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Optimization of processing parameters of in-situ polymerization of pyrrole on woollen textile to improve its thermal conductivity

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ABSTRACT

Electrical and thermal conductivity of wool fabric is modified with applying polypyrrole on its surface by in-situ chemical polymerization in aqueous media using $FeCl_3$ oxidant and p-toluene sulphonic acid dopant. Effects of various process parameters of in-situ polymerization viz. pyrrole concentration, $FeCl_3$ concentration and polymerization time on thermal conductivity of the coated textiles have been reported. A significant improvement of electrical and thermal conductivity is observed when wool fabrics are coated with the polypyrrole. Thermal conductivity of wool fabric can be increased from 0.0312 $Wm^{-1}K^{-1}$ to 1.60 $Wm^{-1}K^{-1}$ after polypyrrole coating. PPy add-on and average surface resistivity of this sample is found to be 8.12% and 1.337 kΩ/ϒ, respectively. SEM images reveal quiet uniform coating of polypyrrole on individual wool fibres. FTIR studies depict significant chemical interaction between wool fibre and polypyrrole. DSC results reveal that thermal stability of wool fibre has been enhanced by PPy coating.

1. Introduction

Wool is second important natural textile fibre after cotton due to its superior characteristic features. In certain climate, it has a more comfortable feel than that of cotton fibres. Wool fibres have low thermal conductivity because of its lack of ability to perform effective conduction of thermal energy due to localization of electrons in their chemical structure. That is why it is often used as a thermal insulator, and wool fabrics are well suited for warmth in cold weather [1]. The thermal insulation of wool fabrics restricts their use in summer or hot weather. Improvement in the thermal conductivity of wool fabrics is required for their successful and comfortable use in summer or hot weather. Electrically conductive materials are often good in thermal conduction. Textile fibres like wool are electrical insulators having resistivity in the range of 10^6 Ω. Electrical conductivity of textiles can be enhanced by coating/applying various conductive materials. Coating with metal powders and carbon can be achieved by various methods. Among them physical vapour deposition (PVD) technique is successful in terms of durability and performance. The PVD method involves the vaporization of a solid or liquid into individual atoms or molecules, transportation (in vapour form) through a vacuum or low pressure gaseous (or plasma) environment to the textile substrate where vapour is condensed onto the textile surface [2,3]. However, the process has its inherent sophistication. On the other hand, coating textile fibres with conductive polymers such as polypyrrole, polypthiophene, polyaniline, etc., by simple in-situ chemical polymerization in aqueous media is a useful means to enhance the electrical conductivity of the textile material less than 1000 Ω [4–7]. However, thermal conductivity of the coated textiles are not assessed or reported. Very few attempts have been made to improve thermal conductivity of wool or other polymeric materials by conductive coatings [8,11,13–15]. Coated wool fibres with polypyrrole and carbon enhanced the thermal conductivity. However, they did not report the exact value of thermal conductivity of modified wool textiles and the degree of improvement achieved.

The aim of this study is the preparation of electro-conductive wool fabric by in-situ chemical polymerization of pyrrole in aqueous solution and investigation on the effects of various process parameters of in-situ polymerization on thermal conductivity.

2. Materials

For the study, 100% raw wool fabric, twill 2/2, GSM = 300, thickness = 0.29 mm, EPI = 48, PPI = 43 is procured from Himachal Silk Mills, India. Wool fabric is used as substrate of in-situ chemical polymerization. Pyrrole (Leonid Chemicals, India) is used as monomer, $FeCl_3$ (Qualigen Fine Chemicals, India) is used as oxidant and p-toluene sulphonic acid (PTSA) (Qualigen Fine Chemicals, India) is used as dopant. Sodium carbonate (Na_2CO_3) (S D fine-chem Ltd., Mumbai, India), and Oleate soap (S D fine-chem Ltd., Mumbai,

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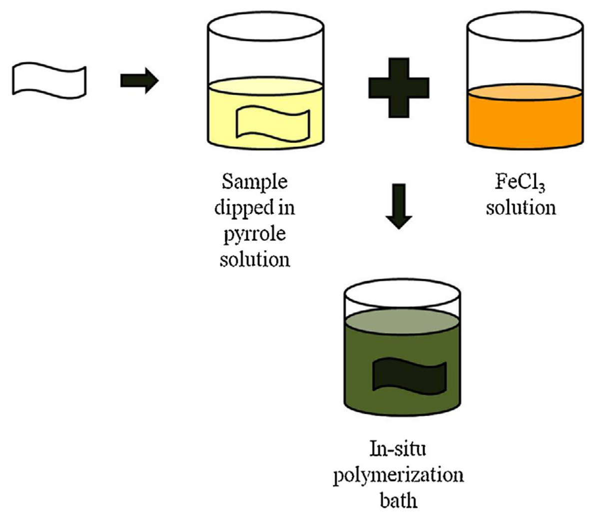

Fig. 1. In-situ chemical polymerization of pyrrole in presence of wool fabric.

