermopile. The electrical current was calculated from V and R_L.

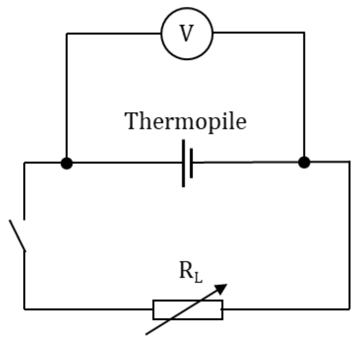

Figure 2 Circuit diagram used for testing the electrical characteristic of the thermopile samples

The sample was placed between a hot plate on the bottom and a Peltier module on top. The fan on the Peltier module blew the cold air to the cold side of the module to establish temperature difference ΔT. A sheet of paper had to be placed on the hot plate to prevent any short circuiting by the metallic hot plate. Two temperature sensors were positioned on both sides of the fabric to measure the temperature differential.

4. RESULT AND DISCUSSION

Figure 3 shows the generated open circuit voltage (the load resistor R_L was disconnected) as a function of the temperature difference ΔT. The slope of this curve is found to be $\alpha = 1219\ \mu V/K$. Taking into account that the 105 thermocouples are connected in series, one gets a value of $11.61\ \mu V/K$ per junction. This value is much less than the theoretical value for a C-Ni cell which is around $18\ \mu V/K$ [7, 8]. This is because the carbon fiber used in this experiment has a smaller number of filaments. It consists of 3000 filament while the one used in the literatures [7] and [8] has 12000 filaments. Logically, the yarn with higher filaments will have a higher surface area and more nickel on the fiber surface. This will give different electrical characteristics including the Seebeck coefficient.

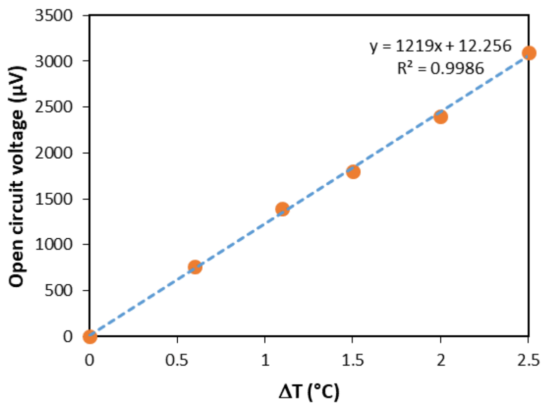

Figure 3 Graph of open circuit voltage vs. temperature difference of the sample

The thermopiles have been connected to a variable resistor as shown in Figure 2. The results obtained are shown in Figure 4. From the slope of these curves, one finds that the device has an internal electric resistance of 251.1 Ω. This is a rather high value due to the high serial resistivity of the carbon yarn. Roughly half of the thermocouple yarn is carbon, the other half is covered with nickel which has a much higher electrical conductivity.

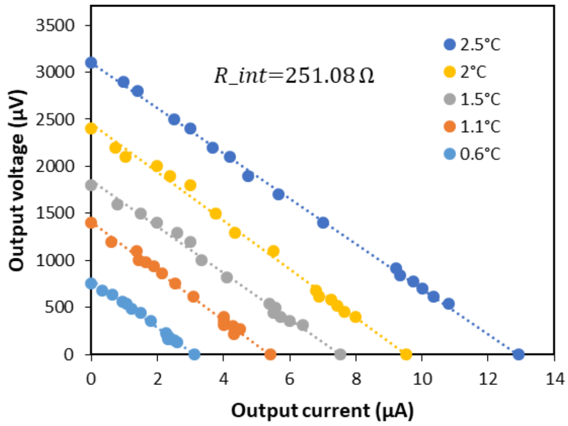

Figure 4 Internal resistance of the thermopile

5. Conclusion

This paper presents the characterization of thermopiles formed of a series of carbon-nickel thermocouples. These thermocouples were created on a tow of carbon fiber inserted into the polyester fabrics and nickel was deposited on it at specific spots by electroplating technique to create thermopile junctions on both sides of the fabric. In this manner, we can obtain a thermo-voltage when temperature differential occurs between the cold and hot sides of the thermopile.

To characterize the thermoelectrical capability of these textile-based carbon-nickel thermopiles, we varied the temperature difference ΔT and accordingly measured the thermo-voltage in open-circuit condition and in different load resistances. The Seebeck coefficient of the sample measured is 1219 μV/K or 11.61 μV/K per junction. The internal electrical resistance of the thermopile sample is 251.08 Ω.

These results again demonstrate that thermoelectric devices can be constructed from textile materials in fabric form. This can be a beginning to fabricate a wearable textile-based thermoelectric device that can use human body heat to generate electricity.

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