Surface modification of polyester-cotton (TC 70%) fabric by corona discharged plasma with tip-cylinder electrode configuration-assisted coating carbon black conductive ink for electromagnetic shielding fabric

Valentinus Galih Vidia Putra, Juliany Ningsih Mohamad, Diana Ross Arieff, and Yusril Yusuf

ABSTRACT
The study aimed to evaluate corona discharge plasma’s effectiveness with tip-cylinder electrode configuration to enhance the coating process for making anti-radiation fabric using coating by carbon black conductive ink. In this research, carbon black conductive ink was applied to various woven fabric types by the knife coating technique and pretreatment using a corona discharged plasma generator to develop an electromagnetic shielding material. The anti-radiation patch fabric was designed by modifying the textile woven fabric’s surface using atmospheric pressure plasma technology using tip-cylinder electrode configuration at room temperature, atmospheric pressure, ambient gases, etc.; the plasma-treated woven fabric was then coated with carbon black conductive ink. In this study, the influence of pretreatment of woven fabric by corona discharge plasma as the wetting properties, the surface modification and the value of the anti-radiation electromagnetic field, i.e., E field and H field radiation, were determined and measured by SEM (Scanning Electron Microscope), digital microscope, Fourier Transform Infrared (FTIR) spectrometer, wetting test (using the drop test with AATCC Test Method), and simulation by a computer program. The result of this research indicated that an anti-radiation woven fabric by pretreatment of corona discharged plasma with tip-cylinder electrodes configuration successfully absorbed electromagnetic radiation from smartphone radiation (as the source of radiation). It can be concluded that the current research will be beneficial for the fabrication of various simple and low-cost electromagnetic shielding fabric based on coating by carbon black conductive ink and pretreatment by corona discharged plasma.

