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Finite element modeling of 3D printed partial-infill stamp forming molds

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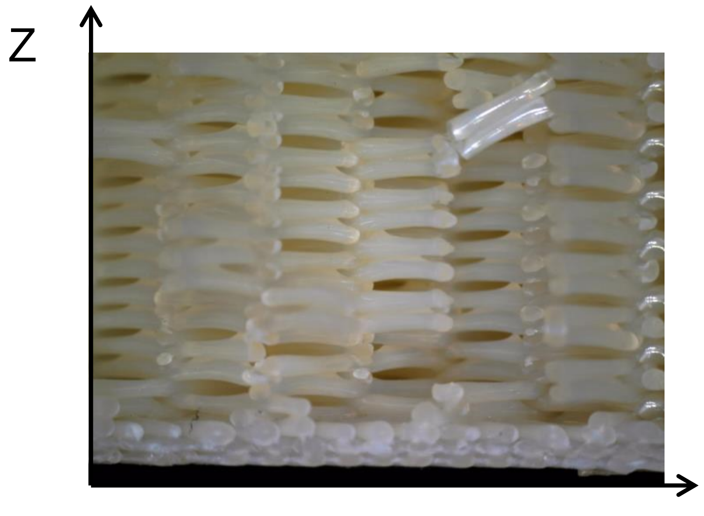
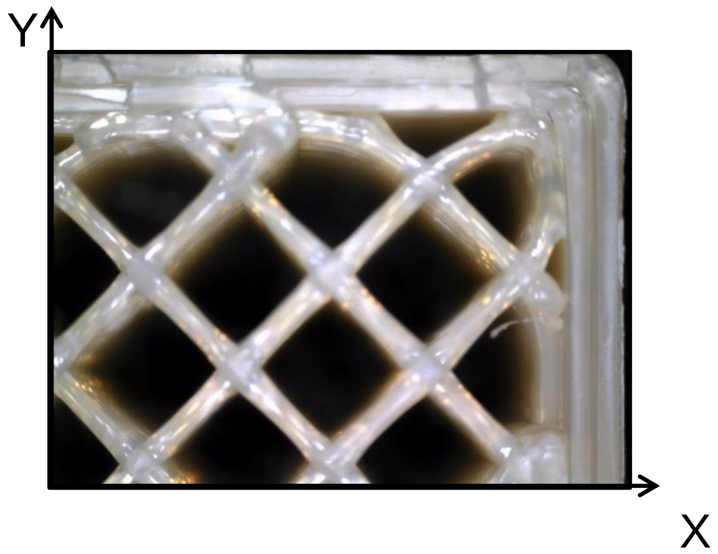
Introduction

- 3D printed molds – Quick to production and rapid design changes
  - RTM, Compression molding, injection molding
  - Stamp forming – Fast process, molds for R&D purposes
- Infill and outer shell
  - Optimize infill and gap parameters



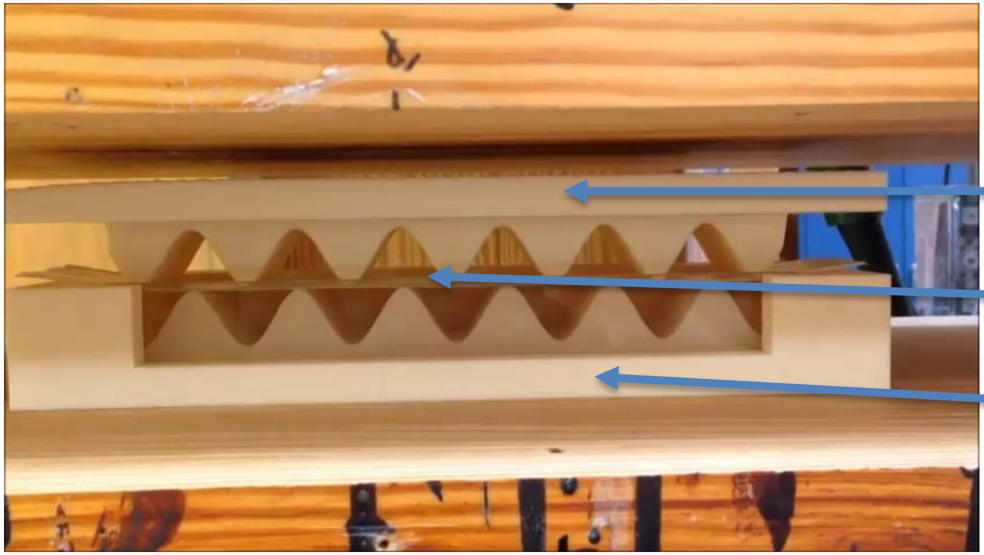
XZ plane (orthogonal to machine bed)



