International Journal on Magnetic Particle Imaging
Vol 11, No 1, Suppl 1, Article ID 2503060, 3 Pages

Infinite Science Publishing

Proceedings Article

Development of a Magnetically Responsive Polydimethylsiloxane Composite with Optimized SPION Distribution for Coating of Medical Devices

H. Seso[a] · A. Malhotra[b] · K. Lüdtke-Buzug[a,b,*]

[a]Institute of Medical Engineering IMT, University of Lübeck, Lübeck, Germany
[b]Fraunhofer Research Institution for Individualized and Cell-Based Medical Engineering IMTE, Lübeck, Germany
[*]Corresponding author, email: kerstin.luedtkebuzug@uni-luebeck.de

Abstract

This study introduces the development of an innovative polydimethylsiloxane (PDMS) composite enhanced with superparamagnetic iron oxide nanoparticles (SPIONs), specifically engineered as a polymer coating for medical devices and as a functional material for Magnetic Particle Imaging (MPI) in diagnostic applications. To achieve uniform spatial dispersion of nanoparticles within the PDMS matrix, ultrasonic treatment was employed, effectively enhancing the homogeneity of SPION distribution throughout the polymer structure. The results demonstrate significant promise for this superparamagnetic composite, offering new avenues in the advancement of polymer-based materials for medical imaging and device technology.

I. Introduction

From a clinical standpoint, it is essential to enhance the visibility of various medical imaging instruments without relying on ionizing radiation. Consequently, developing specialized coatings for these devices is a logical approach. In this study, a novel polydimethylsiloxane (PDMS) composite embedded with superparamagnetic iron oxide nanoparticles (SPIONs) was developed to create a polymer suitable for medical device coatings, with potential applications in Magnetic Particle Imaging (MPI) for non-invasive medical imaging [1],[2],[3],[4]. PDMS is an elastomer known for its excellent optical, electrical, and mechanical properties, making it highly versatile for various engineering applications. Its biocompatibility further supports its extensive use in biomedical contexts [5]. To achieve uniform spatial dispersion of nanoparticles within the PDMS matrix, ultrasonic treatment was employed. Two types of SPIONs were tested – self-synthesized SPIONs and commercially available Perimag (Micromod) – to evaluate their effectiveness in the composite.

II. Methods and materials

In this project, the Sylgard$^{\text{TM}}$ 184 Kit (DOW) was used, consisting of a two-component system – a base polymer and a curing agent – mixed at a 10:1 ratio as recommended by the manufacturer. This specific ratio ensures optimal curing conditions for the silicone, delivering the desired mechanical and physical characteristics in the final composite. To achieve a uniform dispersion of nanoparticles within the silicon matrix, an ultrasonic homogenizer (Bandelin) with an ultrasonic probe was

10.18416/ijmpi.2025.2503060

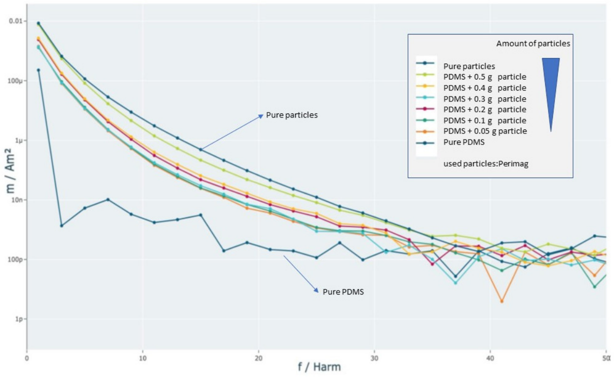


Figure 1: Amplitude spectrum of the polymer with different mixing ratios of SPIONs and PDMS compared to control measurements of pure PDMS and free nanoparticles

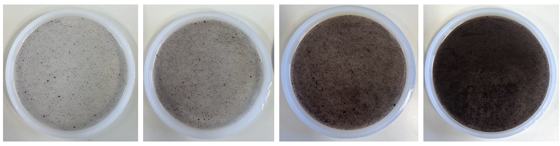


Figure 2: Different polymers with different SPION concentration

utilized. Operating at a frequency of 20 kHz, the homogenizer allows for amplitude control from 10 to 100 percent, enabling precise management of thermal energy produced by the ultrasonic transducer. This ultrasonic treatment was conducted in 5 ml glass vessels to promote effective dispersion.

