Week 11 | Lecture 11
Soft robotics I

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Introduction to Soft Robotics

- Motivation for soft robots
- Soft robotics
  - Material Selection
  - Actuation
  - Sensation

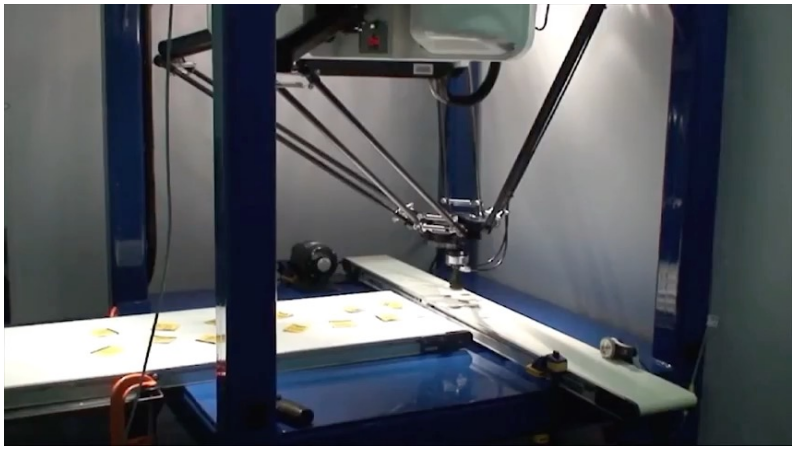
Why soft robots

- The development of robotics as a field has been heavily influenced by industry, especially automation, manufacturing, transportation, and aerospace.
- The robotic platforms that developed aspired to ideals such as **strength, high precision and speed**.

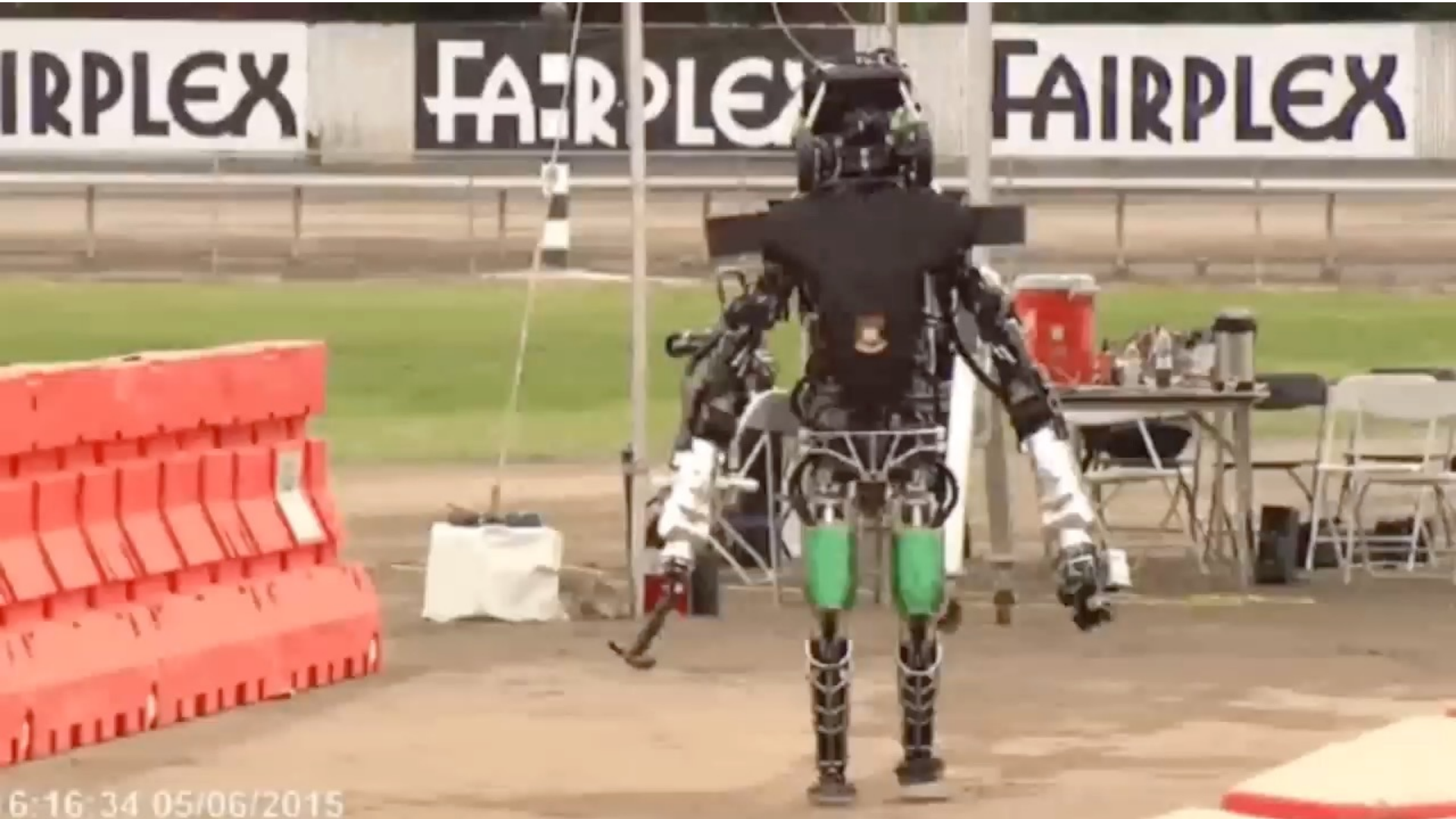
Titan from Kuka

Payload
1000 kg

Quattro from Omron

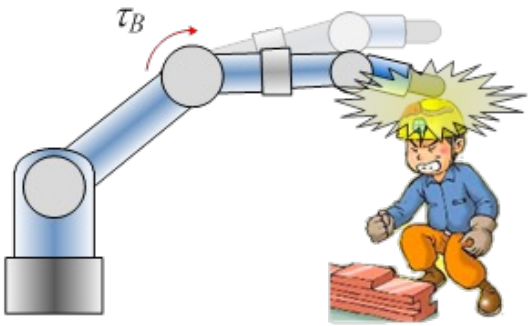


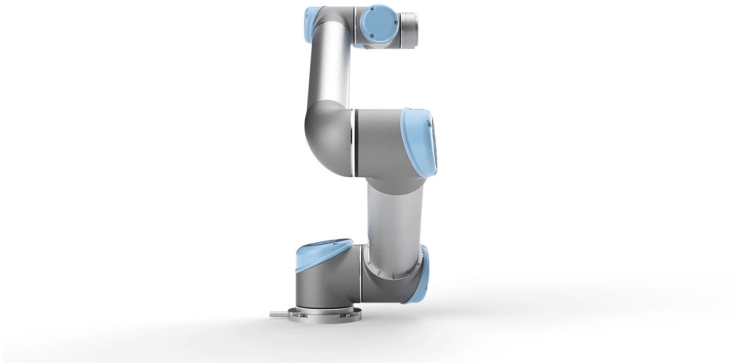
Robots falling down at the DARPA Challenge



Disadvantages of rigid robots

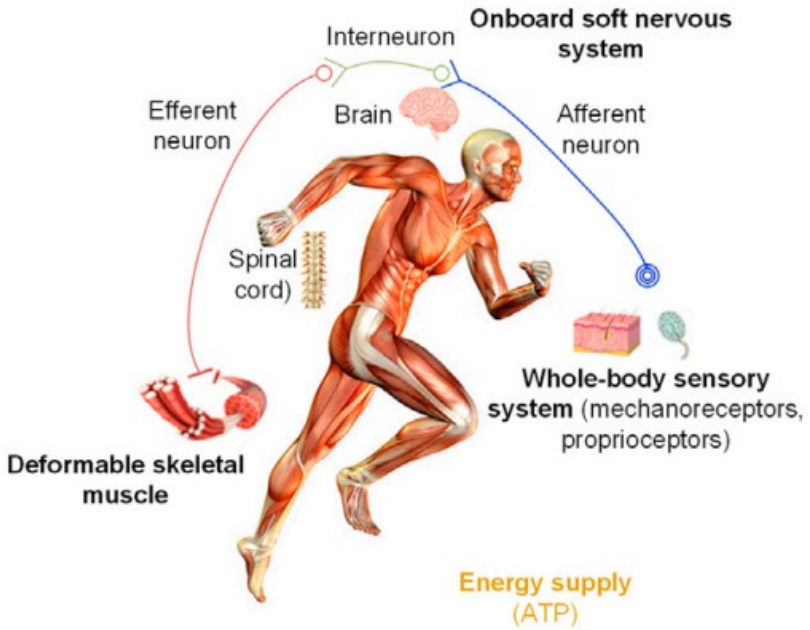
- Rigid links -> dangerous
- Can be mechnically complex
- Lack of compliance -> limited adaptability -> difficult to interact with uncertain environments
- Can be inappropriate for handling delicate or soft materials





