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Mechanical anisotropy of 3D-printed, digital materials at large strains[1]

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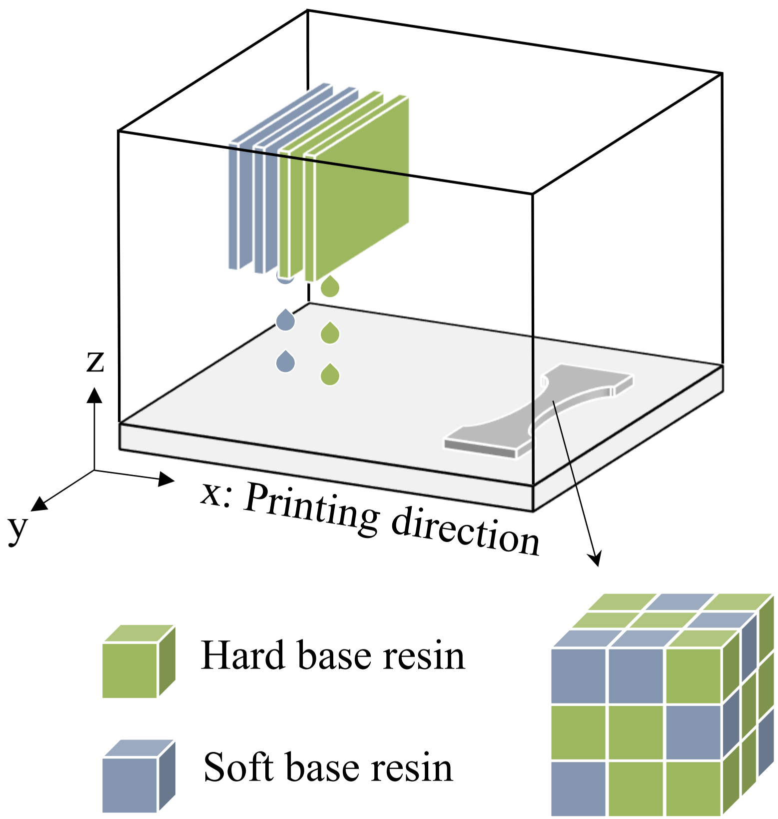
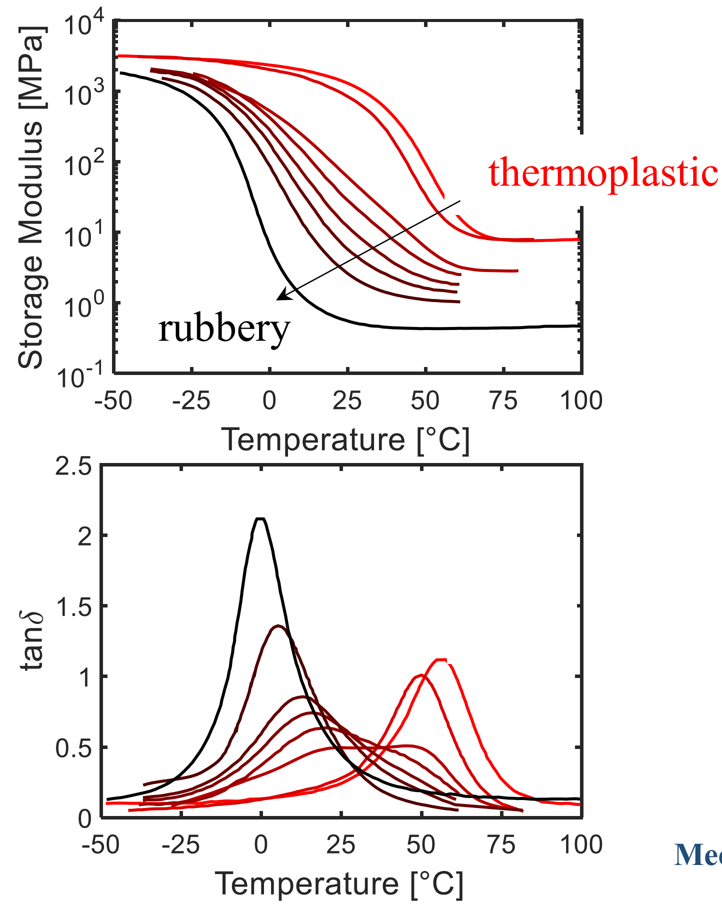
Multi-material, 3D-printed “digital materials”

- Mixtures of hard and soft (photocurable) base resins in material jetting
- Hybrid mechanical properties between **thermoplastic** and **rubbery** polymers[2-5]
  → Widely used for **physical prototyping**[6-9] & Characterized through mechanical testing[10,11], continuum-based constitutive modeling[12,13] and physics-augmented neural networks[14,15]





Objectives

- Address the underlying **deformation mechanisms** governing printing-orientation-dependent behavior through experiment, microscopy analysis, and **micromechanical modeling**

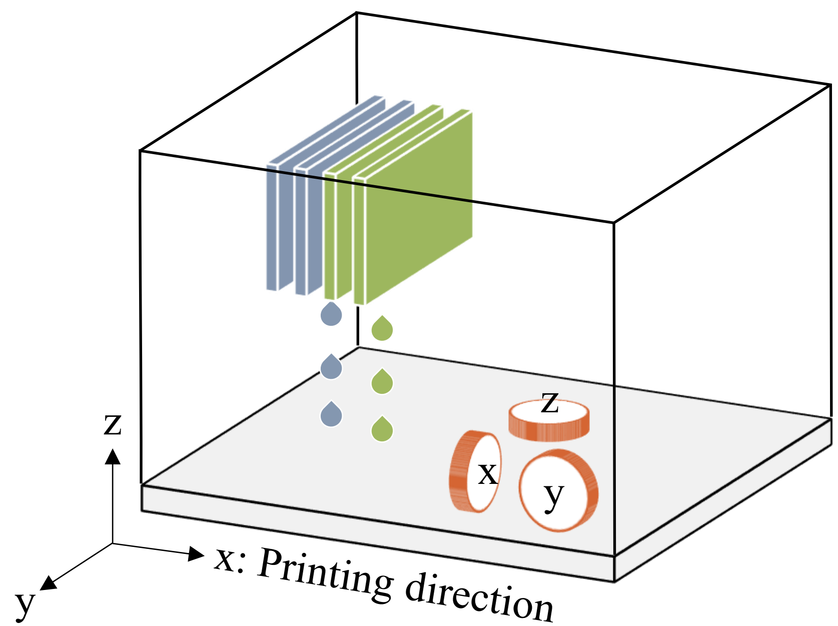
  → Focus on (soft) **digital materials** enabled by **material jetting**

