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SEAMLESS TUBE FORMING SIMULATION: COLD PILGERING AND TUBE DRAWING ANALYSIS

UTN

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Objetives

- Simulate the tube forming by the application of Simufact forming software
  The simulated processes were:
    cold pilgering
    cold drawing

- Determine conditions in order to avoid defects

Cold Pilgering

Diameter and thickness reduction process of tubes and seamless tubes.

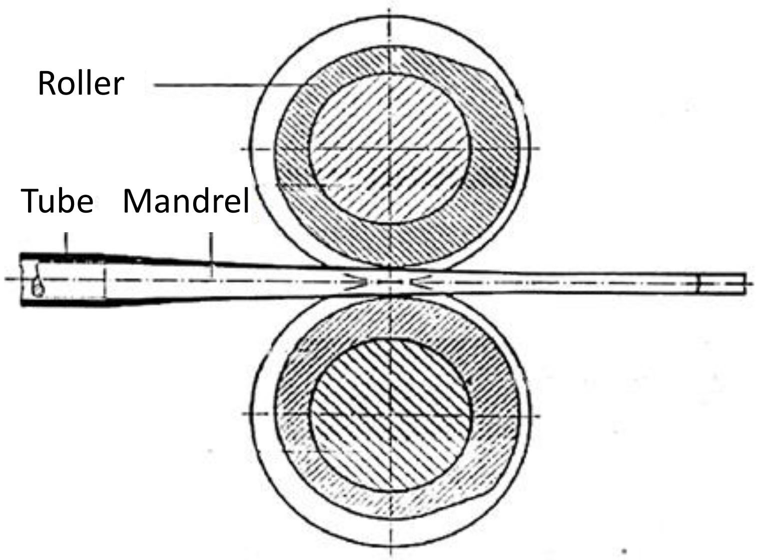
Applied in a wide range of diameter and thickness because of its:

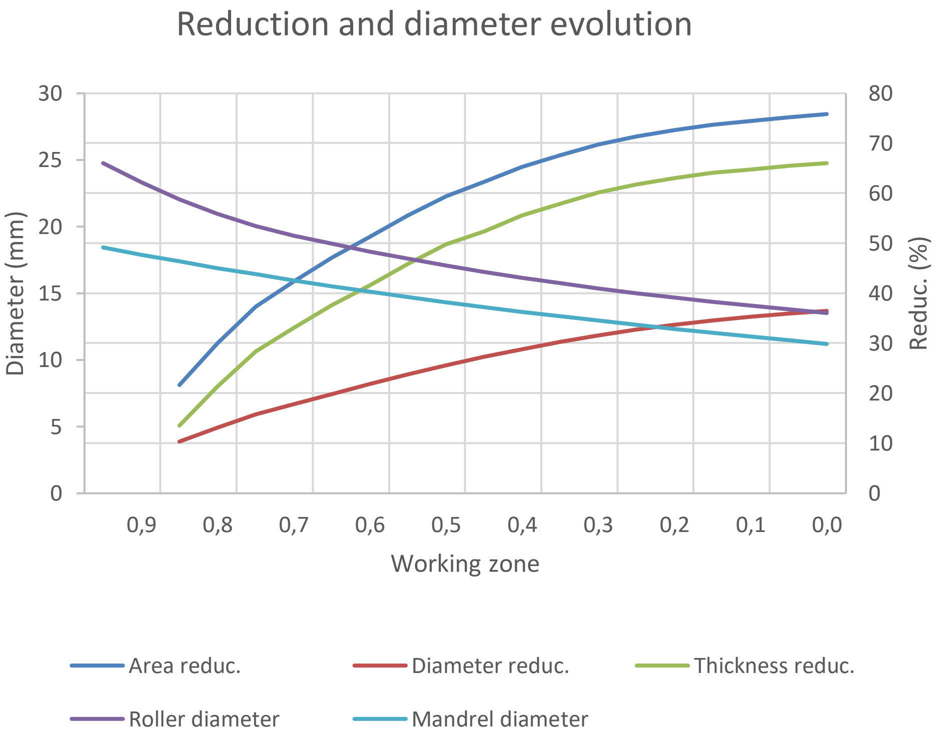
- Very good dimensional precision
- Low eccentricity
- Very good surface finish
- Low incidence of defects

Used in a large number of materials

Cold Pilgering

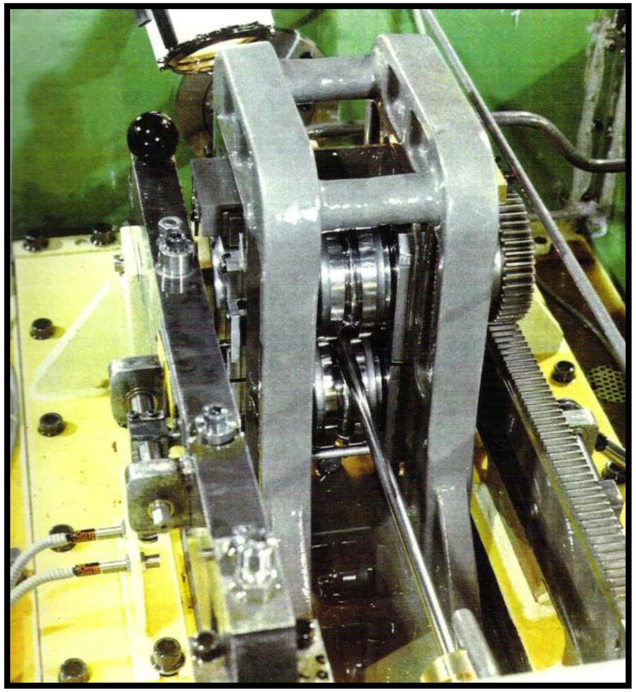
The reduction is produced by the advance and retreat of two rollers on the tube, with an internal mandrel.





Cold Pilgering

The reduction is produced by the advance and retreat of two rollers on the tube, with an internal mandrel.

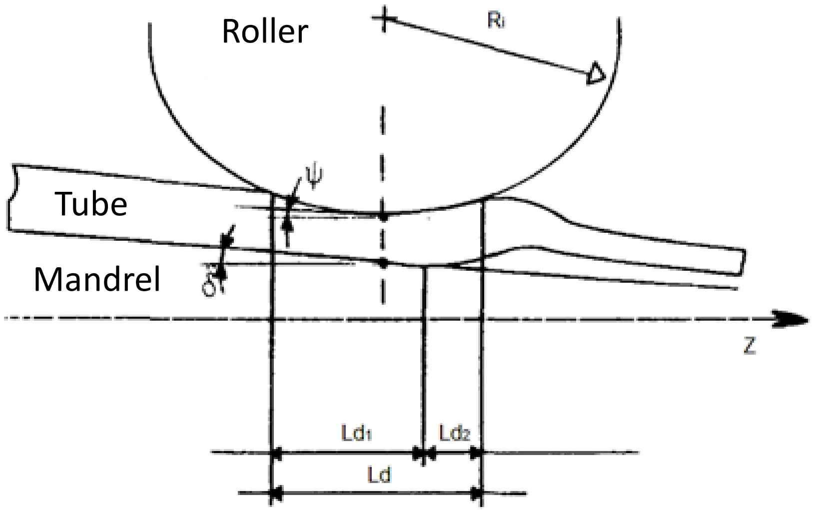


Cold Pilgering

Theoretical loads during lamination

Neumann and Siebel’s model considers:

- Load as a function of position
- Two contact superficies
- Geometry variations
- Material hardening



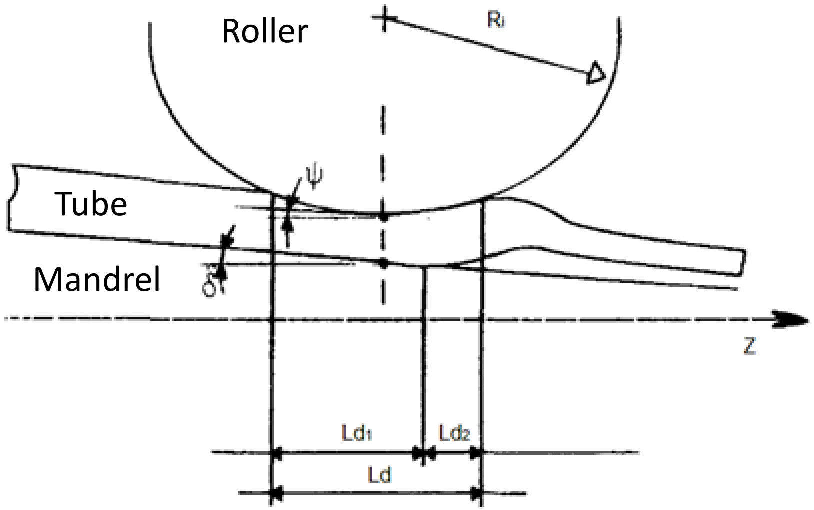
Cold Pilgering

Theoretical loads during lamination

$$F(z) = \sigma_0(z)\left(1+\frac{\mu Ld}{2e(z)}\right)D(z)\sqrt{2R(z)m\left(\frac{S_0}{S(z)}\right)}\left(\sqrt{\varphi(z)-\delta(z)}+\sqrt{\delta(z)}\,2e(z)/D(z)\right)$$

where:

