Rheological and mechanical properties of polystyrene with hydrogen bonding

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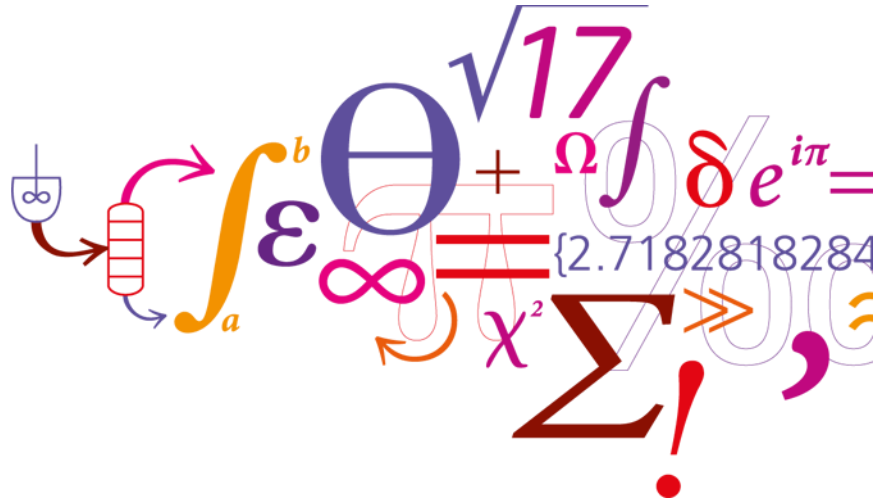


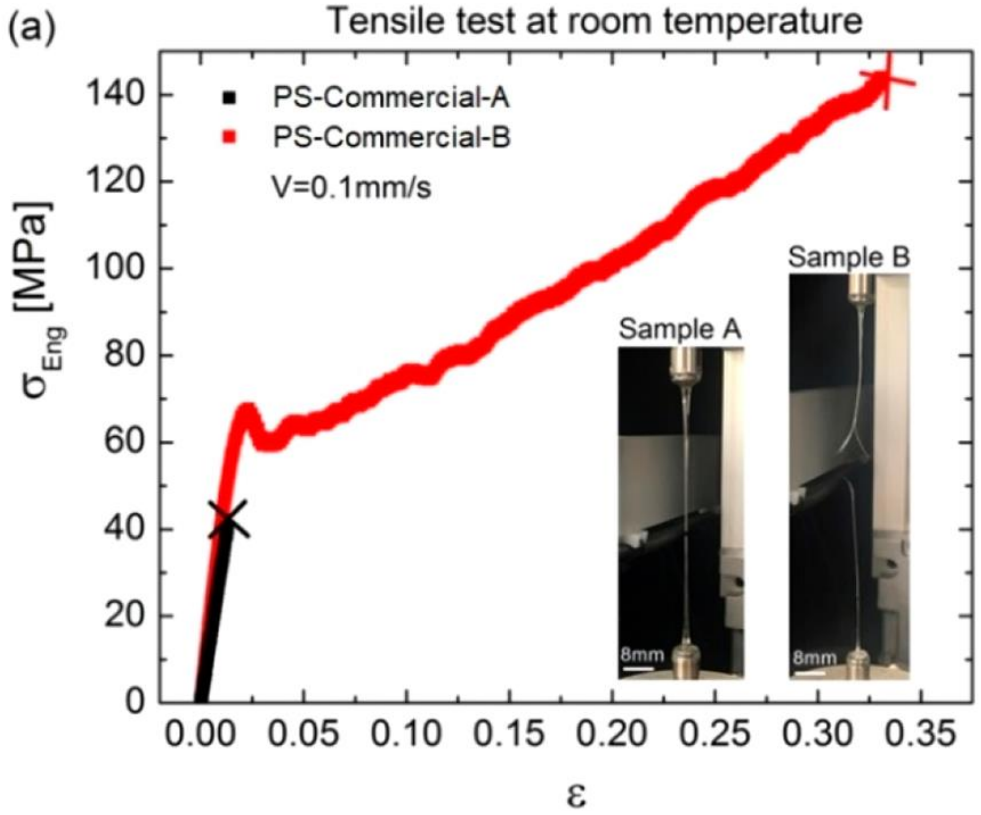
ESR 6: Viscoelastic Response of Double Dynamics Polymer Networks under Transient Elongation

Background

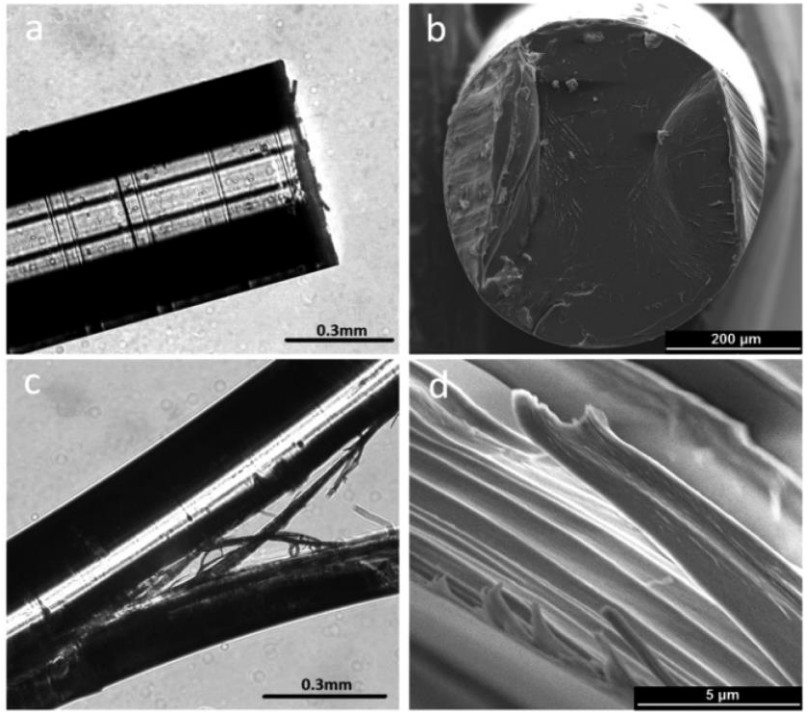
- Isotropic: slowly stretched (fully relaxed)
- Anisotropic: fast stretching (inverse Rouse time) + immediate fast quenching

