

FABRICATION AND CHARACTERIZATION OF POLYDIMETHYLSILOXANE SPONGE WITH PHOTOTHERMAL RESPONSE

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Abstract. Polydimethylsiloxane (PDMS) has attracted attention as a lightweight polymer for thermal management applications because its interconnected porous architecture can effectively regulate heat transfer. In this study, we employ a sugar-template method to prepare the PDMS sponge. Morphological and chemical characterizations confirmed that the porous network formed successfully without modifying the chemical composition of PDMS. Under sunlight irradiation, the PDMS sponge exhibited a measurable increase in surface temperature, indicating its thermal response associated with the porous architecture. The porous architecture could influence light propagation and heat dissipation within the sponge, potentially contributing to the observed thermal response. Although the temperature increase was moderate, the results provide a preliminary view of the thermal response of porous PDMS under sunlight irradiation. The proposed method offers an economical and straightforward alternative for developing porous polymer materials with potential thermal functionality, supporting affordable and clean energy initiatives under Sustainable Development Goal 7.

Keywords: *Polydimethylsiloxane, Light scattering, Sugar-template, Photothermal behavior, Porous polymer.*

1. Introduction

The conversion of solar energy into thermal energy has been widely studied as a sustainable approach to address the increasing demand for energy-efficient technologies (Kannan and Vakeesan, 2016). This conversion process relies on photothermal materials that can efficiently absorb incident solar radiation and convert it into heat (Cheng et al., 2022). Accordingly, photothermal systems have been explored across a wide range of applications, including solar steam generation (Lin et al., 2019), water purification (Irshad et al., 2021), sterilization (Noureen et al., 2023), and anti-icing (He et al., 2022). Their performance is governed not only by their intrinsic optical properties but also by their structural characteristics, including porosity (Xie et al., 2019), surface morphology (Ren et al., 2026), and thermal insulation (Zhong et al., 2025). Among these structural features, porosity plays a particularly important role by providing interconnected pathways for light interaction and regulating heat and mass transport within the material (Yuan et al., 2020, Farber et al., 2025). Consequently, the development of porous materials has emerged as an effective strategy for improving photothermal behavior while maintaining lightweight and energy-efficient characteristics (Shi et al., 2024, Saleque et al., 2022, Zhang et al., 2023a, Farber et al., 2025).

In this context, polymers are particularly attractive for porous photothermal architectures due to their low density, flexibility, ease of processing, and tunable pore structures (Shi et al., 2024, Zhao et al., 2025, Liu et al., 2025). These characteristics provide considerable flexibility in designing porous structures with controlled light interaction and thermal transport properties. In particular, polydimethylsiloxane (PDMS) is one of the most promising polymeric materials due to its excellent chemical stability, thermal resistance, elasticity, and straightforward fabrication process (Zimmermann et al., 2025, Mata et al., 2005). In addition, PDMS can be readily fabricated into a three-dimensional porous structure, also known as a PDMS sponge. PDMS sponges can be readily

fabricated using sacrificial-template techniques (Li et al., 2022, Li et al., 2018, Montazerian et al., 2019), providing a simple and cost-effective approach for producing interconnected porous structures with tunable pore characteristics.

Although PDMS sponge has been widely explored for applications such as oil–water separation (Zhang et al., 2023b, Pan et al., 2021), thermal insulation (Lim and Lee, 2022), flexible electronics (Lu et al., 2024), biomedical engineering (Cutroneo et al., 2021), and solar-driven evaporation (Li et al., 2022, Lim and Lee, 2022), its photothermal behavior under natural sunlight has received less attention. This aspect is particularly relevant to tropical and equatorial regions, where solar exposure is an important environmental condition for outdoor materials and solar-driven technologies. Therefore, porous PDMS sponges were fabricated here via a sacrificial-template method, and their photothermal response was preliminarily evaluated under direct outdoor sunlight, without adding any extra photothermal absorbers. Sponge morphology was examined by scanning electron microscopy (SEM), while their temperature response was monitored using infrared thermal imaging. This study provides a preliminary view of the thermal behavior of porous PDMS under outdoor conditions and may serve as a basis for further studies.

