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Functional Prototyping with Polymeric Materials
NIST Measurement Science Roadmap for Polymers in Additive Manufacturing
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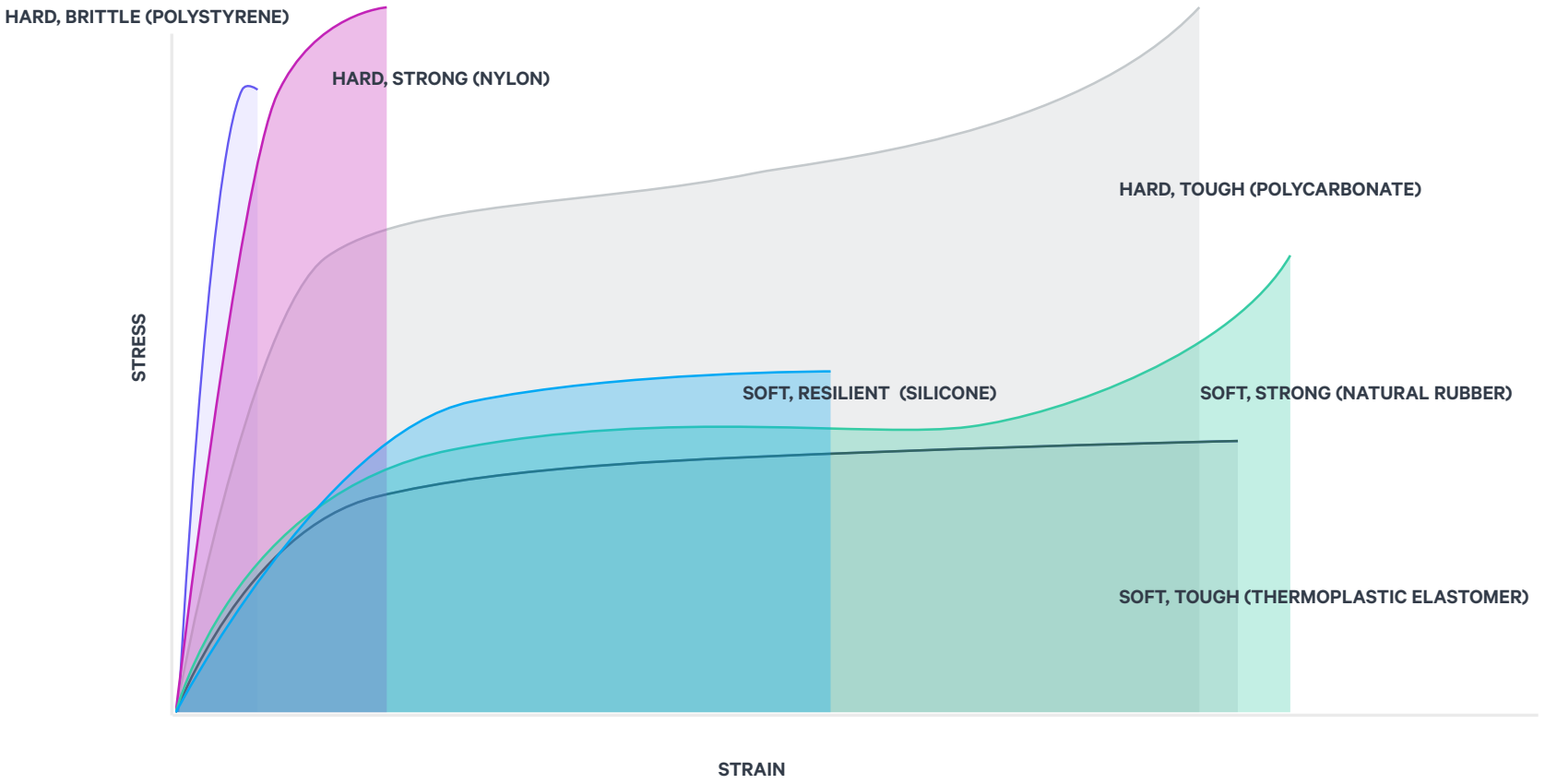
What do I mean by Functional Prototyping?

