Thermal anisotropy of polyethersulfone woven textiles by infrared thermography

Larciprete M(1), Orazi N(2), Gloy YG(3), Paoloni S(2), Sibilia C(1) , Li Voti R(1)*

(1) Dipartimento di Scienze di Base ed Applicate per l'Ingegneria, Sapienza Università di Roma, Via Scarpa 16, 00161 Rome, Italy

(2) Dipartimento di Ingegneria Industriale, Università degli Studi di Roma Tor Vergata, Via del Politecnico 1, 00133 Rome, Italy

(3) Sächsisches Textilforschungsinstitut e.V. (STFI), 09125 Chemnitz, Germany

*Corresponding author's email: roberto.livoti@uniroma1.it

Over the recent period, there has been growing interest in knitted fabrics for the realization of electrically driven functional fabrics, so-called smart textiles. Such an interest is due to several technological advances such as the emergence of conductive and elastic yarns for stretchable electronics, the development of conductive inks as well as advances in miniaturization and printing techniques. In this respect, special attention has been de-voted to the development of flexible patch antennas and electronics for wearable telemedicine and defence applications [1–3], as well as power-assisted garments for personal thermal management. Thanks to their peculiar properties including flexibility and light weight, such devices can be easily integrated into textiles, thus allowing the manufacturing of smart clothes. As regards the production of textile antennas, different fabric materials such as cotton, polyester and nylon are typically employed for the realization of the substrate, while copper adhesive tape, silver conductive ink or conductive paper are usually adopted as radiating materials, to name some [4,5].

Among different material textiles, polyethersulfone (PES) is the most widely employed due to its relevant physical properties. In particular, PES allows the realization of textiles where the fibers are interlaced according to different geometries as those, for in-stance, required for the realization of integrated antennas. However, several problems re-main unsolved and, among others, the dissipation of the heat produced by the integrated electronic devices through the substrate textile is among the most important issue, which still deserves further studies in order to optimize the effective thermal diffusivity and infrared emissivity of these structures [6–8].

Fabrics can be viewed as consisting of repeated units of porous yarns and air spaces. Therefore, the heat flow through textiles depends on several factors such as the thermal conductivity of the fibrous material, air volume content and weave pattern, i.e., the way the warp and weft yarns interlace with each other. It is thus evident that one of the fundamental issues to be addressed in the design of smart textiles is to understand how the microscale thermophysical properties of the single bundle of fibers may affect the effective properties of textiles on the macroscopic scale.

Given the considerations reported above, the characterization of the thermal proper-ties of PES textiles is of crucial importance. In this respect, it is worth mentioning that both mechanical, electrical [9] and thermal [10] properties of fabrics have been shown to be extremely anisotropic and, consequently, woven textiles are also expected to exhibit anisotropic thermal transport properties which are significantly affected by fiber structure. In particular, the heat produced by the current flowing into the electrically conductive yarns has been shown to be mainly spread in the plane of the fibers rather than in the perpendicular direction [11,12]. In this regard, it has been recently reported that the presence of anisotropy in the fiber-woven structure [13,14], such as those due to different density of warp and weft yarns [15] or yarn count differences in warp and weft directions [16], may lead to a significant anisotropic behavior of the thermal transport properties.

The main idea of this study is to get some further insights about the dependence be-tween the textiles features and the macroscopic heat conduction properties. To this aim, thermal diffusivity measurements have been carried out in PES textiles characterized by different fiber density and weaving pattern. Among different textile thermal properties, thermal diffusivity D plays a crucial role in the determination of the transient thermal response of textile material resulting from time-varying heat flow within the material.

