Straw tube mechanical behavior preliminary analysis.

Summary.

- Geometry and material considered.
- Pressure tube seamless with plugged ends.
- Pressure tube seamless opened.
- Pressure tube with seam with plugged ends.
- Pressure tube with seam open ends.
- Conclusions.

- Geometry and material considered.

Straw tube analysis

Geometrical data

$Dis := 5\ mm$ internal straw diamters

$Ris := \frac{Dis}{2}$ $Ris = 2.5\ mm$ internal straw radius

$ths := 20 \cdot 10^{-3}\ mm$ Thickness straw tube

$y := 4000\ mm$ tube lenght

Material data Mylar

$Emm1 := 490\ \frac{kgf}{mm^2}$ $Emm1 = 4.805\ GPa$ Module dir. 1

$Emm2 := 510\ \frac{kgf}{mm^2}$ $Emm2 = 5.001\ GPa$ Module dir. 2

$\nu m := 0.38$ Poisson ratio Mylar

Material data Mylar

Table 1
Typical Physical and Thermal Properties of Mylar® Polyester Film

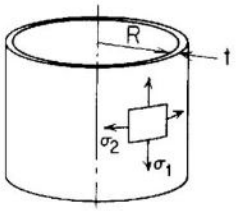
Property	Typical Value	Unit	Test Method
Gauge and Type **End Use**	**92A** **Industrial**		
Ultimate Tensile Strength, MD TD	20 (29) 24 (34)	kg/mm² (kpsi)	ASTM D 882
Strength at 5% Elongation (F-5), MD TD	10 (15) 10 (14)	kg/mm² (kpsi)	ASTM D 882
Modulus, MD TD	490 (710) 510 (740)	kg/mm² (kpsi)	ASTM D 882
Elongation, MD TD	116 91	%	ASTM D 882
Surface Roughness Ra	38	nm	Optical profilometer
Density	1.390	g/cm³	ASTM D 1505
Viscosity	0.56		ASTM D 2857
Melt Point	254	°C	DSC*
Dimensional Stability at 105°C (221°F), MD TD at 150°C (302°F), MD TD	0.6 0.9 1.8 1.1	%	DuPont test
Specific Heat	0.28	cal/g/°C	
Coefficients of Thermal Expansion Thermal Conductivity (Mylar® 1000A)	1.7×10^{-5} 3.7×10^{-4}	in/in/°C $\frac{cal \cdot cm}{cm^2 \cdot sec \cdot °C}$	ASTM D 696 30–50°C (86–122°F) 25–75°C (77–167°F)
UL94 Flame Class	See UL file # E93687	VTM	

*Differential Scanning Calorimeter

Table from DuPont

Tube seamless with plugged ends with 2 bar pressure.

1. Cylindrical



$\frac{R}{t} > 10$

1c. Uniform internal or external pressure, q force/unit area (ends capped)	At points away from the ends
	$\sigma_1 = \frac{qR}{2t}$
	$\sigma_2 = \frac{qR}{t}$
	$\Delta R = \frac{qR^2}{Et}\left(1 - \frac{\nu}{2}\right)$
	$\Delta y = \frac{qRy}{Et}(0.5 - \nu)$
	$\psi = 0$

$Pi = 2\ \textit{bar}$ +

$\sigma 1i := \frac{Pi \cdot Ris}{2 \cdot ths}$ $\quad \sigma 1i = 12.5\ \textit{MPa}$ meridional stress

$\sigma 2i := \frac{Pi \cdot Ris}{ths}$ $\quad \sigma 2i = 25\ \textit{MPa}$ circunferetial stress

$\Delta Rs1 := \frac{Pi \cdot Ris^2}{Emm1 \cdot ths} \cdot \left(1 - \frac{\nu m}{2}\right)$ $\quad Emm1 = 4.805\ \textit{GPa}$

$\Delta Rs1 = 10.535\ \mu m$ Radial variation

$\Delta y1 := \frac{Pi \cdot Ris \cdot y}{Emm1 \cdot ths} \cdot (0.5 - \nu m)$

$\Delta y1 = 2.497\ mm$ Longitudinal variation of lenght

$$\varepsilon_x = \frac{1}{E}(\sigma_x - \nu\sigma_y)$$

$$\varepsilon_y = \frac{1}{E}(\sigma_y - \nu\sigma_x)$$

$$\varepsilon_z = -\frac{\nu}{E}(\sigma_x + \sigma_y)$$

Principal strain

$$\sigma_x = \frac{E}{1-\nu^2}(\varepsilon_x + \nu\varepsilon_y)$$

$$\sigma_y = \frac{E}{1-\nu^2}(\varepsilon_y + \nu\varepsilon_x)$$

Principal stresses

$\varepsilon th := -\nu m \cdot \frac{\sigma 1i}{Emm1} - \nu m \frac{\sigma 2i}{Emm1}$ $\quad \varepsilon th = -0.003$

