Electrospun fiber based non-woven textile for extreme thermal management

Zhuofan Qin[1a], Christopher Markwell [1], Jingwei Li[1,2], Hamdi Torun[1],

Haibao Lu[2], Jianjun Li[2] and Ben Bin Xu[1]*

[1] Faculty of Engineering and Environment, Northumbria University, Newcastle upon Tyne, NE1 8ST, UK.,

[2] Harbin Institute of Technology, Harbin, 150080, China.

*ben.xu@northumbria.ac.uk

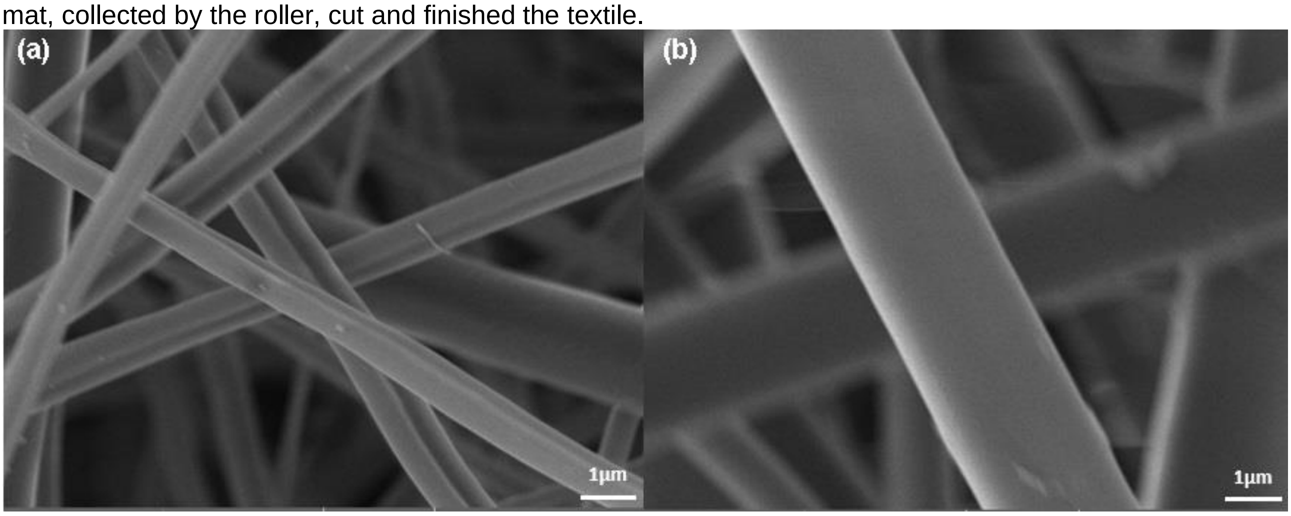
Abstract. Thermoregulating textile is promising offering protective clothing by setting a barrier between human body and extreme environments. In this work, we prepared a flexible, non-woven, SiO_2-TiO_2 hybrid ceramic fiber-based textile by electrospinning with low density of 0.045g/cm3 and high heat-resistance with a failure temperature of 1280 ^{o}C. The performance of thermal conductivity and infrared reflection ability of the textile significantly improve with the additive of TiO_2 expanding the application areas in thermal protective clothing.

Introduction

At present, natural fibers, such as silk, cotton and man-made organic fibers are widely used in textile industry[1-6]. Conventionally, specific additives are used to develop textiles that can be used for further protecting human body from the extreme environments. Silica, as one of the most common ceramic materials has attracted wide attention as a textile additive as well, such as silica aerogel, used for various insulation materials [7-9]. Likewise, titanium dioxide is a typical coating material attributed to its high infrared reflectivity and ultraviolet light absorbance, which is suitable for clothes against with extreme environment [10-12]. In this paper, we describe a new type of textile for which we combine titanium dioxide with electrospun silica fiber using sol-gel chemistry to improve the thermal and optical properties. We obtained the textile with a low density of 0.045g/cm3 that exhibits excellent flexibility, compressibility and low thermal conductivity of 0.044 W/m·K.

Experiment, Results and Application

We mixed Tetrabutyl titanate hydrolysate, Tetraethyl orthosilicate hydrolysate and 2%wt Polyethylene oxide to obtain the SiO_2-TiO_2 precursor. Then, we utilized the electrospinning technique to obtain the nano-scale fiber mat, collected by the roller, cut and finished the textile.



