Hot Hydroforming of Sheets and Tubes : An Overview

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Disclaimer

- The entire presentation is based on published literature. The source of information has been indicated at the bottom of each slide.

Why Hot Hydroforming ?

- High strength alloys – High YS at room temperature
  - Greater frictional force (due to greater forming force)
  - Nonuniform strain distribution
  - Need to deform under hot conditions
  - Usual working media like oil & water good until 300 deg C
- Three questions :
  - Means of heating the workpiece to a high working temperature
  - Working media that will work under high temperatures
  - Pressurising working media at high working temperatures

Working Media & Materials

Working Media

- Granular medium
- Hot Gas

Methods of heating

- Resistance heating
- Furnace heating

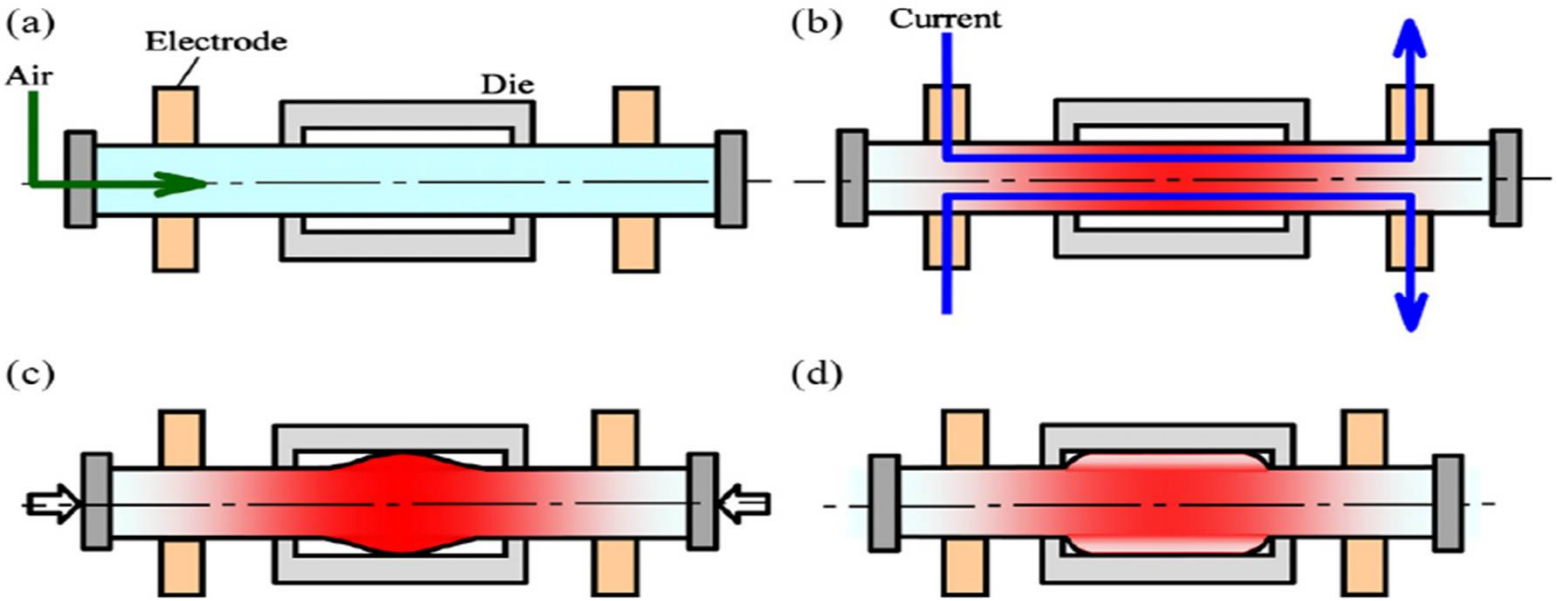
Materials

- Titanium alloys
- Hot forming steels for autobody components

Issues in hot hydroforming

- Heating of workpiece by heaters embedded in the dies
- Die heating too slow due to large energy requirement
- Hot gas hydroforming : Temperature distribution complex
- Process (formability) is sensitive to temperature
- In service properties are sensitive to temperature
- Uniform temperature distribution for a circular tube
- Larger circumferential temperature variation for a rectangular tube
- Microstructure evolves during forming. Processing maps are important to establish manufacturing parameters