XY plane (parallel to machine bed)

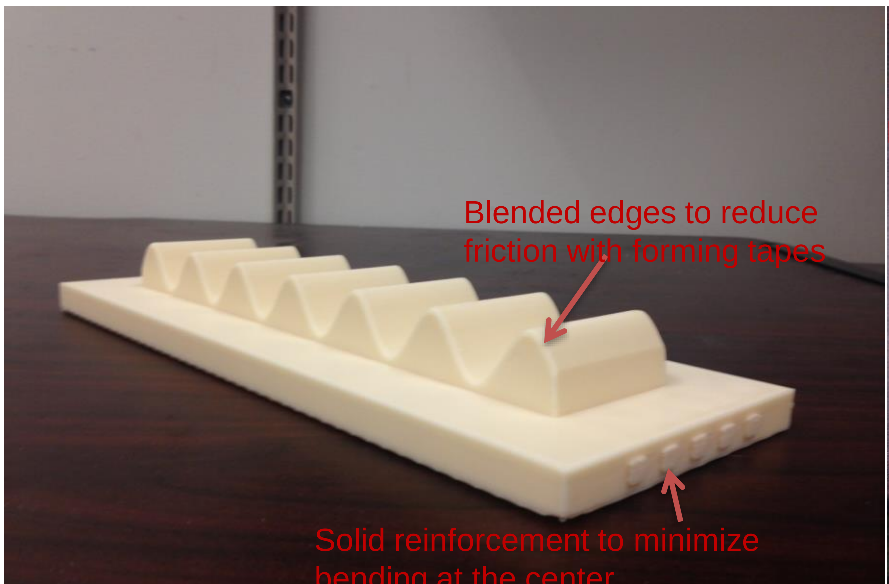
Introduction

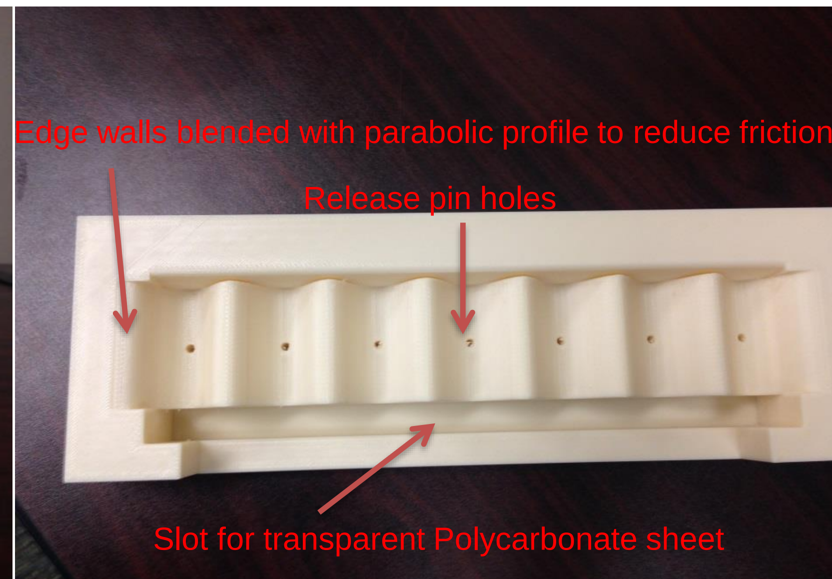
- Create a mold with complex geometry for a part that is relatively difficult to stamp form.