1. Introduction
The use of electronic devices has been increased rapidly in recent years. Several researchers (Al-Saleh & Sundararaj, 2009; Avloni et al., 2007; Ma et al., 2014; Mariotti et al., 2016; Morent et al., 2008; Putra, Mohamad, & Wijayono, 2020) have shown the application of the use of physics in the case of textiles both in materials science and environmental engineering especially in smart and functional material. The application of physics and chemistry, especially in some textile industries, has been widely applied (e.g., plasma physics in textile processes, the electromagnetic field for EMI Shielding, etc.). In this modern era, a smartphone is a device that supports daily activities, but the excessive use of a smartphone also causes undesirable effects, such as cancer. According to The National Radiological Protection Board (NPRB), the UK. The effect caused by electromagnetic wave radiation from cellular telephones is divided into two such as 1. Physiological effects caused by waving radiation electromagnetic resulting disorders of the organs of the human body such as brain and hearing cancer; tumor; changes in eye tissue, including the retina and eyepiece; disorders of reproduction; memory loss and dizziness.; 2. Psychological effects are a psychiatric effect caused by radiation, such as the emergence of stress and discomfort due to radiation exposure. Some of the negative effects of electromagnetic radiation from smartphones and the lifestyle of millennials who often place smartphone devices in their pocket and at very close to the body can endanger their health (Al-Saleh & Sundararaj, 2009; Gherardini, Ciuti, Tognarelli, & Cinti, 2014; Safarova & Militky, 2012). Several researchers (Chen, Lee, Lin, & Koch, 2007; Cheng et al., 2015; Hwang, Chen, Lou, & Lin, 2014;...
Kumar et al., 2015; Li, Zhang, & Yin, 2012; Ozen, Usta, Yuksek, Sancak, & Soin, 2018) in the field of textiles are currently trying to make anti-radiation clothing with a material and coating process that is simple and affordable but also has good washing test resistance. Some researchers (Boonchoat, Satreerat, & Hodak, 2010; Jung & Choi, 2007; Lieberman & Lichtenberg, 1994; Murti & Putra, 2020; Putra, Fitri, Purnama, & Mohamad, 2020; Putra, Mohamad, & Wijayono, 2020; Putra, Mohamad, & Yusuf, 2020) stated that the method of radiation exposure by plasma generators has been shown to strengthen the adhesive material coating force and is proven effective in absorbing the material to be deposited. Some researchers (Ozen et al., 2018; Putra, Fitri et al., 2020) also stated that to obtain anti-radiation material, the textile fabric must have a conductive property but not oxidize easily, one example of the recommended material is carbon black. Several researchers (Putra, Fitri, et al., 2020; Rausher, Perucca, & Buyle, 2010; Shishoo, 2007; Sjaifudin, Widodo, Muhlisin, & Nur, 2014) stated that one type of plasma generator is a corona discharged plasma generator. Corona discharged plasma under atmospheric pressure, ambient gases, and room temperature is a unique treatment for non-partially, without difficulty apparatus and simple procedures for developing coating on fabric in the textile industry. Conductive material (e.g., carbon black or metal) is a familiar practice to apply shielding material for preventing the occurrence of electromagnetic radiation as an anti-radiation material. Some requirements for anti-radiation material (electromagnetic shielding) are thin thickness material with a light of mass and also with a good shielding effectiveness of the electromagnetic wave (Al-Saleh & Sundararaj, 2009; Chen et al., 2007; Cheng et al., 2015; Hwang et al., 2014; Ozen et al., 2018). Cheng et al. (2015) reported that they have succeeded in developing conductive fabrics as anti-radiation material for electromagnetic waves. several researchers (Jung & Choi, 2007; Mariotti et al., 2016; Murti & Putra, 2020; Putra, Fitri, et al., 2020; Putra, Mohamad, & Wijayono, 2020; Rausher et al., 2010) reported that they also researched textile materials with the topic of fine coating engineering studies with either plasma method or conventional method on textile materials. Several studies (Avloni et al., 2007; Kumar et al., 2015; Li et al., 2012; Morent et al., 2008; Safarova, Tunak, Truhlár, & Miltky, 2016; Safarova & Miltky, 2012) showed that electronic devices such as smartphones has electromagnetic radiation that can cause negatively affect the user’s body. According to several researchers (Lieberman & Lichtenberg, 1994; Putra, Mohamad, & Wijayono, 2020; Rausher et al., 2010; Shishoo, 2007; Sjaifudin et al., 2014) Plasma is the fourth material after solid, liquid and gas. Plasma is defined as an ionized gas of free particles. Plasma technology was introduced in the 1960s and has been widely applied in the textile and microelectronic industries. The applications of physics and chemistry in various fields of industry, especially in textiles, have been widely used and applied in theoretical and experimental physics in textile science. Some industries, such as plastics, polymers, textiles, metals, and ceramics, use plasma technology to modify surface properties. Several researchers (Boonchoat et al., 2010; Morent et al., 2008; Putra, Mohamad, & Yusuf, 2020; Putra & Wijayono, 2019; Shishoo, 2007) stated that O2, N2, and Argon (Ar) gases change the fabric’s properties to be more hydrophilic (easier to absorb liquid) while C2F6, SF6’s gases will change the fabric’s properties to hydrophobic (difficult to absorb liquids). It is common practice to coat the textile fabric surface with a thin film as an electronic device (e.g., textile solar cell, textile capacitor, textile sensor, and shielding material). However, some researchers (Avloni et al., 2007; Cheng et al., 2015; Jung & Choi, 2007; Kumar et al., 2015; Li et al., 2012; Ma et al., 2014) have some problems to coat the conductive material and to fabricate uniform coating film. Some researchers (Shishoo, 2007; Rausher et al., 2010; Ma et al., 2014; Morent et al., 2008; Putra, Fitri, et al., 2020; Putra, Mohamad, & Wijayono, 2020) reported that the advantages of using plasma technology include increasing water absorption, increasing adhesion forces, sterilization, improving the etching process and so on. The results demonstrated that the effect of modifying the superficial surface could change the material’s mechanical properties as a whole: mass loss, fabric tenacity and surface roughness, and increased adhesive force. Although plasma technology can improve the coating process in materials, there have been limited studies using corona plasma treatment for increasing the coating on the textile substrate. Looking for an alternative method, we have tried to use corona plasma technology with a new model of electrodes (tip-cylinder electrodes) to modify the fabric’s surface and test the electromagnetic shielding of the material as anti-radiation fabric. We used polyester-cotton (TC 70%) fabric because it is comfortable, durable, quite strong, lightweight, and inexpensive (because TC fabrics are generally cheaper than 100% cotton fabrics). Tetoron cotton or TC fabric is a polyester/cotton blended fabric (a familiar name in the textile industry). Tetoron is the Japanese name of polyester as a synthetic textile fiber. Polyester fiber is made from petrochemical, and cotton is obtained from natural fiber. Polyester-cotton is often used as material for clothes that we use every day, starting from t-shirts,
suits, etc. However, it is also commonly used for needs other than clothing, such as furniture, the automotive industry, household utensils, etc. Some researchers (Morent et al., 2008; Putra & Wijayono, 2019; Rausher et al., 2010) claimed that polyester fabric has properties such as strong enough, durable, and can be used for various purposes (because this material is also not easy to absorb water or sweat as well as anti-fungal or bacterial) but uncomfortable, while cotton has good comfort properties but not strong enough and not durable. In this study, plasma was used to change the surface and wetting properties of the TC 70% fabric to enhance the coating process. We also investigated the surface morphology of the untreated fabric and fabric treated by corona discharged plasma process, which was examined and observed using SEM (Scanning Electron Microscope), digital microscope, Fourier Transform Infrared (FTIR) spectrometer, and also wetting test (using the drop test with AATCC Test Method) to look and observe the changes on fabric’s surface visually. The recent study aims to assess the effectiveness of the corona discharged plasma for surface modification and coating the polyester-cotton (TC 70%) fabric with carbon black conductive ink and testing the anti-radiation fabric. The current research also presents a novel method to fabricate a thin layer on polyester-cotton TC 70% (contains 70% polyester composition) using pretreatment by a plasma generator to develop anti-radiation fabric and enhance the coating process without the use of toxic chemicals and expensive vacuum apparatus. This paper also describes the process of making anti-radiation patch fabric by modifying the polyester-cotton (TC 70%) fabric surface using a tip-cylinder corona discharged plasma technology and coating the fabric with carbon black conductive ink as well as evaluating the E field and H filed in some distances from the sources of the smartphone radiation. Anti-radiation testing with a radiation exposure source from a smartphone was chosen to designate the fabric to be made-up as a pocket or pants on clothes. In this study, this research’s novelty and significance are that the anti-radiation textile woven fabric was designed using atmospheric pressure plasma technology using tip-cylinder electrode configuration at room temperature, at atmospheric pressure, and by using ambient gases. The plasma corona discharge was generated using high voltage electricity with asymmetrical electrodes (tip and cylinder electrodes) and followed by coating the carbon black conductive ink on the woven fabric. The current research will help the fabrication of various simple and low-cost electromagnetic shielding fabric (anti-radiation fabric) based on coating by carbon black conductive ink and pretreatment by corona discharged plasma.