Experimental procedures

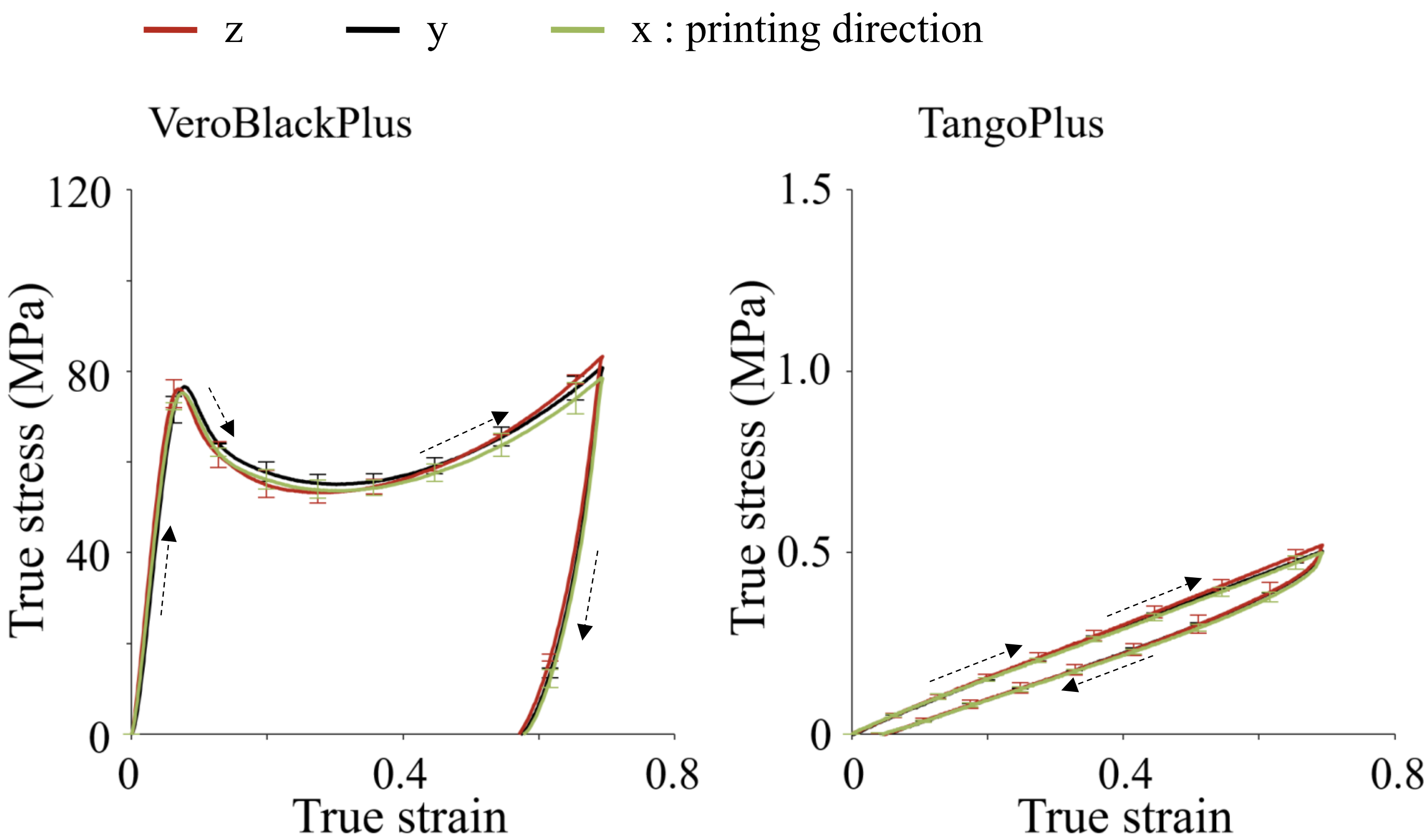
- Using a high-resolution multi-material 3D printer
- Cylindrical specimens printed in three different directions: x-, y- and z-directions

→ Quasi-static, uniaxial compression tests

Connex 3 Objet260,
Stratasys Inc.

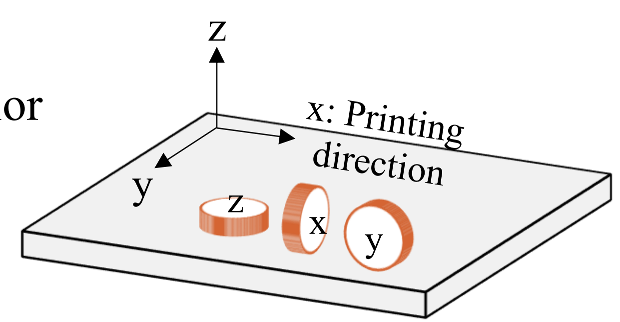


Orientation-dependent mechanical behavior

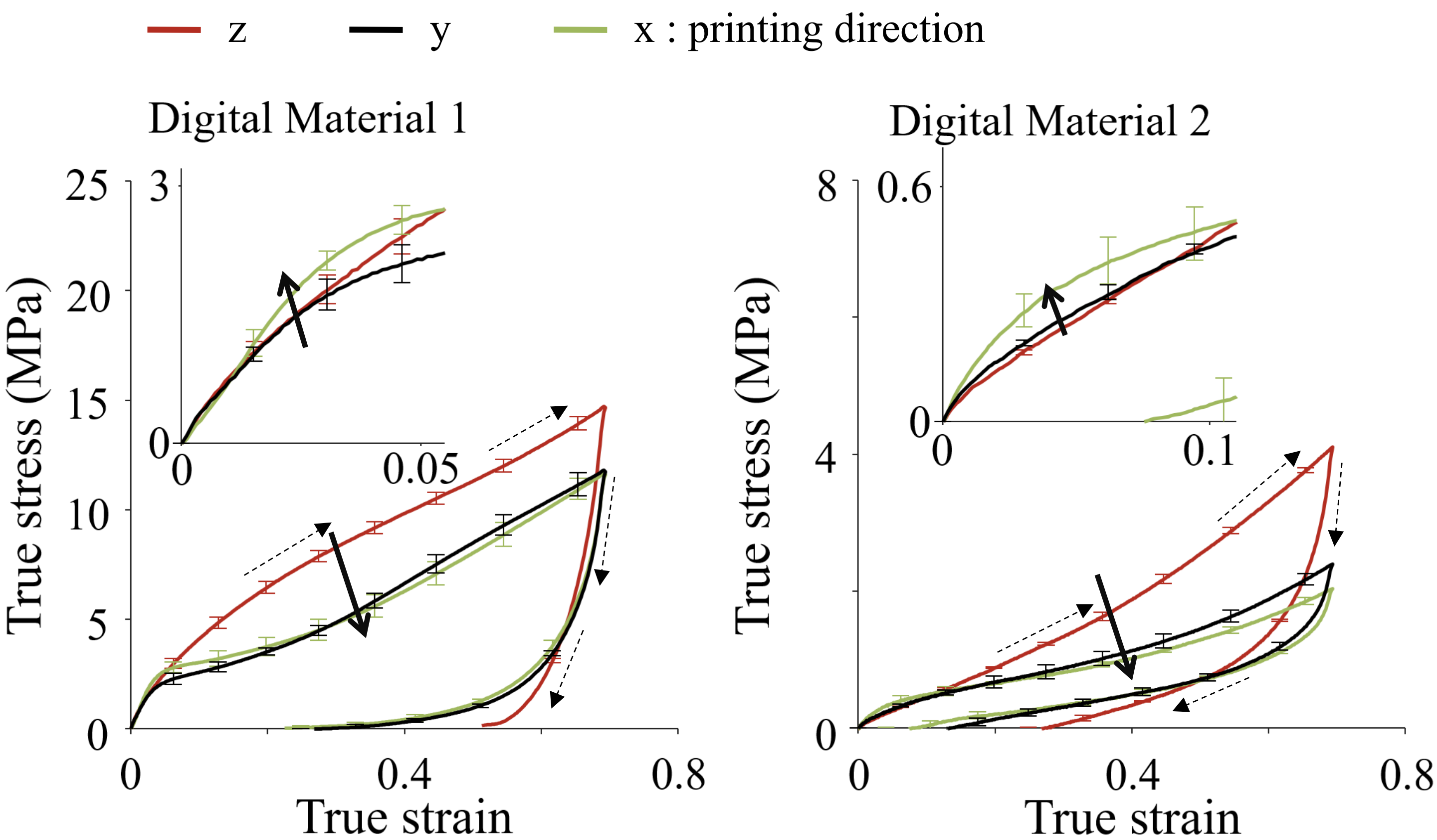


- Base material1 – VeroBlackPlus (VB): **thermoplastic** behavior
- Base material2 – TangoPlus (TP): **elastomeric** behavior

