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Research on the Performance of Polypyrrole Coated Conductive Fabrics Prepared from Different Base Materials

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Abstract
In this paper, polypyrrole coated conductive fabrics were prepared using pyrrole as the monomer, p-toluene sulfonic acid as the doping agent and ammonium persulfate as the oxidant, adopting the simple method of situ polymerization of the liquid phase. Six types of conductive polypyrrole coated fabrics were prepared adopting polyester-cotton blended fabrics, nylon fabrics, wool fabrics, silk fabrics, basalt fabrics and aramid fabric respectively as base materials and using the same process conditions; its electrical conductivity was compared, and the distribution and resistance of the washing fastness of polypyrrole on the surface of those fabrics were studied. Results showed that under the same process conditions, the conductivity of polypyrrole coated terylene fabrics was the best, followed by the polypyrrole coated nylon fabrics and polypyrrole coated wool fabrics. Observed by electron microscope, the distribution of polypyrrole was more homogeneous on different base cloths. After washing, it was concluded that the combination fastness of polypyrrole with polyester-cotton, nylon and wool was better, while the combination fastness of polypyrrole with basalt and aramid was poor.

Keywords
base material; polypyrrole; coating; fabrics; electrical conductivity.

1. Introduction

With the development of science and technology and the rapid improvement of people's quality of life, the demand for flexible wearable electronic products has been increasing in recent years, playing a huge role in the fields of health monitoring, sports tracking, electromagnetic interference shielding, etc. [1-5]. Compared with flexible substrates such as plastic and silicone, textile fabrics have better desirable breathability, flexibility, and wear resistance. They can achieve mechanical deformation such as bending, twisting, and stretching at almost any angle, and can meet the requirements of human movement in daily life. Therefore, building flexible electronic devices on textile fabric substrates is more suitable for the future development of wearable electronic devices [6,7]. With the advantages of good flexibility, breathability, and lightweight, conductive fabrics are widely used in medicine, electromagnetic shielding, sensing, wearable devices, supercapacitors, and other fields [8-12]. The development of conductive fabrics with excellent performance will promote the process of intelligent textiles and accelerate the transformation and upgrading of the textile industry.

With the rapid development of modern communication technology and the widespread use of electronic equipment, electromagnetic wave pollution is becoming an increasingly serious problem. Electromagnetic radiation can affect the normal work of an instrument and even endanger human health [13-15]. It is widely believed that using microwave absorption materials to protect the target object is one of the important strategies to address electromagnetic radiation pollution [16,17]. Among them, conductive fabrics with good flexibility, air permeability, lightweight, and the microwave absorption function have attracted extensive attention from researchers [18-20].

Conventional textile materials are usually insulating. The integration of metals, carbon-based conductive materials, conductive polymers, or other conductive compounds into the textile structure at different stages of the textile (fiber construction, spinning, or fabric fabrication) can impart good electrical conductivity to conventional textiles. Conductive textiles prepared by treating fabrics with conductive polymers have the advantages of lightweight, good elasticity, corrosion resistance, and easy fabrication, which have a wide range of applications in the field of smart textiles [21]. Among the various conductive polymers, polypyrrole (PPy) has attracted much attention due to its simple synthesis, mild and easy to control reaction conditions, and high conductivity [22-24]. At present, among the various preparation methods of polypyrrole conductive fabrics, the in situ polymerization method and impregnation drying method are widely studied due to the advantages of the simple process and low cost. Compared with the composite fabrics prepared by the impregnation drying method, which have disadvantages such as the polymer

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Laboratory reagent	Molecular formula	Molecular weight	Specifications	Character	Manufacturer
Pyrrole	C_4H_5N	67.09	Chemically pure	Yellowish transparent oily liquid	Shanghai Kefeng Industrial Co., Ltd
Ammonium persulfate	$(NH_4)_2S_2O_8$	228.18	Analytically pure	White powder	Tianjin Wind Ship Chemical Technology Co., Ltd
p-toluene sulfonic acid	$C_7H_8O_3S$	172.20	Analytically pure	White crystalline	Tianjin Guangfu Fine Chemicals Institute

Table 1. Main reagents

Instrument	Specifications	Manufacturer
Intelligent digital display constant temperature water bath	HH-S4	Gongyi City Yuhua Instrument Co., Ltd, China
Desktop digital multimeter	34410A	Agilent Technologies, USA
Field emission scanning electron microscope	S-4800	Hitachi Ltd, Japan

Table 2. Main experimental instruments

bonding being not tight enough and easy to fall off, composite fabrics prepared by the in-situ polymerization method have stronger mechanical properties and a longer service life, and they usually have better friction resistance and washing resistance [25,26].

