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Elaboration of a Conductive Textile by Coating for Clothes Equipped with Fourth-Generation Photovoltaic Cells

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Abstract: Conducting polymer coated in textiles possesses a wide range of electrical properties. The surface resistivity is influenced by concentrations of the reactants, thickness of the coating, nature of the substrate surface, extent of penetration of the polymer into the textile structure and the strength of the binding of the coating to the textile surface. Low resistivity in fabric results from highly doped thicker coatings that penetrate well into the textile structure thus enabling good electrical contact between fibers. In this study, we had chosen copper as conductor polymer for coating. The electrical conductivity is influenced by the thickness of coating paste, the nature of the substrate surface. The thickness of the paste and the concentration of the copper were studied in this paper. Furthermore, the electrical surface resistance decreased from 68 MΩ to 8 MΩ with decreasing in coating thickness. However, the thickness of coated fabric is very important factor to determine conductivity and application of textile. In addition, we had noticed that the airflow is affected by the coating thickness which the penetration of the airflow differs from the lower thickness to the higher one. This study confirms that we can use coating woven fabric to develop a textile substrate responding to characteristics such as electrical resistance, drapability, air permeability and tensile strength, which are particularly important to be used as a support for flexible PV (photovoltaic) cells in clothes.

Key words: Conductor textile, technical textile, coating, electrical resistance.

1. Introduction

Textile fabrics nowadays possess a multitude of applications. In addition to their obvious use as materials for clothing, they have a wide variety of highly technical uses, ranging from conventional bulk bags to sophisticated medical implants. Moreover, the miniaturization of electronic devices over the past twenty years or so has expanded textile applications still further. There is extensive interest in the incorporation of sensors into wearable fabrics: for example, for medical, military, sports and leisure applications. In this paper, we explore the innovative use of textiles as supports for electricity-generating PV (photovoltaic) solar cells, contrasting the different approaches that seek to use the performance of a fabric without compromising the operation of the solar cells. The simplest approach, of bonding solar cells to a fabric, is less effective in retaining the textile properties than it is in maintaining the solar cell performance. The other two approaches use contrasting architectures for integrating solar cells with fabrics: Either the cells are constructed on fibers that are subsequently fashioned into a fabric or the cells are formed on a finished fabric. Each of these techniques has its advantages and disadvantages, with rather more effort reported on making coated fibers.

Solar PV is one of the alternative sustainable energy sources that make up increasing amounts of electrical demand in many countries. The renewable sources available include hydroelectric schemes, wind turbines, wave power and tidal power. However, the

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most compelling direct source of energy, and one that will provide an “endless” supply, is the sun. The sun provides the whole Earth with more energy in one hour than the world’s population uses in one year. Despite its variability, in harnessing solar power, success has come from its direct conversion to electricity, using solar cells.

Textile fabrics offer a solution to this difficulty, not least because they are the most widespread flexible materials in everyday use. There is a huge range of textile constructions that can be produced from coating, woven, knitted, embroidered and nonwoven fabrics, comprising a wide choice of natural and synthetic fibres that have been in use not just for centuries but for millennia. Although used primarily for the provision of clothing, they have also in this time enjoyed extensive technical use, for example in sailcloth, tents and sacks [1].

2. Materials and Experimental

2.1. Materials and Method

The products we used in this study are the ICAFIX PUN Polyurethane purchased from GRAPHICHIMIE (Morocco), Copper chloride from SIGMA ALDRICH.

- Coating device

It is used a manual coating device Mathis (Fig. 1): for laboratory

After having done all the preparations of the devise, the coating is moved forward slowly and equally by means of the two handles. The paste coated on fabric can be done with different thicknesses of 0.1, 0.2, 0.3, 0.4 and 0.5 mm and it was dried at 150 °C for 3 min of each treated samples.

Fig. 1 Coating devise Mathis.

- Dynamic drape

The drapemeter research (Fig. 2) developed and performed in the weaving department by the foregoing researchers was limited to the investigation of woven fabrics static darapability.