- Speed
- High resolution/surface finish
- Isotropic properties
- Tunable for specific applications
- Variety of great material properties
- Control over porosity/density
- Economical

Injection Molding meets these needs - the bar is set high!

Light Based (SLA, Inkjet)	Heat Based (SLS, FDM)
Thermosets	Thermoplastics
Poor mechanical properties	Good mechanical properties
High resolution	Poor resolution, poor surface finish
Printed supports	Self-supporting
Solid parts	Porous
Low cost	High waste and high cost

The Problem


HARD, BRITTLE (POLYSTYRENE)
HARD, STRONG (NYLON)
HARD, TOUGH (POLYCARBONATE)
SOFT, RESILIENT (SILICONE)
SOFT, STRONG (NATURAL RUBBER)
SOFT, TOUGH (THERMOPLASTIC ELASTOMER)
STRESS
STRAIN

The Approach

Iterate rapidly on resin formulations

- Understand UV cure properties and ‘printability’
- Measure mechanical properties
- Understand material post-processing

Understand the performance of our materials following standardized tests

- ASTM/ISO Standards - Tensile, Flexural, Impact, Thermal, Durability
- Customer feedback

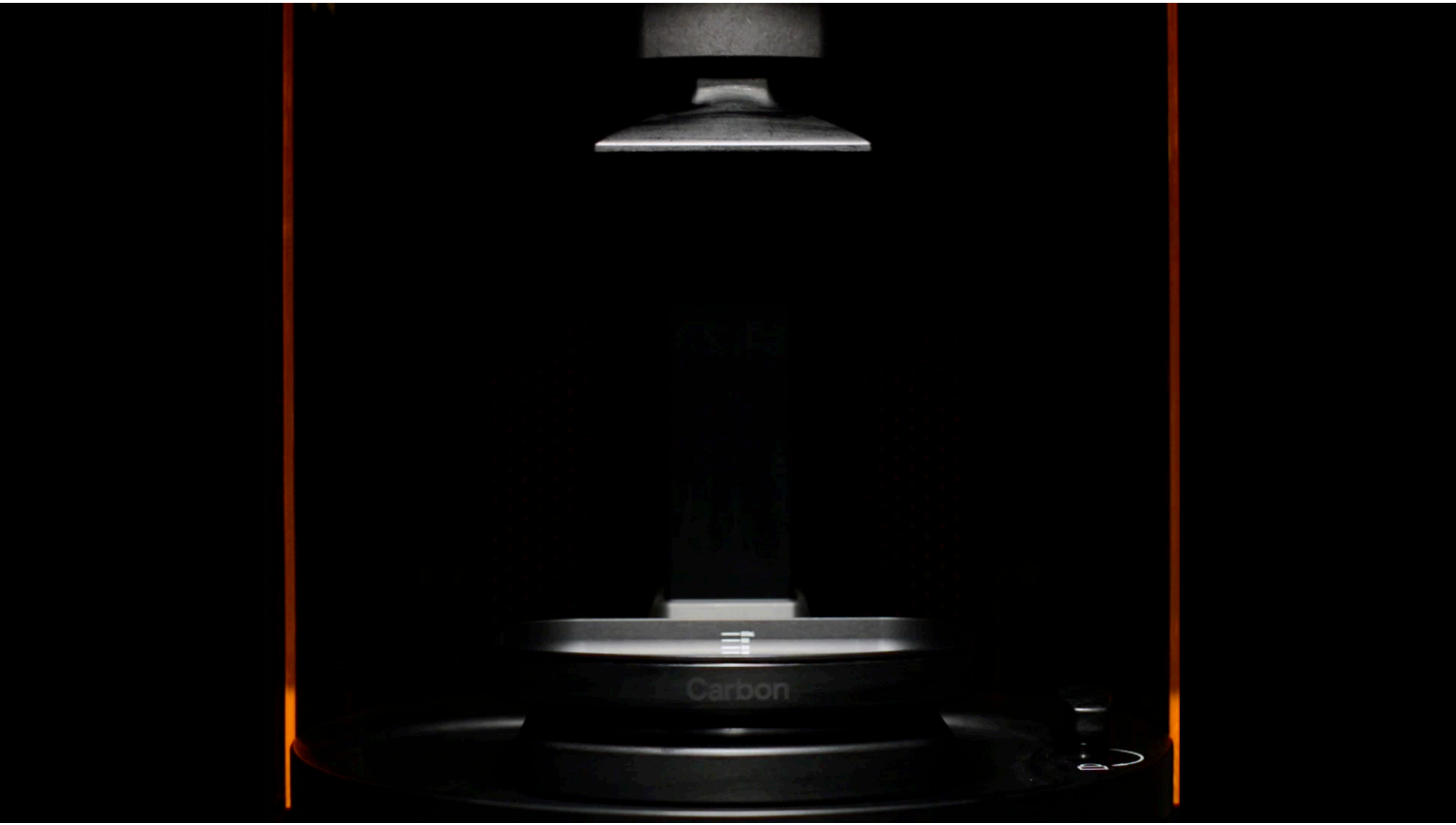
Deeply understand the process of 3D printing through *in situ* measurements and material property measurements

