3D printability of polymer blended/graphene composites for strain sensors applications

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Contents

- Background
- Section of materials
- Experimental results
- FEA analysis
- Comparing to literature data
- Conclusions / future work

Background

- ~3 million people require a prosthetic
- 62,000 people in the UK use prosthetics
- Rate of prosthetic abandonment is 44% for upper limbs

i-Limb

Be-bionic

Michelangelo

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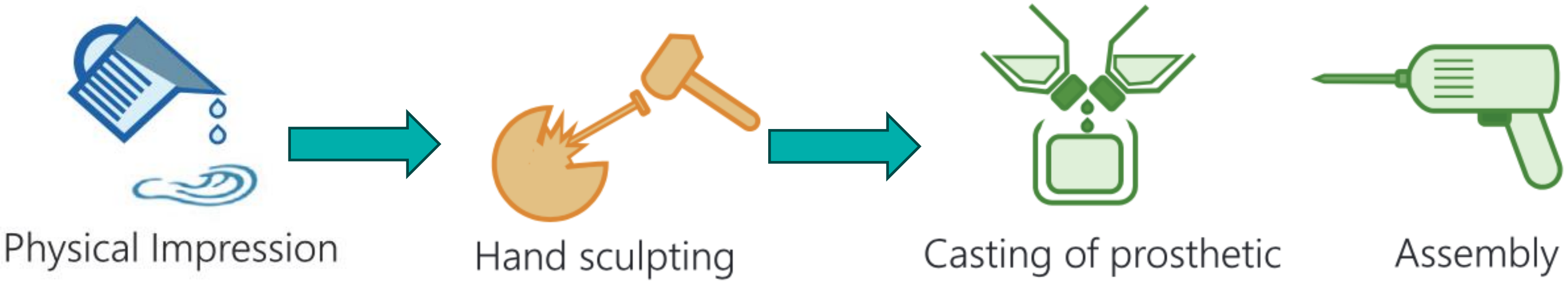
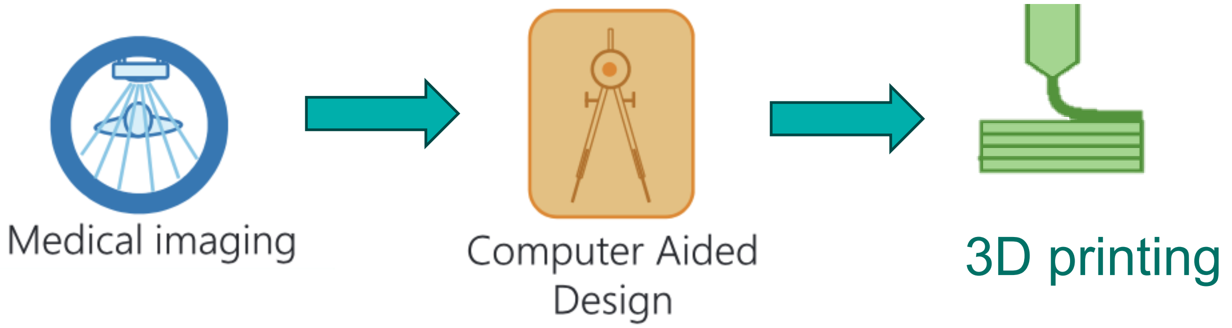
M. Melero *et al.,* J. Healthc. Eng, 2019, vol 2019, pp 1-9
H. Wu *et al.,* Philos. Trans, 2022 , vol 380, pp 1-13
F. Cordella *et al.*, Front. Neurosci., 2016, vol 10, pp 1-14

Background

Traditional manufacturing



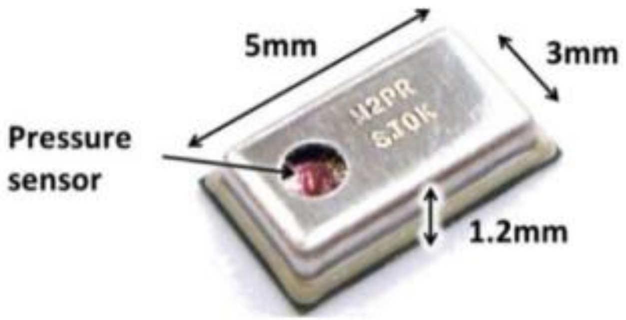
Advanced manufacturing

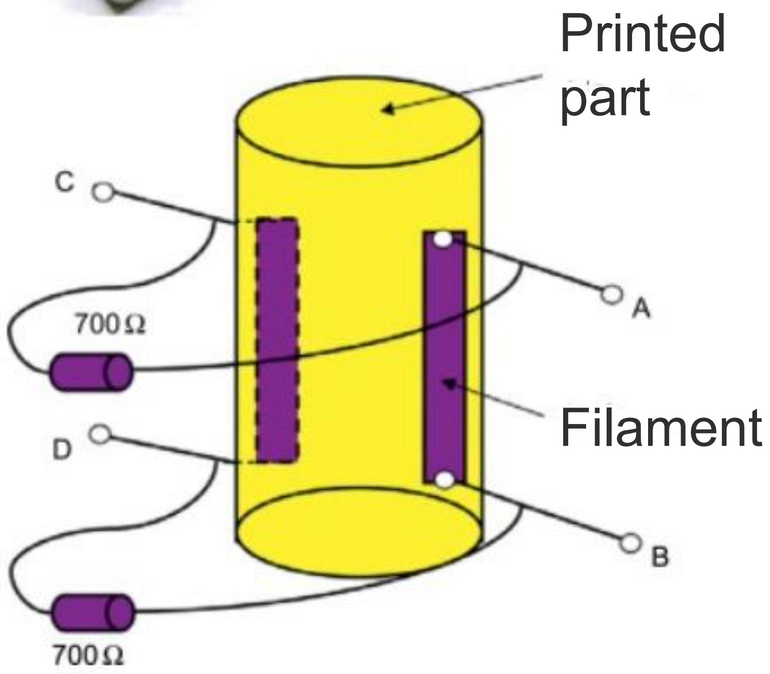


S.K. Powel *et al.*, Adv. Mater., 2020, vol 32, pp 1-21

Pressure sensors in prosthetics

- Pressure sensors provide a restored sensation.
- 3D printing allows greater freedom of design.
- Aim: Develop a model to accurately predict the mechanical properties.

