




Polydimethylsiloxane Thermal Insulation Composite Elastomer Filled with Hollow Glass Microspheres

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Abstract. This study aims to enhance the thermal insulation properties of polydimethylsiloxane by the incorporation of hollow glass microspheres (HGM) as a functional filler, while evaluating the trade-offs in mechanical, surface, and optical performance. The thermal conductivity, tensile mechanical properties, surface characteristics, and optical transparency of the composites were investigated. The incorporation of 10 wt.% hollow glass microspheres decreased the thermal conductivity coefficient by 56.3%, achieving a minimum value of $0.059 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$. However, this enhancement came at the expense of optical transparency, surface properties, and a significant reduction in the critical elongation at the break. The results demonstrate that HGM-filled polydimethylsiloxane composites are promising materials for thermal insulation applications where transparency and stretchability are secondary to thermal performance.

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REFERENCES

1. M. Bäker, T. Fiedler, J. Rösler. Stress evolution in thermal barrier coatings for rocket engine applications. *Mechanics of Advanced Materials and Modern Processes*, 2015, vol. 1, no. 1, art. no. 5.
2. K. Ersoy. Review of electronic cooling and thermal management in space and aerospace applications. *Engineering Proceedings*, 2025, vol. 89, no. 1, art. no. 42.
3. S. Zhu, X. Li, Z. Luo, X. Jia, Y. Qin, H. Guo, J. Tang, Z. Li, H. Wen, Z. Ma, J. Liu. A two-stage insulation method for suppressing thermal crosstalk in microarray sensitive units. *Applied Physics Express*, 2024, vol. 17, no. 3, art. no. 037001.
4. M.K. Sharma, B. Ramos-Alvarado. Thermal management of 3-D heterogeneously integrated microelectronics: Challenges and future research directions. *Communications Engineering*, 2026, vol. 5, no. 1, art. no. 28.
5. G. Gilardi, W. Yao, H. Rabbani Haghighi, X.J.M. Leijtens, M.K. Smit, M.J. Wale. Deep trenches for thermal crosstalk reduction in InP-based photonic integrated circuits. *Journal of Lightwave Technology*, 2014, vol. 32, no. 24, pp. 4864–4870.
6. G. Previati, G. Mastinu, M. Gobbi. Thermal management of electrified vehicles—A review. *Energies*, 2022, vol. 15, no. 4, art. no. 1326.
7. H.M. Kim, Y.J. Noh, J. Yu, S.Y. Kim, J.R. Youn. Silica aerogel/polyvinyl alcohol (PVA) insulation composites with preserved aerogel pores using interfaces between the superhydrophobic aerogel and hydrophilic PVA solution. *Composites Part A: Applied Science and Manufacturing*, 2015, vol. 75, pp. 39–45.
8. D. Ge, L. Yang, Y. Li, J. Zhao. Hydrophobic and thermal insulation properties of silica aerogel/epoxy composite. *Journal of Non-Crystalline Solids*, 2009, vol. 355, no. 52–54, pp. 2610–2615.
9. S.Y. Kim, Y.J. Noh, J. Lim, N.-H. You. Silica aerogel/polyimide composites with preserved aerogel pores using multi-step curing. *Macromolecular Research*, 2014, vol. 22, no. 1, pp. 108–111.
10. H.M. Kim, H.S. Kim, S.Y. Kim, J.R. Youn. Silica aerogel/epoxy composites with preserved aerogel pores and low thermal conductivity. *e-Polymers*, 2015, vol. 15, no. 2, pp. 111–117.
11. K. Li, Y. Wang, X. Zhang, J. Wu, X. Wang, A. Zhang. Intrinsically hydrophobic magnesium oxychloride cement foam for thermal insulation material. *Construction and Building Materials*, 2021, vol. 288, art. no. 123129.
12. C.-K. Jeon, J.-S. Lee, H. Chung, J.-H. Kim, J.-P. Park. A study on insulation characteristics of glass wool and mineral wool coated with a polysiloxane agent. *Advances in Materials Science and Engineering*, 2017, vol. 2017, art. no. 3938965.
13. X. Guo, J. Feng. Facilely prepare passive thermal management materials by foaming phase change materials to achieve long-duration thermal insulation performance. *Composites Part B: Engineering*, 2022, vol. 245, art. no. 110203.
14. J. Zou, S. Li, Z. Yuan, X. Pei, H. Yu, P. Chen, D. Ye. Temperature-mediated construction of a plantar pressure-relieving, thermally insulating, and biodegradable thick-walled cellulose sponge insole. *Chemical Engineering Journal*, 2023, vol. 451, art. no. 138876.
15. M. Vahtrus, S. Oras, M. Antsov, V. Reedo, U. Mäeorg, A. Lõhmus, K. Saal, R. Lõhmus. Mechanical and thermal properties of epoxy composite thermal insulators filled with silica aerogel and hollow glass microspheres. *Proceedings of the Estonian Academy of Sciences*, 2017, vol. 66, no. 4, pp. 339–346.
16. Y. Sun, Y. Chu, C. Deng, H. Xiao, W. Wu. High-strength and superamphiphobic chitosan-based aerogels for thermal insulation and flame retardant applications. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 2022, vol. 651, art. no. 129663.
17. C. Zhang, L. Qu, Y. Wang, T. Xu, C. Zhang. Thermal insulation and stability of polysiloxane foams containing hydroxyl-terminated polydimethylsiloxanes. *RSC Advances*, 2018, vol. 8, no. 18, pp. 9901–9909.
18. Z.A. Abd Halim, N. Ahmad, M.A.M. Yajid, H. Hamdan. Thermal insulation performance of silicone rubber / silica aerogel composite. *Materials Chemistry and Physics*, 2022, vol. 276, art. no. 125359.