σ_0 : initial area of pipe section
$S_{(z)}$: area of a section at distance z
φ, δ : contact angles between tube, roller and mandrel



Cold Pilgering

Q-Factor

Value that allows evaluating the configuration of process parameters. Relationship between reductions in thickness and diameter through a function

$$Q = {}^{\ln(e_f/e_0)}\!\Big/_{\ln(Dm_f/Dm_0)}$$

Where:

e_0 and e_f are initial and final thicknesses

Dm_0 and Dm_f initial and final mean diameters.

Tube drawing

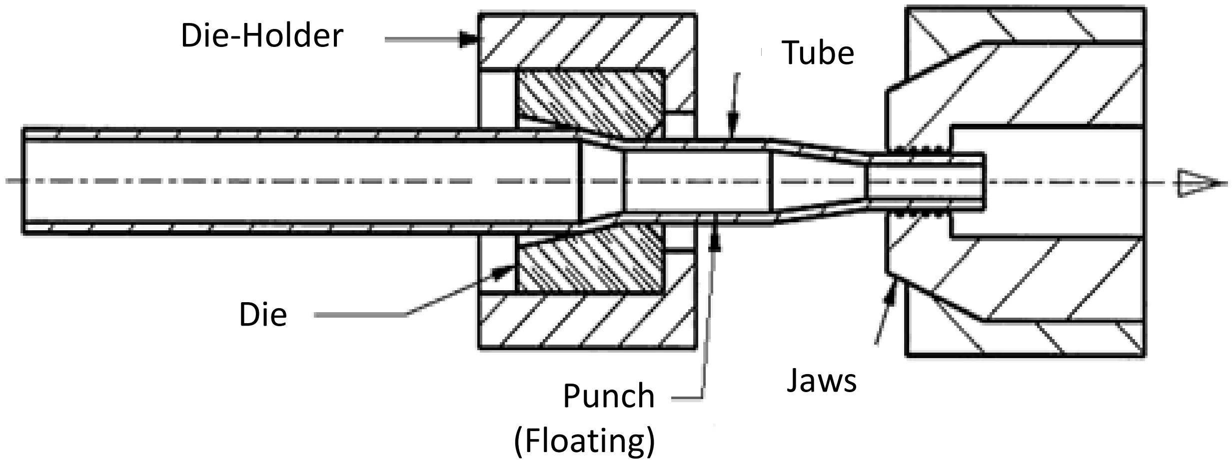
Diameter and thickness reduction process using a fixed die which allows:

- Accurate dimensions
- Good surface finish
- Good mechanical properties

Cold drawing has been used for several centuries, in its beginnings it was oriented to the production of copper, silver and gold wires, among others.

