ISDN2400 Physical Prototyping

Formative Manufacturing

By Rob Scharff

February 2025

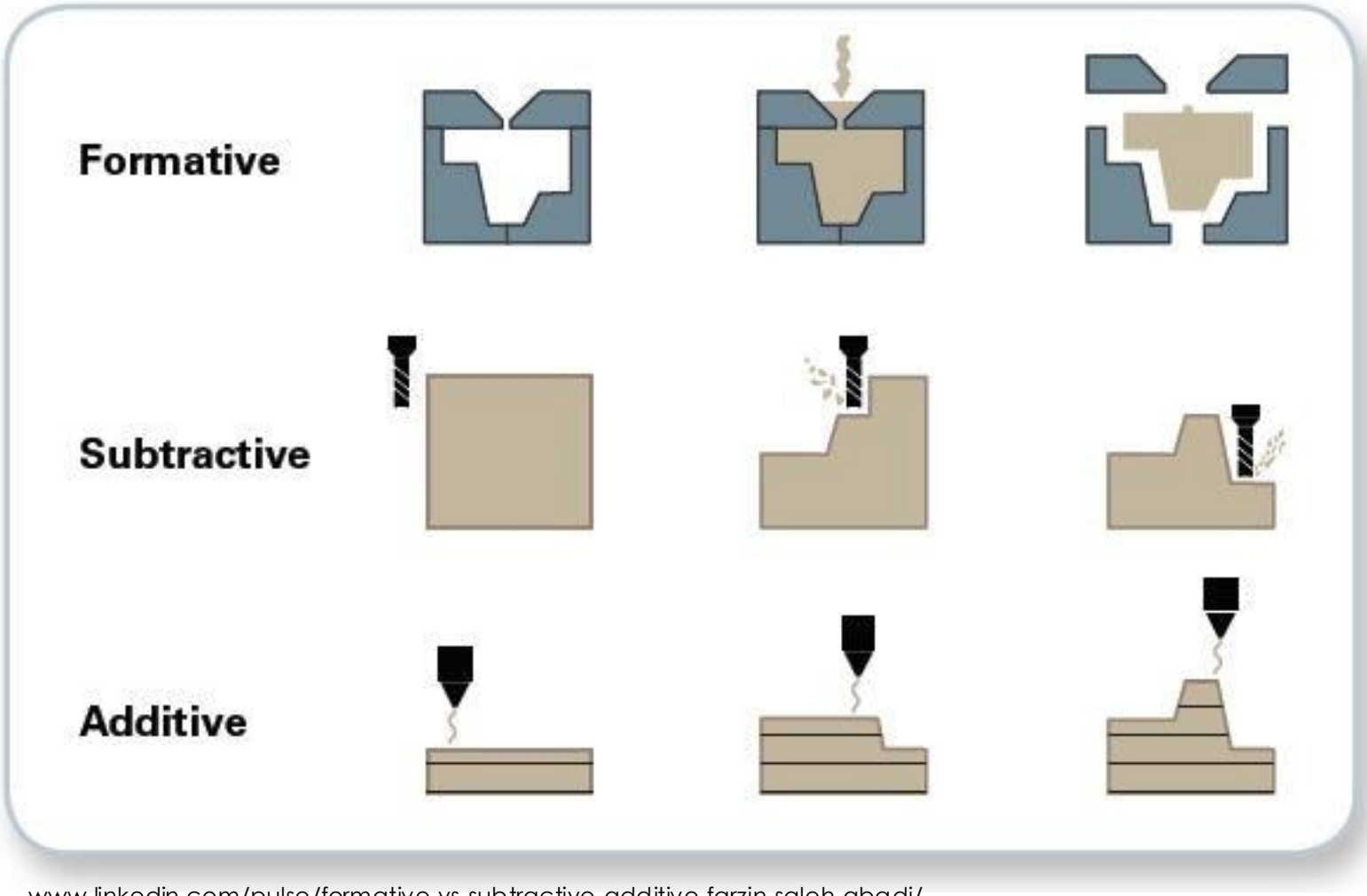
Today's lecture

- Introduction to formative manufacturing
- Silicone casting
- Preparation for the lab
- Time for group work

Formative Manufacturing

A process where mechanical forces or restricting forms are applied on a material so as to form it into the desired shape

Formative, Additive, and Subtractive Manufacturing



www.linkedin.com/pulse/formative-vs-subtractive-additive-farzin-saleh-abadi/

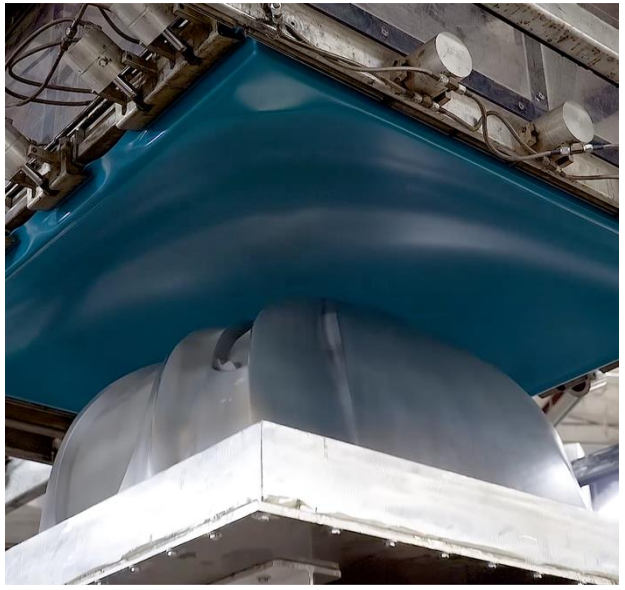
Examples of Formative Manufacturing

- Examples of Formative Manufacturing
  - Stamping
  - Forging
  - Drawing
  - Rolling
  - Extruding
  - Thermoforming
  - Casting

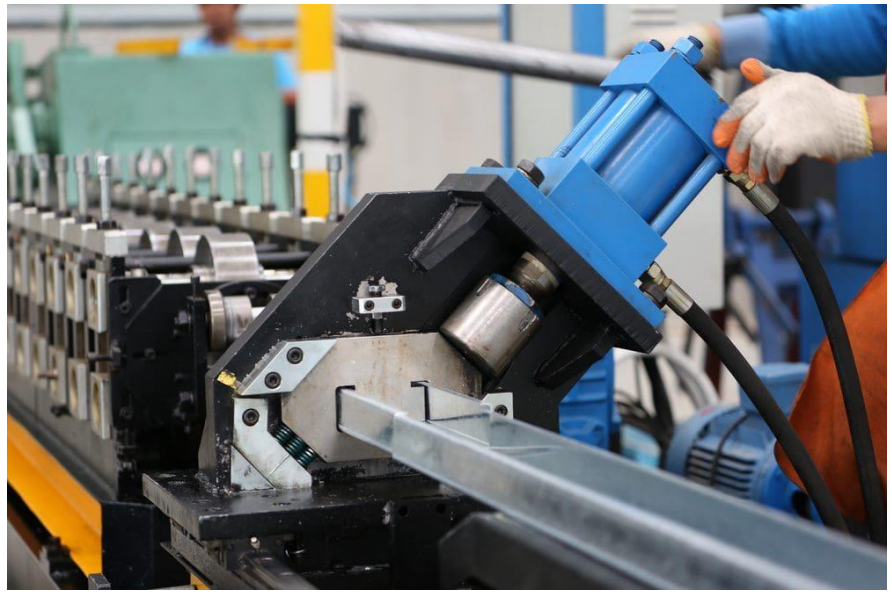
- Formative manufacturing typically involves the use of a mold or die

www.reliance-foundry.com/blog/forging

www.faistgroup.com/news/what-is-metal-stamping/



www.customplasticforming.com/thermoforming/

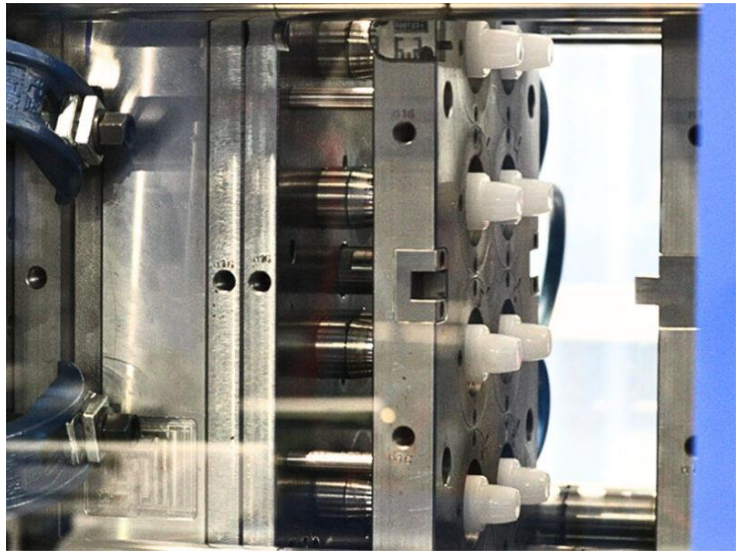


www.rainbowbelts.com/blog/profile-extrusion-what-is-it-and-how-does-it-

Tooling

- Difference between molds and dies?
  - A mold is used to shape materials by allowing them to solidify in the mold
  - A die is used to cut or shape materials using mechanical force