The drapemeter research has employed image analysis techniques to measure fabric’s drape coefficient. The systems used in these studies employ drapemeters together with CCD cameras to acquire fabric drape images, and use computers to calculate drape coefficient. In addition, appropriate lighting systems are used to obtain clear drape images.

The drapemeter employs a supporting disk with a

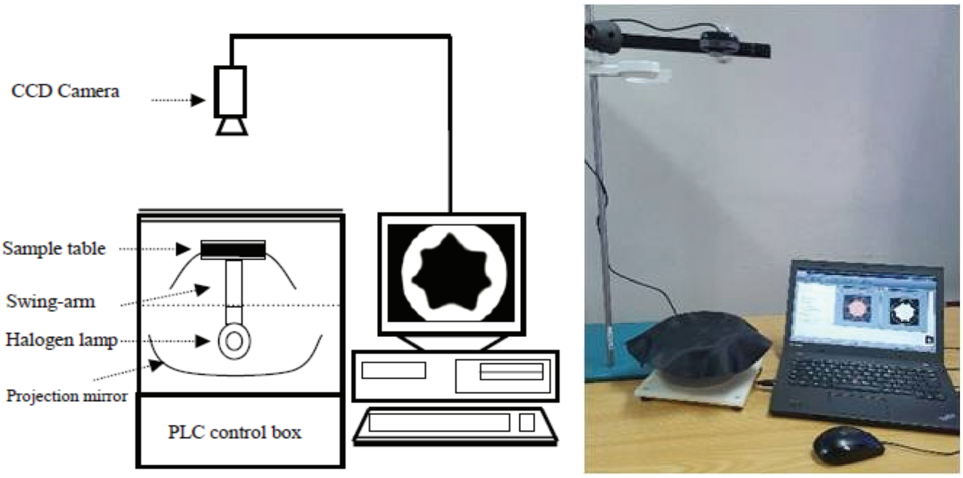

Fig. 2 The drapemeter research.

diameter of 18 cm and a fabric specimen with a diameter of 30 cm.

- Air Permeability:

MESDAN thickness-Lab-1880 (Fig. 3)

➢ Circular test-tube holder (5 cm^2, 10 cm^2, 20 cm^2, 50 cm^2, 100 cm^2)

➢ Pressure indicator (50 Pa, 100 Pa, 200 Pa, 500 Pa)

➢ Device for passing a stable air flow

➢ Flow meter, meters, volumetric or measuring diaphragm

Methodology: The samples to be tested are prepared according to the standard ISO 9237.

- Tensile Test:

Fig. 3 MESDAN thickness-Lab-1880.

Fig. 4 Hounsfield apparatus.

Mechanical properties such as tensile strength and elongation at break of fabrics were studied according to ISO 13934-1. The Hounsfield apparatus was used.

2.2. Experimental Procedure

The satin woven fabric used is made of polyester matriel and with:

➢ 26/14 ends compte (Warp compt/weft compt)

➢ 300/300 dtex Linéare densité (Warp density/Weft density)

The samples were first immersed into acetone solution for 30 min to remove organic solvent and dusts attached on the material and then were washed with de-ionized water twice. The samples were dried at 40 °C after washing.

In this step, we prepared a conductive textile based on copper chloride. This has been accomplished in several steps to achieve the desired results. The substrate chosen for this embodiment is a woven polyester fabric with an average fiber diameter of 18.5 μm. The fabric samples were washed in acetone before coating to remove any grease and plastic reagent from the fabric and dried at 70 °C.

In order to prepare the coating paste, firstly, we dispersed the copper in a solution. Then, the conductor solution prepared was mixed with the polyurethane as a coating polymer and stirred until the preparation of the conductive paste. Secondly, we coated the conductive paste on fabric by coating with different thicknesses of 0.1, 0.2, 0.3, 0.4 and 0.5 mm and it was dried at 150 °C for 3 min of each treated samples (Fig. 4).