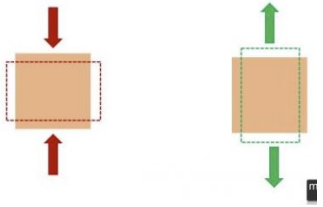
$Thf := ths + \Delta th1$ $\quad Thf = 19.941\ \mu m$

Vom Mises criteria

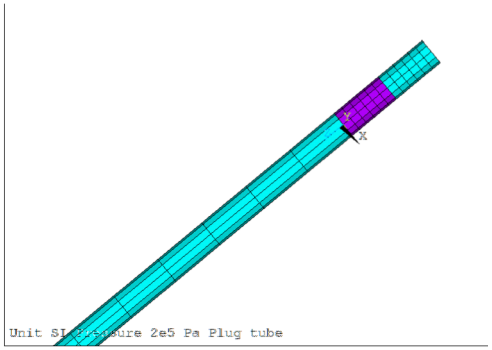
+

$\sigma id\_vm := \sqrt[2]{\sigma 1i^2 - \sigma 1i \cdot \sigma 2i + \sigma 2i^2}$

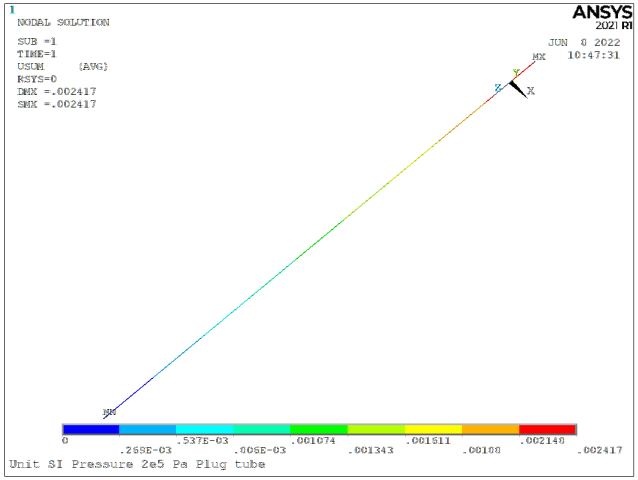
$\sigma id\_vm = 21.651\ \textit{MPa}$



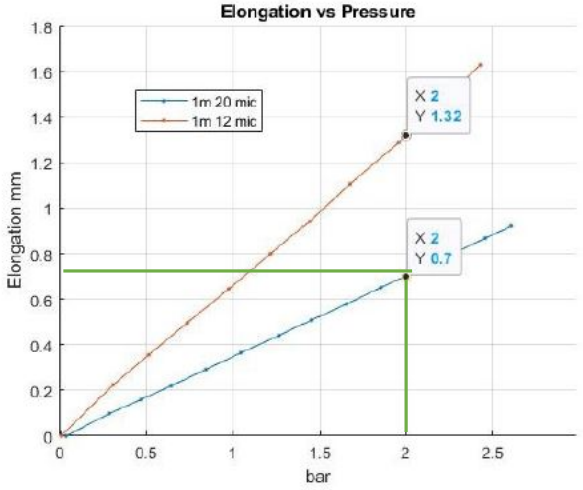
Tube seamless with plugged ends with 2 bar pressure Fem analyses.



No metal



Elongation of fixed tube based on pressure change



FEM Longitudinal disp. 2.417mm analytical 2.497mm stress vm ana 21.6 Mpa FEM 21 Mpa
FEM radial disp. 11 µm analytical µm 10.535 µm.
Experimental result longitudinal disp. Per meter 0.7mm
For 4 meter 4x0.7mm 2.8 mm the relative error very small
Comparison disp. with force:
Analytical with no metal 1 meter 300 gr 1.949mm experimental 1.7mm