2. Research methods

2.1. Materials

The polyester-cotton (TC 70%) fabric was purchased from Tarunakusuma Purinusa Mandiri Co. Ltd., Ungaran, Indonesia. The fabric used was polyester-cotton (TC 70%) fabric with a density of 239 gr/m². Commercial carbon black conductive ink was bought from Bare Conductive Co.Ltd, London. The electromagnetic radiation tester used here was Obtained from DIGILIFE, Jakarta, Indonesia (radiation instrument, BENETECH GM3120). The plasma generator used in this study was a prototype apparatus corona discharged plasma made by Physics Laboratory Politeknik STTT Bandung, The Ministry of Industry, Republic of Indonesia. Corona discharged plasma generator was made with a solid cylinder and three taper electrodes (as a positive electrode). The point electrodes used were tapered bolts (as the point electrodes) and consisted of three pairs attached on a board connected in series with a distance of 1.5 cm per tip bolt. Point electrodes were used as positive electrodes (anodes connected to source voltages) and were laid perpendicular solid cylindrical as negative electrodes (cathodes connected to ground). The distance between the taper bolt electrode and the solid cylinder electrode was 2.5 cm. AC input voltage and DC output voltage was measured using by high voltage multi-tester (ISO 16750-2). The experimental design and instruments in this research are shown in Figure 1. The details of the corona discharged plasma system was given in our previous studies. (Putra, Fitri, et al., 2020; Putra & Wijayono, 2019).

2.2. Fabrication process of seed carbon black conductive ink layer on polyester-cotton (TC 70%) fabric

Anti-radiation patch fabric was made in two stages. The first step was to modify the fabric surface with plasma technology using a plasma generator. A polyester-cotton (TC 70%) fabric was placed inside the plasma device above a solid cylinder (cylinder) under the pointed electrodes (tip). Furthermore, the fabric surface was modified with a corona discharged plasma treatment for 2 minutes and 4 minutes with an output of 3kV DC. The exposed plasma wave of corona discharged plasma was generated using a high DC voltage of 3kV with a room temperature of 27-28 °C, an atmospheric pressure, and an ambient gas medium. Polyester-cotton (TC 70%) fabric given plasma radiation treatment was tested by water absorption test using a
drop test to determine the time-span of wetting time. As the second step, the fabric was coated with carbon black conductive ink. Furthermore, the anti-radiation patch fabric was dried for approximately 24 hours at room temperature.

2.3. Characterization and measurements

The water drop test was conducted with distilled water (absorbency test using a drop test according to the AATCC test method). The drops test was divided into three processes: the first was a polyester-cotton (TC 70%) fabric measuring 240cm² (15 cm x 16 cm) without plasma treatment. The second was for the exposed fabric by plasma radiation for 2 minutes and 4 minutes. The third was recorded all the drops after the treatment by a corona discharged plasma generator.

An anti-electromagnetic radiation test on a smartphone was carried out using a radiation measuring instrument (the electromagnetic radiation tester). The electromagnetic radiation test’s measurement results were in the electric field value (E) in units of V/m and a magnetic field value (H) in units of μT. Radiation tests were carried out by placing the radiation source near the radiation measuring instrument (radiation tester), and the fabric was closer to the radiation source with a specified distance. In this study, the distance measured was 0 cm, 0.5 cm, and 1 cm. We investigated the surface morphology of the untreated fabric and fabric treated by corona discharged plasma process, which was observed using a digital microscope (according to ISO 20705: 2020) and SEM (Scanning Electron Microscope according to ISO 22493), Fourier Transform Infrared (FTIR) spectrometer according to ASTM E168 and also wetting test to observe the changes on fabric’s surface visually.

In this research, we also derived the wetting time model as a function of electric voltage and plasma exposure time. The wetting time prediction was calculated by non-linear multi-variant regression and simulated by a computer program using MATLAB.