2.2.1. Measure of Surface Resistivity (Ω/square)

Surface Resistance was measured according to the American Association of Textile Chemist and Colorists Test Method AATCC [2, 3].

The fabric (10 × 13 cm^2) was placed between two metallic electrodes separated by 3 cm under standard condition (65% HR and 24 °C). The electrical resistance was recorded with a Multimetrix DMM 120 and the surface resistivity was measured according to the equation below (Eq. (1)).

$$Rs(\Omega / m? = \frac{W}{D}.R' \qquad (1)$$

where R' is the resistance measured by the Multimetrix, W and D are the width of the sample and the distance between the two electrodes respectively.

2.2.2 Drapability Test

Drape is one of the parameters characterizing the appearance of textile products. It is especially important for clothing goods because it influences the aesthetic effect of clothing, in particular its fitting to the user's body. The drapability is a parameter that allows evaluating the comfort of the fabrics to wear it. In addition, it is a flexibility index of a fabric.

Drapability is defined as the ability of fabrics to create folds under the influence of gravity in conditions favorable for fold creation. Physically drapeability is an effect of interaction between the fabric mass and its stiffness. Considering that the stiffness of fabrics is influenced by their different structural and physical parameters, we can state that fabric draping is the result of interaction between gravitation and various fabric characteristics [5].

Drape image analysis and calculation of the drape coefficient. The captured drape image was transferred to a computer using Matlab software. The analysis of the fabric drape image included the conversion of the pixels number from the drape image file (BMP) to the drape profile. The fabric image was captured using a 320 × 240 image resolution. The drape coefficient is obtained by calculating the number of pixels covered by the area of the drape image. The definition of the drape coefficient of a fabric is given in Fig. 3 [8].

2.2.3 Air Permeability Test

Air permeability is often used in evaluating and comparing the breathability of various fabrics (coated and uncoated) for such end uses as raincoats, tents and

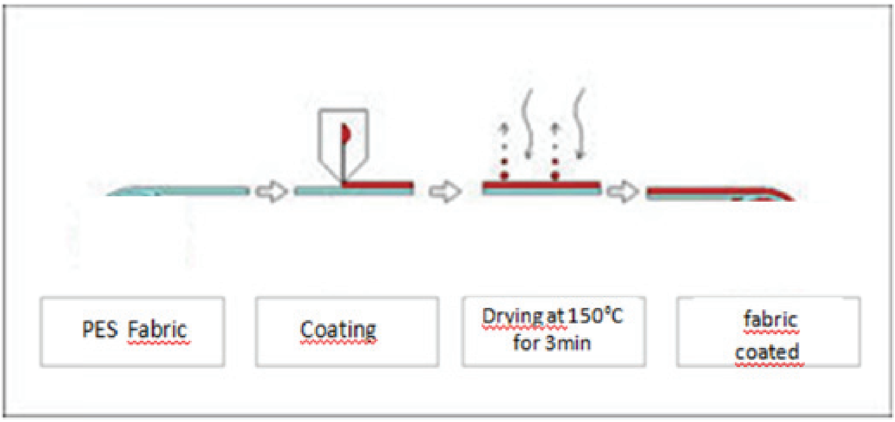

Fig. 4 Coating process for fabrics.

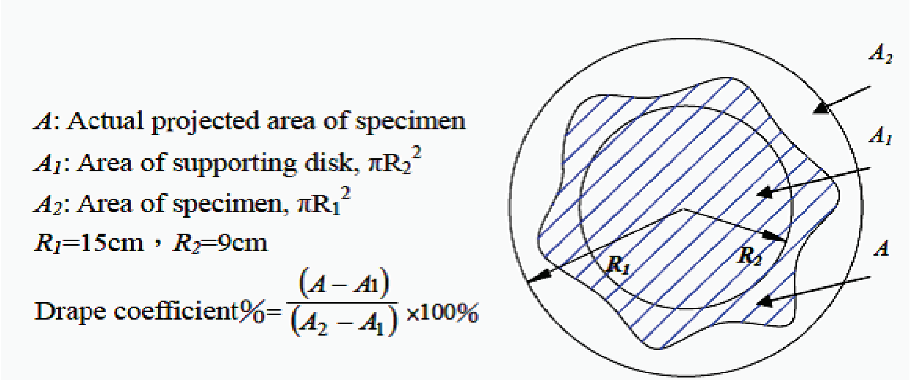

Fig. 5 Definition of the fabric drape coefficient.

