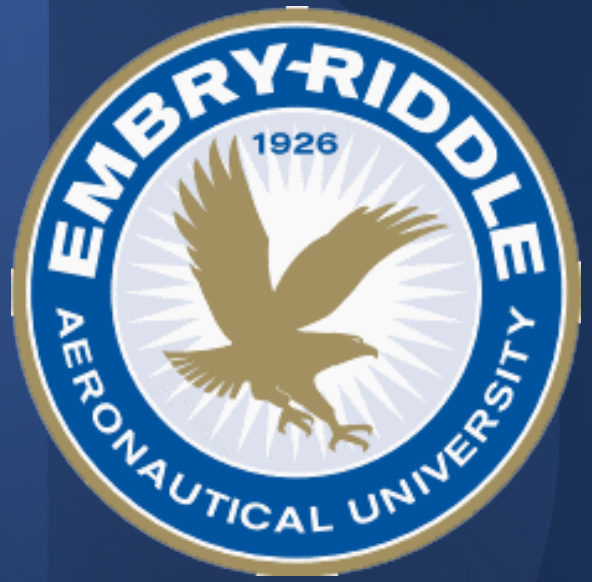
Tensile Testing of 3D Printed TPU Samples for Pediatric Biomaterial Applications



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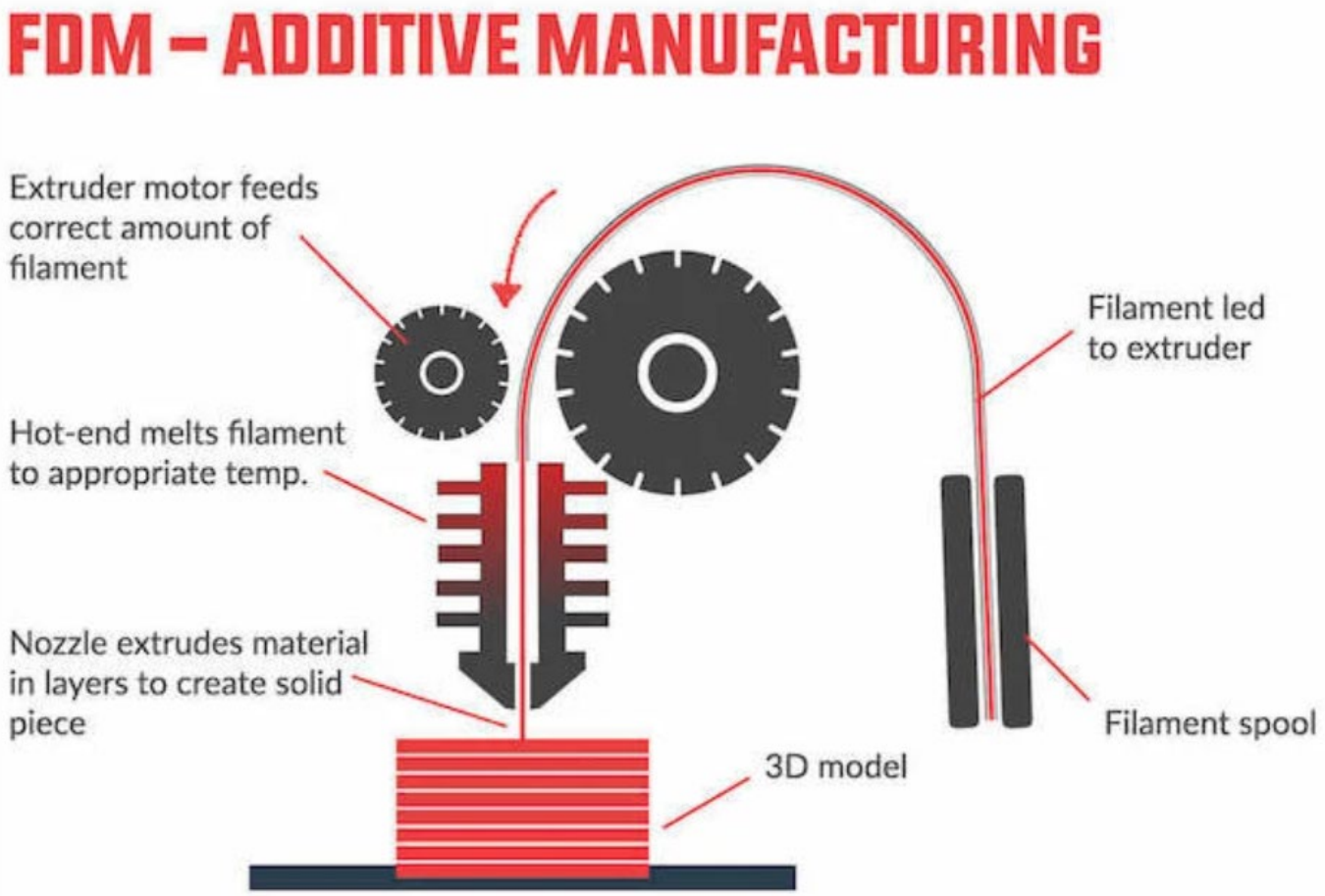
Background

- Additive Manufacturing (AM) is becoming a widespread manufacturing method.
- The most common form of AM is Fused Deposition Modeling (FDM)
- 3D printing relies on material commonly known as filament
- Information on the material properties of filament post printing is scarce
- The information that is available focuses on niche properties and filaments with few generalized analyses available