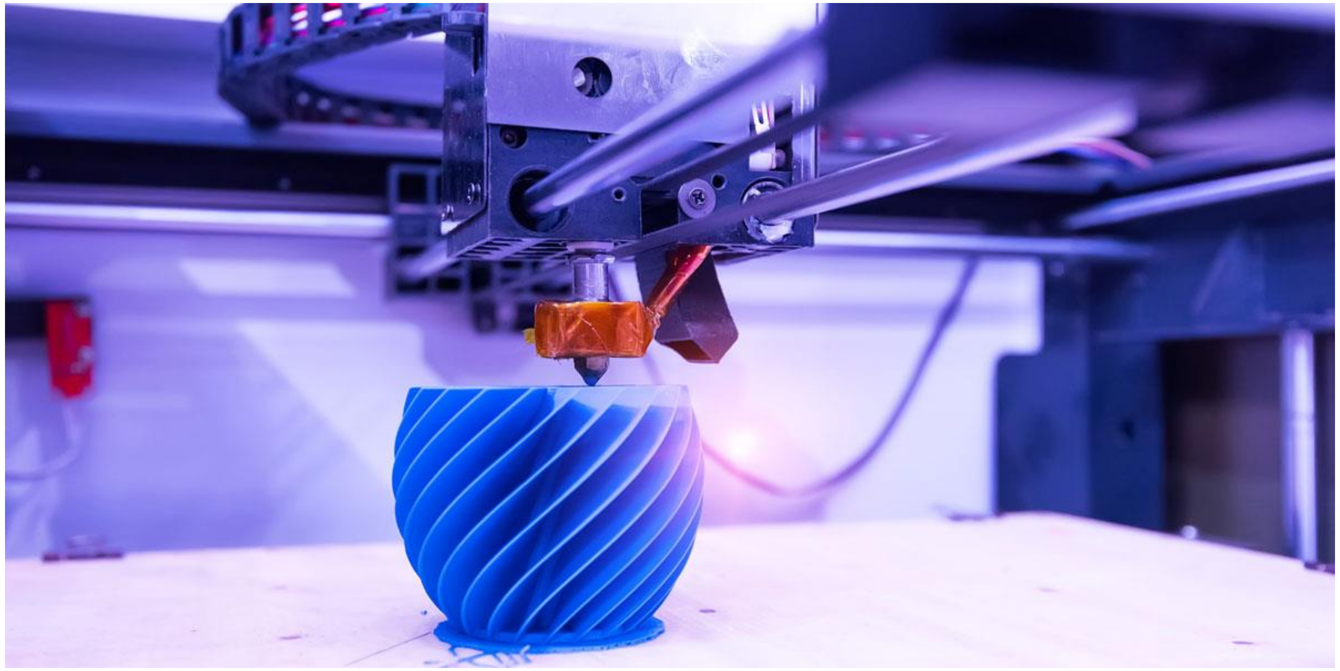




Y. Tenzer *et al.*, IEEE, 2014, vol 28, pp 89-95
https://www.allaboutcircuits.com/textbook/direct-current/chpt-9/strain-gauges/

3D Printing

- ➢Stereolithography (SLA)
- ➢Powder bed and inkjet head (PBIH) 3D printing
- ➢Selective laser sintering (SLS)
- ➢Fused deposition modelling (FDM)
    - Cost-efficient
    - Minimal material waste
    - Enables dual-material printing
    - Complex structures