In this study, the thermal diffusivity measurements have been carried out by means of an active infrared thermography (IRT) technique, which nowadays can be considered one of the most well-established techniques for the remote and nondestructive evaluation of materials thermal properties. In particular, in these investigations the lock-in IRT con-figuration (LI-IRT) [17] has been employed since it allows the straightforward evaluation of the in-plane thermal diffusivity. As mentioned before, such an information can be extremely useful when taking into account that heat dissipation in smart textiles is expected to take place mainly along the sample surface rather than in the orthogonal direction. In addition, the LI-IRT technique enables the prompt evaluation of the thermal diffusivity along different directions on the sample surface [18,19,20] and hence, the detection of a possible anisotropic features of the thermal diffusivity, which may result from the textile physical properties and geometrical structure, which can be optimized and exploited for smart design processes.

References

[1] Roshni, S.B.; Jayakrishnan, M.P.; Mohanan, P.; Surendran, K.P.. Smart Mater. Struct. 26 (2017) 105011.

[2] Karimi, R.; Mohtaram, F.; Mottaghitalab, V.; Mehrizi, M.K. J. Ind. Text. 47 (2018) 765–780.

[3] Ha, S.; Jung, Y.; Kim, D.; Jung, C.W. Microwave Opt. Technol. Lett. 54 (2012) 2697–2702.

[4] SCharjan, C.; Sreemathy, R.; Terdalkar, S. Int. J. Wirel. Mob. Comput. 13 (2017) 232–244.

[5] Mohtaram, F.; Mottaghitalab, V.; Baghersalimi, G. J. Text. Inst. 108 (2017) 1888–1898.

[6] Larciprete, M.C.; Paoloni, S.; Orazi, N.; Mercuri, F.; Orth, M.; Gloy, Y.S.; Centini, M.; Voti, R.L.; Sibilia, C. Int. J. Therm. Sci. 146 (2019) 106109.

[7] Larciprete, M.C.; Paoloni, S.; Voti, R.L.; Gloy, Y.S.; Sibilia, C, Int. J. Therm. Sci. 132 (2018) 168–173.

[8] Larciprete, M.C.; Gloy, Y.S.; Voti, R.L.; Cesarini, G.; Leahu, G.; Bertolotti, M.; Sibilia, C. Int. J. Therm. Sci. 113 (2017) 130–135.

[9] Peng, L.; Fan, W.; Li, D.; Wang, S.; Liu, Z.; Yu, A.J. Adv. Mater. Technol. 5 (2020) 1900599.

[10] Felczak, M.; de Mey, G.; Więcek, B.; Michalak, M. Fibres Text. East. Eur. 4 (2015) 61–65.

[11] Yoshihiro, Y.; Hiroaki, Y.; Hajime, M. Effective thermal conductivity of plain weave fabric and its composite material made from high strength fibers. J. Text. Eng. 54 (2008) 111–119.

[12] Bhattacharjee, D.; Kothari, V.K. Int. J. Heat Mass Transf. 52 (2009) 2155–2160.

[13] Peng, L.; Fan, W.; Di, L.; Wang, S.; Liu, Z.; Yu, A.; Jiang, X. Smart Adv. Mater. Technol. 5 (2020) 1900599.

[14] Wu, E.; Gao, Q.; Li, M.; Shi, Y.; Mandelis, A. NDT E Int. 94 (2018) 56–61.

[15] Dolatabadi, M.K. J. Text. Inst. 2017, (2017) 1537–1544.

[16] Siddiqui, M.O.R.; Sun, D. J. Ind. Text. 48 (2017) 685–712.

[17] Maldague, X. Theory and Practice of Infrared Technology for Nondestructive Testing; Wiley-Interscience: New York, NY, UAS, 2001.

[18] Paoloni, S.; Scudieri, M.E.T.F.; Mercuri, F.; Marinelli, M.; Zammit, U. Appl. Phys. A Mater. Sci. Processing 98 (2010) 461.

[19] Ishizaki, T.; Nagano, H.. Infrared Phys. Technol. 99 (2019) 248.

[20] M. Larciprete, N. Orazi, Y. S. Gloy, S. Paoloni, C. Sibilia and R. Li Voti, Sensors, 22 (2022) 940.