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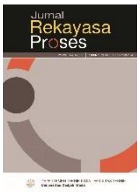

Tip-Cylinder Electrode Plasma to Enhance the Coating of Conductive Yarn Process

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ABSTRACT

This study aims to develop conductive textile materials using a polyester textile yarn by applying a knife coating method and pre-treatment of a tip-cylinder plasma electrode. In this research, carbon ink was coated on polyester staple yarn which was given a pre-treatment with a plasma generator and coated with the knife coating method. The electrical conductivity of conductive yarns produced from this study was divided into two types, as yarns without plasma treatment and with plasma treatment with a ratio of water and carbon ink concentrations of 1:1 and 2:1. The results of the electrical conductivity with plasma treatment and the concentration of carbon ink and water of 1:1 and 1:2 were 69005 $(\Omega m)^{-1}$ and 50144.25 $(\Omega m)^{-1}$, respectively, while the results of the electrical conductivity for threads with concentrations of carbon ink and water of 1:1 and 1:2 without plasma treatment were 18197.64 $(\Omega m)^{-1}$ and 8873.54 $(\Omega m)^{-1}$, respectively. The results showed that the concentration of carbon ink and water and plasma treatment affected the conductive value of the yarn. The results also showed that the presence of plasma pre-treatment improved the coating process of conductive ink on the yarn.

Keywords: carbon ink; conductive yarn; plasma; textile

ABSTRAK

Penelitian ini bertujuan untuk mengembangkan bahan tekstil konduktif menggunakan benang tekstil poliester dengan mengaplikasikan metode knife coating *dan* pre-treatment *plasma elektroda* tip-cylinder*. Pada penelitian ini dilakukan pelapisan dengan tinta karbon pada benang poliester stapel yang diberi perlakuan awal dengan plasma generator dan dilapisi dengan metode pelapisan* knife coating*. Konduktivitas listrik benang konduktif yang dihasilkan*

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dari penelitian ini dibagi menjadi dua jenis, yaitu benang tanpa perlakuan plasma dan dengan perlakuan plasma dengan perbandingan konsentrasi air dan tinta karbon sebesar 1:1 dan 2:1. Hasil konduktivitas listrik dengan perlakuan plasma dan konsentrasi tinta karbon dan air sebesar 1:1 dan 1:2 masing-masing adalah 69005 $(\Omega m)^{-1}$ *dan* 50144,25 $(\Omega m)^{-1}$*, sedangkan hasil konduktivitas listrik untuk benang dengan konsentrasi tinta karbon dan air sebesar 1:1 dan 1:2 tanpa perlakuan plasma masing-masing adalah* 18197,64 $(\Omega m)^{-1}$ *dan* 8873,54 $(\Omega m)^{-1}$*. Hasil penelitian menunjukkan bahwa konsentrasi tinta karbon dan air serta perlakuan plasma berpengaruh terhadap nilai konduktivitas benang serta adanya pre-treatment plasma dapat meningkatkan proses coating tinta konduktif pada benang.*

Kata kunci: *benang konduktif; plasma; tekstil; tinta karbon*

1. Introduction

Yarn is a collection of fibres that are arranged in an elongated direction with a certain diameter and twist obtained from a treatment called spinning (Pawitro, 1973). Yarns are generally made only for conventional fabric raw materials, but along with the times, the use of fabric is not only a function of clothing but also has another function, namely as a smart textile material and smart clothing. Smart textiles are textile materials that have the ability, both inherent and grafted, to be able to respond to external stimuli and react intelligently to surrounding stimulants as examples of changes in temperature, light and pressure (Putra et al., 2019). Some researchers claimed that a smart textile material must be comfortable but has a certain function, the comfort of textile material must be flexible, lightweight, breathable, and strong. Smart textile material is clothing that has a good level of comfort that can give users the ability to be able to respond to the surrounding environment by applying it as a sensor, processing data and communicating to users. Various applications of smart textile materials have led to an increase in research into smart textile materials that has been done and carried out by many researchers, especially in the manufacture of conductive yarns (Dias and Ratnayake, 2015; Kang et al., 2017; Linz et al., 2006; Locher et al., 2005; Lorussi et al., 2005).