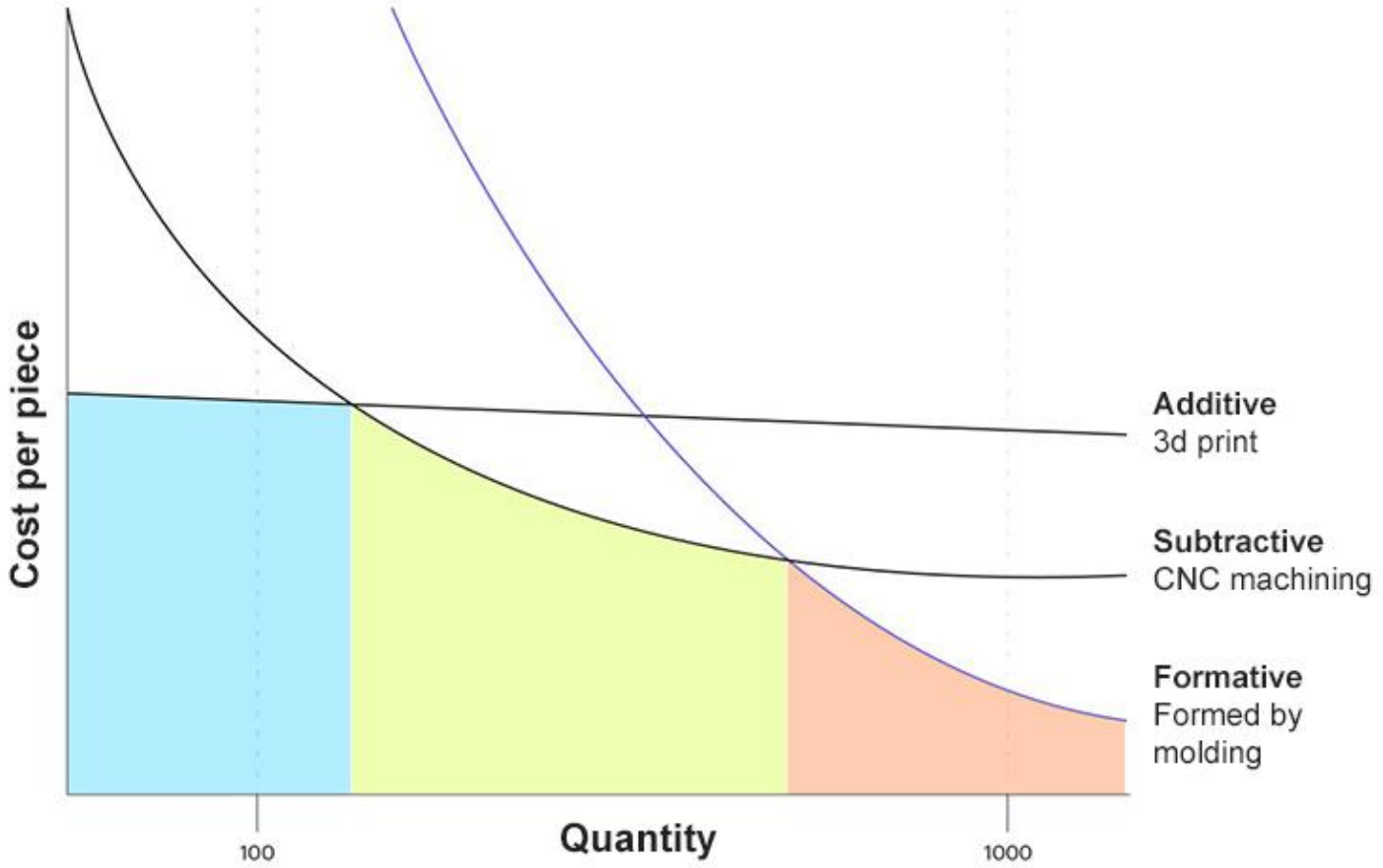
www.faistgroup.com/news/what-is-metal-stamping/



www.sybridge.com/technologies/injection-molding/

Tooling

- Tooling significantly increases initial time and cost investments
- Formative manufacturing becomes economical when large quantities are required



www.linkedin.com/pulse/formative-vs-subtractive-additive-farzin-saleh-abadi/

Mass production

- Injection molding
- Rotational molding
- Blow molding
- Extruding

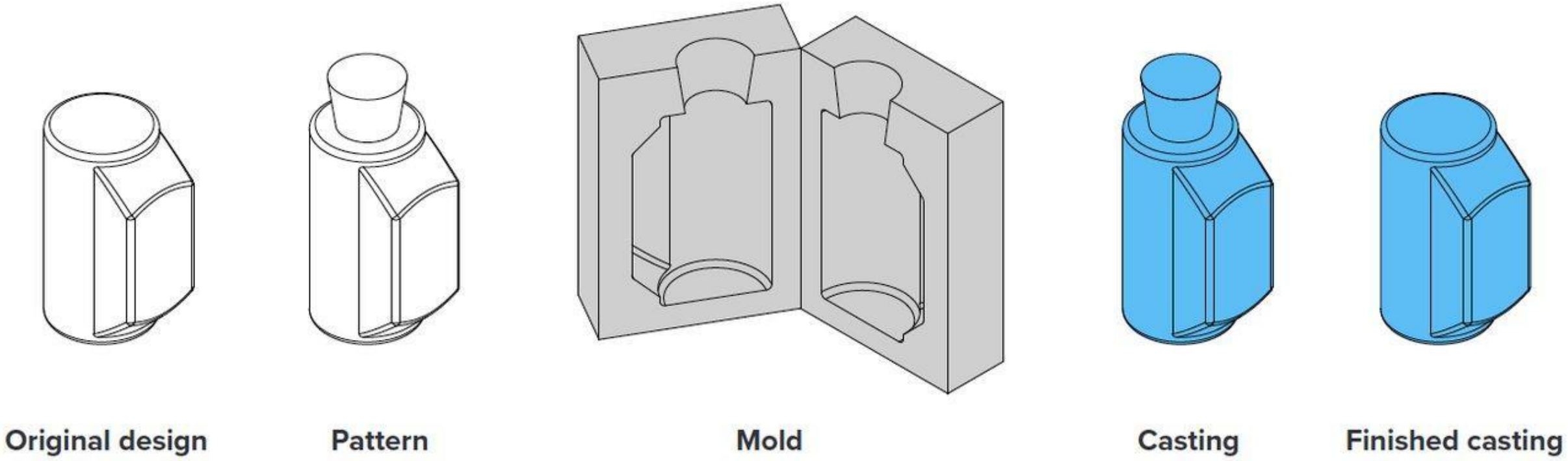
- Why use formative manufacturing for prototyping?

