DESIGN AND EVALUATION OF MAGNETIC POLYMER COMPOSITES FOR S-BAND EMI MITIGATION IN SMALL SATELLITES

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The miniaturization of electronics and the increasing complexity of satellite systems have made managing electromagnetic interference (EMI) increasingly challenging, particularly within the compact environments of small satellites [1]. EMI presents a critical risk to mission performance, as electric fields generated by onboard components, such as power units, antennas, and RF modules, can resonate and amplify within the satellite cavity, potentially affecting subsystem integrity and signal reliability. Conventional approaches to EMI control are often unsuitable for these applications, as they tend to rely on bulky materials or rigid structures that conflict with the tight mass and volume constraints of small satellite platforms. This has created a demand for lightweight, integrated absorber solutions tailored for space environments.

To address this challenge, polymer-based composites incorporating carbonyl iron (CI) particles were fabricated, using both spherical (CIPs) and flake-shaped (CIFs) morphologies. The flake particles were produced via mechanical milling, yielding structures with increased surface area and geometric anisotropy. These characteristics are beneficial for electromagnetic loss mechanisms. Morphological and electromagnetic characterization confirmed that the flake-like structures enhance the material's performance. Specifically, both complex permeability and permittivity were found to increase with higher filler concentrations and anisotropic particle geometry, with the most significant improvements observed near 2 GHz, a key operational frequency band for Tracking, Telemetry, and Command (TT&C) systems.

The experimentally determined electromagnetic parameters were used to perform full-wave 3D simulations within a modular small satellite model (1 m in height, with a 550 mm × 550 mm base). These simulations enabled evaluation of how particle shape, filler content, and material thickness affect the electromagnetic behavior of the absorber under realistic deployment conditions. Results revealed that composites with high concentrations of flake-like CI particles were effective at attenuating electric fields within satellite cavities. Additionally, the role of material thickness in enhancing attenuation was analyzed, with detailed results provided in Table I.

Simulation outcomes were compared to those of a benchmark high-performance reference material [2]. The comparison demonstrated that the enhanced complex permeability achieved through flake morphology can deliver equivalent or improved EMI attenuation, even at reduced composite thicknesses [3]. This indicates the potential for significant reductions in both weight and occupied volume, key advantages in satellite design and integration.

This work, developed in collaboration with the Department of Electromagnetic Compatibility at Thales Alenia Space, confirms that magnetically filled polymer composites—especially those with optimized flake-like CI particles—represent a promising and scalable solution for EMI attenuation in small satellites. Their validated performance in both experimental and simulated environments supports their adoption as advanced absorbers in next-generation space platforms. Future developments should focus on refining particle processing, dispersion, and matrix compatibility to further enhance material efficiency under spaceborne constraints.

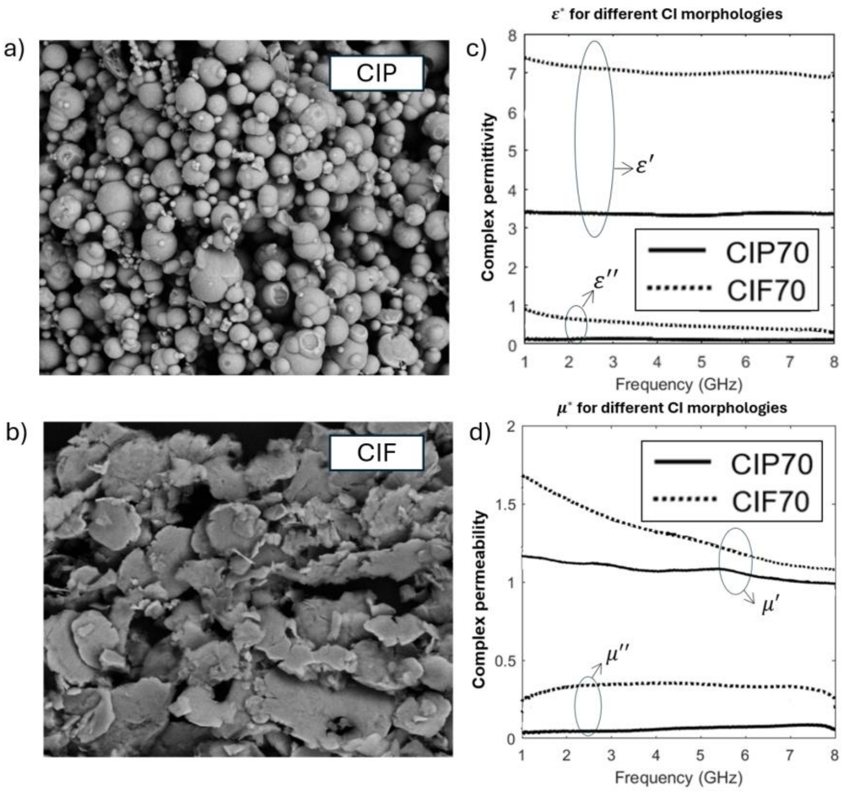

Figure 1. SEM images of carbonyl iron particles: (a) spherical and (b) flake-like morphology. Electromagnetic properties at 70 %wt: (c) permittivity and (d) permeability of composites with both particle types.

TABLE I. 3D FULL-WAVE SIMULATION RESULTS

Samples	Thickness	**S/C Mean Attenuation [dB]**	**Module Mean Attenuation [dB]**
CIP 70%wt	2mm	-1.10	-1.12
	4mm	-2.12	-2.60
CIF 70%wt	2mm	-3.96	-4.39
	4mm	-6.35	-7.38
Benchmark material [2]	2mm	-6.90	-8.12
	4mm	-10.15	-11.76

References

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2. B. Zhang, et al., "Microwave-absorbing properties of de-aggregated flake-shaped carbonyl-iron particle composites at 2-18 GHz," in *IEEE Transactions on Magnetics*, vol. 42, no. 7, pp. 1778-1781, July 2006.
3. Casling A. N., et al. “Performance Assessment of Magnetic Polymeric Composites for EMI Reduction in Small Satellites”, *ESA Workshop 2025*.