Qian Huang et al. *ACS Macro Lett.* 2018, 7, 1126-1130

Background



Engineering stress as a function of strain in tensile tests at room temperature

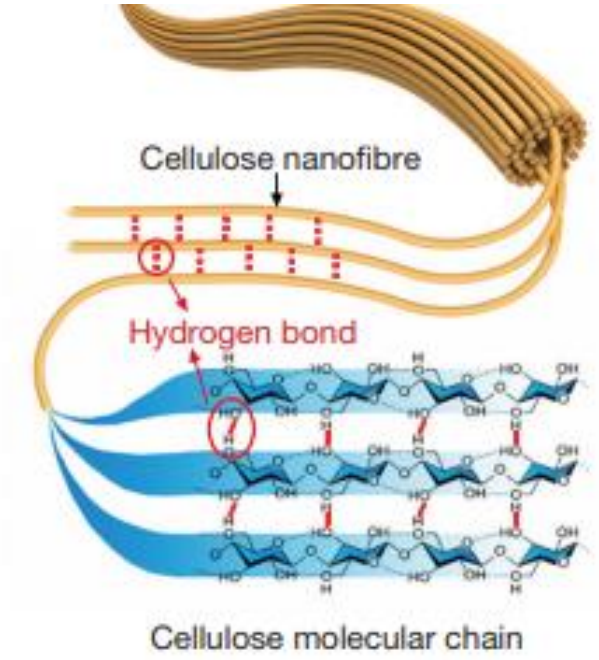


(a) Optical microscopy image and (b) SEM image for the brittle sample PS-Commercial-A; (c) Optical microcopy image and (d) SEM image for the flexible sample PS-Commercial-B

Qian Huang et al. *ACS Macro Lett.* 2018, 7, 1126-1130

Idea

Cracks when trying to recover the sample after bending



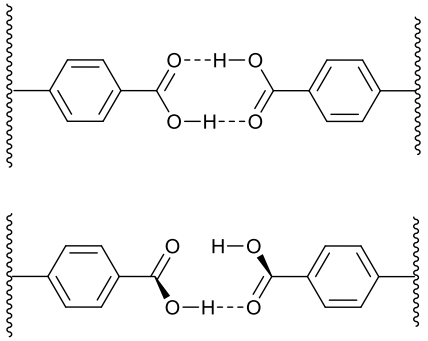
Jianwei Song et al., *Nature*, 2018, vol 554, 224

Idea

Material:

Three PS based sample M_w = 140k g/mol (synthesized by Jeppe Madsen)

- Sample 1: Pure PS, T_g = 100°C;
- Sample 2: PS backbone with 5% acid group, T_g = 114°C
- Sample 3: PS backbone with 9% acid group, T_g = 122°C



Characterizations:

- Linear viscoelastic properties
- Nonlinear extensional properties
- Mechanical properties

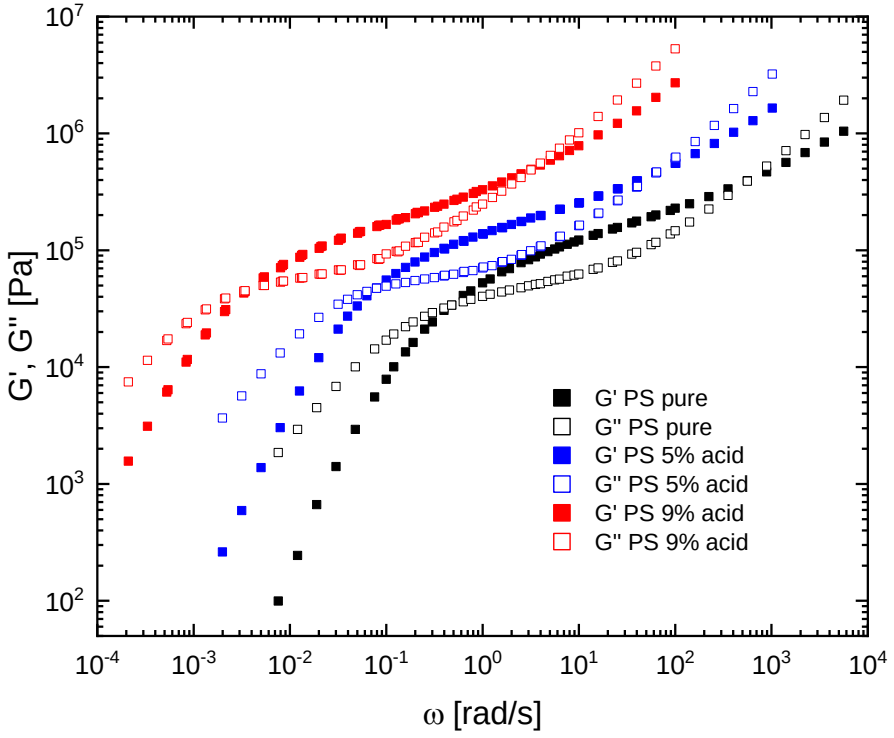
} melt state ($T>T_g$)

- Tensile test
- Three-point bending test

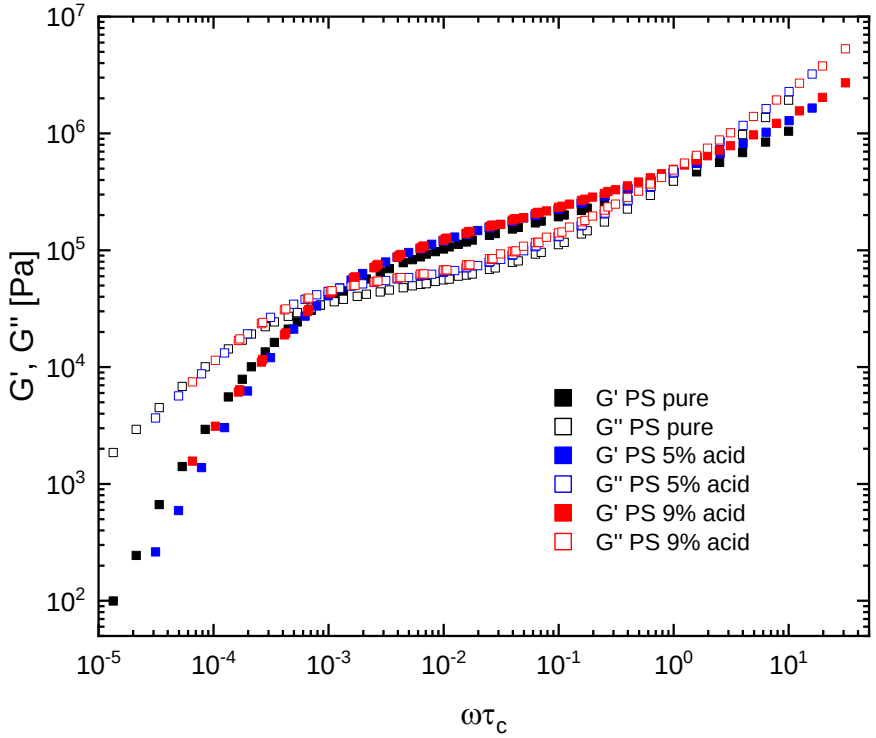
} solid state ($T<T_g$)