rocessing steps in hot hydroforming

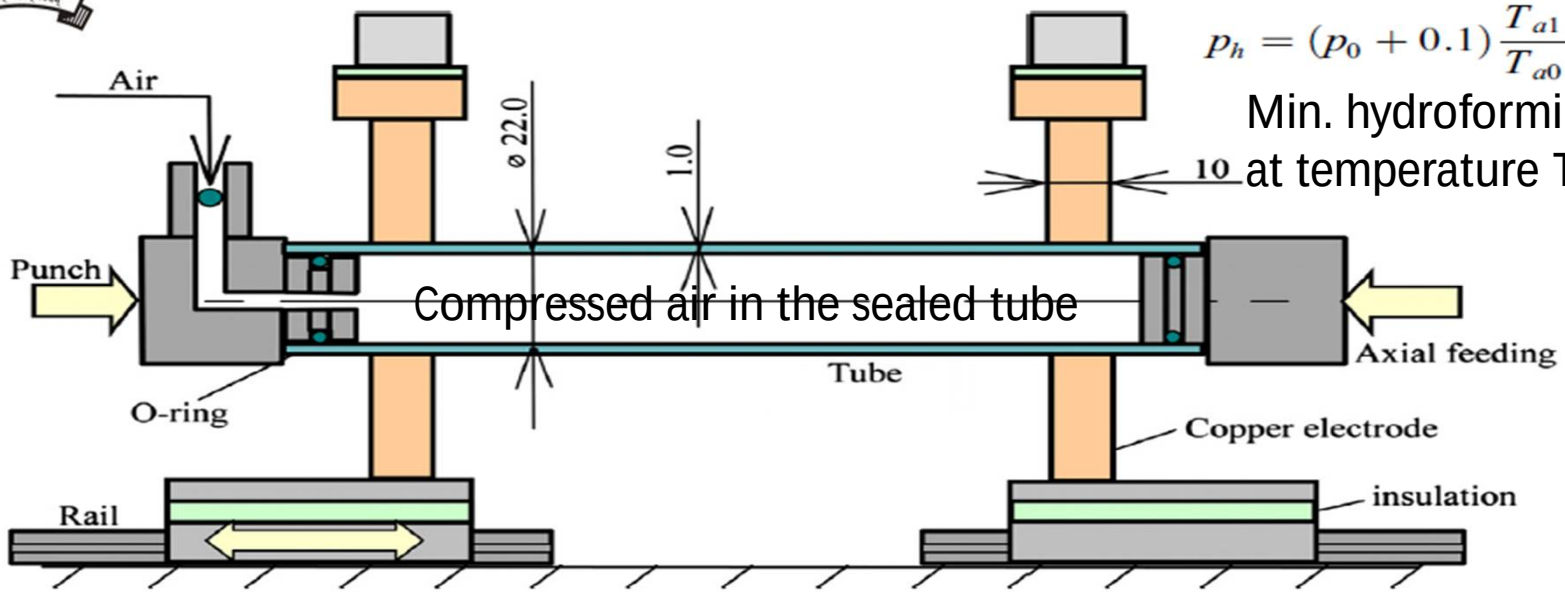


Source : T. Maeno, K-I Mori, K. Fujimoto, Manufacturing Rev. 1(2014)5

A possible manufacturing setup

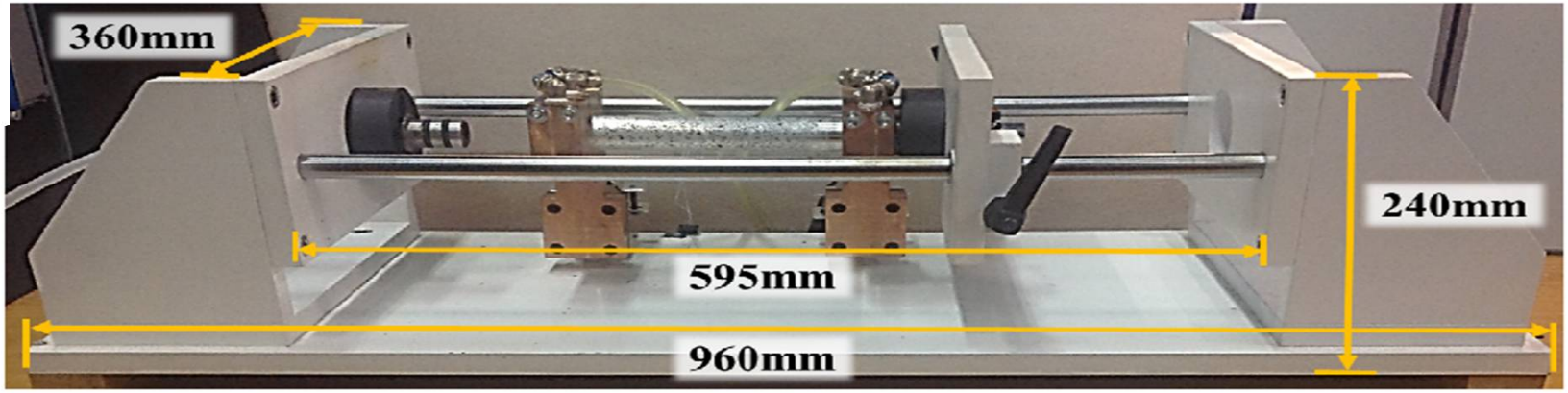
$$p_h = (p_0 + 0.1)\frac{T_{a1} + 273}{T_{a0} + 273} - 0.1$$

Min. hydroforming pressure at temperature T_{a1}



Initial internal pressure p_0 (MPa)	0.2–0.8
Current density J (A/mm^2)	38–91
Velocity of axial feeding v (mm/s)	0–40
Amount stroke of axial feeding s (mm)	0–50.6

Source : T. Maeno, K-I Mori, K. Fujimoto, Manufacturing Rev. 1(2014)5



Power : 60 kW; 10V & 6000A
Electrode (Cu) width : 35mm
Contact area = 32900 mm^2

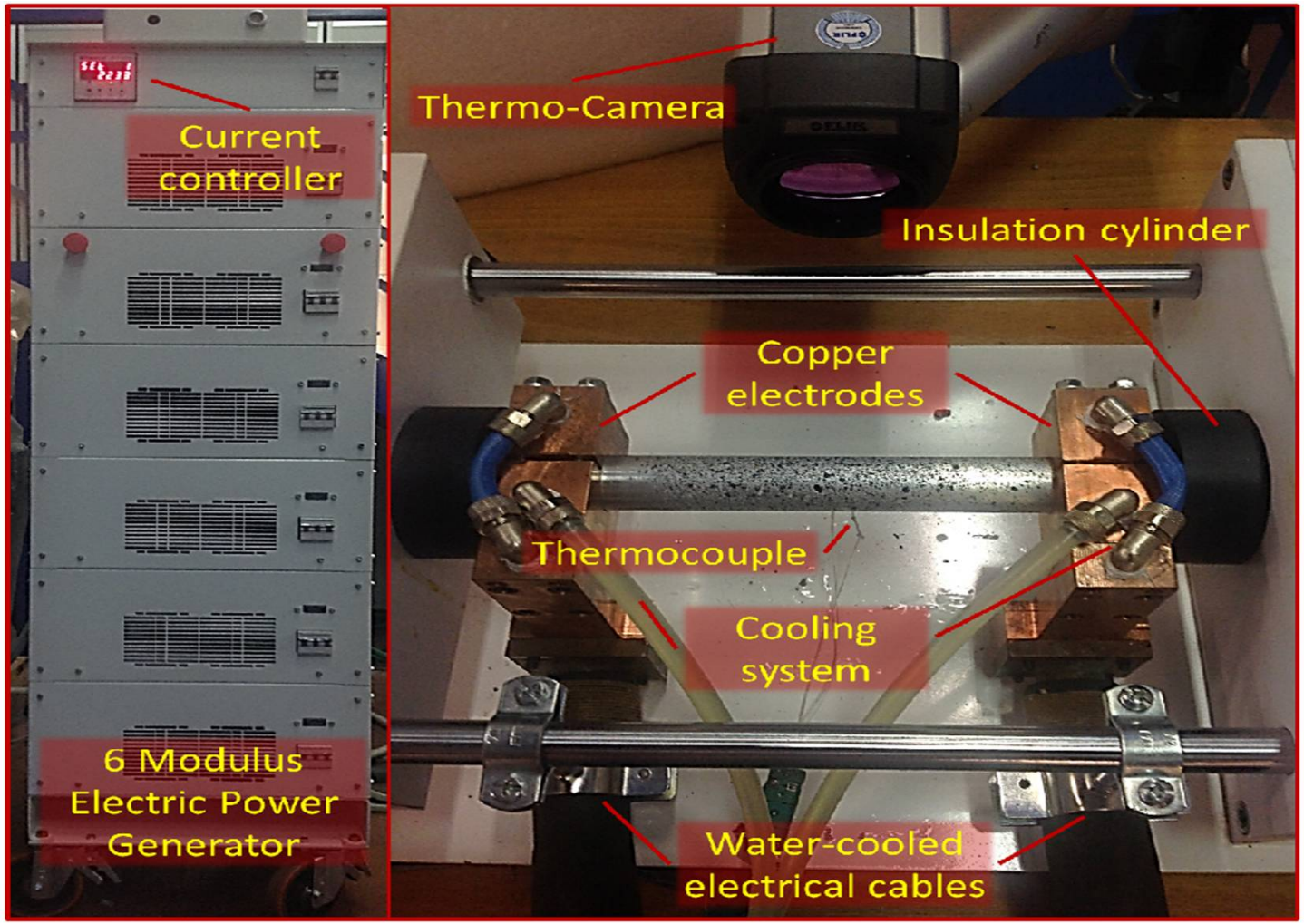
Electrical insulation : PEEK cylindrical elements (between tube and machine frame)