Nature

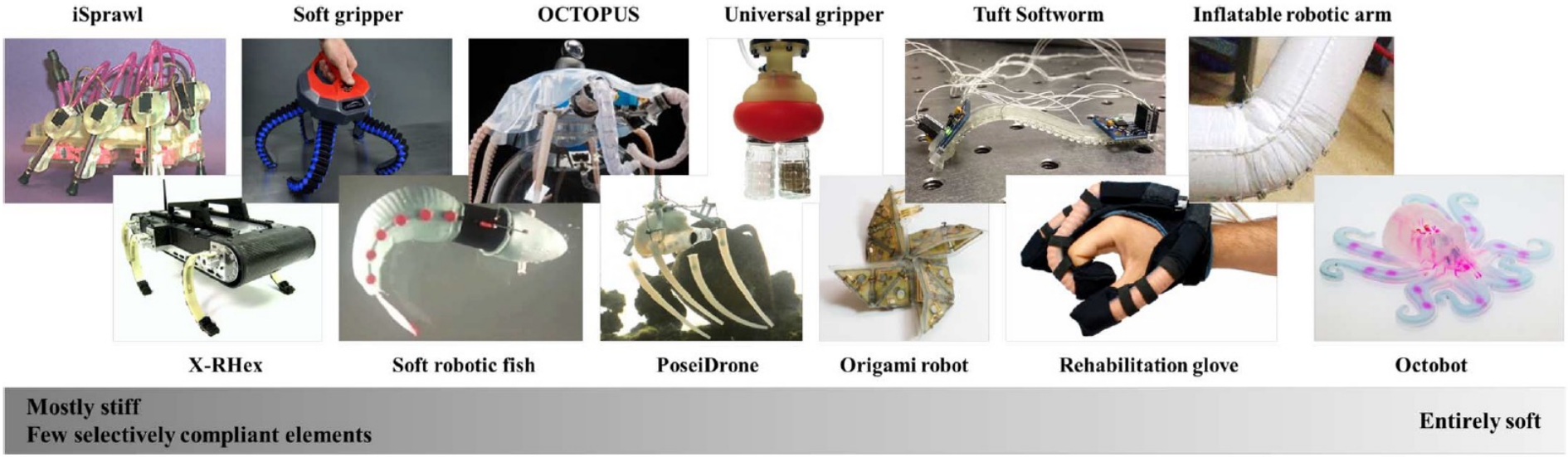
- Soft, sustainable, robust and flexible



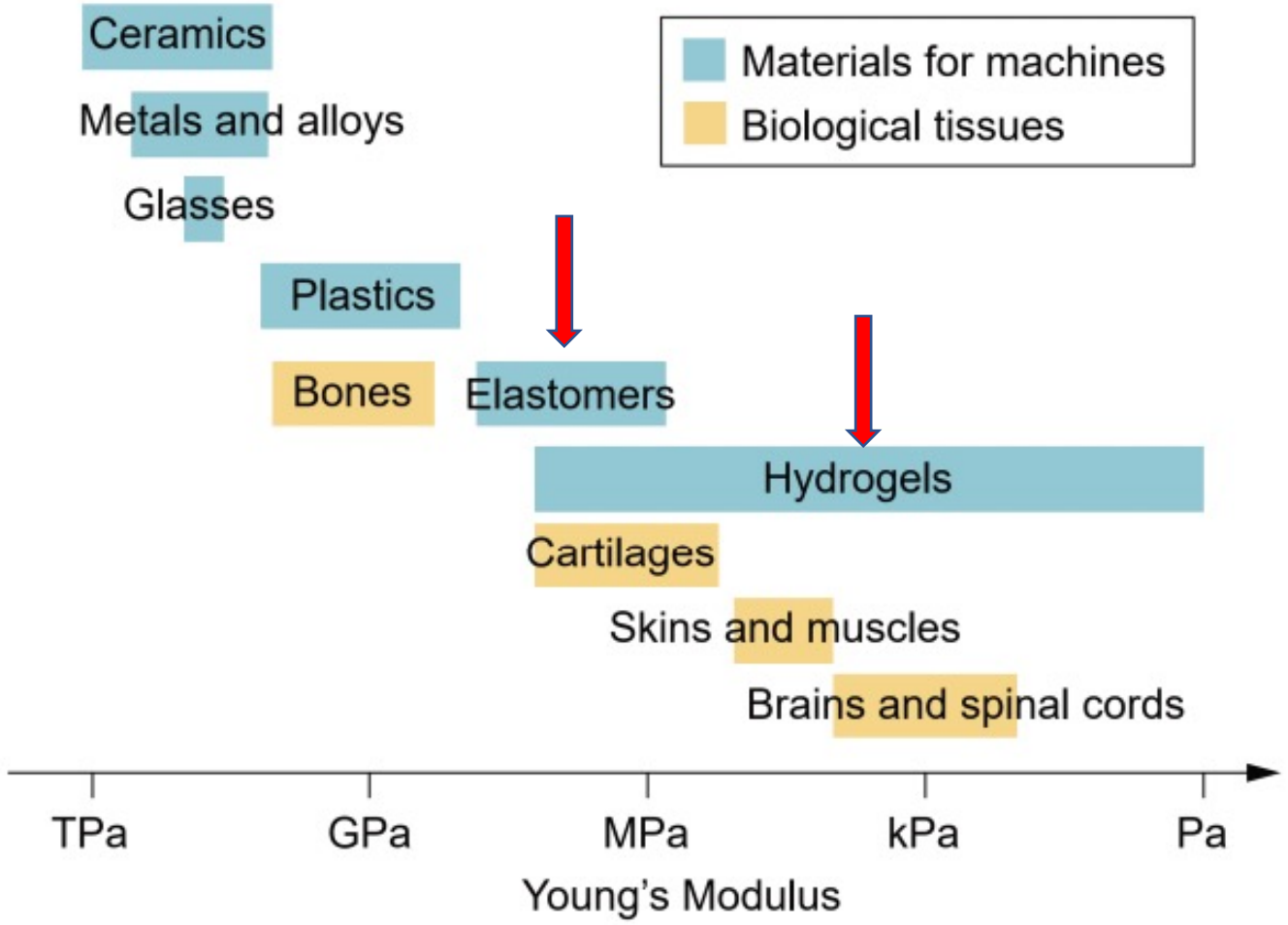
Ren et al., 2021

Soft robotics

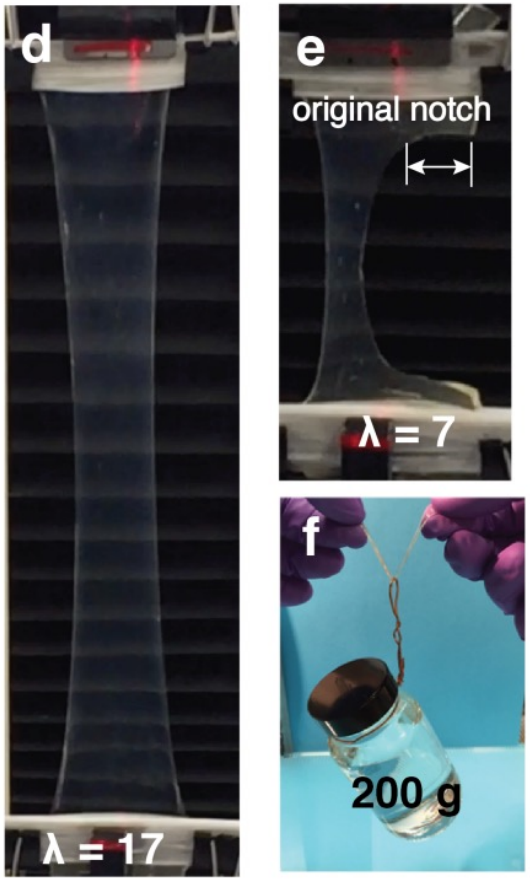
- Goal: Endow robots with new, **bioinspired features** that permit **morphologically adaptive interactions** with **unpredictable environments**.
- Soft robots:
  - systems that are compliant and flexible
  - Have a feedback sensory and control system