Linear viscoelastic properties

- Small Amplitude Oscillatory Shear (SAOS)



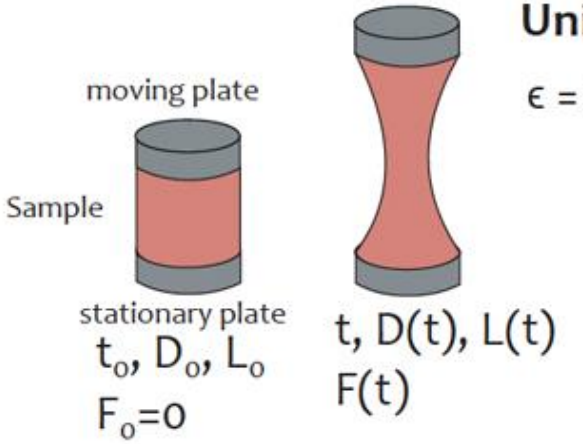
LVE data at 150ºC for different samples



LVE data with normalized frequency at 150ºC

Nonlinear extensional properties

- VADER (Versatile Accurate Deformation Extensional Rheometer)

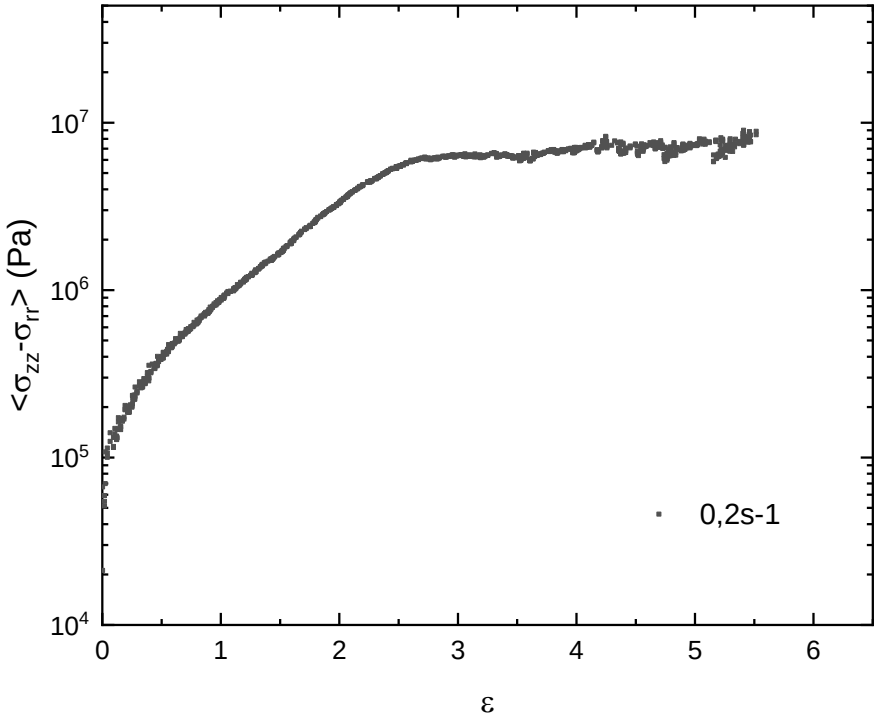


Uniaxial Hencky Strain

$$\epsilon = 2\ln(D_o/D(t)) = \ln(L(t)/L_o)$$

True Stress

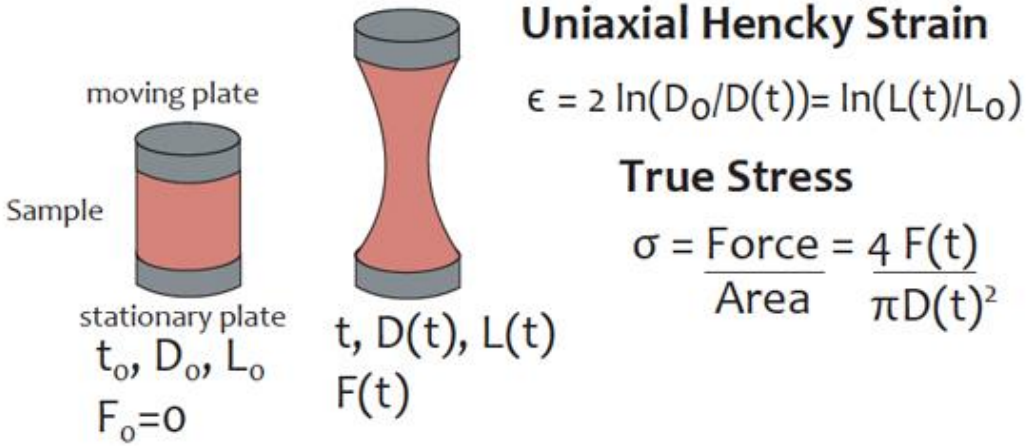
$$\sigma = \frac{\text{Force}}{\text{Area}} = \frac{4F(t)}{\pi D(t)^2}$$

