Hard-Magnetic Soft Elastic Metamaterials for Tunable Wave Manipulation

Quan Zhang[1*], and Stephan Rudykh[1, 2]
[1] School of Mathematical and Statistical Sciences, University of Galway, Ireland
[2] Department of Mechanical Engineering, University of Wisconsin - Madison, United States
[*]Corresponding author: quan.zhang@universityofgalway.ie

Hard-magnetic active elastomers consist of hard-magnetic particles embedded in a soft matrix. Their ability to rapidly and reversibly change the shape and properties under remote magnetic stimuli, makes them an attractive material platform for soft robotics, actuators and sensors, and biomedical devices [1]. The research area has been witnessing explosive growth, driven by the development of material fabrication enabling the programming of intricate magnetization patterns in soft active materials [2]. Recent studies include exploration of shape-morphing, instability phenomenon, and achieving untethered actuation. However, despite these recent advances, a systematic understanding of their dynamic behaviors remains elusive, limiting their tremendous potential in nondestructive testing, energy harvesting, and smart soft wave devices.

Here, we put forward a novel design of Hard-magnetic Soft Elastic Metamaterials (HSEMs) capable of active and remote manipulation of elastic waves, including the highly desirable broadband low-frequency wave attenuation [3,4], invisible cloaking, and solitary propagation [5]. The metamaterial properties originate in their highly ordered microstructures that are fixed once designed and manufactured. Therefore, the active tunability of current metamaterials is limited. We utilize the complex magneto-mechanical coupling in highly ordered HSEMs to break through the limitation in the metamaterial functions. The developed HSEMs will open new levels of performance in applications ranging from broadband vibration isolation at challenging low-frequency ranges to robust energy harvesting with ultra-high transmission rates.

References

1. W. Hu, G. Z. Lum, M. Mastrangeli, M. Sitti, “Small-scale soft-bodied robot with multimodal locomotion”, Nature 554, 81 (2018).
2. Y. Kim, H. Yuk, R. Zhao, S. A. Chester, X. Zhao, “Printing ferromagnetic domains for untethered fast-transforming soft materials”, Nature 558, 274 (2018).
3. Q. Zhang, S. Rudykh, “Magneto-deformation and transverse elastic waves in hard magnetic soft laminates”, Mechanics of Materials 169, 104325 (2022).
4. Q. Zhang, A. V. Cherkasov, N. Arora, G. Hu, S. Rudykh, “Magnetic field-induced asymmetric mechanical metamaterials”, Extreme Mechanics Letters 59, 101957 (2023).
5. Q. Zhang, A.V. Cherkasov, C. Xie, N. Arora, S. Rudykh, “Nonlinear elastic vector solitons in hard-magnetic soft mechanical metamaterials”, International Journal of Solids and Structures 280, 112396 (2023).