- Measure intrinsic properties of parts that are printed
- Understand complex interrelationships between the operation of the printer and the final properties of the part
- Process Control

The burden of proving the performance of additive manufacturing materials is on us.

Materials Characterization is an Essential Part of Performance

- **Tensile Testing**
- Flexural Testing
- Impact Testing
- Heat Deflection Temperature
- **Dynamic Mechanical Analysis (DMA)**
- Creep
- Stress-Relaxation
- Viscometry
- Differential Scanning Calorimetry (DSC)
- PhotoDSC
- **Optical Coherence Tomography**
- Elastomer Resilience and Rebound
- Statistical Analysis
- Components of Variation Analysis
- FTIR Spectroscopy
- Dielectric Properties
- **Accelerated UV and Thermal Aging**
- Hardness and Durometer
- Nanoindentation and Scratch Testing
- Optical Profilometry
- **Fatigue Testing**
- CT Scans
- Hysteresis testing
- Small-angle X-ray Scattering
- Optical Microscopy
- Scanning Electron Microscopy
- PhotoRheology
- Thermal Expansion
- Thermogravimetric Analysis (TGA)
- Rheology
- Compression Set
- FTIR Spectroscopy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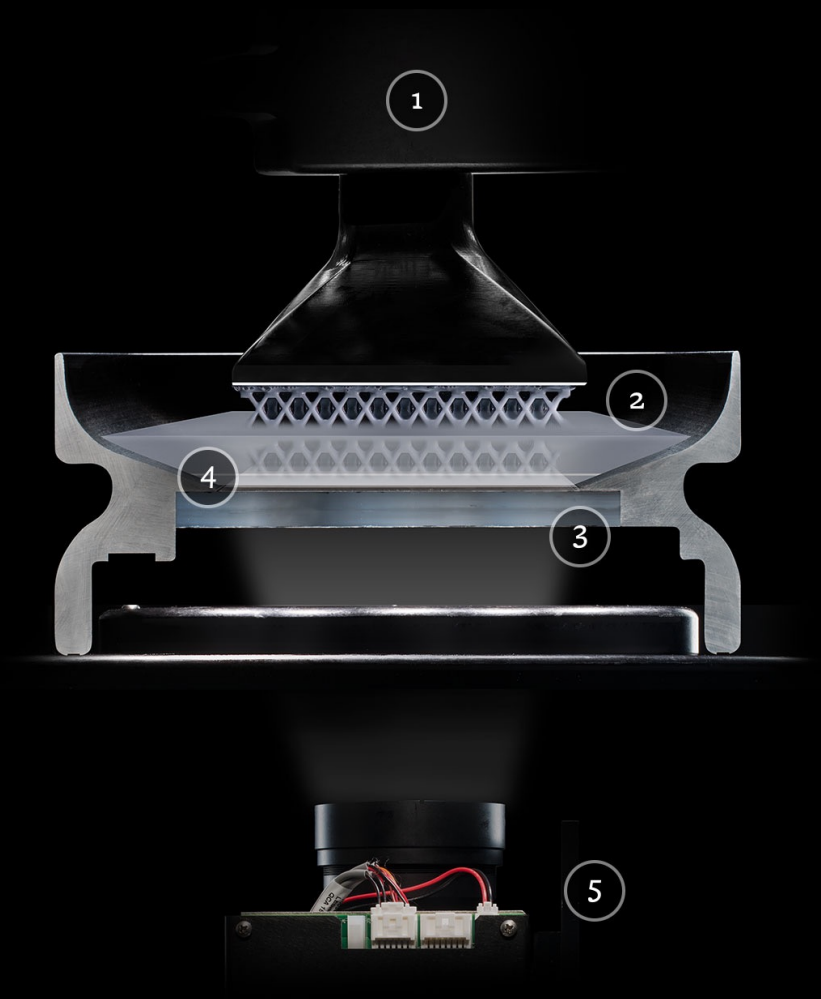
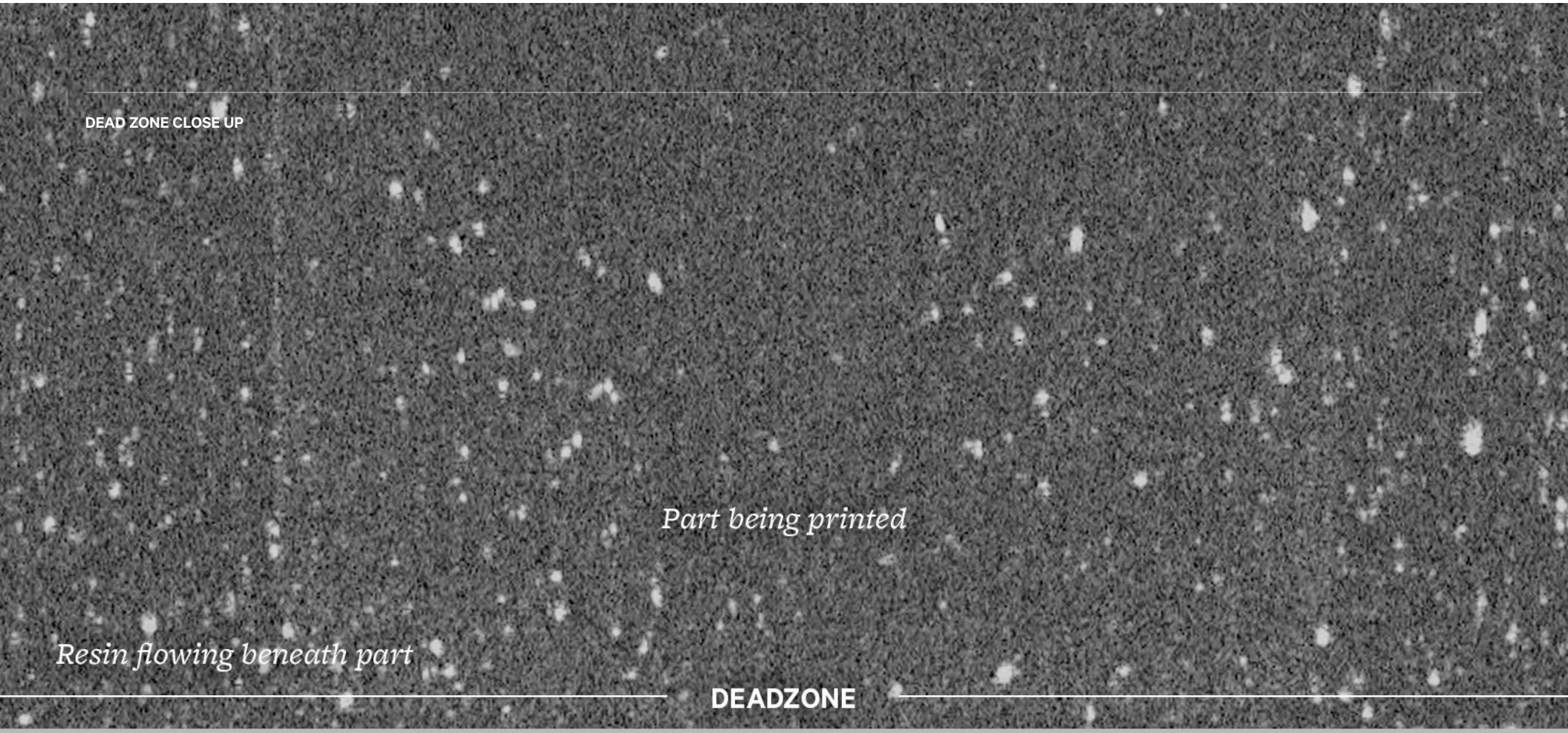
Components of CLIP

