SCREEN-PRINTED ANTI-RADIATION WOVEN FABRIC WITH CONDUCTIVE CARBON LAYER AND CORONA PLASMA TREATMENT OPTIMIZED BY REGRESSION METHOD

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Abstract

Background : Electromagnetic radiation from electronic devices, including mobile phones, has encouraged the development of textile materials that can provide electromagnetic shielding. Conductive materials such as conductive carbon can be applied to textile surfaces to improve their ability to absorb electromagnetic radiation.

Purpose : This study aims to investigate the effect of Corona plasma discharge pretreatment on the electromagnetic radiation shielding performance of woven fabrics coated with conductive carbon. The study also aims to optimize the plasma treatment conditions based on plasma exposure time and electrode distance using regression analysis.

Methodology : Woven fabrics were treated using Corona discharge plasma with a tip-plane electrode configuration under atmospheric pressure, room temperature, and ambient gas conditions. Two plasma treatment parameters were varied: plasma exposure time and electrode distance. Following plasma pretreatment, conductive carbon was applied to the woven fabrics using screen printing and pretreatment coating techniques. The resulting fabrics were then evaluated based on their ability to reduce electromagnetic radiation generated by a mobile phone. Regression analysis was applied to model the relationship between plasma treatment parameters and radiation levels.

Findings : The results indicate that Corona plasma pretreatment combined with conductive carbon coating can improve the electromagnetic radiation shielding performance of woven fabrics. The lowest electromagnetic radiation level was obtained at an electrode distance of 4 cm and a plasma exposure time of 3 minutes. The regression model showed an R-squared value of 0.9231, indicating that the model provided a strong explanation of the relationship between plasma exposure time and radiation level.

Implications : The findings demonstrate that plasma pretreatment can be used as part of the fabrication process for conductive textile materials designed for electromagnetic radiation shielding.

Originality : The originality of this study lies in the application of regression analysis to optimize the design of woven fabrics treated with Corona discharge plasma and coated with conductive carbon for electromagnetic radiation shielding. The combination of plasma pretreatment, conductive carbon screen printing, and regression-based optimization provides an approach for determining suitable plasma treatment conditions for the development of anti-radiation textile materials.

Keywords *: Plasma, conductive carbon, screen printing, electromagnetic, woven fabric*

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INTRODUCTION

Electromagnetic waves are essentially a method of transmitting energy from a source to its environment without heat (Swamardika, 2009). The electromagnetic wave spectrum that we are familiar with spans a wide range of frequencies. Electromagnetic waves include radiowaves, television signals, radar beams, invisible light, x-rays, and gamma rays. The sun, stars, and tornadoes are all natural sources of electromagnetic waves. Nuclear explosions, cell phones, and electric vehicles are examples of artificial electromagnetic sources. High-frequency electromagnetic waves may pose a health risk to humans (Oh et al., 2018). Electrical sensitivity is a potential health risk associated with high-frequency electromagnetic waves. Electrical sensitivity is a physiological disorder characterized by neurological signs and symptoms and sensitivity manifested as various symptoms and complaints. This interference is typically caused by electromagnetic radiation emitted by high or extra-high-voltage power lines and electronic equipment in homes, offices, and industries. For example, cell phones and microwave ovens can potentially cause these complaints. Furthermore, mobile phone electromagnetic waves cause blood glucose levels to rise (Dewi & Wulan, 2015). As a result, reducing electromagnetic emissions and protecting components is an important future task. Previous research has shown that materials that can be used for anti-radiation must be light in weight, have high conductivity, and have good adhesion (Oh et al., 2018).

A polyester-cotton woven fabric coated with conductive material is the electromagnetic shielding material (ESM) to meet these requirements. Previously, metals were used as anti-radiation materials, but conductive fabrics are now preferred because of their light weight, flexibility, and corrosion resistance (Das et al., 2001). Carbon black is used as a conductive material in developing conductive fabrics. Carbon black is widely used in plastics, rubber, coatings, antistatic films, conductive electrodes, and electronics (Kim et al., 2005). Various coating methods can coat conductive materials, such as carbon black and metal, on anti-radiation materials, including sputtering, electrodeposition, electron beam irradiation, screen printing, chemical reduction, and plasma spraying (Qing et al.,