To prevent overheating : water cooled electrodes by demineralised water at 18 deg C

Alloy AA6060 Chemical composition

Al	Mg	Si	Fe	Mn	Zn	Cr	V	Ti
98.9	0.42	0.41	0.19	0.016	0.016	0.012	0.013	0.011

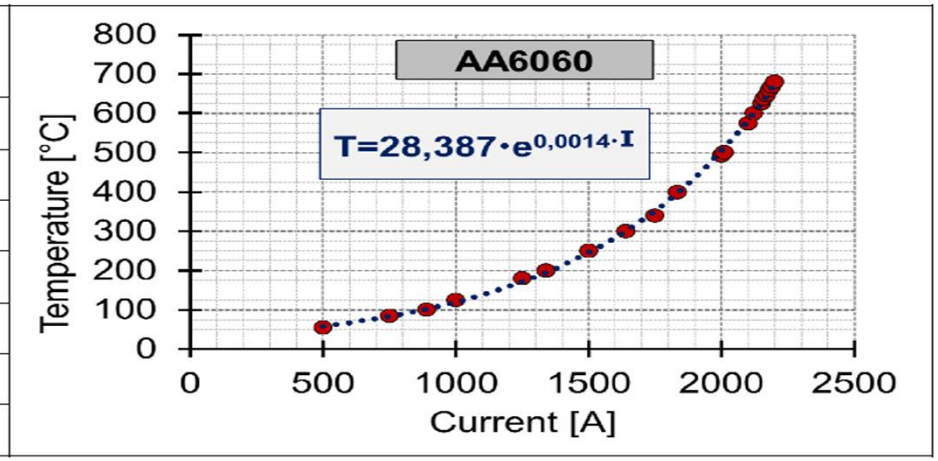
Source : F. Michieletto, A. Ghiotti, S. Bruschi, Key Engg. Materials, 611-612(2014)62-69

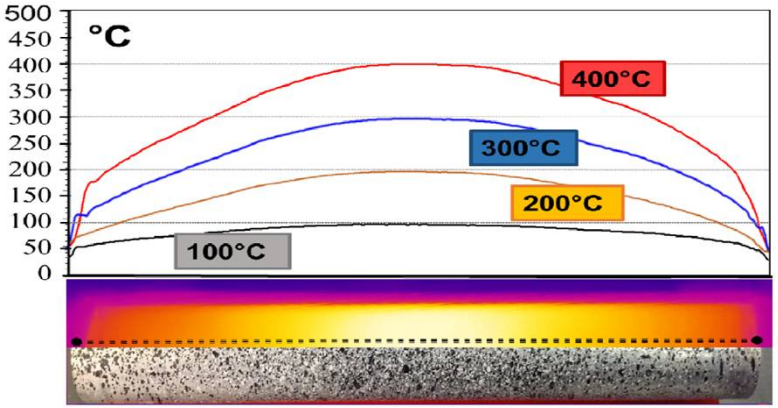


Source : F. Michieletto, A. Ghiotti, S. Bruschi, Key Engg. Materials, 611-612(2014)62-69

Electrical and Thermal parameters

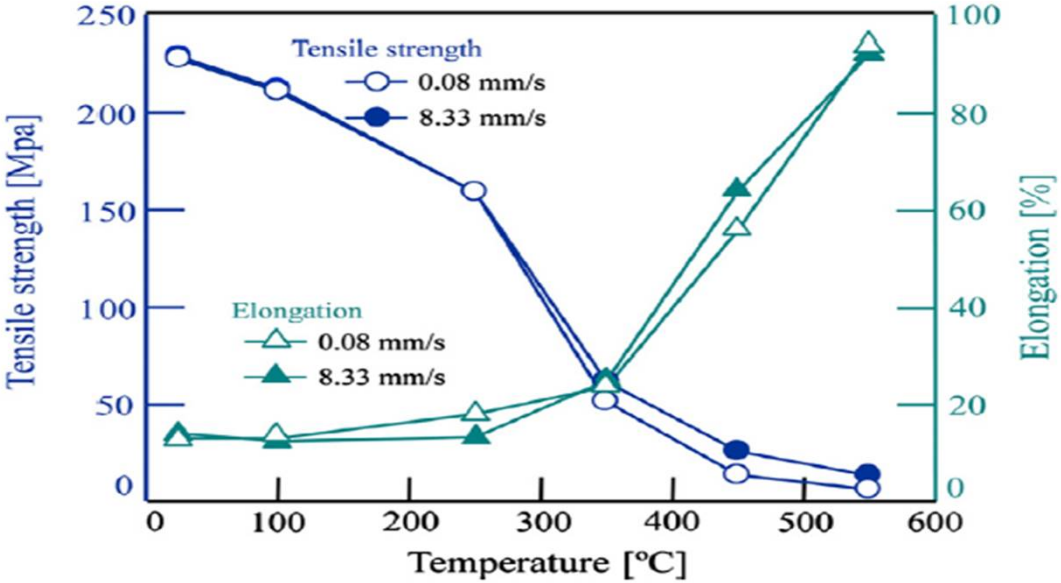
Temperature [°C]	Current Intensity [A]
100	890
200	1340
300	1640
400	1835
500	2010
600	2123
680	2200





Source : F. Michieletto, A. Ghiotti, S. Bruschi, Key Engg. Materials, 611-612(2014)62-69