Introduction

- Mold Features

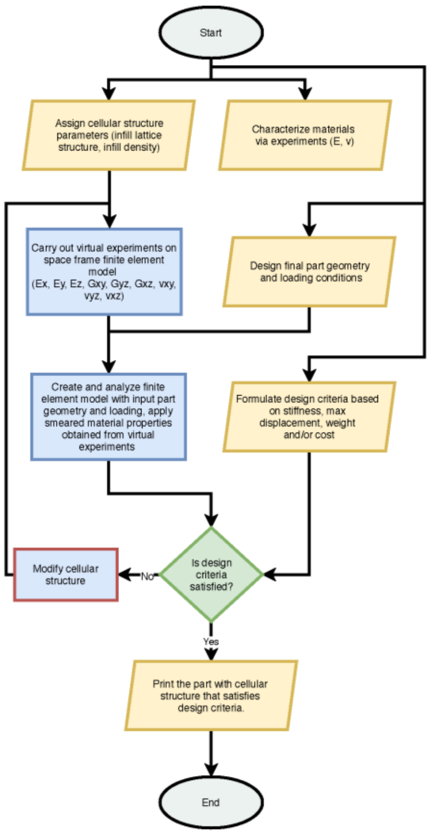




Finite element model

- Two models
  - Coupon level lattice FEM
  - Part level homogenized continuum FEM