2015). This study used the screen printing coating technique. In addition to its simplicity in controlling its thickness and uniformity, screen printing is suitable for media with flat surfaces (Wang et al., 2009). The polyester-cotton woven fabric material is treated with atmospheric pressure plasma before being coated with carbon black. The reactivity of atmospheric pressure plasma to carbon-based materials is high (Chien et al., 2018). In addition to improving the fabric's physical properties and increasing its function through surface modification, plasma treatment

will assist in coating it with carbon black to enhance its performance. Several studies have shown that plasma affects fabric absorbency (Hakim et al., 2019). Plasma treatment of polyester fabrics causes chemical changes that increase

wetting ability (Prayudie & Novarini, 2015). Despite several studies showing that plasma treatment can improve function and physical properties, the effectiveness and efficiency of the plasma process still need to be investigated further. We investigated the effect of plasma discharge on woven fabrics by coating them with conductive carbon as an anti-radiation material. A variety of woven fabrics were treated with Corona plasma discharge (CPD) and screen printed with conductive carbon (CC). This study used two variables, including plasma exposure time and electrode distance. Anti-radiation fabrics were developed at room temperature, atmospheric pressure, and ambient gas by modifying textile woven fabrics with electrodes in a tip-plane configuration. Conductive carbon (CC) was applied to plasma-treated woven fabrics for screen printing. This study measured and modeled plasma pretreatment's effect on anti-radiation ability.

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METHODOLOGY

2.1 Materials and Instruments

This study's raw materials were 70%/30% polyester-cotton fabrics with warp yarn constructions of 65 strands/inch and a total weft of 50 strands/inch, warp and weft yarn numbers of 30 Ne1 with 1/1 plain weave. CV. MJ Chemical, Indonesia, supplied the carbon black. The type of carbon black used had particle sizes ranging from 0.809 m to

3.711 m and a purity of 97.6 Wt%. Carbon-based conductive inks were created using acrylic binders and thickeners. A plasma generator with Corona discharge and with tip-plane electrodes was used in this study (Physics Laboratory, Politeknik STTT Bandung). Corona plasma reactor with multi-point taper electrodes made of pointed screws attached to a board connected in series at 1 cm intervals. The positive electrode (anode connected to the mains voltage source) was perpendicular to the negative electrode plane (cathode connected to the ground). The electromagnetic radiation tester used here was Obtained from DIGILIFE, Jakarta, Indonesia (radiation instrument, BENETECH GM3120). AC input voltage and DC output voltage was measured using by high voltage multi-tester. Screen printing was used to coat the carbon, including a screen in a frame, a rack, a beaker, and a stir bar to make a paste. To complete the drying and curing processes, a stenter machine was used. The stenter machine used had the following specifications: a power of 15.5 KW, a voltage of 220 V, 3 phases, and a current of 32 amps, and it was manufactured in 2005.

2.2. Methods

Polyester-cotton woven fabrics measuring 10 x 10 cm2 were treated with different electrode distances and times in a plasma chamber. The following variations were used in this study: non-plasma fabric, plasma-treated fabric with an electrode spacing of 4 cm and plasma times of 1, 2, and 3 minutes, plasma -treated fabric with an electrode spacing of 4.5 cm and plasma times of 1, 2, and 3 minutes, and plasma-treated fabric with an electrode distance of 5 cm and plasma times of 1, 2, and 3 minutes. Fabric treated with plasma is depicted in Figure 1. The positive electrode area of the taper shows signs of plasma treatment. In this case, UV light results from positive ion charges colliding with the ambient gas, caused by a positive electric voltage opposite the electrons' motion (Putra et al.,2020).



Figure 1. Plasma-treated polyester-cotton fabric.

Carbon black paste was made with the composition of carbon black paste, as shown in Table 1. All of the components were mixed. The test fabrics were laid out on the screen printing table and covered with screen and carbon black paste. The samples were placed in the stenter machine for drying

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at 100°C and a speed of 10 RPM. The drying process was repeated twice. The curing process was done twice by setting the stenter machine to a temperature of 150 °C and a speed of 10 RPM.

Table 1. Carbon black paste composition.

Materials	Compositions (g)
Carbon black	30
Binder	5
Thickner	12.5
Balance	2.5

2.3. Characterization and measurements

Resistance testing was the first test. This test aimed to determine the conductivity value of conductive fabrics. Sanwa CD800A digital multimeter was used for this test. Radiation testing was the second test. This test was performed to determine how much radiation the sample could withstand and was based on ISO 9978:2020, along with the research of Putra et al. (2021). The electromagnetic radiation tester was used for this test. This tool's specifications were applied to electric fields with a precision of 1 V/m and a range of 1-2000 V/m. Magnetic fields could have a precision of 0.01- and a range of 0.01-99.99. The bandwidth was tested from 5 Hz to 3500 MHz.