2. Material and Method

2.1. Material

Sylgard 184 polydimethylsiloxane (PDMS) silicone elastomer, consisting of a base and curing agent, was purchased from Dow Corning. Commercial granulated sugar and deionized water were used as the sacrificial template and processing medium, respectively.

2.2. Method

A PDMS sponge was fabricated using a sacrificial sugar-template method (Choi et al., 2011). Initially, a sugar template was prepared by lightly mixing commercial granulated sugar with a small amount of deionized water until the sugar particles adhered to each other. The moistened sugar was then pressed into the desired shape and allowed to dry at room temperature to obtain a rigid sacrificial template. The PDMS base and curing agent were mixed at a mass ratio of 10:1 and stirred thoroughly until a homogeneous mixture was obtained. The mixture was poured into a glass Petri dish, and the prepared sugar template was carefully placed on the surface of the uncured PDMS. The assembly was transferred to a vacuum chamber and maintained under vacuum at room temperature for 4 h. During this process, the PDMS mixture gradually penetrated the interconnected voids of the sugar template through capillary action. The infiltrated template was subsequently cured in an oven at 80°C for 2 h. Once cured, the sample was washed using deionized water under stirring, and the washing water was replaced several times to facilitate dissolution and removal of the sacrificial sugar template. Finally, the fabricated PDMS sponge was allowed to dry under ambient conditions for three days.

The PDMS sponge's porosity was assessed following a previously reported method (Thurgood et al., 2017). The sample was initially weighed when dry, submerged in deionized water, and reweighed after residual water on its outer surface had been eliminated. The pore volume was estimated from the mass difference between the wet and dry samples using the density of water. The porosity percentage was calculated by dividing the estimated pore volume by the total external volume of the sample. Scanning electron microscopy (SEM) using a JCM-700 NeoScope instrument was employed to examine the sample morphology. Energy-dispersive X-ray spectroscopy (EDS) coupled with SEM was used to determine the elemental profile of the PDMS sponge with the accelerating voltage set to 10 kV. Pore-size analysis was performed by ImageJ software based on the SEM images. The images were calibrated using the scale bar, and the pore boundaries were identified based on the contrast between the pores and the PDMS matrix. The measured pore dimensions were then used to construct the pore-size distribution. Fourier Transform

Infrared (FTIR) spectroscopy was employed to characterize the chemical structure of the sample using a Shimadzu instrument. The temperature of PDMS surface was monitored through infrared thermal imaging camera (UTi260B) during direct sunlight irradiation. The sample was placed in an open outdoor area on a white sheet of paper and exposed directly to sunlight for 20 min. Thermal images were recorded before irradiation and after 20 min of exposure. The initial and final surface temperatures were obtained from the recorded thermal images, and the temperature increase was calculated as the difference between the final and initial surface temperatures.

3. Result and Discussion

Figure 1 presents the schematic illustration of the fabrication process used to obtain the PDMS sponge through a sugar sacrificial-template approach. In this method, the sugar template serves as a temporary scaffold that defines the three-dimensional porous architecture, while the vacuum-assisted capillary infiltration facilitates the penetration of uncured PDMS into the interconnected spaces within the template. After curing, the sugar template was removed by washing with deionized (DI) water, leaving a lightweight PDMS sponge with an interconnected porous network. Compared with other pore-forming techniques, the sacrificial-template method offers a simple, low-cost, and scalable approach for fabricating porous PDMS while allowing the pore architecture to be tailored through the template geometry (Choi et al., 2011).