3. Results and discussions

In this study, We adjusted the generation of particles in plasma radiation with a plasma generator in the type of asymmetrical electrodes through visual analysis. Also, it measured the AC input voltage and DC output voltage using a high voltage multi-tester (ISO 16750-2). In this study, Corona discharge plasma was generated using asymmetrical electrode pairs, as three tip electrodes (as the anode electrodes) and solid cylinders (as the cathode electrodes). In this research, plasma radiation discharge occurred in areas with high electrical potential around positive electrodes or taper electrodes (anodes) that had a sharp geometric shape (in the case of taper electrodes were bolts) compared to solid cylindrical electrodes (cathodes). According to Rauscher, Perucca, Buyle [6], a significant increase in current indicates an increase in ion-electron density and the formation of positive ions followed by the UV light in the space between the electrodes. This increase was due to the easier ionization process of the plasma species. When the density of electrons and ions had a relatively equal value, a plasma region was formed in the taper bolt electrode (anode). The plasma region formed was a non-uniform plasma region or non-uniform plasma due to the inequality between electron mass density and ionic mass density in the area between the electrodes. Electron movement was measured using a high voltage multi-tester in which the current and electric field opposed the direction of the electron movement. The plasma region that began in the generator can be indicated by the UV light occurring and by measuring the high electric voltage. Due to the high voltage potential of electricity, the wave of plasma could be seen by the appearance of blue electromagnetic radiation under

![Figure 1. Plasma Corona Generator: (a) the plasma generator and the tip-cylinder electrode viewed on the front side; (b) the tip-cylinder electrode viewed from the side (Putra, Fitri, Purnama, & Mohamad, 2020).](image-url)
the anode, as shown in Figure 2. In this research, the ionized gas (plasma) in the ionization zone of the plasma zone moved toward the negative cylindrical as the negative electrode (cathode) went through a drift region blue ions could cause ions current called a unipolar saturation current. The movement of positive ions carried molecules and gas atoms in the area between the bolt electrode and the solid cylinder. This positive ion flow also contained reactive oxygen species (ROS) molecules, which could change the fabric’s surface properties by modifying the fabric’s roughness and the collision of positive ions resulting from ionization on the surface of the polyester-cotton (TC 70%) fabric.

The fabric that was surface-modified using a plasma generator was carried out absorbency test using a water drop test apparatus according to AATCC Test Method. The fabric’s absorbency testing was indicated with the wetting time measurements before and after corona discharged plasma treatment. The drop test with AATCC Test Method was used to test the fabrics’ wetting properties using a stopwatch, pipette, and distilled water. The wetting test was carried out on a polyester-cotton (TC 70%) fabric with a density of surface 239 gr/m² measuring area 240 cm² (15 cm x 16 cm) to be modified through plasma treatment for 2 minutes and 4 minutes with ambient gases, room temperature, and atmospheric pressure which became plasma media. The wetting drop test was conducted at the beginning of the process to determine the absorption after the measurement’s plasma treatment process results (the wetting time test can be seen in Figure 3 and Table 1). The figure demonstrates the difference in the absorption time of polyester-cotton (TC 70%) fabric not exposed by plasma radiation. After exposure by plasma radiation within 2 minutes and 4 minutes. The fabric that was not exposed by plasma radiation took an average absorbency time of 180.23 ± 12.39 seconds (197.23 s, 162.19 s, 179.12 s, 182.4 s, and 198.23 s) to absorb droplets of distilled water, while the fabric that was exposed by plasma radiation for 2 and 4 minutes took an average of absorbency time in 12.37 ± 0.67 seconds (12.38 s, 13.38 s, 12.37 s, 12.32 s, and 11.38 s) and an average of absorbency time in 7.49 ± 0.68 seconds (8.38 s, 7.35 s, 6.46 s, 7.49 s, and 7.45 s) to absorb the distilled water. Based on these results, the plasma treatment time of 4 minutes was the optimal time to modify the fabric’s surface, and the plasma treatment has been shown to improve the fabric wettability.

Figure 2. Positive active species of plasma flow (e.g., RNS or Reactive Nitrogen Species, ROS or Reactive Oxygen Species, ions, electrons, UVA, UVB, UVC): (a) plasma species in low-light, (b) and without light.

Figure 3. Drop test: a) on fabrics without exposed by plasma radiation, b) fabrics with plasma radiation exposure by plasma for 2 minutes, c) fabrics with radiation exposure by plasma for 4 minutes.
After the drop test, an anti-radiation patch fabric was produced by coating it using carbon black conductive ink. The fabric used had an area of 240 cm² (15 cm x 16 cm). The woven fabric exposed to plasma radiation (Figure 4) was stored on a flat surface to be coated with a carbon black conductive ink liquid using a knife coating technique method to uniform the carbon solution on the surface. After being coated, the fabric was dried for 24 hours at room temperature and atmospheric pressure.

After drying completely, the level of transmittance of electromagnetic waves emitted by the smartphone was carried out using the BENETECH GM3120 radiation test device. Tests were carried out one time each on a smartphone with an ordinary fabric and anti-radiation patch fabric. The preliminary measurement to do the anti-radiation test at 0 cm from this measurement's radiation source is shown in Figure 5.

Based on the measurement of the electromagnetic wave transmittance level emitted by smartphones and testing using the BENETECH GM3120 radiation test instrument, the results showed that the presence of conductive fabric in Figure 5 could reduce the transmittance rate of electromagnetic waves. An anti-electromagnetic radiation test on cellphones was performed using a radiation measuring instrument by the electromagnetic radiation tester. The electromagnetic radiation test's measurement results were in the type of an electric field value (E) in units of V/m and a magnetic field value (H) in units of μT. Tests were carried out by placing the radiation source on a flat cylinder. The radiation measuring instrument (radiation tester) was taken closer to the radiation source with a specified distance. In this investigation, the distance measured was 0 cm, and 0.5 cm. In this test, 3 types of testing were carried out, as: (1) Testing without any barriers by testing direct electromagnetic radiation with radiation tester; (2) Testing using a non-conductive fabric barrier with a composition of polyester-cotton TC70% (containing 70% of polyester) yarn; (3) Testing using conductive fabric, with the composition of polyester-cotton (TC 70%) and coated by carbon black conductive ink. The purpose of these three tests was to determine the extent of conductive fabrics' influence on electromagnetic radiation. The results of these three tests can be seen in Table 2.