RESULT AND DISCUSSION

Table 2 shows the results of the resistance tests performed. The study indicates that plasma treatment time is inversely proportional to resistance. During plasma treatment, the resistance value of the fabric decreases, and its conductivity increases. A direct relationship exists between the electrode distance in the unit cm and the electric resistance in the unit Ω. A fabric with a greater distance between electrodes has a higher resistance and a lower conductivity.

Table 2. Resistance test results

Samples	**Resistance (Ω)**
Non-plasma	4440
distance 4 cm; time 1 min	1045
distance 4 cm; time 2 min	1020
distance 4 cm; time 3 min	3620
distance 4.5 cm; time 1 min	1860
distance 4.5 cm; time 3 min	2280
distance 4.5 cm; time 2 min	2980
distance 5 cm; time 1 min	4600
distance 5 cm; time 2 min	1480

The results of radiation testing on fabrics are shown in Table 3. During the tests, the carbon-coated fabric could withstand electric field radiation (E) up to 0 V/m. In this case, the carbon-coated fabric's conductivity reduced the intensity of electromagnetic waves emitted by the mobile phone.

Table 3. Radiation test results

Samples	**Radiation intensity without fabric (V/m)**	**Radiation intensity with fabric (V/m)**
Non-plasma	2000	15
distance 4 cm; time 1 min	2000	5
distance 4 cm; time 2 min	2000	3
distance 4 cm; time 3 min	2000	0
distance 4.5 cm; time 1 min	2000	15

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distance 4.5 cm; time 3 min	2000	14
distance 4.5 cm; time 2 min	2000	11
distance 5 cm; time 1 min	2000	15
distance 5 cm; time 2 min	2000	13

The relationship between plasma treatment time and radiation intensity is shown in Figure 2. According to Figure 2, the longer the plasma treatment time on the fabric, the less radiation intensity the fabric can retain. We obtained the least amount of electromagnetic wave radiation during our experiments by placing the electrodes only 4 cm away from the plasma and exposing them for 3 minutes. Based on the study's results, the relationship between radiation levels and exposure time showed an R-squared of 0.9231.

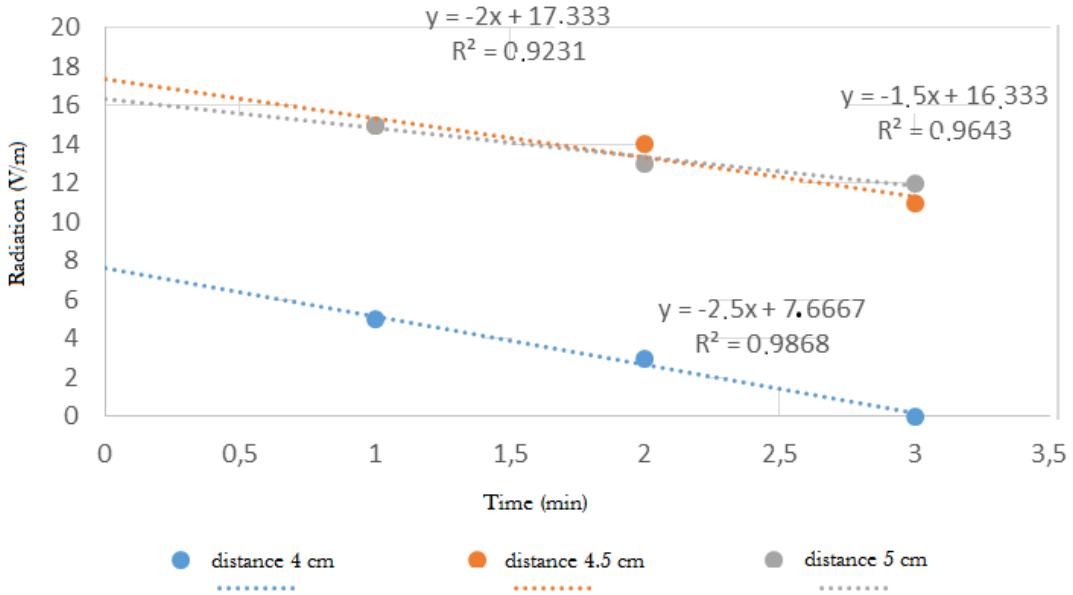


Figure 2. The relationship between plasma treatment time and radiation at each electrode distance.

Discussion

The resistance test results indicate that Corona plasma pretreatment influences the electrical properties of the woven fabric coated with conductive carbon. As shown in Table 2, the non-plasma-treated fabric exhibited a relatively high resistance of 4440 Ω. After plasma treatment, the resistance decreased under several treatment conditions, particularly at an electrode distance of 4 cm. The resistance decreased from 1045 Ω after 1 minute of treatment to 1020 Ω after 2 minutes. This reduction indicates an improvement in the electrical conductivity of the treated fabric. The result suggests that plasma pretreatment can modify the textile surface and facilitate the formation of a more electrically conductive pathway through the conductive carbon coating.

