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Solar thermal energy harvesting properties of spacer fabric composite used for transparent insulation materials

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ABSTRACT

Transparent insulation materials (TIMs) hold an extraordinary potential in solar thermal energy collection, and are gradually and widely applied in the energy-saving buildings. However, due to the limitation of available materials, conventional TIMs are rigid, heavy and uneasy for installation. In this paper, a novel TIM product made of spacer fabric composites was designed and investigated experimentally. Compared with traditional TIMs, the proposed spacer fabric composites are featured with flexibility, low weight and high applicability. Four different types of spacer fabrics composites were developed to analyze the solar energy conversion efficiency using textile material. Their chemical composition, conductivity and water repellency properties were systemically evaluated using UV–VIS–NIR, thermal detector and contact angle measurements. The spacer fabric composites of spacer filament in 'X' type was demonstrated to have a stronger solar thermal collection capacity than that of 'V' type. Also, the poly-p-xylene coating contributed to a higher thermal insulation and stronger water repellency property. To be specific, the stable collection temperature of the optimal composites can reach to 98 °C from the ambient temperature of 32 °C at a radiation of 1100 W/m^2. In conclusion, the spacer fabric composites demonstrated to have large potential and extremely broad application prospect in the field of transparent insulation materials.

1. Introduction

Due to an urgent requirement of tremendous energy need for modern society, it is increasingly important and highly desired to develop renewable and sustainable energy conversion sources [1–3]. Among green energy sources, in particular, solar thermal energy has been widely studied and exploited in recent decades. Significant amounts of solar energy harvesting equipments and accessories have been applied in resident areas, in consideration of the huge energy demand in the fields of construction and buildings [4–7]. And it is revealed that both heat storage materials and insulation materials are essential for facades as well.

Transparent insulation materials (TIMs) is defined as the area type materials with a high solar thermal conversion efficiency through a system of good thermal insulation and high transmission properties for radiation in the range of the solar spectrum [8]. Based on their cellular geometry, TIM can be classified into five general categories: absorber-parallel, absorber-perpendicular, mixed configuration, cavity structures, and homogeneous [9]. Their outstanding properties suggest a broad range of their applications for high-efficiency solar heat recovery using high temperature flat-plate collectors, integrated collector cum storage systems, building facade/roof heating and solar desalination, as well as outdoor systems such as industrial storage tanks and transport pipelines of hot fluids [10–12]. A large number of materials and structures of TIMs have been investigated theoretically and experimentally [13–15]. For the hexagonal honeycomb, the transmittance of parallel light was measured to reach more than 70% [16,17]. Besides it shows decent good heat insulation performance attributing to the restricted thermal convection [18]. However, traditional transparent insulation materials usually include a rigid stiff transparent plate and parallel slat arrays [19]. In this case, the applicability of such rigid and inflexible TIM is largely limited, which is conflicted with the increasing demands for flexible solar thermal harvesting products.

Alternatively, textile fabrics are commendable as flexible substrates for easy fabrication and they have been demonstrated to be an ideal product for collecting solar energy, hindering the heat loss and providing energy for the residents [20,21]. Specifically, the textile-based solar thermal collector is one kind of special heat exchangers that can absorb incident solar radiation, and convert it to useful thermal energy via a photo-thermal conversion process [22,23].

On the fabric construction, warp-knitted mesh spacer fabric could be a compelling and fascinating textile-based product that has been

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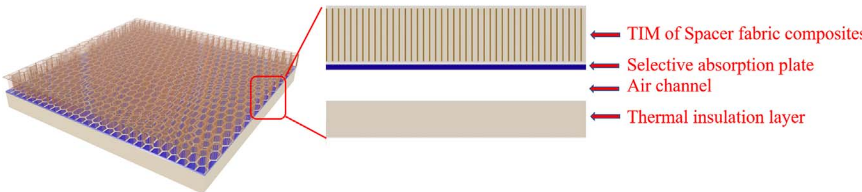

Fig. 1. Schematic representation of the TIM of spacer fabric composites used in the measurement experiment.