The results of the radiation waves test graph for the E field at the distance of the radiation source 0 cm and 0.5 cm to the fabric (the results of these three tests can be seen in Figures 6 and 7). The results of the radiation waves test graph for the H field at the distance of the radiation source 0 cm and 0.5 cm to the fabric (The results of these three tests can be shown in Figures 8 and 9). The carbon black conductive ink mixed with water was chosen because of its conductive properties, which could block the Smartphones' electromagnetic waves. When an electromagnetic wave was emitted in front of it, there was a barrier from a conductive material; therefore, the incoming electromagnetic waves could be reflected, thus significantly reducing the electromagnetic wave radiation (proven by the significant reduction in the H field and E field in Table 2). The main component of carbon black conductive used in this experiment was carbon black conductive ink with a micro powder mixed with water and added acrylic adhesive. The solution was

Table 1. The relationship between exposure time and absorbency time (wetting properties).

| Time of exposure (minutes) | Output voltage DC (kV) | Average of absorbency time (seconds) |
|----------------------------|------------------------|-------------------------------------|
| 0 (control)                | 0.0 ± 0.1              | 180.23 ± 12.39                      |
| 2                          | 3.0 ± 0.1              | 12.37 ± 0.67                        |
| 4                          | 3.0 ± 0.1              | 7.43 ± 0.68                         |

Figure 4. (a) A visual appearance of the coated fabric, (b) A visual appearance on a digital microscope on coated fabric.
a thick and sticky liquid. This solution was then used to coat the fabric treated by plasma corona discharged. After drying and evaporating, the carbon particles could stick permanently to the fabric surface. This layer served to protect radiofrequency radiation emitted by Smartphones; therefore, the body in direct contact with smartphones was protected from high radiation because the radiation level was decreased to a level that was not harmful to the body’s way of reflection and absorption. The time of corona discharged plasma treatment of 4 minutes with the voltage of the plasma generator 3 kV provided the optimum changes in this research’s wetting properties. SEM analysis images showed the example of the morphology of polyester-cotton (TC 70%) fabric surfaces treated by plasma at 2 minutes and voltage used at 3 kV and 4 minutes with the constant electric voltage (Figure 10). SEM analysis confirmed the extensively modifying material (the effect of nano surface modification and structure etching) in the textile fabric caused by the low-temperature corona discharge plasma radiation at 4 minutes. The fabric surface treated by plasma at 4 minutes exhibits more roughness than at 2 minutes.

In this research, we also investigated the surface morphology of the treated fabric at 2 minutes and fabric treated at 4 minutes by corona discharge plasma process which was examined and observed using SEM (Scanning Electron Microscope) and also wetting test to look and observe the changes on fabric’s surface visually. The time of corona discharged plasma treatment of 4 minutes with the plasma generator 3 kV showed the optimum changes in wetting properties. Based on our study, SEM analysis images showed the modification of the morphology of polyester-cotton (TC 70%) fabric surfaces treated by plasma at 4 minutes and voltage of plasma generator at 3 kV and treated fabric at 2 minutes by corona discharge plasma (Figure b). SEM analysis showed the extensive changes (the effect of structure etching) in the textile fabric caused by the low-temperature corona discharge plasma. The fabric surface treated by plasma exhibits more roughness. The more roughness of the surface, the higher was the wetting time reduction occurred on fabric as well as, the more was the active species of plasma (e.g., RNS or Reactive Nitrogen Species, ROS or Reactive Oxygen Species, ions, electrons, UVA, UVB, UVC) confirmed by the high voltage on multi-tester and also by visually blue light occurred on the positive electrode as stated by Rausher et al.

**Table 2.** Results of cell phone electromagnetic radiation test results.

| Kind of experiment                          | distance (cm) | E field (V/m) | Standard Deviation | H Field (μT) | Standard Deviation |
|--------------------------------------------|---------------|---------------|--------------------|--------------|--------------------|
| Source of radiation without fabric         | 0             | 359.6         | 3.52               | 1.81         | 0.1                |
| barrier (no. 1)                            | 0.5           | 171           | 3.01               | 0.77         | 0.03               |
| Source of radiation with nonconductive     | 0             | 346.5         | 3.4                | 1.46         | 0.03               |
| fabric barrier (untreated) (no. 2)         | 0.5           | 117           | 1.2                | 0.55         | 0.02               |
| Source of radiation with conductive fabric| 0             | 0             | 0                  | 0.01         | 0.01               |
| barrier (treated by plasma 4 minutes and    | 0.5           | 0             | 0                  | 0.01         | 0.01               |
| coated by carbon black) (no. 3)            |               |               |                    |              |                    |

**Figure 5.** (a) Preliminary measurement of smartphone electromagnetic radiation before covered with anti-radiation patch fabric (b) Measuring results of smartphone electromagnetic radiation after being covered with anti-radiation patch fabrics.