Young's moduli of biological tissues and common materials for machines

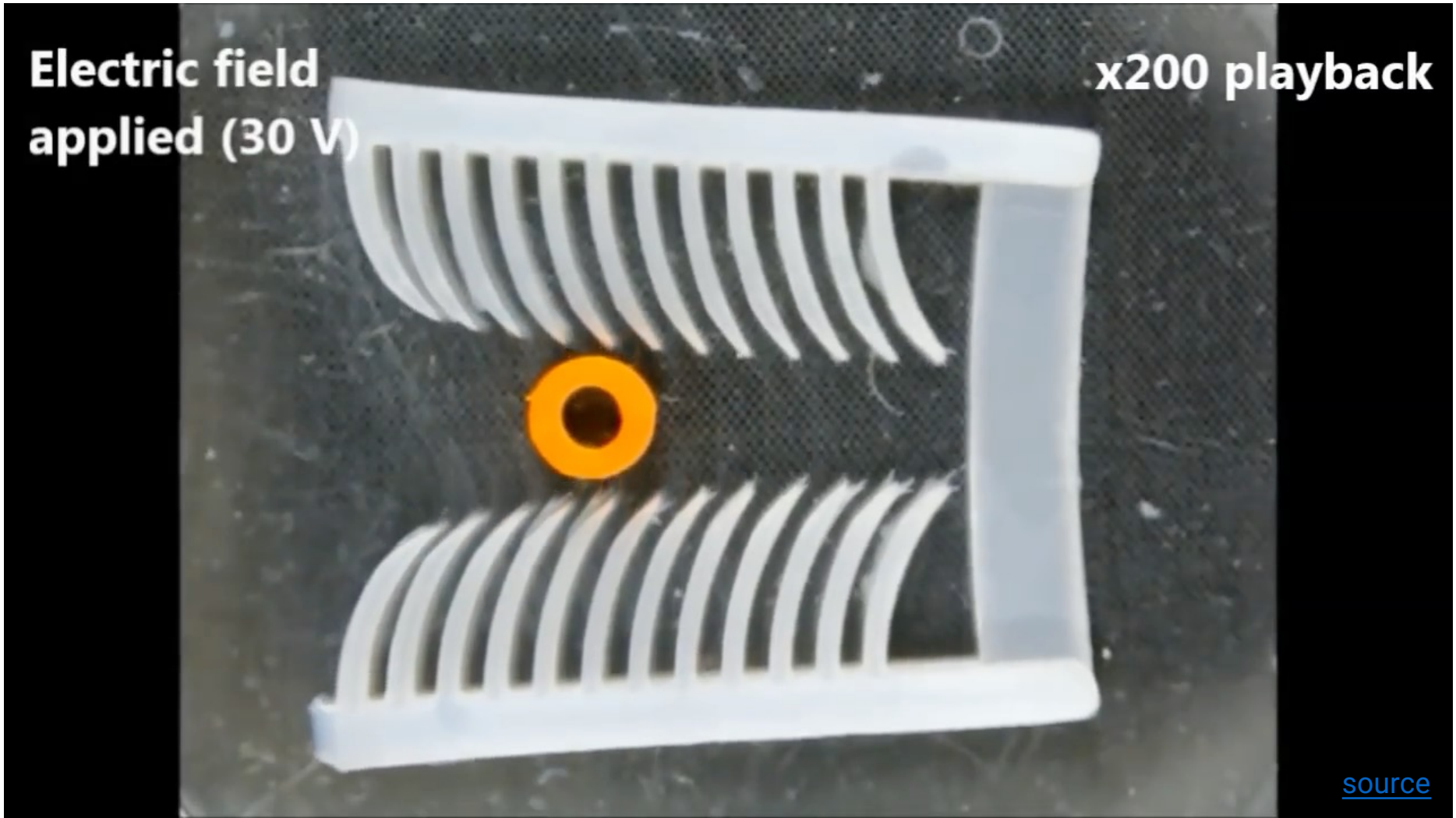


1. Hydrogels 水凝胶，一类极为亲水的三维网络结构凝胶



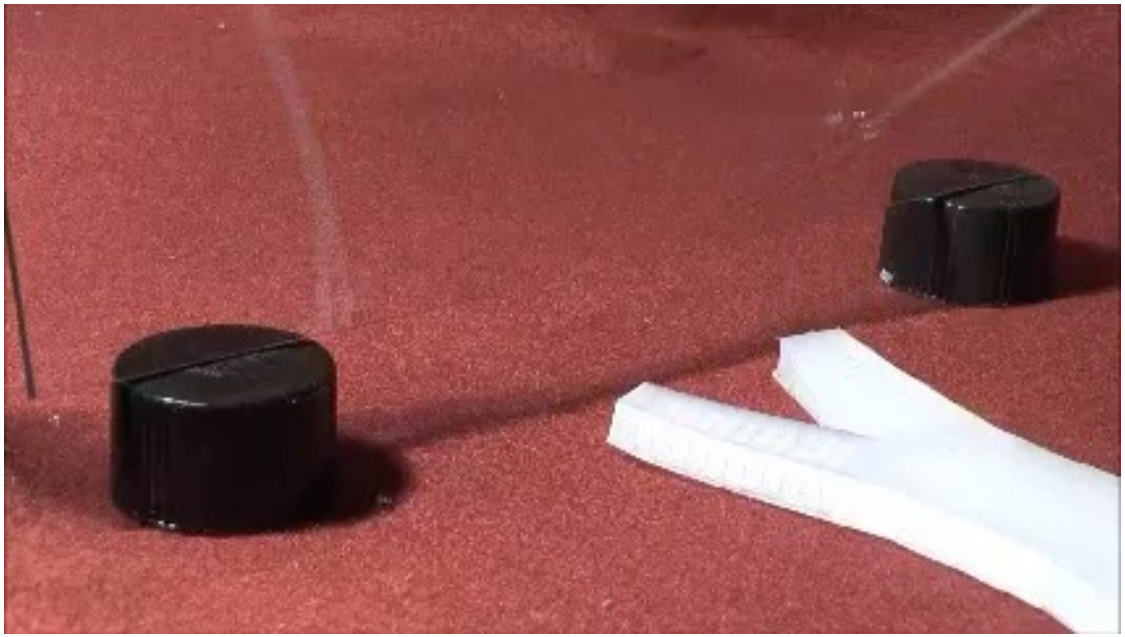
Liu et al., 2017

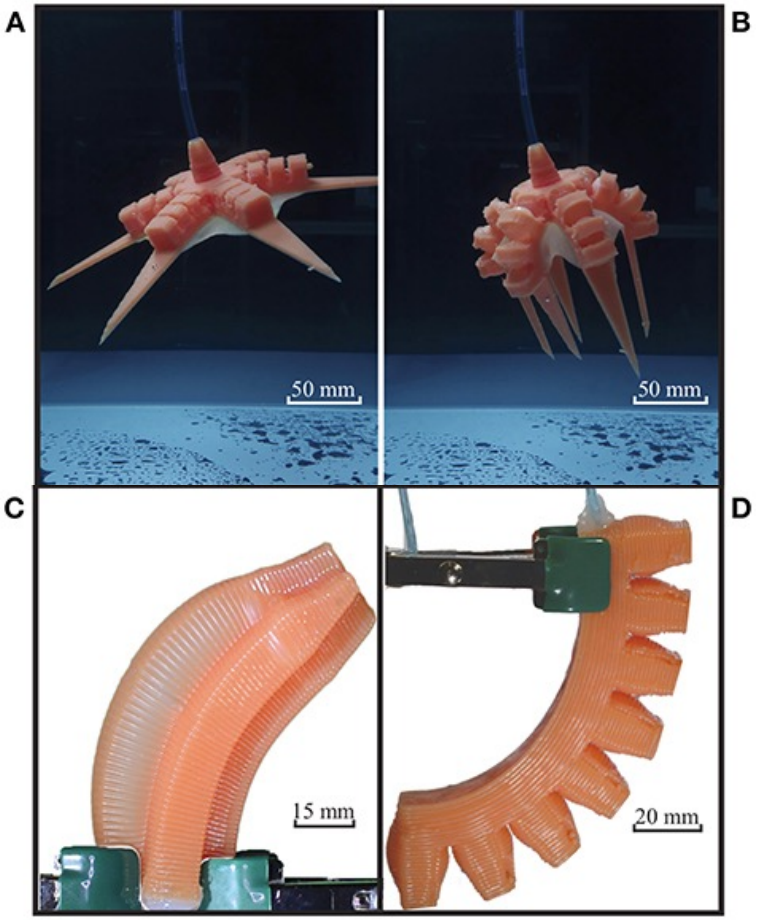
1. Hydrogels 水凝胶，一类极为亲水的三维网络结构凝胶



2. Silicone-based elastomers 硅基的弹性聚合物

- Silicone rubber 硅橡胶 (e.g. Ecoflex, patented material), high strain
- Polydimethylsiloxane (PDMS silicone) 聚二甲基硅氧烷, low strain





Dogan et al., 2019

2. Silicone-based elastomers 硅为基础的弹性聚合物

- Silicone rubber 硅橡胶 (Ecoflex), high strain
- PDMS silicone 聚二甲基硅氧烷, low strain

a) ECOFLEX (+PAPER SHEET)

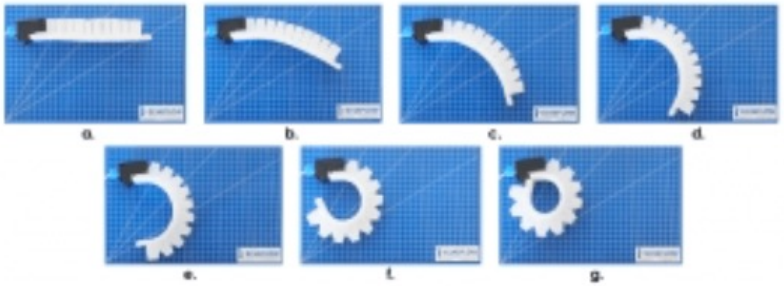


Figure 3: Deformation of the « finger » made of Ecoflex under different pressure: a. p=0mbar, b. p=20mbar, c. p=40mbar, d. p=60mbar, e. p=80mbar, f. p=100mbar, g. p=120mbar

b) PDMS + ECOFLEX (+PAPER SHEET)

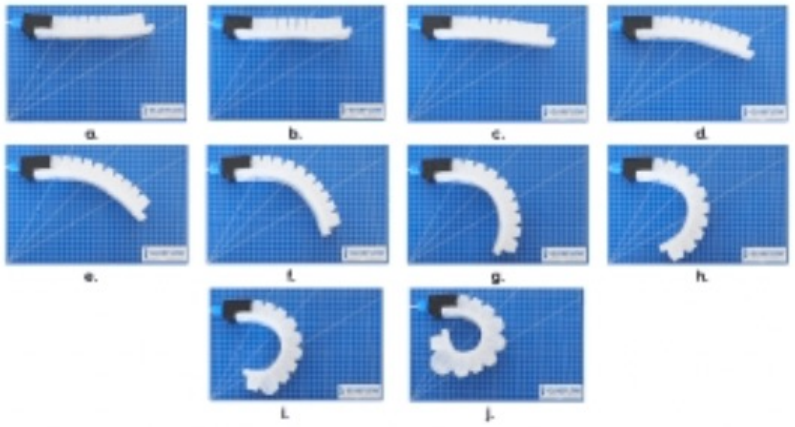


Figure 4:Deformation of the « finger » made of Ecoflex and PDMS under different pressure: a. p=0mbar, b. p=20mbar, c. p=40mbar, d. p=60mbar, e. p=80mbar, f. p=100mbar, g. p=120mbar, h. p=140mbar, i. p=160mbar, j. p=180mbar