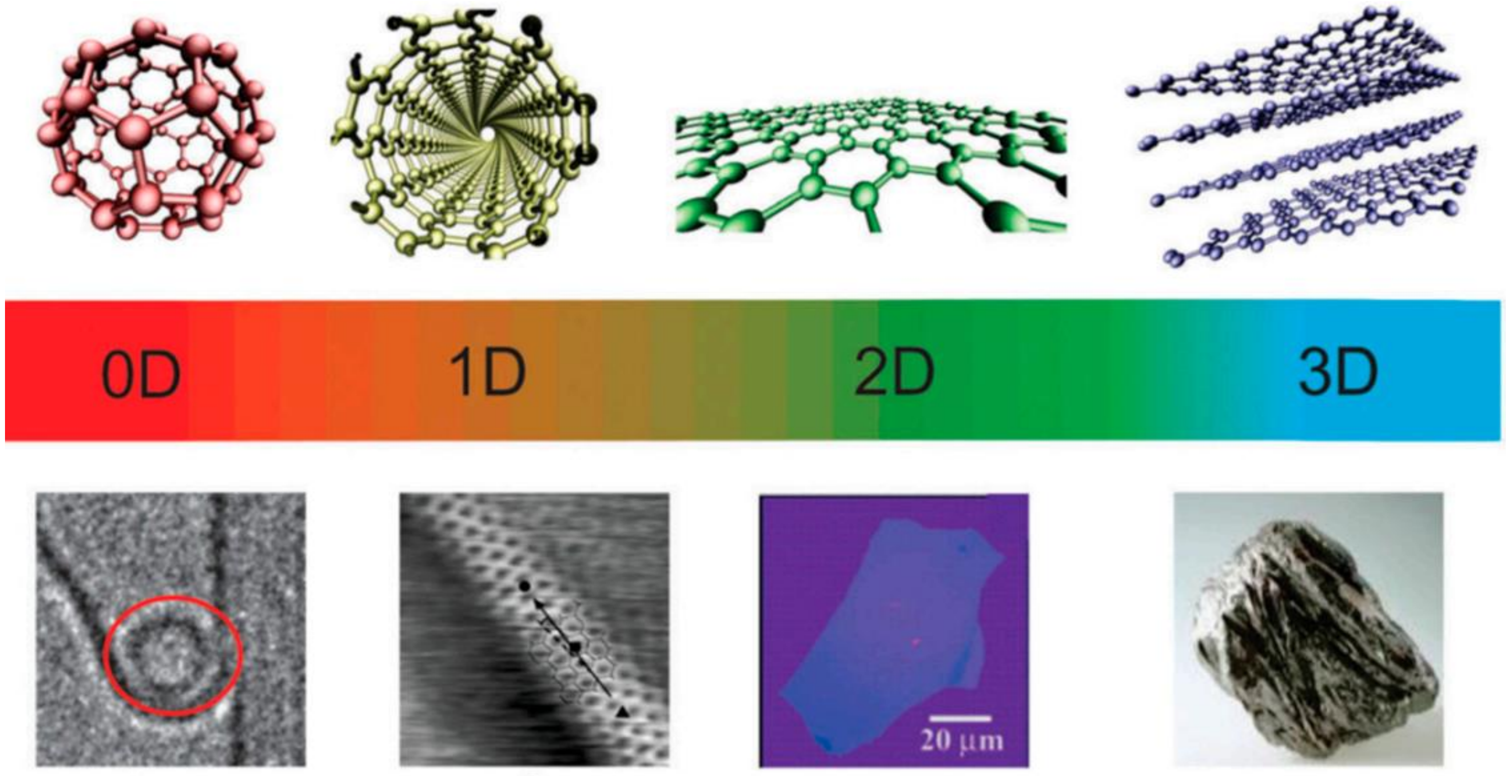


X. Wang *et al.*, Compos. B, 2017, vol 110, pp 442-458

Nanofillers

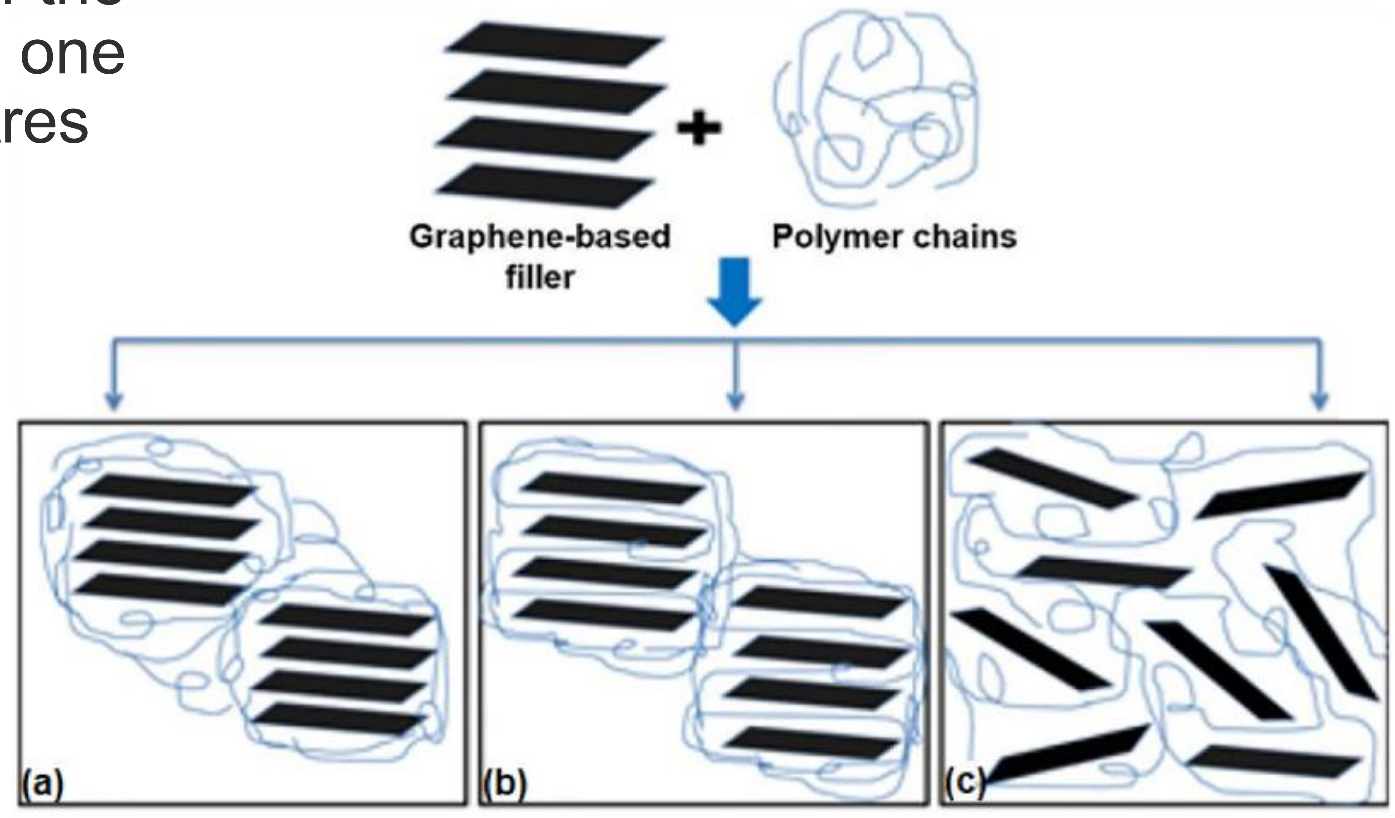
- Nanomaterials:
  - Nanospheres
  - Nanotubes
  - Nanoplatelets
  - Nanoparticles

- Carbon based nanomaterials:
  - 0D (fullerenes)
  - 1D (carbon nanotubes)
  - 2D (graphene)
  - 3D (graphite)



Polymer nanocomposites

- Composite in which at least one of the phase domains has at least one dimension of the order of nanometres
  - Matrix
  - Nanofiller

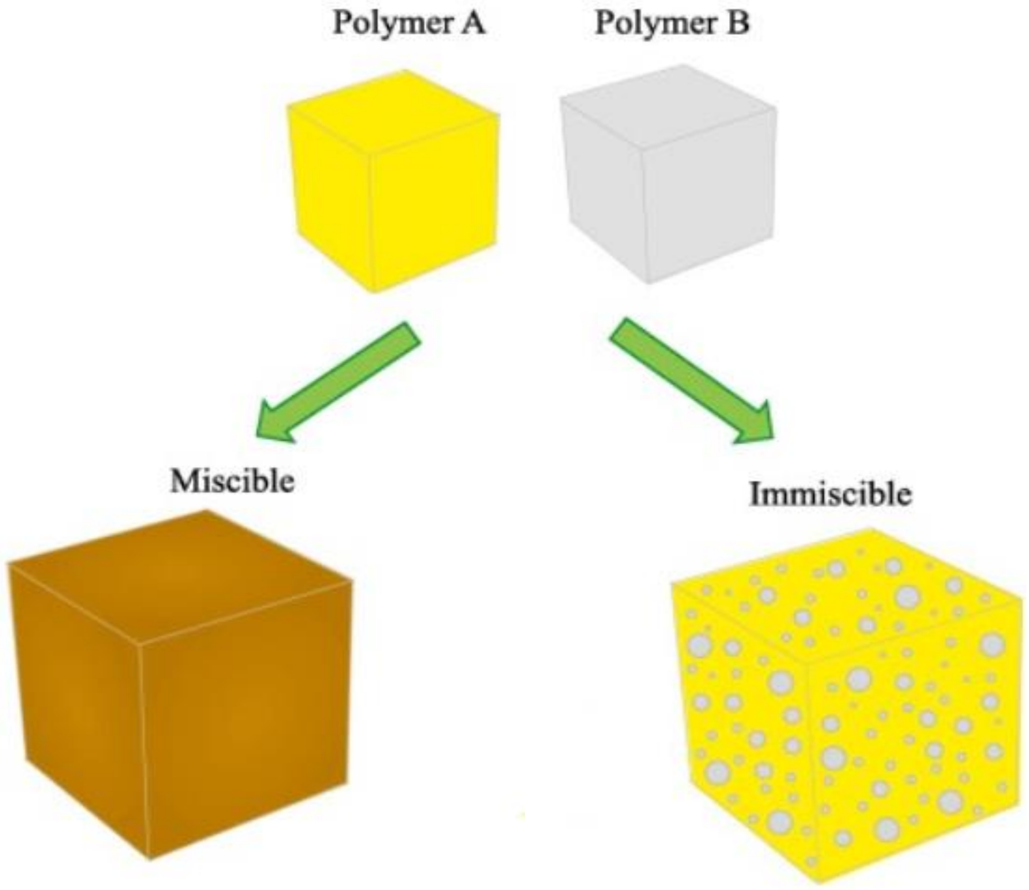


- Polymer nanocomposites can be manufactured through:
  - *In situ* polymerization
  - Solution blending
  - Melt mixing

J. V. Alemán *et al.,* Pure Appl. Chem., 2007, vol 79, pp 1801-1829
J. Hari *et al.,* Applied Plastics Engineering Handbook, 2011, vol 1, pp 109-142
K. Deshmukh *et al.,* Biopolymer Composites in Electronics, 2017, vol 1, pp 27-128