1. Build Platform
2. Resin
3. Dead zone
4. Oxygen Permeable Window
5. Light Engine





VIDEO: DR. MATT PANZER, CARBON

http://www.carbon3d.com/clip-process

The Intersection of Hardware, Software and Polymer Science

Print Speed
- CTE/Shrinkage

Resin Properties
- Absorption
- Printability
- Viscosity
- UV Light Dosage

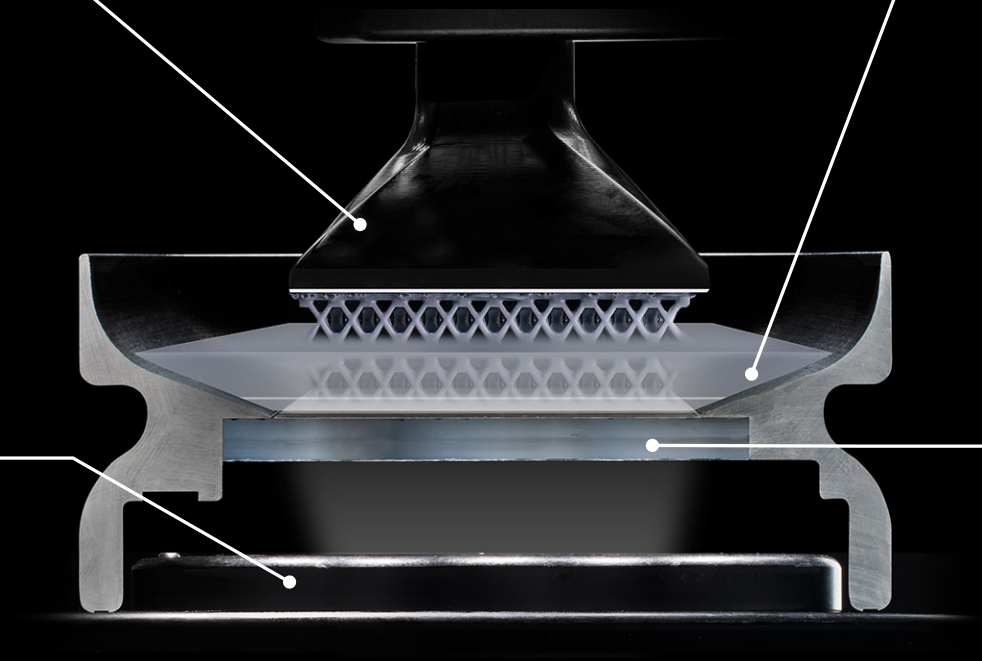
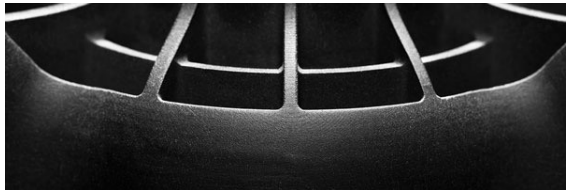