source

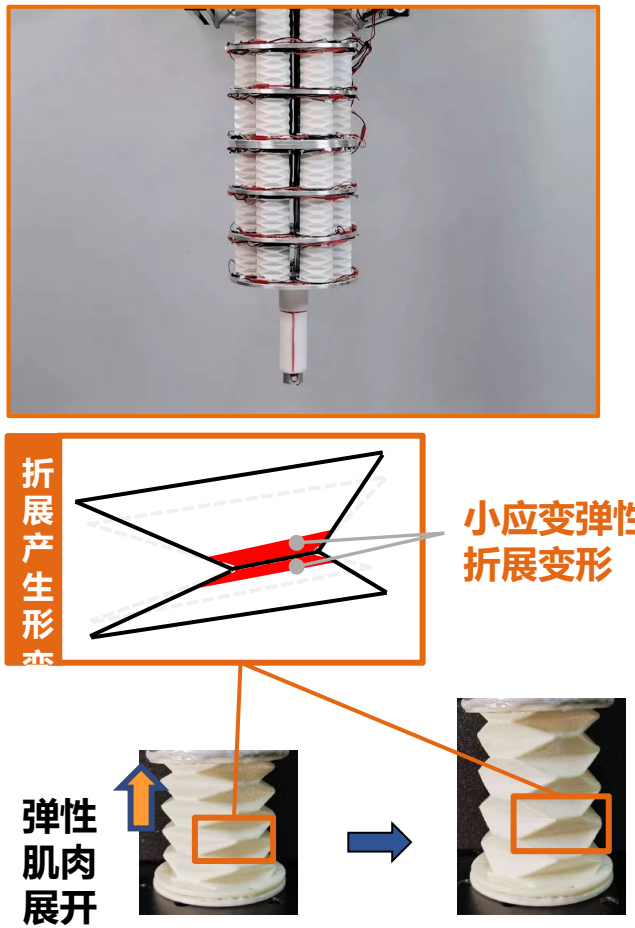
3. Polyurethanes elastomers 聚氨酯弹性体（PU）

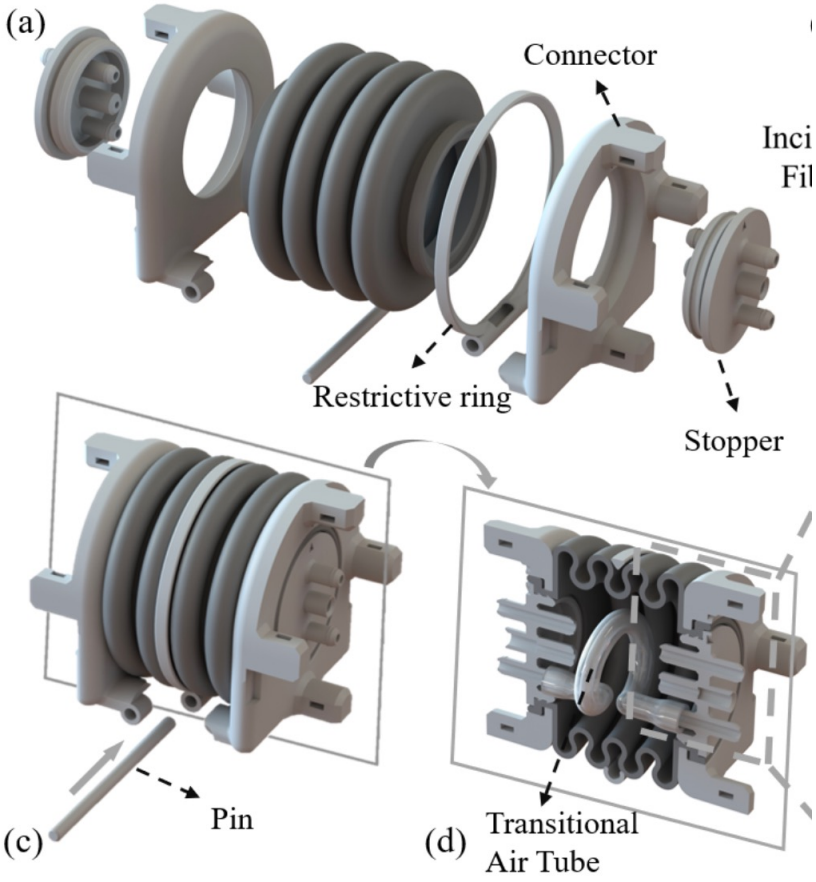
- TPU stands for Thermoplastic Polyurethane (热塑性聚氨酯) and is often referred to as the bridge between rubbers and plastics. The material appears **rubber-like**, which means it is very elastic, flexible, and smooth to the touch, but at the same time, it is extremely **durable and strong**.

Meta material – soft structures

- Compliant 3D structures made from TPU (common for 3D printing).