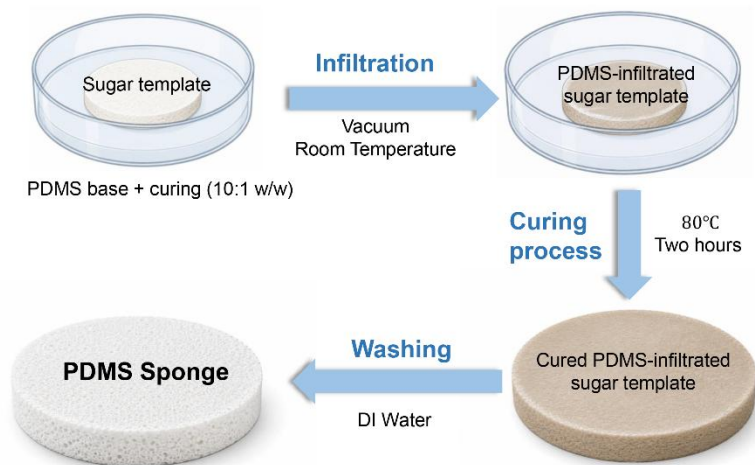


Figure 1. Schematic illustration of the fabrication process of the PDMS sponge.

In Figure 2a, the SEM image of commercial sugar particles exhibited irregular shapes, having an average particle size of $\sim 950\ \mu\text{m}$. These particles served as the sacrificial template for generating the porous within PDMS matrix. The successful formation of the porous structure was then evaluated through macroscopic observation and SEM. The digital photograph (Figure 2b) shows that the fabricated PDMS sponge has a white appearance and a cylindrical shape, measuring 28 mm in diameter and 5 mm in thickness, while maintaining its self-supporting structure after removal of the sacrificial sugar template. Although bulk PDMS is intrinsically transparent, the white appearance of the sponge can be attributed to light scattering caused by the numerous PDMS–air interfaces generated within the porous structure (Tang et al., 2020). The porosity of the fabricated PDMS sponge was estimated following a previously reported method (Thurgood et al.,

2017), yielding an average porosity of 52%. This porosity indicates a substantial void fraction within the sponge structure, supporting its lightweight characteristics.

As presented in Figure 2c, the porous architecture consists of an interconnected three-dimensional network throughout the PDMS matrix, indicating successful replication of the sacrificial sugar template. In addition, no visibly distinguishable residual sugar particles were observed in the examined SEM image. The pores exhibit irregular shapes, creating internal void spaces that contribute to the lightweight nature of the PDMS sponge (Kwak et al., 2021). The pore size distribution determined from ImageJ analysis is presented in Figure 2d. The pore diameter was found to be in the hundreds-of-micrometers range, approximately 300–900 μm . The relatively broad pore size distribution reflects the irregular morphology of the commercial sugar particles (Figure 2a) used as the sacrificial template. It should be noted that the estimated sugar particle sizes were slightly larger than the pore diameters measured in the PDMS sponge. This difference may be attributed to partial dissolution of the sugar particles caused by the small amount of water added during template preparation. Nevertheless, the resulting pore network remained continuous throughout the sponge, demonstrating that the template replication process was effective. The formation of an interconnected microscale porous structure is expected to facilitate light penetration into the sponge and contribute to localized heat generation during light irradiation.

