THE ENGINEER STORY

e-ISSN: 3009 - 0792 Volume 18, 2025, 36-39

PRINTABILITY CHARACTERISATION OF MRE FILAMENTS AS A PRELIMINARY STEP TOWARD 4D-PRINTED ENGINE MOUNTING DESIGNS

Khairul Anwar Abdul Kadir [1,*], Saiful Amri Mazlan [1,2], Mohd Aidy Faizal Johari [1]
[1] Engineering Materials and Structures (eMast) iKohza, Malaysia-Japan International Institute of Technology (MJIIT), Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 Kuala Lumpur, Malaysia.
[2] Automotive Development Centre, Institute for Sustainable Transport (IST), Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia.
[*] Corresponding author: khairulanwar.ak@graduate.utm.my

ABSTRACT

This study investigates the fabrication and printability of thermoplastic magnetorheological elastomer (MRE) filaments containing varying carbonyl iron particle (CIP) contents for fused filament fabrication (FFF). Filaments were produced using a solvent-casting and extrusion method and evaluated through the printing of three basic geometries: circular discs, rectangular strips, and dog bone specimens. These shapes enabled systematic assessment of extrusion stability, surface morphology, geometric accuracy, and interlayer cohesion. Filaments with 20–40 wt.% CIP demonstrated stable extrusion and good dimensional fidelity, indicating suitable rheological behaviour for FFF. In contrast, higher CIP loadings (60 wt.% and above) showed surface defects, intermittent flow, and weak layer formation due to increased viscosity and particle agglomeration. Despite these issues, all compositions remained printable. The findings highlight the optimal CIP range for reliable printing and establish a foundation for developing more complex MRE-based components, including adaptive vibration-control structures such as engine mounts.

KEYWORD

Magnetorheological elastomer, fused filament fabrication, carbonyl iron particles, printability, additive manufacturing, 4D printing, smart materials, vibration-control structures

INTRODUCTION

Magnetorheological elastomers (MRE) have attracted significant research interest due to their ability to alter stiffness and damping characteristics in response to an external magnetic field. This behaviour arises from the reorientation and interaction of magnetic particles embedded within an elastomeric matrix (Fakhree et al., 2022)Because of this tunable response, MRE are widely explored for vibration-control applications, particularly in automotive components such as engine mounts and bushings where adaptive stiffness is advantageous (Abdul Hamid et al., 2022; Mat Song et al., 2022). Despite these advantages, the broader adoption of MRE in functional engineering systems is still constrained by conventional fabrication methods such as moulding and casting, which limit geometric flexibility and hinder rapid prototyping (Díaz-García et al., 2022a; Wei et al., 2022).

The emergence of additive manufacturing (AM) offers a pathway to overcome these fabrication constraints. AM enables complex geometries, improved design freedom, and efficient material usage, while allowing tailored internal architectures not achievable through traditional techniques (Palanisamy et al., 2022). Among the various AM techniques, fused filament fabrication (FFF) has gained traction for MRE development due to its accessibility, cost-effectiveness, and compatibility with thermoplastic matrices that can incorporate magnetic fillers (Park et al., 2022) The growing interest in 4D printing, where printed structures exhibit stimuli-responsive behaviour, further highlights the relevance of integrating MREs into extrusion-based AM systems (Lalegani Dezaki & Bodaghi, 2023). However, the printability of MRE composites remains challenging because high-density carbonyl iron particles (CIP) significantly alter melt viscosity, disrupt flow uniformity, and increase the likelihood of particle agglomeration, all of which affect extrusion stability, layer adhesion, and dimensional accuracy (Peng et al., 2024).

This study investigates the printability of thermoplastic MRE filaments with varying CIP contents using FFF technology. By printing three fundamental geometries such as circular discs, rectangular strips, and dogbone specimens, the study evaluates extrusion stability, surface morphology, geometric fidelity, and interlayer cohesion as functions of particle loading. The primary aim is to identify the CIP concentration range that supports stable and consistent printing and to determine the limitations associated with higher filler levels. Establishing the printability performance of these filaments after successful fabrication represents a crucial step toward enabling more complex and functionally demanding MRE structures. These findings provide the foundation for future development of intricate 4D-printed components, including adaptive engine-mounting designs where material responsiveness and structural reliability are essential.