**Figure 6.** Comparison of E field (V/m) for a distance of 0 cm for kind of experiment on no. 1, no. 2 and no. 3.

**Figure 10.**
A significant increase in current indicates an increase in ion-electron density and the formation of positive ions followed by the UV light in the space between the electrodes. This increase was due to the easier ionization process of the plasma species. When the density of electrons and ions had a relatively equal value, a plasma region was formed in the taper bolt electrode (anode). The plasma region formed was a non-uniform plasma region or non-uniform plasma due to the inequality between electron mass density and ionic mass density in the area between the electrodes. Electron movement was measured using a high voltage multi-tester in which the direction of electron movement was opposed to the direction of current and electric field $E$. In this investigation; We also found that the higher the active species of plasma, the higher was the modification of the fabric’s surface (confirmed by the Scanning Electron Microscope analysis by looking at the nano-granule morphology and more roughness) as well as the higher was the wet-ability of the fabric. The Fourier Transform Infrared (FTIR) spectra also showed an intensive distinct band with peak intensity at 1714 cm$^{-1}$, characteristics of $\text{C} = \text{O}$ and $-\text{COOH}$ peak in the sample (b) was significantly higher than that in the sample (a), which revealed the presence of additional carbonyl and carboxyl groups.

In this investigation, we found the formula to calculate the wetting time as a function of the exposure time of plasma and the electric voltage used. It was calculated and observed from Table 3 that the wetting time (absorbency time) of fabric was influenced by the exposure time and the electric voltage used. It was measured for predicting with the following Equations: To determine the form of non-linear equations of wetting time, hence it was used the form of multivariate regression equation which was a form of a static model with variable input that had more than one value, such as the relationship between the exposure time in the unit (minute) and also the electric voltage used in the unit (kV). Such as modeled as follows derived from Equation(1) to Equation (17):

$$
\sum_{i=1}^{n} \tilde{g}_i = \alpha_0 + \alpha_1 \sum j_{i1} + \alpha_2 \sum j_{i2} + \ldots + \alpha_k \sum j_{ik}
$$

$$
\tilde{g}_1 = \alpha_0 + \alpha_{j11} + \alpha_{j12} + \ldots + \alpha_{j1k}
$$

$$
\tilde{g}_2 = \alpha_0 + \alpha_{j21} + \alpha_{j22} + \ldots + \alpha_{j2k}
$$

$$
\tilde{g}_n = \alpha_0 + \alpha_{jnk1} + \alpha_{jnk2} + \ldots + \alpha_{jnkk}
$$

$$( \tilde{g}_1 \ldots \tilde{g}_n ) = ( 1 \ldots j_{1k} ) ( \alpha_0 \ldots \alpha_k )$$

Illustrates the Fourier Transform Infrared (FTIR) spectra obtained for the untreated sample (a) and atmospheric plasma-treated polyester-cotton fabric sample (b). Plasma treated on fabric sample (b) showed a new sharp absorption band with peak intensity at 3348 cm$^{-1}$, characteristics of $\text{C OH}$, which revealed the presence of additional hydroxyl groups (oxygen that is single bonded to a carbon and single bonded to a hydrogen atom) on the plasma-treated sample (sample b). Moreover, the higher hydroxyl groups on the sample, the higher is the wet-ability of the fabric.
The difference between experimental data and predictive modeling data is referred to as error $\epsilon$ and has a value of

$$\sum_{i=1}^{n} (g_i - \hat{g}_i) = \epsilon$$  \hspace{1cm} (5)

If Equation (5) is squared, it will generate Equation (6) as shown below

$$\epsilon^T \epsilon = M$$  \hspace{1cm} (6)

To find the value of $a$, optimization can be done through the squared differential Equation (5) with respect to $a$, hence we get

$$\frac{dM}{da} = \frac{d}{da} \left( g^T j - g^T ja - (g^T ja)^T + a^T j^T ja \right) = -2g^T j + 2a^T j^T j$$  \hspace{1cm} (7)

$$2g^T j = 2a^T j^T j$$

$$a^T j^T j = g^T j \text{with } a^T = (j^T j)^{-1} g^T j$$

$$\left( a^T j^T j \right)^T = (g^T j)^T$$  \hspace{1cm} (8)

$$\left( J^T J \right) a = J^T g$$  \hspace{1cm} (9)

$$a = \left( J^T J \right)^{-1} J^T g$$  \hspace{1cm} (10)

$$\hat{g} = Ja = J(j^T j)^{-1} j^T g$$  \hspace{1cm} (11)