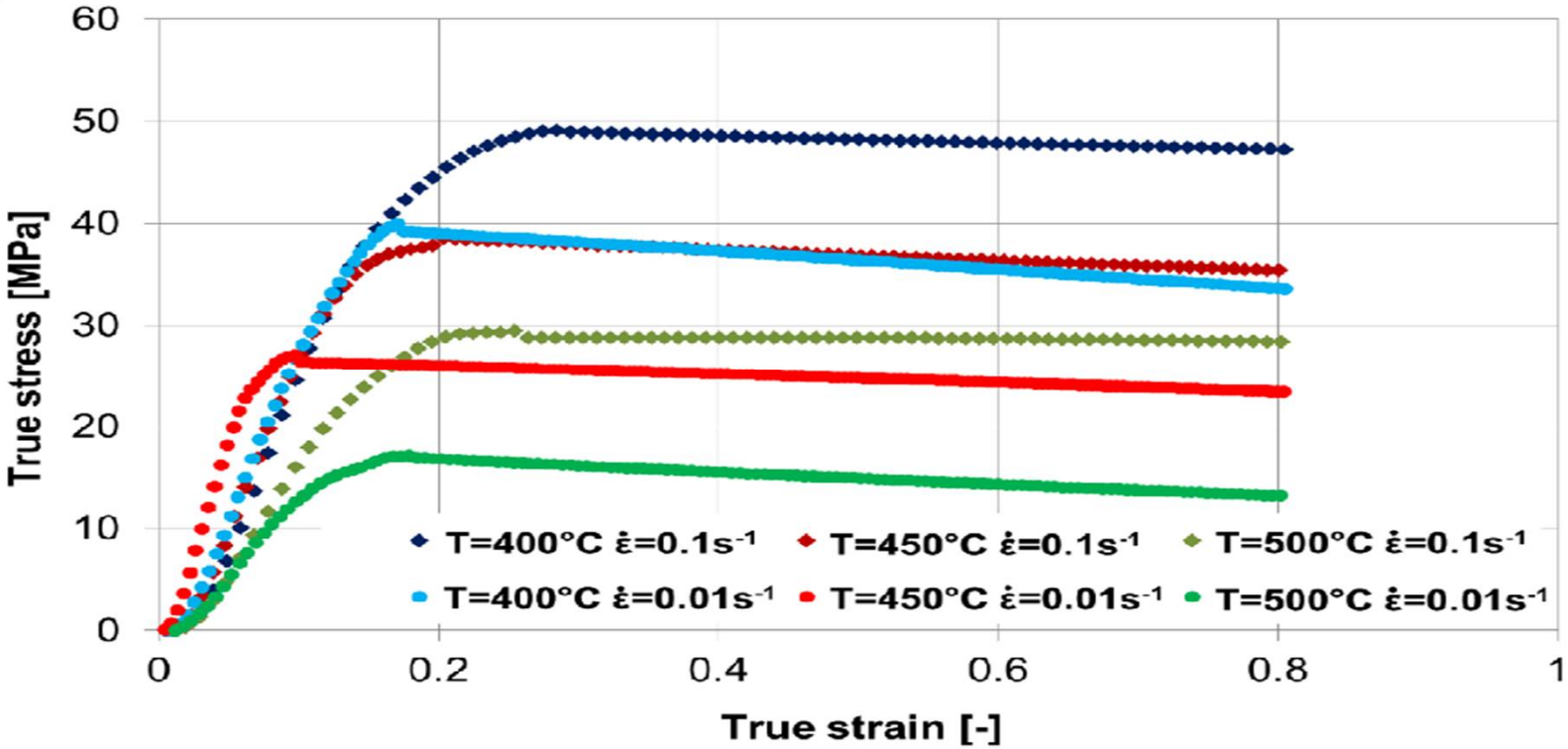
High temperature behaviour of Al 6063 alloy



The Al alloy has practically ZERO strain rate sensitivity

Source : T. Maeno, K-I Mori, K. Fujimoto, Manufacturing Rev. 1(2014)5

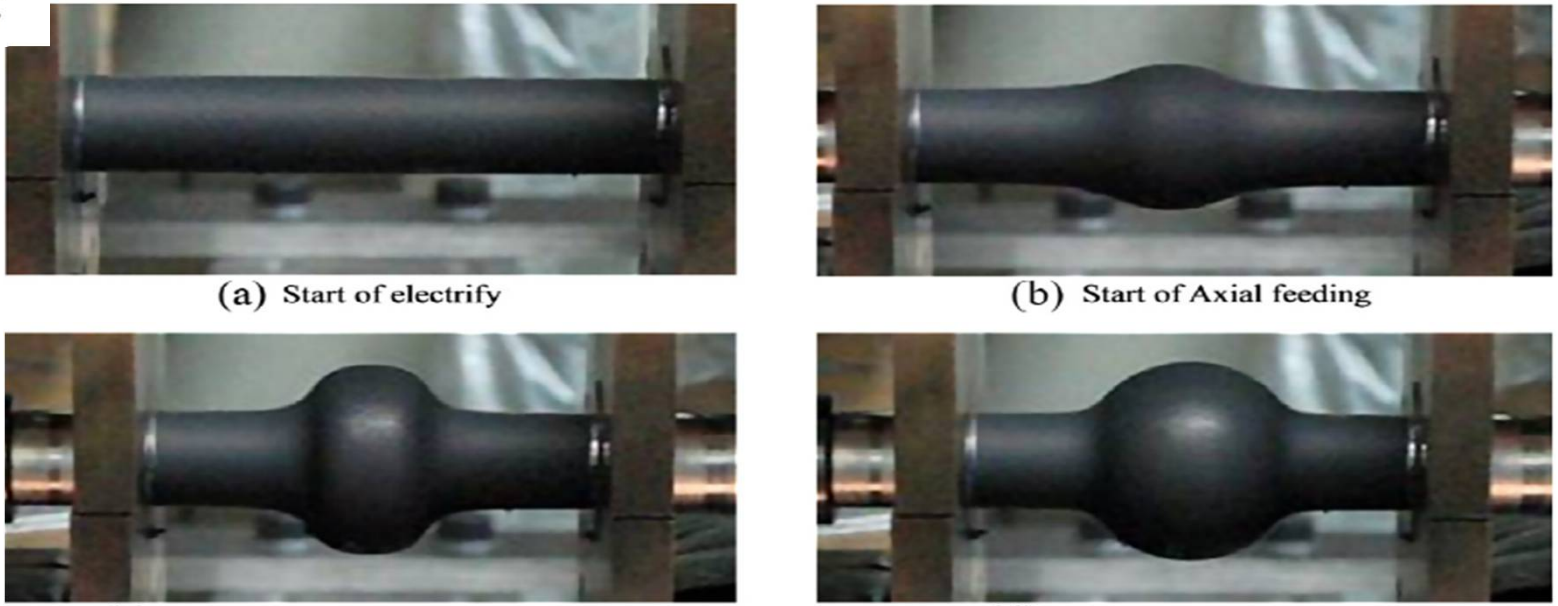
Mechanical Behaviour of AA 6060 alloy



Shows small strain rate sensitivity

Source : F. Michieletto, A. Ghiotti, S. Bruschi, Key Engg. Materials, 611-612(2014)62-69