MATERIAL AND METHODOLOGY

Fabrication of MRE Filament

MRE filaments were fabricated using a solvent-casting and extrusion process to promote uniform dispersion of CIP within a TPU matrix. TPU pellets were dissolved in THF to form a homogeneous solution, after which CIP were incorporated at 20 wt.%, 40 wt.%, 60 wt.%, and 80 wt.% and mechanically stirred. The mixture was cast into thin films and dried under ambient and oven-assisted conditions to remove residual solvent. The dried composites were cut and extruded into filaments using a single-screw filament extruder, with temperatures optimized to achieve consistent diameter and smooth surface quality. Filaments were stored in sealed containers prior to printing to minimize moisture absorption.

Printability Evaluation Using Basic Geometries

Printability was assessed using a FFF 3D printer (Artillery Sidewinder X1). Three geometries such as circular discs, rectangular strips, and dogbone specimens, were selected as they represent curved paths, straight-line deposition, and tapered transitions, enabling systematic examination of extrusion behaviour and interlayer adhesion. These prints also served as samples for subsequent mechanical and rheological analysis. All CIP compositions were printed under the same processing parameters, with only minor adjustments made when necessary to prevent nozzle clogging or extrusion instability. Printability was evaluated through extrusion continuity, dimensional accuracy, surface morphology, and layer bonding quality to determine material–process compatibility before further mechanical testing.

Assessment Criteria for Printability

During printing, several characteristics were closely monitored to evaluate the overall print Print performance was assessed by monitoring extrusion stability (continuous or intermittent flow), surface quality, and any protrusion of embedded particles. Geometric fidelity was evaluated by comparing printed dimensions with CAD models. Layer formation like its consistency, cohesion, and the presence of voids, was inspected to assess deposition quality. Nozzle behaviour, including clogging tendency or abnormal pressure, was also recorded as an indication of flow issues. These observations provided quantitative and qualitative insight into how CIP loading influences printability and extrusion behaviour.

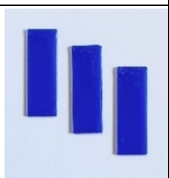
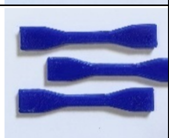
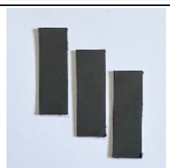
RESULT AND DISCUSSION

The printability of MRE filaments with varying CIP contents was evaluated by printing circular discs, rectangular strips, and dogbone specimens (Table 1). These geometries enabled assessment of extrusion stability and provided samples for subsequent mechanical testing. Filaments containing 20–40 wt.% CIP were printed successfully, exhibiting smooth surface morphology, accurate geometric definition, and good interlayer adhesion. These results indicate that lower filler concentrations allowed effective particle dispersion and maintained rheological properties suitable for FFF processing.

At higher filler contents, particularly 60 wt.% and above, several printability issues emerged. Surface roughness, irregular layer formation, and intermittent extrusion were observed, especially in the 80 wt.% samples. These defects are primarily attributed to particle agglomeration, as increased magnetic interactions at high CIP loadings promote localized clustering that disrupts uniform melt flow. The resulting agglomerates hinder nozzle passage and contribute to inconsistent deposition. Additionally, the rise in viscosity at high CIP levels reduces melt homogeneity and weakens interlayer bonding. Similar trends have been reported by (Wei et al., 2022) and Díaz-García et al., 2022, ho noted elevated viscosity and reduced print consistency in magnetic composite filaments.

High-viscosity materials are also more susceptible to thermal lag during extrusion, where uneven cooling leads to incomplete solidification and dimensional inaccuracies. Despite these challenges, all MRE compositions remained printable to some extent, demonstrating that the TPU matrix provides sufficient thermal stability and elasticity for processing even at elevated filler concentrations. Nevertheless, for CIP contents above 60 wt.%, further formulation improvements, such as dispersion aids or matrix modifications, are recommended to enhance flow uniformity and print consistency. These findings are essential for identifying material–process compatibility in the fabrication of functional, precision-dependent 4D-printed MRE components.