Based on Equation (12) above with the matrix $J$, therefore we obtained Equation (13) to Equation (16) below

$$T_w = a_o \tau_p^{a_1} V^{a_2}$$  \hspace{1cm} (13)

$$\ln T_w = \ln a_o + a_1 \ln \tau_p + a_2 \ln V$$  \hspace{1cm} (14)

$$G = A_0 + A_1 J_1 + A_2 J_2$$  \hspace{1cm} (15)

$$\left( \begin{array}{c} \hat{g}_1 \\ \hat{g}_2 \\ \hat{g}_3 \end{array} \right) = \left( \begin{array}{ccc} 1 & \ln(0.001) & \ln(0.1) \\ 1 & \ln(2.001) & \ln(3.1) \\ 1 & \ln(4.001) & \ln(3.1) \end{array} \right) \left( \begin{array}{c} A_0 \\ A_1 \\ A_2 \end{array} \right)$$  \hspace{1cm} (16)

by using MATLAB programming, we get Equation (17) with $a_o = e^{0.0}$ and $a_1 = A_1$, $a_2 = A_2$, hence the formula of the wetting time as a function of exposure time and electric voltage can be shown as Equation (17)

$$T_w = 8.0591 \tau_p^{-0.7241} V^{0.8227}$$  \hspace{1cm} (17)
Where $T_w$ is the wetting time (absorbency time) in the unit (seconds), $\tau_p$, the exposure time of plasma in unit (minutes), $V$, is the electric voltage used in the unit (kV). The model of the wetting time or absorbency time in the unit (seconds) has been investigated and is shown in Table 3. The simulation of the wetting time as a function of electric voltage in the unit (kV) and also exposure time in the unit (minute) carried out using Equation (17) and the computer program by MATLAB (as shown in Figure 12).

Based on the calculation and simulation, we found that the higher the voltage of the plasma generator (from 0 kV for control fabric to 3 kV for treated fabric by plasma), the lower is the wetting time of fabric and also exposure time in the unit (minute) carried out using Equation (17) and the computer program by MATLAB (as shown in Figure 12).

Table 3. The relationship between exposure time and absorbency time (wetting properties) prediction.

| Modeling of Time of exposure (minutes) | Modeling of Output voltage DC (kV) | Prediction of wetting time as absorbency time $T_w$ = $8.05911 \times 10^{-0.7241V0.0227}$ | Real of wetting time as absorbency time (seconds) |
|---------------------------------------|-----------------------------------|---------------------------------------------|-----------------------------------------------|
| 0.001                                 | 0.1                               | 180.255                                     | 180.23 ± 12.39 (at 0 minutes and 0 kV) |
| 2.001                                 | 3.1                               | 12.371                                      | 12.37 ± 0.67                                 |
| 4.001                                 | 3.1                               | 7.490                                       | 7.43 ± 0.68                                  |
| 6.001                                 | 3.1                               | 5.585                                       | –                                            |
| 8.001                                 | 3.1                               | 4.535                                       | –                                            |

Figure 12. Wetting time as a function of exposure time and electric voltage.

Conclusion

This study has shown physics and chemistry applications in surface modification of polyester-cotton (TC 70%) fabric by corona discharged plasma with tip-cylinder electrode configuration-assisted coating carbon black conductive ink for electromagnetic shielding fabric. The method to develop a smartphone anti-radiation patch fabric attached to a sportswear pocket using a tip-cylinder electromagnetic plasma treatment has been discussed. The thin carbon black conductive layer was effectively fabricated on Polyester-cotton (TC 70%) fabric with different times of exposure of wave by corona discharged plasma generator with tip-cylinder electrode configuration. The fabrications of the material were characterized using SEM, wetting test, and anti-electromagnetic radiation test. The results of the treated fabric by plasma at 4 minutes and coated by carbon black conductive ink were succeeded in reducing almost 100% of smartphone radiation in an active state. The result of this research indicated that an anti-radiation woven fabric by pretreatment of corona discharged plasma with tip-cylinder electrodes configuration was successfully shielded electromagnetic radiation from Smartphone radiation. The current research will be advantageous for fabricating various low-cost electromagnetic shielding fabric based on carbon black conductive ink coating.

Acknowledgement

We would like to express our gratitude to Politeknik STTT Bandung and Universitas Nusa Cendana as the research funders as well as to the contribution of colleagues, Mr Budi Soewondo, Mr Hardiyanto, and Mr Roni Sahroni who helped us during the research and discussion.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Al-Saleh, M., & Sundararaj, U. (2009). Electromagnetic interference shielding Mechanisms of CNT/polymer composites. Carbon, 47(7), 1738–1746. doi:10.1016/j.carbon.2009.02.030

Avloni, J., Lau, R., Ouyang, M., Florio, L., Henn, A., & Sparavigna, A. (2007). Shielding effectiveness evaluation of metallized and polypyrrole-coated fabrics. Journal of...
Thermoplastic Composite Materials, 20(3), 241–254. doi: 10.1177/0892705707076718

Boonchoat, P., Sateerarot, & Hodak, (2010). Hydrophobic and hydrophilic surface nano-modification of PET fabric by plasma process. Journal of Nanoscience and Nanotechnology, 10, 7050–7054. pp

Chen, H., Lee, K., Lin, J., & Koch, M. (2007). Comparison of electromagnetic shielding effectiveness properties of diverse conductive textiles via various measurement techniques. Journal of Materials Processing Technology, 192, 549–554.