Introduction - Process



Coupon level lattice FEA material characterization

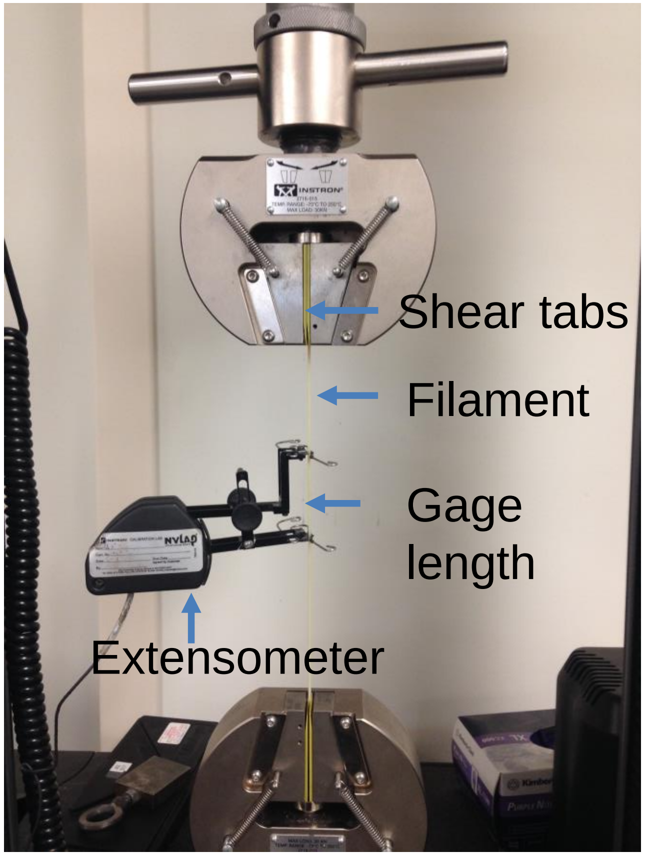


Fig: Tension test of filament

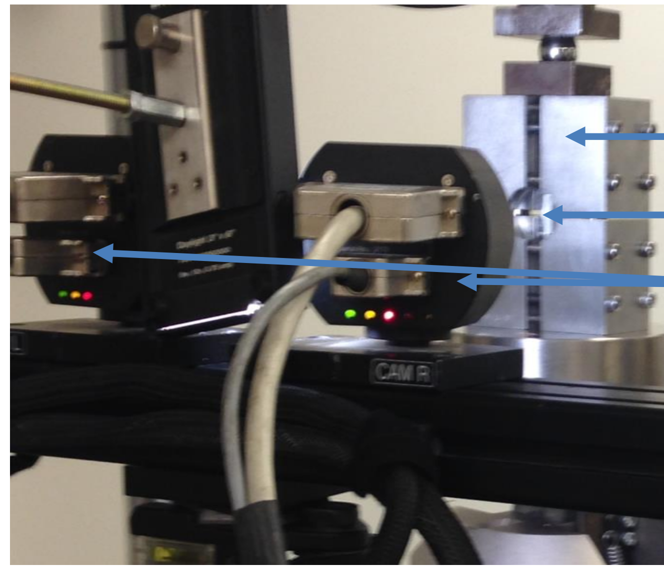


Fig: Compression test of 3D printed specimen

Finite element model – coupon level lattice

- A space frame lattice and shell finite element model can be used to predict the linearly elastic response of a 3D printed part that has cellular internal structure.
- The internal structure is modeled as a space frame and the outer perimeter is modeled as a shell.

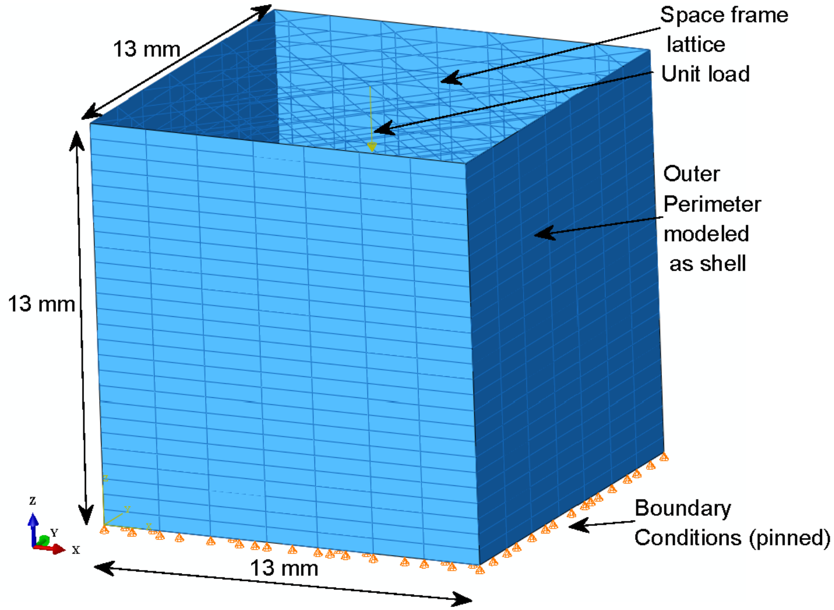
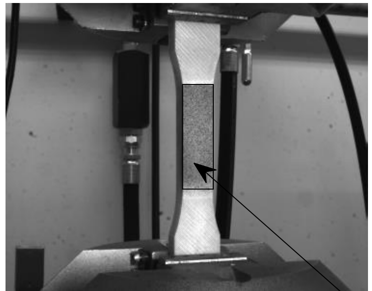
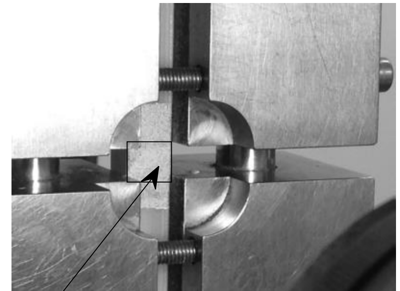