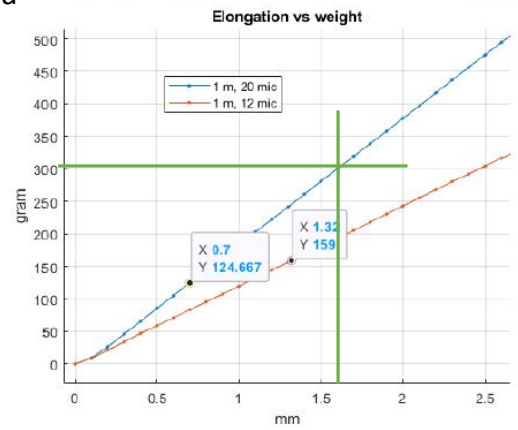
$m1 := 300\ gm$ $F1 := m1 \cdot g$ $F1 = 2.942\ N$ Force

$Ast := 2 \cdot \pi \cdot Ris \cdot ths$ $Ast = 0.314\ mm^2$ Area

$\varepsilon L := \frac{F1}{Emm1 \cdot Ast}$ $\varepsilon L = 0.002$ Strain

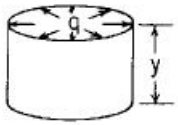
$Ld := 1\ m$ $\Delta Ld := \varepsilon L \cdot Ld$ $\Delta Ld = 1.949\ mm$

Tube elongation with weights with no pressure



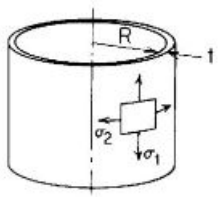
Pressure tube seamless opened with 2 bar.

1b. Uniform radial pressure, q force/unit area



$$\sigma_1 = 0$$
$$\sigma_2 = \frac{qR}{t}$$
$$\Delta R = \frac{qR^2}{Et}$$
$$\Delta y = \frac{-qRvy}{Et}$$
$$\psi = 0$$

1. Cylindrical



$$\frac{R}{t} > 10$$

$$\sigma 1o := 0$$

$$\sigma 2o := \frac{Pi \cdot Ris}{ths} \qquad \sigma 2o = 25\ MPa$$

$$\Delta Ro := \frac{Pi \cdot Ris^2}{Emm1 \cdot ths} \qquad \Delta Ro = 13.007\ \mu m$$

$$\Delta yo := -\nu m \cdot \frac{Pi \cdot Ris \cdot y}{Emm1 \cdot ths} \qquad \Delta yo = -7.908\ mm$$

The maylar tube will shrink of 7 mm when is free ends.

$$\varepsilon 2o := \frac{\sigma 2o}{Emm1} \qquad \varepsilon 2o = 0.005$$

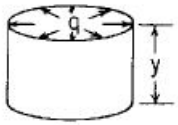
$$\varepsilon 1o := -\nu m \cdot \frac{\sigma 2o}{Emm1} \qquad \varepsilon 1o = -0.002$$

If the ends are constrain and their not a pulling force can collapse.

$$\Delta lt := \varepsilon 1o \cdot y \qquad \Delta lt = -7.908\ mm$$

Pressure tube seamless opened with 2 bar.

1b. Uniform radial pressure, q
force/unit area



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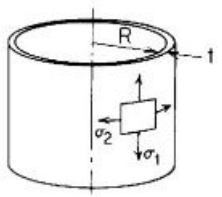

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If the ends are constrain and their not a pulling force can collapse.

$\Delta lt := \varepsilon 1o \cdot y$ $\quad \Delta lt = -7.908\ mm$

Pressure tube seamless opened with 2 bar end restrained.

$Pi = 2\ bar$ initial pressure

$Po := 1\ bar$ operatin pressure

$\varepsilon 2i := \frac{Pi \cdot Ris}{Emm1 \cdot ths} \cdot (0.5 - \nu m)$ $\varepsilon 2i = 6.243 \cdot 10^{-4}$

$\varepsilon op := -\nu m \cdot \frac{Po \cdot Ris}{Emm1 \cdot ths}$ $\varepsilon op = -9.885 \cdot 10^{-4}$