In this paper, six types of polypyrrole coated conductive fabrics were prepared using pyrrole as the monomer, p-toluene sulfonic acid as the doping agent and ammonium persulfate as the oxidant, adopting the simple method of situ polymerization of the liquid phase. Its electrical conductivity was mainly compared, and the distribution and washing fastness of polypyrrole on the surface of those fabrics were studied.

2. Experiment

2.1. Main reagents

The main reagents used in this experiment are shown in Table 1.

2.2. Main experimental instrument

The main instruments used in this experiment are shown in Table 2.

2.3. Preparation of polypyrrole coated fabrics

Samples of fabrics weighting 1 g, and a certain amount of pyrrole monomer were put in beakers containing 200 ml of water. The fabric samples were soaked, drained, put into a beaker, then stirrred and left to absorb for a certain time. A certain amount of ammonium persulfate as an oxidant was added slowly, and then a certain amount of p-toluene sulfonic acid as the doping agent while fully stirring at the room temperature. After the specified time of reaction, polypyrrole coated fabrics were obtained, which were then washed and dried. The specific process parameters are shown in Table 3.

2.4. Test indexes and methods

2.4.1. Conductivity test

Polypyrrole coated fabrics were put on a clean and insulated laboratory table, and then a 34410 type Agilent Technologies, USA desktop digital multimeter was used to determine the resistance. A distance of 1 cm was measured using multimeter pen needles on the polypyrrole coated fabric, and the surface resistance between the two points was measured. In this way, ten groups of different locations of the two points were taken to measure the resistance value, and the average value was calculated.

2.4.2. Exterior morphology test

The distribution of polypyrrole on the fabrics was observed using an S-4800 field emission scanning electron microscope, Hitachi Ltd, Japan.

2.4.3. Test of the washing fastness

Test of the washing fastness was carried out according to the GB/T 3921-3921 standard. Soaping process conditions and parameters were as follows: soap concentration 5 g/L, bath ratio 1:50, soaping temperature 40 °C, time 30 minutes.

3. Results and discussion

Research of the conductivity, distribution on the surface of fabrics and fastness of polypyrrole coated fabrics

Six types of conductive polypyrrole coated fabrics were prepared adopting polyester-cotton blended fabric, nylon fabric, wool fabric, silk fabric, basalt fabric and aramid fabric, respectively, as base materials and using the same process conditions, its electrical conductivity was compared and the distribution and fastness of polypyrrole on the surface of those fabrics were studied.

Doping agent (mol/L)	Mole ratio of oxidant and pyrrole	Pyrrole concentration (mol/L)	Adsorption time of pyrrole (min)	Reaction time (min)	Reaction temperature (℃)
0.2	1	0.15	30	30	Room temperature

Table 3. Process parameters

Base cloth	Blended polyester/cotton	Nylon	Wool	Silk	Basalt	Aramid
Resistance (kΩ)	3.8040	4.2074	5.2350	8.2393	21.592	31.465