Tube drawing

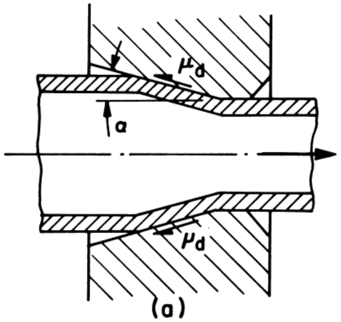
Process



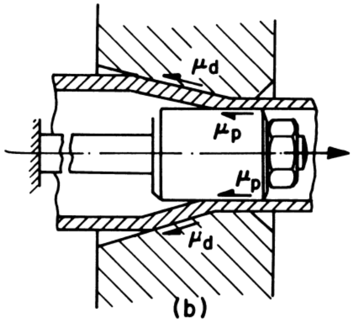
Tube drawing

Configuration

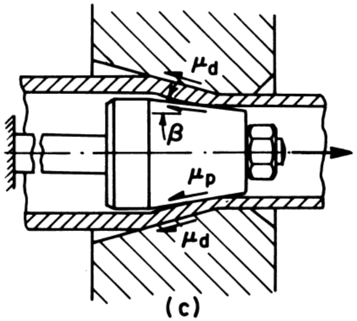
Tube sinking

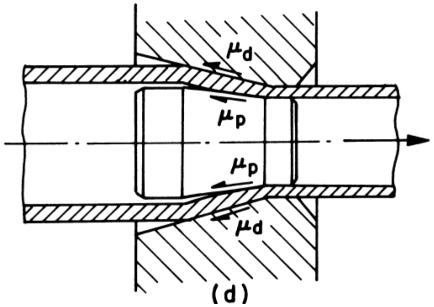


Drawing with fixed cylindrical plug

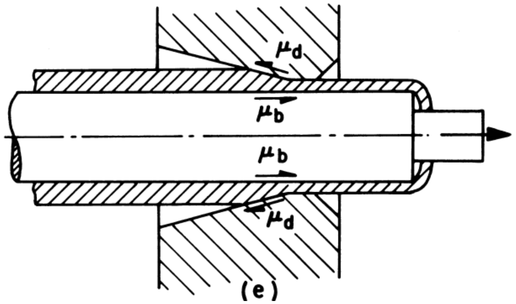


Drawing with fixed conical plug





Drawing with floating plug

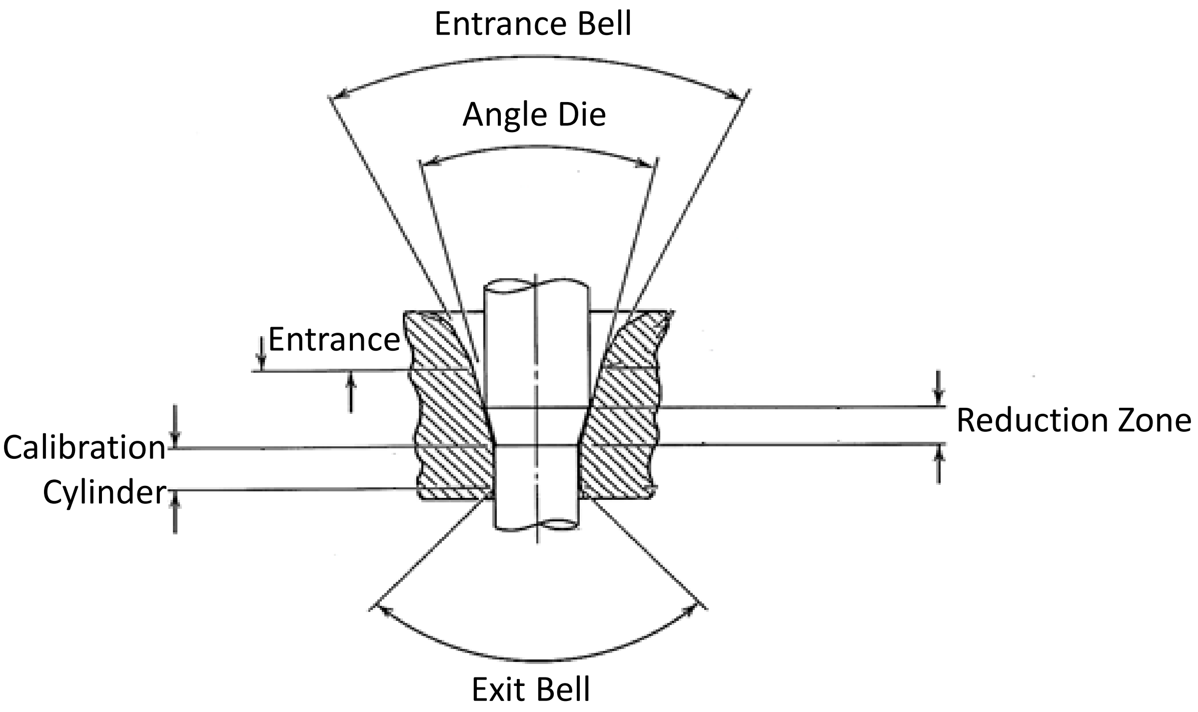


Drawing on a bar for mandrel

Tube drawing

Tooling

Die



Process simulation

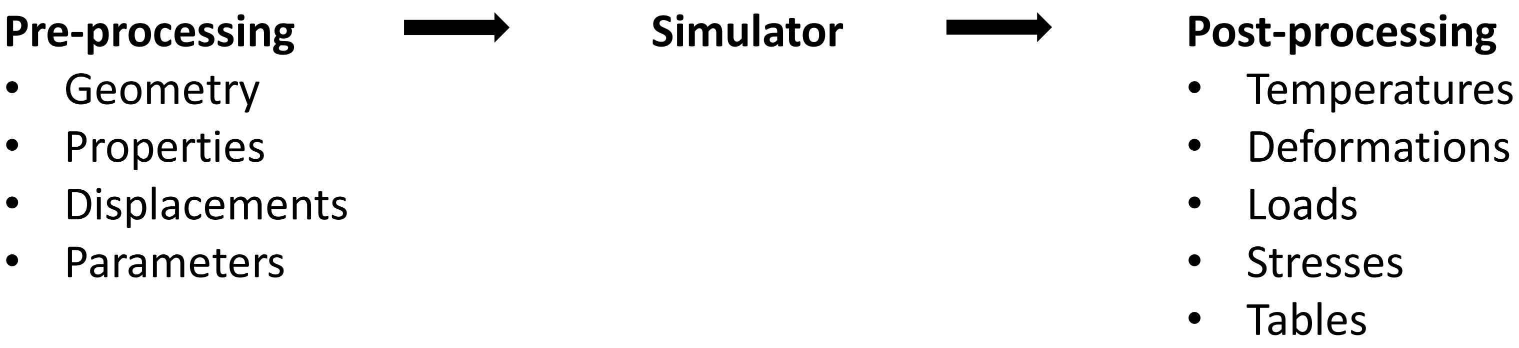
The simulation of metal forming processes is a tool that is taking great value when determining the operational and economic feasibility of a design or a process.

This allows evaluate:

- operational parameters
- tooling designs
- material evolution during the forming process

Process simulation

Finite element simulation



Pre-processing

- Geometry
- Properties
- Displacements
- Parameters

Simulator

Post-processing

- Temperatures
- Deformations
- Loads
- Stresses
- Tables

Simufact Forming®

Software capable of representing a wide variety of forming processes
It allows you to configure several factors such as:

- Behavior of the material during processing
- Friction between the tooling and the pieces to be formed
- Matrix kinematics
- Thermal conditions

It includes tools for

- Create and import part files
- Perform meshing
- A database of Materials, Simufact Material

Simufact Forming®

Models implemented in the simulations

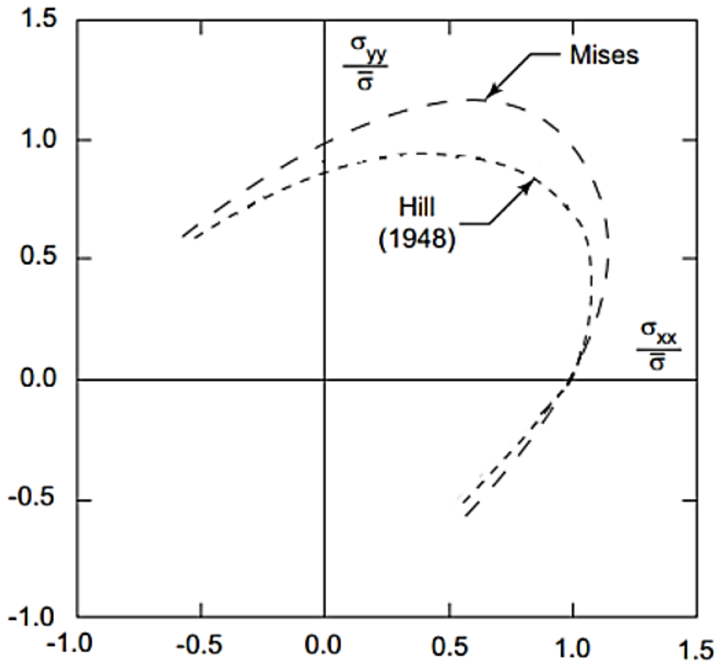
Yield Criterion - Hill 48 anisotropy model

Yield criteria are fundamental equations in the analysis of plastic deformation when the material is exposed to complex stress states.

The data required by the program are

- Tensile yield stresses
- r-coefficient

$$r = \varepsilon_{\text{width}} / \varepsilon_{\text{thickness}}$$



Simufact Forming®

Models implemented in the simulations

Latham-Cockroft Damage

A damage function allows evaluating the processing limits of a material

Damage is calculated as follows:

$$\int_0^{\varepsilon f} \frac{\sigma}{\bar{\sigma}} d\varepsilon \leq C$$

This damage model is independent of process and material.

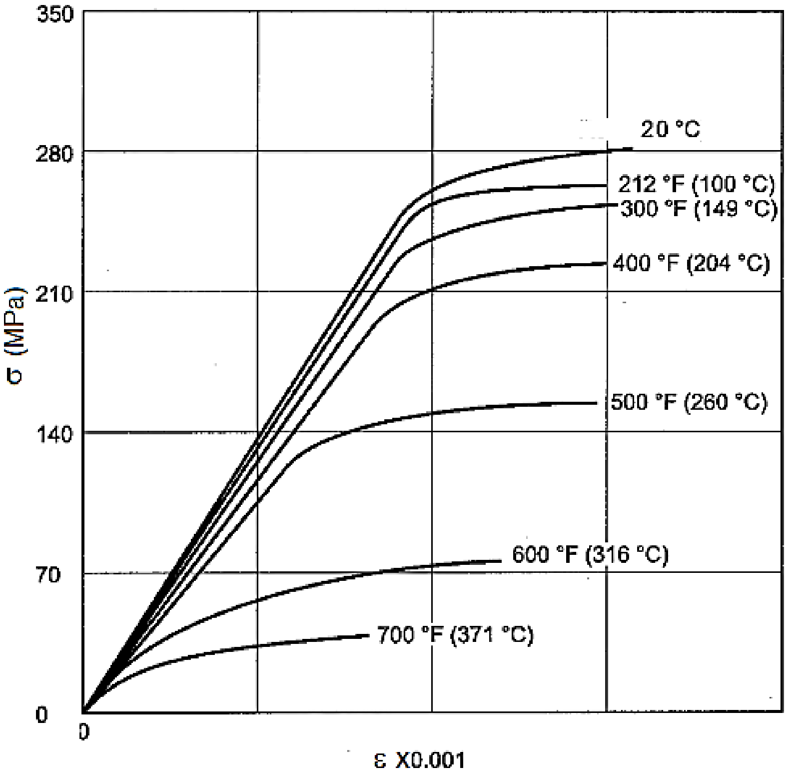
Good correlation with the processes analyzed in this work.

Simufact Forming®

Models implemented in the simulations

Flow curves

- It is the relationship between stress and true strain at which creep occurs.
- In a simulation it is a factor that represents the deformation of the material which depends on the temperature and
  the deformation mode



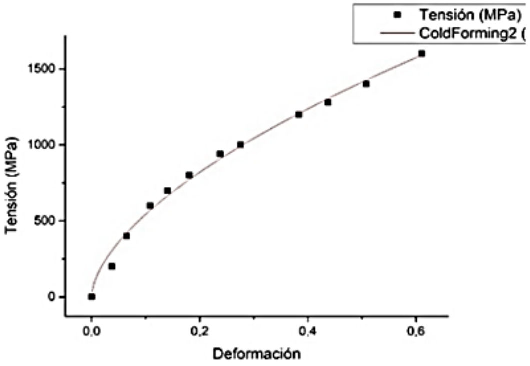
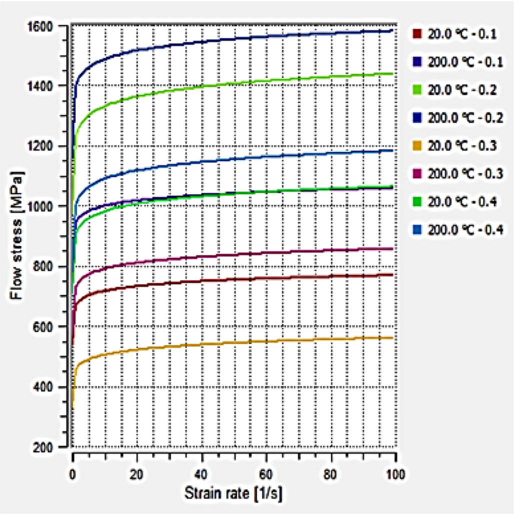
Cold pilgering simulation

Zircaloy 4

Zirconium alloys has a thermal conductivity 30% higher than that of stainless steel, a third of the coefficient of thermal expansion, better resistance to different types of corrosion and a low neutron absorption cross section, properties suitable for use in nuclear reactors.