Free Bulging



(a) Start of electrify

(b) Start of Axial feeding

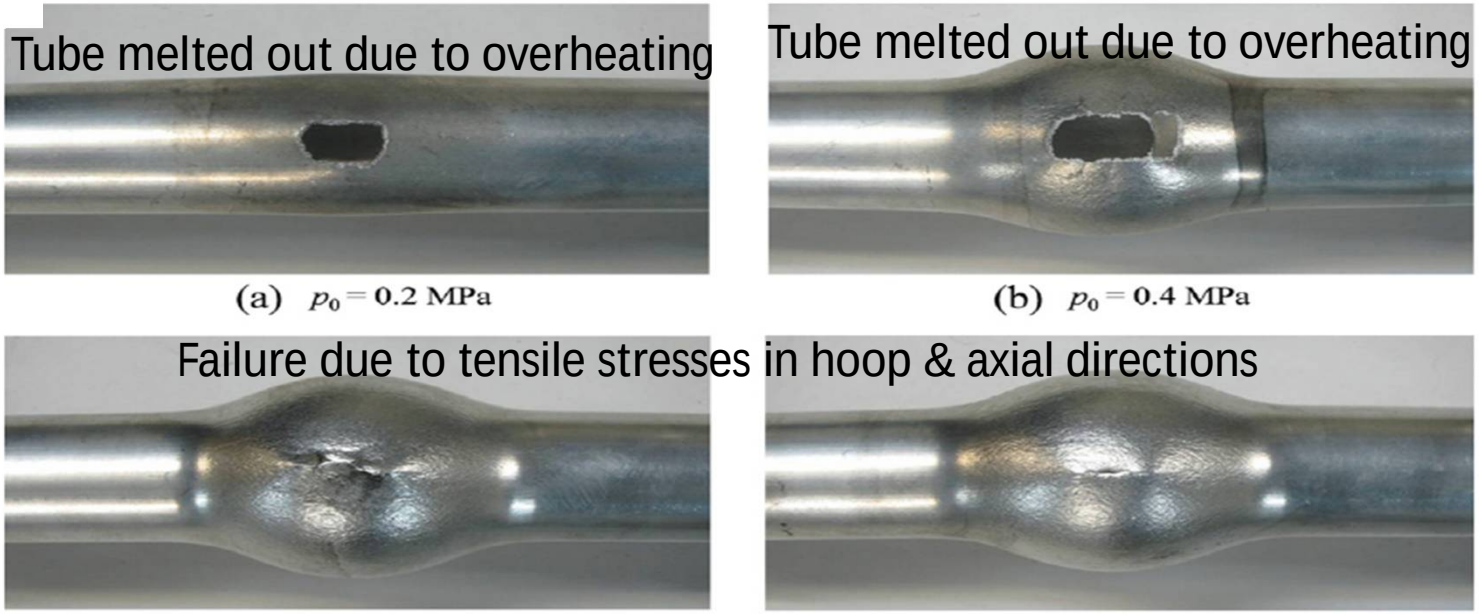
(c) End of electrify and axial feeding

(d) Bulging during cooling

$p_0 = 0.8$ MPa, $J = 76$ A/mm^2 and $v = 20$ mm/s.

Source : T. Maeno, K-I Mori, K. Fujimoto, Manufacturing Rev. 1(2014)5

What may go wrong



(a) $p_0 = 0.2$ MPa (b) $p_0 = 0.4$ MPa

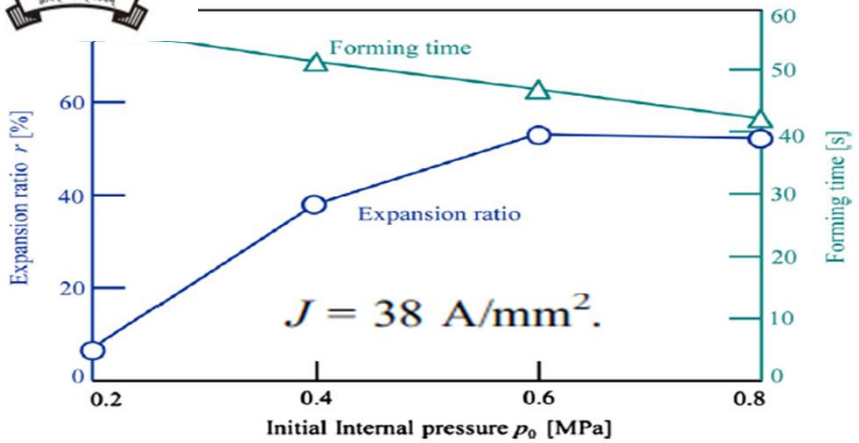
(c) $p_0 = 0.6$ MPa (d) $p_0 = 0.8$ MPa

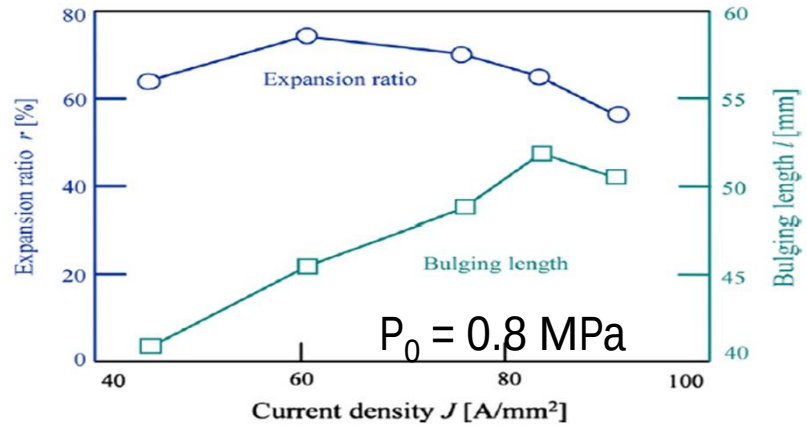
$J = 38\ \mathrm{A/mm^2}$.

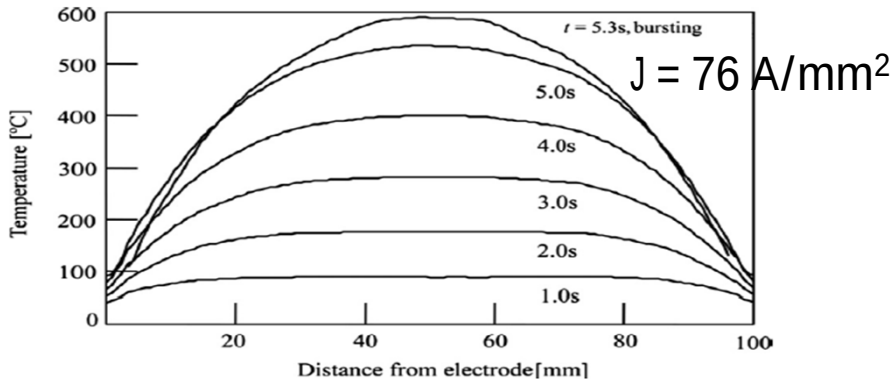
NO axial feeding

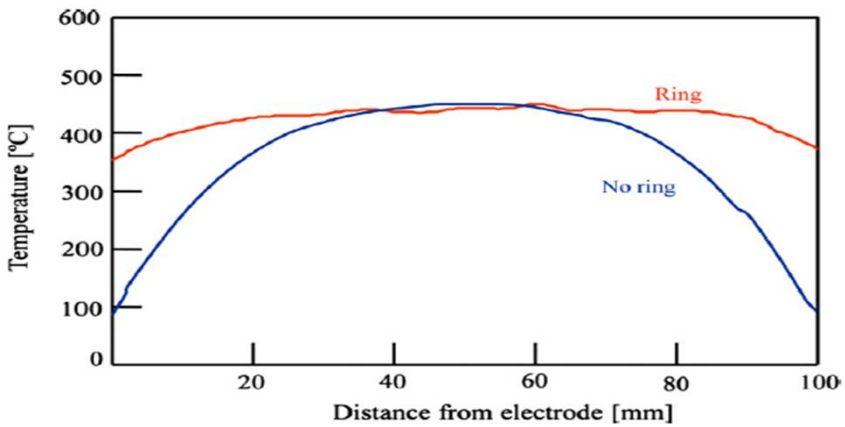
Source : T. Maeno, K-I Mori, K. Fujimoto, Manufacturing Rev. 1(2014)5