India) are used for scouring of wool fabric. All these chemicals are laboratory grade and used as received.

2.1. Sample pretreatment

Raw wool has natural wax and impurities on their surface. These wax need to be removed from fibre surface before in-situ chemical polymerization by suitable pretreatment process named as scouring. Scouring of wool fabric is carried out with a solution of 3% oleate soap and 2% sodium carbonate at 50 °C for 15 min.

2.2. Preparation of monomer and oxidant bath

The monomer solutions are prepared by dissolving pyrrole in de-ionized water in a beaker. Oxidant solutions are prepared by dissolving $FeCl_3$ and PTSA in de-ionized water in a separate beaker. Material to liquor ratio is maintained 1:200 for both the cases. Concentration of pyrrole are in the range 0.1–0.3 M, that of for $FeCl_3$ are in the range of 0.15–0.35 M, and that of PTSA is kept constant at 0.1 M. All these concentration of the pyrrole, $FeCl_3$ and PTSA are chosen based of the literature where the previous researchers find satisfactory results.

2.3. Preparation of electro-conductive wool fabric by in situ chemical polymerization

A single bath process is followed for in situ chemical polymerization of pyrrole using wool fabrics substrate as shown in Fig. 1. At first, both oxidant and monomer solutions are cooled down to 5 °C in a cryostat. After cooling, they are poured and mingled together in another beaker where wool fabric specimen of predetermined weight is kept. Then the mixture is stirred continuously. As a result, oxidative polymerization starts and polypyrrole begins to precipitate in solution in bulk and deposit on the fabric surface as well by adsorption. After polymerization of predetermined time, fabric specimen is taken out of the solution and rinse thoroughly with deionized water. Then the specimen is woven dried at 80 °C for 6 h before any measurement.

After polymerization samples are taken out, thoroughly rinsed with cold water and are allowed to dry at room temperature (25 ± 2 °C temperature and 65 ± 2% relative humidity) for 72 h before measurement.

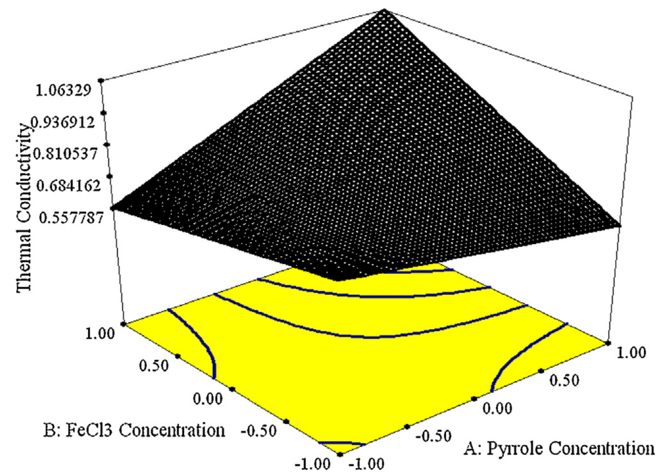

Fig. 2. Effect of Pyrrole and $FeCl_3$ concentration on thermal conductivity of PPy coated wool textiles.

Table 1
Process parameters and their levels.

Factors	Labels	Levels		
		Low −1	Medium 0	High +1
Pyrrole concentration [M]	*A*	0.1	0.2	0.3
Oxidant concentration [M]	*B*	0.15	0.25	0.35
Polymerization time [Min]	*C*	30	60	150

Table 2
Schemes of experimental runs.

Run	$A_{[M]}$	$B_{[M]}$	$C_{[min]}$
1	−1	−1	0
2	1	−1	0
3	−1	1	0
4	1	1	0
5	−1	0	−1
6	1	0	−1
7	−1	0	1
8	1	0	1
9	0	−1	−1
10	0	1	−1
11	0	−1	1
12	0	1	1
13	0	0	0
14	0	0	0
15	0	0	0
16	0	0	0
17	0	0	0

2.4. Box-Behnken design

Box-Behnken response surface design is employed for investigation the effects of process parameters of in situ chemical polymerization on surface resistivity and thermal conductivity of wool fabrics. The three process parameters which are considered in this study for optimization are molar concentration of pyrrole, molar concentration of oxidant, and polymerization time. The dopant concentration is kept 0.2 M and polymerization temperature is maintained constant at 5 °C for all experiments. For each process parameter, three levels (low, medium, and high) are chosen as shown in Table 1. The levels of process parameter are chosen in this range by literature survey and experimental observations. The scheme of experimental runs in accordance with 3^3 Box-Behnken experimental design is presented in Table 2. The mathematical