uniform shirting's. It helps evaluate the performance of parachutes sails, vacuum cleaners, air bags, sail cloth and industrial filter fabrics. Air permeability is an important factor in the comfort of a fabric as it plays a role in transporting moisture vapor from the skin to the outside atmosphere. The assumption is that vapor travels mainly through fabric spaces by diffusion in air from one side of the fabric to the other [9].

Air permeability was measured via standard norm ISO 9237, it is defined as the volume of air in liters which is passed through 10 cm^2 of the fabric in one minute at a pressure of 500 Pa. Due to the way which yarns, and fabrics are constructed, a large proportion of the total volume occupied by a fabric is usually airspace. The distribution of this airspace influences a number of important fabric properties such as warmth and protection against wind and rain in clothing [5].

Air permeability describes the rate of flow of a fluid through a porous material. The mathematical expression is given by Eq. (2):

$$k = \frac{Q}{S.t} \tag{2}$$

where k is rate of flow $L/(m^2{\cdot}s)$, Q is volume of flow of fluid through the sample [L], t is time [s] and S is the cross-sectional area [m^2]. Air-Tronic instrument was used to determine the air permeability of coated textile as per the ASTM D737, which measures the air flow passing vertically through a surface of 10 cm^2 under pressure of 500 Pa [6].

2.2.4 Tensile Test

Two sets of specimens were taken in the warp direction of the fabric. Each set includes five test tubes of 5 cm × 30 cm. Each specimen is attached to the center of the apparatus so that its central longitudinal axis passes through the center of the outer edges of the jaws. The test length of the traction device is 200 mm. The speed of extension of the apparatus is 100 mm/min under a 5,000 N preload. The results of force and elongation at break were expressed by the arithmetic mean of the 4 specimens in the warp direction of the strips of the fabric.

3. Results and Discussion

3.1. Electrical Properties

The characteristics and measurements of the coated samples are shown in Table 1.

The resistance of the samples decreased from 34 MΩ to 4 MΩ by increasing the thickness from 0.1 mm to 0.3 mm. Against, the resistance of the samples increased from 0.8 MΩ to 5 MΩ by increasing the thickness from 0.01 to 0.05 mm. The low resistance of the fabric results from a thicker and more doped coating layer which penetrates well into the textile structure thus allowing a good electrical contact between the fibers. In our case and for integrating organic photovoltaic cells, we opted for fabrics with the lower electrical resistance values, which are suitable with our cells, and for the sample with the high electrical resistance value, we can use it for other electromagnetic applications such as medical and antenna.

The low resistance of the fabric results from a thicker and more doped coating layer which penetrates well into the textile structure thus allowing a good electrical contact between the fibers

The decrease in surface resistance is due to the

Table 1 Characteristics and electrical measurements of coating fabrics.

Fabric ID	Standard	1	2	3	4	5
Mass per unit area (g/m^2)	112.6	123.76	134.92	146.08	157.24	168.4
Thickness of textile (mm)	0.23	0.33	0.43	0.53	0.63	0.73
Thickness of coating (mm)	-	0.1	0.2	0.3	0.4	0.5
Electrical resistance (MΩ)	0	34	28	18	12	4
Surface Resistivity (MΩ/m^2)	-	68	41	23	14	8

increase in the thickness of the conducting polymer layer

3.2 Drapability Properties (Table 2)

The characteristics and measurements of the drapability samples are shown in Table 2.

From our results, we note that the samples 1 and 2 are more flexible than sample 3 due to the coating thickness. More we increase the thickness more the fabric becomes more rigid which influences the comfort of the fabrics (Fig. 2). In our case, we decided to decrease the coating thickness to have more flexible and comfortable fabric.