Fused Deposition Modeling (FDM)

- FDM printing relies on a simple feeding system
- The extruded material is fed onto a bed.
- Extruded material binds to the previous layer fusing layers together which is why FDM is sometimes referred to as Fused Filament Fabrication (FFF)



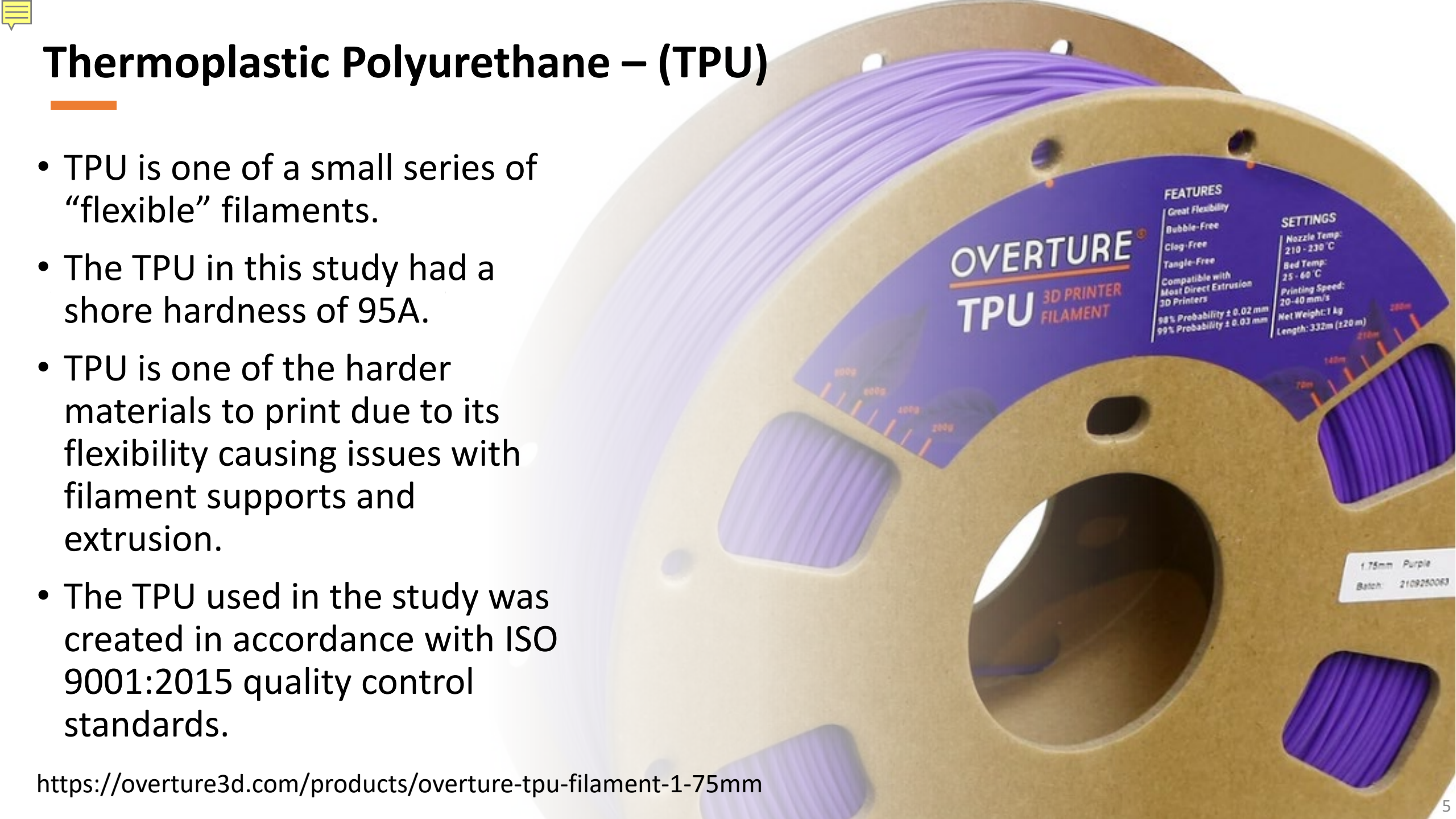
https://apm-designs.com/fdm-vs-sla-3d-printer-tech-comparison/

Materials

- 3D printing filament is commonly a thermoplastic.
- Carbon fiber and metal filaments are less prevalent, but still available to the consumer market.
- Common filaments include Polylactic Acid (PLA), Thermoplastic Polyurethane (TPU), Acrylonitrile Butadiene Styrene (ABS), and Polycarbonate (PC).
- Some companies produce filled filaments and filaments with additives that change the color, heat resistance, chemical resistance, and/or coefficient of friction.