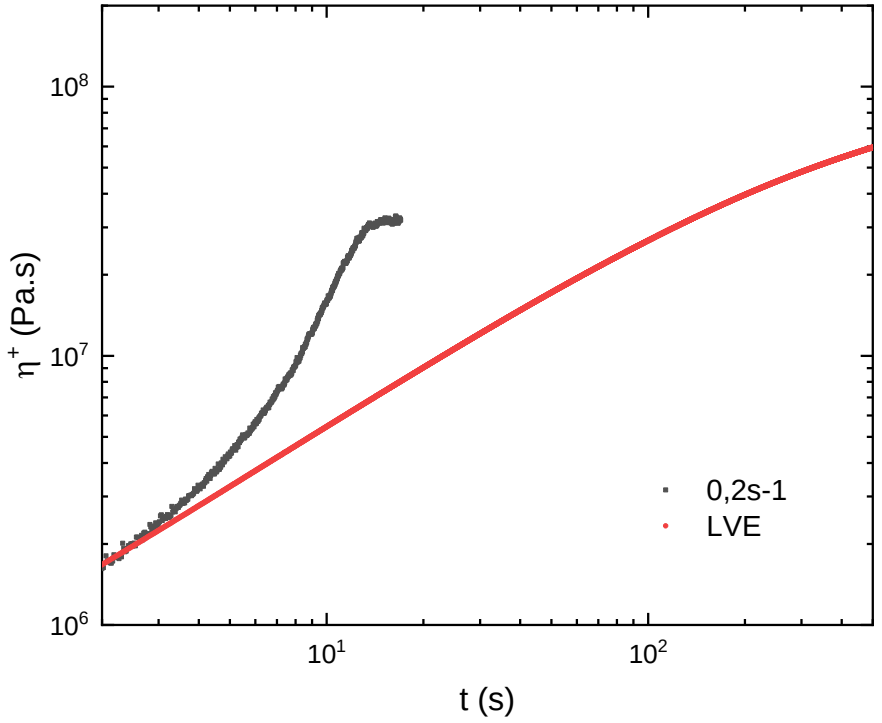


Example of extensional stress as a function of Hencky strain

Nonlinear extensional properties

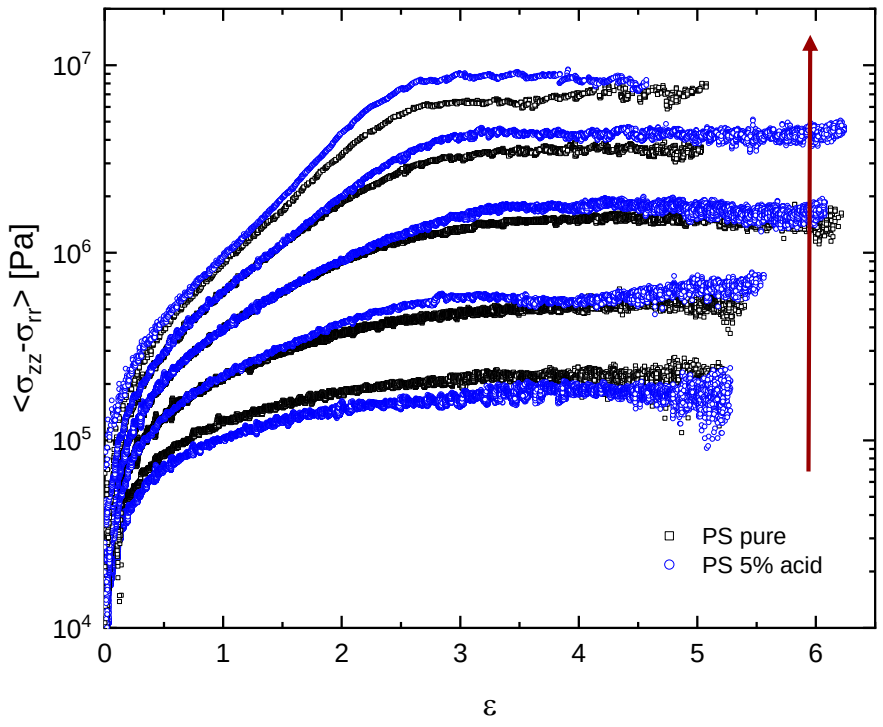
- VADER (Versatile Accurate Deformation Extensional Rheometer)



