Multifunctional yarn based e-textile for wearable strain sensing and thermal heating applications

Mohammad Shak Sadi and Eglė Kumpikaitė

Department of Production Engineering, Faculty of Mechanical Engineering and Design, Kaunas University of Technology, Studentų Str. 56, LT-51424 Kaunas, Lithuania, e-mail: mohammad.shak@ktu.edu *and* egle.kumpikaite@ktu.lt

Abstract: A yarn-based electronic textile (e-textile) was developed incorporating copper nanoparticles with the polyamide (PA 6) yarn. The electroless deposition of copper endowed the PA 6 yarn with higher conductivity (2.3 Ω/cm). Moreover, the Cu/PA 6 yarn showed excellent strain sensing performance for human motion detection such as repeated finger bending-straightening and outstanding wearable thermal heating performance.

Introduction: E-textiles are of great interest and are being widely investigated to meet the ever-increasing demands for flexible wearable technology in human daily life. The inherent flexibility of textile materials offers a wide array of design opportunities for the construction of sophisticated wearable electronics that can be easily compatible with the complex architecture of the human body in comparison to traditional rigid and uncomfortable wearables [1,2]. Among variant hierarchies (e.g., fiber, yarn, fabric) of textiles, yarn offers a versatile platform for developing e-textiles not only in a continuous form, but also can be further weaved or knitted to form cloth. Moreover, yarn-shaped e-textiles can also be used to interconnect different functional units within the wearable system and to attach the device seamlessly to the traditional clothing always worn by humans. Therefore, in this study, we have developed a highly conductive Cu/PA 6 yarn for variant wearable applications.

Keywords: *copper, polyamide, strain sensing, joule heating*

Materials: 100% PA 6 yarn (78 Dtex 24 F) was provided by a local supplier. All the chemicals e.g., stannous chloride ($SnCl_2$), hydrogen chloride (HCl), ammonium hydroxide (NH_4OH), silver nitrate ($AgNO_3$), sodium hydroxide (NaOH), copper (II) sulfate ($CuSO_4.5H_2O$), formaldehyde (HCHO), potassium sodium tartrate tetrahydrate ($KNaC_4H_4O_6 \cdot 4H_2O$), and ethanol (C_2H_6O) were purchased from Merck, Germany.

Methods: Electroless deposition of copper on the PA 6 yarn consisted of three steps, namely sensitization, activation, and deposition. In brief, the pristine PA 6 yarn was initially immersed in a sensitization bath containing $SnCl_2$ and HCl and kept under 30 minutes of ultrasonication at room temperature. The sensitized substrate was then transferred to an activation bath containing $AgNO_3$ and NH_4OH for another 30 minutes under ultrasonication. Finally, the electroless copper deposition of the activated substrate was performed in an ultrasonication bath containing a metal source ($CuSO_4.5H_2O$), a reducing agent (HCHO), and a complexing agent ($KNaC_4H_4O_6 \cdot 4H_2O$). A digital multimeter and infrared camera were used to analyze the strain sensing and thermal heating performance.

Results and Discussion:

The surface morphology of the PA 6 yarn revealed by scanning electron microscopy confirms that after copper deposition, the entire surface of the yarn was uniformly covered with small granules of metal particles (Fig. 1a). The presence of copper on the surface provided the yarn with superior conductivity (2.3 Ω/cm) and great potential for wearable applications. To evaluate the strain sensing capabilities of the yarn, it was attached to the index finger of a volunteer to monitor its response upon bending and straightening. Upon repeated actions, the resistance of the yarn promptly changed and maintained a cyclic pattern with greater repeatability and stability (Fig. 1b), which confirms the viability of the Cu/PA 6 yarn to capture human motions in real-time. The Cu/PA 6 yarn was attached to a piece of normal cloth while both ends of the yarn were connected to an external DC power source to demonstrate the joule heating behaviour. When a minimum voltage (2 V) was supplied, the temperature of the yarn surface immediately rose to 40 °C and maintained a uniform temperature distribution profile (Fig. 1c). Furthermore, the Cu/PA 6 yarn exhibited better fastness properties (76% retention of metal particles) against repeated washing (with liquid detergent, 30 min, continuous stirring) for 8 cycles.

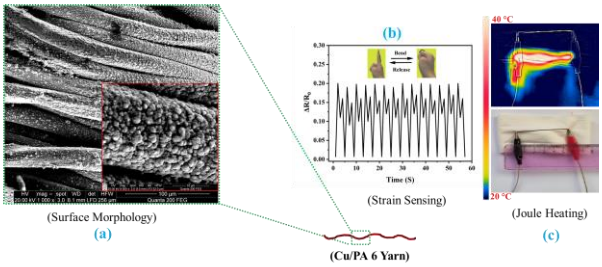

Figure 1 Surface morphology of the Cu/PA 6 yarn (a) and its application in strain sensing (b) and joule heating (c).

REFERENCES

[1] Sadi, M.S. and Kumpikaitė, E., 2023. Highly conductive composites using polypyrrole and carbon nanotubes on polydopamine functionalized cotton fabric for wearable sensing and heating applications. Cellulose, 30(12), pp.7981-7999.

[2] Sadi, M.S. and Kumpikaitė, E., 2022. Advances in the robustness of wearable electronic textiles: strategies, stability, washability and perspective. Nanomaterials, 12(12), p.2039.