Formative Manufacturing for Prototyping

- Requirements on both material properties (eliminating additive manufacturing) and geometry (eliminating subtractive manufacturing)
  - Thermal resistance
  - Surface finish
  - Stretchability
  - Strength
  - Etc.
- This lecture will focus on casting
- How many of you have used casting before?

www.formlabs.com/blog/metal-casting/?s=resin+casting

The Casting Process



www.formlabs.com/asia/blog/metal-casting/

Traditional moldmaking

- How to reproduce this part using casting?
- Two part molds
  - Silicone moldmaking
  - Sand casting
- Prototyping typically requires creating a new geometry!

www.compass-anvil.com/blog/index.php/2021/02/05/die-casting-vs-sand-casting/

www.instructables.com/Two-Part-Molds/

Traditional Moldmaking

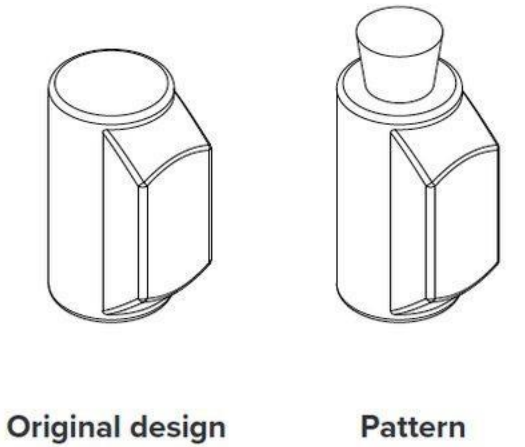
- CNC Milling
- CNC Electrical Discharge Machining
- Molds for complicated parts can easily cost more than 1M HK$ and can take several months to build

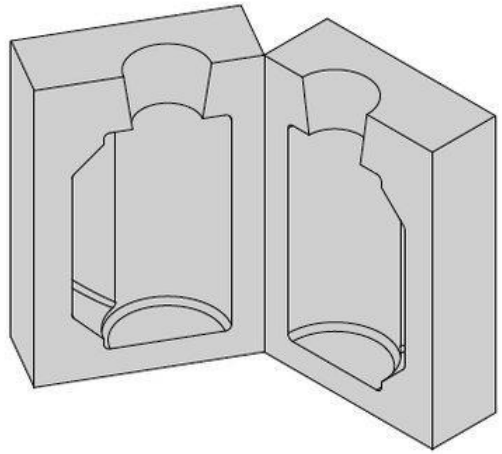
www.basilius.com/blog/edm-for-injection-mold-building/

- Too expensive and too slow for prototyping purposes!

Additive Manufacturing for Moldmaking

- Additive manufacturing of the original design/pattern
- Additive manufacturing of the mold





www.formlabs.com/asia/blog/metal-casting/

Additive Manufacturing of the original design/pattern

- Lost wax casting
  - Wax resin for SLA
  - FDM filament (Polymaker polycast or PLA)

www.formlabs.com/blog/metal-casting/?s=resin+casting

BETTER RESULTS W/ POLYMAKER?

Replicating Cultural Heritage

- Creating porcelain replicas of 17th century glassware

www.cargocollective.com/maaikeroozenburg/Discovered-in-Delft

3D Scanning the Glassware

- Computed Tomography (CT) scan
  - X-rays

www.cargocollective.com/maaikeroozenburg/Discovered-in-Delft

3D Printing the Pattern

- Scaled to account for shrinkage of the porcelain
- Why not directly print the mold?

www.instructables.com/Recreating-17th-century-glassware-from-Delft/

Moldmaking

- Porous and absorbent plaster mold to harden the slip (liquid clay)
- Why do we not need an inner mold (like for the tail of the robotic fish)?



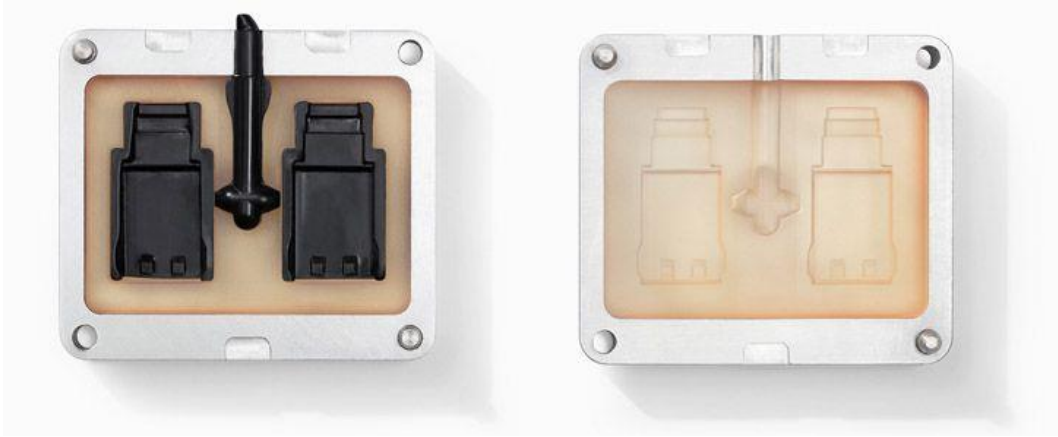

www.instructables.com/Recreating-17th-century-glassware-from-Delft/

Casting the Porcelain Replicas

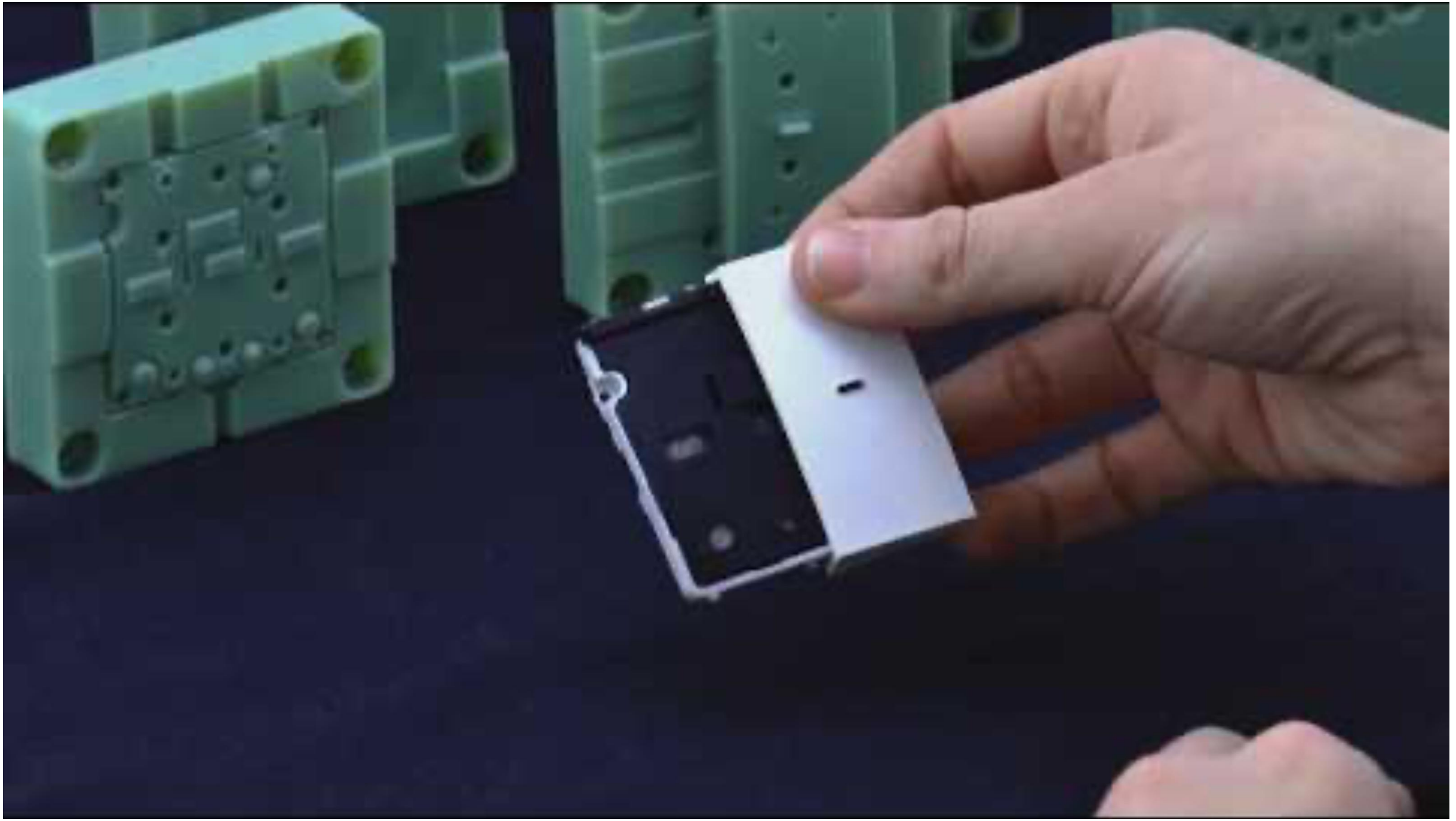
www.cargocollective.com/maaikeroozenburg/Discovered-in-Delft

