2025 Shape Memory Materials Virtual Contest

Shape Memory Interlocking Metasurfaces: A Framework for Adaptive and Reconfigurable Joining

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Abstract:

This work presents the design and demonstration of *active interlocking metasurfaces* (ILMs) fabricated using shape memory alloys (SMAs) for reversible mechanical joining. By leveraging the shape memory effect in additively manufactured near-equiatomic NiTi alloys, we developed two ILM architectures—Pinch Grip (PG) and Expanding Anchors (EA)—capable of engaging, disengaging, and reengaging upon thermal activation. Finite Element Analysis (FEA) was used to ensure strains during actuation remained within the 5% recoverable transformation strain of NiTi.

Using a laser powder bed fusion (L-PBF) process with optimized parameters and a calibrated melt pool model, fully dense, defect-free NiTi components were fabricated. Thermomechanical testing revealed high locking forces (up to 1.2 MPa for PG and 2 MPa for EA), 95% strain recovery, and stable performance over repeated heating–cooling cycles. Digital image correlation (DIC) validated model predictions and localized strain evolution during cyclic actuation. This integration of design, modeling, and fabrication offers a scalable platform for creating intelligent mechanical interfaces.

These active ILMs offer transformative potential for medical devices, such as modular implants, reconfigurable surgical tools, and self-assembling components that benefit from minimally invasive deployment. The temperature-triggered response eliminates the need for manual manipulation or complex actuation systems, enabling safer and more adaptive medical technologies. By combining the unique properties of SMAs with architected mechanical interfaces, this work introduces a new paradigm for dynamic, reusable, and biocompatible mechanical joints. Our findings establish a foundation for future exploration of SMA-enabled metamaterials in biomedical, aerospace, and soft robotics applications.