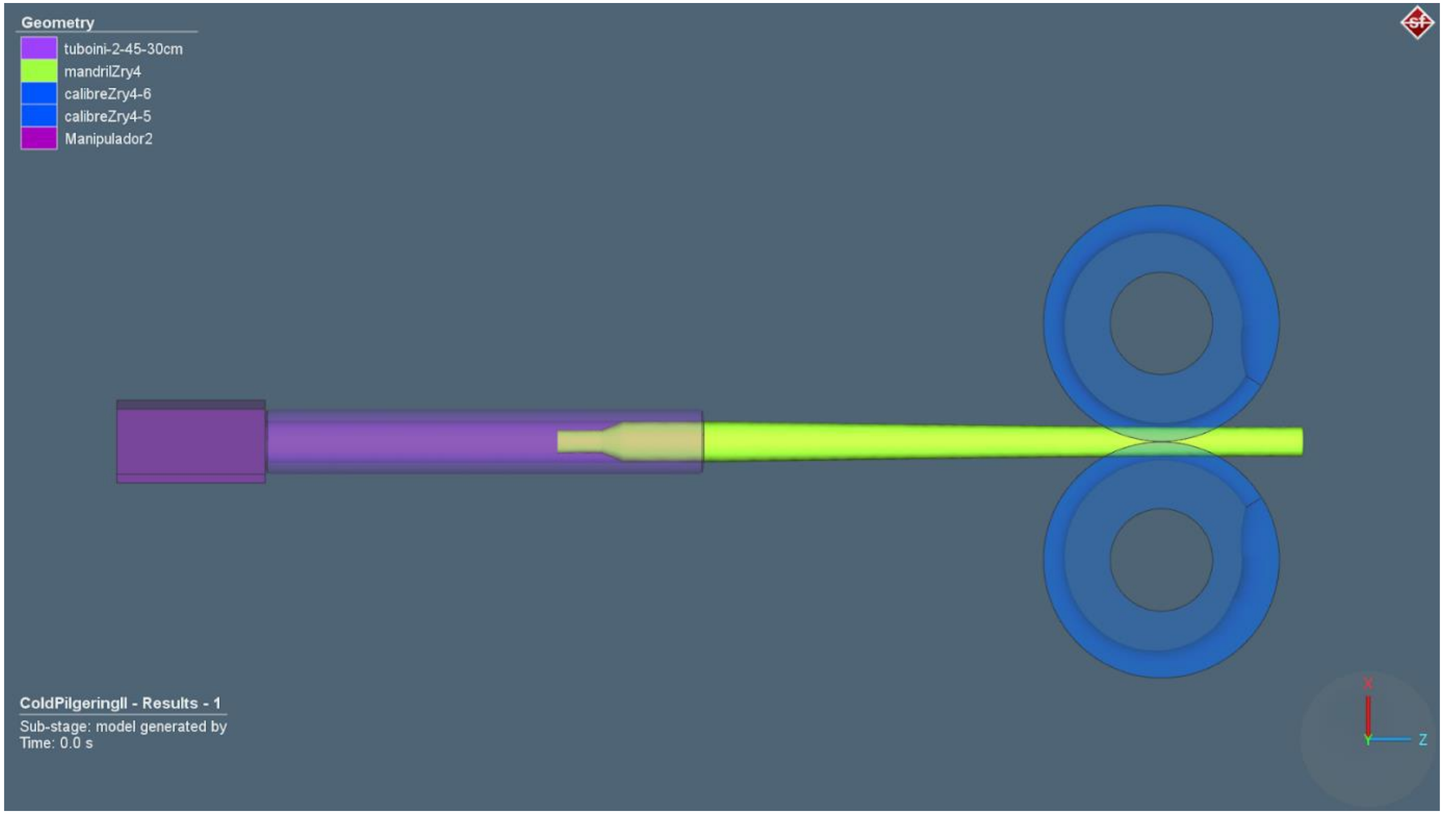
Cold pilgering simulation

Zircaloy 4

Material	**Zircaloy 4**			
Chemical Comp.	1.20-1.70 Sn - 0.18-0.24 Fe - 0.07-0.13 Cu - 0.12 O_{max}			
Mechanical Prop.	Yield stress		450 MPa	
	Young M.	99.3 GPa	Poisson M.	0.37
Anisotropy (*) [16]	$r_{0°} = 0.16$ $r_{45°} = 0.60$ $r_{90°} = 0.98$ $\sigma_{0°}$=357.5 MPa $\sigma_{45°}$= 460 MPa $\sigma_{90°}$= 591.7 MPa			
Flow Curve	 $\sigma_F = 2153MPa\ \varepsilon^{0.61}$		 	
	Zircaloy 4 – Test		**Zircaloy 4 – BDSM**	

Cold pilgering simulation

Configuration



Cold pilgering simulation

Configuration

Tube, Rolls and mandrel kinetics

Based on 60 strokes/min

		Displacement + Rotation Rollers		Tube + Mandrel Rotation
		0.35 sec		0.15 seg
Tube advance (mm)	Vel. Tube advance (mm / sec)	Vel. Rollers (mm / sec)	Vel. Rot. Rollers (rpm)	Vel. Rot. Tubo-Mandrel (rpm)
1.3	8.66	1114.28	131.78	56.62

Initial geometry	Zircaloy 4 TREX. Dext=44.45 mm, e= 7.62 mm, length= 300 mm
Lubrication	New ETNA lubricant m=0.459
Mesh	Hexahedral elements (Ringmesh, cylindrical symmetry) with 5.5 mm as maximun element. All simulations had more than 17000 elements.
Simulation time	130 seconds
Time step	0.0005 seconds
Output results	0.003 seconds
Calculation time	120-140 hours each simulation