Additive Manufacturing of Molds

- High temperature resins for casting molten material
  - Formlabs High Temp resin: HDT 238°C
  - Stratasys Digital ABS: HDT 100°C
  - Both printers present at ISD!
- Suitable for small series of injection molded products

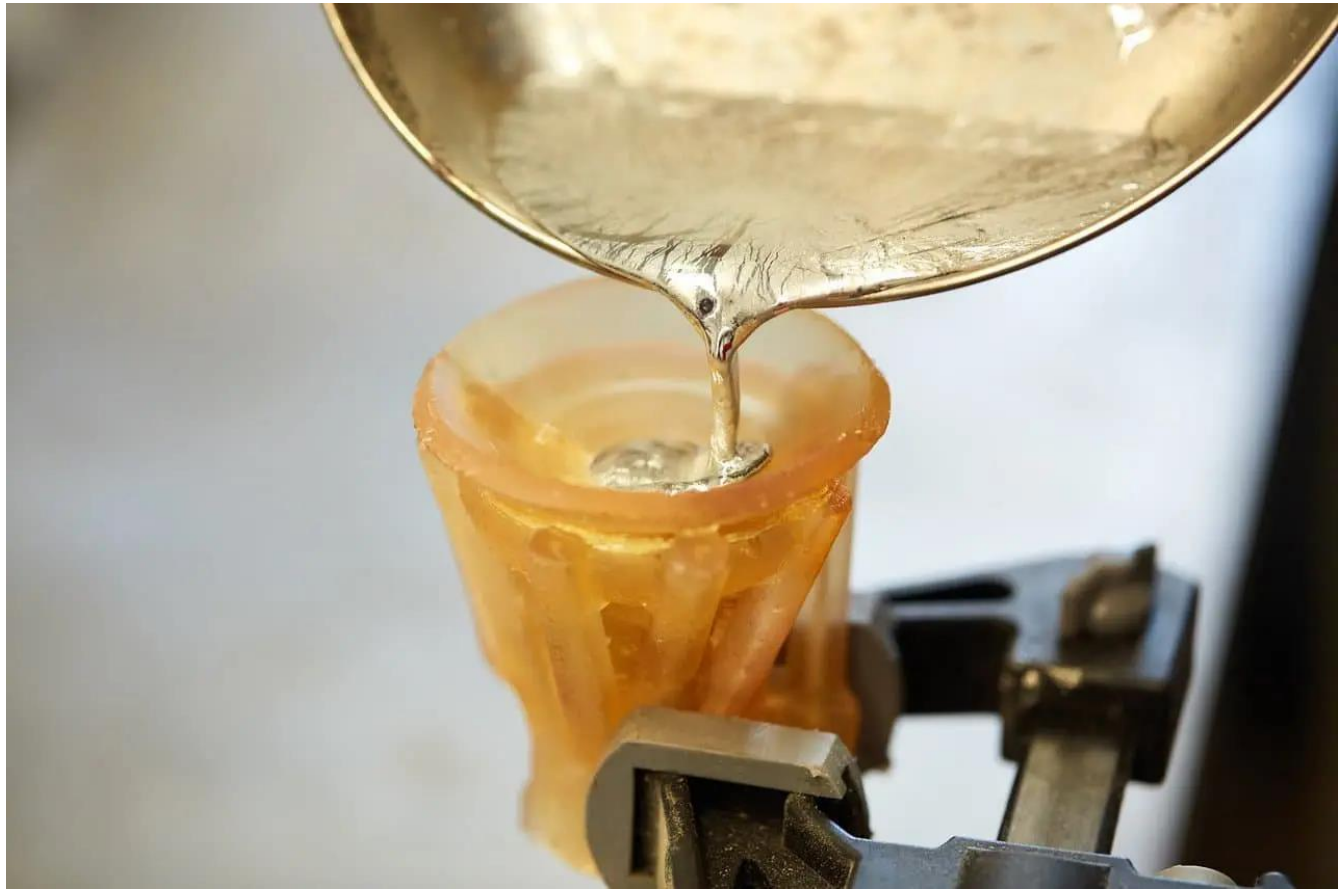


www.support.formlabs.com/s/article/Using-High-Temp-Resin?language=en_US



Pewter casting

- Malleable metal alloy with a low melting point (~200°C)
- Mostly tin with small amounts of other metals



www.formlabs.com/blog/metal-casting/

Additive Manufacturing of Molds

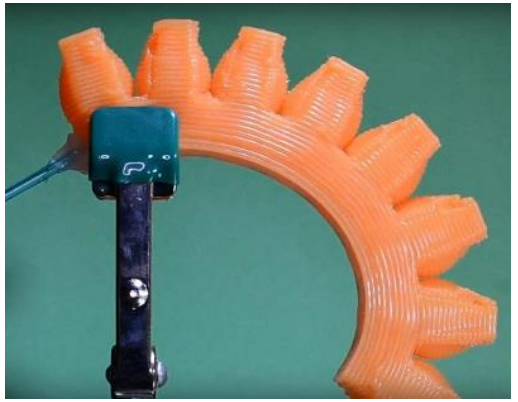
- 3D-printed molds for casting resins and silicones

www.instructables.com/Air-Powered-Soft-Robotic-Gripper/

Silicone casting

- Silicones have many desirable properties
  - Non-flammable
  - Thermal resistance for both high and low temperatures
  - Chemical resistance
  - Electrical insulators
  - Highly stretchable
- Additive Manufacturing difficult and Subtractive Manufacturing not an option

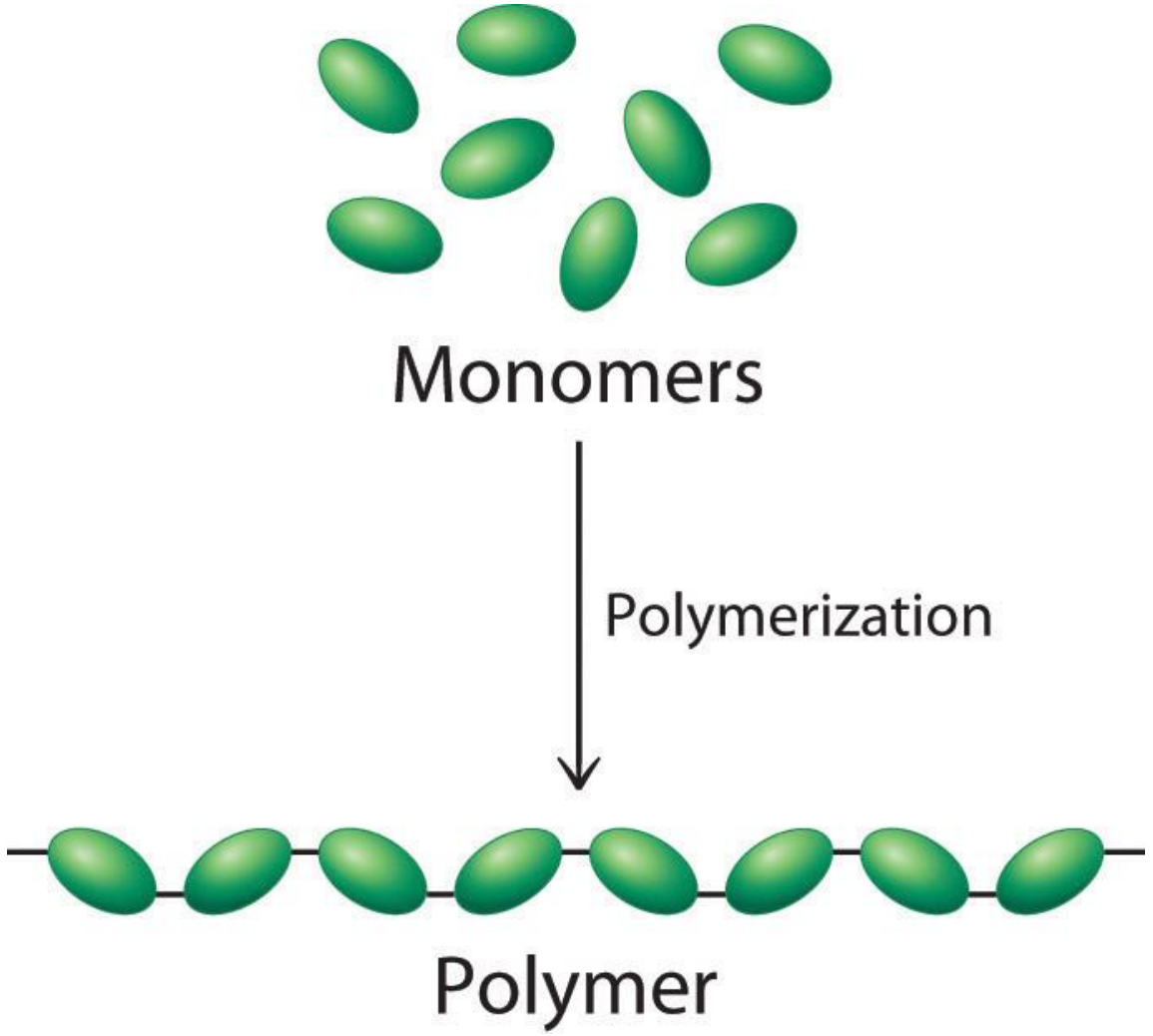
Tolley et al., "A Resilient, Untethered Soft Robot", 2014



