Crystallography-inspired Hierarchical Multiscale Mechanical Metamaterials

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Introduction

Architected metamaterials achieve exceptional mechanical properties through tailored topologies, enabling performance beyond conventional materials. At the nanoscale, dominant surface and size effects create new design opportunities. Molecular dynamics simulations of nickel-based nano-architected metamaterials reveal tunable elastic modulus, strength, and Poisson's ratio through variations in topology, density, crystallinity, and grain size, outperforming existing designs at similar densities. Inspired by crystallography, hierarchical polymeric metamaterials are also 3D printed, exhibiting topology-dependent stiffness, strength, ductility, and enhanced toughness.

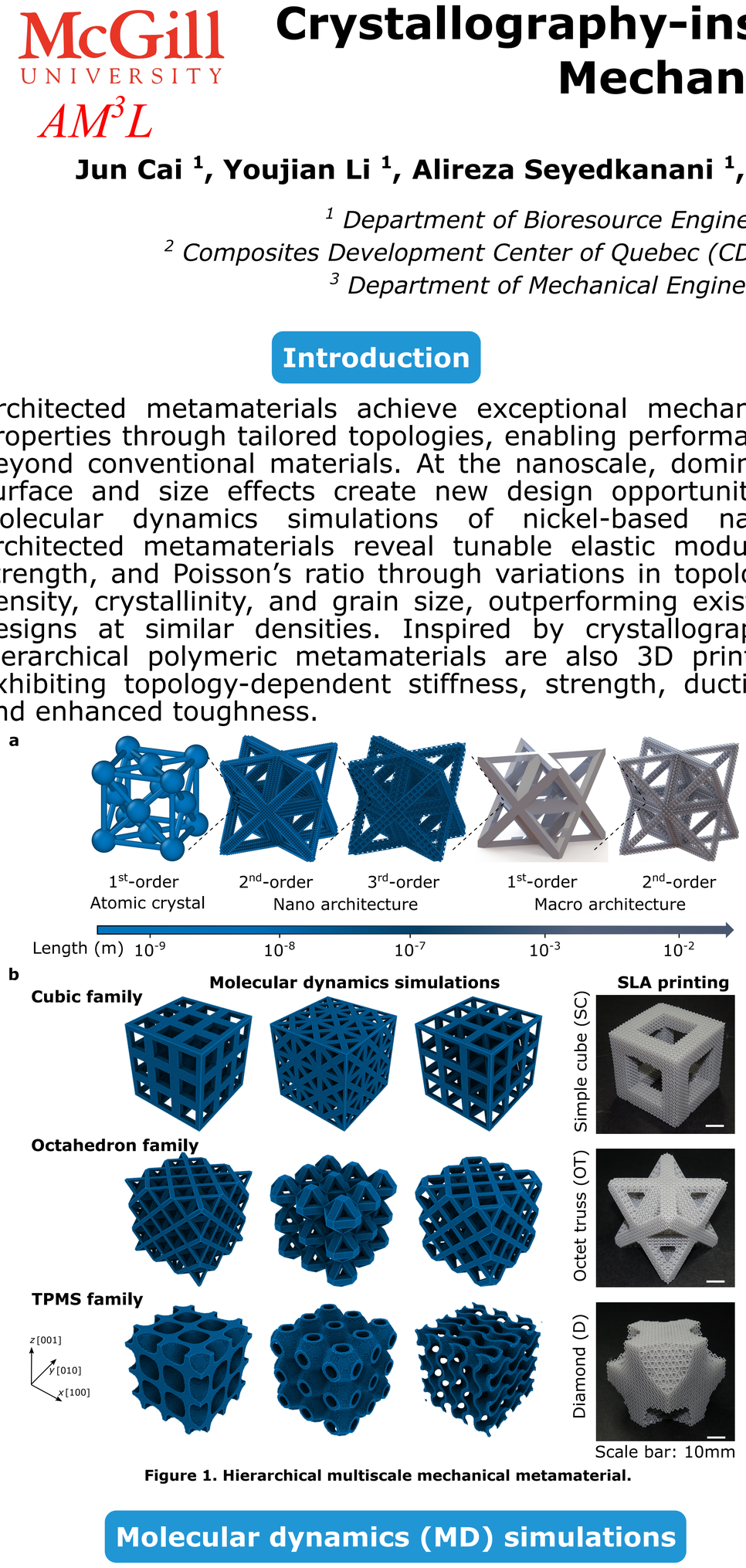

Figure 1. Hierarchical multiscale mechanical metamaterial.