Polymer blends

Polymer blends are divided into two categories

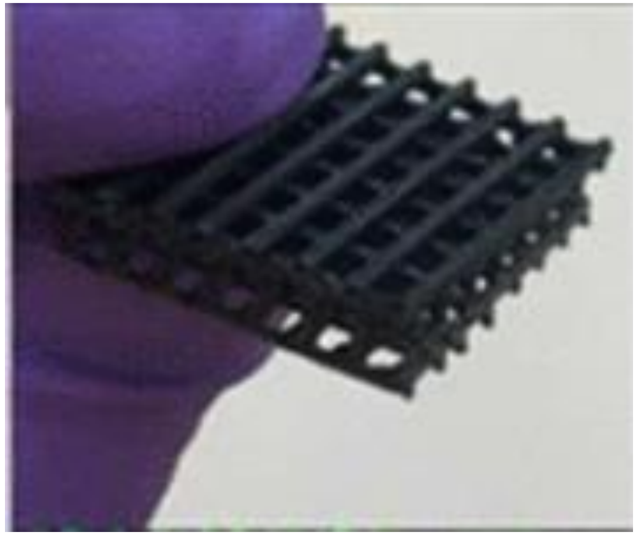


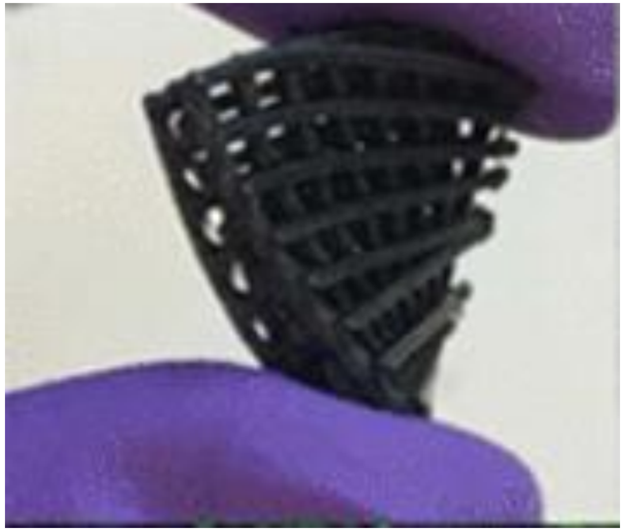
N. Panapitiya *et al.*, Materials, 2016, vol 9, pp 1-23

Polymer blend nanocomposites

- Graphene nanoplatelets have been successfully incorporated in PMMA/PEO and PC/ABS polymer blends

- FDM 3D printing was used to manufacture PLA/TPU polymer blended carbon nanocomposites for sensor applications



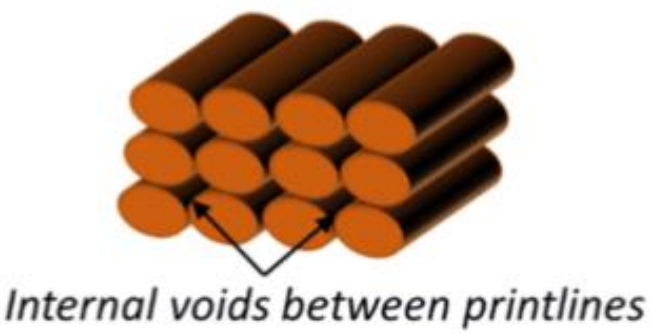


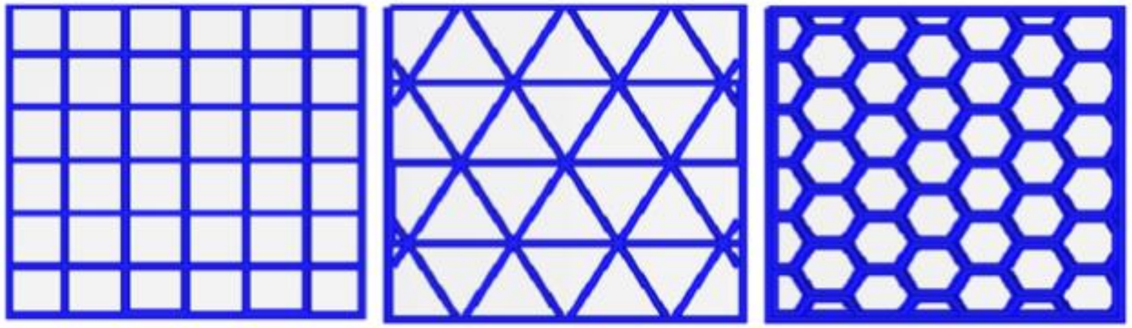
E. Aram *et al.,* J. Thermoplast. Compos. Mater., 2018, vol 32, pp 1176-1189
V. Tambrallimath *et al.,* Compos. Comm., 2019, vol 15, pp 129-134
Q. Chen *et al.,* ACS Appl. Mater. Interfaces 2017, vol 9, pp 4015-4023

Selection of materials

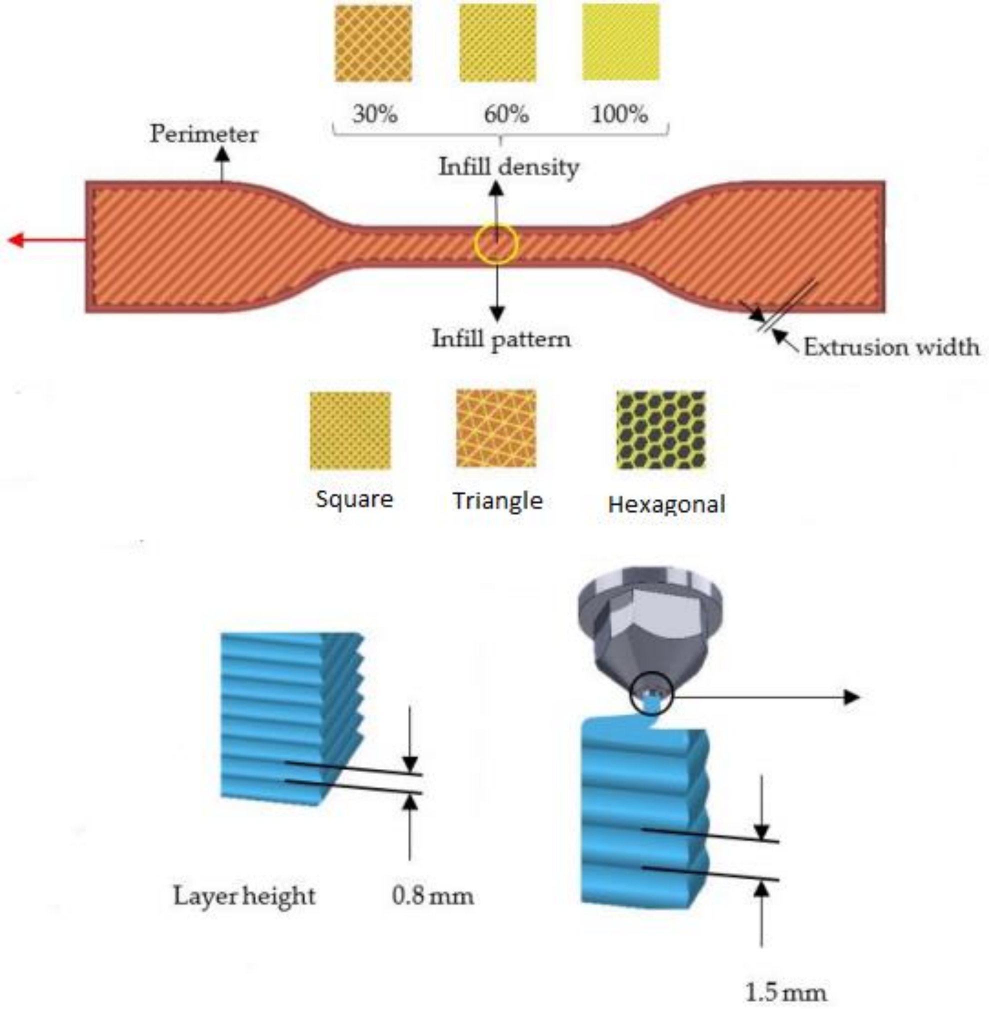
3D printable			
Elastic	Strength		
TPU	PLA	ABS	PP