www.fluidpowerworld.com/research-competition-advances-soft-robotics-designs/

Polymers

- Class of natural or synthetic substances
- Very large molecules (macromolecules)
- Multiples of simpler chemical units (monomers)

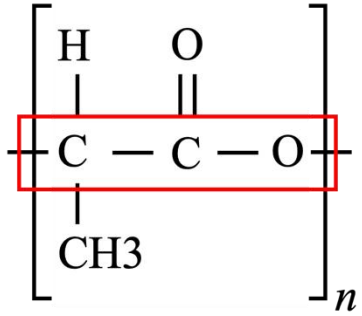


https://tinyurl.com/ycy2jmxk

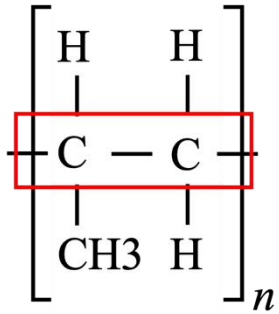
Polymers

- Backbone typically contains carbon

Polylactic acid (PLA)
Repeat unit:

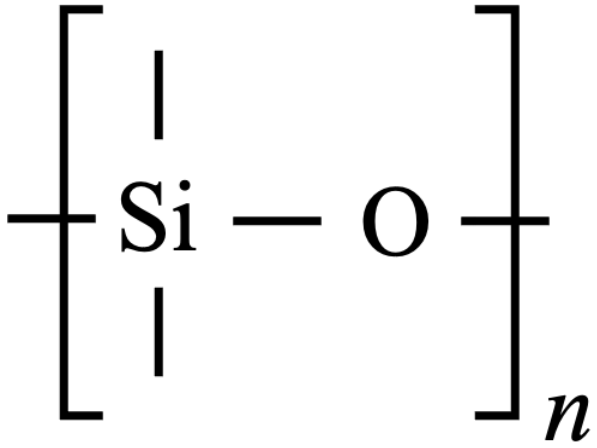


Polypropylene (PP)
Repeat unit:



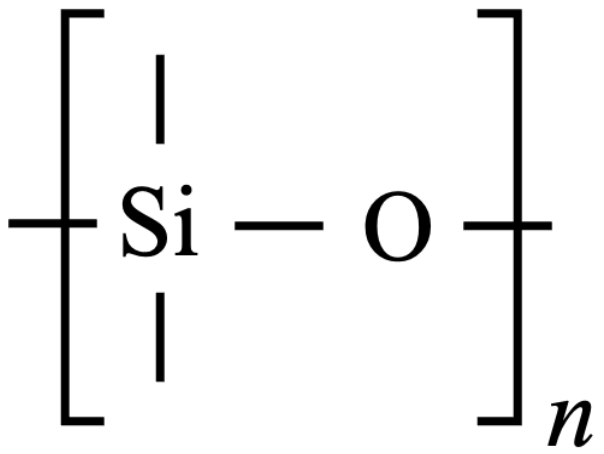
Silicone

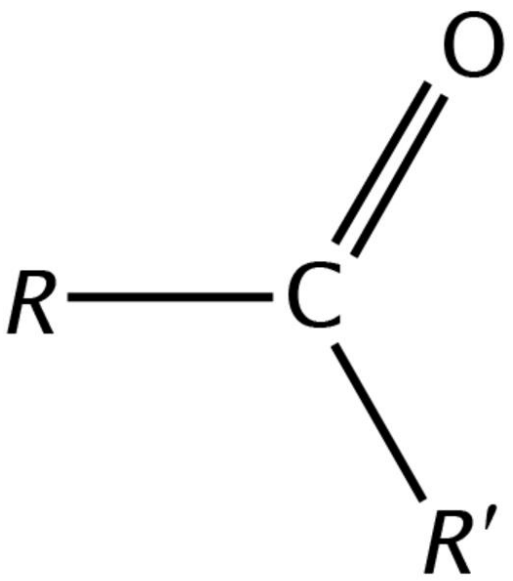
- Composed of silicon, carbon, hydrogen, and oxygen
- Silicon-oxygen backbone (no carbon)
- Side groups are spaced further apart: more flexible backbone
- More energy required to break silicon-oxygen bond: more stable and less chemically active



Silicone

- Discovered by Professor Frederic Stanley Kipping in 1905
- First believed it had a ketone-like backbone with silicon substituting the carbon (hence silic-one)
- Technically correct: Polysiloxane





