Automated Design of Graded Material Transitions for Educational Robotics Applications

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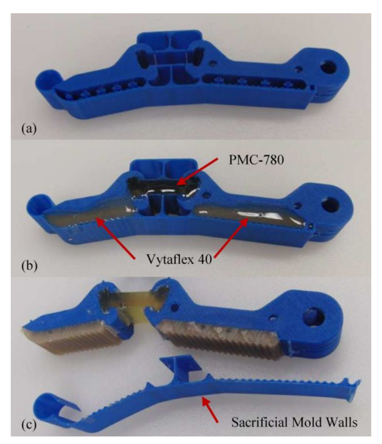
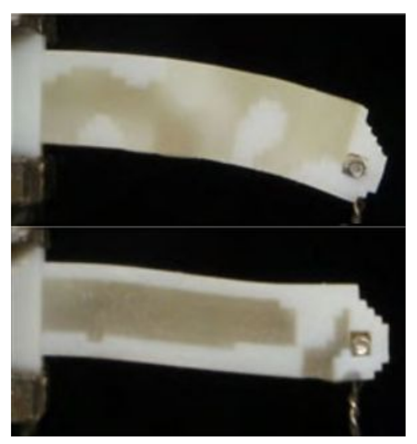
Introduction

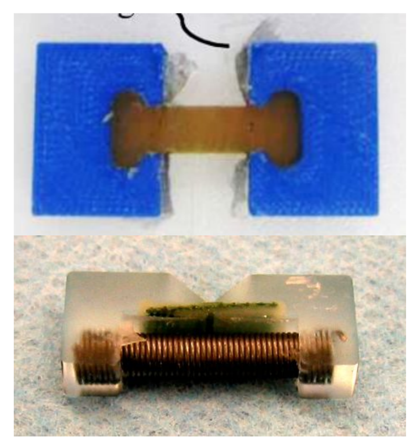
Multi-material manufacturing produces individual parts made with multiple materials and processes. This allows for single parts that can take the place of entire assemblies made using conventional techniques. Example applications include embedded joints and grip surfaces, or beams with tunable deformation profiles. These parts have material boundaries which may be points of failure. Current methods of addressing these boundaries include adding dog bone joints and embedded reinforcement fibers. These methods still leave a distinct change in material properties and pose challenges in generalization and/or manufacturing.



Embedded Joints and Grip Surfaces [1]



Beams with Tunable Deformation Profiles [2]



Dog Bone Joint [1] and Embedded Reinforcement [3]

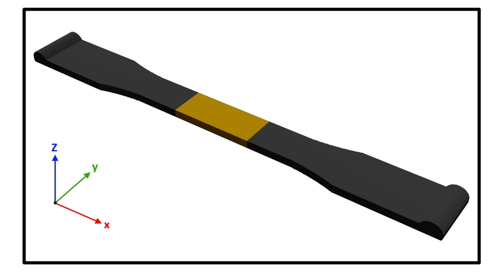
Graded materials can provide a better alternative to these methods. Graded materials yield a gradual change in material properties throughout a model. When used with multi-material manufacturing, they can be applied to creating a transition between two dissimilar materials. In addition, graded material transitions are more easily generalized to any boundary surface.

Goals

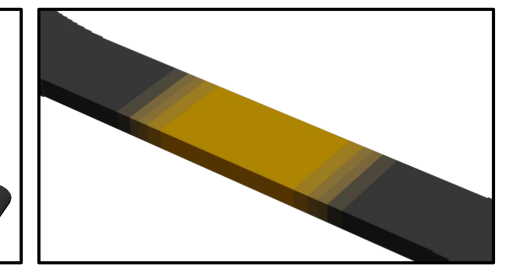
- Identify methods for creating graded material transitions that are compatible with low-cost equipment
- Determine which methods can improve the ultimate tensile strength of a multi-material component
- Identify and mitigate the effects that adding graded material transitions has on other model properties.

Transition Types

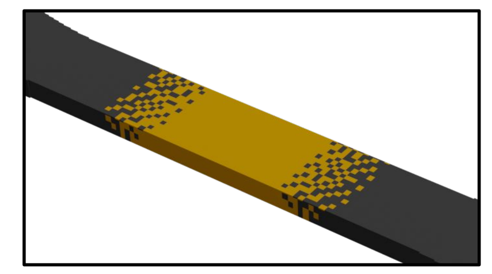
- Test Sample
  - ASTM D638
  - Centered flexible material region
- Blur
  - True graded transition
  - 5 material steps
- Dither
  - Only 2 materials
  - Small disconnected components
- Lattice and Triply Periodic Minimal Surface (TPMS)
  - Easy to produce
  - Less accurate to blur
- Fibers
  - Large increase in surface area