Expansion ratio



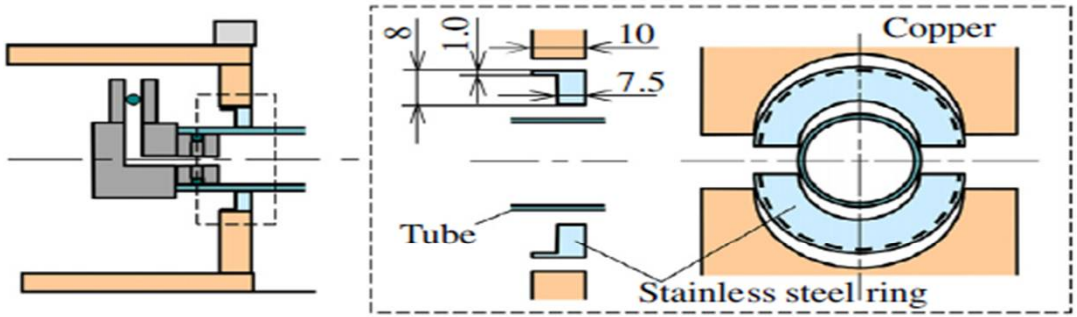




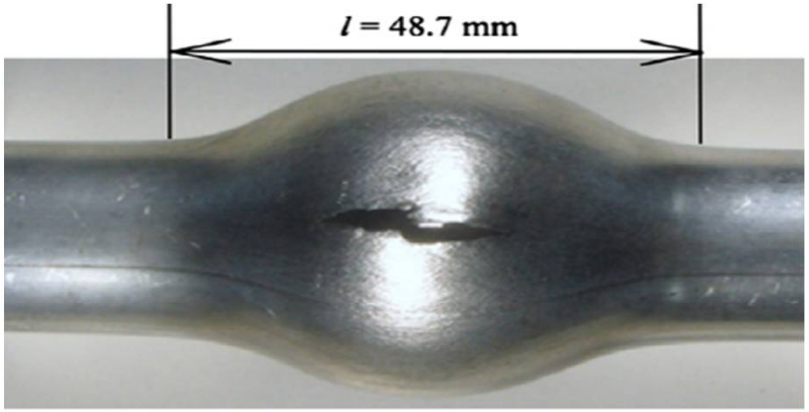


Source : T. Maeno, K-I Mori, K. Fujimoto, Manufacturing Rev. 1(2014)5

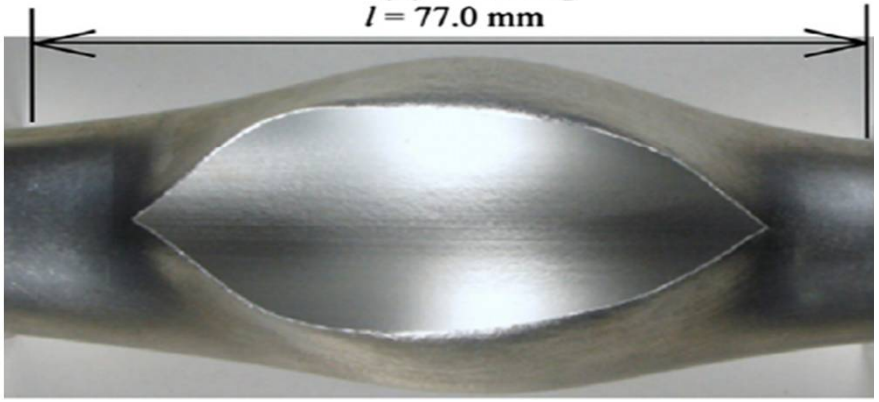
More Uniform temperature distribution



	Stainless steel	Copper
Thermal conductivity [W/(m K)]	15	393
Electrical resistance (Ω m)	7.20×10^{-7}	1.68×10^{-9}