TPU/PLA





Infill pattern / density

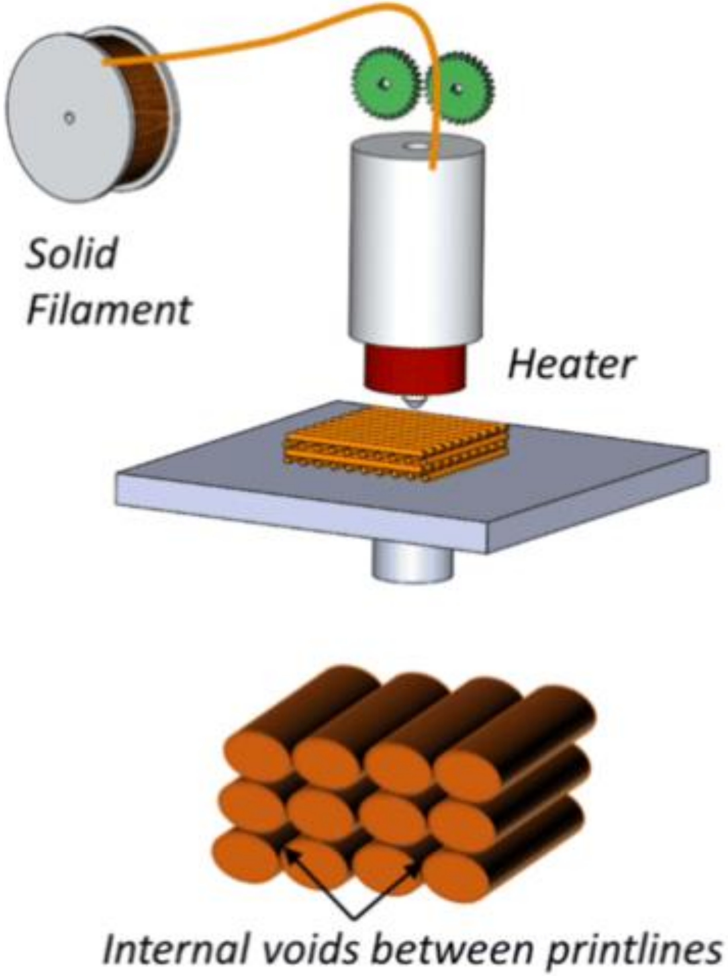


Infill pattern	Equation
Triangle	$E = 1.15 E_s \left(\frac{t}{l}\right)$
Square	$E = E_s \left(\frac{t}{l}\right)$
Hexagonal	$E = 2.3 E_s \left(\frac{t}{l}\right)^3$

Direction	Equation
In-plane	$E_1 = (1 - p_1)E$
Out plane	$E_2 = (1 - \sqrt{p_1})E$

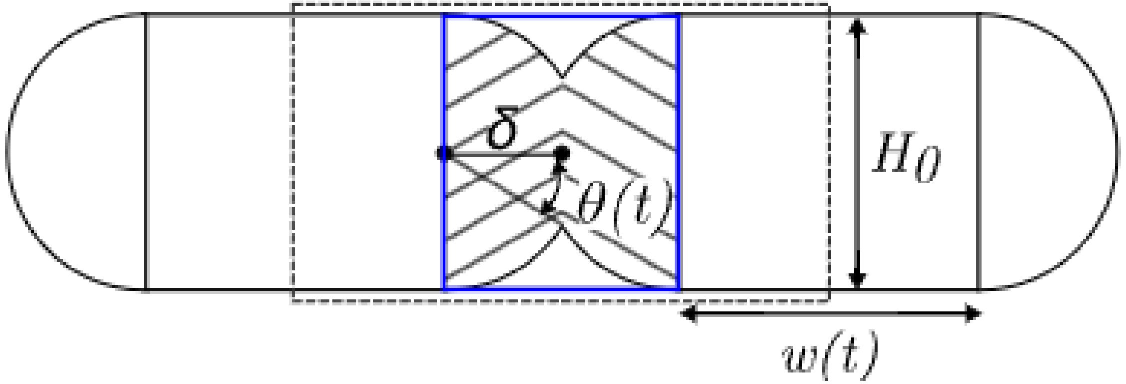
H. Bakhtiari *et al.*, Appl. Sci, 2023, vol 13, pp 904-931
J. León-Becerra *et al., ACS Omega,* 2021, vol 6, pp 29830–29838

Predicting porosity



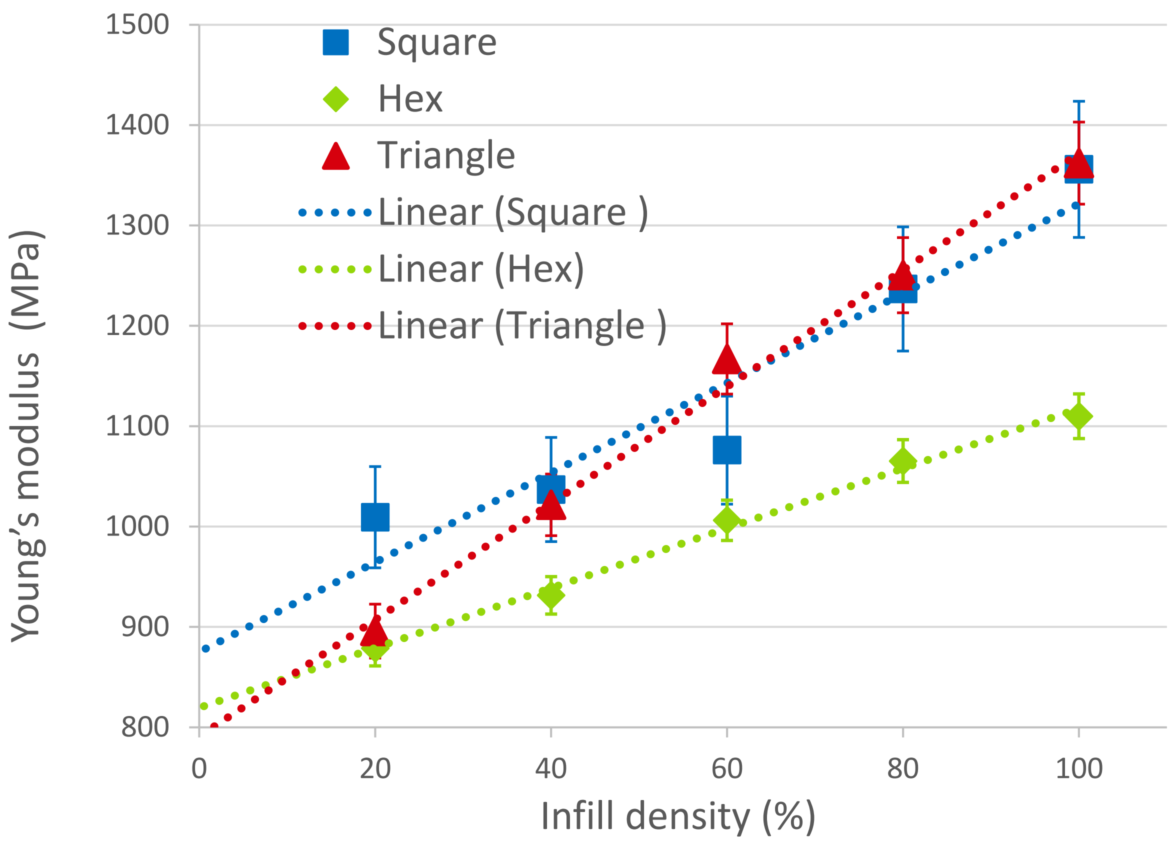
$$p_1 = \frac{H_0^2 \cos\theta - \left[\pi\left(\frac{H_0}{2}\right)^2 - \left(\frac{H_0}{2}\right)^2 (2\theta - \sin 2\theta)\right]}{H_0 w(t) + H_o^2 \cos\theta}$$

