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Functionalizing nonwoven polyester fabrics with polypyrrole

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Polypyrrole-coated nonwoven polyester fabrics, prepared by in situ chemical polymerization, show promise for heat-generation, electromagnetic interference shielding, and sensing applications.

Intrinsically conductive polymers (ICPs) are a class of organic conductive materials with an electrical conductivity just below that of metals. Electroconductive textiles prepared from ICPs—such as polypyrrole (PPy), polyaniline, and polythiophene—have been the subject of increased research in recent years. Interest has grown in these materials due to their characteristics (i.e., they are lightweight and easily deployed), which could make them suitable for a range of applications in a number of different areas. The most common applications proposed in the literature are multifunctionalized textile products for use in, e.g., heating pads, flexible keyboards, and sensors. Such products could also be used to introduce microwave attenuation, static charge dissipation, and electromagnetic interference (EMI) shielding in electrical devices.

Of the available ICPs, PPy is the most popular because it is highly processable and non-toxic. PPy cannot, however, be spun into filament or fiber form, and preparing it in film form is highly challenging. These issues, which arise because of its brittleness, limit the application space of neat PPy. The polymer must therefore be applied on a suitable substrate for the preparation of strong and flexible multifunctionalized composites that are suitable for diverse applications.

To achieve PPy-based multifunctionalized composites, various textile materials—in the form of fiber, yarn, and fabric—have been used as a substrate for PPy. In these approaches, PPy has been applied as a coating by various means and characterized for various applications.[1–10] In all of these approaches, woven and knitted fabrics are used as substrates to prepare sheet-like composites. The woven and knitted fabrics are quite compact in structure and therefore restrict penetration of reagents into the core (i.e., fiber interstices), resulting in deposition of PPy only on the fabric surface. In contrast, nonwoven fabrics (e.g., needlepunched structures) are more bulky, porous, and thick than woven and knitted structures. It is therefore expected that nonwoven fabrics will hold more PPy inside the fiber interstices, giving rise to higher PPy add-on (i.e., a larger amount of PPy deposited on the substrate) and better functionality (e.g., EMI shielding). Moreover, the advantages of these PPy-functionalized textiles compared with metallized materials include their light weight, flexibility, moldability, durability, and ease of fabrication.[1–9] In particular, porous textile substrates with a higher specific surface area are useful because the mechanism behind the adhesion of PPy is adsorption at the liquid-solid interface during in situ polymerization. The use of nonwoven textile fabric (a porous and bulky material)—which may enable high PPy add-on and real-life applications—has not, however, been fully explored.

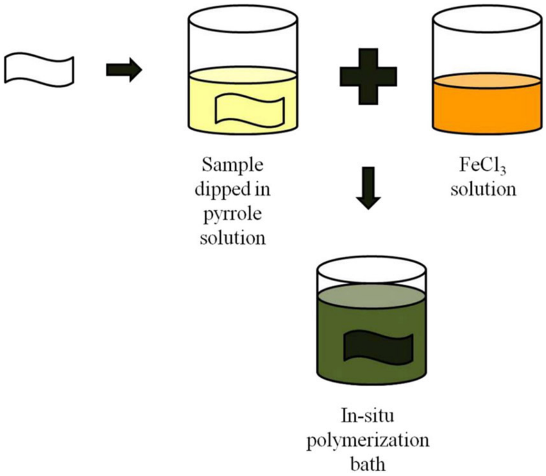

Figure 1. *Illustration showing the in situ chemical polymerization process of pyrrole.*

In our work, we are therefore interested in investigating the potential of PPy-functionalized nonwoven textiles. To prepare PPy/textile fabric

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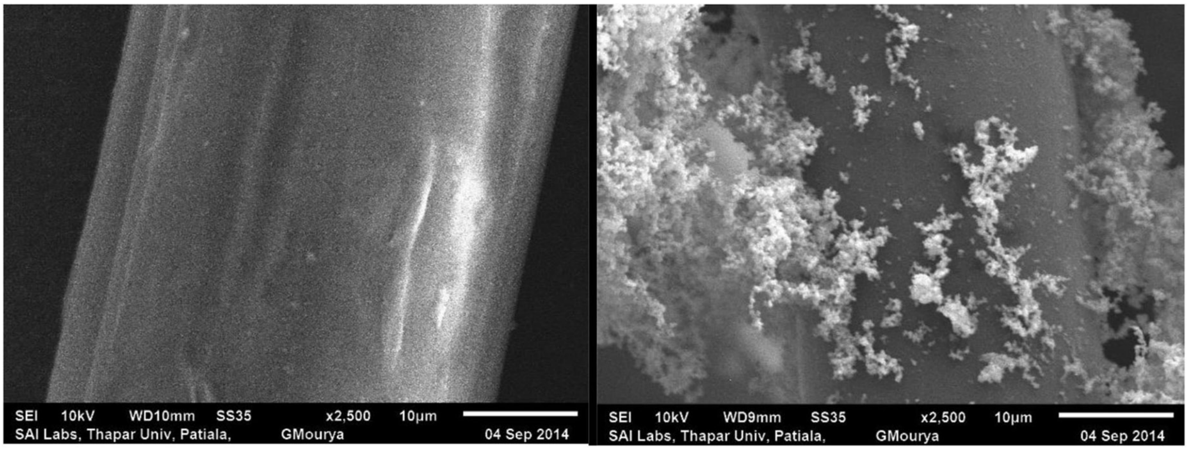