Thermoplastic Polyurethane – (TPU)

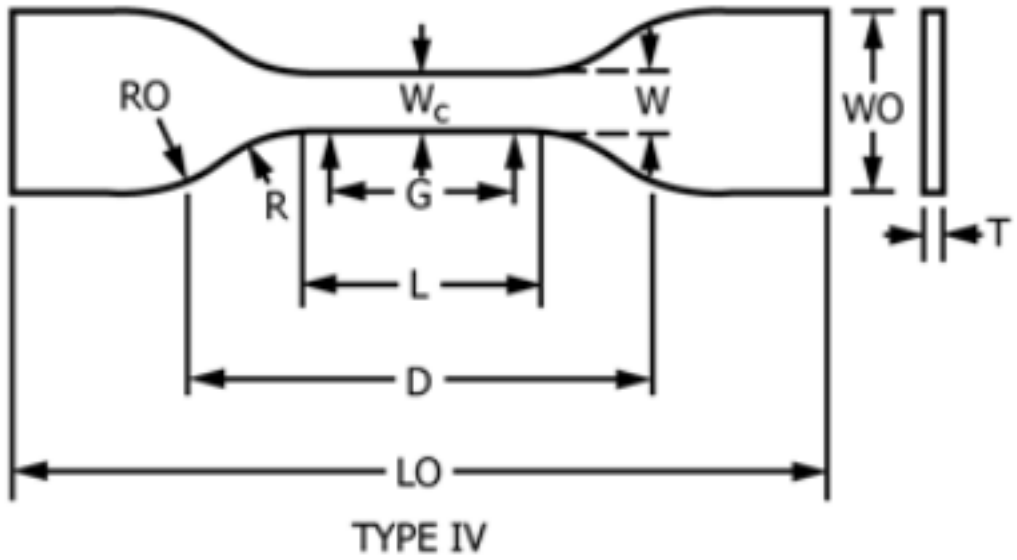
- TPU is one of a small series of “flexible” filaments.
- The TPU in this study had a shore hardness of 95A.
- TPU is one of the harder materials to print due to its flexibility causing issues with filament supports and extrusion.
- The TPU used in the study was created in accordance with ISO 9001:2015 quality control standards.



https://overture3d.com/products/overture-tpu-filament-1-75mm

Testing Method

- Standard for AM testing is ASTM D638-14 with ASTM D883-00 and ASTM F2971 used as references.
- D638-14 specifies the Type IV sample for comparing rigid and nonrigid samples.



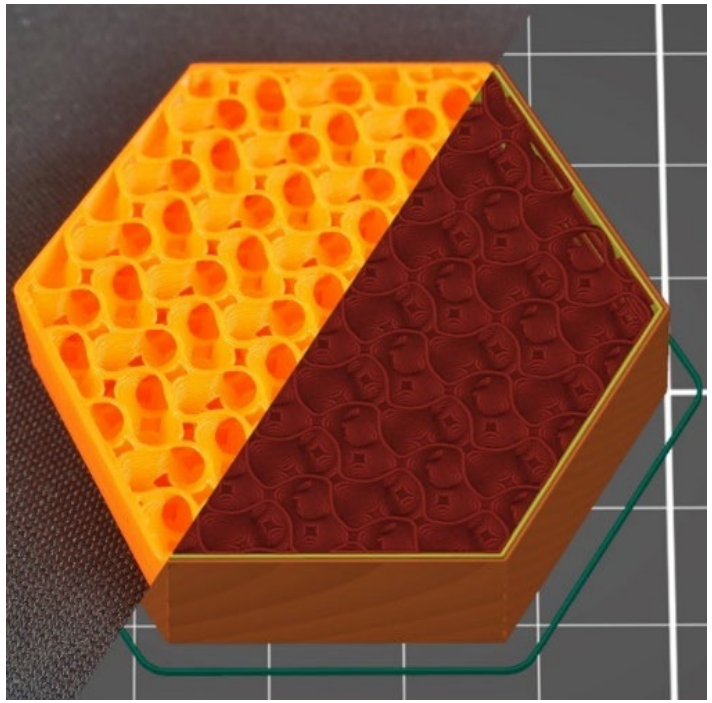
TYPE IV

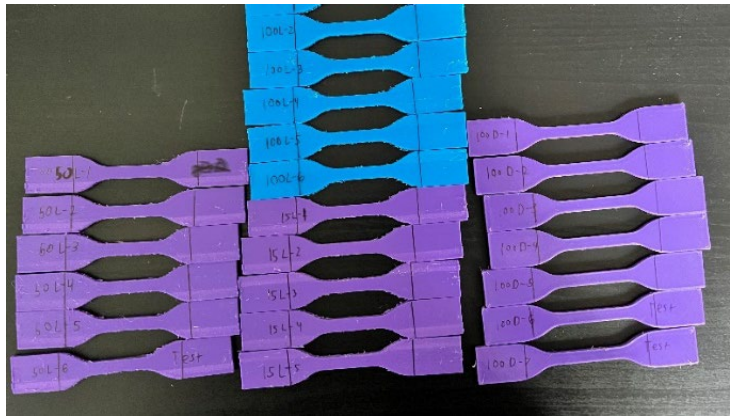
Dimension Variables	Dimension (mm)
Width (W)	6.0 ± 0.50
Cross Sectional Width (Wc)	6.0 +0.00 -0.100
Length (L)	33.0 ± 0.50
Outer Width (WO)	19.0 + 6.40 -0.00
Outer Length (LO)	115 no max
Gauge Length (G)	25 ± 0.13
Grip Distance (D)	65 ± 5.00
Inner Radius (R)	14 ± 1.00
Outer Radius (RO)	25 ± 1.00
Thickness (T)	3.2 ±0.40

