

Characterization of Biodegradable Magnetic Elastomers for Mechanical Stimulation in Organ-on-Chip Platforms

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Summary:

This work reports the characterization of a biodegradable magneto-active elastomer composite based on poly(octamethylene maleate (anhydride) citrate) (POMaC) embedded with carbonyl iron particles (CIP). Biodegradable magneto-active elastomer composites with 10–40 wt.% CIP are characterized for morphology, magnetic response, mechanical behavior, and cytocompatibility. Processed into thin bilayer scaffolds, the optimized 20 wt.% composite delivers reproducible cyclic deformation with millimeter-scale tip displacement and ~7% tensile strain under 70 mT fields, with >97% cytocompatibility.

Keywords: magneto-active elastomer, biodegradable composite, POMaC, carbonyl iron particles, magnetic actuation

Background, Motivation and Objective

Magneto-active elastomers, soft polymers loaded with magnetic microparticles, are an attractive class of stimuli-responsive materials for wireless mechanical actuation. They enable contact-free, programmable deformation under externally applied magnetic fields and can be shaped into thin, compliant structures suitable for biological environments [1]. However, most magneto-active elastomers reported to date are based on non-degradable matrices such as PDMS or silicone rubbers, which limits their use in applications where transient mechanical function and eventual material resorption are desirable. Translating these materials into biodegradable formulations requires a polymer matrix that combines elasticity, processability, and cytocompatibility while accommodating high filler loadings without losing mechanical integrity. In this work, we characterize a biodegradable magneto-active composite based on POMaC loaded with carbonyl iron particles (CIP), focusing on the relationship between filler content, morphology, magnetic response, mechanical behavior, and cytocompatibility.

Description of the System

The composite is prepared by dispersing CIP within liquid POMaC pre-polymer and crosslinking the mixture into thin bilayer films (Fig. 1). The base layer consists of pure POMaC and provides a transparent, compliant substrate, while the upper layer incorporates the magnetically responsive POMaC–CIP composite. Patterned

windows are introduced into the POMaC–CIP layer by laser processing to define the final scaffold geometry. SEM imaging confirms the homogeneous distribution of CIP particles within the POMaC matrix. Under an externally applied oscillating magnetic field, the embedded CIP particles experience a magnetic torque that translates into cyclic out-of-plane bending of the composite. This configuration removes the need for tethered or pneumatic actuation, while keeping the entire structure within a fully biodegradable material system.

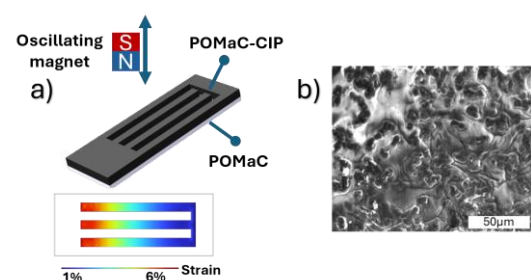


Fig. 1. (a) Bilayer POMaC–CIP composite scaffold and FEM strain distribution under a 70 mT magnetic field. (b) SEM morphology of the POMaC–CIP composite (scale bar: 50 μ m).

Results

FEM simulations were used to evaluate the strain distribution within the bilayer composite under magnetic actuation (Fig. 1a). For the designed geometry, FEM predicts tensile strains of ~7% in the window region under a 70 mT magnetic field. The magnetic response of the

composite was characterized by SQUID magnetometry across the 10–40 wt.% CIP loading range (Fig. 2), confirming that the magnetization of the composite scales with CIP content while retaining the soft-magnetic, low-remanence behavior typical of carbonyl iron fillers.

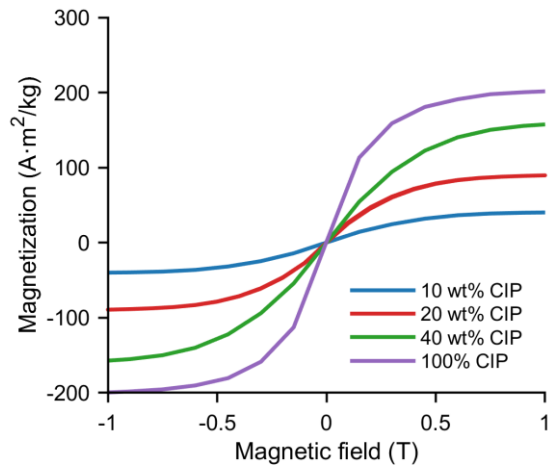


Fig. 2. SQUID magnetometry of POMaC–CIP composites at varying CIP loading.

Mechanical behavior of the composite was characterized by DMA across the 10–40 wt.% CIP loading range (Tab. 1). The Young's modulus increases from 9.5 kPa for pure POMaC to 130 kPa at 40 wt.% CIP, while strain at break decreases from 137.1% to 50.7%, consistent with the expected stiffening effect of rigid filler incorporation in an elastomer matrix. Among the tested formulations, 20 wt.% CIP provides the best compromise between magnetic responsiveness and elastomeric compliance and was selected for further evaluation. Cytocompatibility of the optimized formulation was assessed using LN229 cells exposed to POMaC and POMaC–CIP conditioned media, with viability remaining above 97% after 24 h, confirming that the composite is well tolerated under standard culture conditions (Fig. 3).

Tab. 1: DMA-derived Young's modulus and strain at break of POMaC–CIP composites at varying CIP loading

Sample	E(kPa)	Strain(%)
Pure POMaC	9.5	137.1%
10% POMaC-CIP	14.6	95.1%
20% POMaC-CIP	45	65.2%
40% POMaC-CIP	130	50.7%

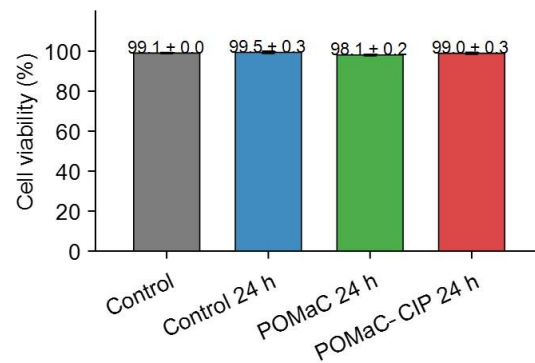


Fig. 3. Viability of LN229 cells exposed to POMaC and POMaC–CIP conditioned media for 24 h compared to untreated controls. Data are presented as mean ± SD.

Conclusions

This work characterizes a biodegradable magneto-active elastomer composite based on POMaC loaded with carbonyl iron particles. Combined SEM, SQUID magnetometry, and DMA characterization across 10–40 wt.% CIP loading establish the relationship between filler content, morphology, magnetic response, and mechanical behavior. The optimized 20 wt.% formulation maintains elastomeric compliance, exhibits cytocompatibility above 97%, and produces cyclic out-of-plane deformation with millimeter-scale tip displacement and ~7% tensile strain under low magnetic field (70 mT). These results establish the POMaC–CIP system as a wireless, biodegradable magneto-active elastomer suitable for further integration into compliant actuating structures.

References

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