HEAT GENERATION IN ELECTRICALLY CONDUCTIVE POLYPYRROLE COATED COTTON FABRIC

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Abstracts

In situ polymerization was employed to deposit polypyrrole (Ppy) on the cotton fabrics by using ferric chloride as oxidizing as well as doping agent. The Ppy coated cotton fabric showed conductivity of about 0.21S/cm. When subjected to a constant DC voltage of 10V, owing to considerable resistance the temperature of Ppy coated fabric increases rapidly up to 60°C. Further, the repetitive heating showed reduction in conductivity to 0.11S/cm. The polypyrrole coated cotton fabric has many potential applications like medical or warmth clothing, heating pads.

Keywords: *conductive cotton, heat generation, polypyrrole*

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Introduction

In recent years intrinsically conductive polymers (ICPs) have been investigated widely because of their excellent electrical and optical properties and many potential applications [1]. Among them polypyrrole (PPy) has attracted much attention because of its high electrical conductivity, comparatively high stability in air with low toxicity, ease of preparation and simplicity of the doping process [2,3]. Textile substrates have many advantages like, high surface to mass ratios, good mechanical performance, resistance to chemicals and harsh environmental conditions, flexibility and ability to be shaped in various forms. Polypyrrole coated fabrics used in electromagnetic insulation, microwave absorbance, heat generation, smart clothing etc. [4,5].

Oxidation of pyrrole causes polymerization to takes place on the fabric substrate which gives the continuous thin conducting film and current will flow through these fabrics without incorporation of any conductor wiring through them. The continuous conductive film also produces a more even flow of heat than that of fabrics containing wires [6]. The absence of wires also allows for a thin, flexible construction, if tactile properties are important, for instance in a heated seat, the use of conducting fabric necessitates no additional cushioning. Regardless of conductive material, textiles are particularly well suited for large area radiant or contact heating. Hence it gives rise to fast, even heating over the entire surface and also improves reliability, since a tear in any area will not disrupt the current [7].

Considering these advantages, there are many applications where a conducting fabric, such as car seats, mattress pads, heating winter sports wear, gloves, blankets and clothing could be easily be made to provide warmth simply by including a piece of conducting fabric in the construction and providing a power source. The generation of heat is due to the resistive heating of the conducting fabric on the passage of the current as per the joule effect [8, 9]. Current, voltage and power requirements for heat made of conducting textiles will vary depending on the applications. The present attempt has been made to prepared conductive cotton fabrics by Ppy deposition for heating application and its characterization.

2 Materials and Methods

2.1Materials

Commercially desized, scoured and bleached 100% cotton fabric having weight of 120 g/m^2, and plain weave was used as textile substrate. AR grade chemicals such as pyrrole (Spectrochem, India) as monomer and ferric chloride anhydrous (SDFCL, India) as oxidant were used to develop in situ Ppy. The monomer to oxidant molar ratio was used 1:1, with the 0.3M of concentrations of pyrrole and ferric chloride.

2.2Methods

2.2.1 In situ polymerization of pyrrole

The solutions of 0.3M Pyrrole and 0.3M Ferric chloride of desired concentrations were prepared separately with constant stirring, each in 50 ml distilled water. The cotton fabric was treated with $FeCl_3$ solution for 30 minutes. Thereafter, polymerization was initiated by the drop wise addition of pyrrole solution in the same bath with continuous stirring for 4h at the 4°C temperature. After the completion of treatment fabric samples were removed, washed thoroughly with distilled water and air dried.

2.2.2 SEM Imaging

Scanning electron microscopy-imaging was carried out using EVO 50 microscope for surface characterization of PPy deposited cotton fabric.

2.2.3 Measurement of Resistance

The resistance of Ppy coated cotton fabric samples was measured by Digital multimeter Mic 6000Z. From these resistance values, the resistivity and conductivity of the Ppy-cotton composites was calculated. The conductivity of the resulted composites was expressed in S/cm. The conductivity was computed according to following equation.

$$\rho = \frac{R.t.b}{l}$$

$$\sigma = \frac{1}{\rho}$$

Where, ρ and σ is the resistivity and conductivity of Ppy cotton composites. *R, t, b* and *l* be the resistance reading, thickness, width and length of Ppy cotton composite fabrics.

2.2.3 Temperature measurements

The Ppy coated fabric sample having the size of 12 × 5 cm was clamped by two copper plates and connected to constant DC supply in the range of 1 to 12 V. The temperature raised on conducting cotton fabric was measured by direct contact of resistance temperature detector (RTD) PT 100.

3. Results and Discussions

In situ polymerization takes place on cotton fabrics by the oxidation of the pyrrole monomer which gives deposition of polypyrrole- cotton fabric and during the polymerization process; the white surface of fabric turns light green to black gradually resulting in a thin homogeneous conducting film.