Figure 2. *Scanning electron microscope images of uncoated (left) and polypyrrole (PPy)-coated (right) polyester.*

composites, we used an in situ chemical polymerization process. We then characterized our composite by carrying out investigations into its morphological, electrical, and thermal properties.

To fabricate our PPy/textile fabric composite, we first dipped needlepunched nonwoven polyester fabric in a solution of pyrrole (0.5 molar). The resulting pyrrole-enriched sample was then dipped in an oxidant solution in the presence of $FeCl_3$—iron(III) chloride, an oxidant—and p-toluene sulfonic acid (a dopant) to initiate the in situ chemical polymerization process. In the in situ polymerization process, individual polyester fibers that are present in the nonwoven structure are coated with PPy. This process (illustrated in Figure 1) is simple and reagent exhaustive, and is similar to dyeing and other wet processing of textiles. The method is therefore easy to conduct in a laboratory setting and even in industrial practice.

Scanning electron micrographs of our thus fabricated samples—see Figure 2—show that the individual uncoated polyester fibers have clean surfaces and that, after treatment, they are uniformly coated with PPy. The PPy polymer exhibits a granular morphology on the fiber surface, showing that sufficient PPy is deposited on the surface of the individual fibers as well as within the fiber interstices.

For a typical fabric (i.e., with an areal density of $250gm^{-2}$, an average pore diameter of 183μm, and a thickness of 5mm), we found PPy add-on (expressed as a percentage of its mass) to be 16.28%. We measured the surface resistivity of the fabric to be 18 ohms per square, and found that the shielding effectiveness is 20.07dB at a frequency of 4GHz (see Figure 3). In contrast to metallized surfaces or materials, the EMI-shielding property of our PPy-coated fabrics is primarily due to the absorption of electromagnetic waves, rather than their reflection. For this reason, the fabrics can effectively protect electronic gadgets working at frequencies of ≤4GHz. In tests, we found that a total of 65.46% of the power of an incident electromagnetic wave is absorbed by the sample, and 34.51% is reflected from its surface. Only 0.03% of the incident electromagnetic wave is therefore transmitted through the sample. These results suggest that our fabrics are suitable for EMI-shielding applications.

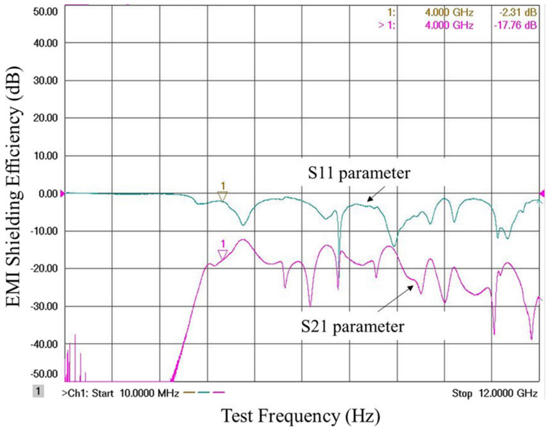

Figure 3. *The electromagnetic interference shielding effectiveness of PPy/nonwoven neeedle-punched polyester fabric.* S_{11}*: Reflection loss.* S_{21}*: Transmission loss.*

By studying the pore-size distribution of control and PPy-coated samples, we found that the composite fabrics retained substantial breathability after being coated with PPy. However, the pore-size distribution pattern of the fabrics—see Figure 4 and Table 1—is

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significantly altered. The coated fabric demonstrates an overall reduction in pore size, causing the distribution to shift toward the left (see Figure 4). The PPy does not fully block the pores of the nonwoven structure, however, which could make the composite suitable for application in EMI-shielding apparel for personal protection, where moisture and air permeability are required to achieve a certain level of comfort.

In the final stage of our experiments, we investigated the voltage-temperature characteristics of the electroconductive fabrics. To do so, we applied a range of DC voltages and measured the associated effects on temperature. We found that, initially, the temperature increases quickly with time. However, after about 7 minutes, this rise in temperature levels off for all applied voltages (see Figure 5). This behavior suggests that the fabric is highly suited for application in heating garments or heating pads.