19. J. Ren, X. Huang, J. Shi, W. Wang, J. Li, Y. Zhang, H. Chen, R. Han, G. Chen, Q. Li, Z. Zhou. Transparent, robust, and machinable hybrid silica aerogel with a “rigid-flexible” combined structure for thermal insulation, oil/water separation, and self-cleaning. *Journal of Colloid and Interface Science*, 2022, vol. 623, pp. 1101–1110.
20. M.L. Hammock, A. Chortos, B.C.-K. Tee, J.B.-H. Tok, Z. Bao. 25th Anniversary article: The evolution of electronic skin (E-skin): A brief history, design considerations, and recent progress. *Advanced Materials*, 2013, vol. 25, no. 42, pp. 5997–6038.
21. S. Torino, B. Corrado, M. Iodice, G. Coppola. PDMS-based microfluidic devices for cell culture. *Inventions*, 2018, vol. 3, no. 3, art. no. 65.
22. C. Majidi. Soft robotics: A perspective—Current trends and prospects for the future. *Soft Robotics*, 2014, vol. 1, no. 1, pp. 5–11.
23. I.M. Sosnin, S. Vlassov, L.M. Dorogin. Application of polydimethylsiloxane in photocatalyst composite materials: A review. *Reactive and Functional Polymers*, 2021, vol. 158, art. no. 104781.
24. M. Taha, A. Khalid, M.G. Elmahgary, S.S. Medany, Y.A. Attia. Fabricating a 3D floating porous PDMS – Ag/AgBr decorated g-C₃N₄ nanocomposite sponge as a re-usable visible light photocatalyst. *Scientific Reports*, 2024, vol. 14, no. 1, art. no. 4184.
25. J.-Y. Kim, K.-S. Jang. Facile fabrication of stretchable electrodes by sedimentation of Ag nanoparticles in PDMS matrix. *Journal of Nanomaterials*, 2018, vol. 2018, art. no. 4580921.
26. L. Chen, C. Ma, L. Li, C. Zhu, J. Gu, H. Gao, Z. Zhu, C. Du, T. Wang, J. Xu, G. Chen. Using PDMS plasma cavity SERS substrate for the detection of aspartame. *Journal of Spectroscopy*, 2020, vol. 2020, art. no. 4212787.
27. M.P. Wolf, G.B. Salieb-Beugelaar, P. Hunziker. PDMS with designer functionalities—Properties, modifications strategies, and applications. *Progress in Polymer Science*, 2018, vol. 83, pp. 97–134.
28. D. Cambié, C. Bottecchia, N.J.W. Straathof, V. Hessel, T. Noël. Applications of continuous-flow photochemistry in organic synthesis, material science, and water treatment. *Chemical Reviews*, 2016, vol. 116, no. 17, pp. 10276–10341.
29. S. Ling, W. Chen, Y. Fan, K. Zheng, K. Jin, H. Yu, M.J. Buehler, D.L. Kaplan. Biopolymer nanofibrils: Structure, modeling, preparation, and applications. *Progress in Polymer Science*, 2018, vol. 85, pp. 1–56.
30. Z. Chen, G. Cheng, Y. Zhu, H. Wu, E. Dong, P. Gu, Y. Zhao. Biomimetic polydimethylsiloxane (PDMS)/carbon fiber lamellar adhesive composite in thermal vacuum environment. *International Journal of Adhesion and Adhesives*, 2021, vol. 105, art. no. 102778.
31. Z. Xie, Y. Cai, Z. Wei, Y. Zhan, Y. Meng, Y. Li, Y. Li, Q. Xie, H. Xia. Robust and self-healing polydimethylsiloxane/carbon nanotube foams for electromagnetic interference shielding and thermal insulation. *Composites Communications*, 2022, vol. 35, art. no. 101323.
32. N. Al-Khudary, P.Y. Cresson, Y. Orlic, P. Coquet, P. Pernod, T. Lasri. Measurement of the thermal conductivity of polydimethylsiloxane polymer using the three omega method. *Key Engineering Materials*, 2014, vol. 613, pp. 259–266.
33. J.-H. Hao, Q. Chen, K. Hu. Porosity distribution optimization of insulation materials by the variational method. *International Journal of Heat and Mass Transfer*, 2016, vol. 92, pp. 1–7.
34. T. Zhao, Y. Yu, Y. Zhang, Z. Lyu, C. Li, D. Hu, Q. Li. Lightweight and dual-functional composites with stiff-soft microstructure for energy absorption and thermal insulation. *Composites Communications*, 2021, vol. 26, art. no. 100778.
35. H. Lee, D. Lee, J. Cho, Y.-O. Kim, S. Lim, S. Youn, Y.C. Jung, S.Y. Kim, D.G. Seong. Super-insulating, flame-retardant, and flexible poly(dimethylsiloxane) composites based on silica aerogel. *Composites Part A: Applied Science and Manufacturing*, 2019, vol. 123, pp. 108–113.
36. M. Timusk, I.A. Nigol, S. Vlassov, S. Oras, T. Kangur, A. Linarts, A. Šutka. Low-density PDMS foams by controlled destabilization of thixotropic emulsions. *Journal of Colloid and Interface Science*, 2022, vol. 626, pp. 265–275.
37. I.-L. Ngo, S. Jeon, C. Byon. Thermal conductivity of transparent and flexible polymers containing fillers: A literature review. *International Journal of Heat and Mass Transfer*, 2016, vol. 98, pp. 219–226.
38. A. Trofimov, L. Pleshkov, H. Back. Hollow glass microspheres for high strength composite cores. *Reinforced Plastics*, 2006, vol. 50, no. 7, pp. 44–46, 48–50.