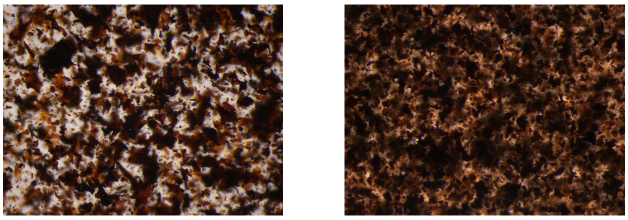
The PDMS mixture was subsequently cured either at room temperature or under elevated temperatures in an oven. The curing time varied depending on temperature: at 25 °C, curing required 48 hours, while at 100 °C it was reduced to 35 minutes, and at 150 °C, curing completed in just 10 minutes. This curing process involves a cross-linking reaction between the base polymer and curing agent, resulting in a solid, elastic silicone structure.

III. Results and discussion

III.I. Magnetic Particle Spectroscopy (MPS)

To evaluate the magnetic properties of the modified polymer composite, samples were analyzed using MPS. Measurements were conducted under standardized, constant conditions to ensure reproducibility and accuracy. During testing, the samples were subjected to an excitation field with a strength of 20 mT and a frequency of 25 kHz. Each measurement included 10 cycles at a repetition rate of 12,500 to capture consistent magnetic responses.

For a comparative analysis of MPS results (Fig. 1), samples were prepared following a standardized protocol, maintaining uniform sample dimensions while varying the concentration of SPIONs across samples (Fig. 2). This approach allowed for an assessment of how different SPION concentrations influence the magnetic response of the PDMS composite under identical measurement conditions.



(a) (b)

Figure 3: Microscope image of the polymer with Perimag (a) simply stirred and (b) after 60 min. treatment with ultrasound

III.II. Microscopy

Imaging of particle cluster distribution and size was performed using a SteREO Discovery.V8 microscope (ZEISS) with consistent parameters, including a fixed zoom, for comparability across samples. Connected to AxioVision SE64 Rel. 4.9.1 software, the microscope offers a resolution of up to 1 μm. In the resulting microscopic image (Fig. 3), distinct cluster formations within the polymer matrix are observed, illustrating the aggregation behavior of SPIONs.

Notably, ultrasonic treatment during polymerization enhances particle distribution, resulting in a more uniform dispersion within the matrix.

The developed coating is flexible and demonstrates strong adhesion properties on various substrates, including glass and other polymeric materials.

IV. Conclusion

The study demonstrated that ultrasonic treatment serves as an effective technique for enhancing nanoparticle dispersion within the silicone matrix, achieving a notably more homogeneous distribution of particles throughout the composite. However, precise control and monitoring of the process parameters are critical to optimize this method. Key factors, such as the ultrasonic frequency and thermal management – specifically cooling during sonication – play essential roles in ensuring consistent particle dispersion and preventing potential agglomeration or thermal degradation.

Author's statement

Conflict of interest: Authors state no conflict of interest.

References

[1] B. Gleich and J. Weizenecker. *Tomographic imaging using the nonlinear response of magnetic particles.* Nature, 435(7046):1217-1217, 2005. doi: 10.1038/nature03808.

[2] I. Miranda, et al., *Properties and applications of pdms for biomedical engineering: A review*, Journal of Functional Biomaterials, vol. 13, no. 1, 2021.

[3] S. Seethapathy and T. Górecki, *Applications of polydimethylsiloxane in analytical chemistry: A review*, Analytica chimica acta, vol. 750, p. 48–62, 2012.

[4]] A. Esteves, et al., *Influence of cross-linker concentration on the cross-linking of pdms and the network structures formed*, Polymer, vol. 50, no. 1, p. 3955–3966, 2009.

[5] S. Kuddannaya,et al, *In Vitro biocompatibility of chemically modified Poly(dimethylsiloxane) surfaces for stable adhesion and long-term investigation of brain cerebral cortex cells*, ACS Appl. Mater. Interfaces 2015, 7, 25529–25538.

10.18416/ijmpi.2025.2503060