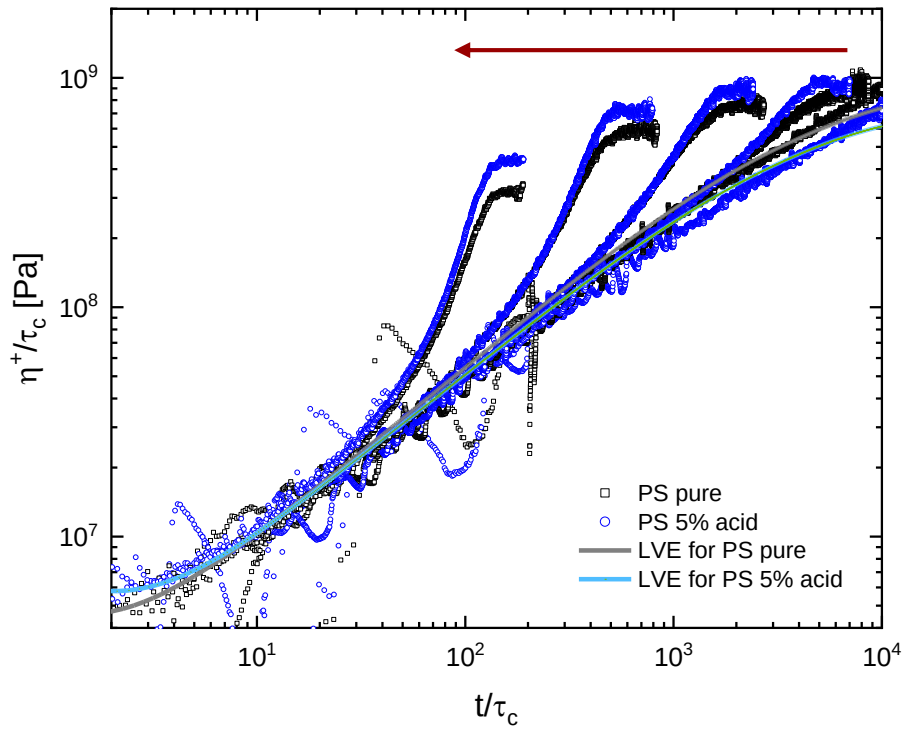


Example of extensional stress growth coefficient as function of time

Nonlinear extensional properties

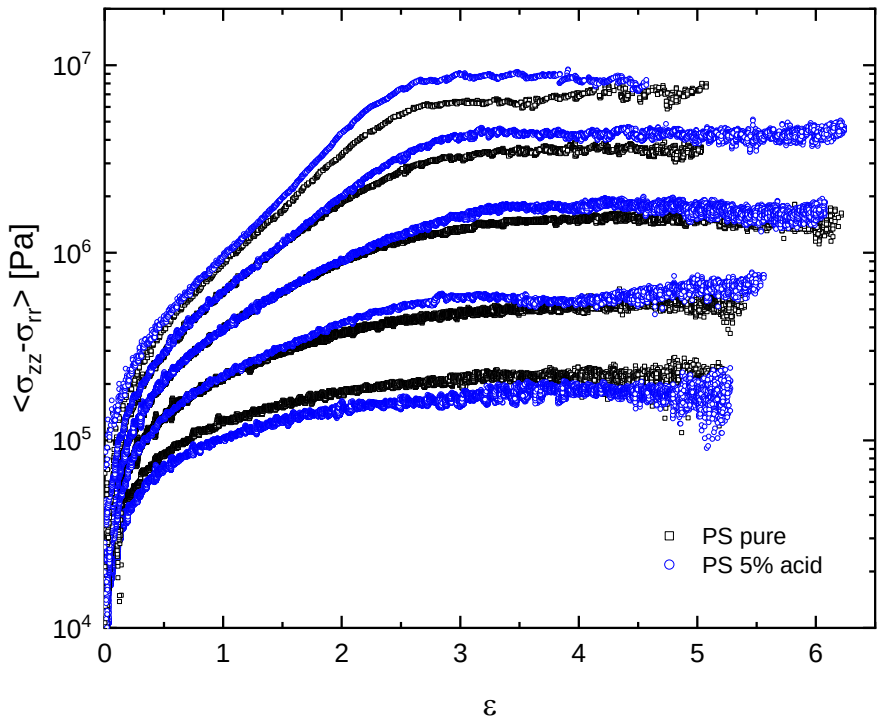


Comparison of extensional stress as a function of Hencky strain for pure PS and PS with 5% acid group

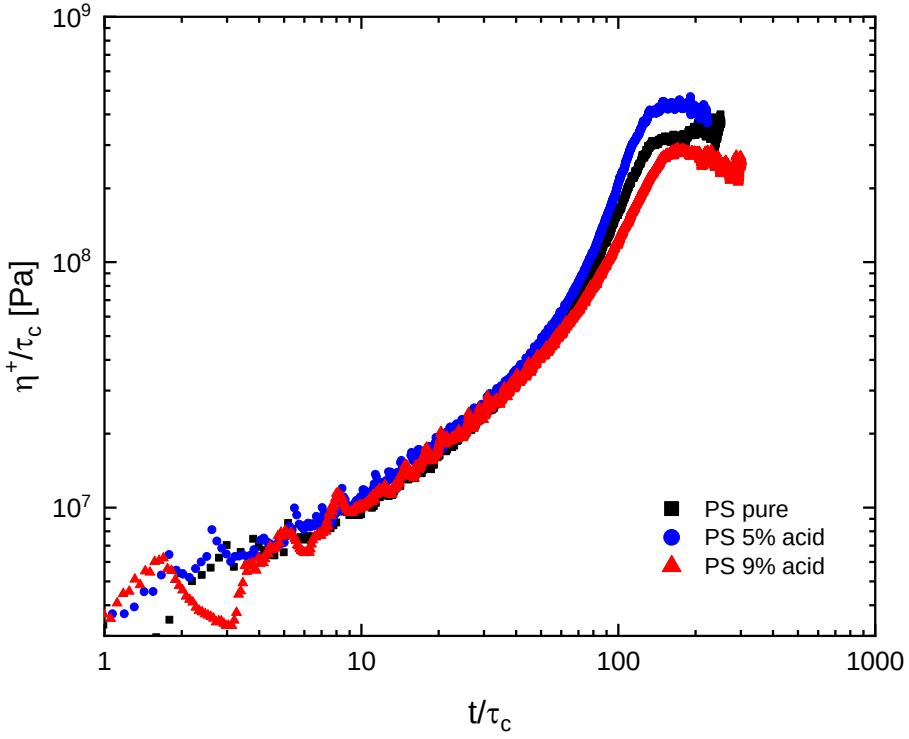


Comparison of normalized extensional stress growth coefficient for pure PS and PS with 5% acid group

Nonlinear extensional properties

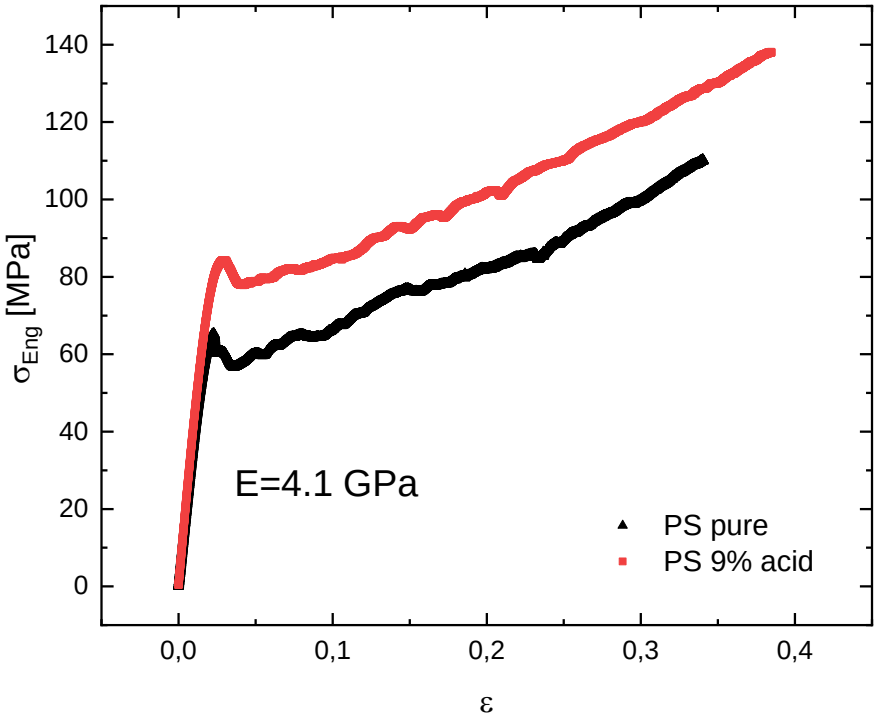


Comparison of extensional stress as a function of Hencky strain for pure PS and PS with 5% acid group