39. E.V. Antonov, I.M. Sosnin, S. Vlassov, L.M. Dorogin. Polydimethylsiloxane/glass-based composite elastomer for thermophysical applications. *Reviews on Advanced Materials and Technologies*, 2022, vol. 4, no. 1, pp. 28–32.
40. S. Vlassov, S. Oras, M. Timusk, V. Zadin, T. Tiirats, I.M. Sosnin, R. Lõhmus, A. Linarts, A. Kyritsakis, L.M. Dorogin. Thermal, mechanical, and acoustic properties of polydimethylsiloxane filled with hollow glass microspheres. *Materials*, 2022, vol. 15, no. 5, art. no. 1652.
41. T.-L. Han, B.-F. Guo, G.-D. Zhang, L.-C. Tang. Facile synthesis of hollow glass microsphere filled PDMS foam composites with exceptional lightweight, mechanical flexibility, and thermal insulating property. *Molecules*, 2023, vol. 28, no. 6, art. no. 2614.
42. L. Dorogin, B.N.J. Persson. Contact mechanics for polydimethylsiloxane: From liquid to solid. *Soft Matter*, 2018, vol. 14, no. 7, pp. 1142–1148.
43. R. Tadmor. Line energy and the relation between advancing, receding, and Young contact angles. *Langmuir*, 2004, vol. 20, no. 18, pp. 7659–7664.
44. A. Tiwari, L. Dorogin, A.I. Bennett, K.D. Schulze, W.G. Sawyer, M. Tahir, G. Heinrich, B.N.J. Persson. The effect of surface roughness and viscoelasticity on rubber adhesion. *Soft Matter*, 2017, vol. 13, no. 19, pp. 3602–3621.
45. L. Dorogin, A. Tiwari, C. Rotella, P. Mangiagalli, B.N.J. Persson. Adhesion between rubber and glass in dry and lubricated condition. *Journal of Chemical Physics*, 2018, vol. 148, no. 23, art. no. 234702.