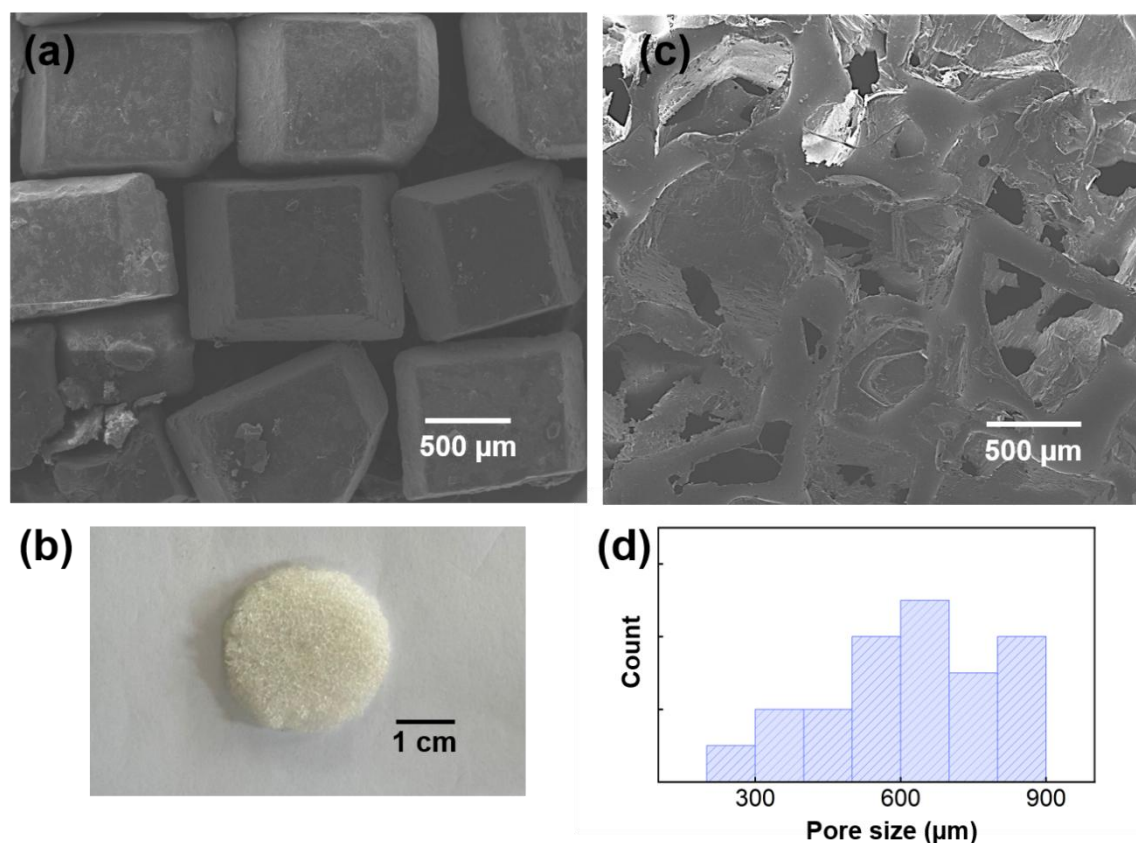


Figure 2. (a) SEM image of the commercial sugar particles. Characterization of the fabricated PDMS sponge: (b) digital photograph, (c) SEM image, and (d) pore-size distribution obtained from ImageJ analysis.

While the SEM observations confirmed the formation of an interconnected porous architecture, the chemical integrity of the fabricated PDMS sponge was further evaluated

using FTIR spectroscopy and EDS as shown in Figure 3. These analyses were conducted to verify that the sacrificial-template fabrication process preserved the characteristic chemical structure of PDMS after sponge formation. The FTIR profiles presented in Figure 3a compare the chemical structures of pristine non-porous PDMS film (black) and PDMS sponge (blue). The molecular representation provided in the inset depicts the repeating unit of polydimethylsiloxane, characterized by a Si–O–Si backbone in which each silicon atom is linked to two methyl (CH₃) groups (Johnson et al., 2013). A prominent absorption feature within the 2950–2960 cm⁻¹ range corresponds to the asymmetric stretching mode of methyl groups attached to silicon atoms (Johnson et al., 2013). Another characteristic peak at 1260–1259 cm⁻¹ corresponds to the deformation vibration of the Si–CH₃ groups (Johnson et al., 2013). The strong absorption band located at 1020–1074 cm⁻¹ corresponds to the stretching mode of the Si–O–Si linkages in the siloxane backbone, which constitutes the main polymer chain of PDMS (Johnson et al., 2013). In addition, the absorption peak appearing at 789–796 cm⁻¹ is associated with the CH₃ rocking and Si–C stretching vibrations (Johnson et al., 2013). The PDMS sponge exhibits similar characteristic absorption bands to the pristine non-porous PDMS film, with no significant additional absorption bands observed. This similarity indicates that the characteristic chemical structure of PDMS was maintained after the fabrication and template-removal processes, with no additional absorption bands attributable to the sugar template detected in the PDMS sponge spectrum.