Origami 折纸构型

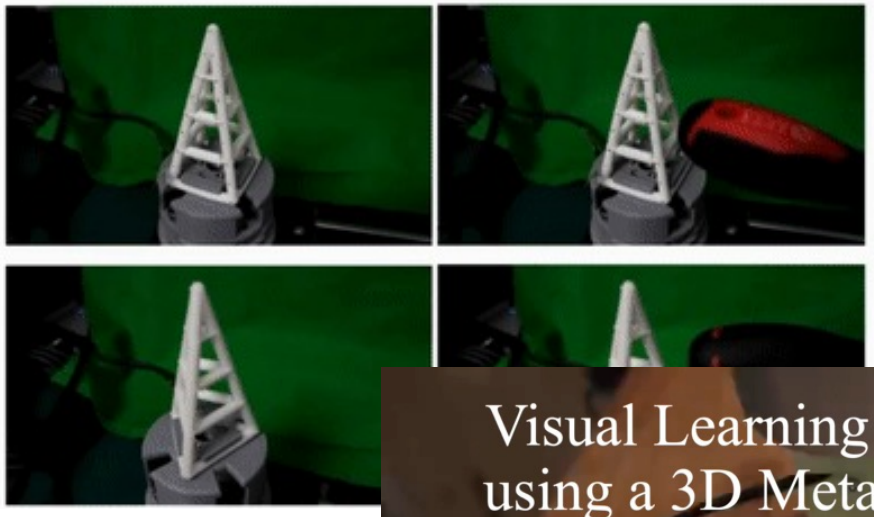


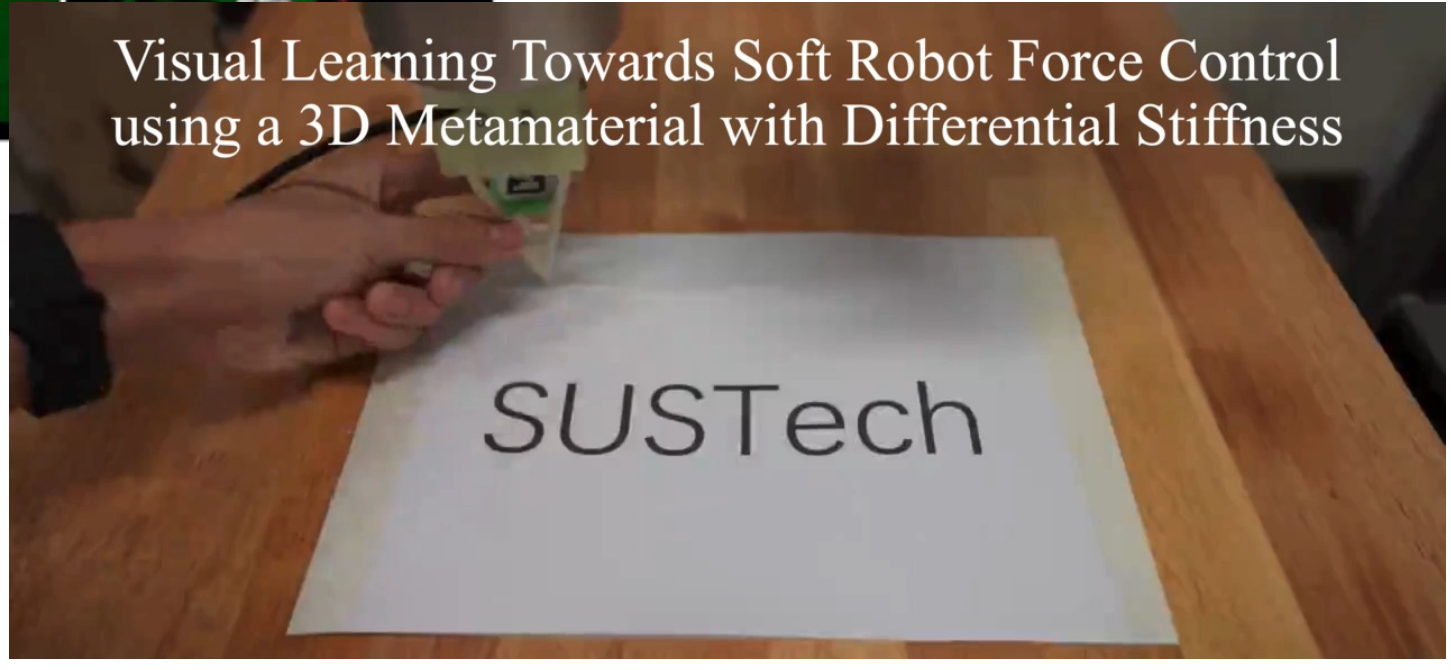


Wang et al., 2021

Meta material – soft structures

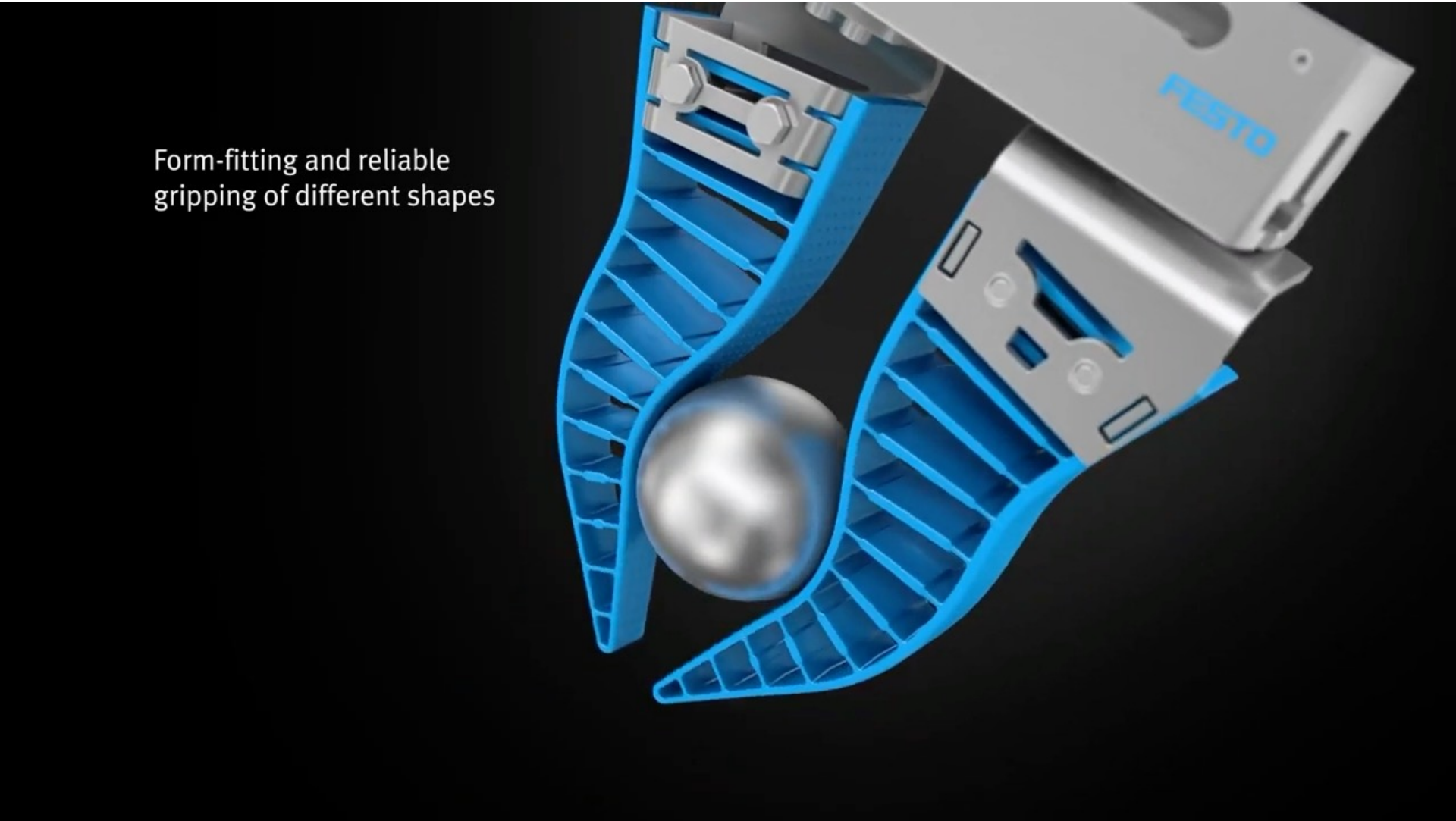
- Compliant 3D structures made from PU





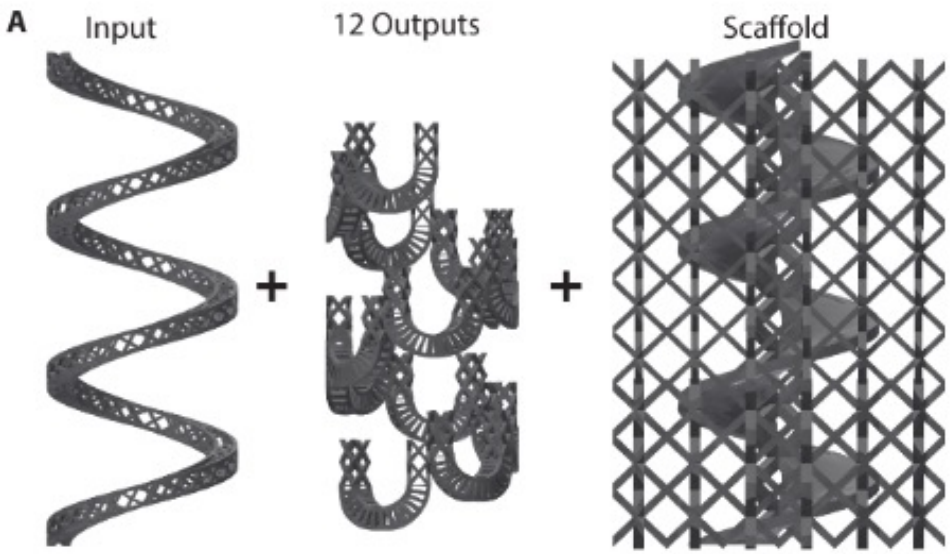
Meta material – soft structures

- Compliant 3D structures made from PU

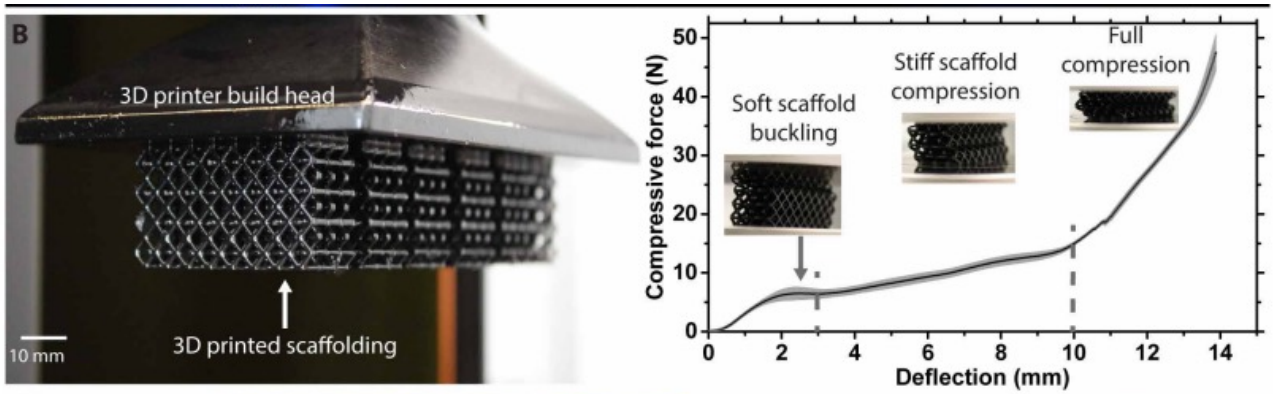


Meta material – soft structures

- Compliant 3D structures made from Elastic Polyurethane (EPU)



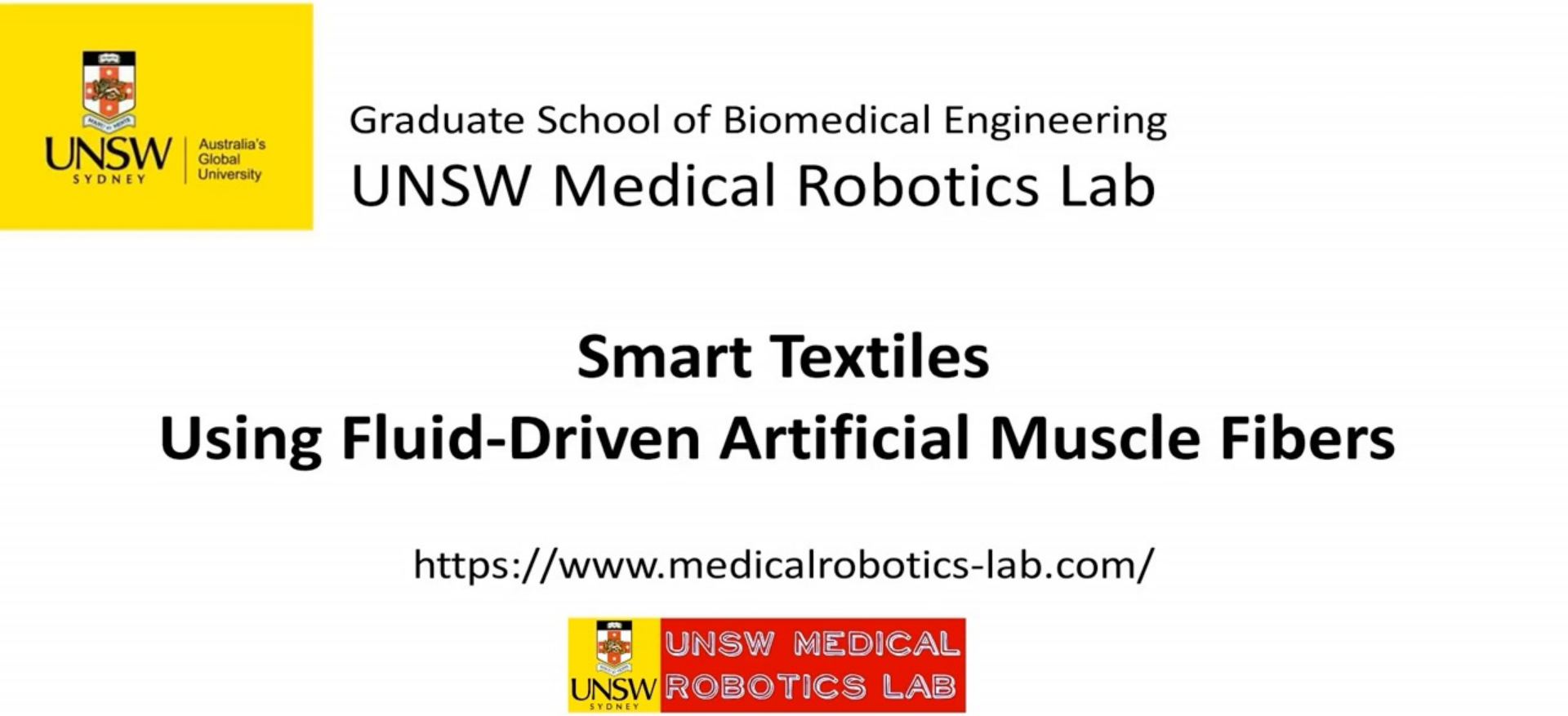
A urethane-based material that has been developed to compensate for the shortcomings of TPU, such as transmittance, smoothness, impact resistance, and lack of resilience.