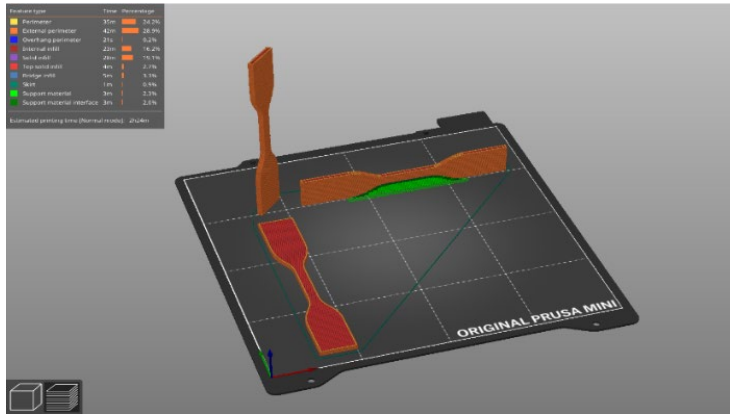
3D Printer – Prusa 3D Mini

- The nozzle was an E3d 0.4 mm nozzle
- Heating block and heat break are original to the printer
- Stepper motors are custom made for Prusa3D’s printers
- Widely considered one of the best companies for hobby 3D printing.

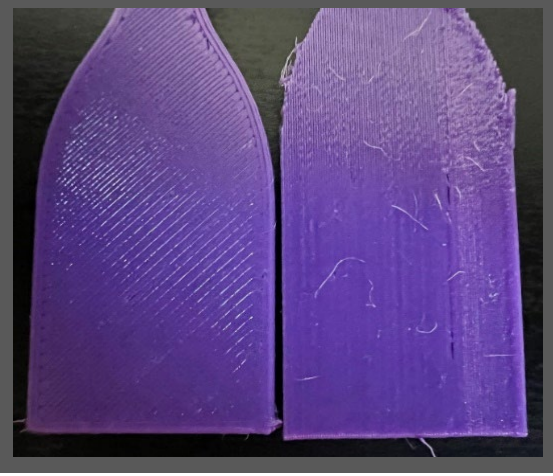
Samples and Printer Settings



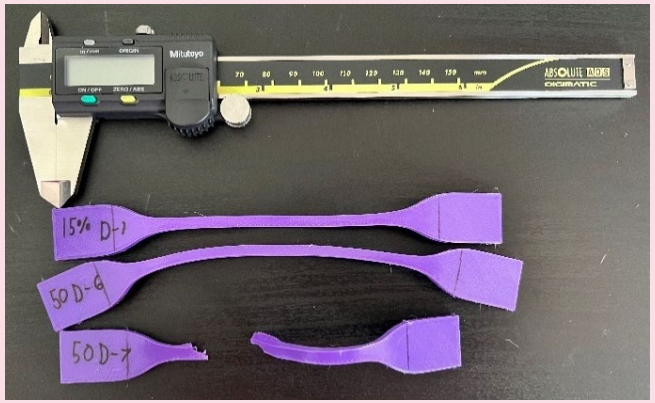




Printer setting	Values
Detect bridging perimeters	ON
Nozzle	230 C
Enable Auto Cooling	OFF
Fan Speed	100%
Bridge Fan speed	100%
Disable fan for the first	0 layers