Fig: Space frame and shell model

Lattice FEA - Validation

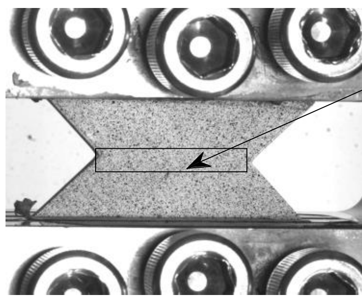


D638 Tension specimen



D6641 Compression specimen

Gauge Area



D7078 Shear specimen

Fig: ASTM Quasi-static test specimens and the gage area used for strain calculation.

Lattice FEA - Results

	Elastic Modulus from Modeling (MPa)	Elastic Modulus from Experiments with range in parenthesis (MPa)	% difference
Compression in the Z-direction	1160	1090 (990 -1370)	+5.2
Compression in the X-direction	909	925 (835 - 1030)	-1.8
Tension in the X -direction	1200	1140 (1060 -1220)	+5.5
Tension in the Z-direction	903	921 (888– 962)	-2.0
Shear in the XY Plane	726	789 (693 – 838)	-8.0
Shear in the XZ plane	785	796 (738 – 872)	-1.4

	Poisson's Ratio from Modeling	Poisson's Ratio from Experiments	% diff
υ_{XY} (compression test)	0.248	0.246	+0.80
υ_{XZ} (compression test)	0.235	0.286	-17.8
υ_{XZ} (tension)	0.350	0.376	-6.9
υ_{XY} (tension)	0.189	0.235	-19.6

Finite element model – homogenized continuum model

- As the size of the part grows larger, the lattice model grows bigger with increasing number of DOF. The maximum size of element in the lattice model is limited by geometry of the cellular structure.
- A homogenized model with smeared properties can be used to overcome this limitation.

  Eg - DOF with lattice model : 26,763,264

  DOF with continuum model : 793,978

  Analysis time (T) is usually for linear static analysis $O(n^2) < T < O(n^3)$

- Virtual experiments can be carried out on finite element models of the lattice structure to generate material properties for an equivalent homogenous continuum solid.

