Preparation and Evaluation of Electro-Conductive Threads from Waste Carpet

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Abstract
The present study relates to the preparation and evaluation of electrically conductive thread from waste woolen handmade carpet through surface modification. Woolen threads recycled from waste woolen hand knotted and hand tufted carpets, all made of 100% woolen fibers were made electrically conductive by in situ chemical polymerization of pyrrole with p-toluene sulfonic acid as dopant. Before polymerization reaction takes place, hydrolysis of woolen threads were done for better deposition of polypyrrole on the material. The average surface resistivity were found to be 1013.08 Ωm for woolen threads. The electro-conductive threads displayed exponential rise of surface temperature on application of voltage and the rise of temperature was found to be related to the time duration of applied voltage. The electro-conductive threads show linear voltage–current relationship at low voltage range. The surface resistivity of the electro-conductive threads were increased substantially on prolong exposure to atmosphere.

Keywords: *dopant, hand knotted, hand tufted surface resistivity waste; woolen*

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1. Introduction

Research on electro-conductive textiles prepared from conductive polymers such as polypyrrole, polyaniline, areas for their light weight and ease of deployment. Most of the applications proposed in the literature are to multi-functionalize textile products, such as heating pads, flexible keyboard, sensors, microwave attenuation, static charge dissipation, electro-magnetic interference shielding polythiophene etc. has increased in the recent years due to their high application potentials in different etc. [1-4].Use of metal wires or metal coating is a common practice for imparting electrical conductivity to textiles [5-10]. Also, metal fibers were used during staple spinning to manufacture electro-conductive yarns [11-13]. Those yarns were used in weaving or knitting to produce electro-conductive fabrics. But, the processing of those yarns is difficult and they lose their textile properties [14]. Many such limitations associated with processability, low mechanical strength, and poor flexibility could be successfully overcome by coating/ applying conducting polymers on strong and flexible textile substrates [15]. Polypyrrole has been mostly used polymer due to its high conductivity, low toxicity, commercial availability, and high stability in air compared to other conducting polymers [16]. Heating effect of polypyrrole coated polyethylene terepthalate-lycra woven fabrics was studied by Kaynak and Håkansson [17]. Those coated fabrics exhibited reasonable electrical conductivity and effective heat generation. At applied voltage of 24 V maximum temperatures achieved was 40.55°C. In another study, polypyrrole was incorporated in cotton woven fabrics and various properties such as anti-static, anti-microbial and heat generation were investigated [18]. Conducting textiles were prepared by embedding polypyrrole in natural and man-made cellulosic fibers, such as cotton, viscose, cupro, and lyocell, by in situ vapour-phase polymerization and their various electrical properties such as voltage–current characteristics, voltage–temperature characteristics etc. were studied. It was suggested by Sparavigna, Florio, Avloni, and Henn (2010) and Macasaquit and Binag (2010) that 100% polyester fabrics could easily be made electrically conductive by polypyrrole coating and they were practically useful for many applications, including flexible, portable surface-heating elements for medical or other applications.

An electrical resistor was formed within a fabric by sewing a highly conductive silver coated yarn into less conductive polypyrrole treated knitted fabric [19]. This was found to be a useful method for enabling electrical connection to a fabric for characterization of a fabric's resistivity and design of a fabric resistor. In another study, it was reported that the fabrics knitted with silver yarn along with elastomeric yarn could generate sufficient heat

to warm-up the body. Those fabrics could be used to manufacture personal heating garments that can generate heat in relation to applied voltage. Most of the studies for preparation of electroconductive textiles were carried out using woven and knitted fabric substrates. Not much information is available about use of nonwoven materials as substrate which we have chosen for our present study. Najar, Kaynak, and Foitzik [20] found that porous and bulky wool yarns having less twist showed better conductivity than that of wool yarns having compact structure with higher twist. This result was attributed to the more open and bulkier structure of wool yarn at lower twist levels, enabling better penetration of the FeCl3 and pyrrole between the fibers; hence, giving rise to a more extensive polymerization.Therefore, it is assumed that nonwovens such as needlepunched and spunlace might give superior conductivity due to their porous and bulky structure. Again, literature says that polypyrrole can be deposited or coated effectively on wool/cotton substrate to impart conductivity [21].
Since wool is hydrophilic in nature, imparting hydrophilicity by surface treatment may improve polymer fixation [22]. Therefore, the aim of this study is to prepare electro conductive woolen threads from waste hand knotted and hand tufted carpet after surface modification and to analyze its heat generation characteristics.