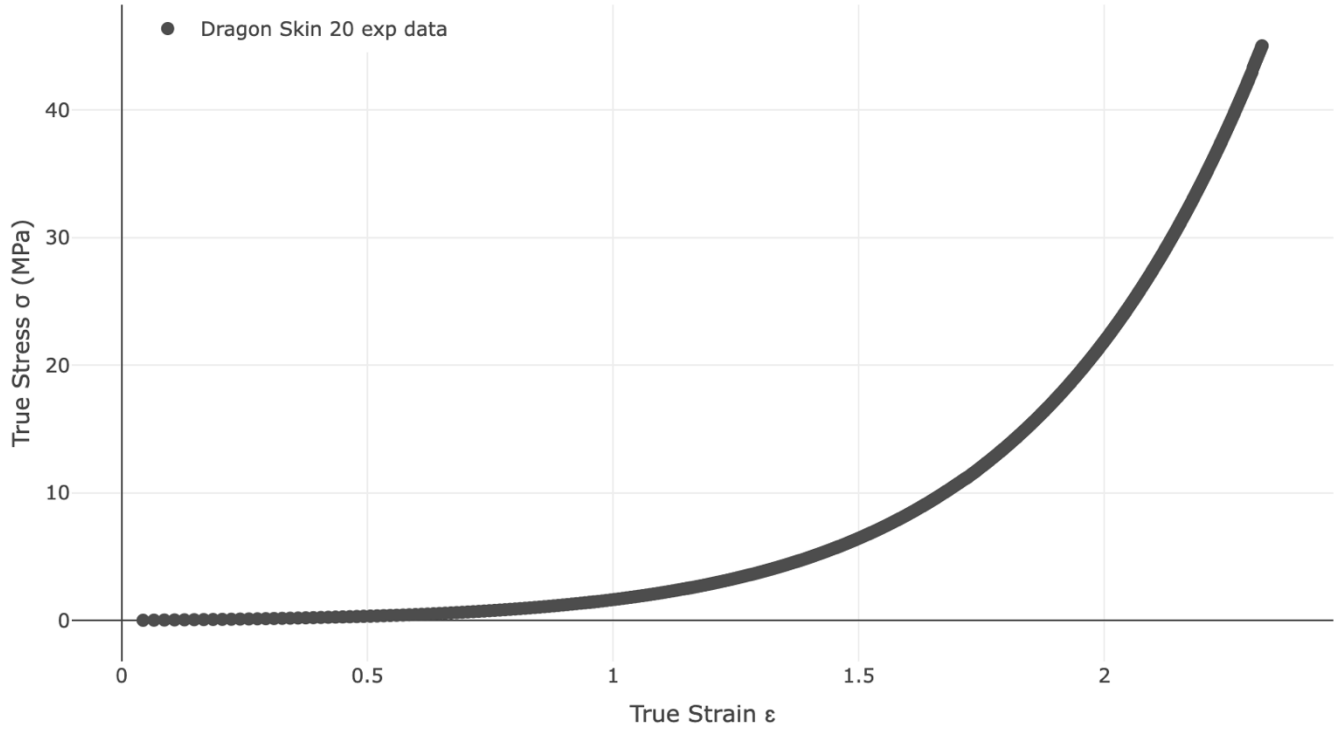
Types of Silicones

- Condensation silicones
  - Tin curing agent
  - Keeps reacting and exuding byproducts
  - Lower library life
  - Less prone to cure inhibition
- Addition silicones
  - Platinum curing agent
  - No volatile byproducts
  - Can be FDA compliant for food and skin applications
  - Longer library life
  - More prone to cure inhibition

Dragon Skin

Material Behavior

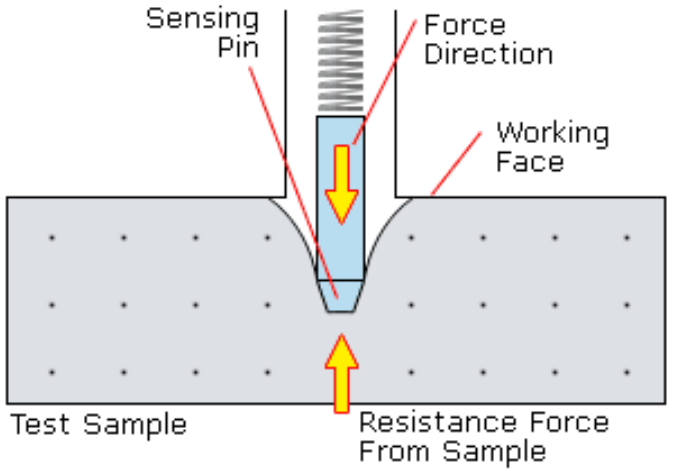
- Linear elastic model does not accurately describe material behavior of silicones
- Hyperelastic material models
  - Mooney–Rivlin
  - Neo-Hookean
  - Ogden
  - Arruda–Boyce
- Viscoelastic behavior



www.soro-materials-database.onrender.com/

Shore Hardness

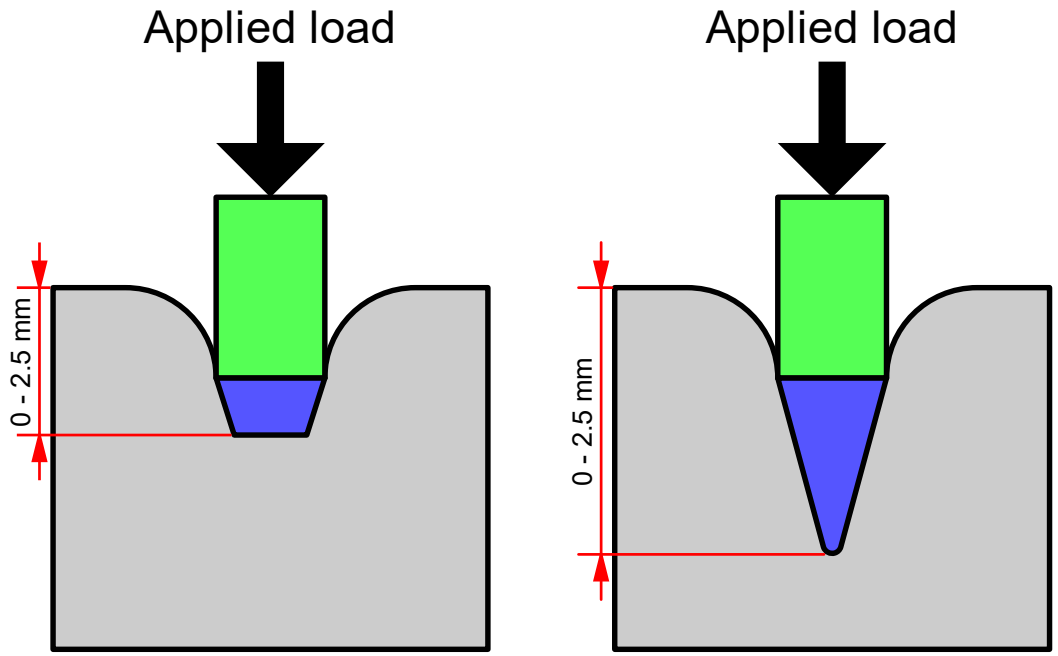
- Defined by Albert Ferdinand Shore in the 1920s
- Durometer measures depth of an indentation for a given force
- Depth dependent on:
  - Material hardness
  - Viscoelastic properties
  - Shape of the presser foot
  - Duration of the test
- Device for testing: shore durometer
- Different combinations of spring forces and indenters for different scales (ASTM D2240)

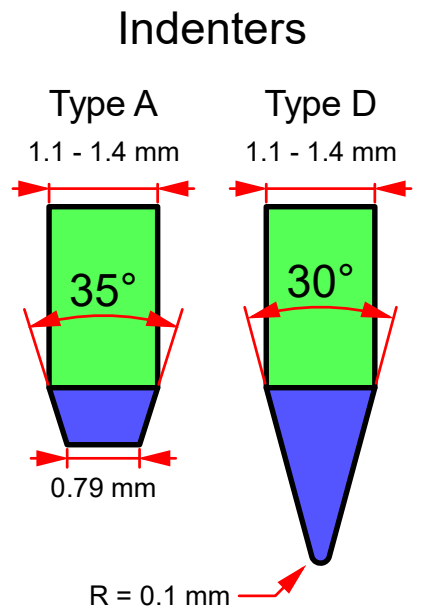


www.checkline.com/product/Durometer-Technical-Information

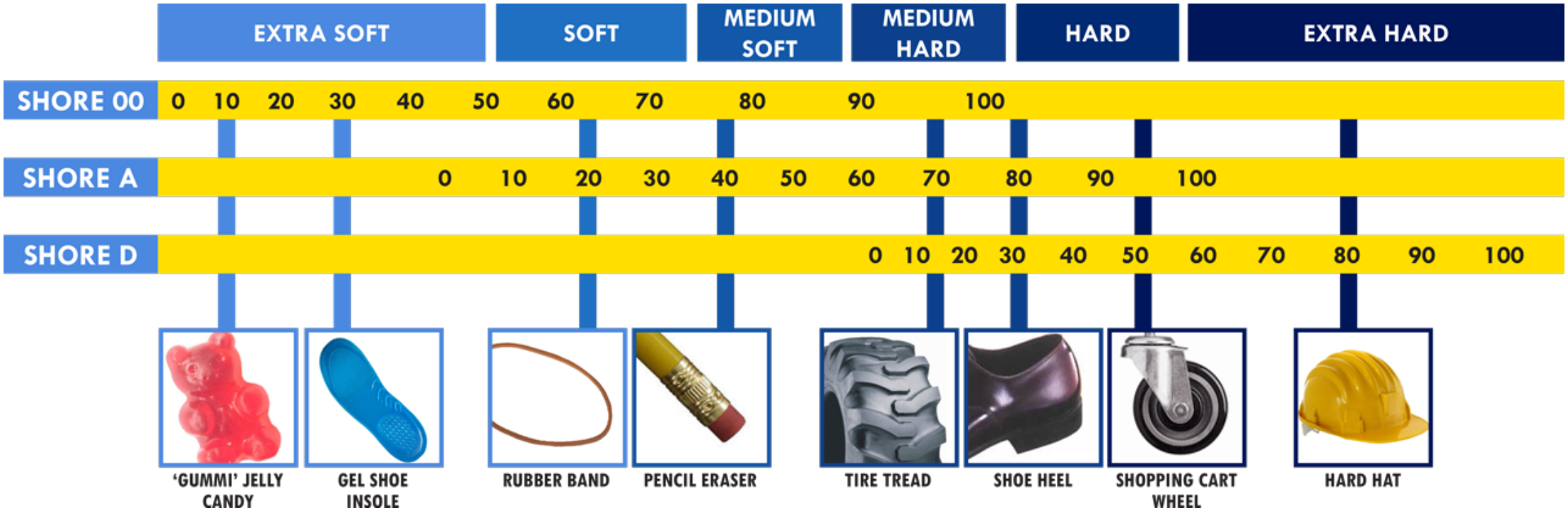
Shore Hardness

- 2.5mm indentation: Shore hardness value 0
- 0mm indentation: Shore hardness value 100
- Shore 00 hardness scale: for soft rubbers and gels
- Shore A hardness scale: for soft to somewhat firm rubbers
- Shore D hardness scale: for hard rubbers, semi-rigid plastics, and hard plastics