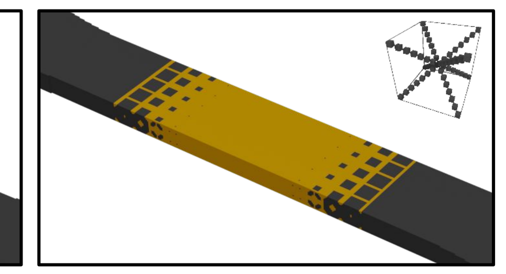
Sample Model: ASTM D638



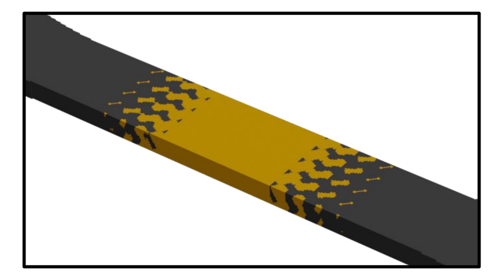
Blur



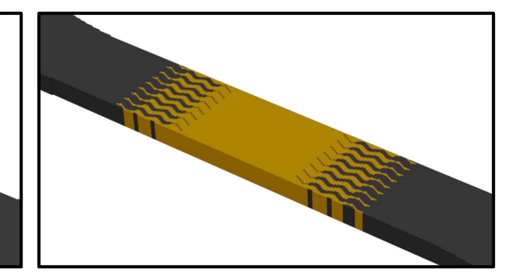
Dither



Lattice Structure



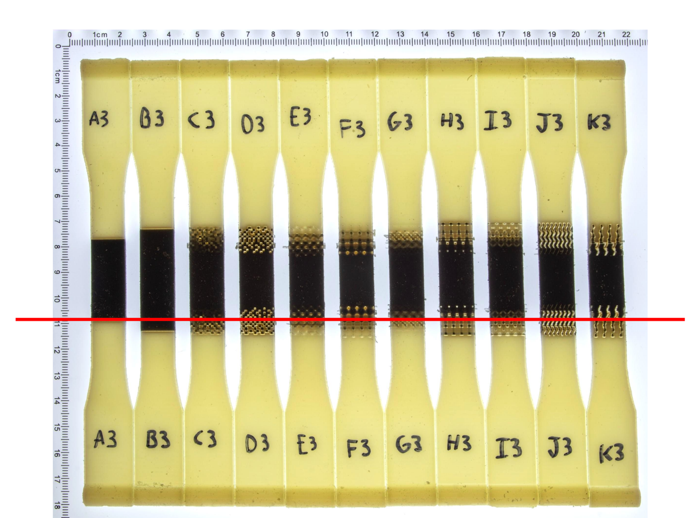
TPMS: Gyroid



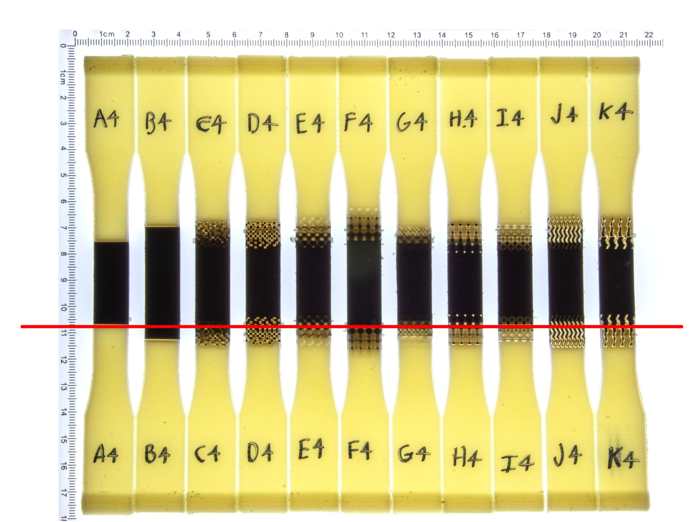
Fibers

Experiment

- 3D Printer: Stratasys Objet 350
  - Rigid ABS (ends) and 60A rubber (center)
- Tensile Testing: Instron 8801 Fatigue Testing System
  - Pulled until failure at a rate of 5 mm/min