Comparison of normalized extensional stress growth coefficient for three samples

Tensile test



Engineering stress as a function of strain in tensile tests at room temperature, with a strain rate 0.001 s^{-1}

Three-point bending

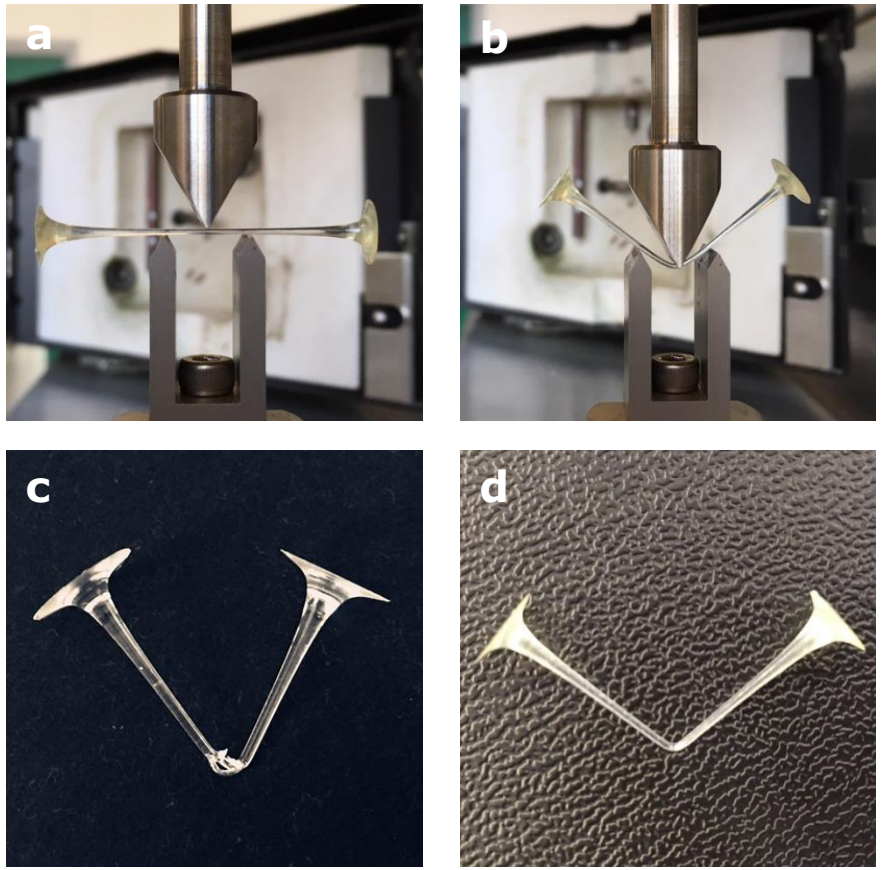
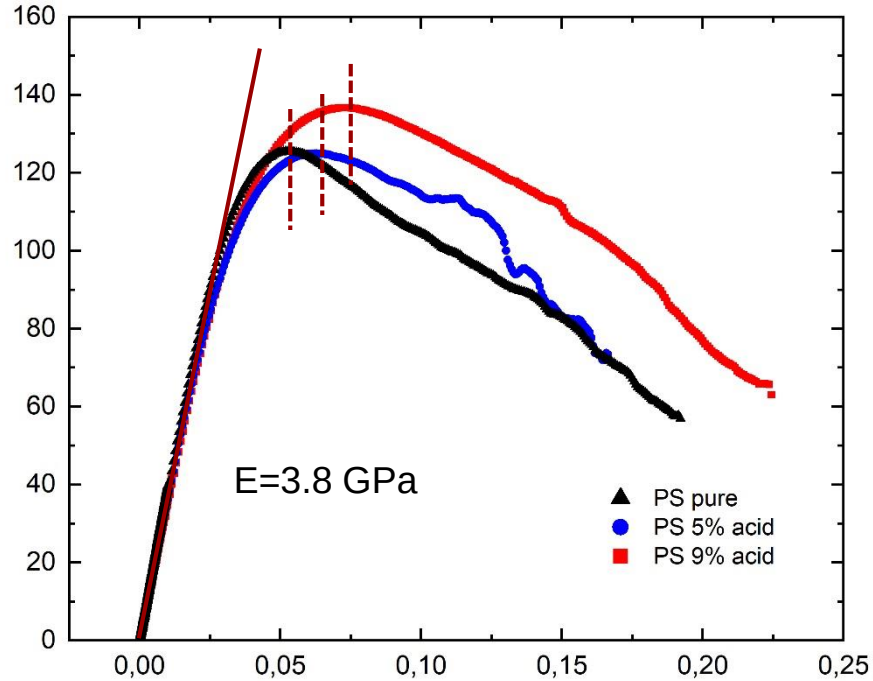


Figure **a** and **b**: corresponding figures for 3-point bending
Figure **c**: flexible pure PS, cannot be totally recovered
Figure **d**: better recovery, small crack in the filament (PS 5% acid)