Cold pilgering simulation

Results

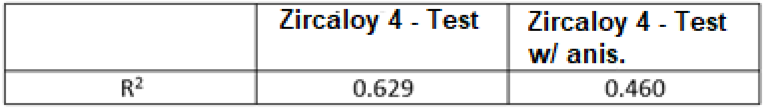
Load analysis – Material test

Load fluctuations

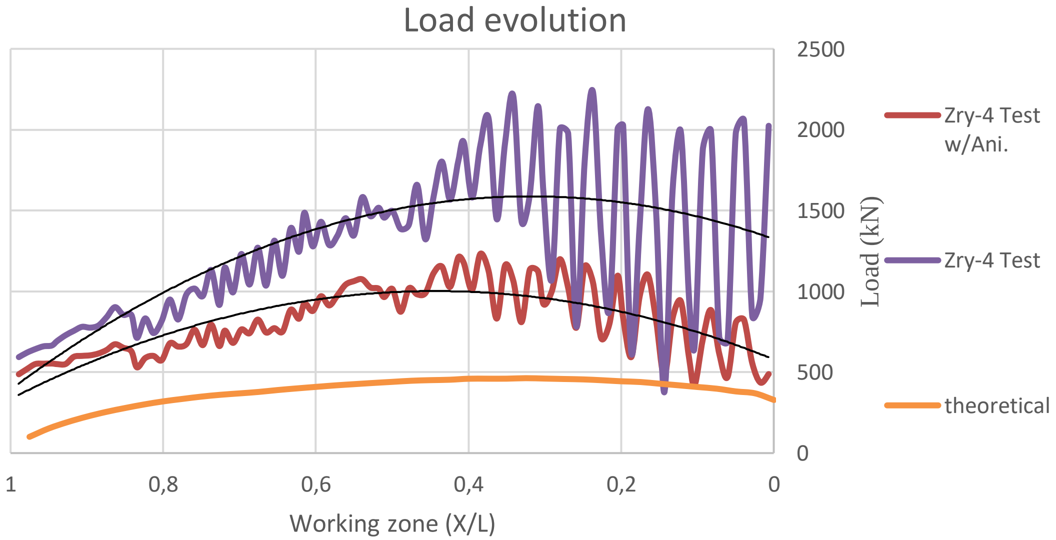
Major Loads

Peak loads at 0.3-0.4

Lower loads and fluctuation with anisotropy



	Zircaloy 4 - Test	Zircaloy 4 - Test w/ anis.
R^2	0.629	0.460



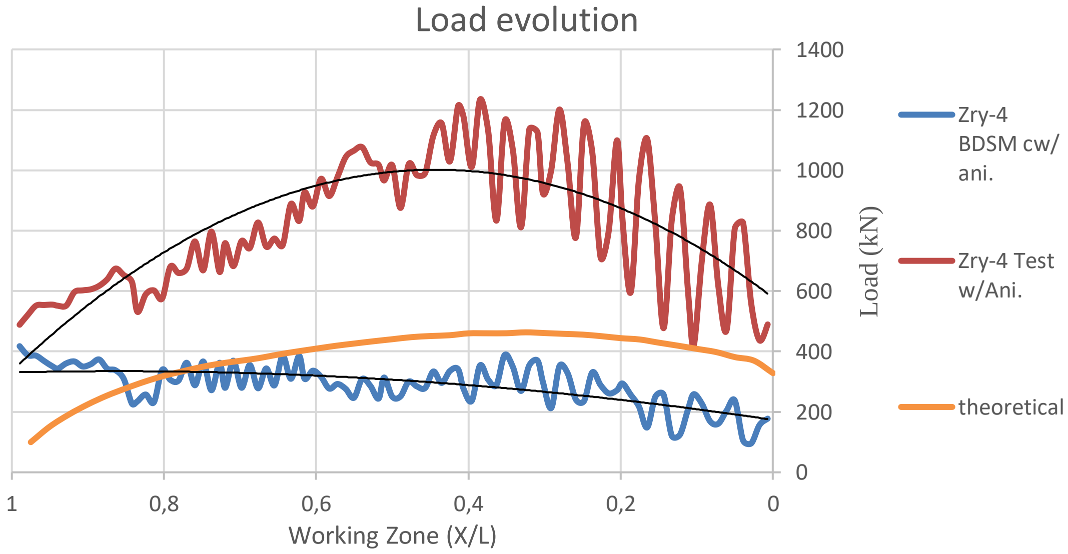
Cold pilgering simulation

Results

Load analisys – Material test and BDSM w/ anisotropy model

Great difference in loads between models.
BDSM material shows minor loads no maximum value.

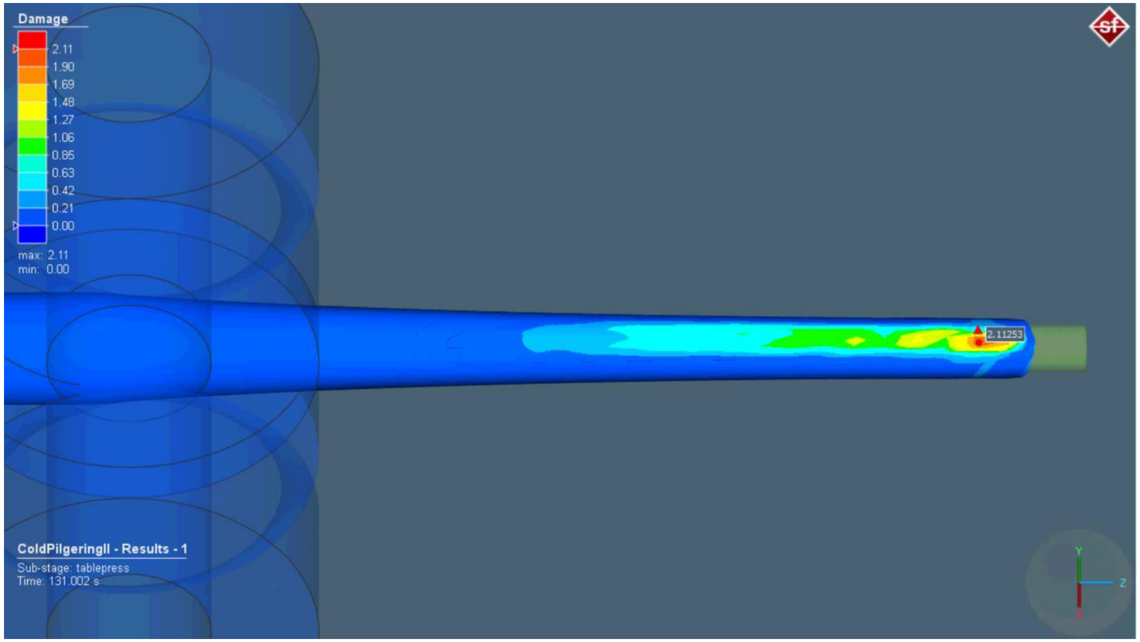
Hill 48 marked effect
but it depends on the CF.