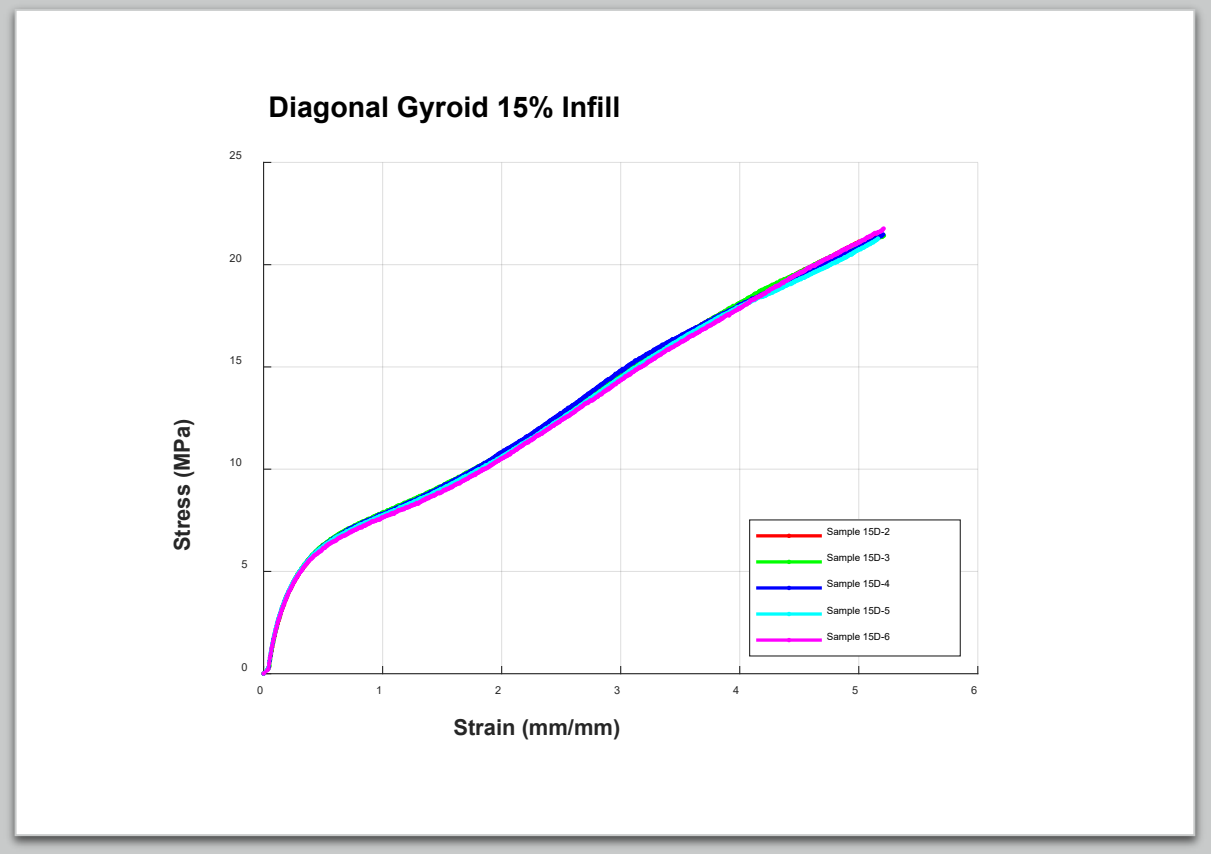
Testing Parameters and Setup

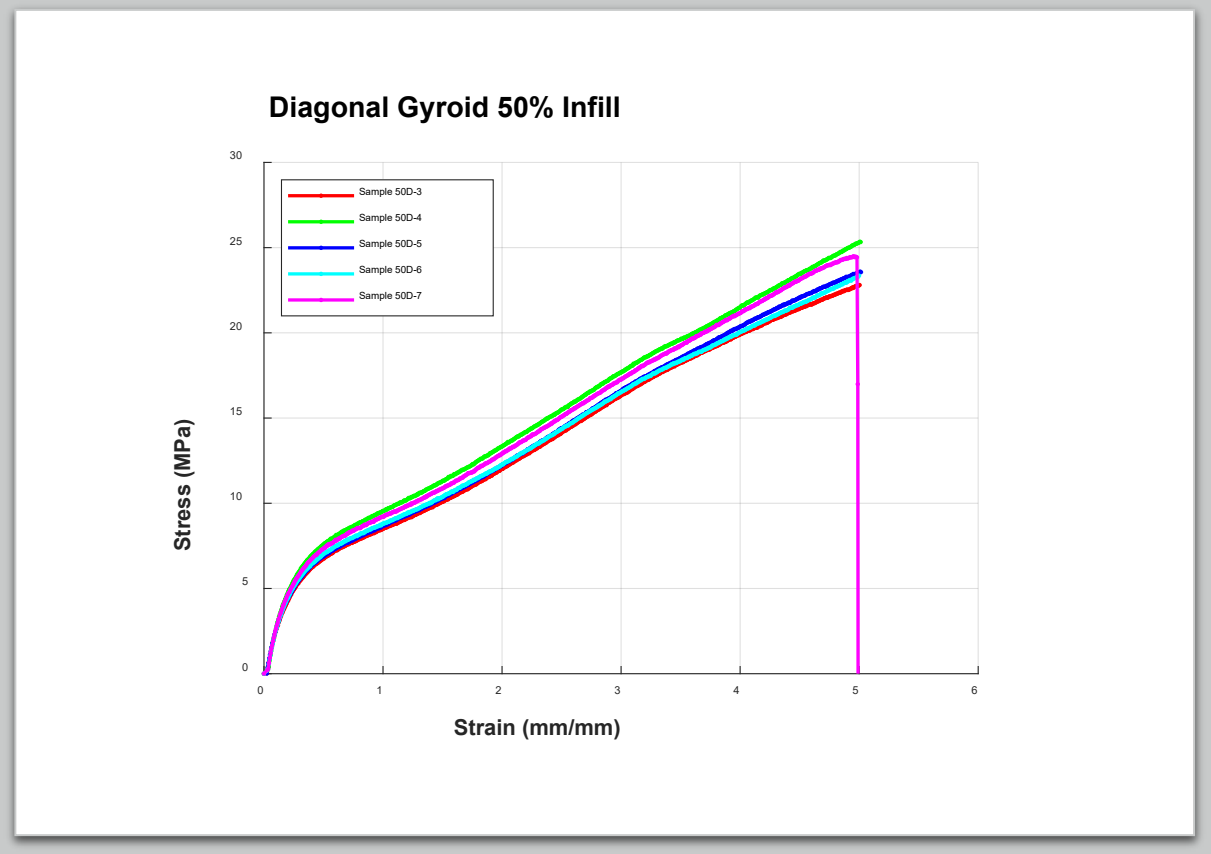


- MTS Criterion Model 43.504 with extended height modification
- Max load of 50kN
- ASTM D638 specifies that for nonrigid plastics with an E of less than 70 MPa a testing rate of 500 mm/min.