Image Quality
- Distortion
- Pixel Contrast

Mechanical
- Tolerances
- Window Flatness

Carbon Materials

Materials Overview

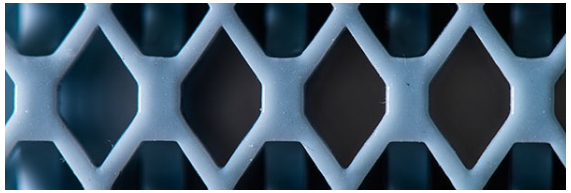


Tough and abrasion resistant, stiff

RPU Rigid Polyurethane

Tough, impact and abrasion resistant with moderate stiffness

FPU Flexible Polyurethane



Highly elastic, resilient

EPU Elastomeric Polyurethane

High temperature resistance, strength, and stiffness

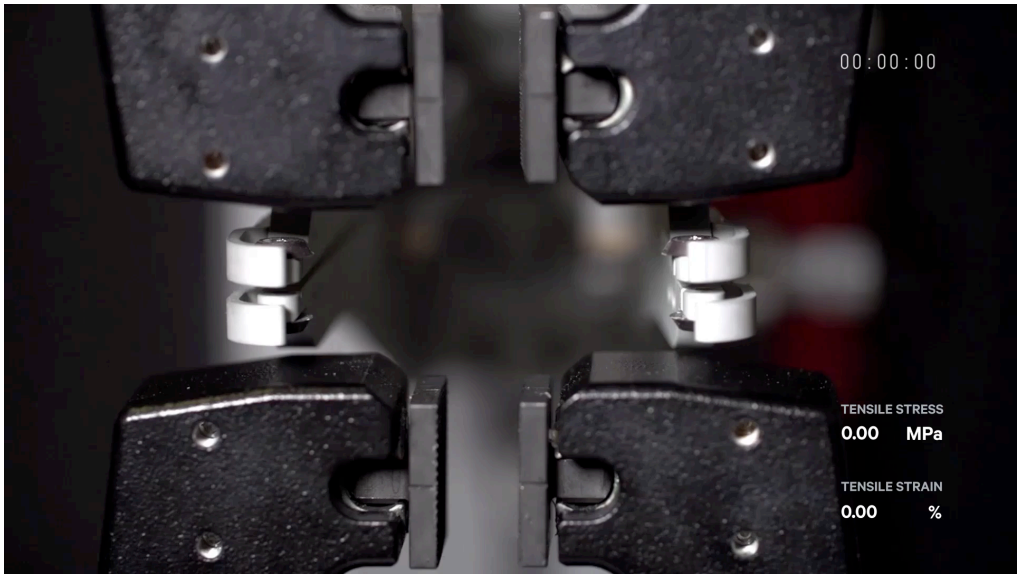
CE Cyanate Ester

General purpose

PR Prototyping Resin

Materials Testing

CE, 1 mm/min

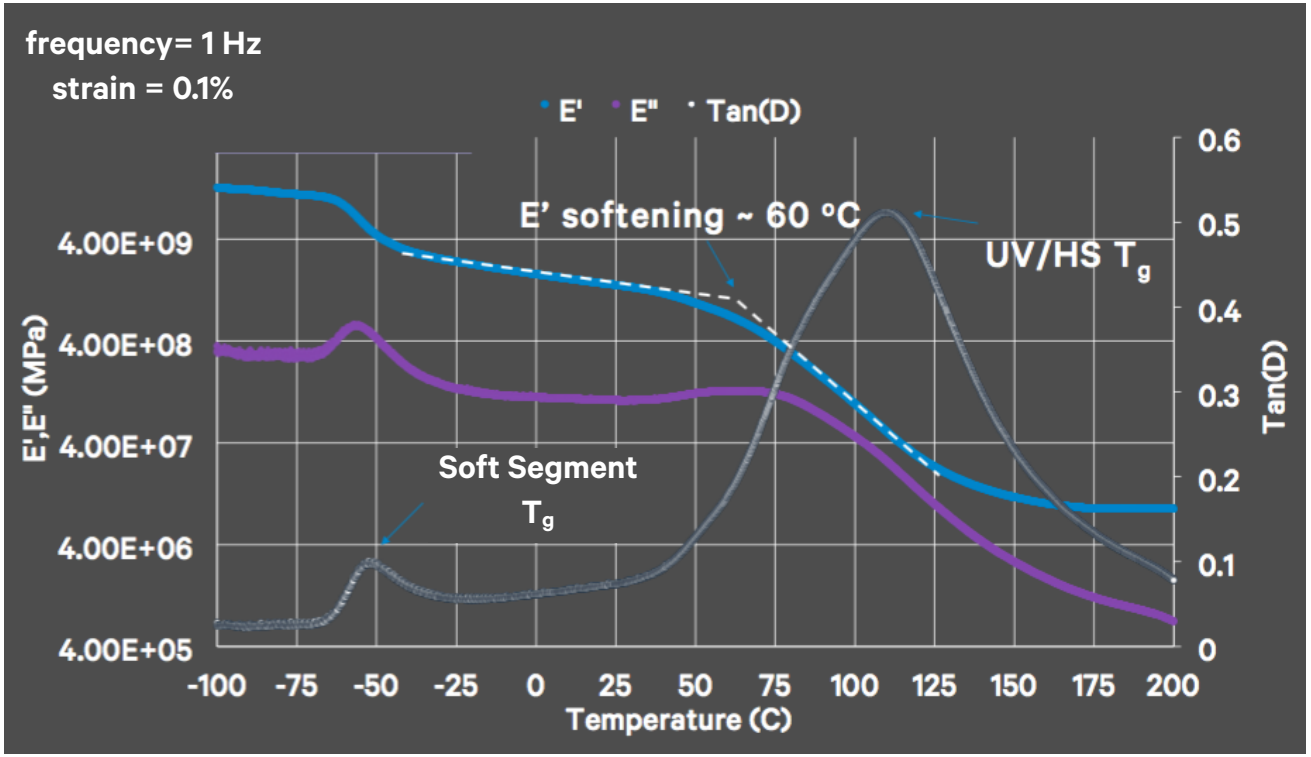


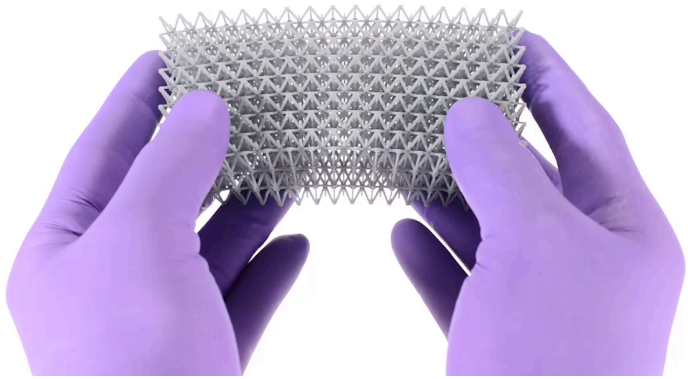
FPU, 10 mm/min

Tensile testing using an Instron tells us a great deal about the properties of our materials.