$\varepsilon axial := \varepsilon 2i + \varepsilon op$

$\varepsilon axial = -3.642 \cdot 10^{-4}$ residual strain

$\sigma res := \varepsilon axial \cdot Emm1$ residual stress

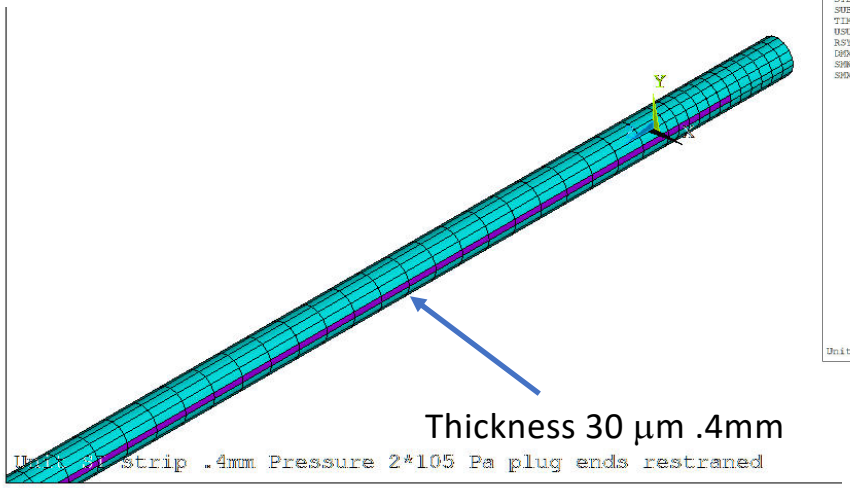
$\sigma res = -1.75\ MPa$ Very small

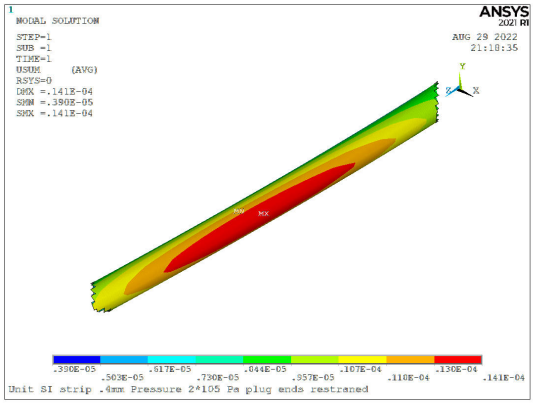
Considering infinite rigid frame. A pressurized tube is Glued With 2 bar of internal pressure. It is stretch from the pressure. His strain is given by the pressure of 2 bar considering that this is maintained.

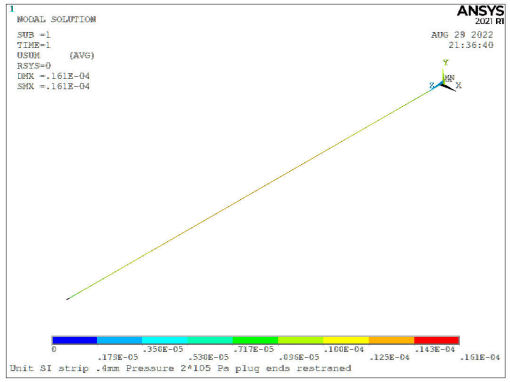
Now if we applied 1 bar of pressure the we have to superimpose the shrinkage due to the pressure.

In this particular case the final strain is negative. Mean that the straw have axially a compressive load.

Pressure tube with seam with plugged ends.



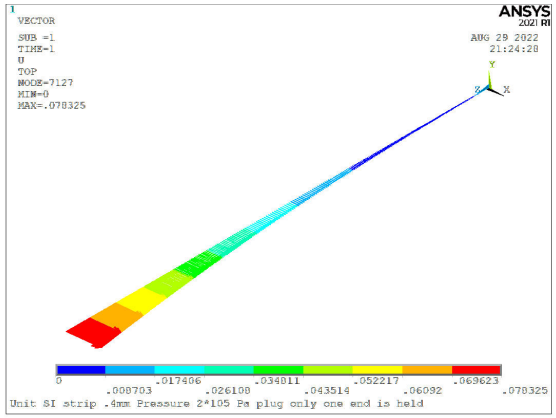


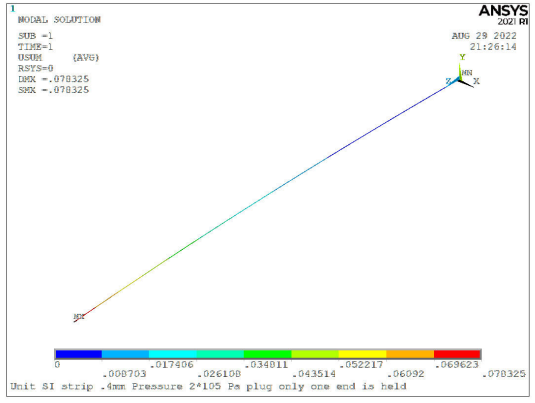


Straw with both ends plugged with two ends held.