Testing Results

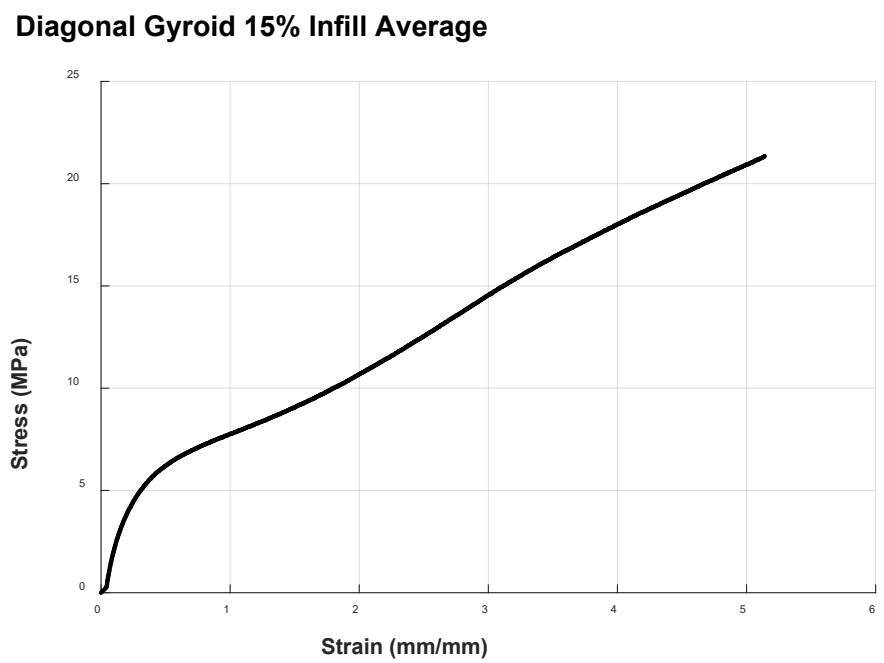
- Stress-Strain curves were plotted in MATLAB.
- The elastic limit is reached nearly instantaneously
- The ultimate stress is relatively low, but the elongation of the material is comparable to elastomers