Table 4. Conductivity of polypyrrole coated fabrics after washing

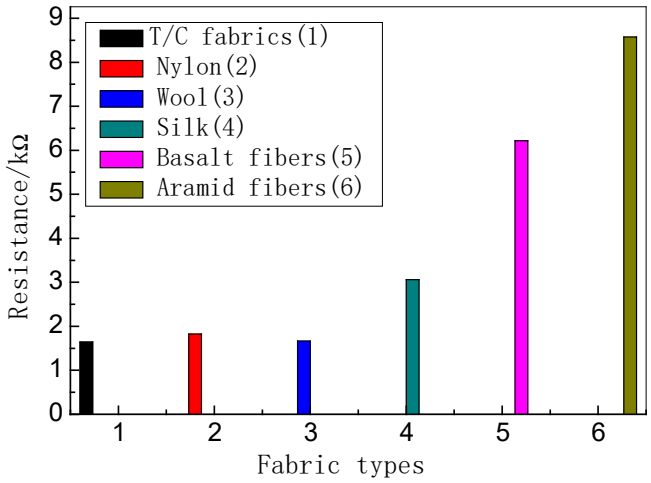


Fig. 1. Conductivity of polypyrrole coated fabrics

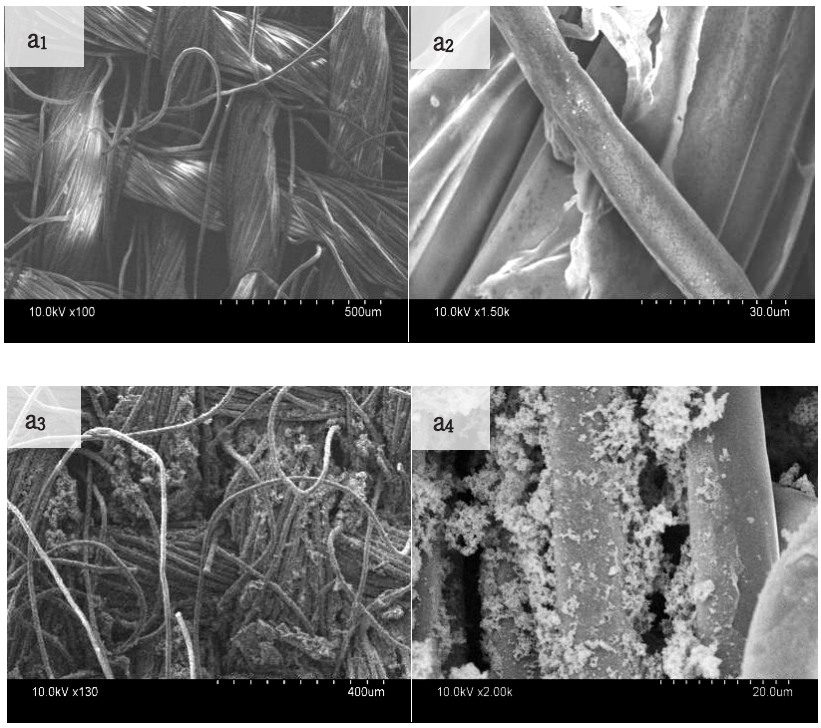


Fig. 2. Images of electron microscopy (SEM) of polypyrrole coated terylene fabrics. Note: a_1, a_2 are electron microscopy images of untreated polyester-cotton blended fabrics; a_3, a_4 are electron microscopy images of polyester-cotton blended fabrics finished with polypyrrole

3.1. Influence of different base materials on the conductive performance

Figure 1 shows that under the same reaction condition, the conductive effect of polypyrrole coated polyester-cotton blended fabric was the best, followed by the effects of nylon and wool. This may be because polypyrrole has macromolecules of long chains and good linear structures, where it is easy to form hydrogen bonds and the van der Waals force with cotton and other fabrics with better planarity, reinforcing the combination fastness between the two, consequently, the conductive effect of polypyrrole coated polyester-cotton blended fabrics was the best. There were amide and a small number of alcohol groups on fabrics such as polyamide, wool and silk, where it was easy to form hydrogen bonds between molecules of polypyrrole; consequently, the conductive effect may be better.

3.2. Differences in washing fastness

Table 4 shows that after washing, values of the surface resistance of six types of polypyrrole coated fabrics were improved, among which the values of the surface resistance of polyester-cotton blended fabric, nylon fabric and wool fabric were somewhat improved, while the improvement in the surface resistance of silk, basalt and aramid fibers was larger.