→ Nearly **isotropic** behavior at small to large strains

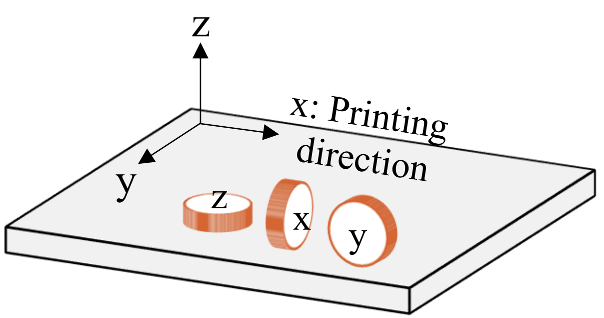


Orientation-dependent mechanical behavior



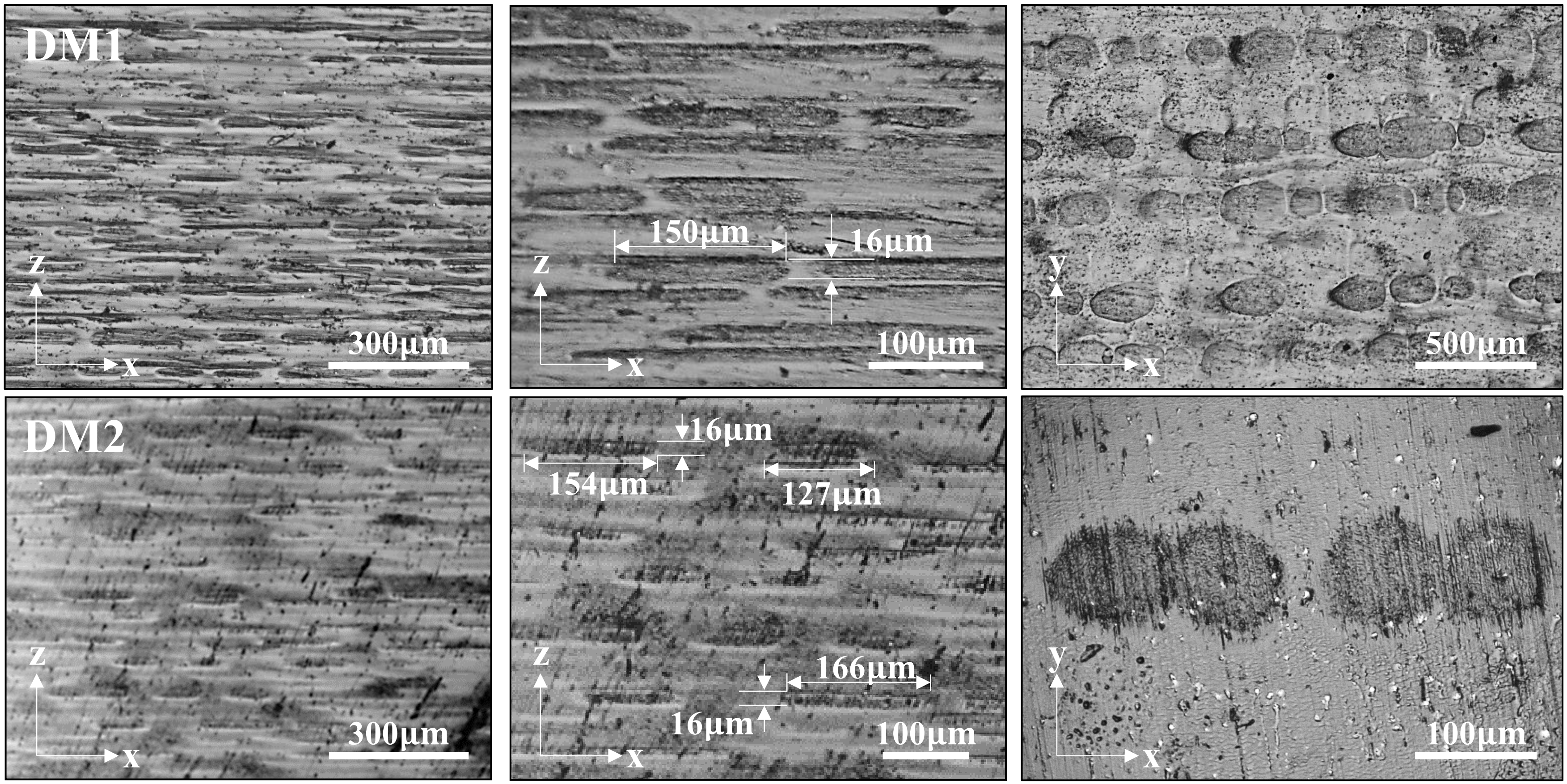
- Digital material 1 (DM1): **64wt%** TangoPlus (TP)
- Digital material 2 (DM2): **80wt%** TangoPlus (TP)

→ Completely **anisotropic** behavior at small to large strains



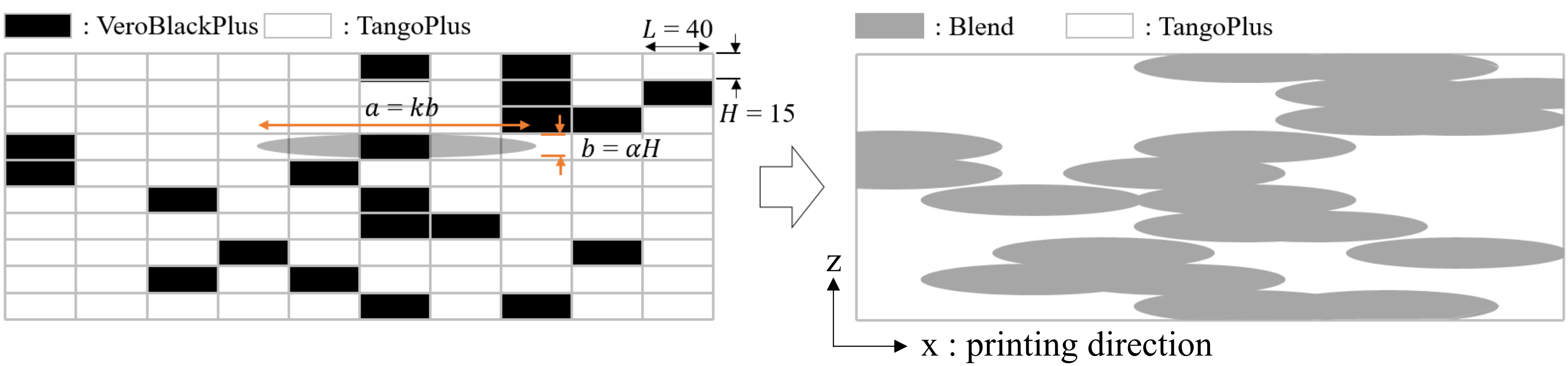
Microstructures

- Well-aligned **elliptical (hard) domains** embedded in the **surrounding (soft) matrix**
- **Diffusion and mixing** of base materials during **layer-by-layer printing**[16]



Representative volume elements (RVEs)

- Start from the **deposition pattern** that defines where each base resin is deposited during the printing process
- Then, replace VB cells with **ellipses**
  - $b = \boldsymbol{\alpha} H$ → $\boldsymbol{\alpha} \sim 1$ due to limited interlayer diffusion
  - $a = \boldsymbol{k} b$ → $\boldsymbol{k} \sim 8 – 10$ due to significant diffusion within a layer