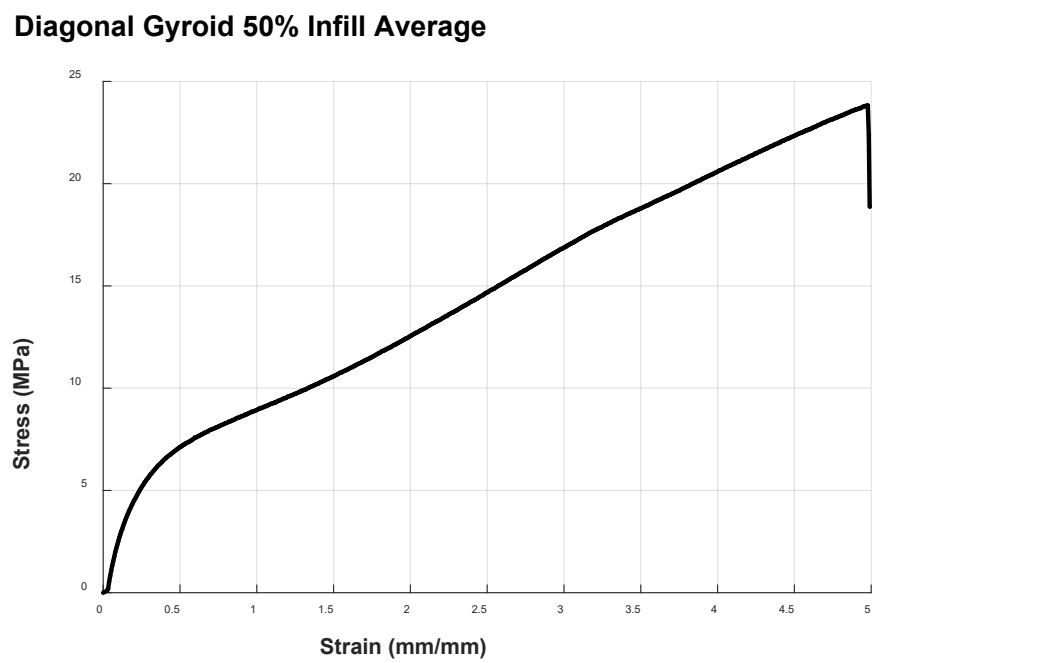




Testing Results

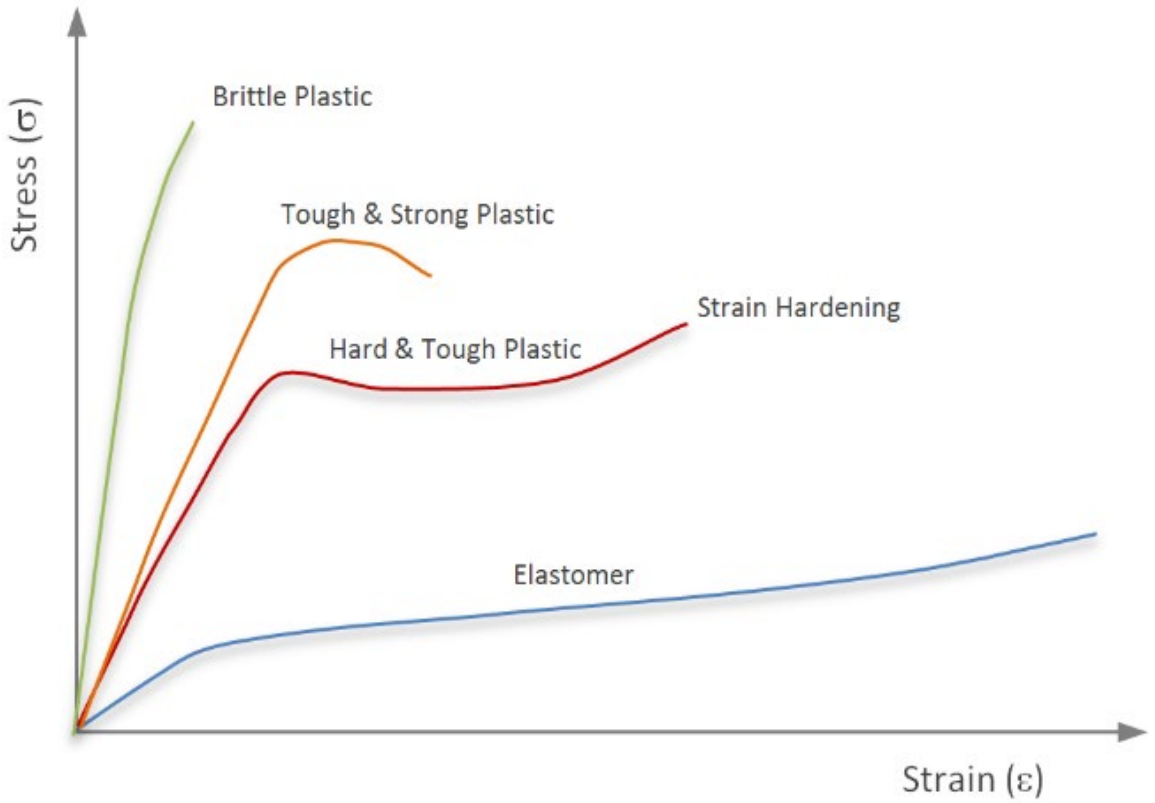
- Stress-Strain curves were plotted in MATLAB.
- Averages were created from existing data using MATLAB commands





Discussion

- TPU behaves similarly to the elastomer
- TPU is technically classed as a Thermoplastic Elastomer (TPE)
- The samples don’t fail due to their large plastic deformation region
- The assumption of nonrigid was proved



Average Mat. Properties	15% Diagonal Infill	50% Diagonal Infill
Moduli of Elasticity	19.09 MPa ±0.38	23.13 MPa +0.91 -0.87
Peak Stress	21.50 MPa +0.3 -0.2	23.92 MPa +1.38 -1.12