Cold pilgering simulation

Results

Damage measurements in simulations



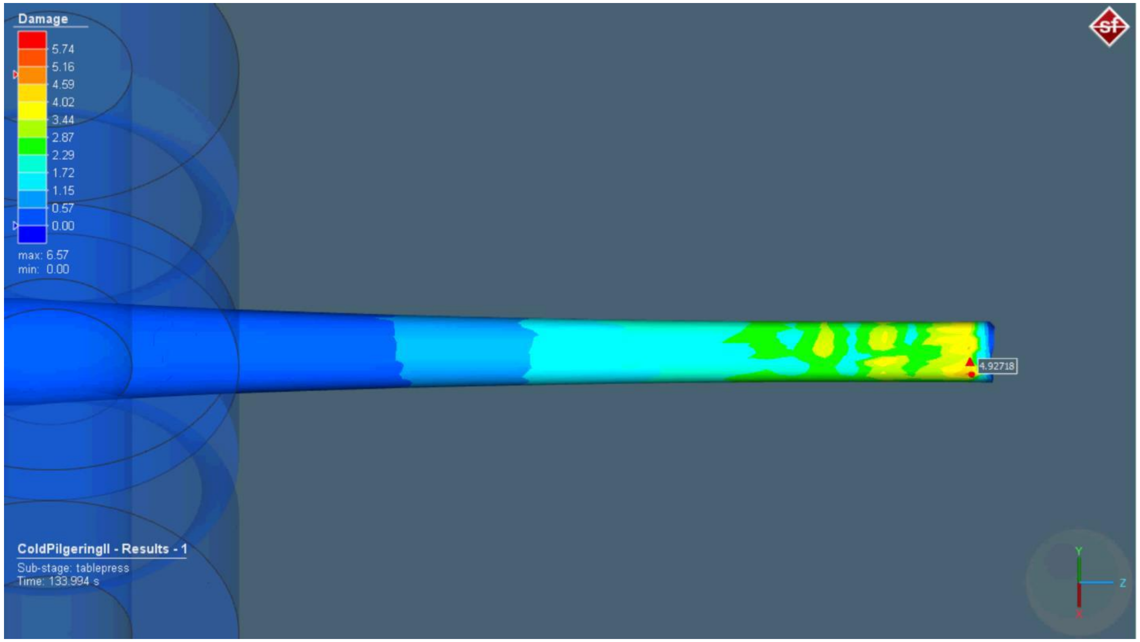
Zircaloy 4 – Test w/anisotropy

Two distributions were observed

Cold pilgering simulation

Results

Damage measurements in simulations

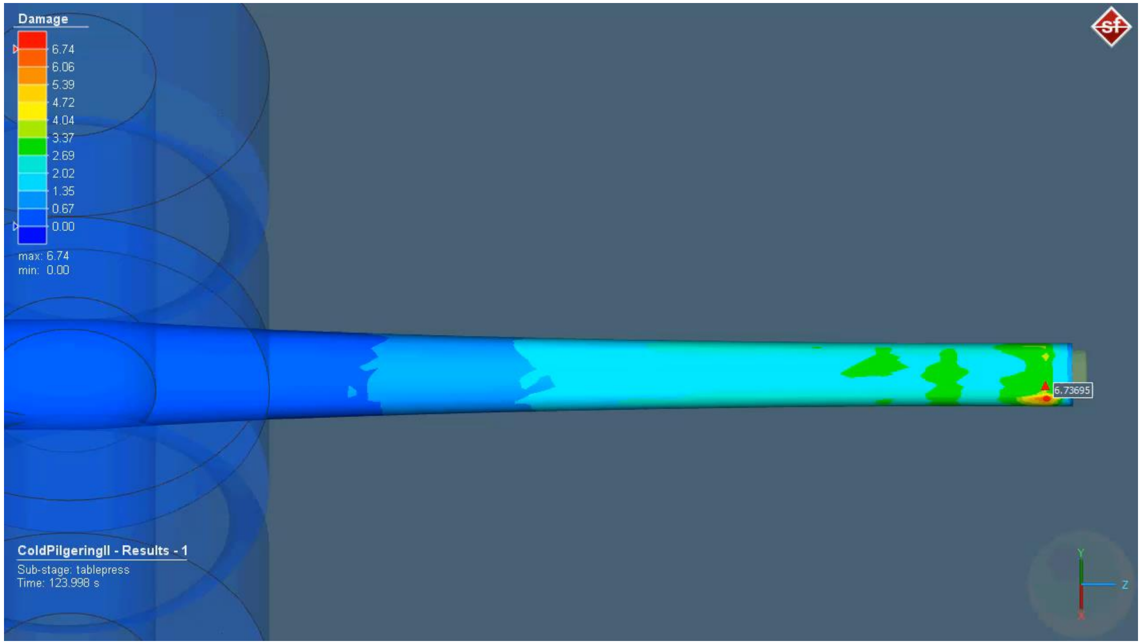


Zircaloy 4 – Test w/anisotropy

Cold pilgering simulation

Results

Damage measurements in simulations



Zircaloy 4 – Test w/anisotropy

Cold pilgering simulation

Results

Damage measurements in simulations

Simulation	Base damage	Peak Damage
Zircaloy 4 – BDSM w/ Ani.	0.40	2.39
Zircaloy 4 – Test w/ Ani.	0.30	2.11
Zircaloy 4 – Test	2.00	4.92

Variation with the use of the anisotropy model.

Cold pilgering simulation

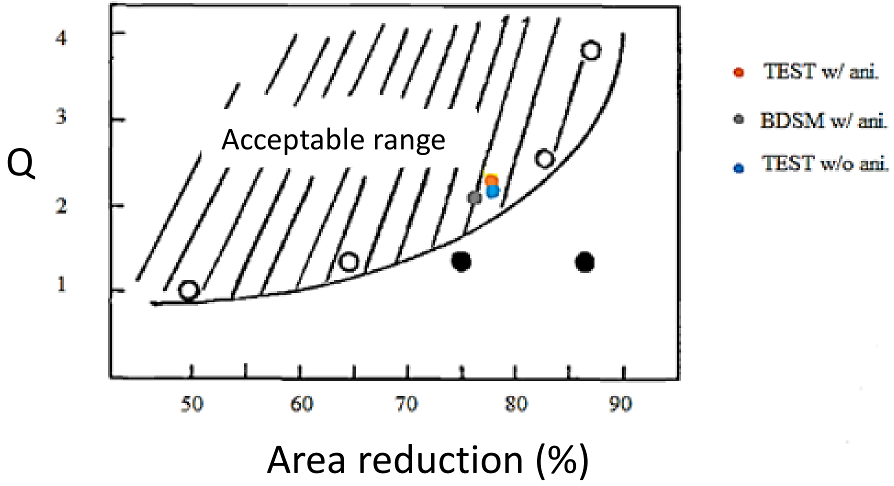
Results

Final dimensions

Simulation	Outside diameter (mm)	Thickness (mm)	Area reduction (%)	Q
Zircaloy 4 – BDSM w/ Ani.	25.36	2.62	76.3	2.219
Zircaloy 4 – Test w/ Ani.	25.42	2.53	76.9	2.318
Zircaloy 4 – Test	25.64	2.59	76.2	2.303
Theoretical	25.40	2.44	80.0	2.401

Within acceptance zone

No crack formation on the surface



Tube Drawing Simulation

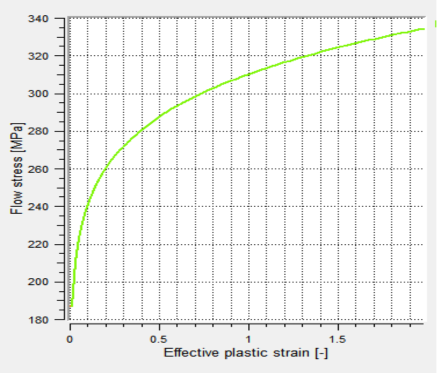
Tube drawing w/ a mandrel of 7075 T0 aluminum seamless tubes at different reductions and different die angles.

7075 aluminum

This alloy is characterized by having good properties such as high fatigue resistance, good machining, low density and high strength. It can also be heat treated to achieve the strength of steel.

Tube Drawing Simulation

7075 aluminum

Material	**Aluminio 7075 (*)**			
Chemical Comp.	5.65 Zn - 1.70 Cu - 0.23 Cr - 0.34 Fe - 0.40 Si 0.30 Mn – 2.50 Mg – Al			
Mechanical Prop.	Yield stress		180 MPa	
	Young M.	71 GPa	Poisson M.	0.33
Critical Damage Value Latham-Cockroft	0.28/0.32			
Flow curve	 $\sigma_F = 310MPa\ \varepsilon^{0.11}$			

*Annealed at 413 °C for 150 minutes and then cooling to 260 °C at a rate of 30 °C/min. The compression test was carried out at 12 mm/min.

Tube Drawing Simulation

Configuration

Matrix geometries	10°, 16° and 22° die angles, diameter and length of calibration zone (equal to the diameter of the matrix), the constant exit bell angle (60°), work zone and cylinder splice 0.1 mm.
Initial geometry	A tube with dimensions: Dext = 25.40 mm, thickness = 2.54 mm, Length = 160 mm
Lubrication	Friction coefficient μ = 0.05
Running speed	4 m/min
Mesh	Mesh with square elements (Quadmesh). 0.25mm maximum Edge In all simulations the number of elements was greater than 6000.
Simulation time	It depends on the simulation, but always less than 4 seconds
Time step	0.003 seconds
Output results	0.03 seconds
Calculation time	0.5-1 hours each simulation

Tube Drawing Simulation

Configuration

Reductions and dimensions proposed for each pass and simulation

	Outside diameter (mm)	**Thickness** (mm)
1st reduction pass (1/3)	25.00	2.45
2nd reduction pass (2/3)	24.50	2.38
3rd Pass Reduction (3/3)	24.00	2.31
10% reduction	24.50	2.38
15% reduction	24.00	2.31

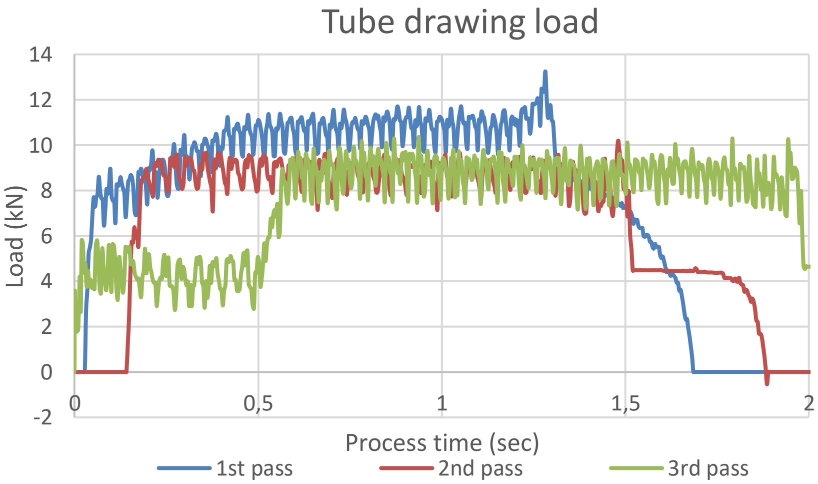
Tube Drawing Simulation

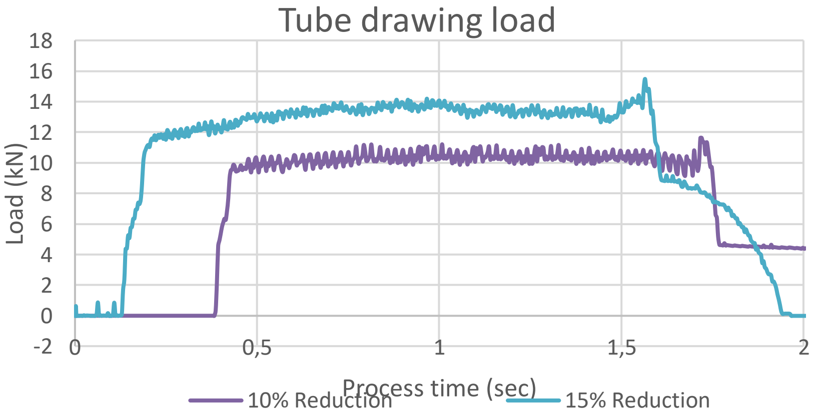
Results

Tube drawing load – 22° angle die

Similar load evolution

Correspondence with bibliography





Tube Drawing Simulation

Results

Tube drawing load

Simulation loads (kN)						
Simulation	**10°**		**16°**		**22°**	
	Average	**Deviation**	**Average**	**Deviation**	**Average**	**Deviation**
1st pass	12,25	0,27	8,16	0,72	10,30	1,01
2nd pass	9,33	0,17	7,98	0,37	8,86	0,53
3rd pass	8,33	0,28	8,30	0,60	8,84	0,70
10% Red.	26,96	0,65	11,26	0,73	10,02	1,22
15% Red.	28,12	---	24,67	0,67	13,15	0,60