The material used as a conductive material is generally carbon or using polyaniline (PANI). Conductive textile materials can generally be used in many technical applications such as human protection and electronic equipment from electromagnetic interference (radiation) and static electricity, heating, electronic devices, data storage and transmission, sensors and actuators (Cherenack et al., 2010) Other researchers such as Fugetsu et al. (2009) have made conductive yarns with spinning-core yarn spinning systems in which metals from copper and stainless are treated as core materials. whereas rayon and TR yarn (polyester/rayon) function as cover material (Fugetsu et al., 2009). The weakness of the method developed by Fugetsu et al. (2009) is that the resulting yarn becomes very stiff and uncomfortable as a textile material. Meanwhile, Koncar and Kim (2006) have developed conductive yarns using a third method, namely the coating process using polyaniline (PANI) as a coating agent on polyethene terephthalate (PET) fibres (Kim and Koncar, 2006) but not using plasma pre-treatment as an attempt to improve the coating process. Kim and Koncar (2006) said that selection of polyester yarn as core yarn or yarn coated with a conductive material because polyester is the most widely used synthetic fibre and is the easiest to find for textiles and textile products. Polyester is one of the fibres used as an object of modification using plasma technology. Polyester is superior in terms of high strength, anti-creasing, and abrasion resistant, resistant to various chemicals and has a high lustre. However, polyester has hydrophobic (waterproof) properties, low absorption and adhesion is less comfortable to use and produces static electricity (Kim and Koncar, 2006, Prayudie and Novarini, 2015).

According to several researchers (Murti et al., 2020; Park et al., 2017; Putra et al., 2019; Rauscher et al., 2010; Shishoo, 2007; Temmerman and Leys 2005), corona discharge plasma treatment is generally produced at atmospheric pressure and generally, the gas used is ambient air. Some researchers such as Mehmood et al. (2014), Murti and Putra (2020), Rauscher et al. (2010), Shishoo (2007), and Temmerman and Leys (2005), applied plasma treatment for polyester material because polyester material has hydrophobic or low absorption properties but has good mechanical properties and long-lasting properties so that the treatment of plasma radiation exposure is expected to increase the absorption of polyester material. From the results of research conducted by Prayudie and Novarini (2015), polyester fabrics treated with plasma undergo chemical changes that make wetting ability increased. Based on several literatures (Murti and 2020; Park et al. 2017; Putra and Wijayono, 2019; Rauscher et al., 2010; Shishoo, 2007; Temmerman and Leys, 2005), the presence of plasma pre-treatment can help to improve the absorption properties of the material and the adhesive properties of the material. The novelty in this study is the use of a combination of plasma pre-treatment and knife coating methods with conductive ink to produce a better conductive thread as a textile material compared to the research of several previous researchers, such as Kim and Koncar (2006), Fugetsu et al. (2009). This study aims to develop conductive textile materials using a polyester textile yarn by applying the knife coating method and pre-treatment of the tip-cylinder plasma electrode. In this research, carbon ink was coated on polyester staple yarn which was given a pre-treatment with a plasma generator and coated with a knife coating method.

2. Research Methodology

In this research, the materials used were Ne 30/2 polyester yarn (polyester yarn that has been cut 8.5 cm and given a plasma treatment), plastic container as a coating place for yarn, conductor ink in the form of thick liquid and dropper pipette. The preparation was conducted by cutting the yarn along the 8.5 cm so that no more with the length of the prototype discharge plasma prototype field used. The coatings used are conductor inks (commercial carbon black micro particle ink was purchased from Bare Conductive Co. Ltd. (London, England)) with the following specifications: made from graphite mixed with acrylic adhesives and water; can glue on paper, board, iron, plastic, etc.; and not easily broken/cracked when dry. The instrument used for this experiment was a prototype of a cross-section distance measuring device in determining the magnitude of electrical conductivity (test equipment with patent number EC000120017) and plasma prototype specifications were a type of cold plasma; gas used by the gas in the surrounding air; input voltage = 0-220 Volts (AC); output voltage = 0-40kV (DC); tip-cylinder electrode with 3 tip anodes and one cylindrical cathode. Tip-cylinder configured plasma devices used in this research are generated using a DC source 5 kV. Figure 1 shows the scheme of the tip-cylinder plasma device used in this study. Point electrodes were used as positive electrodes, whereas solid cylindrical electrodes acted as negative electrodes. The distance between the electrodes used was 3 cm. Point electrodes consisted of 3 tip metals connected in series with a distance of 2.5 cm each bolt. Figure 2 shows a picture of the plasma device used in this study. The presence of plasma was observed when there was a glowing violet light in the space between the active electrodes and electrode passives.