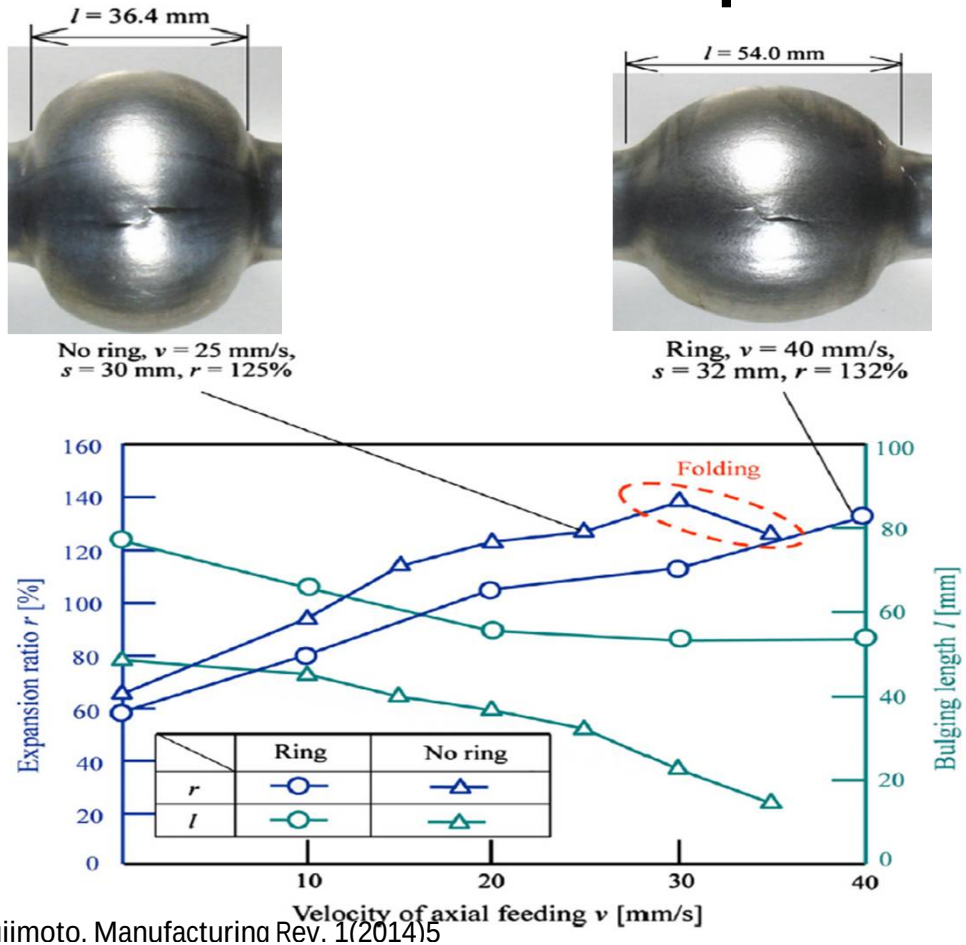
(a) No Ring



(b) Ring

Source : T. Maeno, K-I Mori, K. Fujimoto, Manufacturing Rev. 1(2014)5

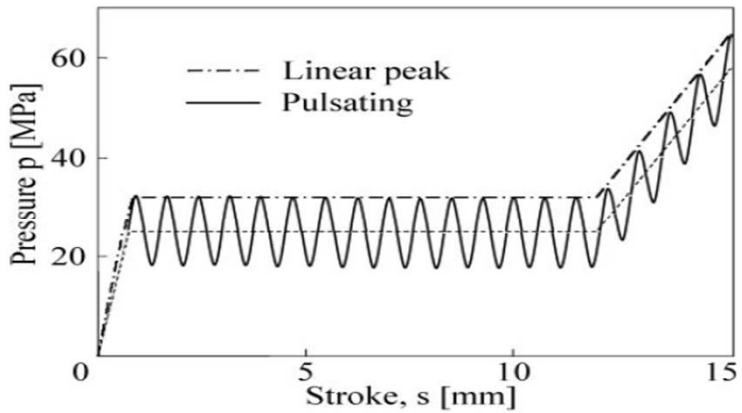
Axial feed + temperature

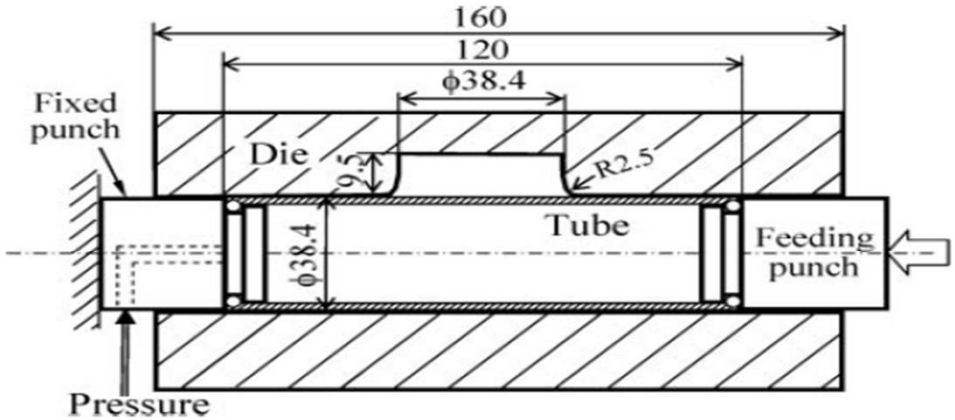


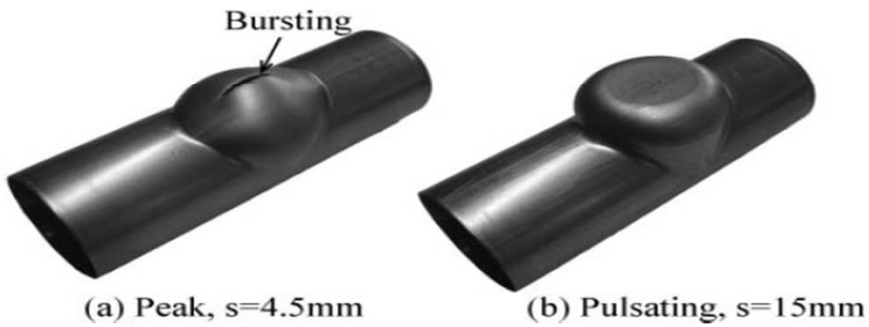
Source : T. Maeno, K-I Mori, K. Fujimoto, Manufacturing Rev. 1(2014)5