Molecular dynamics (MD) simulations

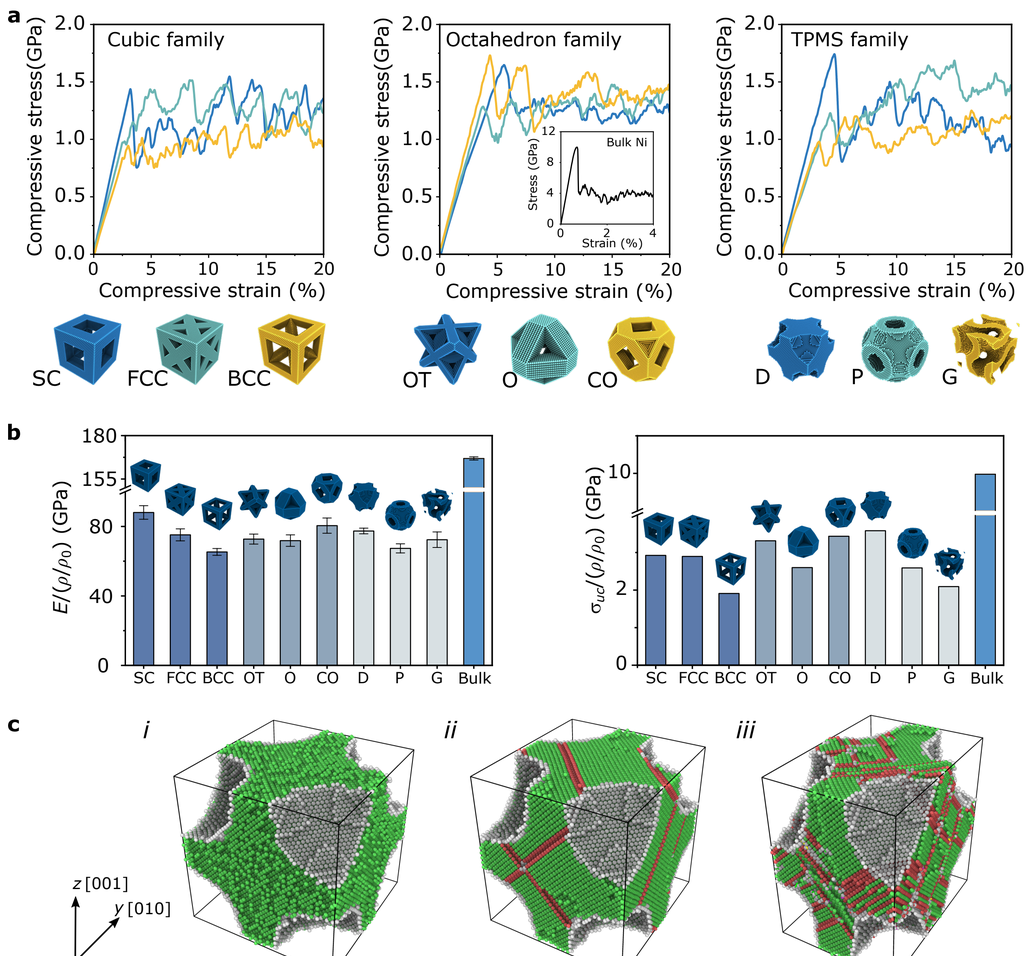

Figure 2. Mechanical properties of nano-architected metamaterials determined by MD simulations