3.3 Air Permeability Properties

The characteristics and measurements of the Air permeability samples are shown in Table 3.

The airflow through the textiles is mainly affected by the pore characteristics of the fabric. The size and distribution of the pores depend on the geometry of the fabric, the thickness of the paste coated on the textile and the technique of the formation of the surface affects the porosity of textiles. In our case, the percentage of penetration of airflow in our coated samples differs from one sample to another depending on the thickness of the paste coated, for the thickness of 0.1 the airflow is about 258 L/m²·s, although the thickness of 0.3, the air permeability is about 138 L/m²·s which explains the influence of the thickness of coating in the structure of fabrics. To summarize the air permeability of our coated samples, decrease with increasing on the thickness of coating (Fig. 3).

3.4 Tensile Properties

The characteristics and measurements of the tensile test of coated samples are shown in Table 4.

Table 4 shows the different parameters of the results obtained from the five tests; the maximum force that our coated textile can support is 881 N with a thickness of 0.5 mm comparing the thickness of 0.1 mm,

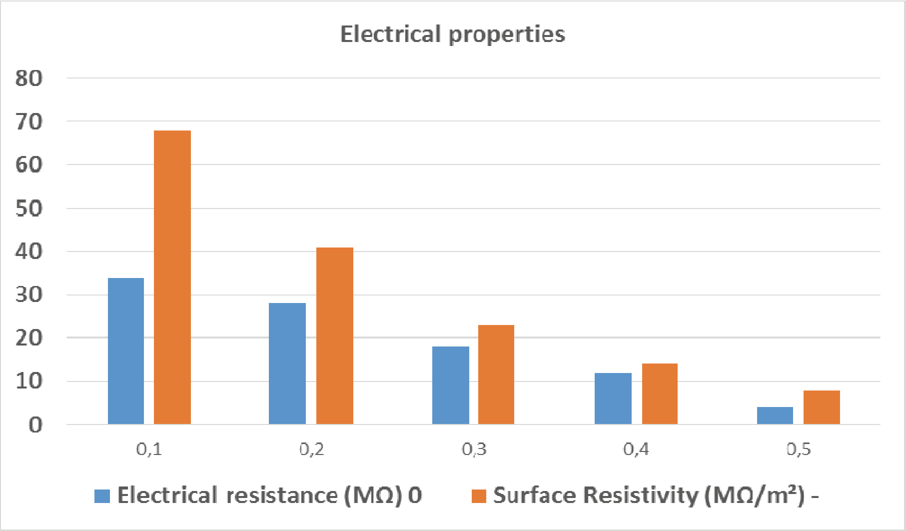

Fig. 1 Effects of thickness of coating on the electrical properties.

Table 2 Drapability properties.

Samples	Standard	1	2	3	4	5
Mass per unit area (g/m^2)	112.6	123.76	134.92	146.08	157.24	168.4
Thickness of textile (mm)	0.23	0.23	0.23	0.23	0.23	0.23
Thickness of coating (mm)	-	0.1	0.2	0.3	0.4	0.5
Average radius (mm)	130	129	127	123	116	108
Draping coefficient (%)	61.11%	59.31%	55.76%	48.81%	37.19%	24.75%