2. Materials and Chemicals

Woolen threads (2 Nm) were used as substrate. All these threads were made of 100% woolen fiber and semi-worsted fibre recycled from hand-knotted and hand tufted capets and spun in woolen and semi-worsted spinning line in the spinning workshop of IICT,Bhadohi. Pyrrole (Leonid Chemicals, Bangalore, India) was used as monomer, FeCl3 was used as oxidant, and p-toluene sulphonic acid (PTSA) monohydrate was used as dopant. All these chemicals were laboratory grade and used as received.

3. Experimental methods

All the samples were scoured before use. After scouring, a two stage double bath process was adopted for in situ chemical polymerization of pyrrole. In the first stage, sample was soaked with monomer in monomer bath and in the second stage, the in situ polymerization was done in oxidant bath. Monomer bath of 0.5 M concentration was prepared by dissolving pyrrole in de-ionized water. Material to liquor ratio of monomer bath was 1:40. Oxidant bath was prepared by dissolving FeCl3 and PTSA in de-ionized water. The amount of FeCl3 and PTSA used were 0.25and 0.05 M, respectively. MLR is 1:100.

Scoured samples were allowed to soak in monomer bath for 1 h in room temperature. Oxidant bath was cooled at 5°C and pyrrole enriched carpet samples were taken out from monomer bath and dipped into oxidant bath for in situ polymerization. Time of in situ polymerization was 2 h. After polymerization samples were taken out from the oxidant bath, thoroughly rinsed with cold water and dried at room temperature for 48 h before measurement.

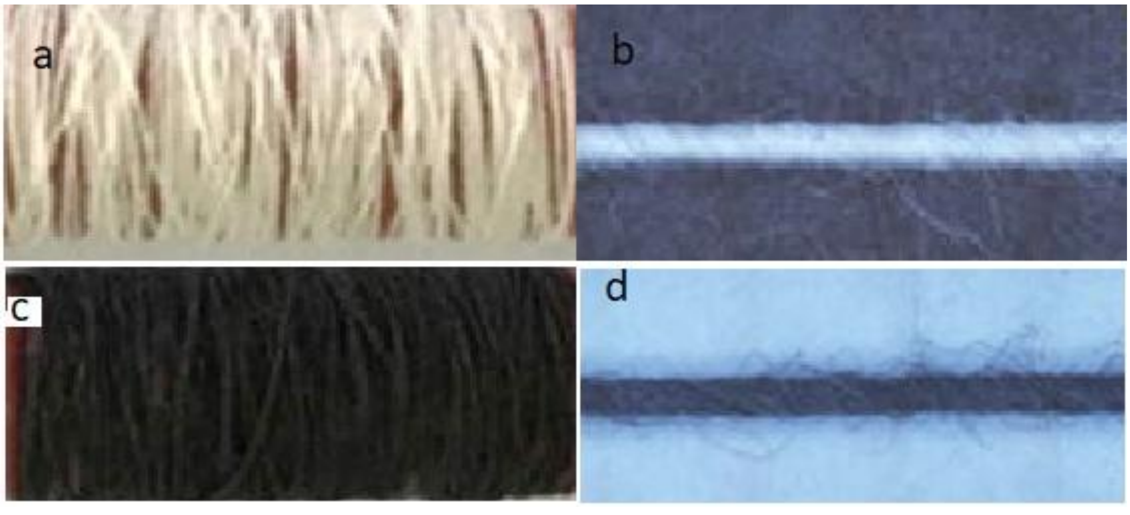

Figure 1 - (a. Woolen bobbin, b. Woolen thread, c. poly-pyrole coated bobbin, d. poly-pyrole coated thread)