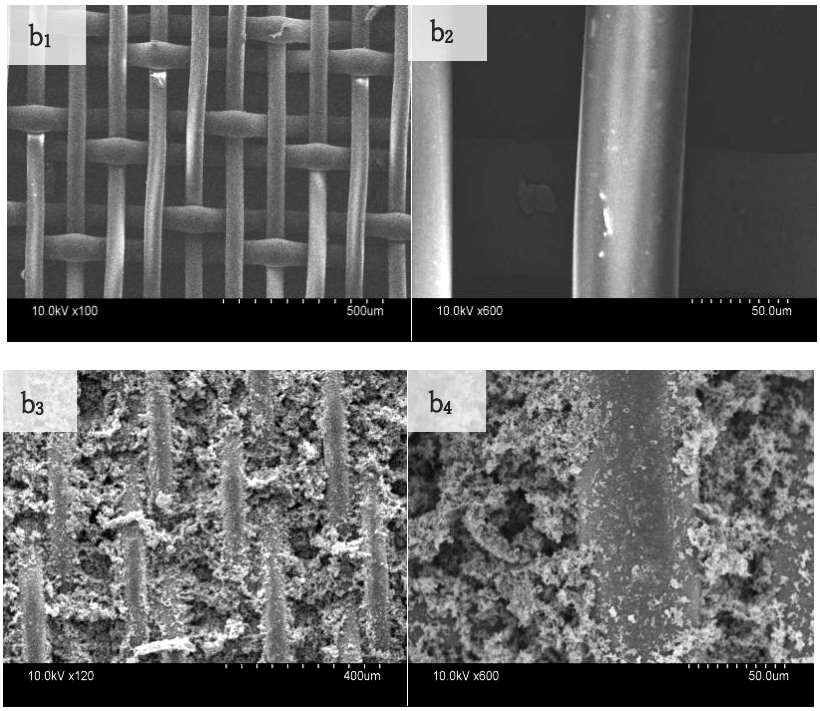


Fig. 3. Images of electron microscopy (SEM) of polypyrrole coated nylon fabrics. Note: b_1, b_2 are electron microscopy images of untreated nylon fabrics; b_3, b_4 are electron microscopy images of nylon fabrics finished with polypyrrole

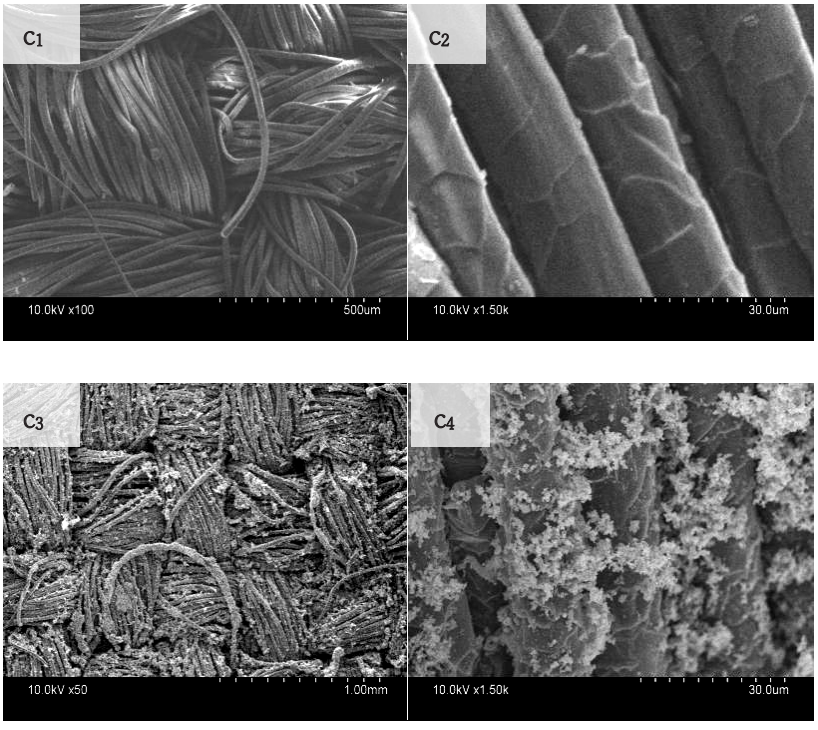


Fig. 4. Images of electron microscopy (SEM) of polypyrrole coated wool fabrics. Note: c_1, c_2 are electron microscopy images of undigested wool fabrics; c_3, c_4 are electron microscopy images of wool fabrics finished with polypyrrole

3.3. Distribution of polypyrrole on different types of base fabrics

(1) Distribution of polypyrrole on polyester-cotton fabrics

Figure 2 shows images of electron microscopy of untreated polyester-cotton blended fabrics and polyester-cotton blended fabrics after the treatment of polypyrrole. It illustrates that after the treatment of polypyrrole, there was a larger number of “cauliflower”-shaped particles generated among polyester-cotton fibers and on their surface.

(2) Distribution of polypyrrole on nylon fabrics

Figure 3 shows the difference between nylon fabrics before and after the treatment of polypyrrole, The surface of nylon fabrics not finished by the coating is flat and smooth, and the cross section of fibers is cylindrical. There is a large number of polypyrrole particles deposited in the shape of a “cauliflower” on the surface of nylon fibers finished with polypyrrole coatings; basically polyamide fibers were completely covered.