3D-printing & Experiments

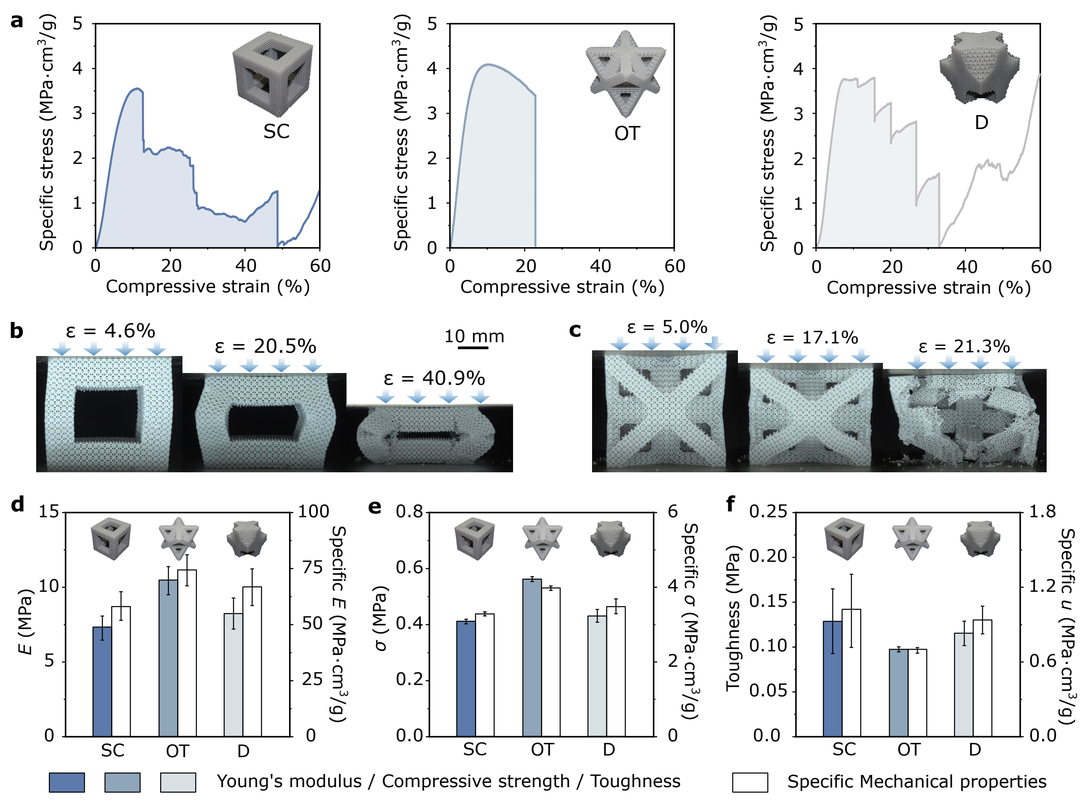

Figure 3. Additive manufactured hierarchical metamaterials and experimentations.