Continuum FEM - material characterization

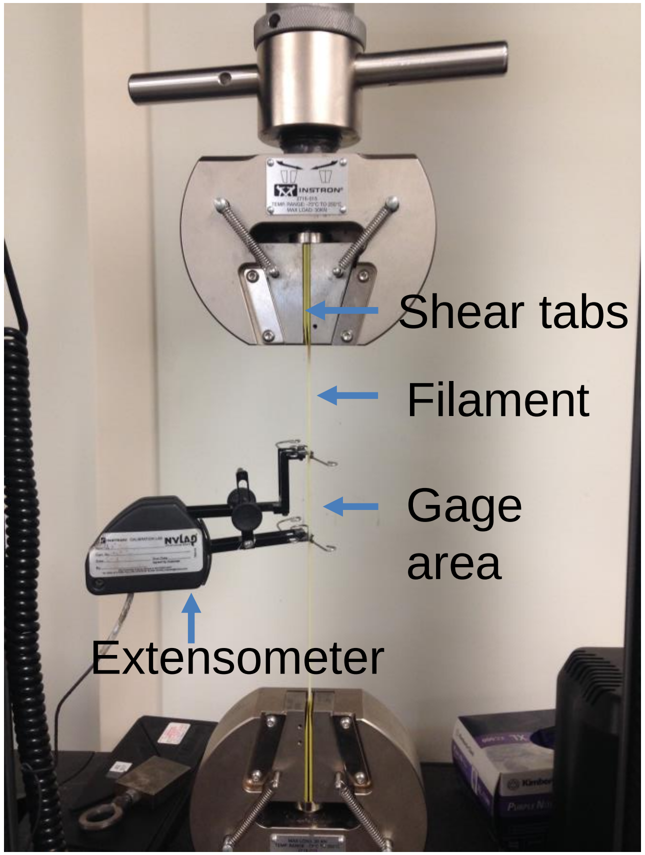


Fig: Tension test of filament

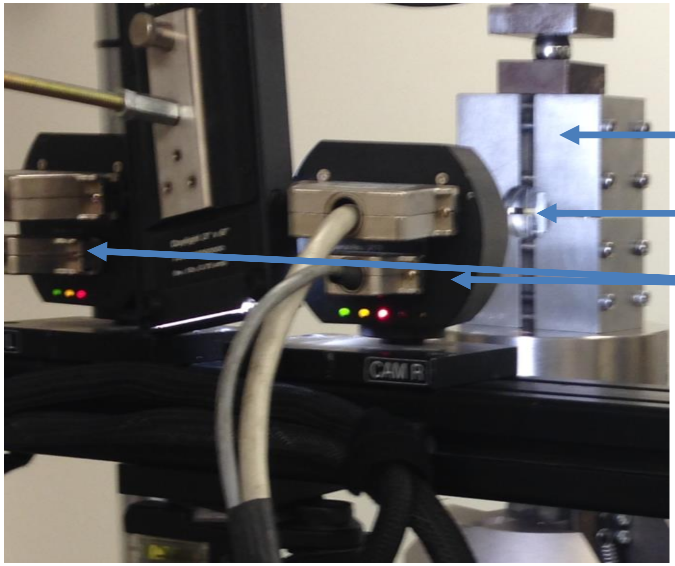


Fig: Compression test of 3D printed specimen

Continuum FEM

- Modelled as orthotropic solid.
- Infill pattern of +-45 degrees gives rise to transverse isotropy.
- Material constants derived form virtual experiments Ex=Ey, Ez, vxy, vxz= vyz, Gxy, Gyz=Gxz.
- The outer boundary layer modelled as shell (skin of the orthrotropic solid part).