Lower monomer concentration of polymerization gives the minimum conductivity than the higher concentration of monomer. Due to the large surface area of textile substrate available, the deposition of polypyrrole occurred only on the fabric surface which supports adsorption of growing polymers and hence it gives smooth and adherent coating of the fabric which gives the uniform conductivity. The polymerization process was carried out at low temperature of 4°C for longer time of 4 hours with the molar ratio of pyrrole monomer to Ferric Chloride of 1:1. This supports slow polymerization and uniform surface deposition. The resistance of polypyrrole generates heat when subjected to DC voltage. The details of experimentation are as under:

3.1 Morphological Studies

The SEM images of untreated cotton fabric and Ppy in situ treated sample with 0.3M pyrrole and 1:1 ratio of monomer and oxidant are as shown in Fig No. 1 under 5,000X magnifications. SEM Image (1b) shows a clear surface and deposition of polypyrrole on the cotton fibers. The polymerization of polypyrrole on cotton fabrics takes place through diffusion of polymer inside the fiber bulk as well as the deposition on the fiber surface and the interstices in the fabric [10].

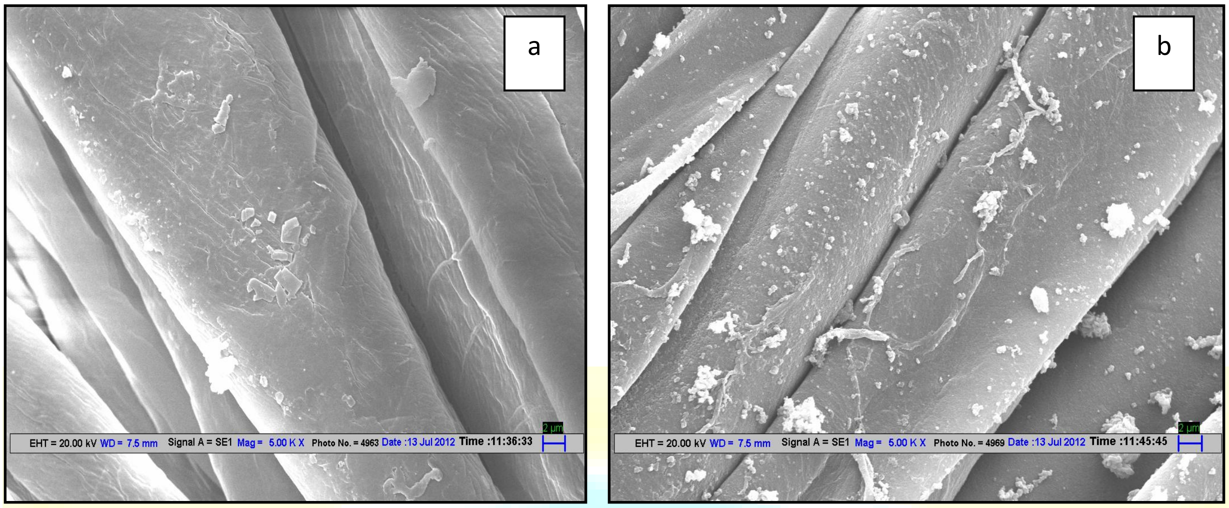

Fig No.1: SEM micrographs at 5000X magnification of (a) untreated cotton (b) Polypyrrole deposited cotton fabric

3.2 Conductivity

The Ppy coated cotton fabric at 1:1 molar ratio of pyrrole to $FeCl_3$, conductivity of 0.21S/cm was observed. The total average add-on of Ppy on cotton sample was about 22.5%. This uniformly deposited conducting material increases the thickness of cotton fabric from 0.026cm to 0.04cm.

The resistance values obtained from 12 × 5cm fabric specimen having 0.04cm thickness were used to calculate the resistivity and conductivity of samples with the help of aforementioned equation. The resistivity ρ, was observed 4.6Ω.cm. This value of resistivity is close to semiconductor range indicating high resistance [2].

3.3 Heat generation in conductive cotton fabric

The generation of heat is due to the resistive heating of the conducting fabric on the passage of the current as per the Joule effect [8, 9]. Joule effect is expressed in the relationship between heat generated in a conductor and current flow, resistance, and time [11]. The sample under investigation was clamped between two copper plates, 12cm apart from each other through which DC voltage was employed in the range of 1 to 10V. owing to resistivity and voltage applied, the heat generated in terms of temperature was measured using RTD, placed firmly over the sample. The temperatures generated with respect to time on polypyrrole coated cotton fabric when subjected to various DC voltages are represented in Fig. No.2.

The ambient temperature was 26°C and when 1V current was applied, marginal rise in temperature of 2°C was found even after 10 minutes of treatment. Further, after application of 6V, the temperature was raised to 50°C within 5 minutes and remained constant after 10 minutes. Higher the voltage, higher the temperature was found generated at short period. At 10V of DC application, the temperature was raised up to 70°C within 5 minutes and with time there was slow rise was observed in its values.