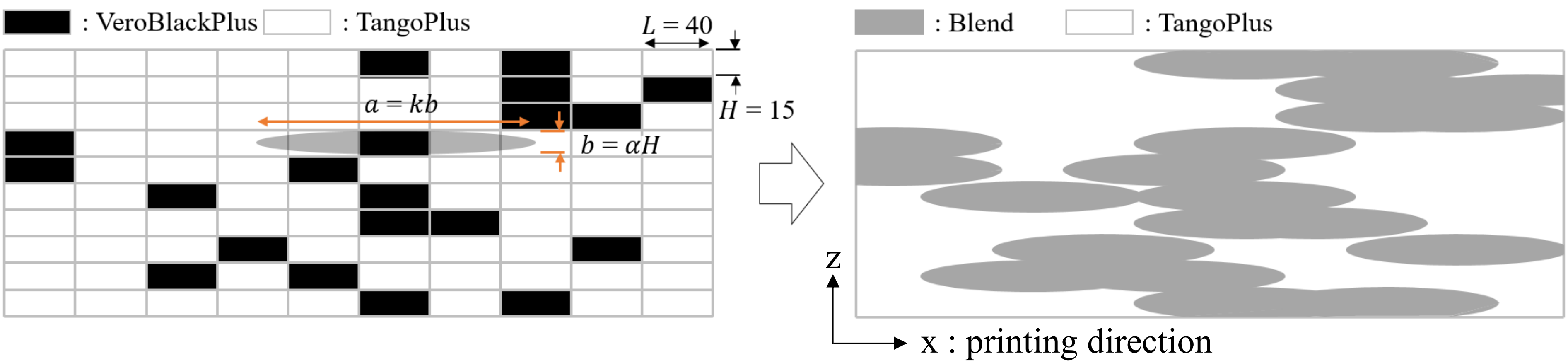
Representative volume elements (RVEs)

- **Constitutive behavior** of both domains

→ We assume …

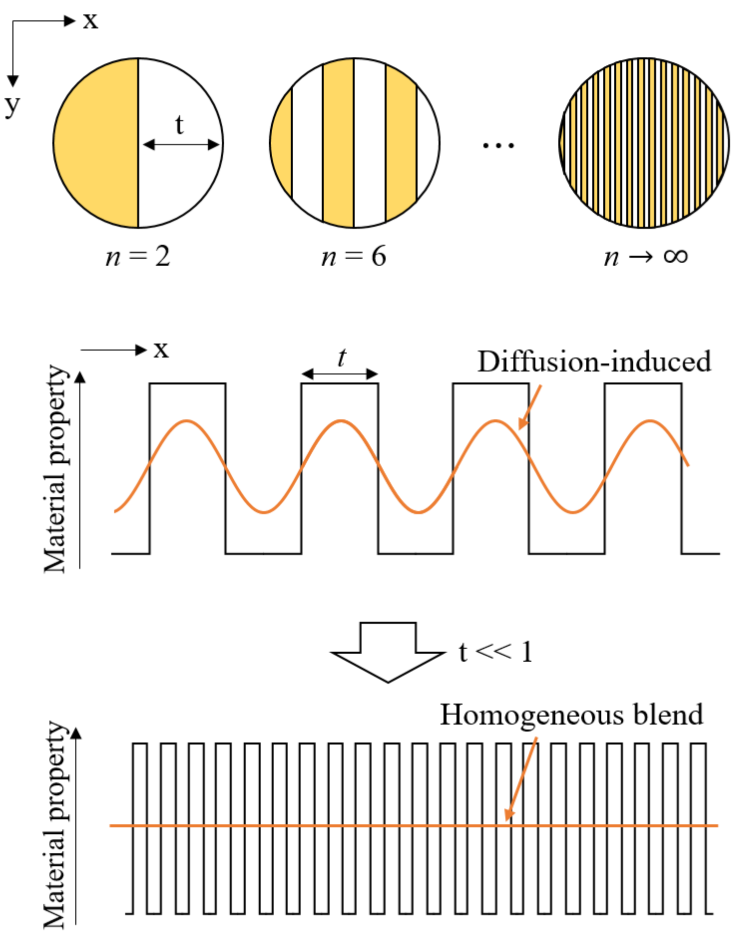
Hard domain: homogeneous 50%/50% blend of hard and soft base materials

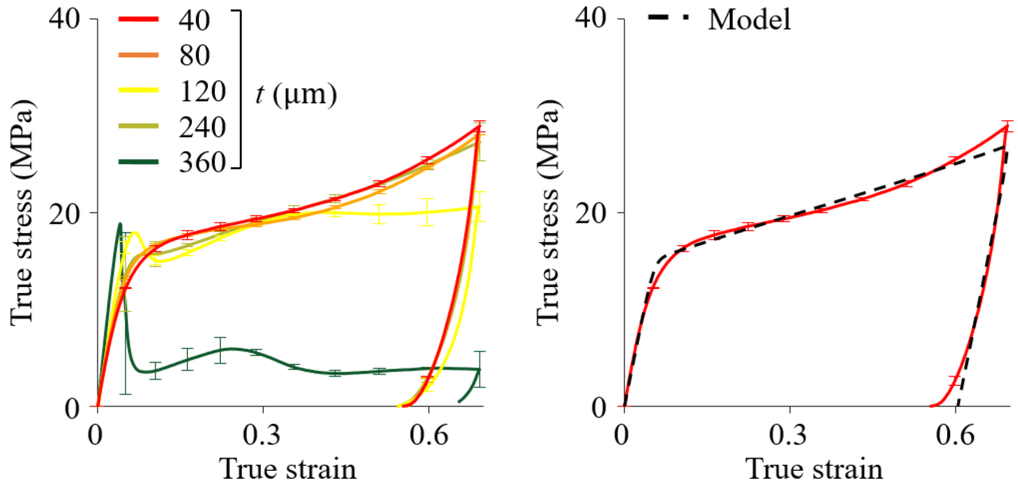
Soft domain: pure soft base material

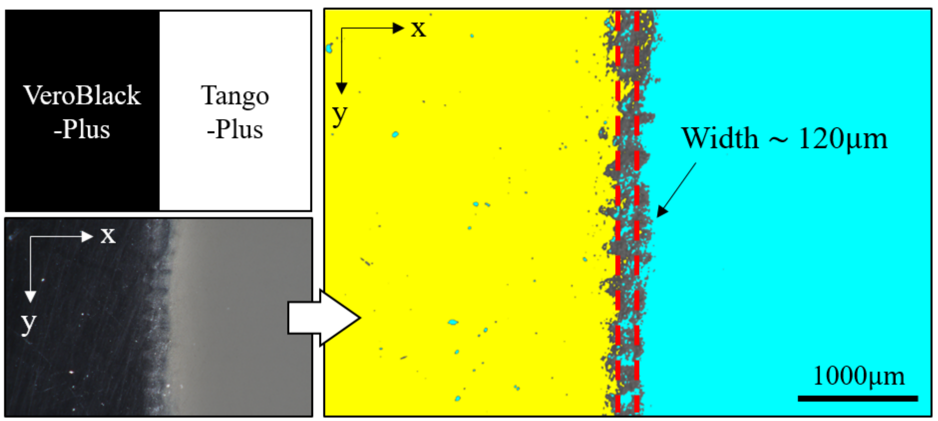


Representative volume elements (RVEs)

- To obtain the large strain mechanical behavior of the blend (i.e., hard domain)
  → We fabricate specimens with **alternating layers**