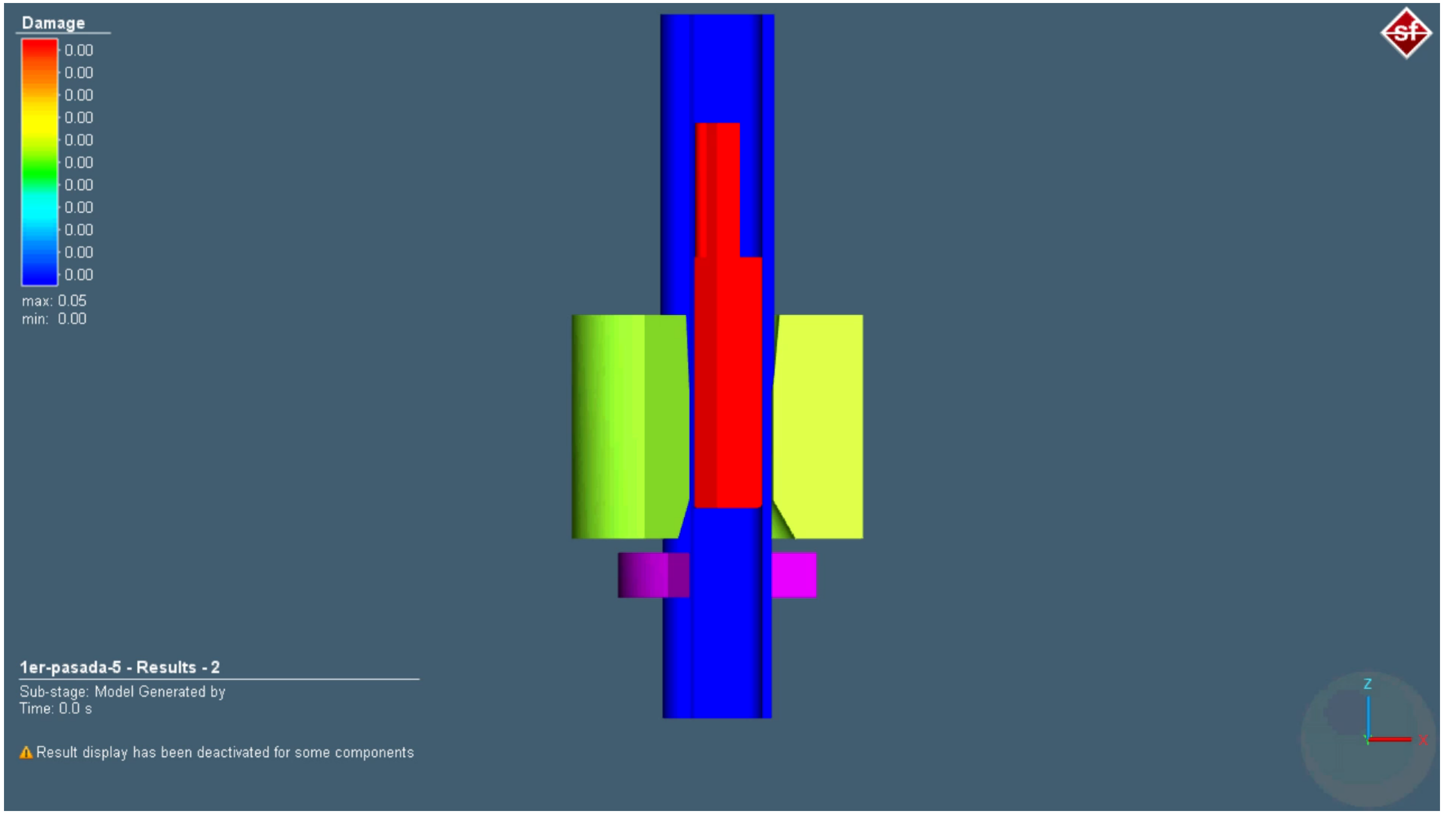
Higher Single Pass Loads

Load fluctuation attributed to abnormal draft carriage advance.

16° is the recommended die-angle for aluminum wire drawing.

Tube Drawing Simulation

Results



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Sub-stage: Model Generated by
Time: 0.0 s

⚠ Result display has been deactivated for some components

Tube Drawing Simulation

Results

Tube Drawing Simulation

Results

max: 2.61
min: 0.00

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Sub-stage: Model Generated by
Time: 0.0 s

⚠ Result display has been deactivated for some components

Tube Drawing Simulation

Results

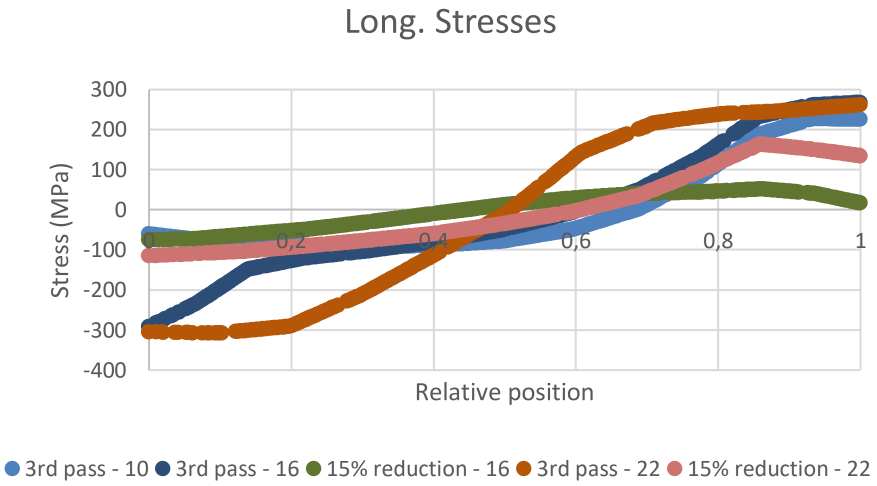
Residual Stresses

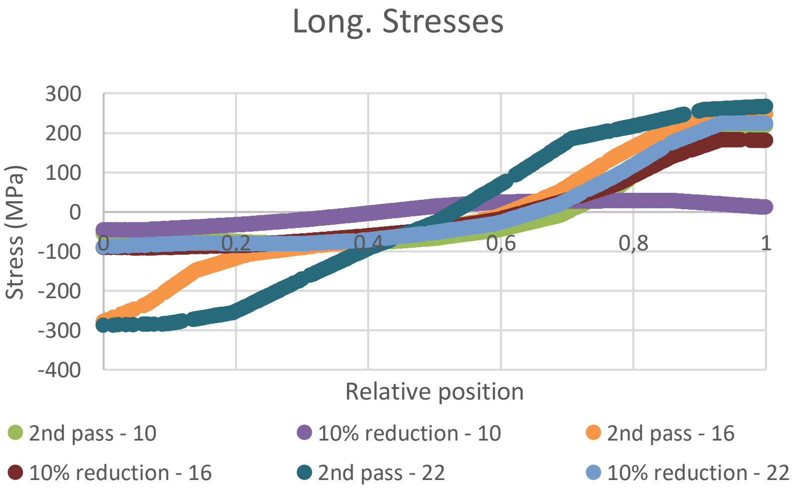
	Circumferential Stresses (MPa)						**Longitudinal stresses** (MPa)					
	10°		**16°**		**22°**		**10°**		**16°**		**22°**	
	Int.	Out.	Int.	Out.	Int.	Out.	Int.	Out.	Int.	Out.	Int.	Out.
2nd pass	-27,9	120,2	-111,8	130,5	-127,7	169,9	-83,1	218,1	-278,5	248,3	-288,2	266,2
3rd pass	-34,7	124,4	-112,9	141,7	-156,0	173,9	-92,1	226,0	-292,4	266,8	-308,6	260,3
10% Red.	-22,4	13,3	-34,7	104,4	-32,6	121,0	-46,4	27,7	-92,4	182,1	-89,3	223,5
15% Red.			-34,1	35,5	-41,9	94,3			-76,1	50,8	-115,7	162,4

Tube Drawing Simulation

Results

Residual Stresses





Minimum tensile stresses, reduction simulations of 10% with 10° die angle and 15% with 16° die angle.