Table 1: The Printability of MRE filaments with varying CIP contents was evaluated by printing three basic geometries.

Mixture of CIP (wt%)	TPU	20	40	60	80
Circle					
Rectangle					
Dog bone					

CONCLUSION

This study demonstrated the successful fabrication and printability of thermoplastic MRE filaments with varying CIP contents using FFF technology. Filaments containing 20–40 wt.% CIP showed stable extrusion, smooth surface quality, and good geometric accuracy, indicating suitable rheological and thermal characteristics for additive manufacturing. In contrast, higher CIP loadings (60 wt.% and above) exhibited intermittent extrusion, surface defects, and weak layer formation due to increased viscosity and particle agglomeration, which disrupted melt flow and interlayer cohesion. Despite these limitations, all formulations were printable, highlighting the robustness of the TPU matrix in accommodating high particle concentrations.

Overall, the findings establish 20–40 wt.% CIP as the optimal range for reliable, defect-free printing and provide essential insight into the material–process relationship governing MRE printability. These results form a critical foundation for advancing toward more complex 4D-printed MRE components, including adaptive vibration-control structures such as engine mounts. Future work will focus on enhancing high-CIP formulations through improved dispersion or matrix modification to support the fabrication of intricate, load-bearing designs for real engineering applications.

ACKNOWLEDGEMENT
This work was supported by the Higher Institution Centre of Excellence (HICoE) program of the Ministry of Higher Education (MOHE) Malaysia under HICoE Research Grant.

REFERENCE

Abdul Hamid, M. I., Abd Fatah, A. Y., Mazlan, S. A., Ubaidillah, U., Imaduddin, F., & Nordin, N. A. (2022). Force and stiffness behavior of natural rubber based magnetorheological elastomer bushing. International Journal of Applied Electromagnetics and Mechanics, 71(1), 1–19.

Díaz-García, Á., Law, J. Y., Felix, M., Guerrero, A., & Franco, V. (2022a). Functional, thermal and rheological properties of polymer-based magnetic composite filaments for additive manufacturing. Materials and Design, 219, 110806.

Díaz-García, Á., Law, J. Y., Felix, M., Guerrero, A., & Franco, V. (2022b). Functional, thermal and rheological properties of polymer-based magnetic composite filaments for additive manufacturing. Materials and Design, 219.

Fakhree, M. A. M., Nordin, N. A., Nazmi, N., Mazlan, S. A., Aziz, S. A. A., Ubaidillah, U., Ahmad, F., & Choi, S. B. (2022). Field-Dependent Rheological Properties of Magnetorheological Elastomer with Fountain-Like Particle Chain Alignment. Micromachines, 13(4), 492.

Lalegani Dezaki, M., & Bodaghi, M. (2023). Magnetorheological elastomer-based 4D printed electroactive composite actuators. Sensors and Actuators A: Physical, 349, 114063.

Mat Song, R., Mazlan, S. A., Johari, N., Imaduddin, F., Abdul Aziz, S. A., Abd Fatah, A. Y., & Ubaidillah, U. (2022). Semi-Active Controllable Stiffness Engine Mount Utilizing Natural Rubber-Based Magnetorheological Elastomers. Frontiers in Materials, 9, 875787.

Palanisamy, C., Raman, R., & Dhanraj, P. kumar. (2022). Additive manufacturing: a review on mechanical properties of polyjet and FDM printed parts. Polymer Bulletin, 79(9), 7065–7116.

Park, J., Becnel, A., Flatau, A. B., & Wereley, N. (2022). Magnetic Particle Reinforced Elastomer Composites for Additive Manufacturing. IEEE Transactions on Magnetics, 58(2), 1–5.

Peng, Z., Zhai, Z., Yang, R., Xu, H., & Wu, Y. (2024). Fabrication and property research of a new 3D-Printable magnetorheological elastomer (MRE). Materials Today Physics, 45, 101467.

Wei, X., Jin, M. L., Yang, H., Wang, X. X., Long, Y. Z., & Chen, Z. (2022). Advances in 3D printing of magnetic materials: Fabrication, properties, and their applications. Journal of Advanced Ceramics, 11(5), 665–701.