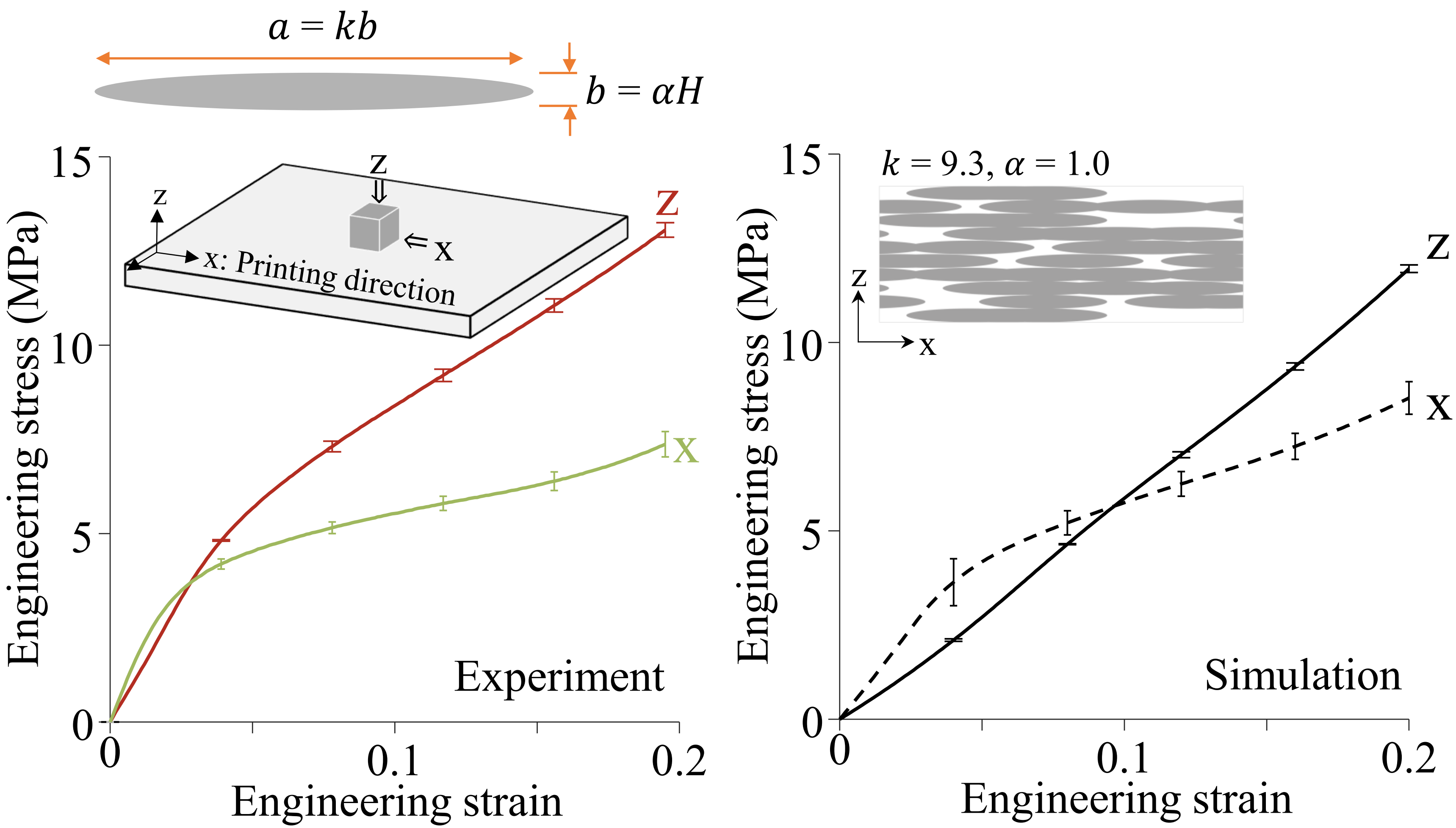






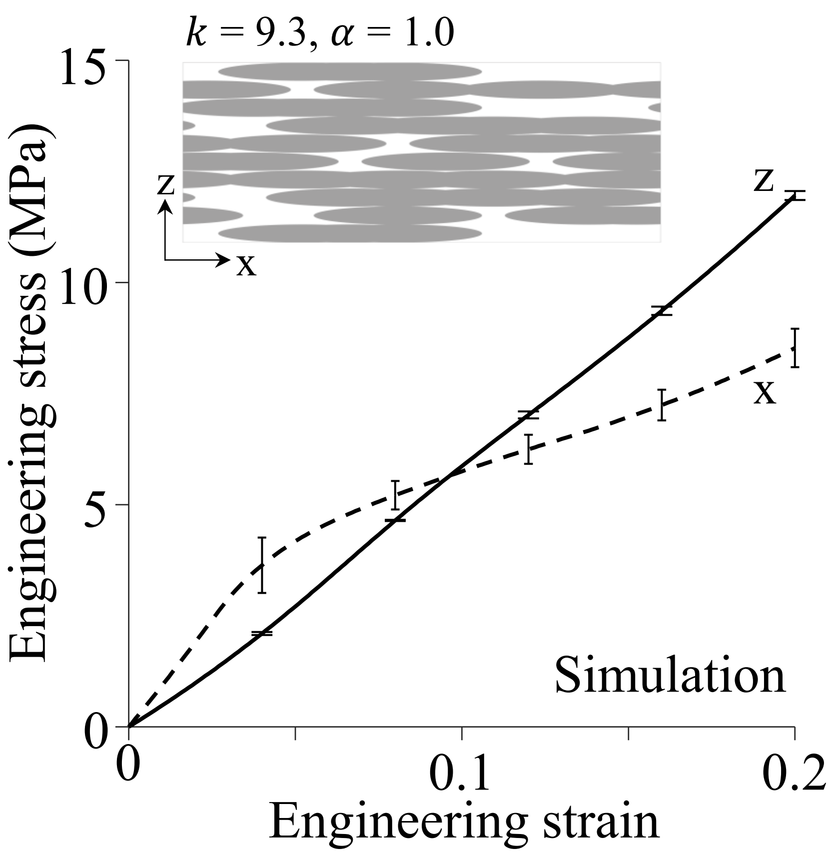
Micromechanical modeling results

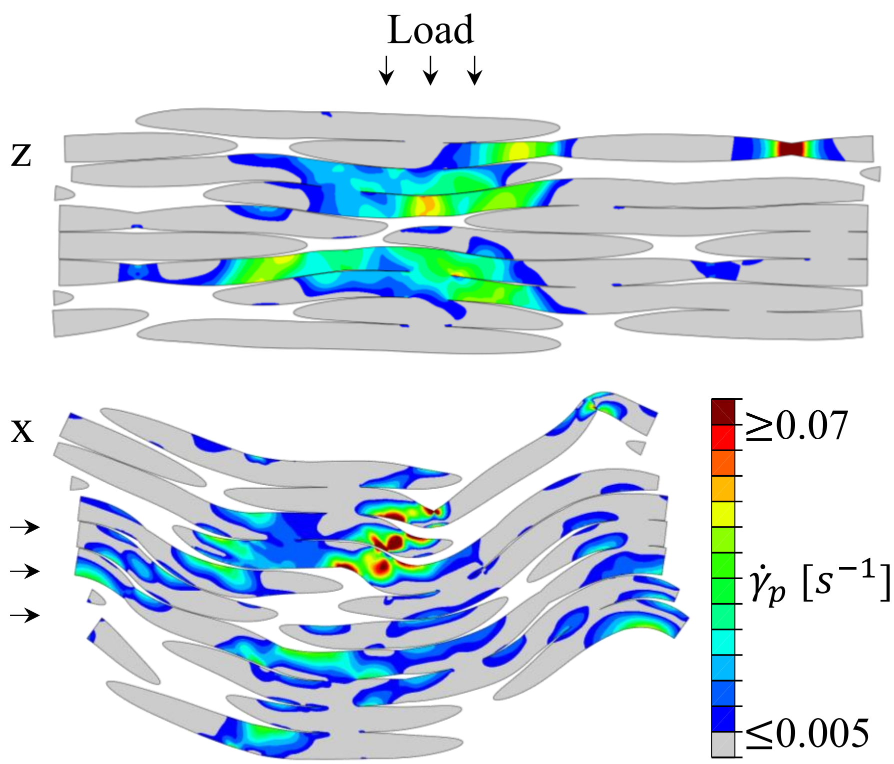
- RVEs nicely capture the anisotropic behavior of **DM1** (**64wt%** TP) at small to large strains