https://polymerdatabase.com/polymer%20physics/Stress-Strain%20Behavior.html

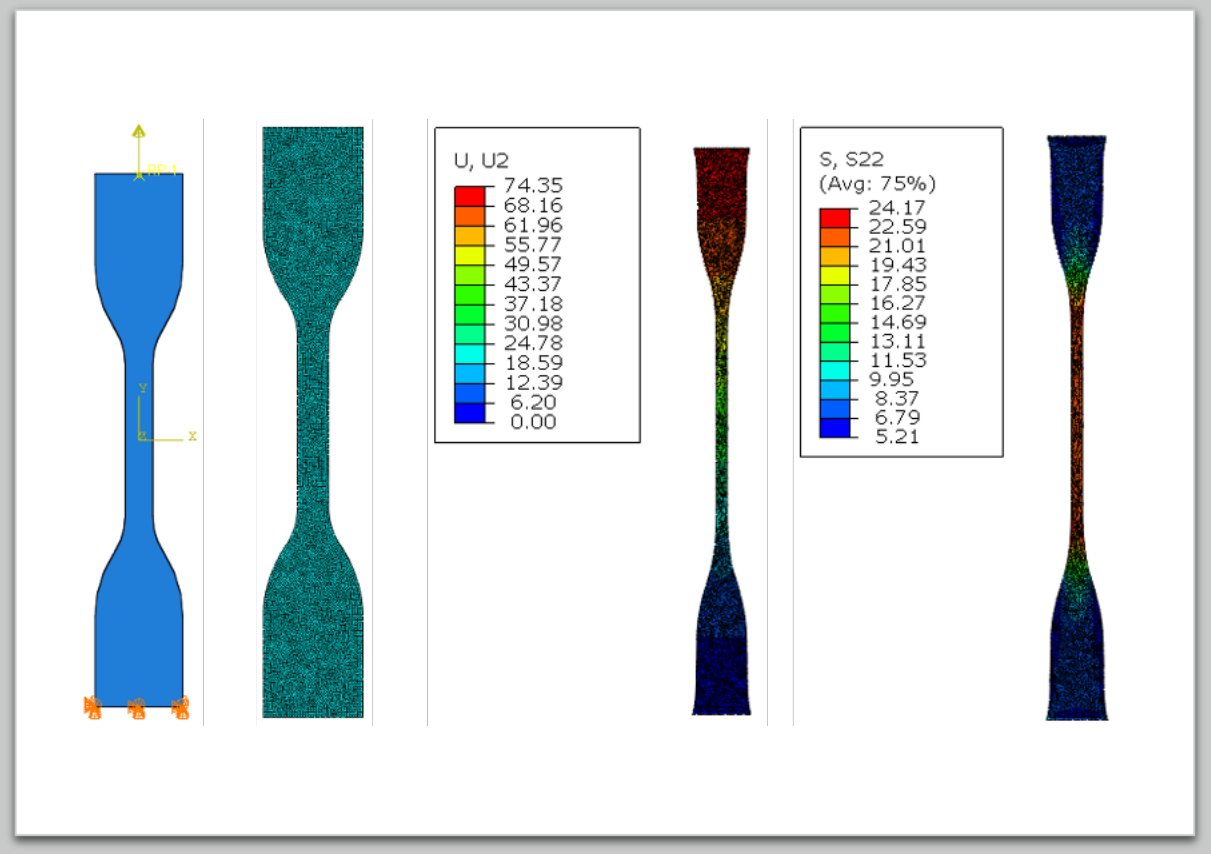
FEA Simulation-Material Assignment

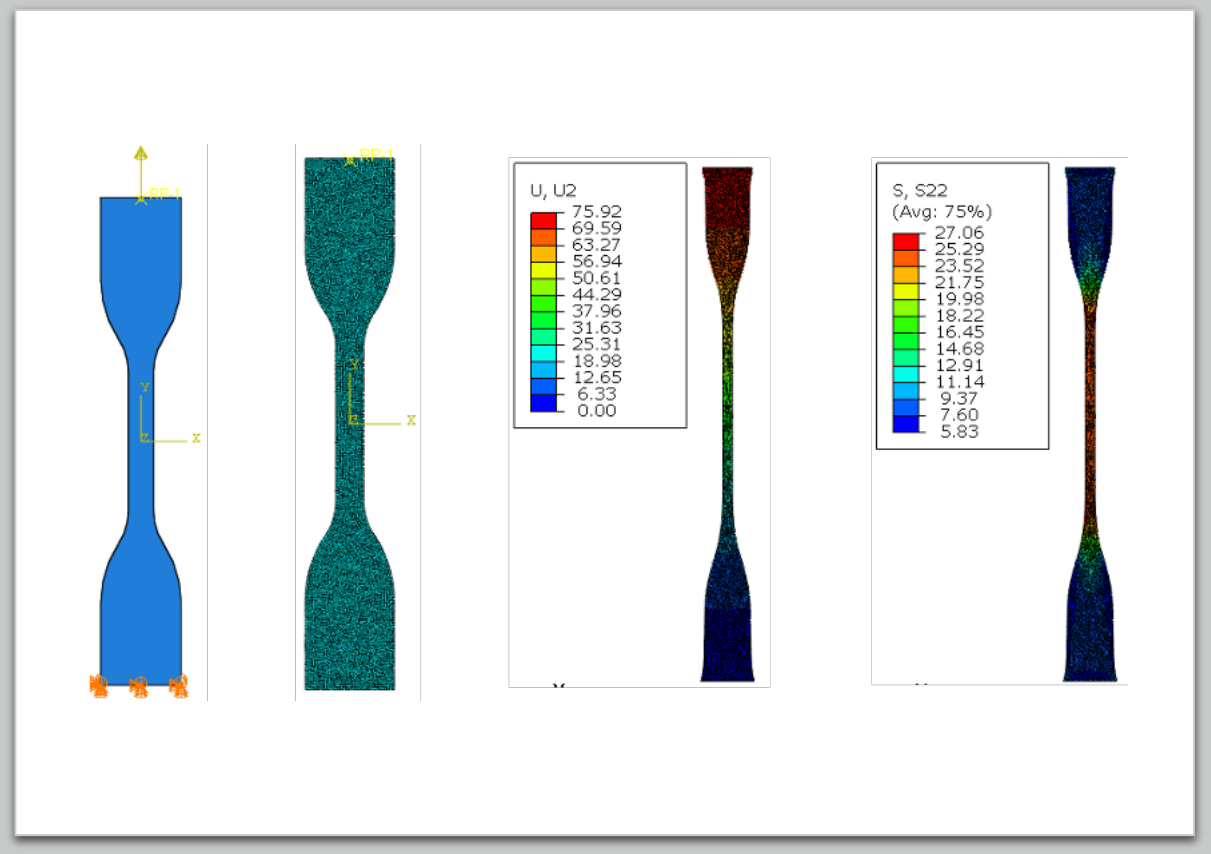
Material Assignment	Moduli of Elasticity	Poisson's Ratio
15D	19.09 MPa	0.3897
50D	23.133 MPa	0.3897

- Finite Element Analysis using the same geometry and experimentally given data [Lee,H. et. al 2019].
- Average Moduli of Elasticity was used.
- Average Peak force was assigned as the boundary condition

FEA Simulation Setup

- Elements used are C3D8R which is a type of 8 node brick element
- Final node and element count is 52,725 and 43,554 respectively
- Both experimental results were tested, and a mesh convergence analysis was performed.





FEA Simulation Results

- Peak Stress and Displacement are in agreement with the experimental results
- Discrepancies can be attributed due to assuming elastic isotropic
- Note that the displacement does vary significantly and is dependent on slippage.

FEA RESULTS	MAXIMUM NORMAL STRESS	MAXIMUM DISPLACEMENT
15%	24.17 MPA	74.35 MM
50%	27.06 MPA	75.92 MM

Limitations

- Several additional infills were unable to be tested
- Controlling the temperature during printing was not possible
- Slippage affected the results of the samples
- Were not able to run compressive testing due to not being able to find an acceptable standard for nonrigid plastics
- Non unified testing and printing could cause discrepancies in results

Conclusions and Next Steps

- To conclude TPU 95A behaves as an elastomer and has a relatively low ultimate stress.
- The next logical step is to continue FEA analysis on complex nonlinear geometries
- Additionally, testing prints out of these nonlinear geometries could validate the use of the data in FEA simulations.
- A unique protocol could be created allowing for future researchers to expand the bank of existing information

Acknowledgements

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Questions