Cheng, L., Zhang, T., Guo, M., Li, J., Wang, S., & Tang, H. (2015). Electromagnetic shielding effectiveness and mathematical model of stainless steel composite fabric. The Journal of the Textile Institute, 106(6), 577–586. doi: 10.1080/00405000.2014.929275

Gherardini, L., Ciuti, G., Tognarelli, S., & Cinti, C. (2014). Searching for the perfect wave: The effect of radiofrequency electromagnetic fields on cells. International Journal of Molecular Sciences, 15 (4), 5366–5387. doi:10.3390/ijms15045366

Hwang, P., Chen, A., Lou, C., & Lin, J. (2014). Electromagnetic shielding effectiveness and functions of stainless steel/bamboo charcoal conductive fabrics. Journal of Industrial Textiles, 44(3), 477–494. doi:10.1177/1528083713502995

Jung, M., & Choi, H. (2007). Surface treatment and characterization of ITO thin films using atmospheric pressure plasma for organic light emitting diodes. Journal of Colloid and Interface Science, 310(2), 550–558. doi:10.1016/j.jcis.2007.02.011

Kumar, P., Shahzad, F., Yu, S., Hong, S., Kim, Y., & Koo, C. (2015). Large-area reduced graphene oxide thin film with excellent thermal conductivity and electromagnetic interference shielding effectiveness. Carbon, 94, 494–500. [Database] doi:10.1016/j.carbon.2015.07.032

Li, X., Zhang, L., & Yin, X. (2012). Synthesis and electromagnetic shielding property of pyrolytic carbon-silicon nitride ceramics with dense silicon nitride coating. Journal of the American Ceramic Society, 95, 1038–1041.

Lieberman, M., & Lichtenberg, A. (1994). Principles of plasma discharges and materials processing. New York, NY: John Wiley and Sons.

Ma, S., Bromberg, V., Liu, L., Egitto, F., Chiarot, P., & Singler, T. (2014). Low temperature plasma sintering of silver nanoparticles. Applied Surface Science, 293, 207–215. doi: 10.1016/j.apsusc.2013.12.135

Mariotti, D., Belmonte, T., Benedikt, J., Velusamy, T., Jain, G., & Svrcek, V. (2016). Low-Temperature atmospheric pressure plasma processes for “green” third generation photovoltaics. Plasma Processes and Polymers, 13(1), 70–90. doi:10.1002/ppap.201500187

Morent, R., De Geyter, N., Verschuren, J., De Clerck, K., Kiekens, P., & Leys, C. (2008). Non-thermal plasma treatment of textiles. Surface and Coatings Technology, 202(14), 3427–3449. doi:10.1016/j.surfcoat.2007.12.027

Murti, W., & Putra, V. (2020). Studi Pengaruh Perlakuan Plasma Terhadap Sifat Material Anti Bakteri Kain Kasa Menggunakan Minyak Atsiri (Zingiber OfficinalRosc). Jurnal Teori Dan Aplikasi Fisika, 8 (1), 69–76. doi:10.23960/jtf.v8i1.2432

Ozen, M., Usta, I., Yuksel, M., Sancak, E., & Soin, N. (2018). Investigation of the electromagnetic shielding effectiveness of needle punched nonwoven fabrics produced from stainless steel and carbon fibres. Fibres & Textiles in Eastern Europe, 26, 94–100.

Putra, V., Fitri, A., Purnama, I., & Mohamad, J. (2020). Prototipe Pakai Anti Radiasi Unisex Sportswear Smartphone dengan Paparan Radiasi Plasma Pijar Korona Elektroda Tip-Silinder. Jurnal Kumparan Fisika, 3(1), 19–24. doi:10.33369/jkf.3.1.19-24

Putra, V. G., Mohamad, J., & Wijayono, A. (2020). Efek Modifikasi Plasma Untuk Meningkatkan Sifat Tahan Api Dari Kain Katun. Jurnal Dinamika Penelitian Industri, 31 (1), 59–70. doi:10.28959/jdpi.v31i1.5878

Putra, V. G., Mohamad, J. N., & Yusuf, Y. (2020). Study of surface tension properties looked on contact angle value on 100% nylon textile fabric using corona discharge plasma technology. Wahana Fisika, 5(1), 10–17. doi:10.17509/wafi.v5i1.22382

Putra, V., & Wijayono, A. (2019). A preliminary study of wetting properties on 100% polyester fabric using corona discharge plasma,(in: Suatu Studi Awal Modifikasi Sifat Pembasahan Pada Permukaan Kain Tekstil Poliester 100% Menggunakan Teknologi Plasma Pijar korona). Prosiding Seminar Nasional Fisika (E-Journal), 8, 15–20.

Rausher, H., Perucca, M., & Buyle, G. (2010). Plasma technology for hyperfunctionals surfaces. Weinheim: Wiley-VCH.

Safarova, V., & Militky, J. (2012). Comparison of methods for evaluating the electromagnetic shielding of textiles. Fibers Text, 19, 50–55.

Safarova, V., Tunak, M., Truhljar, M., & Militky, J. (2016). A new method and apparatus for evaluating the electromagnetic shielding effectiveness of textiles. Textile Research Journal, 86, 44–56.

Shihoo, R. (2007). Plasma technology for textile. Cambridge: Woodhead Publishing.

Sjaifudin, A., Widodo, M., Muhliszin, Z., & Nur, M. (2014). Modifikasi Permukaan Bahan Tekstil Dengan Plasma Lucutan Korona. Prosiding Seminar Nasional Tekstil (pp. 1–22). Bandung: Politeknik STTT Bandung.