Continuum FEM – virtual experiments for homogenized properties

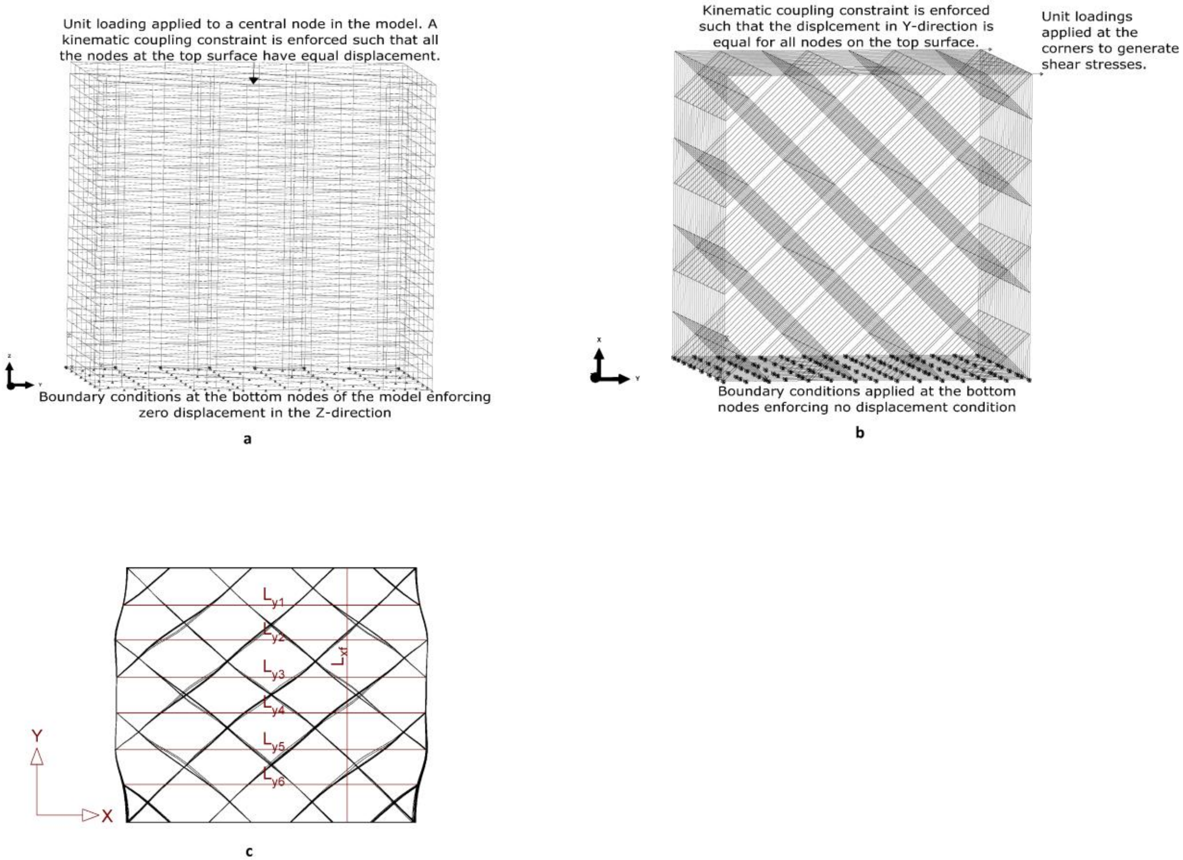
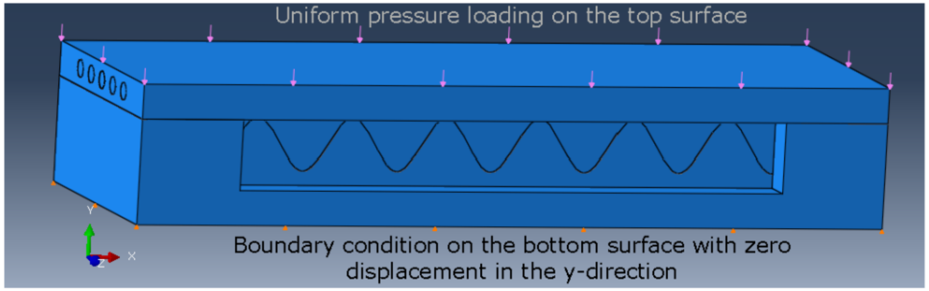


Fig: Finite element model of virtual experiments to determine material properties for continuum model.

Continuum FEM – material properties

Mechanical Property	Value
E_x	132 MPa
E_y	132 MPa
E_z	186 MPa
ν_{xy}	0.824
ν_{xz}	0
ν_{yz}	0
G_{xy}	5.27 MPa
G_{xz}	34.3 MPa
G_{yz}	34.3 MPa

Continuum FEM – analysis



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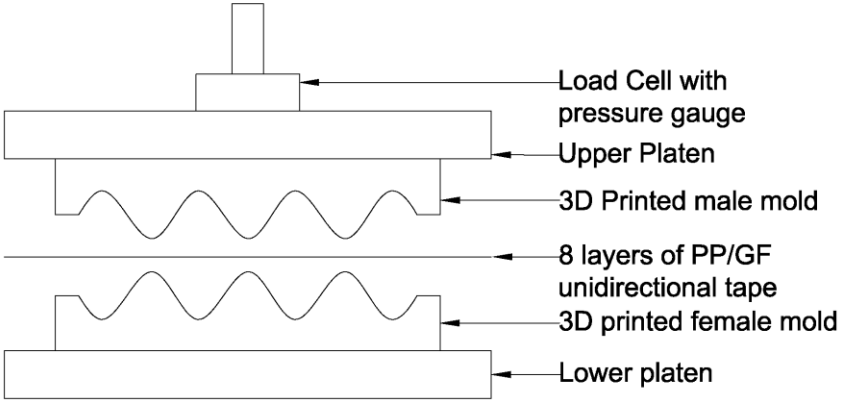