Micromechanical modeling results

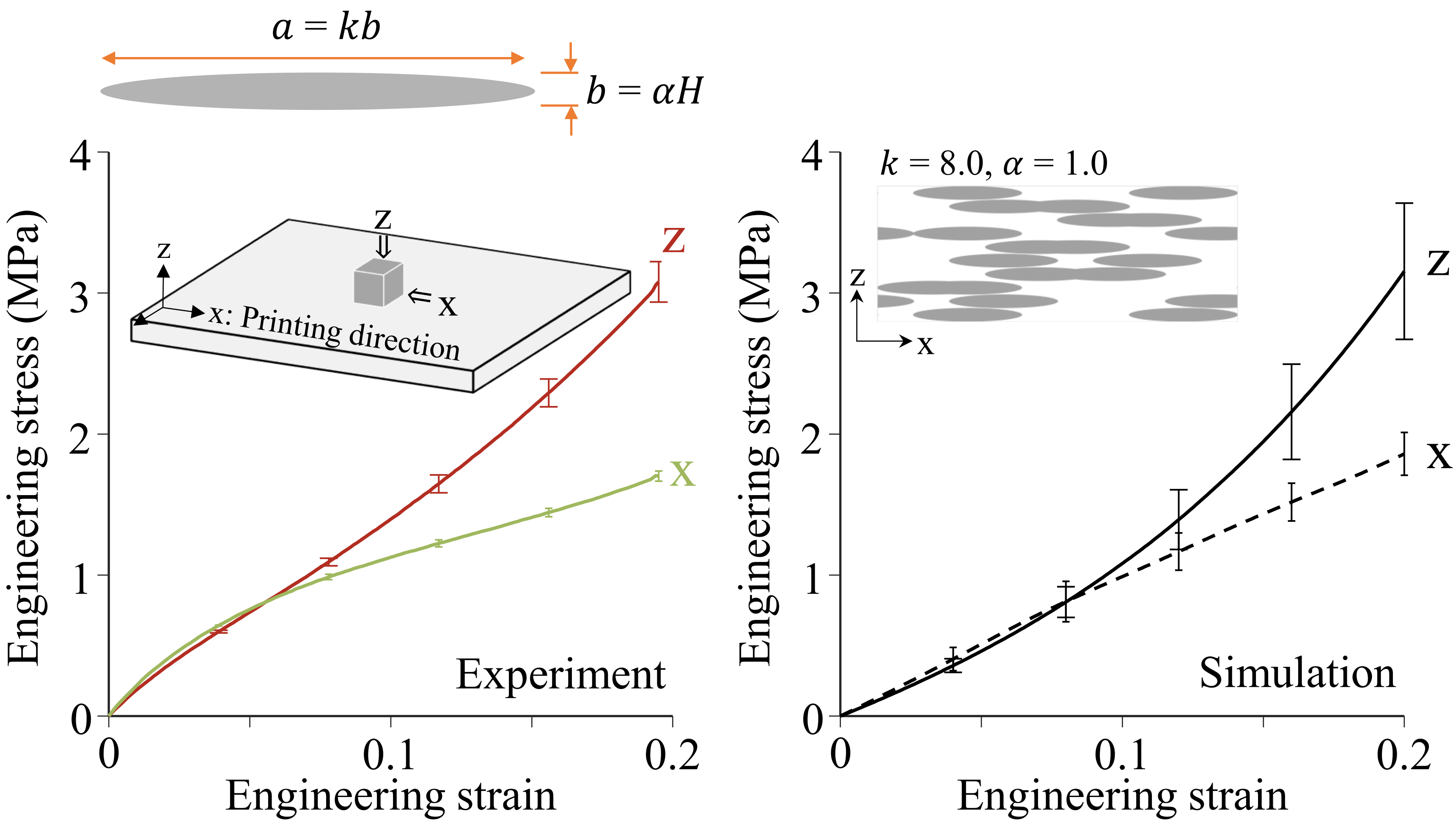
- Deformation mechanisms underlying the anisotropic behavior
  : **Local buckling** of high-aspect-ratio elliptical hard domains





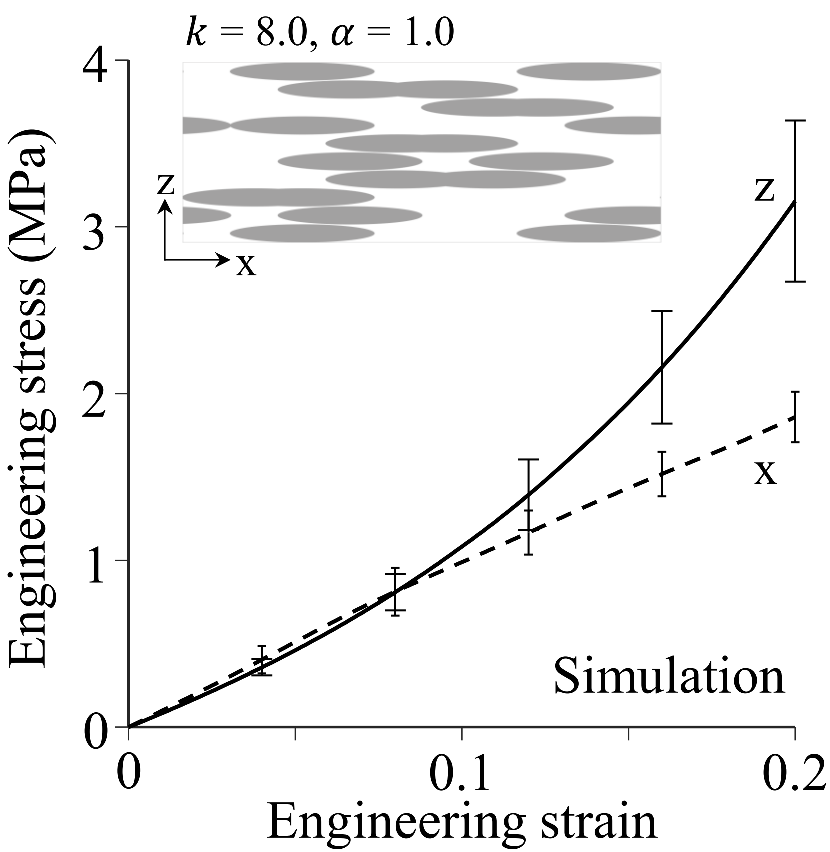
Micromechanical modeling results

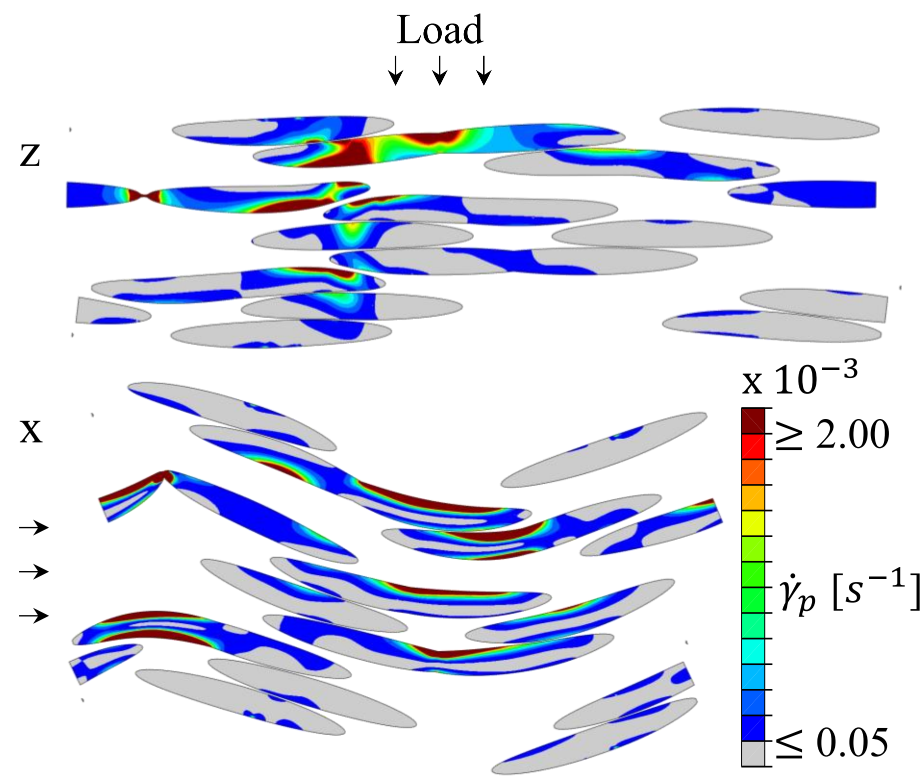
- RVEs nicely capture the anisotropic behavior of **DM2** (**80wt%** TP) at small to large strains



