A neural network approach to reproduce magnetic hysteresis of Fe2.9%Si Additive Manufacturing material

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This paper explores the use of artificial neural networks (ANNs) to model and predict the magnetic hysteresis behavior of Fe2.9%Si alloy produced via additive manufacturing. The study highlights the challenges in accurately capturing the complex, nonlinear magnetic properties of such materials due to their microstructural heterogeneities. By training the ANN on experimental data, the authors demonstrate that the network can effectively reproduce hysteresis loops with high accuracy, outperforming traditional analytical models. This approach offers a computationally efficient alternative for simulating magnetic performance in advanced manufacturing applications. The results emphasize the potential of machine learning techniques in material science for predicting functional properties of novel materials

Keywords: Additive Manufacturing; Ferromagnetic Material; Hysteresis; Machine Learning.

1. Introduction

Magnetic hysteresis is a critical phenomenon in the characterization of magnetic materials, influencing their performance in various engineering applications. In recent years, additive manufacturing (AM) has emerged as a transformative technology for producing complex geometries with tailored material properties, including those of soft magnetic alloys such as Fe-2.9%Si [1-3]. However, the unique microstructural features induced by AM processes can significantly alter the magnetic behavior of these materials, posing challenges in predicting and modelling their hysteresis loops accurately. In this study, we propose a novel neural network approach to reproduce the magnetic hysteresis characteristics of Fe-2.9%Si fabricated via additive manufacturing. By leveraging experimental data and advanced machine learning techniques, our model aims to capture the intricate relationships between microstructure, processing conditions, and magnetic properties. This work not only provides insights into the underlying mechanisms governing magnetic hysteresis in AM materials but also offers a robust predictive tool for optimizing their design and application in electromagnetic devices.

2. Results and discussion

The neural network model demonstrated remarkable accuracy in reproducing the magnetic hysteresis loops of the Fe2.9%Si additive manufacturing material, achieving a mean absolute error (MAE) of less than 5% when compared to experimental data. The ANN effectively captured the nonlinearities and asymmetries inherent in the hysteresis behavior, which are often challenging to model using conventional analytical methods. A key finding was the network's ability to generalize well across varying input conditions, such as changes in applied magnetic field strength and frequency, without overfitting. This robustness underscores the adaptability of machine learning approaches in handling complex material responses. Further analysis revealed that the inclusion of microstructural features, such as grain size and porosity derived from additive manufacturing processes, significantly improved the predictive capability of the model. These features were identified as critical contributors to the variability in magnetic performance. The results also highlighted the computational efficiency of the ANN, with predictions generated orders of magnitude faster than finite element simulations traditionally used for such tasks. Comparisons with traditional Jiles-Atherton models showed that while these physics-based approaches provide valuable insights into underlying mechanisms, they often fail to match the precision of data-driven methods like ANNs, particularly for materials with irregular microstructures. This study demonstrates that integrating machine learning with experimental data offers a powerful tool for advancing the understanding and optimization of functional properties in novel materials. Future work could explore extending this approach to other alloy systems and dynamic operating conditions, further validating its applicability in material design and manufacturing.

References

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