The exposure of Ppy material to higher voltage for longer time causes decay in conductivity. The most likely cause of this is oxidative degradation of the conductive polymer [6]. Therefore, to explore the possibility of material under consideration for warm clothing and heating pads applications the maximum temperature of 60°C and 10V application of DC was employed for cyclic investigation.

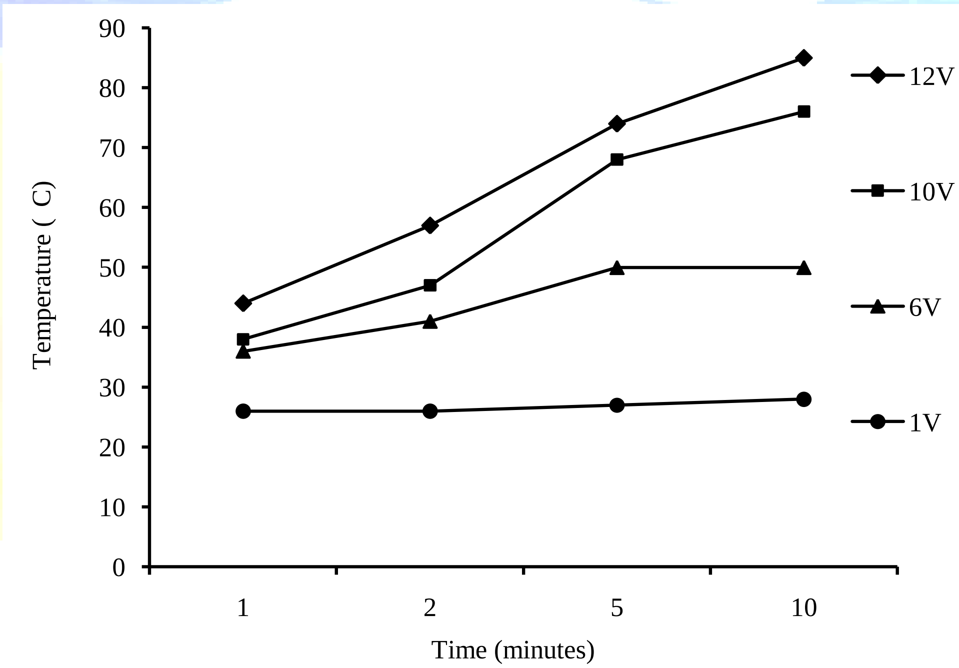

Fig No.2: Temperature generated with respect to time on polypyrrole coated cotton fabric subjected to various DC voltages

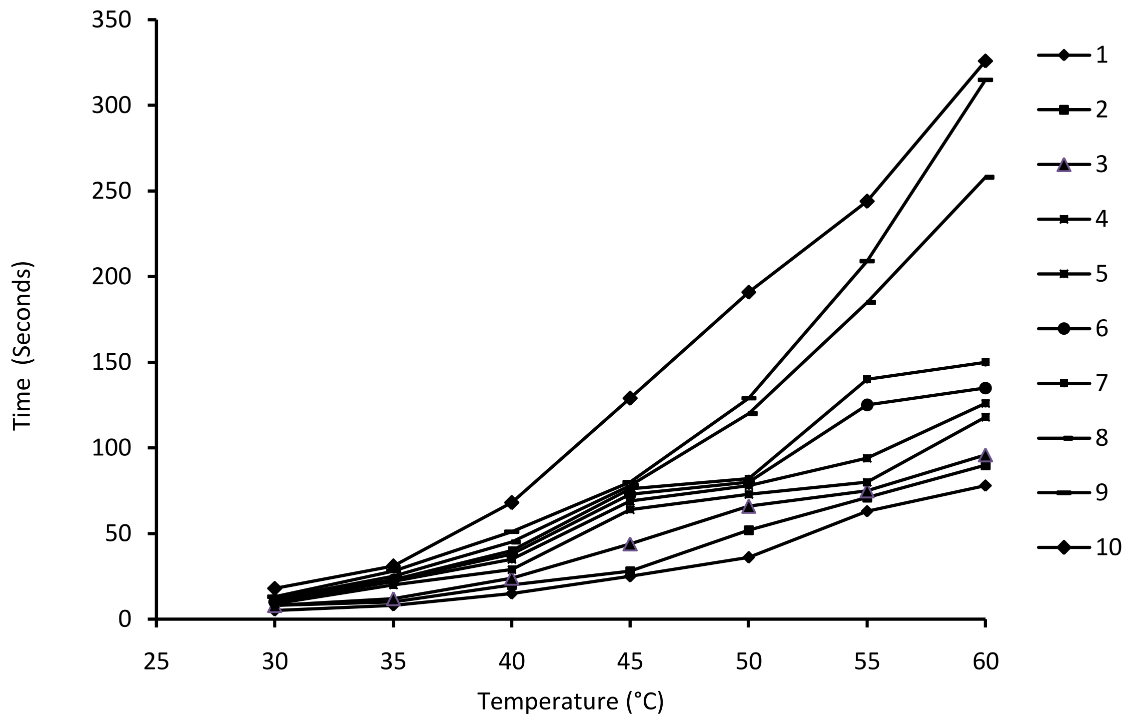

Fig No.3: The time required to achieve 60°C on polypyrrole coated cotton fabric after repetitive application of 10V DC supply