(3) Distribution of polypyrrole on wool fabrics

Figure 4 shows the contrast between wool fabrics before and after the treatment of polypyrrole. There are large amounts of polypyrrole deposited in the shape of a “cauliflower” on the surface of wool fibers finished by polypyrrole coatings;the overall distribution is uniform.

(4) Distribution of polypyrrole on silk fabrics

Figure 5 shows electron microscopy images of silk fabrics before and after the treatment of polypyrrole, depicting that there is a large amount of polypyrrole deposited in the shape of a “cauliflower” on the surface of silk fibers finished with polypyrrole coatings, and there are uniform films on the surface of silk fibers.

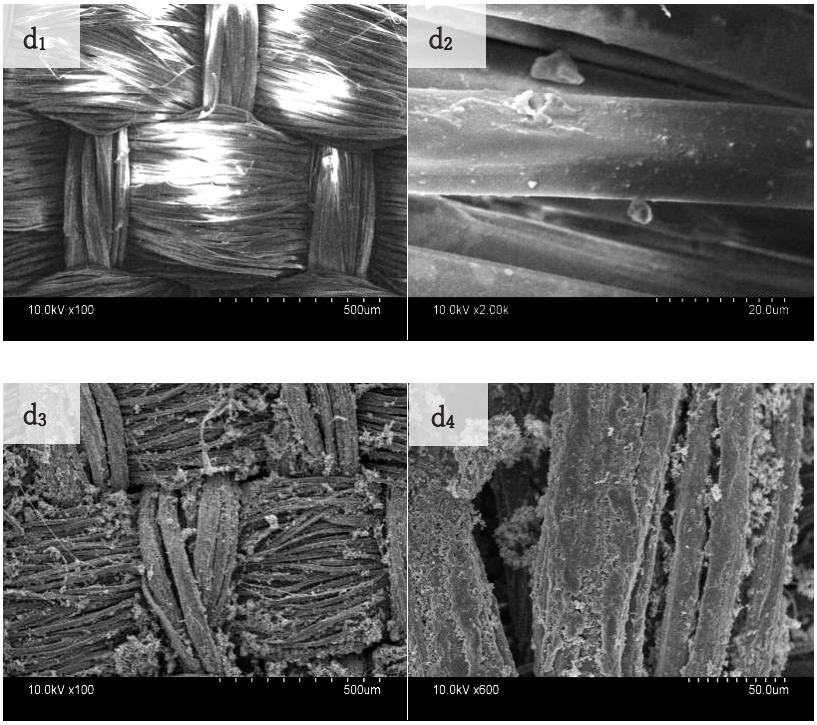


Fig. 5. Images of electron microscopy (SEM) of polypyrrole coated silk fabrics. Note: d_1, d_2 are electron microscopy images of undigested silk fabrics; d_3, d_4 are electron microscopy images of silk fabrics finished with polypyrrole