Micromechanical modeling results

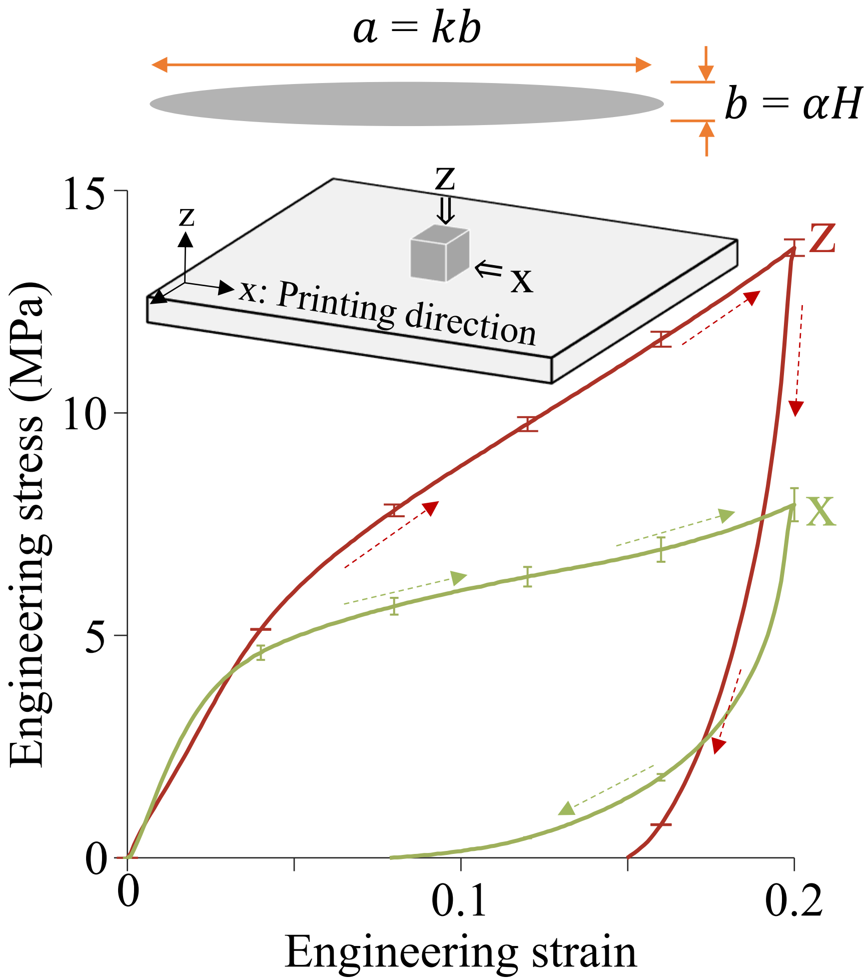
- Deformation mechanisms underlying the anisotropic behavior
  : **Local buckling** of high-aspect-ratio elliptical hard domains

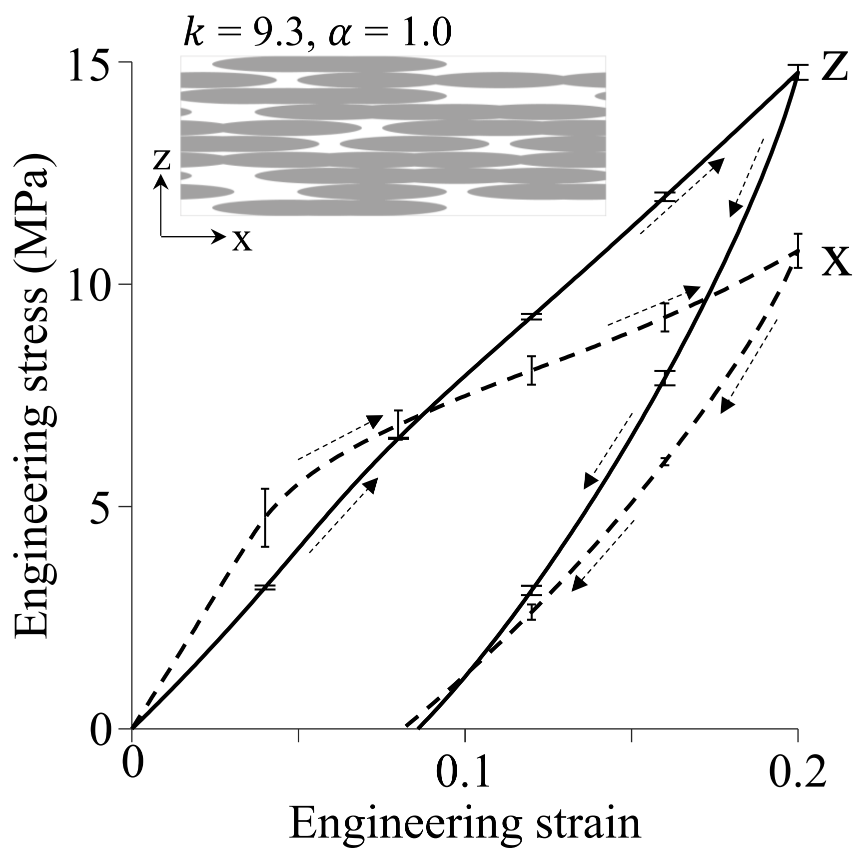




Micromechanical modeling results

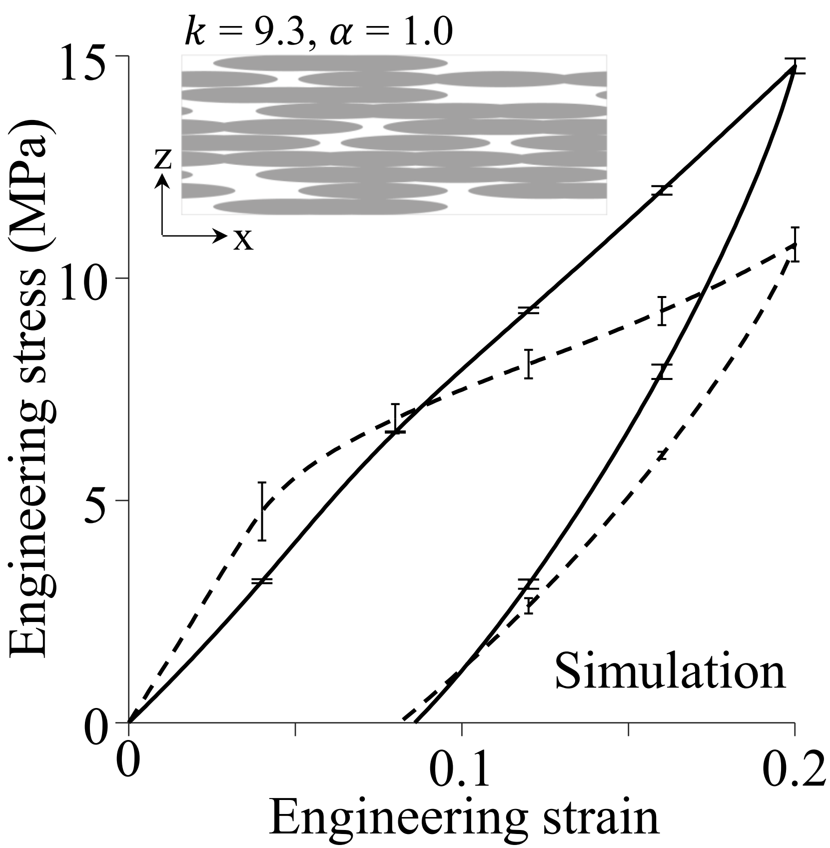
- Anisotropic **unloading** behavior of DM1 (64wt% TP)