4. Methods for Analysis

For calculation of polymer add-on percentage, electro conductive thread samples were dried in hot air oven before and after in situ polymerization. Weights of dried samples were measured by digital balance. The polymer add-on percentage was calculated by measuring the difference between final weight and initial weight of sample and expressing as percentage of initial weight. Surface resistivity of sample was measured at 25 ± 2°C temperature and 65% relative humidity by concentric ring electrode probe method as per AATCC Test Standard

76-2005. All the measurements were done with the help of a digital Multimeter. The surface temperature of the sample due to application of voltage was measured by a non-contact type infrared thermometer. The current flowing through the sample by application of voltage was measured by joining a digital ammeter in the circuit in series.

5. Results and Discussion

The polypyrrole add-on percentage was measured and it was found that as hydrolysis time increased add-on percentage increased. The increase of polymer add-on might be due to the improvement of hydrophilicity of wool after hydrolysis [23].

5.1 Surface resistivity of electro-conductive woolen thread

The surface resistivity of electro-conductive woolen thread was measured and average surface resistivities of 20 observations were found to be 1013.08 for woolen thread.

5.2 Voltage–current (V–I) characteristics of electro-conductive thread

Higher the electrical conductivity of the thread, higher will be the Joul's effect of heat generation. Because, H α I where H is the generated heat and I is the current. So, measurement of V–I characterics will help to predict the heat generation behavior of the conductive thread. For this measurement, specimen was cut in 10 cm size. Two copper plates of sizes (12.5 cm × 2.5 cm) were placed on the two opposite edges of the specimen. The distance between two electrodes was 10 cm. Then, electrode plates were connected with variable DC power supply. The applied voltage was progressively increased and observed values of current across the thread were noted from ammeter.

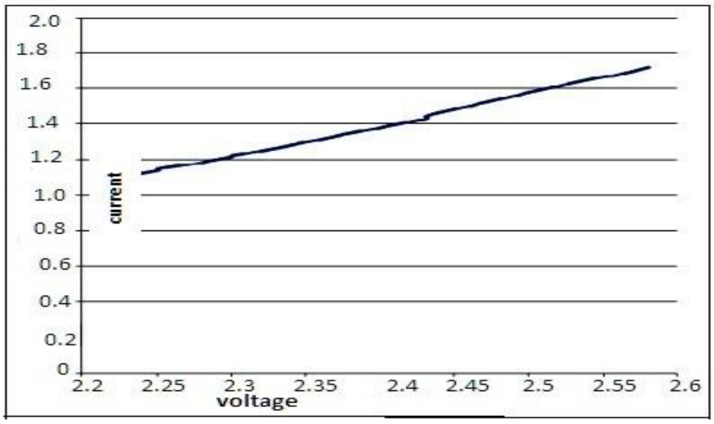

Figure 2 - voltage and current characteristics of electroconductive thread

The data plotted as V–I characteristics have been shown in Figure 2. It can be seen from Figure 2 that at low voltage range, all the samples show a linear V–I characteristics like Ohmic conductor. Similar trend was found by Dall'Acqua et al, [24] in case of polypyrrole treated cellulosic fibers by vapor-phase polymerization in low $FeCl_3$ concentration. In the present study, for woolen thread, the slope of the V–I curve was found to be highest among the others. So, hand woolen thread was considered as the most suitable substrate for heat generation.

5.3 Voltage–temperature (V–T) characteristics of electro-conductive woolen thread

The electro-conductive thread was tested for their voltage–temperature characteristics by applying a range of DC voltage. Temperature measurement was done after an interval of 1 min of voltage application. The results are shown in Figure 3.