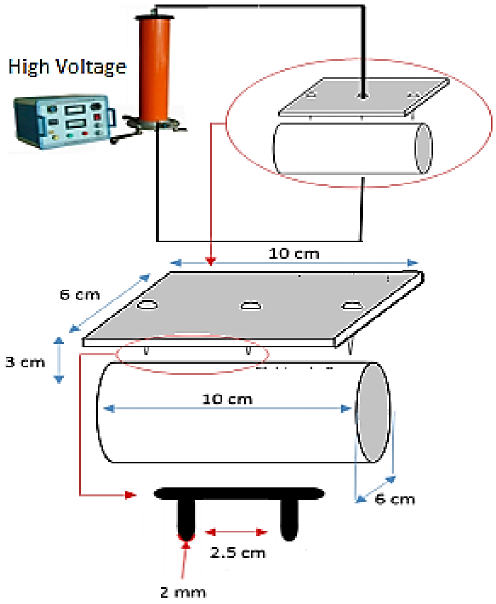

Figure 1. Schematic of a plasma device with tip-cylinder configuration with a maximum voltage of 5 kV

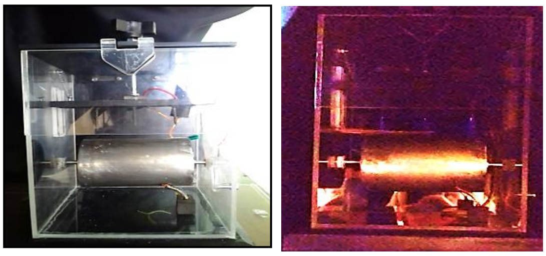

Figure 2. Tip-cylinder corona discharge plasma device with a voltage of 5 kV

The research procedures for making conductive yarns that have been treated with corona plasma with tip-cylinder electrode configuration include: mixing conductor ink and water with a specific dose using a dropper pipette in a plastic container (Figure 3); coating the yarn with conductor ink that has been mixed with water until it was spread evenly using the knife coating method (Figure 4); and the drying process of the yarn which has been coated with conductor ink at room temperature for 10 minutes until it was completely dry.

Figure 3. Mixing of conductor inks with water

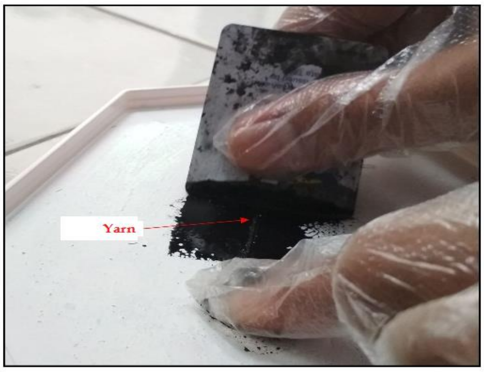

Figure 4. Coating of polyester yarn with water-filled conductor ink

After obtaining plasma treatment and also coatings on polyester yarn, the yarn test sample was tested by testing the resistance obtained using a multi-tester (Digital Multi-tester Sanwa CD800a, Japan) and testing the diameter measurement using a prototype of a cross-section distance measuring device (Yarn cross section measuring tool, Director General of Intellectual Property, Republic of Indonesia, EC00201848396) (Figure 5).

Figure 5. Display of yarn diameter measurement

Multi-tester (Digital Multi-tester Sanwa CD800a, Japan) testing was carried out every 0.65 cm from one end, then bit by bit to the other end of the conductive yarn. To find the electrical conductivity of the yarn the following measurements could be used:

1. Measurement of yarn diameter to determine the cross-sectional area of conductive yarn, *A*, using Equation (1).

$$A = \frac{1}{4}\pi . D^2 \tag{1}$$

Where *A* is the cross-sectional area of the conductive yarn (m^2) and *D* is the diameter of conductive yarn (m).

2. Resistance testing to get conductivity was done using Equation (2).

$$R = \rho \frac{L}{A} \tag{2}$$

Where ρ is called the resistivity of the conducting material. The unit of resistivity is the ohmmeter (Ωm). The opposite of resistivity is called conductivity. The conductivity value of a material depends on the intrinsic properties of the material. Electrical conductivity is the ability of a material to conduct electric current (Irzaman, 2010). The formula for electrical conductivity can be determined as follows (Equation (3) and Equation (4)):

$$R = \rho \frac{L}{A} = \frac{L}{\sigma A} \tag{3}$$

$$\sigma = \frac{L}{RA} \tag{4}$$

Where *R* is the resistance (Ω); *I* is the current (Ampere); *L* is the yarn length (m) and *A* is the cross-sectional area of the yarn (m^2).

3. Results and Discussion

Measurement of yarn diameter to determine the cross-sectional area of conductive yarns (*A*) was performed using Equation (1). The average diameter of conductive yarns with concentrations of carbon ink and water 1:1 and 1:2 drops were 0.4109 mm (1.325×10^{-7} m^2 cross-sectional area, *A*) and 0.3651 mm (1.046×10^{-7} m^2 cross-sectional area, *A*). Whilst without plasma treatment, the average diameter of conductor yarns with 1:1 and 1:2 drops of carbon ink and water were 0.4029 mm (1.274×10^{-7} m^2 cross-sectional area) and 0.3836 mm (1.155×10^{-7}

m^2 cross-sectional area). The results of the conductivity can be shown in Table 1.

