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Thermal Protective Properties of Aerogel-coated Kevlar Woven Fabrics

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Abstract

In this work, silica aerogels were incorporated with high-performance Kevlar fabrics by coating to deal with heat transfer problems under a severe environment. Thermal protective properties of the prepared fabrics were evaluated by using a laser system coupled with a thermometer which records the back-surface temperature of the fabric under laser radiation. The effect of aerogel content as well as pixel time used for laser radiation on thermal protection was investigated and discussed. Meanwhile, thermal properties of the fabrics under ambient temperature were tested with a thermal camera, thermal insulation values of the fabrics with different coatings were compared and analyzed. Moreover, fly ash nanoparticles were used for coating as well to investigate their effect on thermal performance. The findings in this study can be used for further research in aerogel-based high-performance materials for thermal protection.

Keywords: Kevlar; Aerogel; Thermal Protective Properties; Laser Radiation

1 Introduction

Aerogels, prepared by the polymerization of silicic acid or by the aggregation of particles of colloidal silica through a supercritical drying process, are highly porous open cell solid materials that features thermal conductivities as low as 0.013 $Wm^{-1}K^{-1}$ [1-3]. Since the silica aerogels comprise highly open structures in which the secondary particles of silica are connected to each other with only few siloxane bonds, the silica aerogels generally have poor mechanical stability, such as low strength and high brittleness. Resulted from the lower production costs of aerogel granules and simple preparation process, existing aerogel particles are usually incorporated with fibres or textile structure to achieve improved thermal performance of the overall structure [4].

It is known that aramid fibers possess lower density, lower thermal conductivity and higher mechanical strength with flexibility, which makes it a good choice for an ever-growing number of applications where a reduction of weight, increase in strength and resistance to corrosion produce

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significant improvements in safety and efficiency [5]. High-performance fabrics and composites made of aramid fibers are used in Military body armor, firemen's uniforms, protective clothing and motorcyclist's suits. Thermal behavior analysis of these materials under a severe environment, is important. The decomposition temperature of aramid fibers in air reaches up to 450 °C which is much higher than that of other organic fibers [6]. It can be inferred that the silica aerogel embedded aramid fabrics would be suitable for some higher temperature insulation rather than the ambient temperature only.

Studies on combining silica aerogel with aramid are mainly focusing on composites of aramid fiber reinforced silica aerogel in which the aramid fibers acted as reinforcements. The composites have been prepared by sol-gel method via ambient pressure drying [6]. The heat transfer characteristics of the composites under a transient plane heat source and hot plate experiment revealed that both the aramid fibers and the aerogel matrix contribute to the overall thermal conductivity. Meanwhile, the temperature differences of the composites increased with the fiber content and displayed linearity to some extent. Aramid fibers have been successfully grafted with the mesoporous structure of silica aerogel to reduce the fiber thermal conductivity through a serious process [7]. Thermal conductivity of the as-prepared aramid fiber blanket is 25% lower than that of the original ones, whereas the thermal stability changes little. A study on Kevlar nanofiber aerogel films fabricated through spin-coating, sol-gel processing and subsequent freeze-drying found that the typical aerogel structure endowed the films with excellent thermal insulation ability to prevent effective heat transfer and reduce the IR radiation [8]. All these studies were focusing on thermal comfort properties of the composites composed by aramid fibers and aerogels, however, thermal protective properties of aerogel-based Kevlar fabric were not well investigated.

The present paper deals with aerogel coated Kevlar fabrics for thermal protection. Kevlar woven fabric coated with aerogel particles were fabricated by using RTV silicone as binding materials. Thermal protection of the prepared materials under high temperature up to several hundred degree was determined with a laser system and thermometer. The effect of aerogel and fly ash nanoparticles on thermal protection were investigated and discussed. Thermal properties of the prepared fabrics under ambient temperature were evaluated by a thermal camera.

2 Experimental

2.1 Materials

Plain woven fabric of Kevlar 29 with 5.7 ends/cm and 10 picks/cm was selected to carry out coating. The fabric had an areal density of 265.80 g/m^2 and a thickness of 0.562 mm. Silica aerogel granules used were hydrophobic, mesoporous and had nearly 98% of air and 2% solid. The specifications are presented in Table 1. Due to the interconnected nanoporous characteristic, aerogel can hold air within its structure and does not allow free flow of air, which enables it to be a superior thermal insulation material. Fly ash class F, the most common coal-fly ashes, was used for coating as well to investigate its effect on thermal properties of the coated fabrics. The fly ash is very fine grained with a fineness between 2 micrometers and 300 micrometers, with a density of 1.34 g/cm^3. Thermosetting resin, Zhermack ZA 13 Mould 45, was used as binder to combine the aerogel and fly ash particles with Kevlar fabrics. ZA 13 MOULD WT 45 is a bi-component addition cured RTV silicone rubber compatible with all plasters, coatings, polyurethane resins, acrylic resins and polyester resins. The chemical and physical characteristics of this RTV silicone