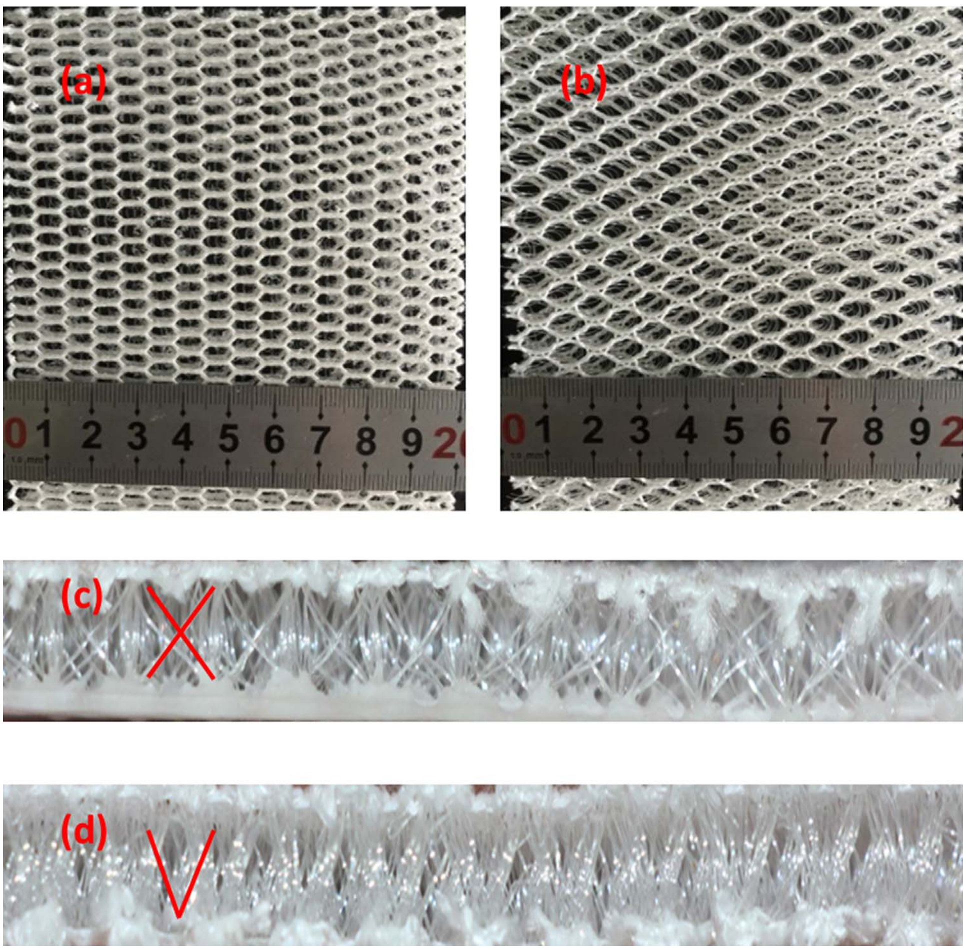

Fig. 2. Physical type of spacer fabric photos and sectional view of S1 (A, C) and S2 (B, D).

widely used in the fields of acoustics, geotextiles, protective textiles and composites [24–26]. The warp-knitted mesh spacer fabrics are made by two separated warp-knitted mesh fabrics which constitute the upper and bottom layer. Also, the upright filaments constitutes the middle layer. Bahners et al. proposed the potential value of fiber-based materials in flexible and translucent thermal insulations for solar thermal applications [27]. Later on, Engelhardt et al. used spacer fabrics to constitute a multiple-layers solar utilization collector and it was demonstrated to exhibit a fair good solar collection property [28]. From the above, the mentioned composite process for the multiple-layers structure is quite complex. And the influence of spacer fabrics' structures on the solar energy harvesting has not been analyzed in detail. Moreover, the heat loss mechanism from the surface of the collector is still a critical problem and needs to be further addressed. Therefore, for the first time a transparent coating technique was performed on this kind of TIM made of spacer fabric and it was analyzed to improve the thermal insulation property by considering the effects on the transmittance of light.

In this paper, we have presented a comparatively simple and low-cost manufacturing process for flexible TIM production. As illustrated in Fig. 1, this flexible TIM product combines a spacer fabric with two layers of polydimethylsiloxane (PDMS) in the upper and bottom surface. Surface PDMS layer has good transmittance, and can hinder the energy loss from inner heat part by infrared radiation, namely the wavelength is higher than 2500 nm [29,30]. Besides, PDMS layers' low transmittance in the UV part, it also helps to avoid the damage from ultraviolet light [31,32]. Moreover, the product design of two kinds of spacer fabrics has been manufactured and optimized by comparing their transmittance, thermal insulation performance and especially solar harvesting properties when combined with the selective solar collection plates. In order to further improve the thermal insulation property, the upper surface of these products was coated by poly-p-xylene materials, and correspondingly the enhanced thermal insulation properties were also experimentally investigated.

The working mechanism of this developed product is similar to a traditional TIM. Specifically, a high percentage of solar irradiation can penetrate this transparent product and reach to the absorption base where sunlight energy can be converted into thermal energy. However, the infrared radiation energy of the bottom base can be extremely hindered by the double PDMS layers and at the same time, thermal energy would not be easily lost through convection by the surrounding air trapped in the spacer fabric. Additionally, the product is