Xu et al., 2019

Meta material – soft structures

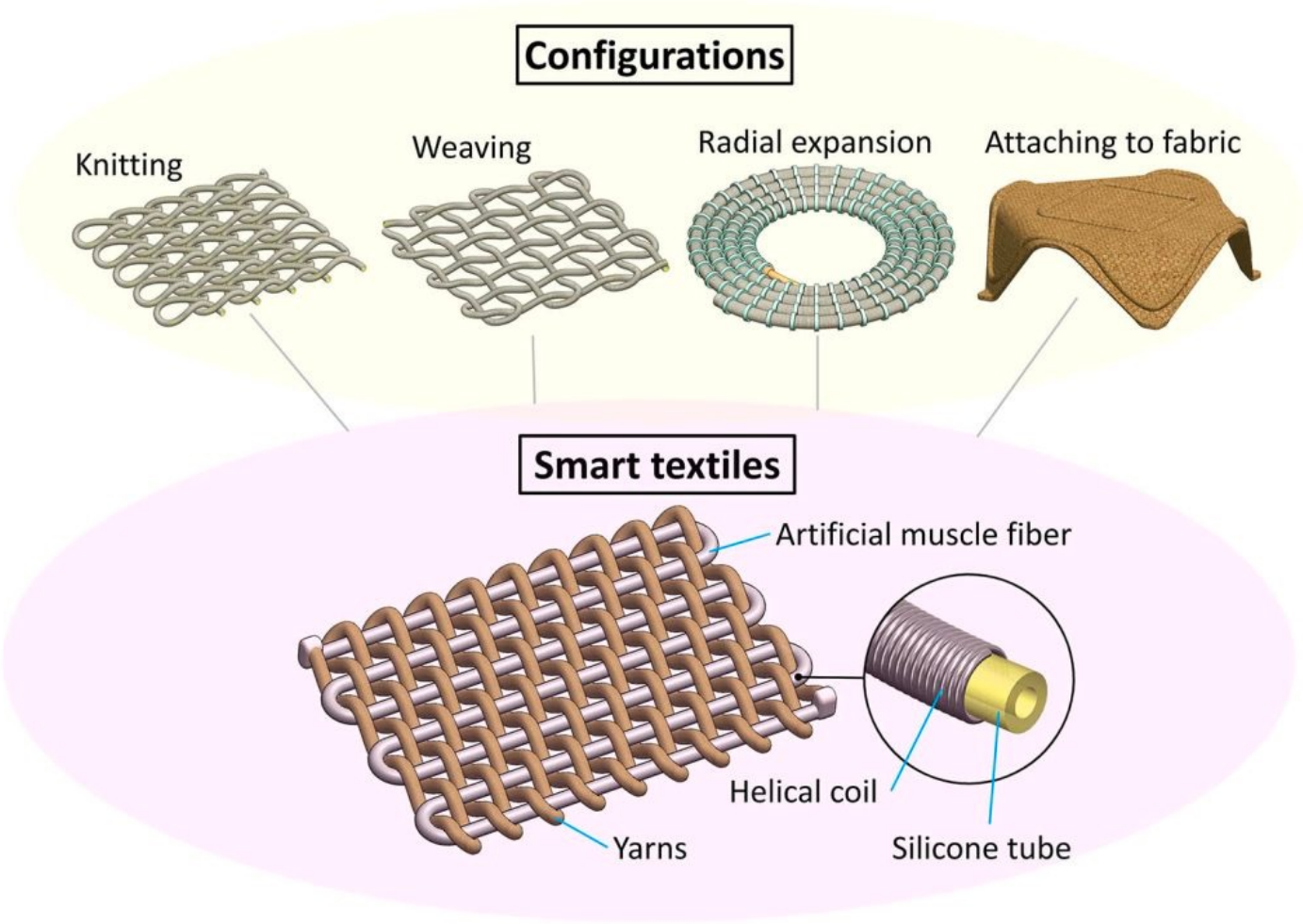
- braided fabrics 纺织物:



Phan et al., 2022

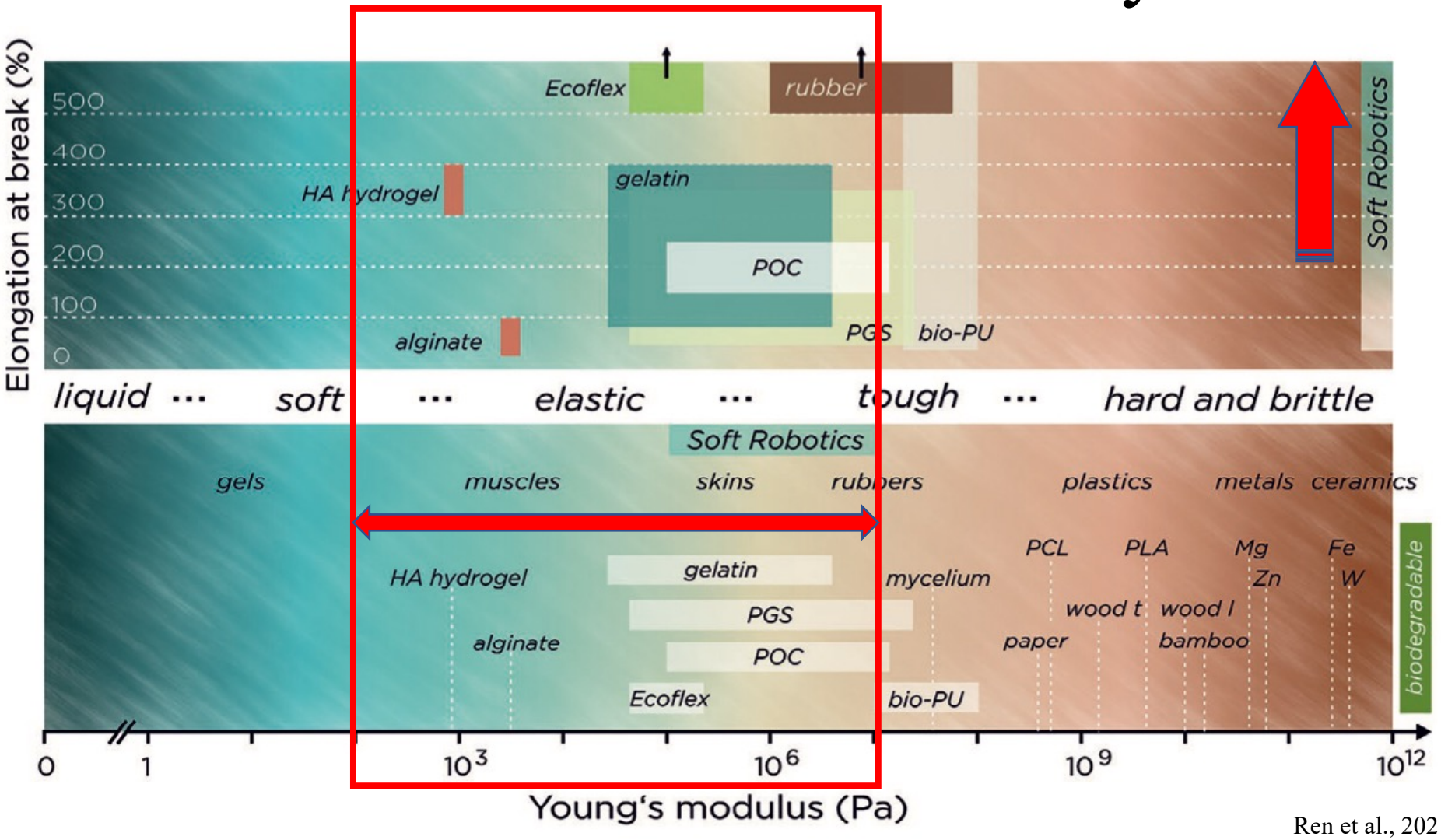
Meta material – soft structures

- braided fabrics: smart textiles combining textiles with artificial muscles



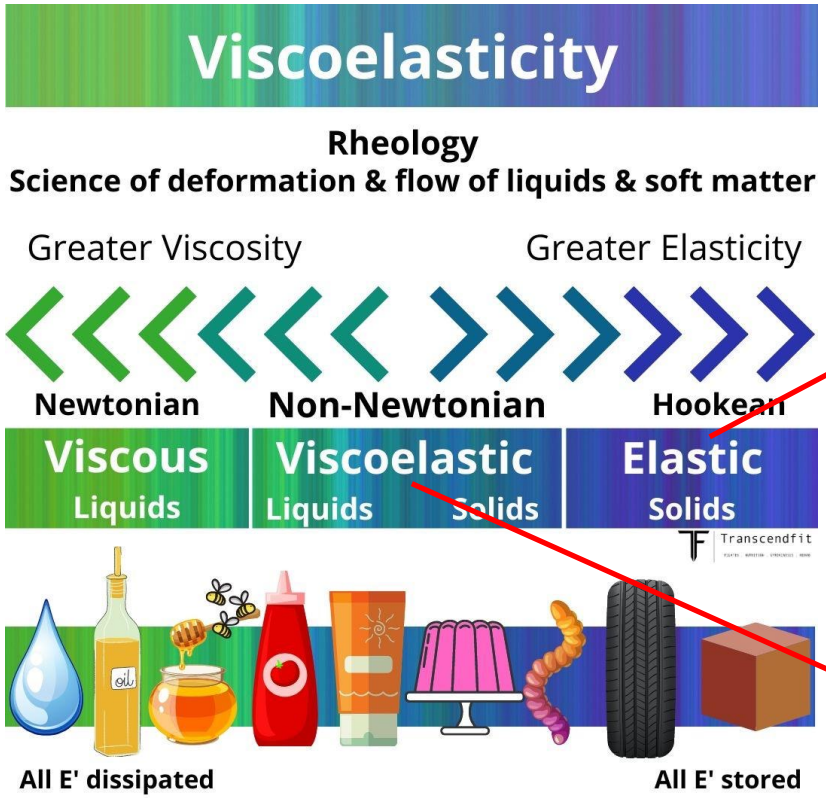
Phan et al., 2022

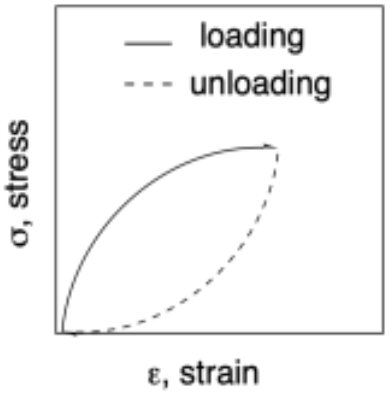
Material Selection Criteria 1: Softness and Stretchability