A fresh sample, clamped between copper plates 12cm apart from each other was subjected to DC potential difference of 10V and the temperature generated was measured. After cooling for about 10 minutes the cycle was repeated and time required to raise the temperature up to 60°C at the interval of 5 units was recorded and represented graphically in Fig. No. 3. From this, it is clear that the rate of generation of heat was varied with repetition of cycle. At first cycle, the temperature was raised up to 50°C rapidly within 35 seconds and further reached to 60°C in another 20 seconds. The similar trend was observed for initial seven cycles where temperature raised to 50°C comparatively faster and further, the rate of rising the temperature was found reduced. The maximum time required to achieve desired temperature for seventh cycle was 2.5 minutes. Further, after repetitive cycles the rate of temperature rising was found lower and at tenth cycle 50°C was achieved after 3.2 minutes and 60°C was reached after 5.4 minutes when subjected to 10V. The conductivity of sample after 10 cycles was calculated and found to 0.11S/cm. The reduction in rate of heat generation can be attributed to the oxidative degradation of the conducting polymer which causes loss of conjugation of the polymer [6].

Conclusion

In-situ polymerization of pyrrole on cotton substrate using ferric chloride with 1:1 molar ratio at 4°C showed conductive composite with conductivity of 0.21S/cm. When subjected to DC supply in the range of 6 to 10V, by Joule effect, the heat in terms of temperature was found released up to 80°C with experimental conditions. After repetition, the rate of rising the temperature was found decreased due to oxidative degradation where the conductivity was also found reduced to 0.11S/cm at tenth cycle, due to loss of conjugation. The property of heat generation leads to open up many avenues of applications.

References

1. X. Jin, K. Gong, "*Diffusion-Deposition of Polyaniline onto Textile with high electric conductivity and improved Adhesion*", Journal of Industrial Textiles, 26, July 1997, P 36-44.
2. H. R. Mattila, "*Handbook of Intelligent Textiles and Clothing*", Woodhead published, (2006).
3. A. Macasaquit, & C. Binag, *Preparation of Conductive Polyester Textile by In Situ Polymerization of Pyrrole*", Philippine journal of science, 139 (2), Dec 2010, P 189-196.
4. X. Cheng, Y. Li, X.Tao, Y. Tsang, M. Leung, P. Xue, X.Cheng, & C. Yuen, "*Polypyrrole coated fabric strain sensor with high sensitivity and good stability*", Proceedings of the 1st IEEE international conference on nano/micro Engineered and molecular systems, JAN 18-21, 2006, Zhuhai, China.
5. M.S. Kim, H.K. Kim, S.W. Byun, S.H. Jeong, Y.K. Hong, J.S. Joo, K.T. Song, J.K. Kim, C.J. Lee, J. Y. Lee, "*PET fabric/polypyrrole composite with high electrical conductivity for EMI shielding*", Synthetic metals, 126, 2002, P 233-239.
6. A. Kayank, E. Hakansson, S.Nahavandhi, "*Conductive fabrics for heating applications*", Mechatronics, Aug 2004, P 111- 121.
7. V.A. Dorugade, Satyapriya D, *"Electrically conducting textiles",* Journal of Textile Association, Vol.69, No.3, Sept 2008, P 119-132.
8. W. C. Smith, "*Handbook of Smart Textile Coatings and Laminates"*, Woodhead publishing limited (2010).

9. J. P. Boutrois, R. Jolly, C. Petrescu, "*Process of polypyrrole deposite on textile. Product characteristics and applications*", Synthetic metals, 85, 1997, P 1405-1406.

10. A.J Patil and A. K. Pandey, "*A novel approach for in situ polymerization of polypyrrole on cotton substrates*", Indian Journal of fiber & Textile Research, Vol.37, June 2012, P 107-113.

11. Crew, Henry, "*General physics: an elementary text-book for colleges, 2nd Edition*. The University of Michigan: The Macmillan Company, 1910, P 402–404.

12. A. Sparavigna, L. Florio, J. Avloni, A. Henn, "*Polypyrrole coated PET fabrics for thermal applications*, Material sciences and applications, 1, 2010, P 253-259.