The elemental composition of the fabricated sponge was further examined by EDS, as shown in Figure 3b. The spectrum is dominated by carbon (C), oxygen (O), and silicon (Si), which are the constituent elements of PDMS. The presence of silicon and oxygen is consistent with the siloxane backbone, whereas the carbon signal originates from the methyl groups attached to the silicon atoms. These FTIR and EDS results collectively confirm that the porous fabrication process successfully preserved both the molecular structure and elemental composition of pristine PDMS sponge.

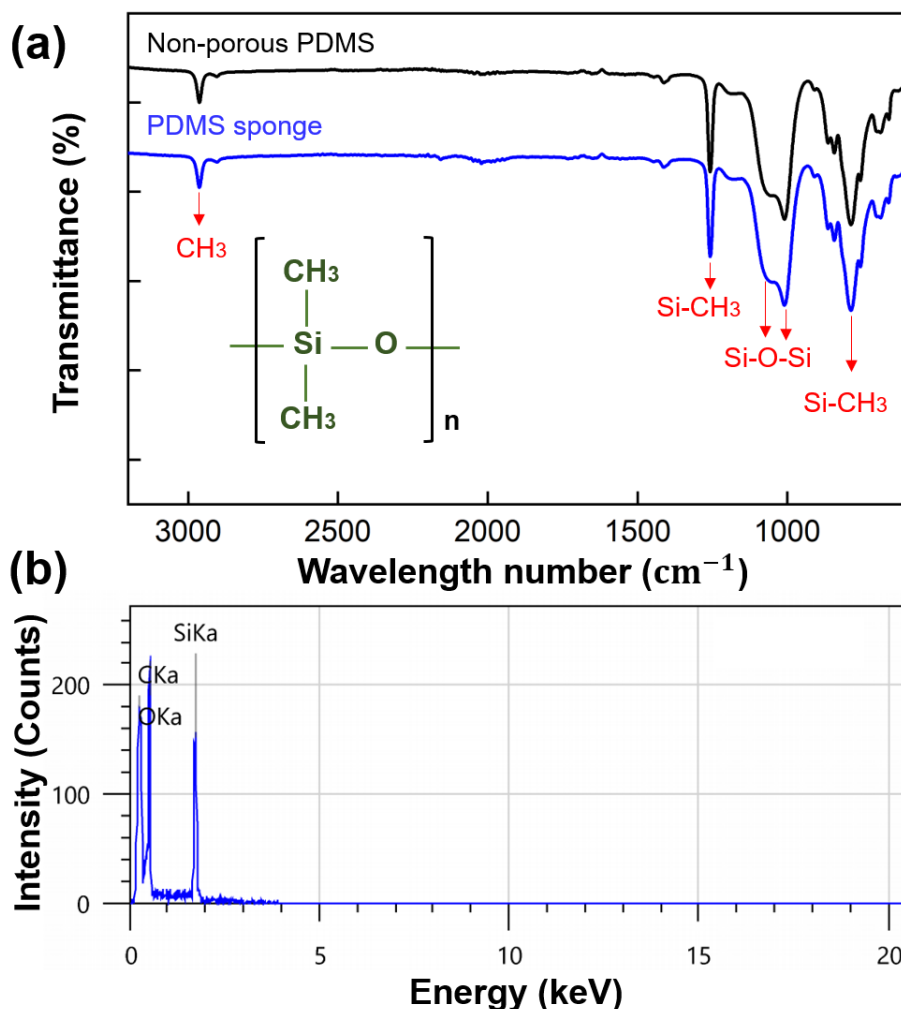


Figure 3. (a) FTIR spectra of pristine non-porous PDMS film (black line) and fabricated PDMS sponge (blue line), with the repeating molecular structure of PDMS shown in the inset, and (b) EDS spectrum of the fabricated PDMS sponge.