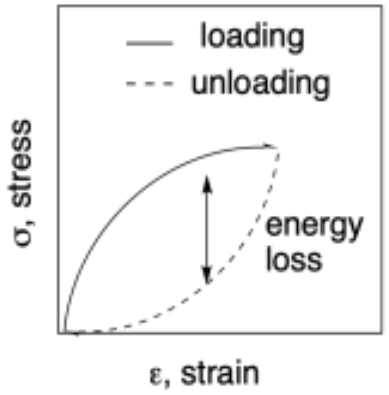


Ren et al., 2021

Material Selection Criteria 2: Reversibility







Material Selection Criteria 2: Reversibility

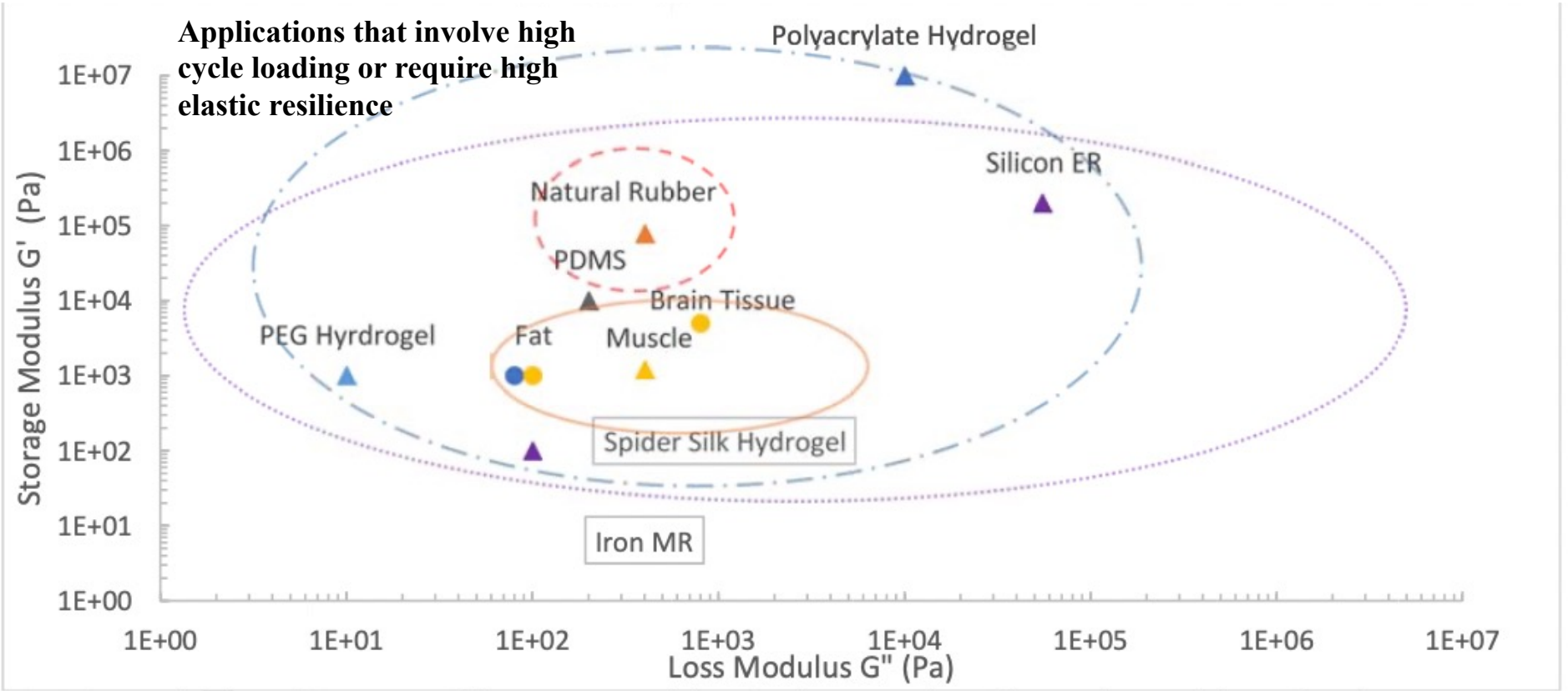
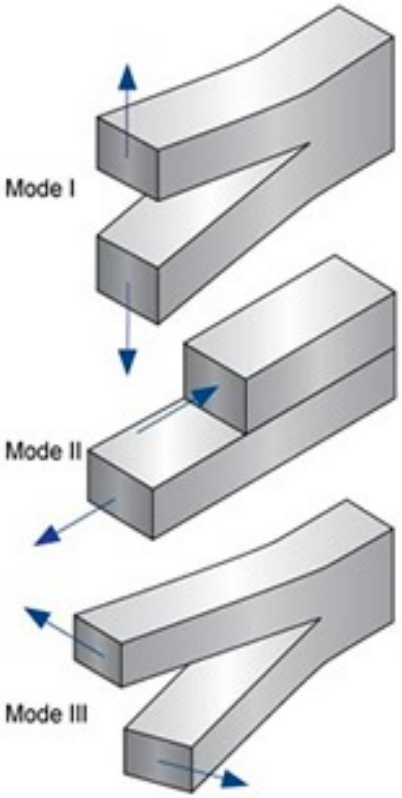


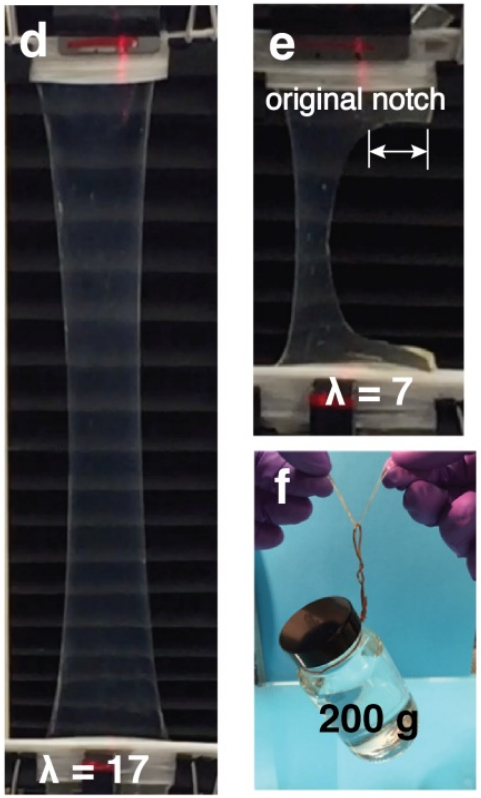
Fig.1. Approximation of Storage Modulus vs Loss Modulus of various organic and inorganic materials. Hydrogels: _ . _ . _ ; Biological Tissue: ____ ; Natural Rubber: _ _ _ ; Electrorheological (ER) And Magnetorheological (MR) Fluid Based Polymers: ..... ; Materials that have been used in soft robots: Triangle; Hard Materials: Diamond

Coyle et al., 2018

Material Selection Criteria 3: Fracture toughness

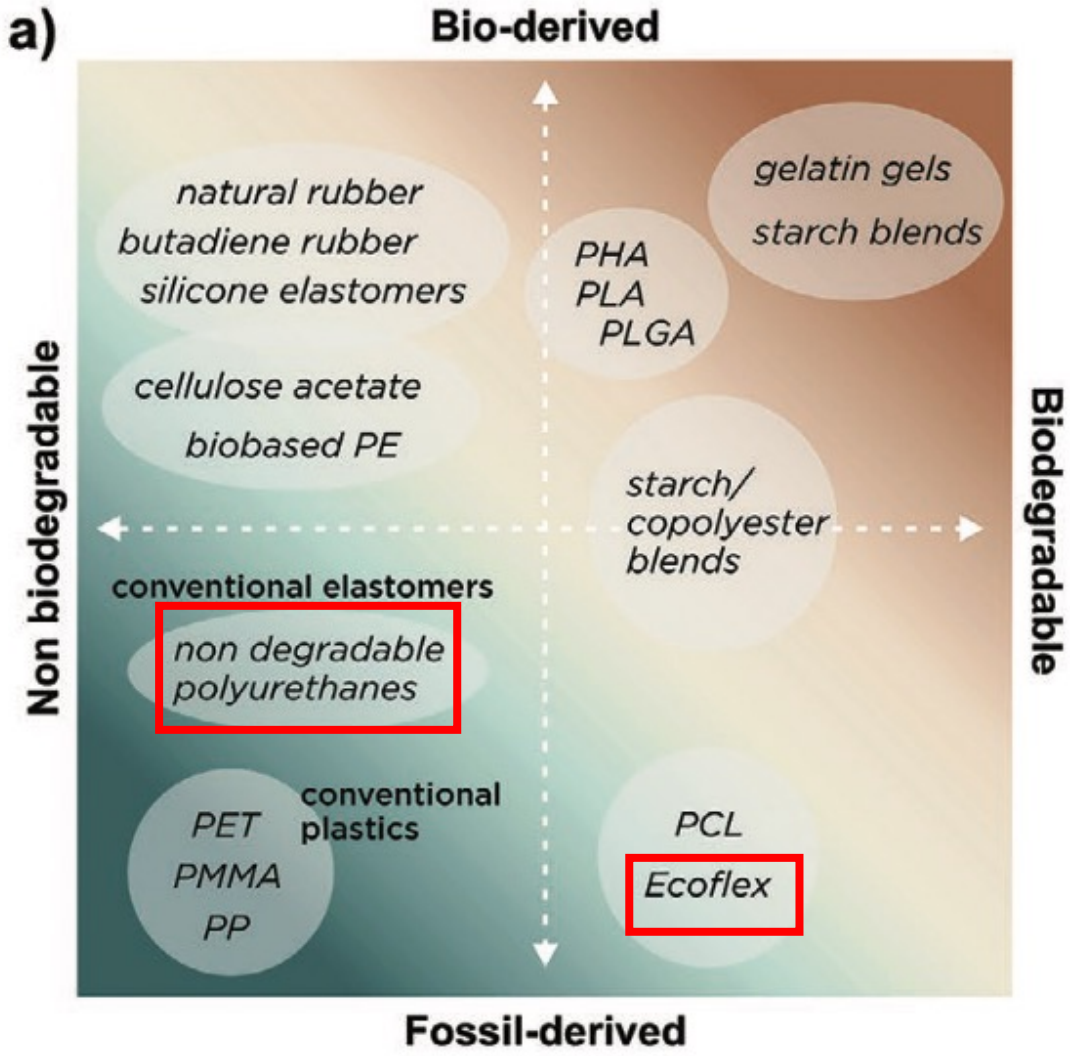
- The critical stress intensity factor of a sharp crack where propagation of the crack suddenly becomes rapid and unlimited.