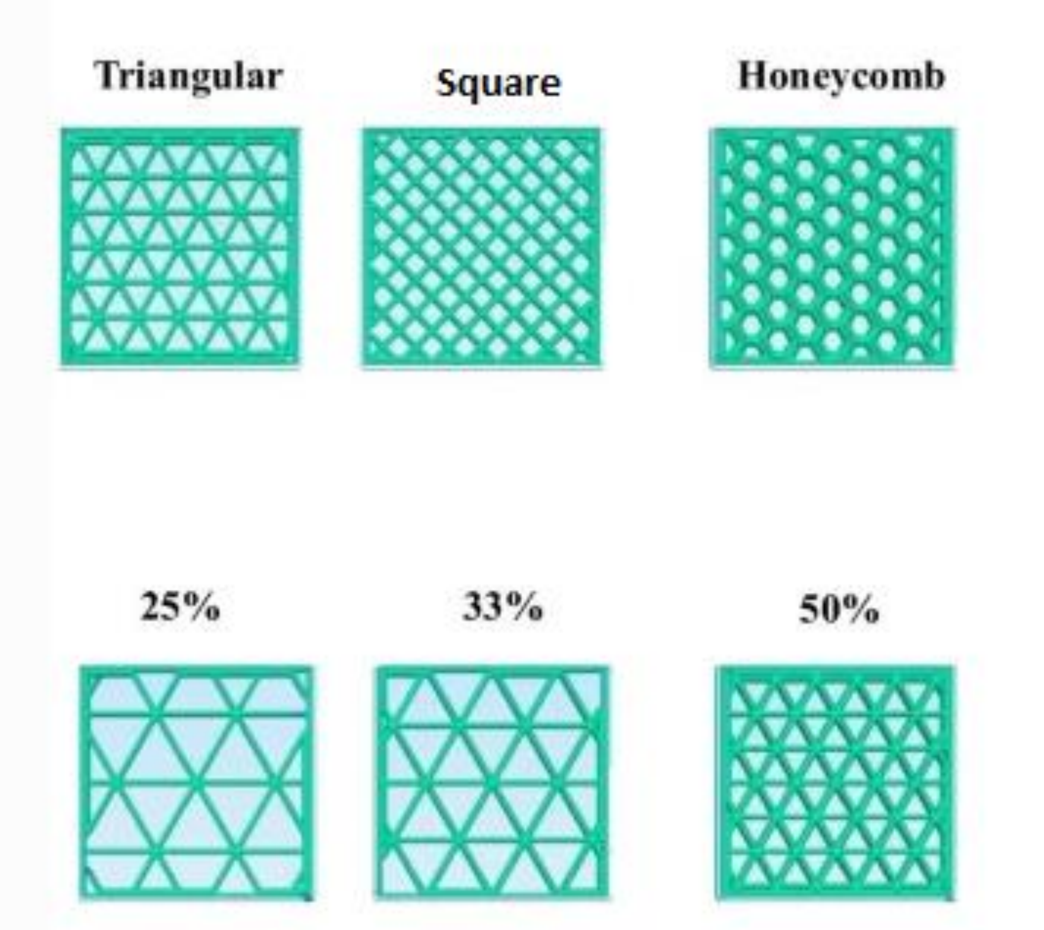
$$w(t) = w_0 + \frac{H_0\theta}{4} - \frac{H_0 \sin 2\theta}{8}$$



N. Nawafleh *et al.,* J. Mater. Sci., 2020, vol 55, pp 11284-11295
S. Garzon-Hernandez *et al.,* Mater. Des., 2020, vol 188, pp 1-9

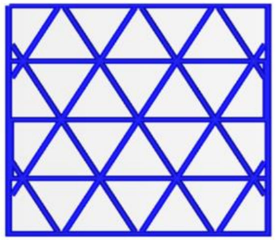
Experimental results of printing



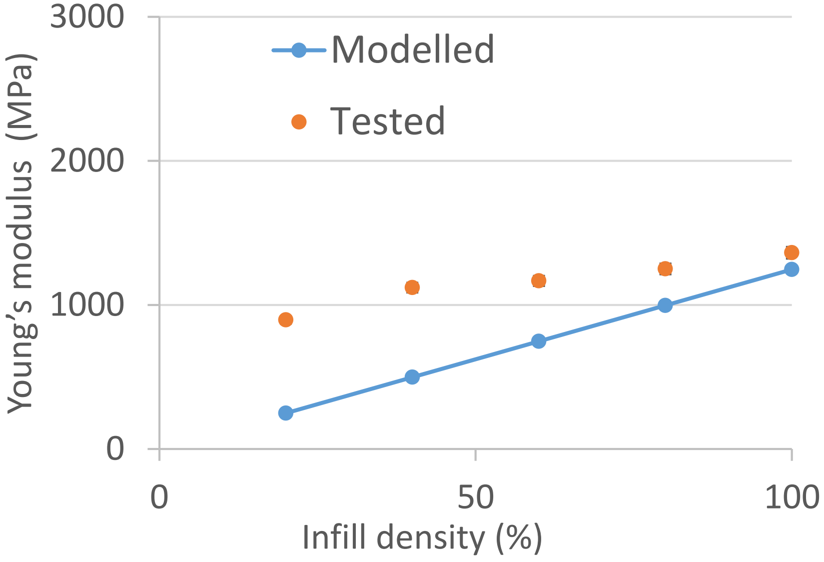


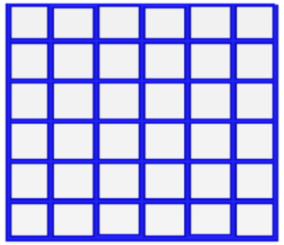
- Stiffness has a linear relationship with infill density / rate controlled by infill pattern