The photothermal behavior of the fabricated porous PDMS sponge under direct sunlight is presented in Figure 4. The infrared thermal images show the surface temperature of the sponge before solar irradiation (Figure 4a) and after 20 min of solar irradiation (Figure 4b). The PDMS sponge used for the photothermal measurement had the dimensions shown in Figure 2b. The temperature increased from 33.6 °C to 42.6 °C, corresponding to a temperature increase of 9.0 °C. The infrared thermal image further confirms localized heating within the irradiated region, indicating that the porous PDMS sponge is capable of generating a measurable photothermal response under continuous light exposure. This behavior may be associated with the formation of an interconnected porous architecture, which introduces numerous PDMS–air interfaces throughout the material. These interfaces can promote multiple scattering of incident light (Zhou et al., 2021), potentially influencing light propagation within the sponge. Consequently, although the intrinsic optical properties of PDMS remain unchanged, the porous architecture may influence light propagation and contribute to the observed photothermal response. In addition, the porous structure contains a large volume of trapped air, which possesses a much lower thermal conductivity than solid PDMS (Zhou et al., 2021). This characteristic

may contribute to reduced heat dissipation from the irradiated region. Thus, the porous architecture may contribute to the observed photothermal response through its potential effects on light propagation and heat dissipation.

It should be noted that the temperature increase obtained in this study is relatively moderate because no additional photothermal absorbers were incorporated into the PDMS matrix. Nevertheless, the present results demonstrate that the fabricated porous PDMS sponge exhibits a measurable thermal response under direct sunlight. Therefore, this work provides a preliminary investigation of the photothermal behavior of porous PDMS and highlights the potential role of porous structural features in influencing its thermal response. Future studies may provide a deeper understanding of the factors influencing the thermal response of porous PDMS and further improve its photothermal performance through structural optimization or incorporation of efficient light-absorbing materials while preserving the lightweight and porous characteristics of the sponge.

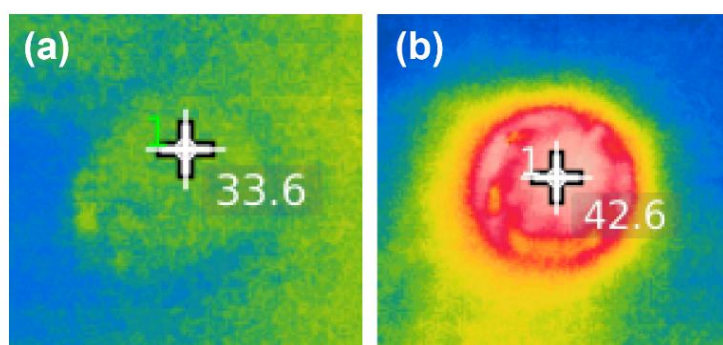


Figure 4. Infrared thermal images of the porous PDMS sponge under direct sunlight (a) before irradiation and (b) after 20 min of solar irradiation.

4. Conclusion

A porous PDMS sponge was successfully fabricated using a simple sacrificial-template method with commercial sugar. The resulting sponge exhibited an interconnected microscale porous structure while maintaining the characteristic chemical structure and elemental composition of pristine PDMS. Under direct sunlight irradiation, the porous PDMS sponge exhibited a photothermal response, with a temperature increase of 9 °C. The white appearance of the porous PDMS sponge is likely associated with light scattering at the numerous PDMS–air interfaces within the porous structure. The observed thermal response could be associated with the porous architecture, which may influence light propagation and heat dissipation within the sponge. Although these proposed effects were not directly verified by optical characterization in the present study, the photothermal performance remains moderate. The present work therefore provides a preliminary investigation of the photothermal behavior of porous PDMS under direct sunlight and a foundation for further studies on the factors influencing its thermal response. Future studies may provide further insights into the factors influencing the photothermal behavior of porous PDMS and explore approaches to improve its performance.

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