Liu et al., 2017

Becoming Sustainable

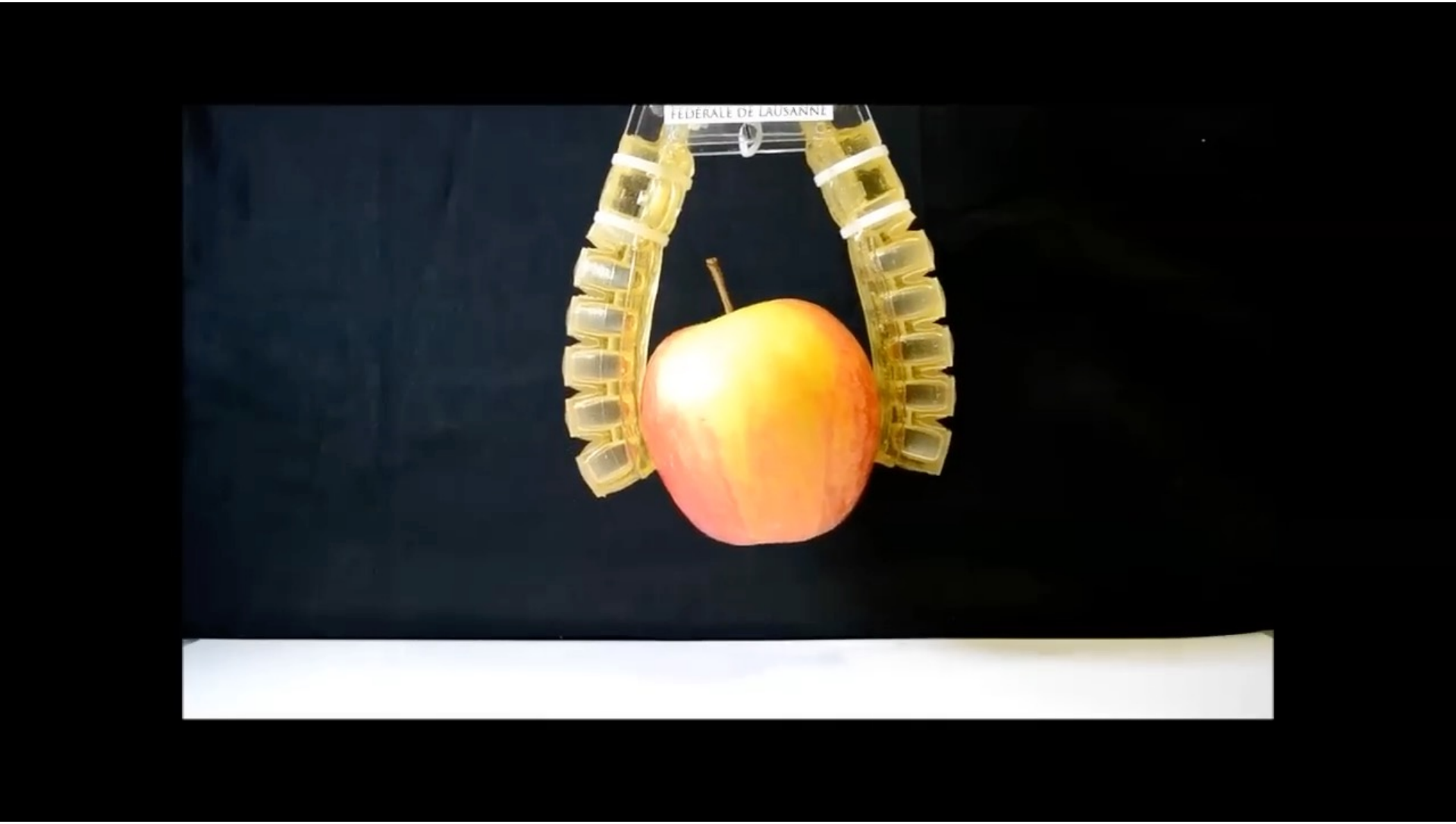


Ecoflex:

- Fossil-derived 化石基
- Biodegradable through industrial compost 可工业降解

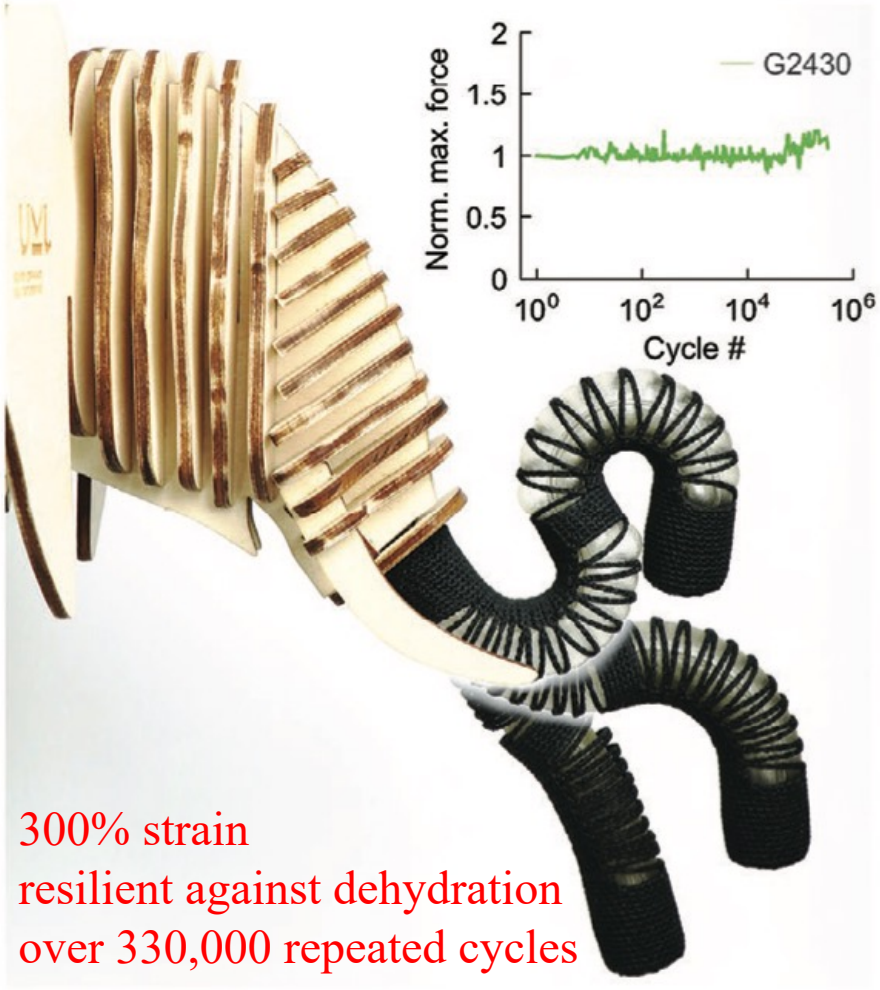
(Hartmann et al., 2021)

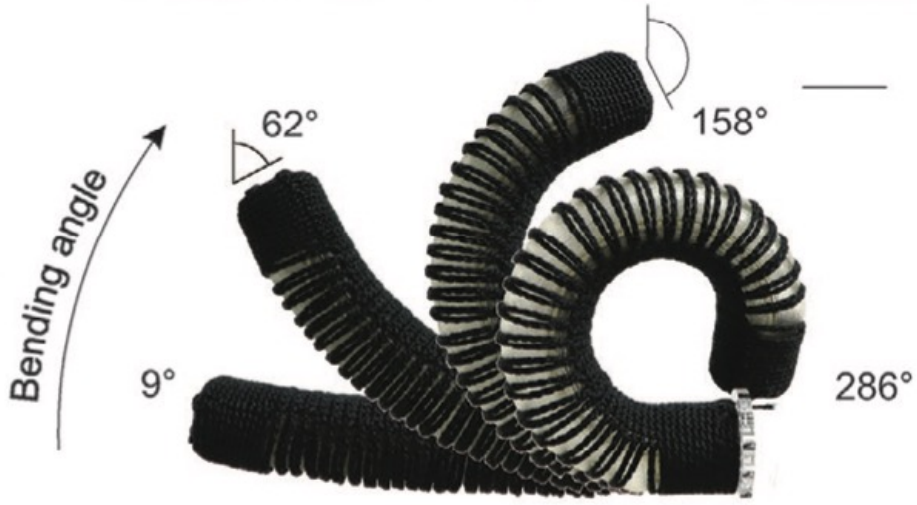
Edible Robotics from Gelatin



(Shintake et al., 2017)

Edible Robotics from Gelatin





- 300% strain
- resilient against dehydration
- over 330,000 repeated cycles

(Baumgartner et al., 2020)

Thank you~

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