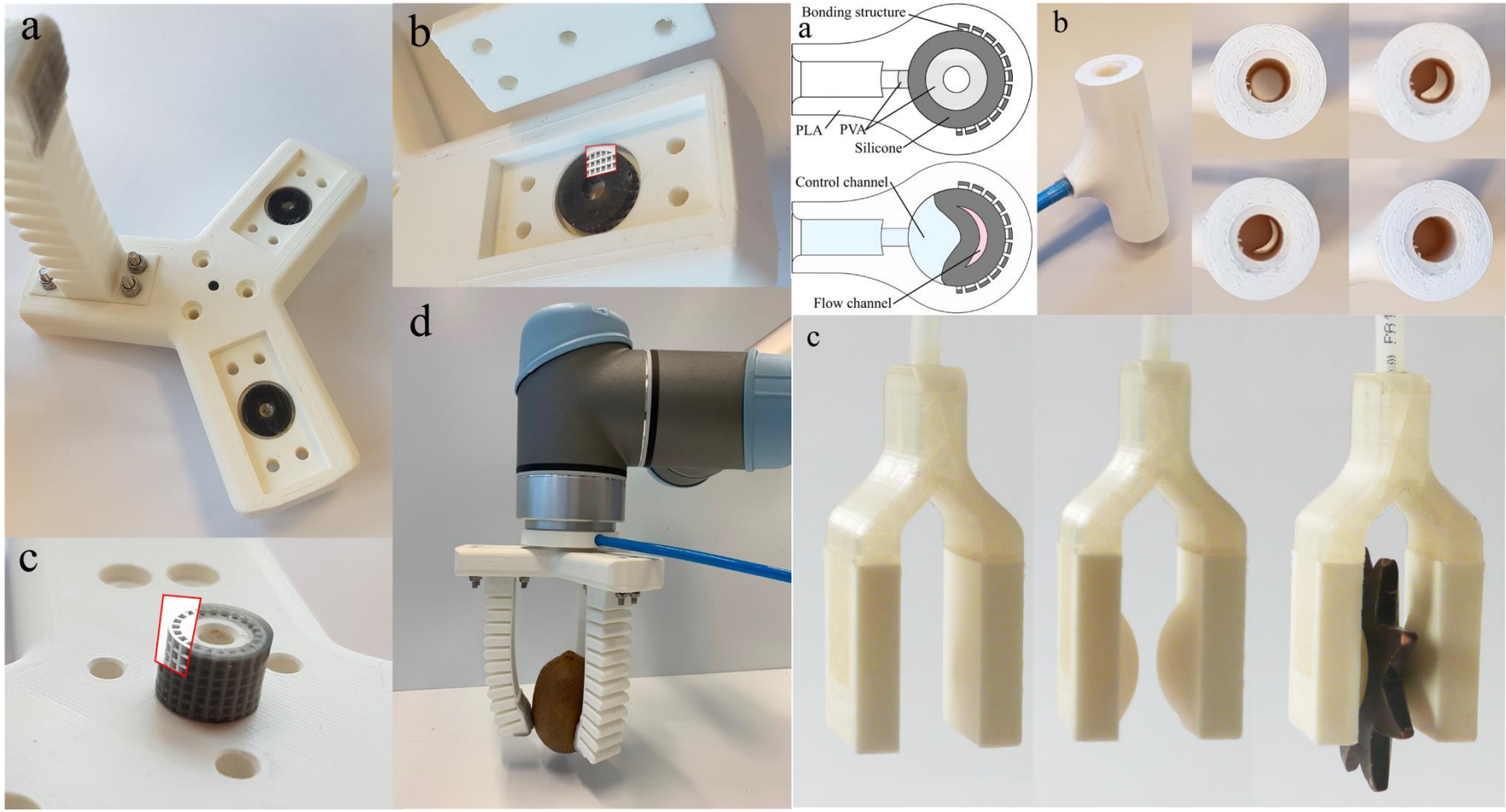
www.en.wikipedia.org/wiki/Shore_durometer



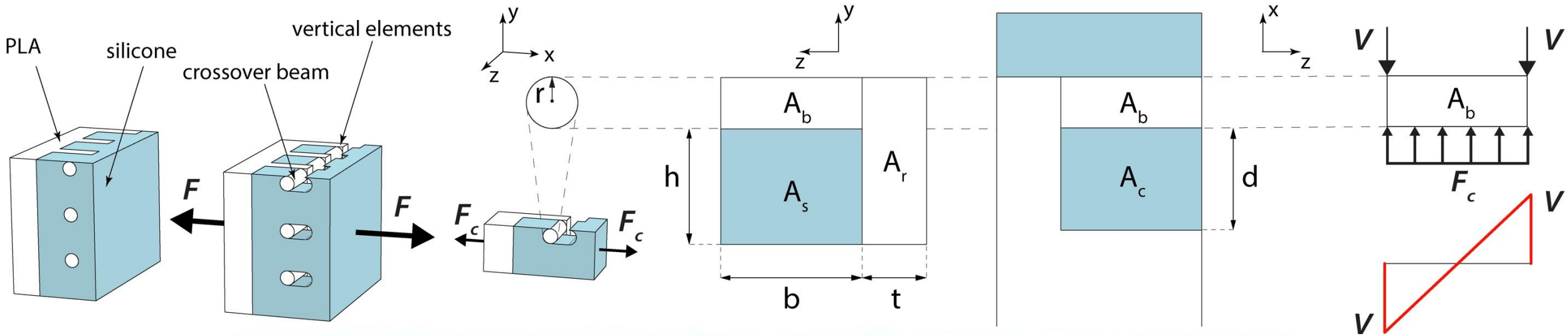
www.smooth-on.com/page/durometer-shore-hardness-scale/