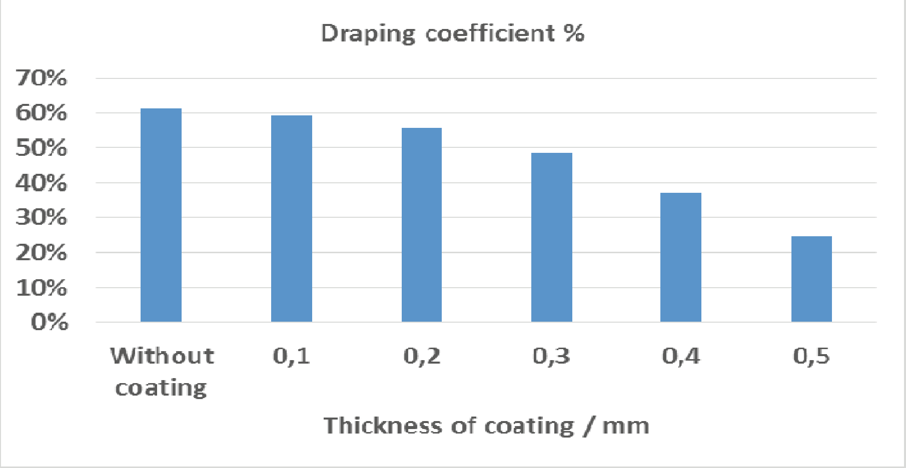

Fig. 2 **Effects of thickness of coating on drapability properties.**

Table 3 **Air Permeability properties**

Samples No.	Thickness of coating	Air permeability (L/m²·s)
Standard sample	Without coating	356
1	0.1	258
2	0.2	193
3	0.3	138
4	0.4	112
5	0.5	86

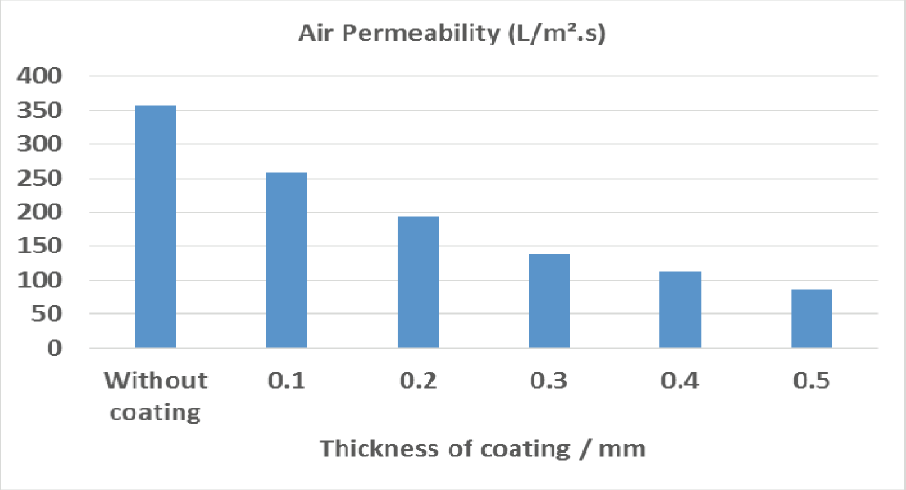

Fig. 3 **Effects of thickness of coating on air permeability properties.**

Table 4 **Tensile test properties.**

Samples No.	Thickness of coating	Force max (N)	Elongation max (%)
Standard sample	Without coating	681	5.44
1	0.1	741	7.47
2	0.2	851	6.36
3	0.3	881	5.84
4	0.4	848	5.33
5	0.5	905	4.75