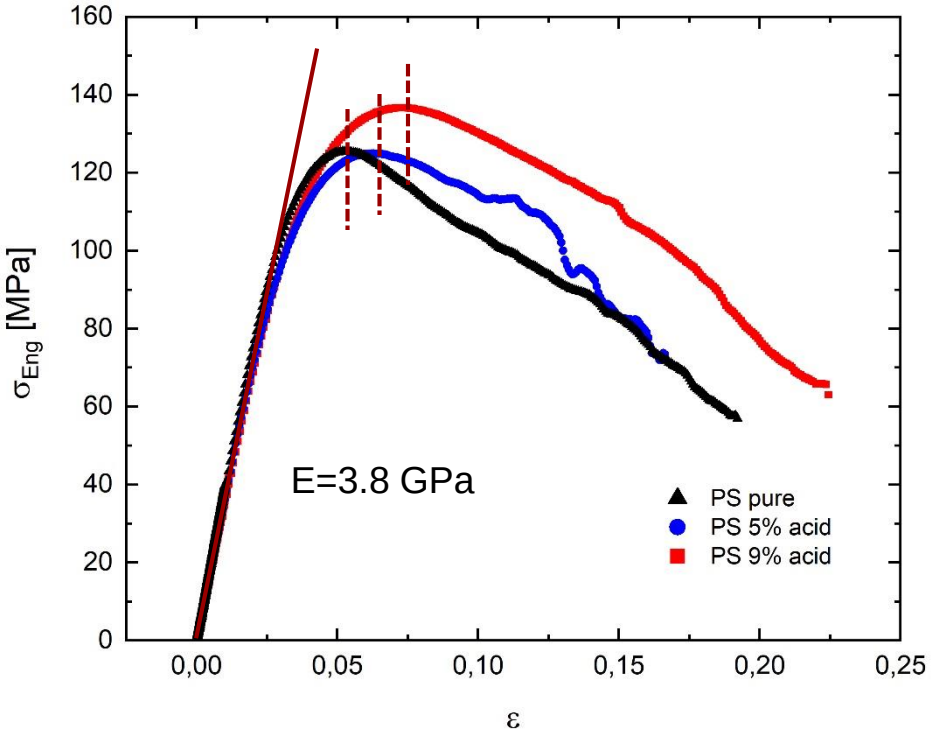
$$\sigma = \frac{PL}{\pi R^3}$$



$$\epsilon = \frac{12R\delta}{L^2}$$

3-point bending test on different samples: Sample is stretched to ε=3.5 at melt state followed by fast quenching to RT; The 3-point bending test is performed at room temperature.

Three-point bending



	Test 1	Test 2	Test 3	Average	s
pure	0.0527	0.0529	0.0536	0.0531	0.0005 (0.9%)
5%	0.0622	0.0624	0.0659	0.0635	0.0021 (3.3%)
9%	0.0724	0.0728	0.0754	0.0735	0.0016 (2.2%)

3-point bending test on different samples: Sample is stretched to ε=3.5 at melt state followed by fast quenching to RT; The 3-point bending test is performed at room temperature.

$$s = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N-1}}$$

Three-point bending

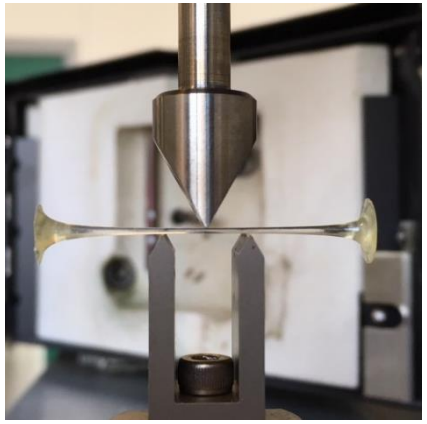
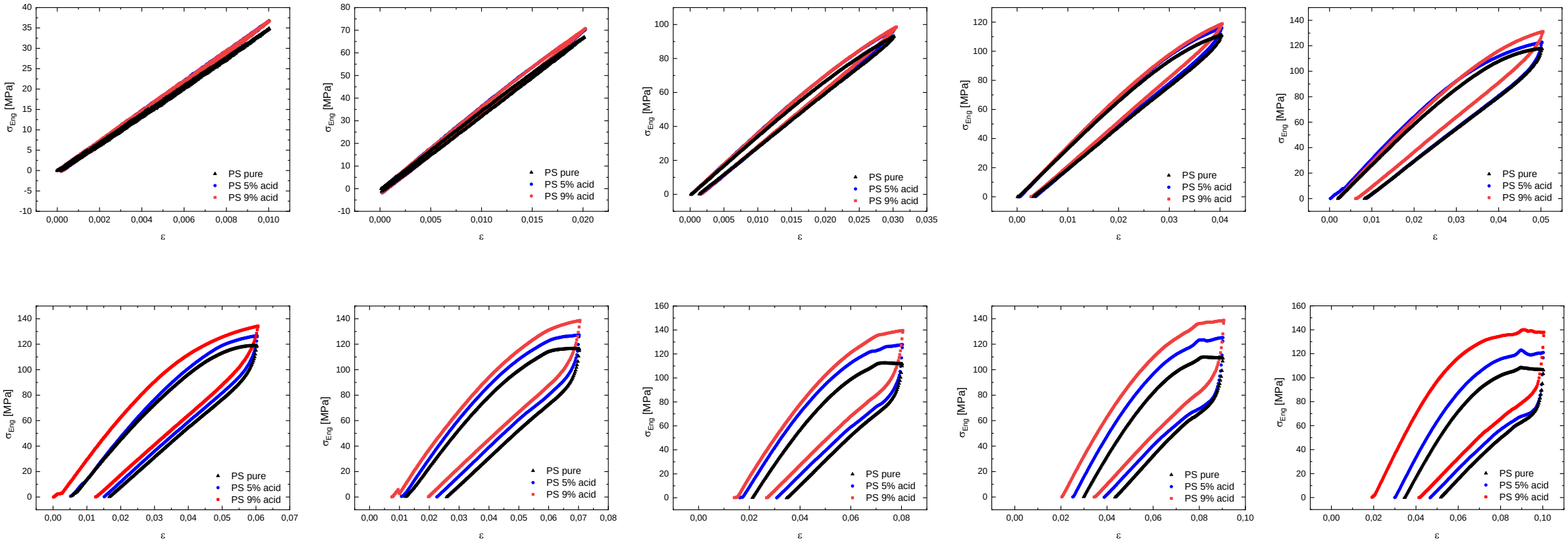