Tube Drawing Simulation

Results

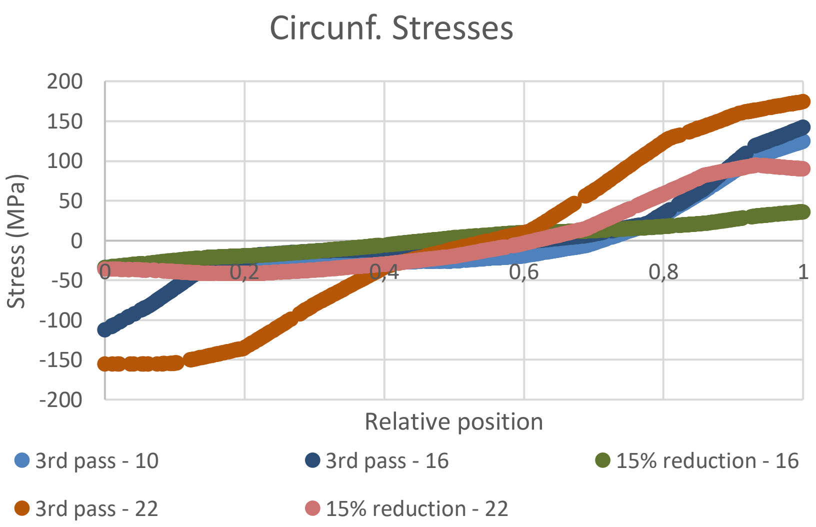
Residual Stresses

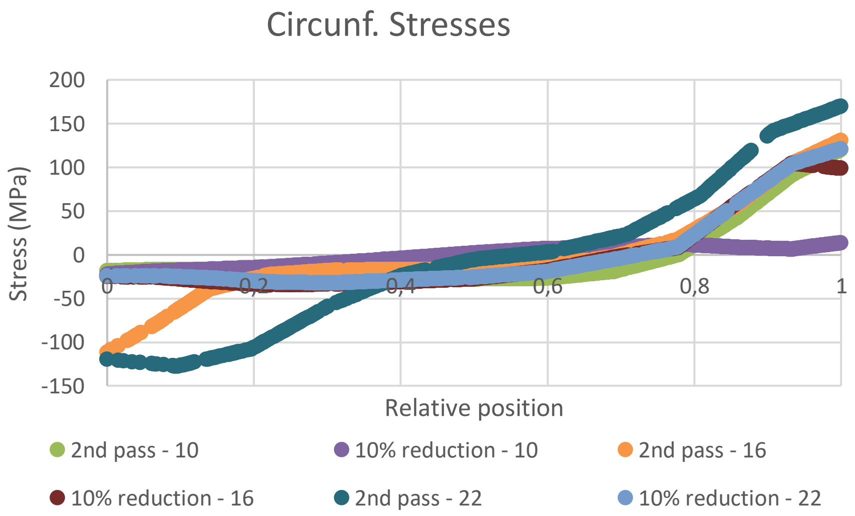
	Circumferential Stresses (MPa)						Longitudinal stresses. (MPa)					
	10°		16°		22°		10°		16°		22°	
	Int.	Out.	Int.	Out.	Int.	Out.	Int.	Out.	Int.	Out.	Int.	Out.
2nd pass	-27,9	120,2	-111,8	130,5	-127,7	169,9	-83,1	218,1	-278,5	248,3	-288,2	266,2
3rd pass	-34,7	124,4	-112,9	141,7	-156,0	173,9	-92,1	226,0	-292,4	266,8	-308,6	260,3
10% Red.	-22,4	13,3	-34,7	104,4	-32,6	121,0	-46,4	27,7	-92,4	182,1	-89,3	223,5
15% Red.			-34,1	35,5	-41,9	94,3			-76,1	50,8	-115,7	162,4

Tube Drawing Simulation

Results

Residual Stresses





Minimum tensile stresses reduction simulations of 10% with 10° die angle and 15% with 16° die angle.

Tube Drawing Simulation

Results

Damage

Minimum values

10% reduction with 10° die angle

15% reduction with 16° die angle

Any simulation exceeds the limit of 0.32

15% reduction with 11° die angle

Maximum damage			
Simulation	**10°**	**16°**	**22°**
2nd pass	0,10/0,07	0,14/0,12	0,15/0,11
3rd pass	0,15/0,11	0,21/0,15	0,25/0,22
10% Red.	0,05/0,09	0,09/0,13	0,13/0,12
15% Red.	----	0,10/0,11	0,14/0,18

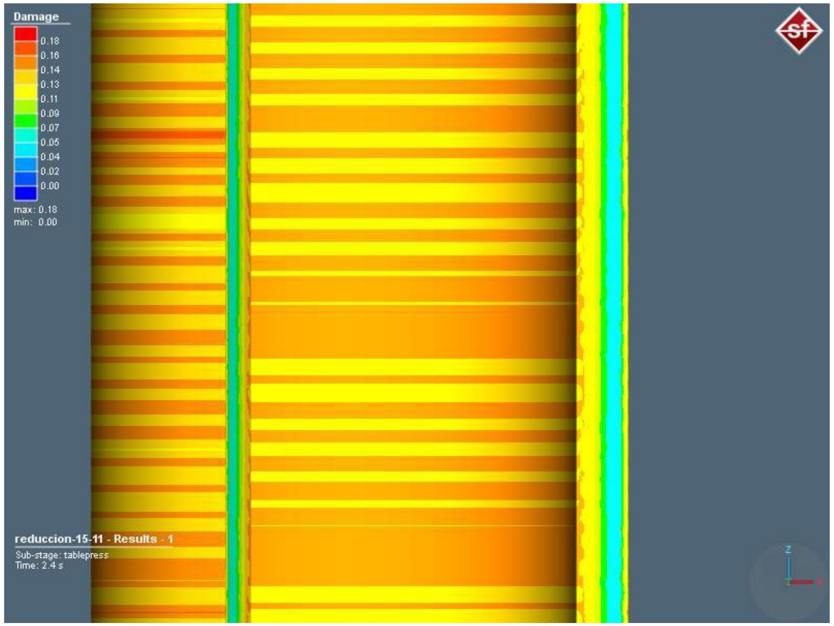
Tube Drawing Simulation

Results

<u>Damage</u>

Damage distribution with lines

Bulging - Wire Drawing Experience



Tube Drawing Simulation

Results

Final dimensions

	10°		16°		22°	
Simulation	**Outside diameter** (mm)	**Thickness** (mm)	**Outside diameter** (mm)	**Thickness** (mm)	**Outside diameter** (mm)	**Thickness** (mm)
2nd pass	24,496	2,380	24,496	2,380	24,464	2,358
10% Red.	24,506	2,383	24,496	2,380	24,478	2,371
Teórico	24,500	2,380	-	-	-	-
3rd pass	23,992	2,307	23,980	2,301	23,940	2,276
15% Red.	---	---	24.000	2,310	23,994	2,308
Theoretical	24,000	2,310	-	-	-	-

Good dimensions with 10° and 16° die-angle.
With α = 22°, less precision is obtained.
And a greater variation in areas of greater damage.

Conclusions

- The software turned out to be very versatile to be able to configure simulations of lamination by cold pilgering and tube drawing, also the compatibility it has with various models allows a more precise analysis of the state of the material once the process has been simulated.
- The results of the simulations showed a strong dependence with the flow curve used, as well as the models added in the analysis.

Conclusions

- Verification with the real process is important, this allows feedback in the simulation and obtaining results closer to the process and the state of the part and its properties.
- The simulations of lamination by cold pilgering show that a good analysis of the final dimensions and the presence of defects can be made.
- The analysis of drawing tubes with different configurations allowed to make an analysis of all the cases and to be able to select among those with the best dimensions obtained, less damage and residual stresses in the final piece.

Questions…

Thank you very much for your attention !

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