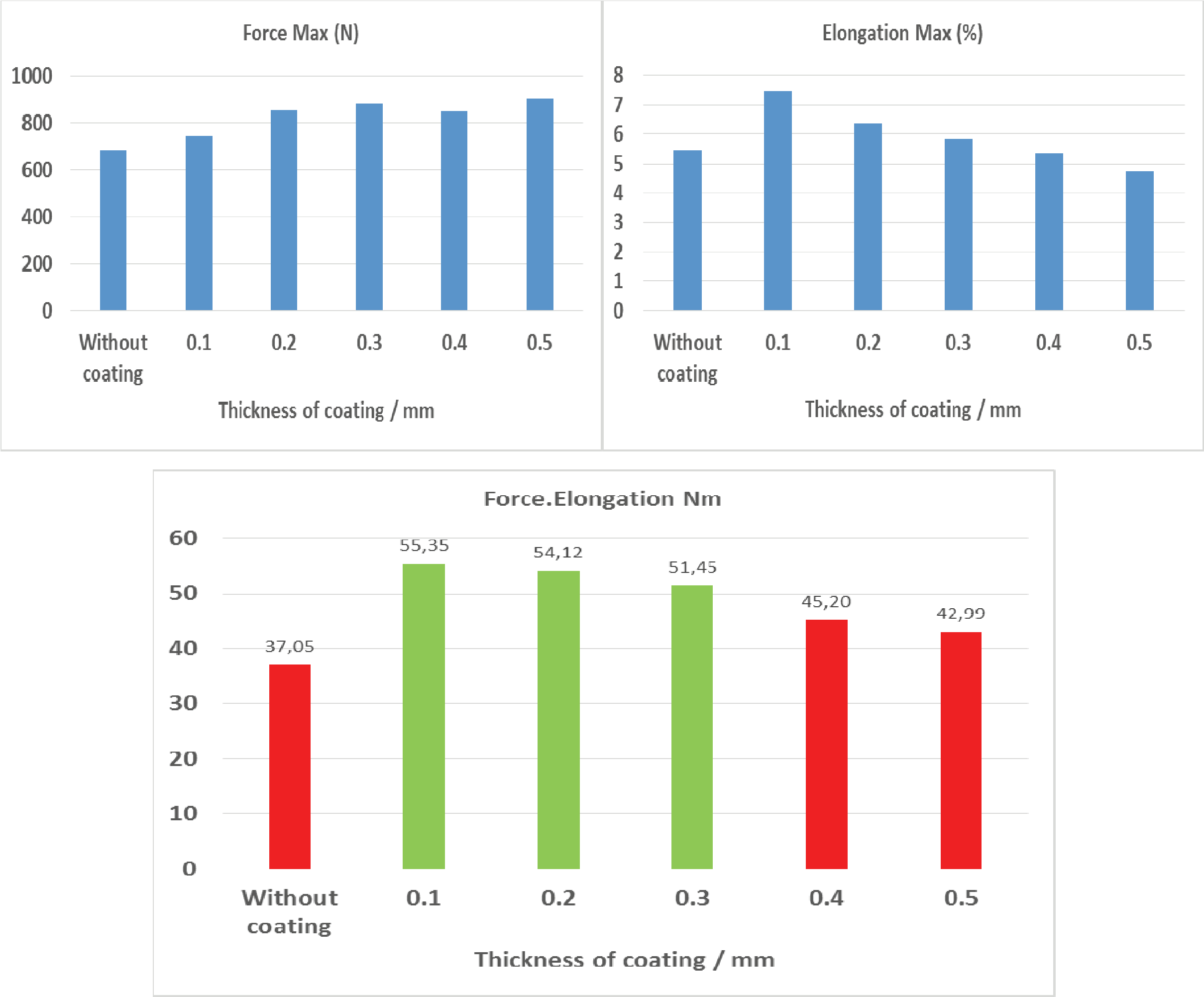

Fig. 4 Effects of thickness of coating in tensile properties.

which is about 741 N (Fig. 4), and with an uncoated textile that can support a resistance of 681 N. That explains that the coated textile becomes more resistant by increasing the coating thickness, which also influences the flexibility of our samples.

4. Conclusion

The study showed that samples coated with copper chloride from 0.1 to 0.3 mm have the best physical, mechanical and electrical characteristics to be used as a conductive textile support for use in clothing intended to be equipped with the fourth-generation PV cells.

Degradation electrical resistance is one of the major drawbacks of conducting polymers that needs to be characterized before considering these materials for conductor textile. However, there are challenges in the areas of electrical stability and mechanical properties that need to be studied.

The electrical resistance of our coated samples was controlled by the variation of the thickness of the coating conductive polymer, with this variation of parameters we had found a resistance around 68 MΩ as a higher resistance and 8 MΩ as a lower resistance with a thickness of paste varying from 0.1 to 0.3 mm. These results were confirmed by the tests carried out as drapability, traction and air permeability, which gave good result that allows us to use our samples for clothing.

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