Table 1. The average resistance and conductivity

	Plasma treatment (the average for 10 tests data)		Without plasma treatment (the average for 10 tests data)	
	1:1	1:2	1:1	1:2
Average Resistance (Ω)	1.01	2.13	6.7	9.76
Average Conductivity $(\Omega m)^{-1}$	69005.12	50144.25	18197.64	8873.54
Standard deviation of conductivity $(\Omega m)^{-1}$	31702.33	27262.06	11105.20	4844.80

The results of the knife coating method in making conductive yarns showed that the results of this study can conduct electricity with a low resistance value. The difference in solution concentration will affect the electrical conductivity of the yarn (as shown in Figure 6).

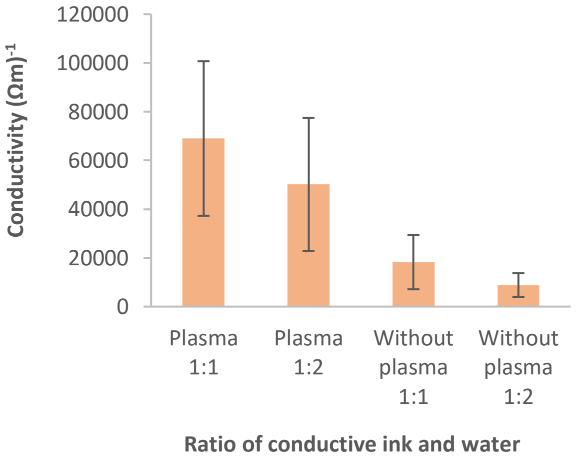

Figure 6. The effect of the variation of the doses of carbon ink and water on electrical conductivity

The variation of carbon ink concentration with water was performed by varying the concentration of water given in a ratio of 1:1 and 1:2. In this study, yarns with plasma treatment and variations in the concentration of carbon and water inks obtained resistance and conductivity which had good values as conductor materials, i.e. at a ratio of carbon and water ink concentrations of 1:1 having an average conductivity value of 69005.12 $(\Omega m)^{-1}$ and the ink concentrations of carbon and water 1:2 had an electrical conductivity of 50144.25 $(\Omega m)^{-1}$. The results of electrical conductivity in yarns without plasma treatment and 1:1 concentration of ink and water ink had an average value of electrical conductivity of 18197.64 $(\Omega m)^{-1}$ and concentrations of carbon and water 1:2 inks of 8873.54 $(\Omega m)^{-1}$. In Figure 6, it can be shown that the conductivity results obtained from the two different treatments get a decrease in the conductivity value due to the addition of water as a thinner of the conductive ink used, the more water used as a thinner, the smaller the conductivity value produced. The lower the resistance of a conductor, the higher the conductivity, so the better conductivity results were conductive yarns with carbon ink and water concentrations of 1:1, compared to carbon ink and water concentrations of 1:2. Based on the experimental results, it was found that the higher the concentration of carbon ink attached to the yarn layer, the higher the electrical conductivity of the thread, this follows the results of research conducted by Cherenack et al. (2010) which stated that the material used as a conductive material is generally carbon. Polyester is a hydrophobic textile material. Polyester moisture regain is only about 0.4%. This makes the absorption of polyester water relatively low and tends to be difficult to wet. Several studies have shown that plasma treatment has succeeded in increasing the hydrophilic nature of polyester fabrics so that they become easily wetted. According to Prayudie and Novarini (2015), the increase in wetting rate is more likely due to the etching (erosion) effect that occurs due to degradation on the polyester surface. The etching effect will form a roughness on the surface of the polyester which can provide space to be occupied by water molecules so that the polyester wetness increases (Prayudie and Novarini, 2015). From Figure 6, we can see a comparison between a polyester yarn that was given plasma treatment with polyester yarn without plasma treatment. This can be due to the plasma treatment carried out on polyester yarns before being coated by carbon ink which was due to the yarns treated with plasma could be easier to absorb carbon ink solutions and more adhesive than polyester yarns that were not given plasma treatment. Due to the increase in carbon absorption and the adhesive properties of the plasma treated yarn, there may be an increase in the electrical properties of the plasma treated yarn (there was a higher concentration of carbon in the plasma process yarn). Electrical conductivity test results showed that the yarn treated with plasma had more carbon absorption than those without the plasma treatment process. This proves the research of Putra and Wijayono (2019) that the plasma treatment results in increased absorption and adhesive material.

4. Conclusions

This study concluded that the conductivity produced from carbon yarn with a carbon ink and water concentration of 1:1, and with a plasma treatment is 69005.12 $(\Omega m)^{-1}$. The good composition for making conductive yarns is a concentration of carbon ink and water solution of 1:1 and plasma pre-treatment must be applied on the coating.

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