Comparing experimental to modelled

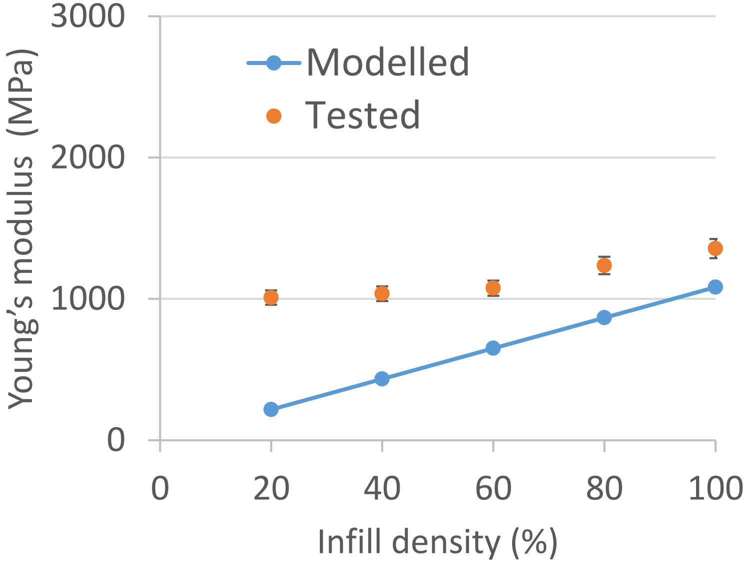


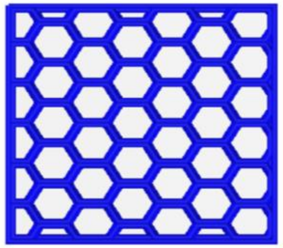
Triangle



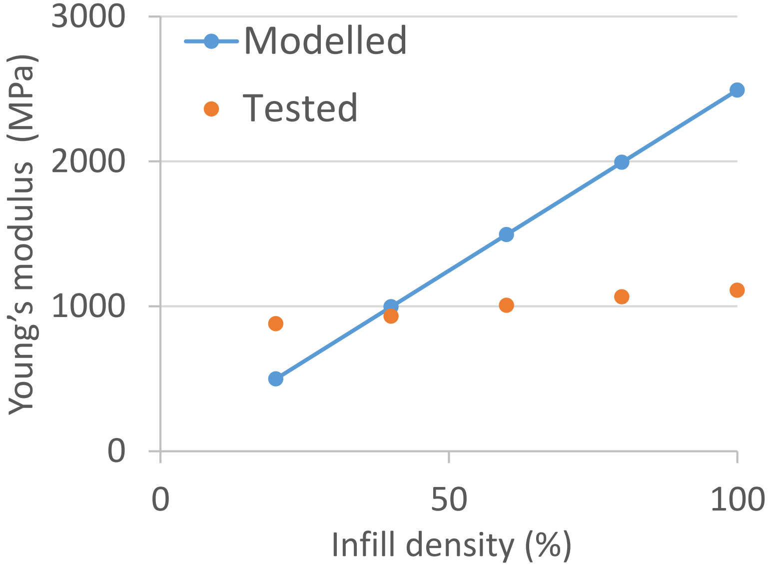


Square





Hexagonal



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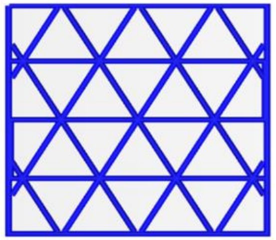
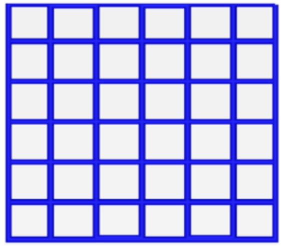
FEA

- The FEA study found that the stress-to-displacement ratio determines the rate of Young's modulus increase



Triangle



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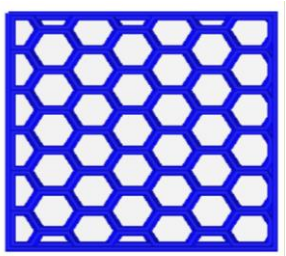
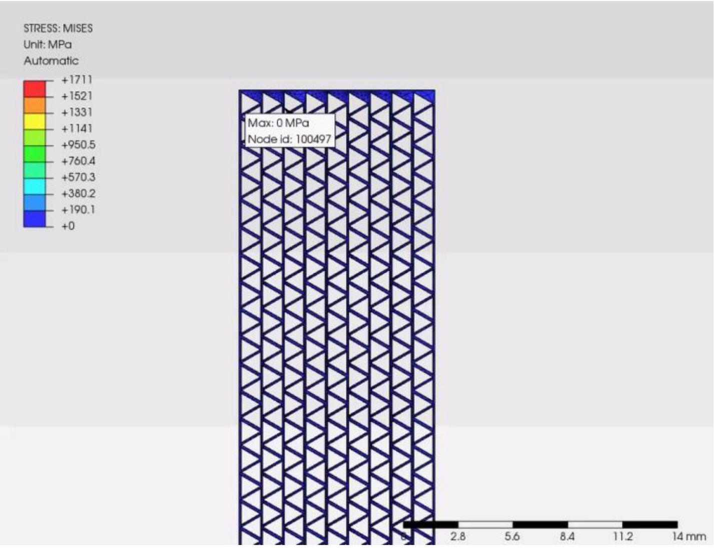
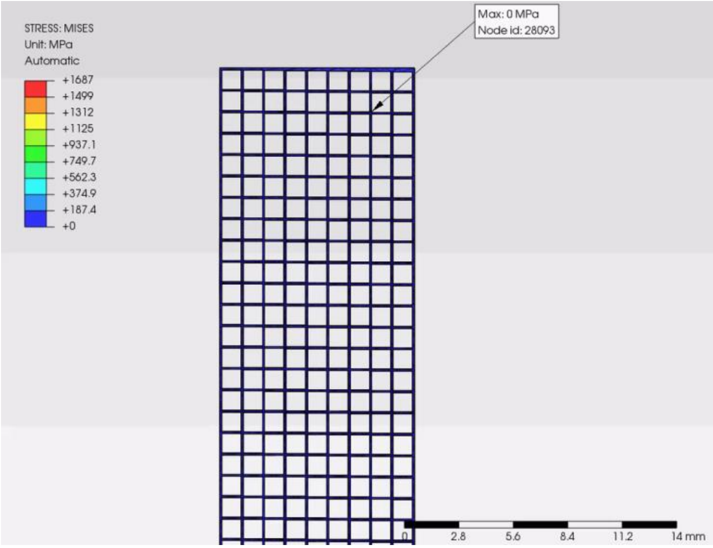
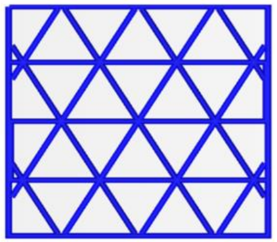