The effect of electrode distance can also be observed from the resistance measurements. In general, increasing the electrode distance tends to produce higher resistance under comparable treatment conditions. At 1 minute of plasma exposure, for example, the resistance increased from 1045 Ω at a 4 cm electrode distance to 1860 Ω at 4.5 cm and 4600 Ω at 5 cm. This result indicates that the electrode distance is an important parameter in determining the effectiveness of plasma treatment. A shorter distance allows the plasma discharge to interact more effectively with the textile surface, which can contribute to improved surface modification and electrical conductivity.

However, the resistance results also show that the relationship between plasma exposure time and resistance is not strictly linear. At a distance of 4 cm, the resistance increased considerably to 3620

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Ω after 3 minutes of exposure, compared with 1020 Ω after 2 minutes. A similar variation can be observed at a distance of 4.5 cm, where the resistance changed from 1860 Ω at 1 minute to 2980 Ω at 2 minutes and 2280 Ω at 3 minutes. These variations suggest that extending plasma exposure does not necessarily produce a continuous reduction in resistance. Excessive plasma exposure may alter the textile surface differently from shorter treatment durations, resulting in changes in the conductive coating and consequently in the measured electrical resistance. Therefore, an optimum plasma treatment condition is required rather than assuming that longer treatment always provides better electrical conductivity.

The radiation test results further demonstrate the potential of the plasma-treated and conductive-carbon-coated fabric as an electromagnetic shielding material. The mobile phone radiation source produced a radiation intensity of 2000 V/m in the absence of the fabric. The coated fabrics were able to reduce the electromagnetic radiation detected during the shielding test, indicating that the conductive carbon layer contributed to the attenuation of electromagnetic waves. This behavior can be associated with the conductive nature of the carbon coating, which allows part of the electromagnetic energy to interact with the conductive surface and consequently reduces the radiation reaching the measurement point.

The relationship between plasma treatment and radiation attenuation is particularly important because electrical conductivity is one of the factors associated with the electromagnetic shielding performance of conductive textile materials. A fabric with a more conductive surface can provide a pathway for induced electrical currents, which can contribute to the attenuation of incident electromagnetic radiation. Nevertheless, the shielding performance should not be interpreted solely from the resistance value because electromagnetic shielding can also be influenced by coating uniformity, fabric structure, surface characteristics, and the interaction between the electromagnetic wave and the conductive layer.

Figure 2 shows that the radiation response varies with plasma exposure time and electrode distance. The optimum condition observed in this study was obtained at an electrode distance of 4 cm with a plasma exposure time of 3 minutes. This condition produced the lowest electromagnetic radiation level among the tested conditions. The result indicates that the combination of electrode distance and exposure time plays an important role in determining the final shielding performance of the fabric. The optimum radiation response therefore cannot be determined from plasma exposure time alone, but must be considered together with the electrode configuration.

The regression analysis provides further support for the relationship between plasma treatment and radiation performance. The model obtained an R-squared value of 0.9231, indicating that approximately 92.31% of the variation in the measured radiation response can be explained by the model. This relatively high coefficient of determination suggests that the selected plasma treatment parameters have a strong relationship with the radiation response within the experimental conditions investigated. However, the R-squared value should be interpreted as an indication of model fit rather than proof of a causal relationship. Additional experimental validation would be necessary to confirm the predictive capability of the model under different fabric types, conductive carbon concentrations, electrode configurations, and radiation frequencies.

CONCLUSION

With Corona discharge plasma (CPD) pretreatment and tip-plane electrode configuration, an anti-radiation woven fabric could absorb electromagnetic radiation from a mobile phone (as a source of electromagnetic radiation). W e obtained the most negligible electromagnetic wave radiation when the electrodes were placed 4 cm apart and exposed to plasma for 3 minutes. In the study, the R-squared for

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a model of radiation levels versus exposure time was 0.9231. Accordingly, we concluded that the current research could produce a variety of electromagnetic shielding fabrics

AUTHOR'S CONTRIBUTION

Mutiara Tanjung: Conceptualization, methodology, literature review, experimental investigation, data analysis, and manuscript preparation. Valentinus Galih Vidia Putra: Methodology, data analysis, validation, interpretation of results, and manuscript review. Fadil Abdullah: Conceptualization, data analysis, supervision, interpretation of findings, and manuscript review. All authors contributed to the final manuscript, critically reviewed the manuscript, and approved the submitted version.

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DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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