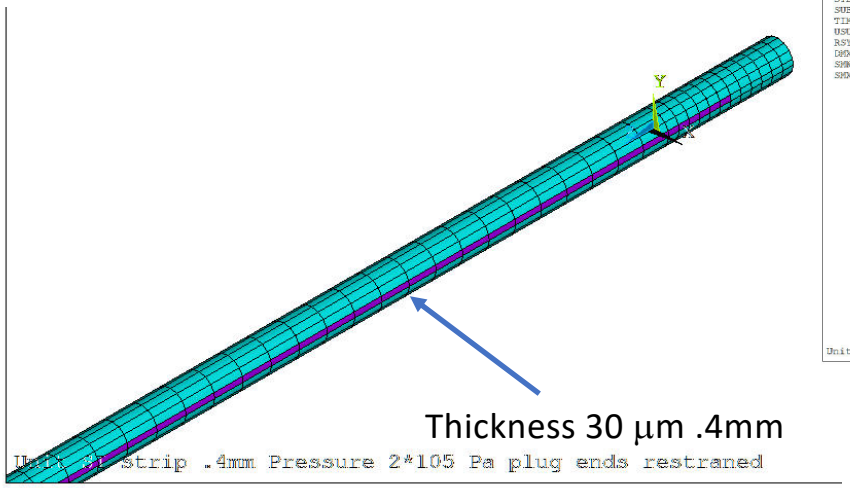
Straw total length 4 meter

If the two end are restrained the displacement is 14 μm if only one end is held the total displacement is 70mm. In the two restrained ends I have to verify the reaction on the restrain ends.





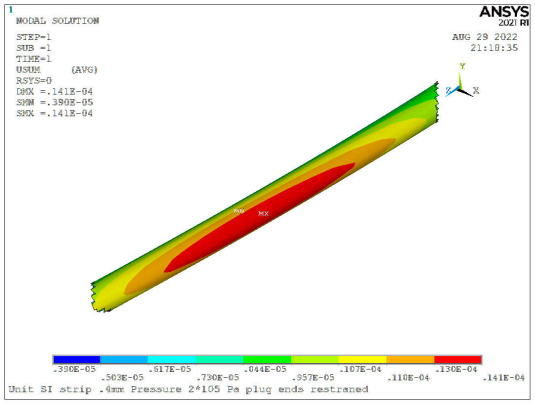
Straw with both ends plugged with one end held.

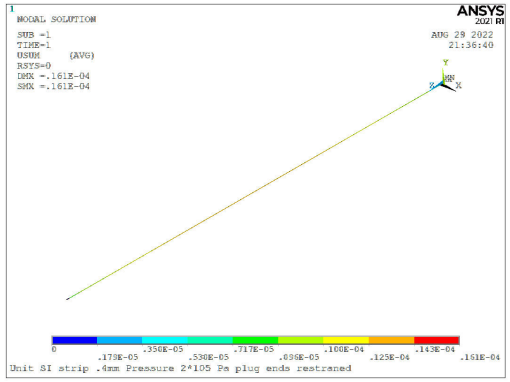


Thickness 30 µm .4mm

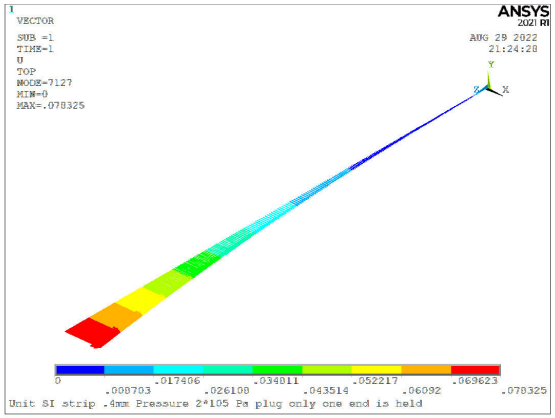
Straw total length 4 meter

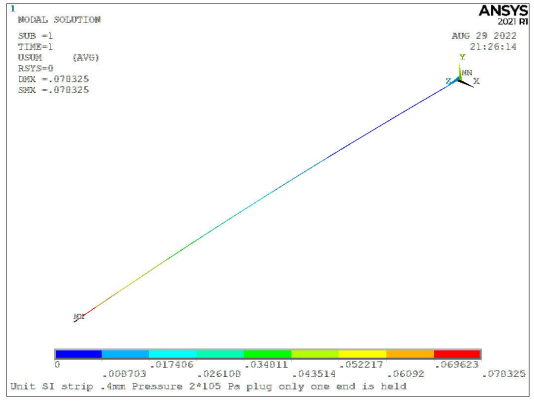
If the two end are restrained the displacement is 14 µm if only one end is held the total displacement is 70mm.