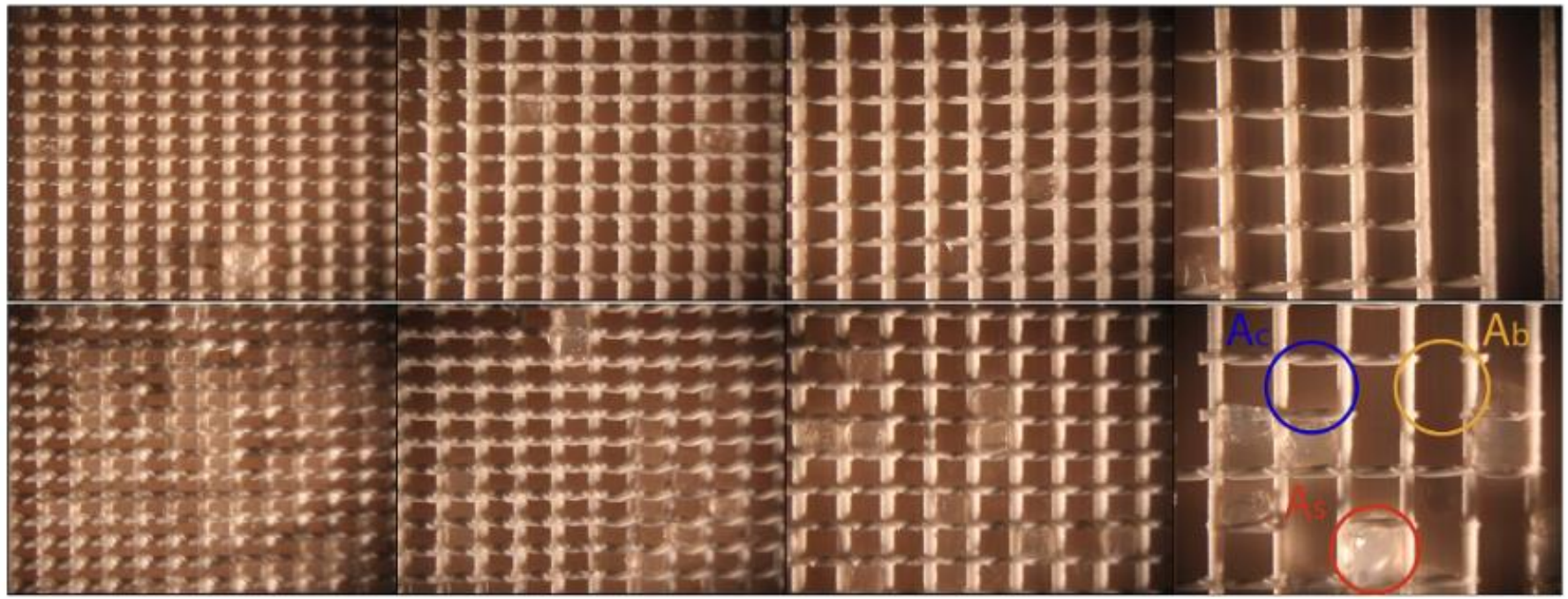
Hybrid Manufacturing

- Combining additive manufacturing (FDM) and formative manufacturing (silicone casting)

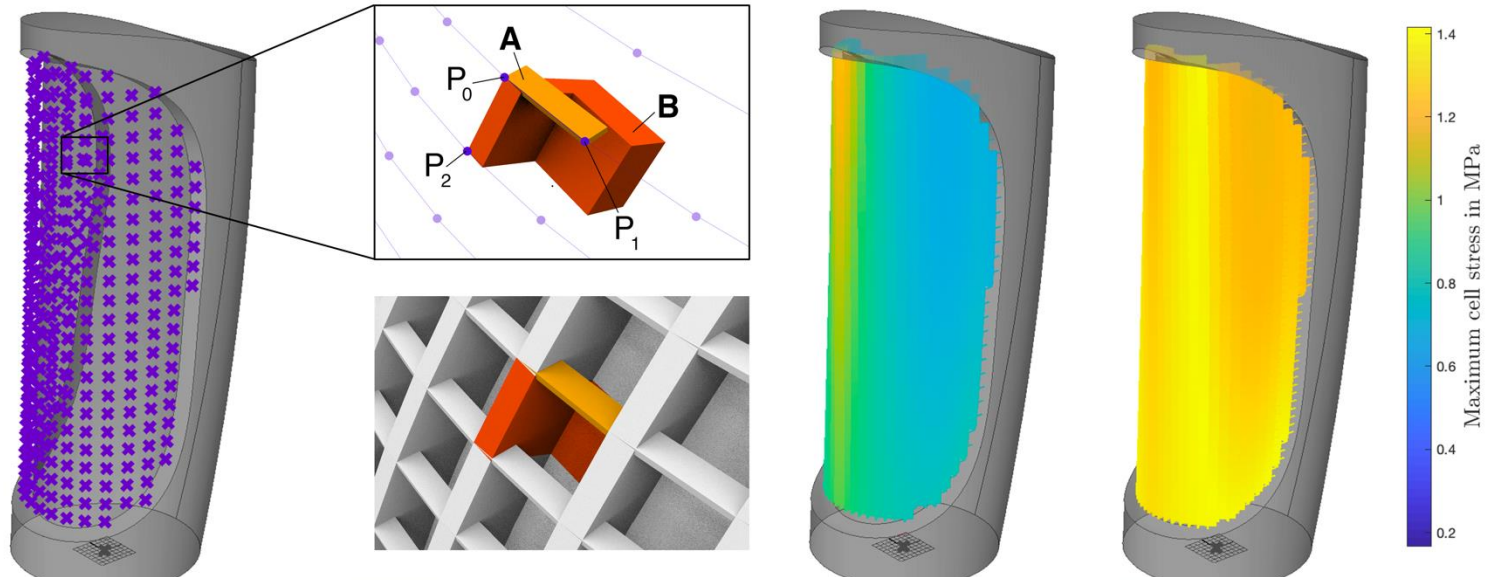


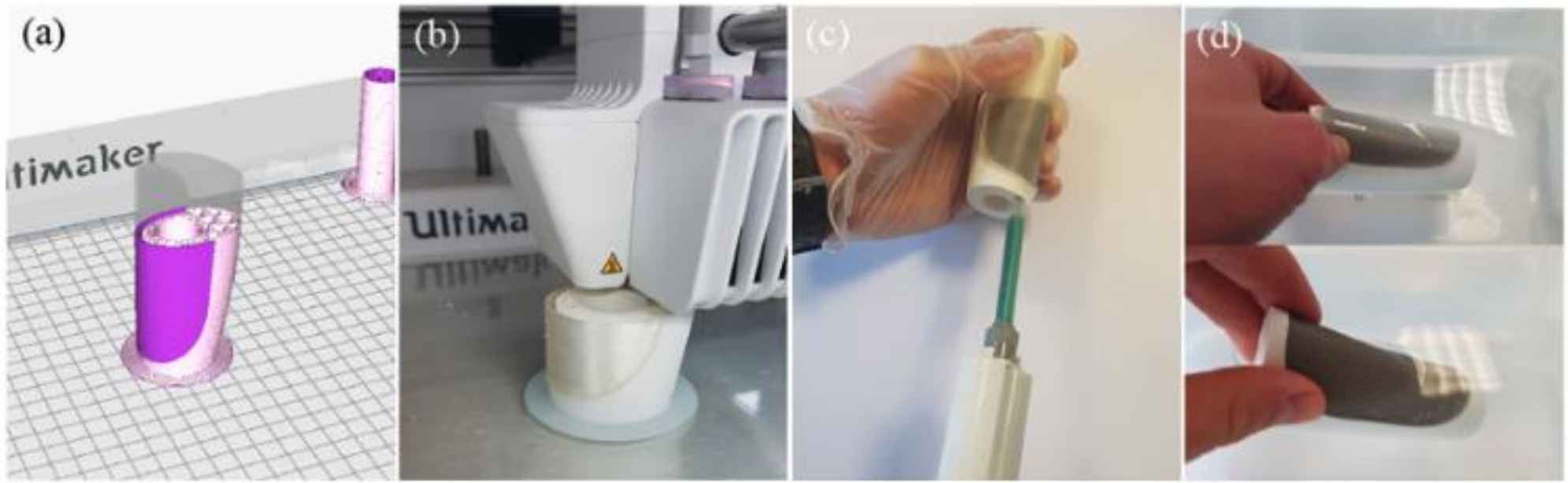
Rossing et al., "Bonding between silicones and thermoplastics using 3d printed mechanical interlocking", 2020





Rossing et al., "Bonding between silicones and thermoplastics using 3d printed mechanical interlocking", 2020





Rossing et al., "Bonding between silicones and thermoplastics using 3d printed mechanical interlocking", 2020

Preparation for the lab

- Read the silicone casting manual on Canvas
- Always use vinyl gloves (no latex gloves!)
- Keep the lab clean
  - Always work on a table covered with plastic sheets
  - Dirty gloves can only touch the mixing cup, mixing spatula, mold, and cleaning paper
  - Clean gloves can only touch the release spray, silicone bottles, vacuum chamber, and pump
  - No gloves are allowed to touch anything else
  - It is OK to replace gloves several times!

Calculate the amount of silicone you need

- Density of the silicone
  - Ecoflex 00-50 (platinum cure): 1.07 g/cc
- Volume of the silicone tail
  - Use SolidWorks mass properties
- 20% extra material to account for losses
- Mixing ratio by weight
  - Ecoflex 00-50: 1A:1B

Questions?