http://www.carbon3d.com/materials

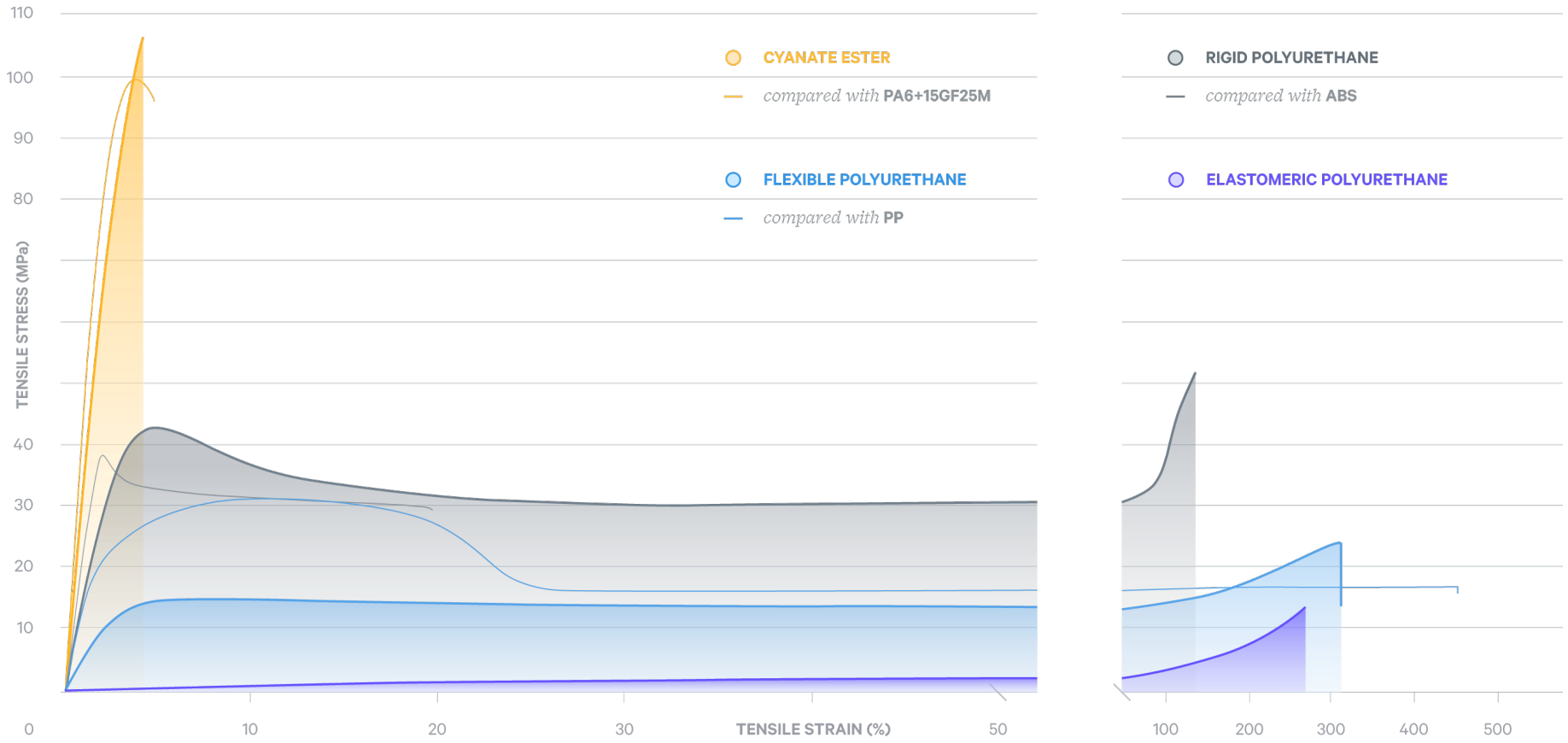
Materials Testing





Dynamic Mechanical Analysis is an invaluable technique for understanding the morphology of our materials.

Carbon Materials are Comparable to Injection Molded Materials



Functional Prototyping and Customization with End-Use Parts

What about durability?

- RPU passed **7 month field test** on car exterior
- RPU passes **ISO 105-B06 accelerated UV weathering test**
- RPU passes **20,000 cycle wear test** from auto partner
- RPU passes **500,000 cycle test** from orthotics partner
- EPU passes **250,000 compression cycle test** from footwear partner
- CE passes **15 cycles** of autoclave steam sterilization
- FPU passes internal 400 cycle living hinge test

We have a lot more to characterize and understand about the durability and performance of our parts.

Where do we go from here?

There are several challenges that face polymeric additive materials

- Continue to measure and understand the durability of finished parts
- Understand how the performance of your hardware and software affects your materials
- Go beyond standardized tests to understand your process
- The best data comes from users - engage them!
- **Maintain an open dialogue on characterization**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Thank You!
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