Straw with both ends plugged with two ends held.





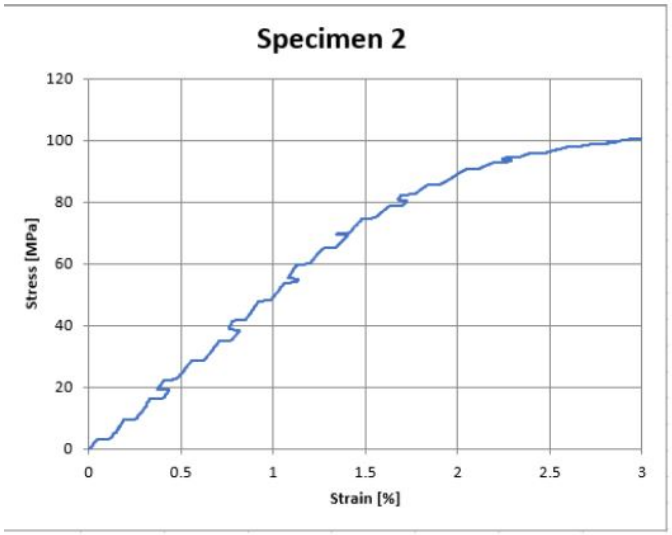
Straw with both ends plugged with one end held.

Conclusions.

- Preliminary analytical and fem calculations look very promising to predict the tube mechanical behavior.
- Further analyses need to be done to define the best strategy to guarantee the mechanical stability under the operation conditions.
- Further analysis will be done including the metallization.

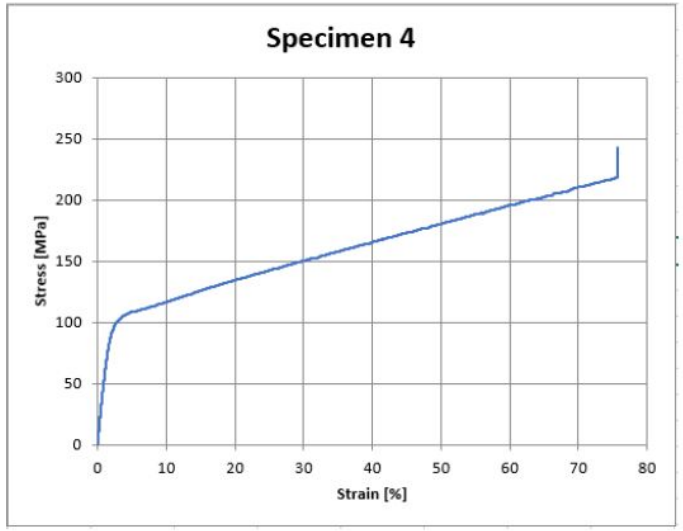
Longitudinal tensile tests

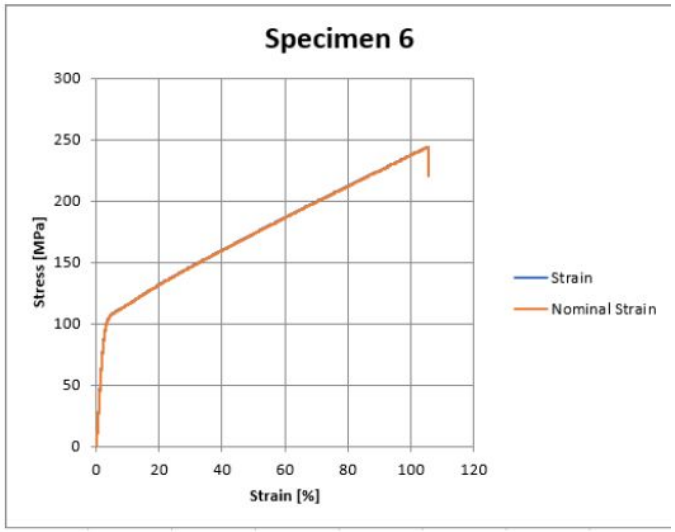
Specimen tests example on scraps:



Noise due to pen marks

Loose of marks





Perfect fit of the video-extensometer and the crosshead travel