In summary, we have developed an in situ polymerization process for applying PPy to nonwoven polyester fabrics as a coating. The simplicity of our approach makes it suitable for both laboratory- and industrial-scale practice. For this reason, it may attract commercialization for various novel applications (e.g., in heating pads, flexible keyboards, and sensors). The fabrics could also be used to introduce microwave attenuation, static-charge dissipation, and EMI shielding in electronic devices. Furthermore, they could find use in wastewater-treatment processes. Currently, we are undertaking preliminary studies into the potential applications of these composites for wastewater treatment, pH and humidity sensing, and cooling garments. We are achieving positive results and expect more diversified applications to be developed based on our PPy-coated functionalized textiles in the near future.

Table 1. *Minimum, average, and maximum pore sizes of control and PPy-coated samples.*

Sample	Pore size (μm)		
	Minimum	Average	Maximum
Control sample	64.168	183.23	225.48
PPy	22.641	104.99	174.59

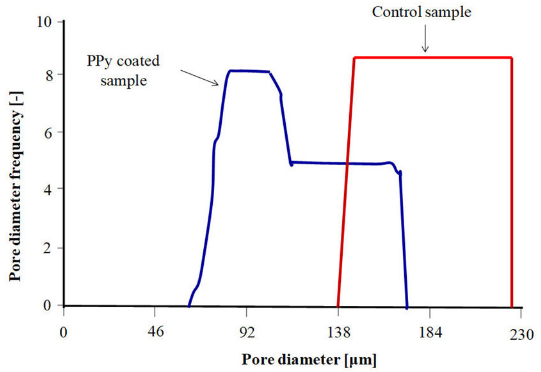

Figure 4. *Pore-size distribution of the control nonwoven fabric (red) and the PPy-coated nonwoven composite fabric (blue).*

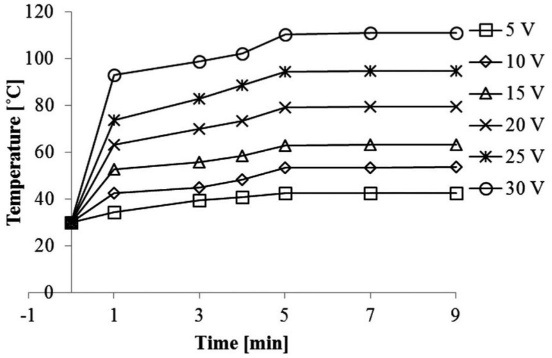

Figure 5. *Heat-generation behavior of PPy-functionalized nonwoven polyester fabric under different voltages (from 5 to 30V, in steps of 5V).*

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References

1. S. Maity and A. Chatterjee, *Polypyrrole functionalized polyester needlepunched nonwoven fabrics for electro-magnetic interference shielding*, **Polym. Compos.**, 2017. doi:10.1002/pc.24399
2. S. Maity, *Optimization of processing parameters of in-situ polymerization of pyrrole on woollen textile to improve its thermal conductivity*, **Prog. Org. Coat. 107**, pp. 48–53, 2017. doi:10.1016/j.porgcoat.2017.03.010
3. S. Maity and A. Chatterjee, *Conductive polymer-based electro-conductive textile composites for electromagnetic interference shielding: a review*, **J. Ind. Text.**, 2016. doi:10.1177/1528083716670310
4. A. C. Manivannan and S. Maity, *Electro-conductive palmyra fibers by in-situ polymerization of pyrrole*, **J. Nat. Fibers 14**, pp. 185–195, 2016. doi:10.1080/15440478.2016.1193082

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5. S. Maity and A. Chatterjee, *Textile/polyprrole composites for sensory applications*, **J. Compos. 2015**, p. 120516, 2015. doi:10.1155/2015/120516
6. U. Malhotra, S. Maity, and A. Chatterjee, *Polypyrrole-silk electro-conductive composite fabric by in situ chemical polymerization*, **J. Appl. Polym. Sci. 132**, p. 41336, 2015. doi:10.1002/app.41336
7. S. Maity and A. Chatterjee, *Polypyrrole based electro-conductive cotton yarn*, **J. Textile Sci. Eng. 4**, p. 171, 2014.
8. S. Maity, A. Chatterjee, B. Singh, and A. P. Singh, *Polypyrrole based electro-conductive textiles for heat generation*, **J. Textile Inst. 105** (8), pp. 887–893, 2014. doi:10.1080/00405000.2013.861149
9. D. Das, K. Sen, and S. Maity, *Studies on electro-conductive fabrics prepared by in situ chemical polymerization of mixtures of pyrrole and thiophene onto polyester*, **Fibers Polym. 14**, pp. 345–351, 2013. doi:10.1007/s12221-013-0345-7
10. S. Maity, K. Singha, P. Debnath, and M. Singha, *Textiles in electromagnetic radiation protection*, **J. Safety Eng. 2**, pp. 11–19, 2013.