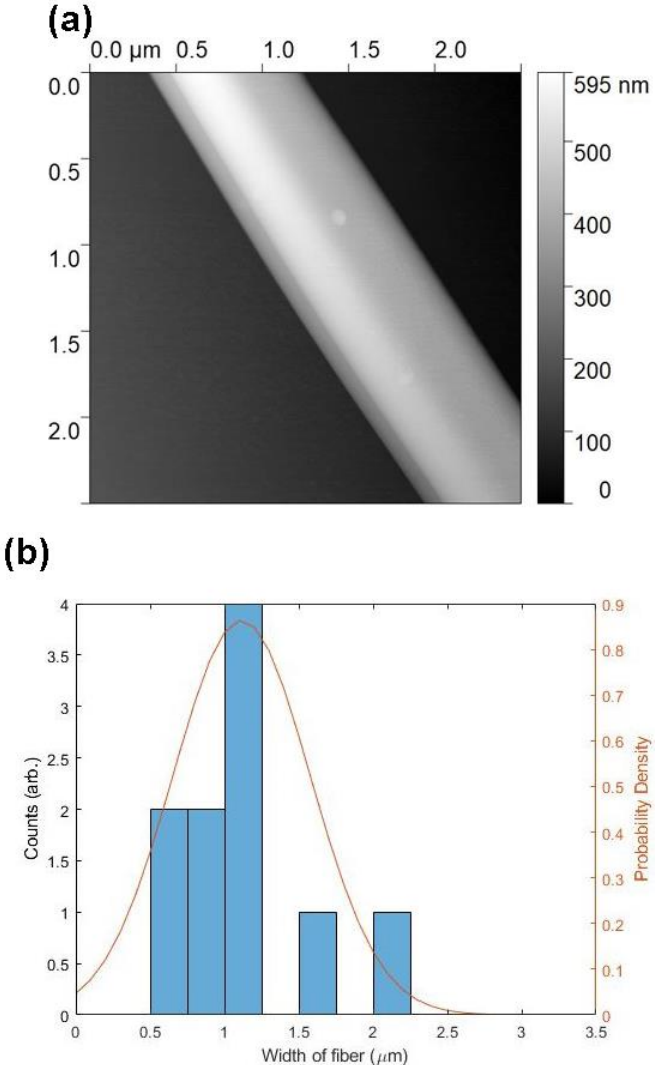
Figures 1. (a) SEM images of silica fiber sample before heat treatment of 1200 ^{o}C;(b) SEM images after heat treatment of 1200 ^{o}C.

After the fabrication, we characterize the samples using a scanning electrode microscope (SEM) and an atomic force microscope (AFM). The SEM images revealed that the textile samples can withstand high temperatures up to 1200 ^{o}C. Figure 1 shows the high length-width ratio of single fibers before and after heat treatment. After treatment, the surface topology of the single fiber indicates that there was no obvious damage or deformation (Figure 1). Besides, the twisted fiber mat also exhibited good strength since self-weight ratio is up to 1:1900. We further investigated the samples using an AFM for quantitative assessment, and observed the profile of single fiber for further illustrating the morphology of the electrospun fiber (Figure 2a) together with the width distribution of single fiber (Figure 2b). The results demonstrate the fabrication protocol provides precision control to develop the hybrid fiber by electrospinning.

For demonstrating application, we did the burning test. We used the SiO_2-TiO_2 electrospun textile as the lining and wrapped by the polyester cover. The infrared and thermal insulation are impressive since the value of thermal conductivity is 0.044 W/m・K and inner fiber mat can endure 1200 ^{o}C high temperature.

Conclusion

In summary, we present a new type of SiO_2-TiO_2 hybrid non-woven, light-weight textile with excellent thermal and mechanical properties fabricated by electrospinning using SiO_2 and TiO_2 components. We characterized single fibers in the fabricated textile samples, and revealed large length-width ratios with an average width of 1 μm, distributed within a range of 0.5-2.5 μm. The interlaced network of the nanofiber mat brings thermal insulation, i.e., 0.044 W/m・K thermal conductivity and tolerate ultra-high temperature up to 1200 ^{o}C. TiO_2 component further enhances infrared absorption and heat retardant capability. Therefore, the prominent thermal and mechanical properties yield a promising lining of protective clothing.



Figures 2. (a) Profile of single fibre by AFM;(b) Width histogram and distribution of single fiber.

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