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Thermal Insulation Properties of Electrospun Nanofibrous Layers ⋆

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Abstract

The aim of the study is to understand the heat transfer behavior of low-density nanofibrous layers. Understanding heat transfer through nanofibrous layers embedded with silica aerogel structures will allow us to explore the unique properties of polymer nanofibers for high performance textile applications. It was intended to study the mechanisms of heat transfer through fibrous insulation where the fiber diameter is less than 1 micrometer (μm). Flexible electrospun PUR and PVDF nanofibrous layers embedded with silica aerogel was produced using electrospinning process. Further, the thermal properties of the electrospun nanofibrous layers embedded with SiO_2 aerogel was analyzed to find their application in enhanced thermal insulation. The thermal properties of the samples were evaluated and statistically analyzed. The microscopic examination confirmed presence of aerogel particles. The results showed enhancement of thermal insulation by increasing the number and the weight per unit area of both nanofibrous layers. The results confirmed that embedding silica aerogel in nanofibrous layers leads increased thermal insulation. From the study, it can be concluded that nanofibrous layers can provide efficient thermal insulation.

Keywords: Nanofiber; Aerogel; Thermal Insulation; Conduction; Heat Transfer

1 Introduction

Electrospinning is a simple and low-cost method for making polymer and ceramic fibers with superfine diameters [1-3]. It is gaining increasing acceptance due to the promising properties of

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structured and assembled nanofibers developed via electrospinning. Understanding heat transfer through nanofiber structures will allow us to exploit the unique properties of polymer nanofibers for applications such as improved cold weather clothing and hand wear, sleeping bags, and tent liners, as well as applications for food service refrigeration and storage equipment [4]. Literature searches on the subject of submicron fibers in thermal insulation reveal very limited fundamental or applied work using polymer nanofibers for thermal insulation applications. Silica aerogel is a highly porous material with pore diameters in the range of 2–50 nm [5, 6]. The nanoporous structure of the silica aerogel having a high porosity above 90% makes the aerogel a highly thermal insulating materials with a super-low thermal conductivity as low as 0.013 $W \cdot m^{-1} \cdot K^{-1}$. It has wide applications in aircrafts and aerospace, chemical engineering, building constructions, and so forth [7-9].

In this paper, we studied the mechanisms of heat transfer through fibrous insulation where the fiber diameter was less than 1 micrometer (μm). The thermal insulating efficiency of fiber-based insulation is known to increase as the fiber size is reduced. Flexible electrospun nanofibrous layers embedded with silica aerogel was produced via electrospinning process. The electrospun PUR and PVDF nanofibrous microstructures were fabricated and then used to reinforce the SiO_2 aerogel. The effects of thermal properties of the electrospun nanofibrous layers embedded with SiO_2 aerogel were evaluated.

2 Materials and Methods

2.1 Materials

Silica aerogel powder and granules were purchased from Cabot aerogel Corp. Polyurethane (PUR) & PVDF was used from the CXI lab (nanocenter, TUL, Czech Republic). Sample H1 is Needle punched struto nonwoven structure having One layer of PP web (Top layer) + One layer of spunbond PP web having melt blown polyamide nanofibers on both sides (Middle layer) + One layer of PP web (Bottom layer). Sample H2 is Needle punched struto nonwoven structure having one layer of PP web (Top layer) + Two layers of spunbond PP web having meltblown polyamide nanofibers on both sides (Middle layer)+One layer of PP web (Bottom layer).

2.2 Methods

2.2.1 Electrospinning of PVDF & PUR Nanofibrous Layers

The PUR nanofiber was dissolved in Dimethylformamide (DMF) at room temperature at a concentration of 18wt.% (g/mL) and at the same concentration PVDF also was first stirred for 2 hours and then with SiO_2 aerogel in both powder and granule forms were added. These mixtures were stirred for 1-2 hrs at room temperature prior to electrospinning and were then electrospun at room temperature. The prepared solution was placed in a cylinder containing active electrode parallel to collecting electrode. The fibers were collected on a spunbond polypropylene fabric.

2.2.2 Instruments and Characterizations

The electrospun PUR and PVDF nanofibrous layer embedded with silica aerogel have been investigated on their morphology and microstructure by using a SEM (VEGA TESCAN Inc. USA) at