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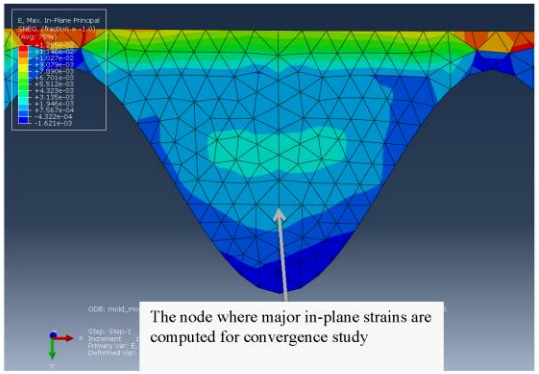
Continuum FEM results



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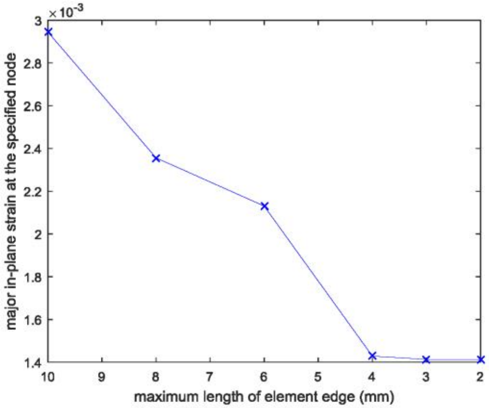

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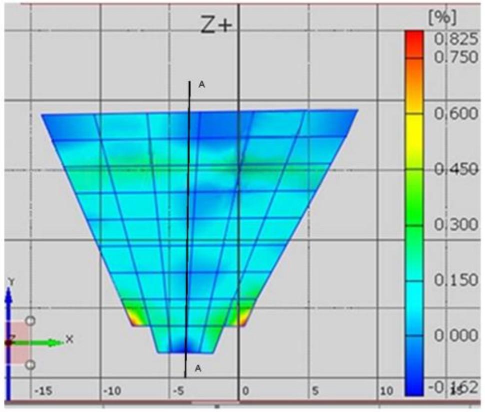

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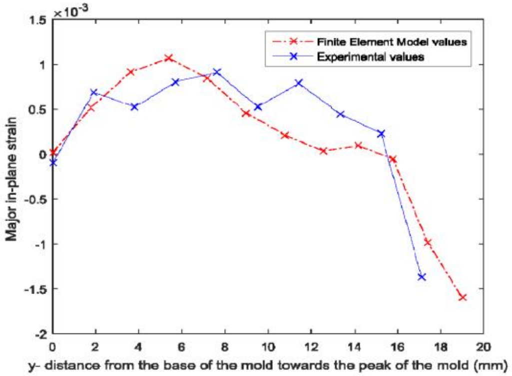

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Conclusions

- A space frame and lattice model can be used to predict effective properties of a 3D printed part that has cellular internal structure.
- A continuum model based on homogenization of lattice FEM can be used analyze 3D printed part that has cellular internal structure.
- Since a continuum model based on homogenization of lattice structure can be modelled with smaller number of element, the finite element analysis can be faster compared to space frame and shell lattice model.
- Future work : Iterative design optimization problems might be sped up if homogenized continuum model is used instead of lattice model.

Questions

- ???

References

- *Sunil Bhandari, Roberto Lopez-Anido, Finite element analysis of thermoplastic polymer extrusion 3D printed material for mechanical property prediction, Additive Manufacturing, Volume 22, August 2018, Pages 187-196, ISSN 2214-8604, https://doi.org/10.1016/j.addma.2018.05.009.*
- *Sunil Bhandari, Roberto Lopez-Anido, Finite element modeling of 3D-printed part with cellular internal structure using homogenized properties (In review)*