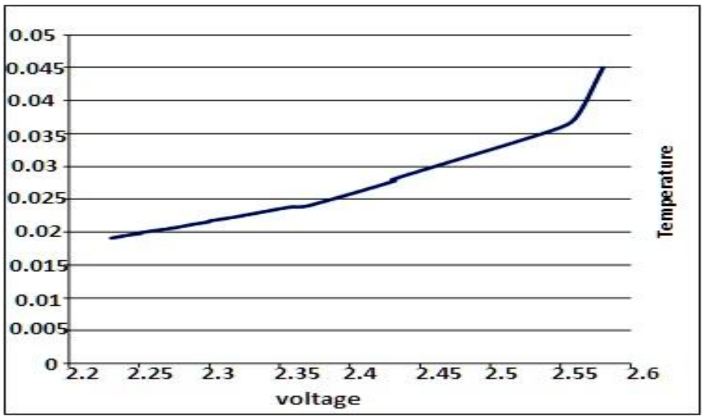

Figure 3 - Voltage Temperature characteristics of conductive thread

It can be seen that as voltage is increasing, temperature is also rising and the V–T behavior is found to be non-linear. Similar observations were earlier reported for electro-conductive polyester woven fabric prepared by in situ chemical polymerization of thiophene by Das, Sen, Saraogi, and Maity [25] and for electro-conductive cellulosic substrate prepared by vapor phase polymerization of pyrrole by Dall'Acqua et al. [26]. It can be seen from Figure that woolen threads perform better for heat generation than the others.

5.4 Atmospheric aging of electro-conductive thread

The electro-conductive thread samples were kept in open atmosphere at 25°C ± 2°C and 65 ± 5% RH for prolong time. After the duration of 2, 3, 4, and 5 weeks, the resistance measurements were done.

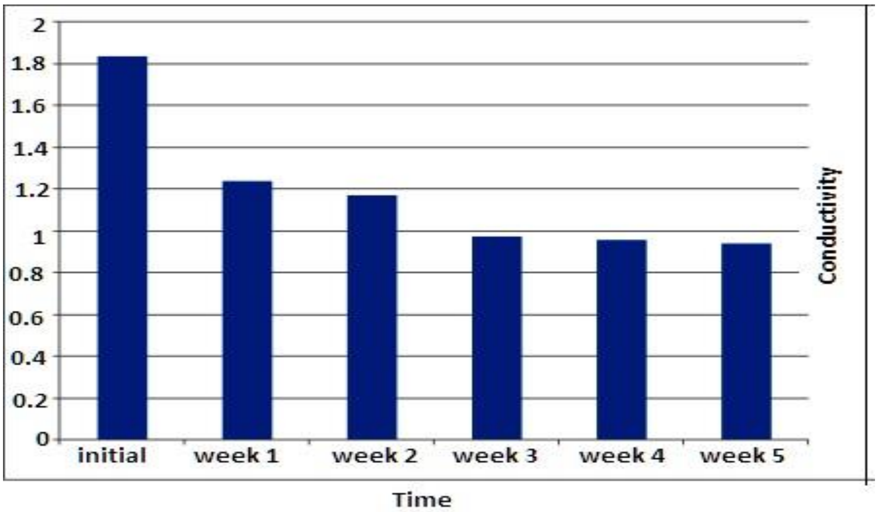

Figure 4-Atmospeheric ageing phenomena

Average resistivity was calculated and result has been shown in Figure 4. It can be seen that surface resistivity is increasing gradually with time. This increase in resistivity thus observed may be due to the de-doping of polymer due to reaction with atmospheric oxygen [27].

6. Conclusions

The average surface resistivities were found to be 1013.08 Ωm for woolen threads prepared from recycled carpet. For all these samples, the V–I characteristics followed linear trend in low-volage range. The rise in temperature was found to be related to the time duration of voltage applied for all types of samples. The resistivity of the electro conductive thread was increased of atmospheric aging. These electro-conductive threads can be used as flexible and portable heating pad for therapeutic use or any decorative light purposes.

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