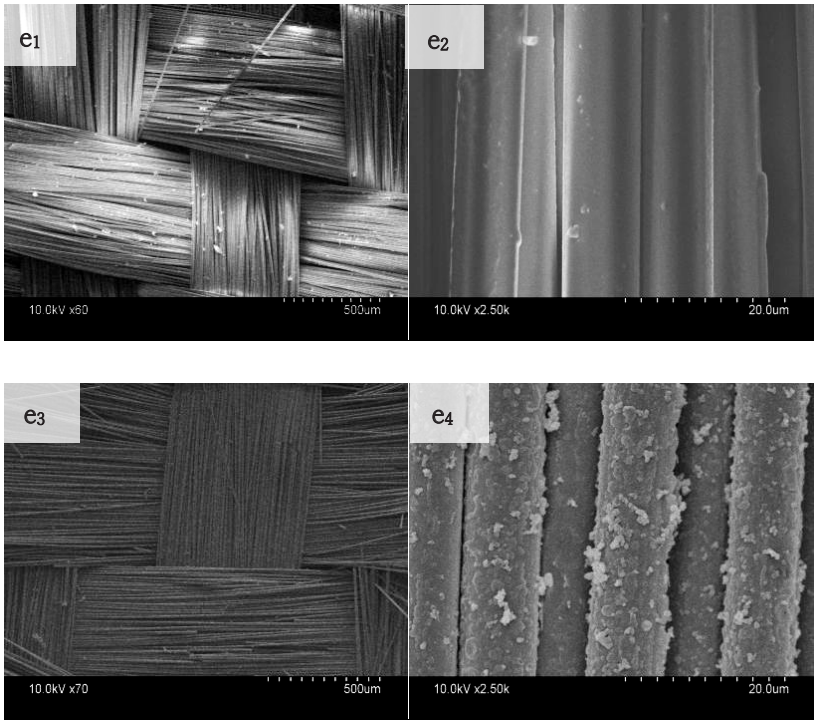


Fig. 6. Image of electron microscopy (SEM) of polypyrrole coated basalt fabrics. Note: e_1, e_2 are electron microscopy images of undigested basalt fabrics; e_3, e_4 are electron microscopy images of basalt fabrics finished with polypyrrole

(5) Distribution of polypyrrole on basalt fabrics

Figure 6 presents the contrast between basalt fabrics before and after the treatment of polypyrrole. Figure 6 shows that the surface of untreated basalt fibers is flat and smooth, and there are no crimps. There is a layer of polypyrrole film formed on the surface of basalt fibers finished with polypyrrole; basically fibers are completely covered and the luster on the surface has disappeared.

(6) Distribution of polypyrrole on aramid fabrics

Figure 7 presents the difference between aramid fabrics before and after the treatment of polypyrrole, Figure 7 shows that there are large amounts of polypyrrole in the shape of a “cauliflower” on the surface of wool fibers finished with polypyrrole coatings, but the distribution on polypyrrole is uneven; with the stacking dispersed.

4. Conclusion

In the same process conditions, the conductivity of polypyrrole coated polyester-cotton blended fabrics was the best, followed by that of polypyrrole coated nylon fabrics and polypyrrole coated wool fabrics. Observed by electron microscope, distributions of polypyrrole were more homogeneous on different base clothes. It was concluded that the washing fastness of polypyrrole with polyester-cotton, nylon and wool fabrics was rather good, while that of polypyrrole with basalt and aramid fabrics was poor.

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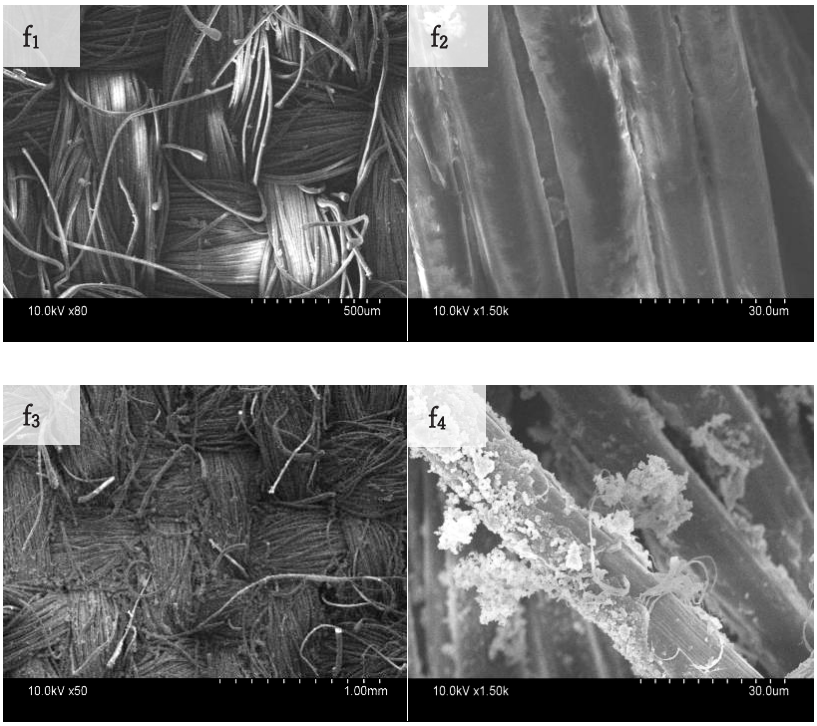


Fig. 7. Image of electron microscopy (SEM) of polypyrrole coated aramid fabrics. Note: f_1, f_2 are electron microscopy images of untreated aramid fabrics; f_3, f_4 are electron microscopy images of aramid fabrics finished with polypyrrole

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