Hexagonal

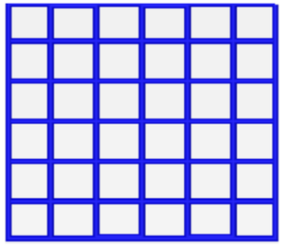




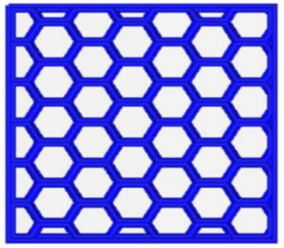
Correcting the model based on FEA



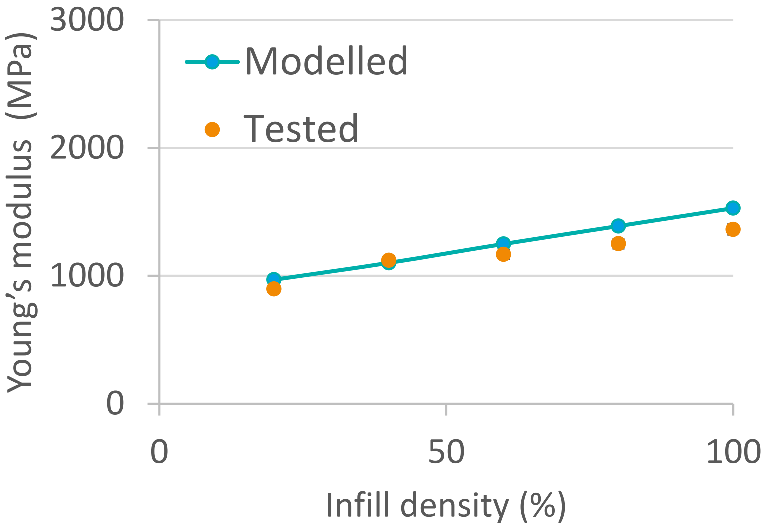
Triangle

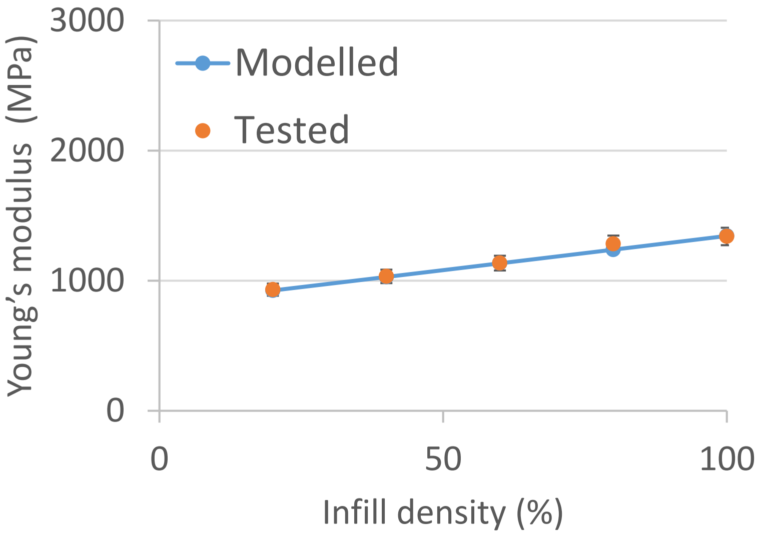


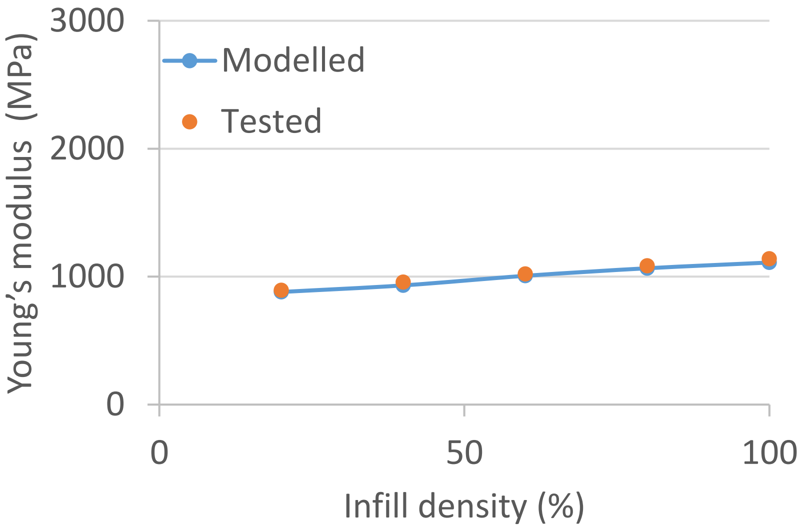
Square



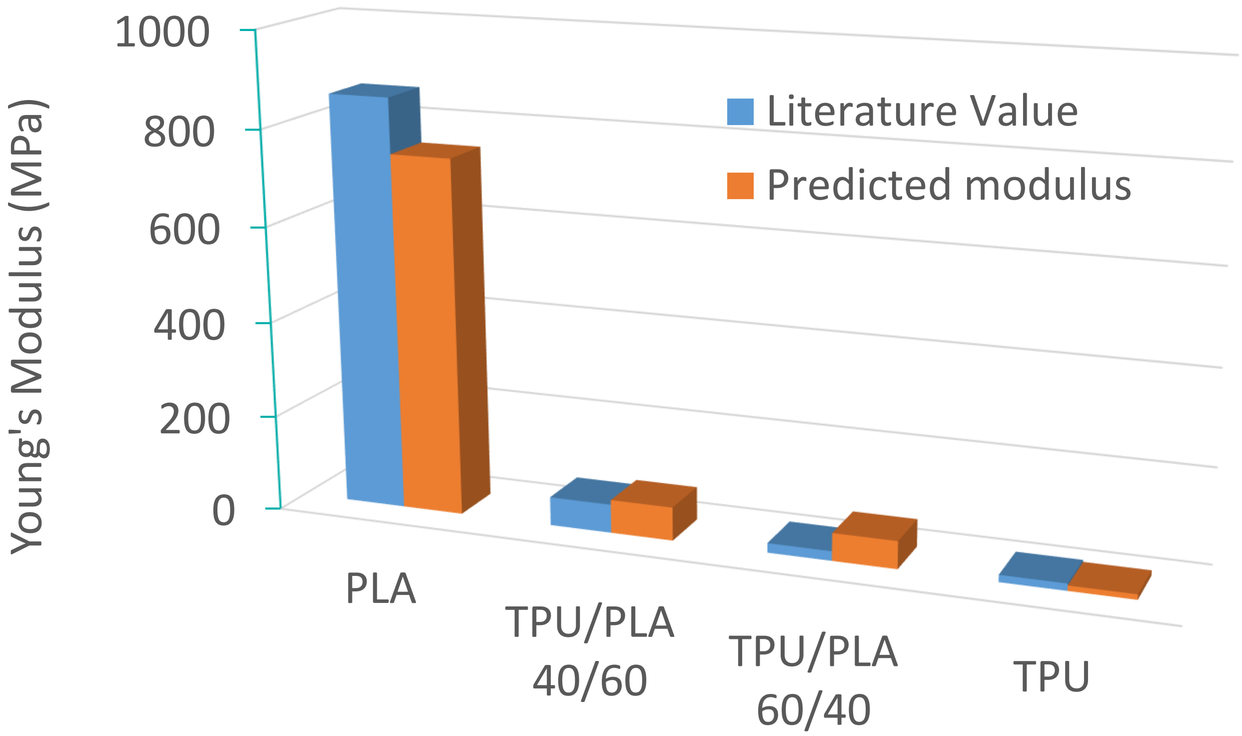
Hexagonal







Comparing to literature data



- The model under predicted for the polymers however over predicted for the polymer blend.

A. Darnal *et al.*, Compos. Struct., 2023,vol 318, pp 117075-117098

Conclusions

- The models in literature do not take into account the outer walls of the print
- Through FEA analysis the rate of change of stiffness with infill density is depended on the infill pattern
- Applying the knowledge from experimental and FEA analysis the model showed alignment with literature values

<u>Future work</u>

- Further model validation with different materials

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Thank you

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