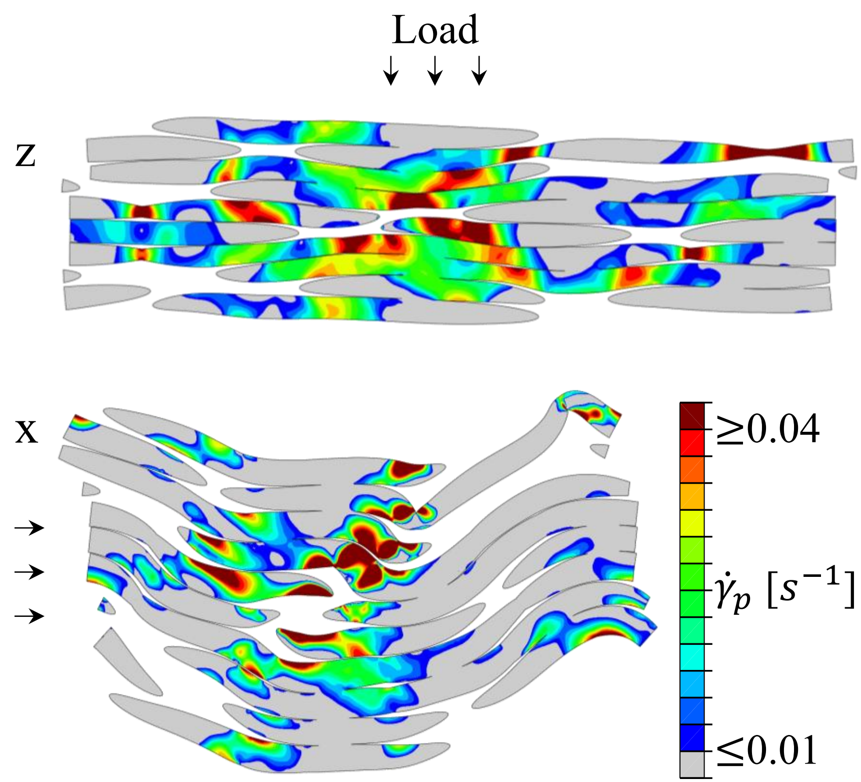




Micromechanical modeling results

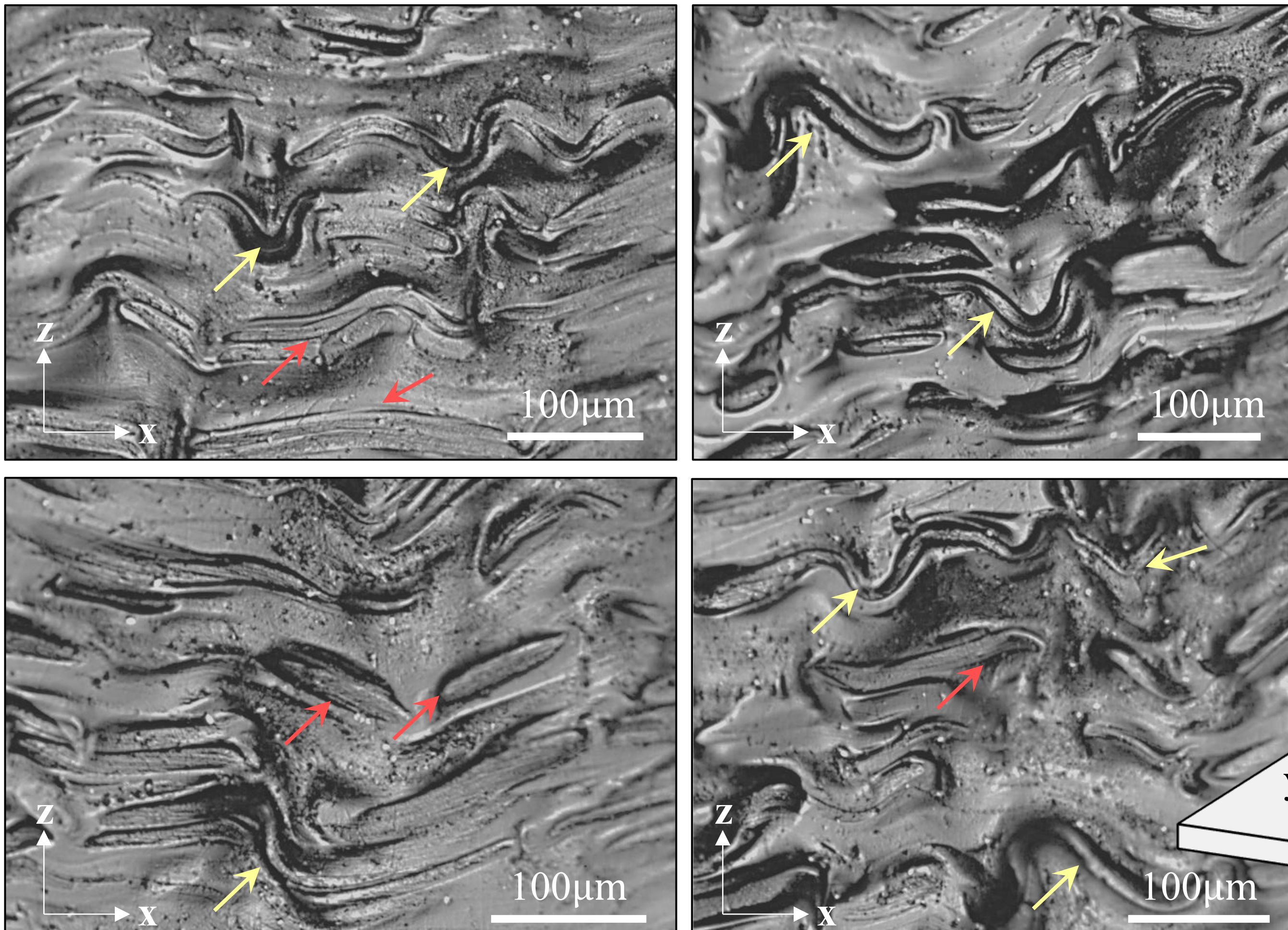
- Deformation mechanisms underlying the anisotropic **unloading** behavior
  : Interplay between **instability** and **plasticity**

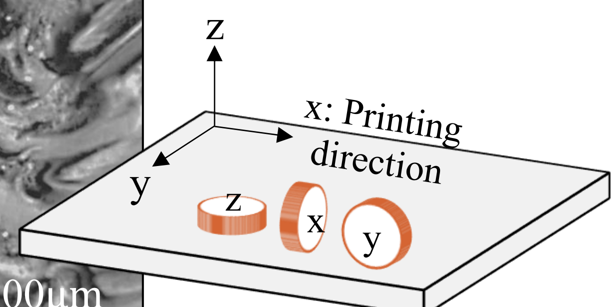




Experimental observation of local buckling

- **Experimentally observed** local buckling of hard domains
- Distinct buckling modes depending on "effective" aspect ratios





Conclusion and future work

- **Buckling instability** (coupled with plastic deformation) of the **microstructures**
  → Emergence of the **mechanical anisotropy** in the digital materials
- Through a combination of large strain mechanical experiments, microscopy analysis and **micromechanical modeling**

- Future work
  1) investigating **orientation-dependent damage** and **fracture** behavior of 3D-printed digital materials through **experiments** and **numerical simulations**[17-19]

  2) exploring the interplay between **rate (temperature)-dependent** mechanical behavior and **microstructural instability** at small to large strains[20,21]

  3) developing **orientation-dependent viscoelastic-viscoplastic constitutive models** for these digital materials[22,23]

Acknowledgement

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