Stage 1: Centered Material Transitions

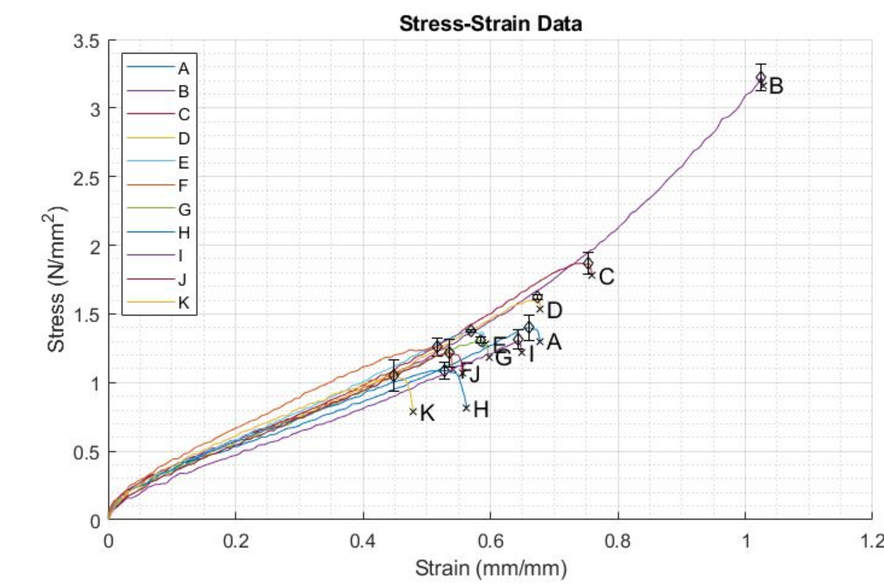


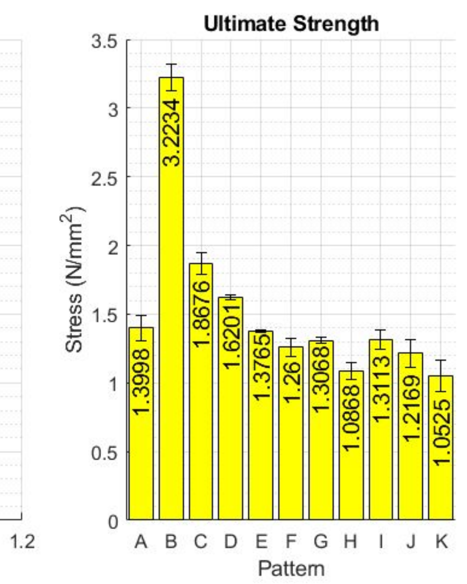
Stage 2: Normalized Modulus of Elasticity

Label	Design
A	Binary
B	Blur
C	3D dither
D	2D dither
E	Gyroid
F	P-surface
G	D-surface
H	+ lattice
I	X lattice
J	Small fibers
K	Large fibers

Results

Stage 1: Centered Material Transitions





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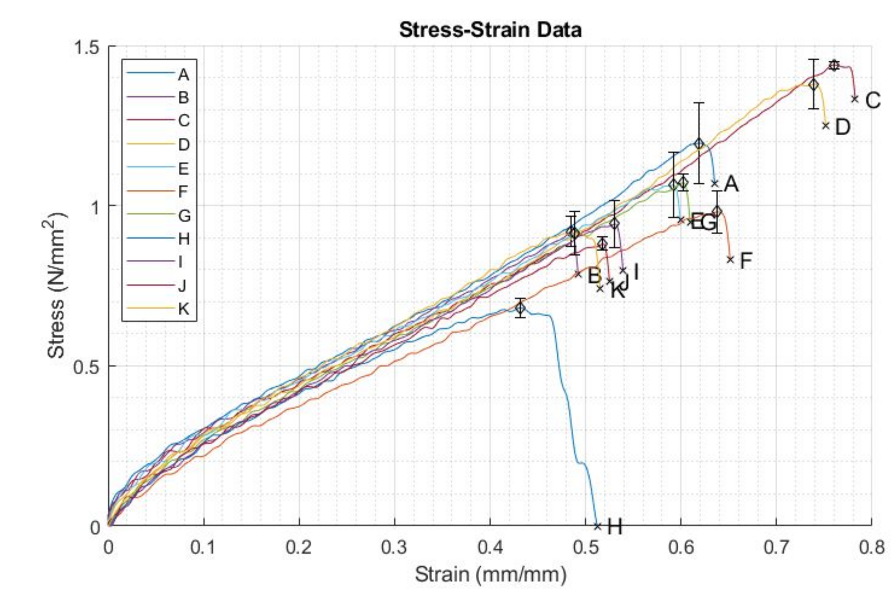

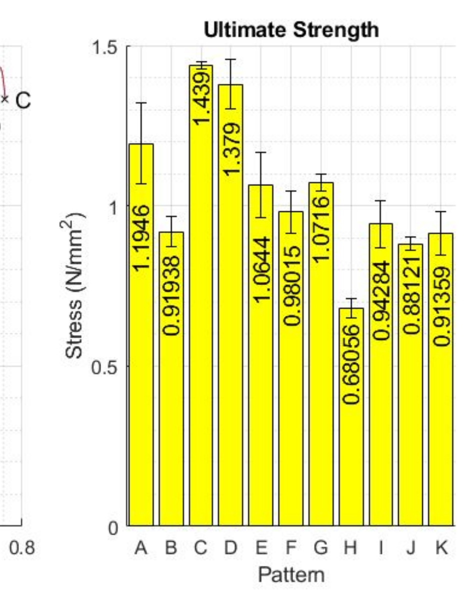

Discussion

- Graded material transitions can improve part performance
- When the printing process has strong bonding between materials, the best performing patterns are those closest to a true blur
- The overall performance decrease between stages is likely due to production or test conditions

Future Work

- Further testing of the blurred design
- Testing using other manufacturing methods
- Testing with other loading conditions