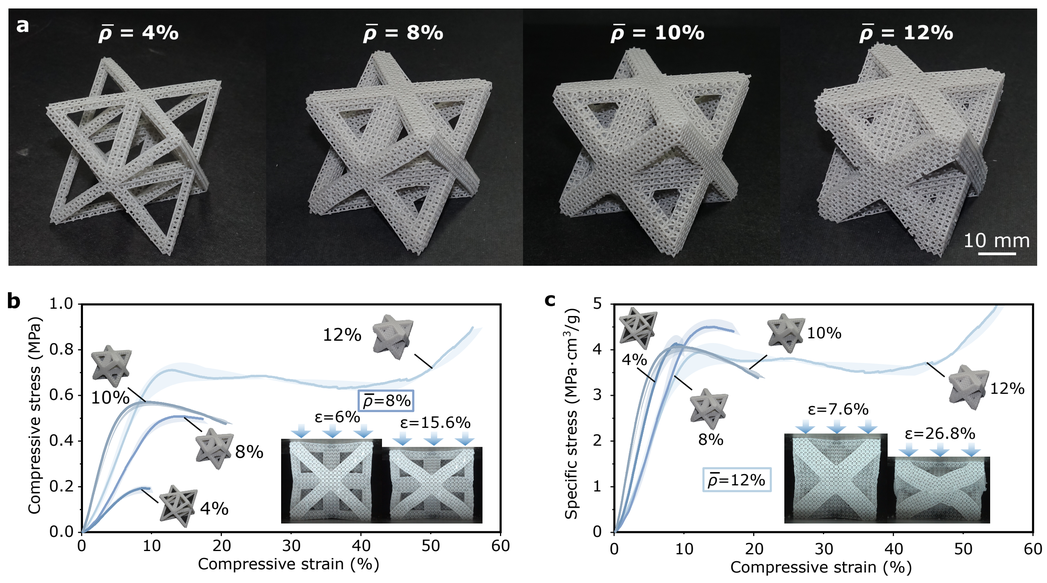

Figure 4. Effects of relative density

Conclusions

- Designed nickel-based nano-architected metamaterials across cubic, octahedral, and TPMS topology families. Identified an inverse Hall–Petch relationship in polycrystalline nano-architected structures, highlighting grain size as a critical parameter in nanoscale metamaterial design.
- Fabricated crystallography-inspired hierarchical metamaterials using SLA-based 3D printing.
- Demonstrated the scalability of the crystallography-inspired design strategy by achieving topology-dependent stiffness, strength, and improved toughness in macroscale structures.

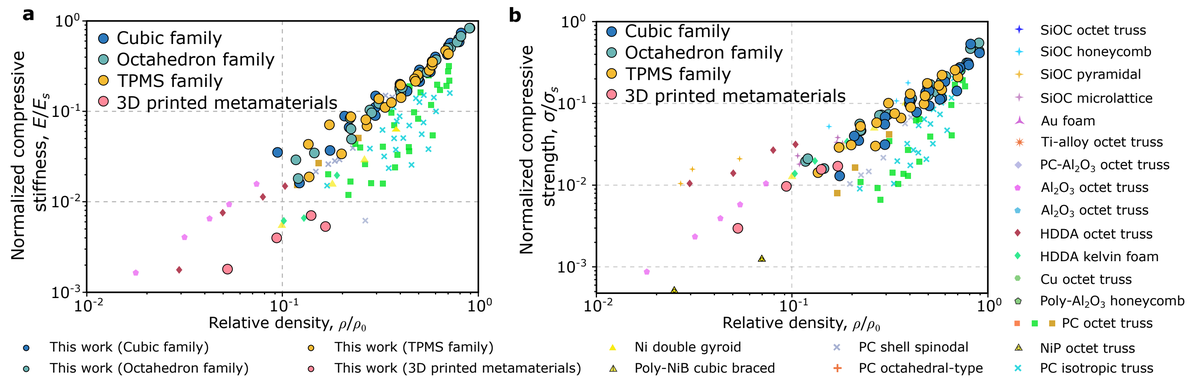

Figure 5. Comparison with literature data

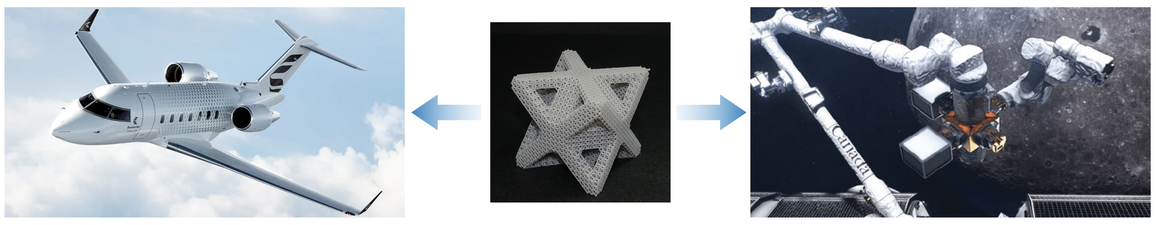

Figure 6. Applications for the nano-architected metamaterials

Acknowledgements

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