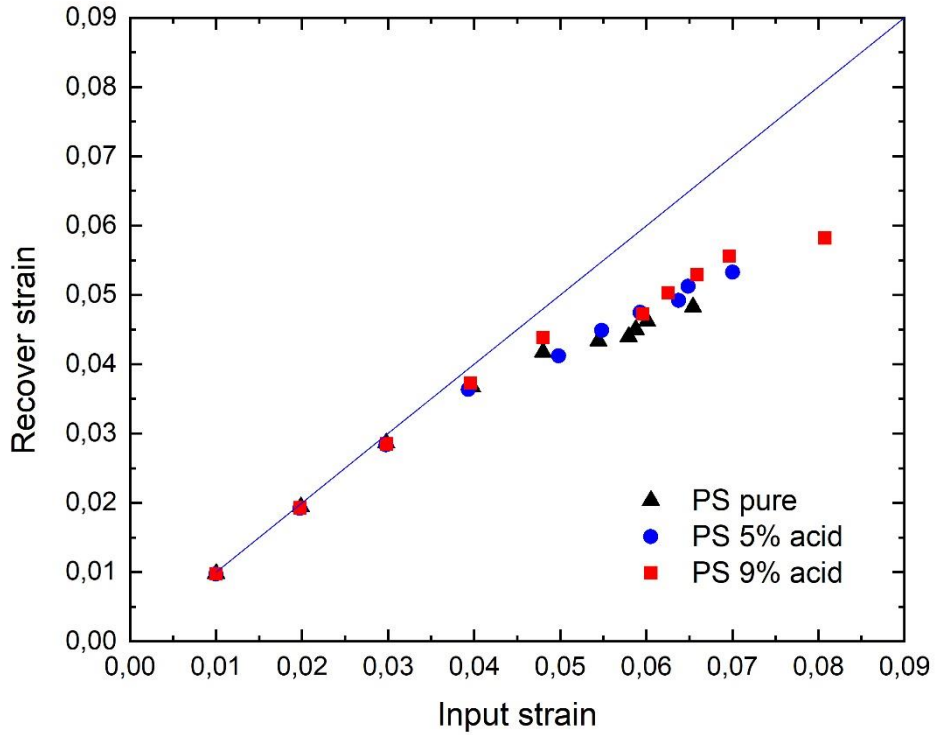
Illustration for step strain measurements

Three-point bending



Step strain measurements for samples with different acid group contents (strain increases from left to right, top to bottom)

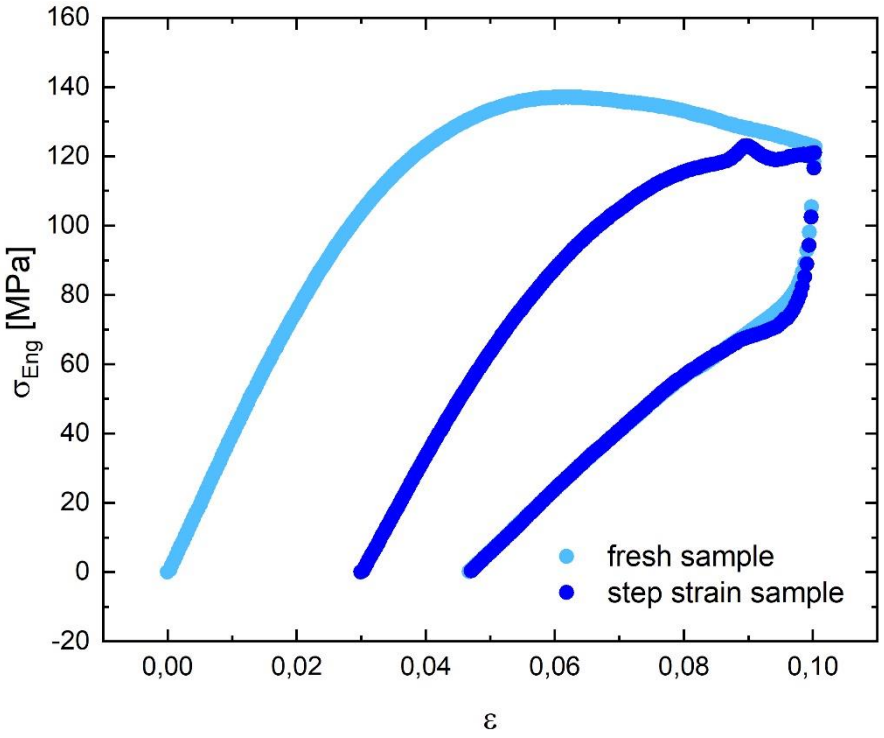
Three-point bending



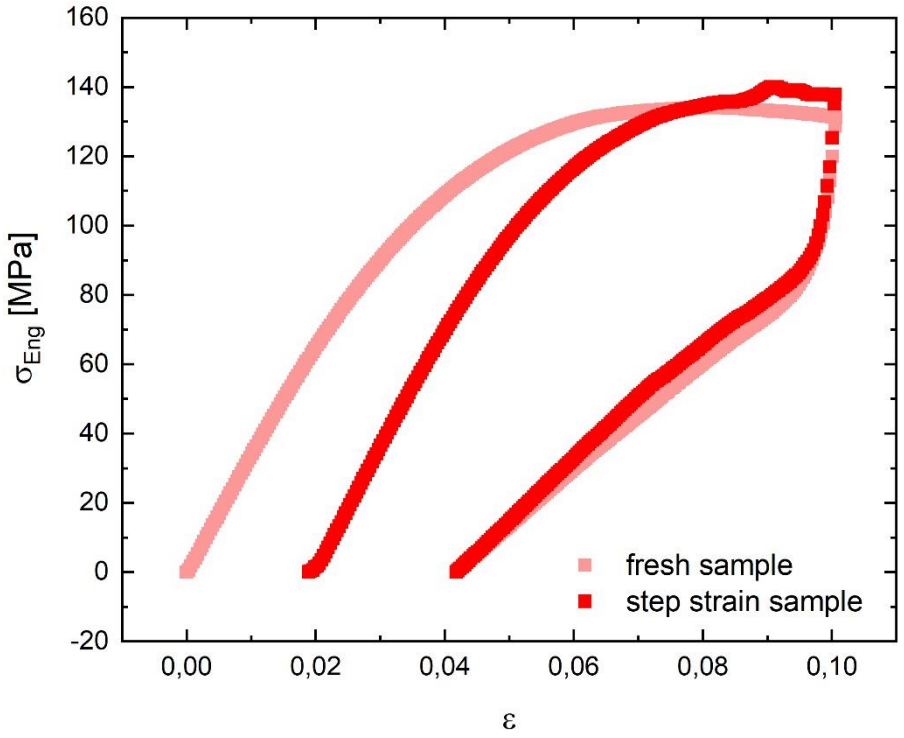
Recovered strain as a function of input strain

Three-point bending

- Compare with fresh samples



PS with 5% acid



PS with 9% acid

Conclusion & Future work

- Conclusion
- Hydrogen bonding enhances yield stress in tensile test
- Hydrogen bonding improves ductility and reversibility of sample

- Future work
- Use stronger ionic bond

Thank you for your attention!