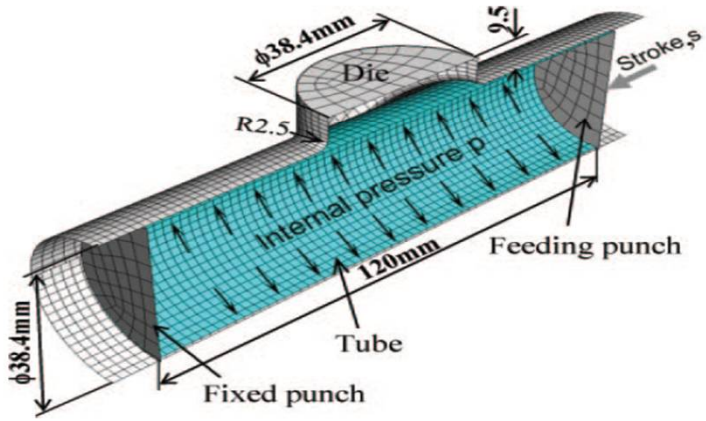
Pulsating pressure in hydroforming

$$p = \Delta p \sin 2\pi\omega (s-1) +$$









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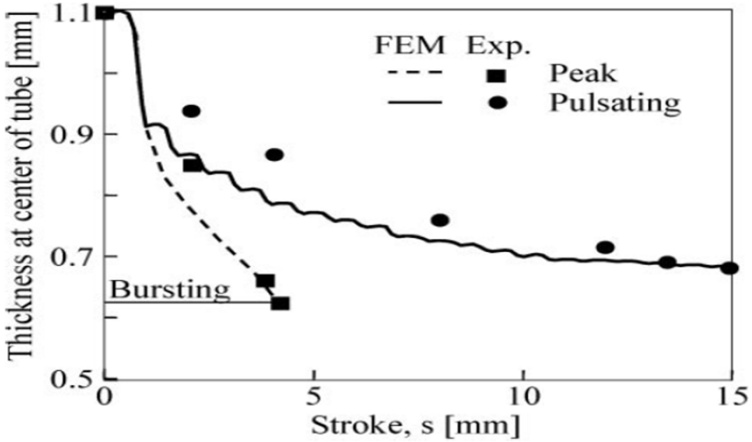
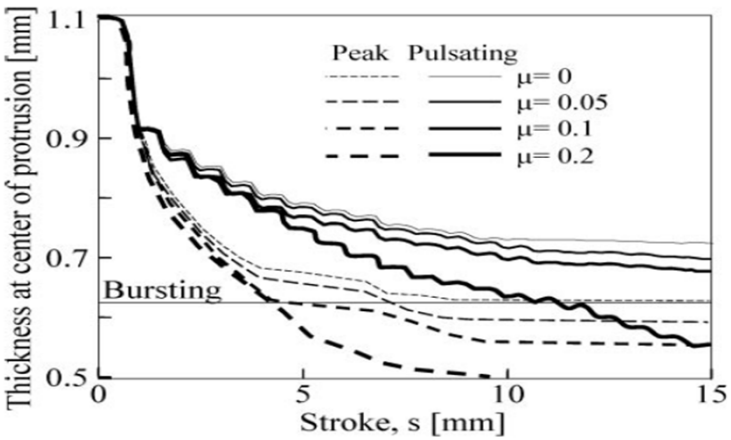
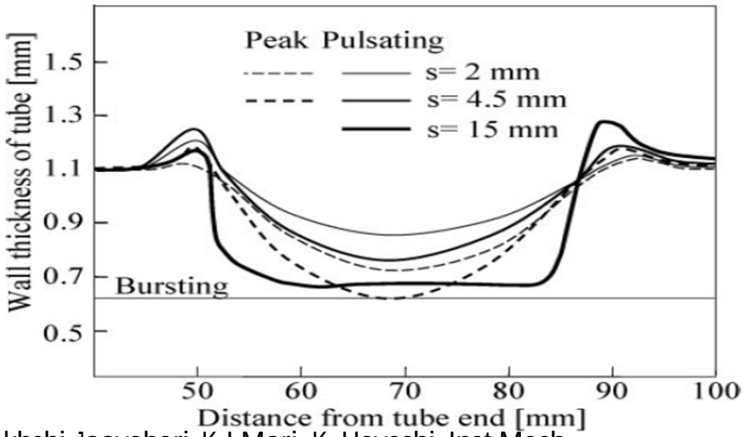
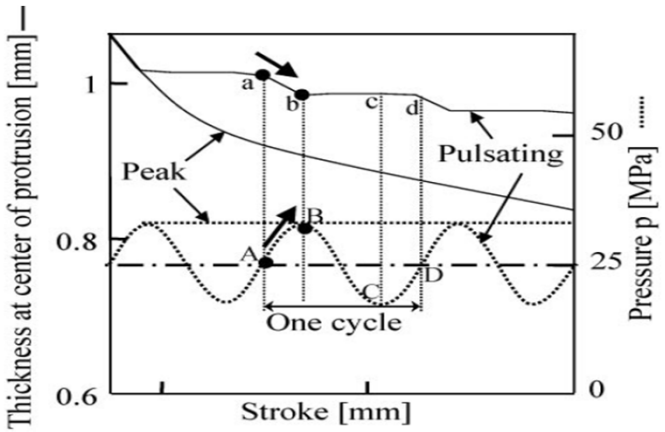
Thickness distribution









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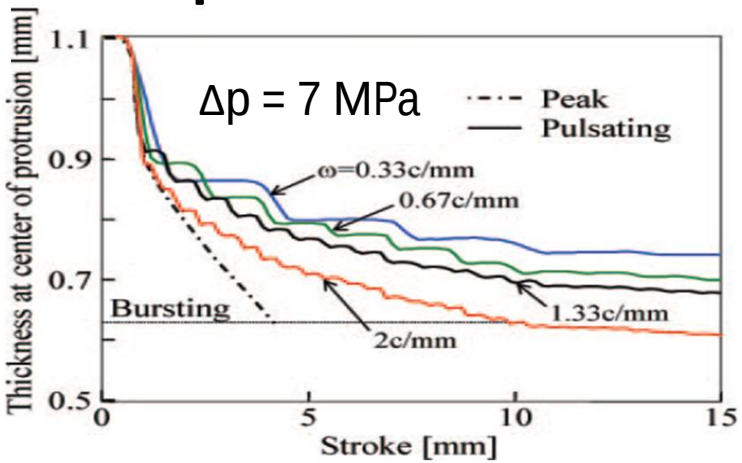
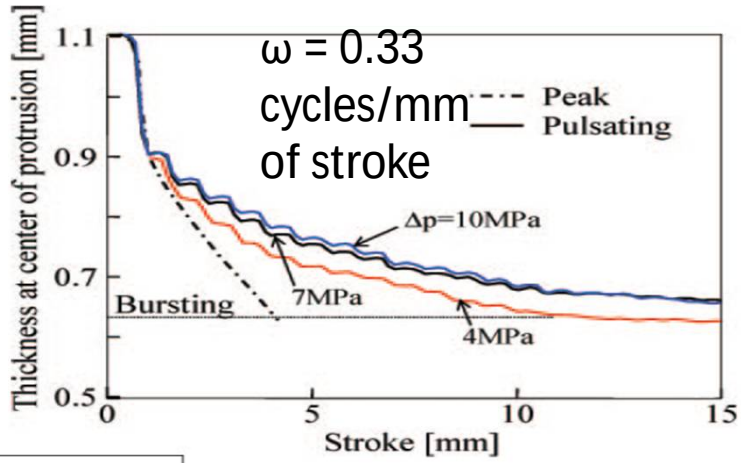
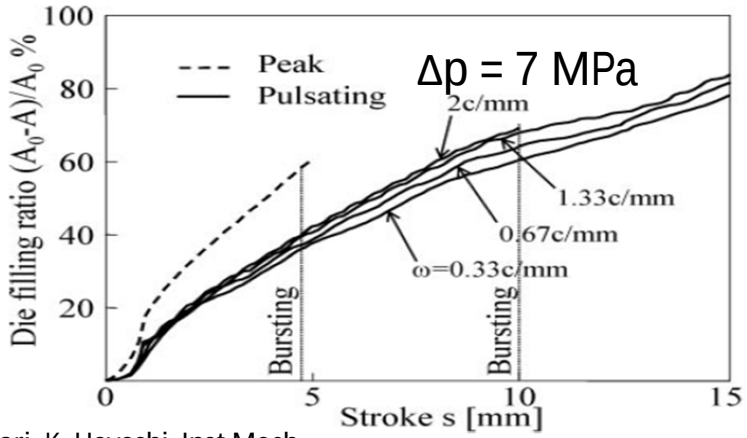
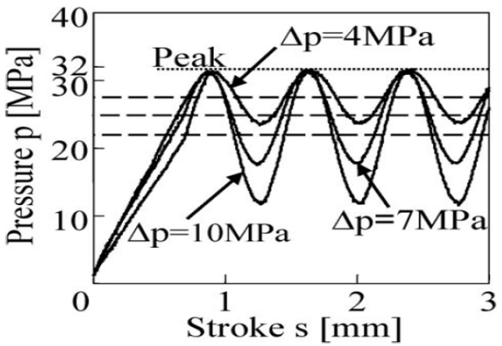
Amplitude and Frequency of Pulsation









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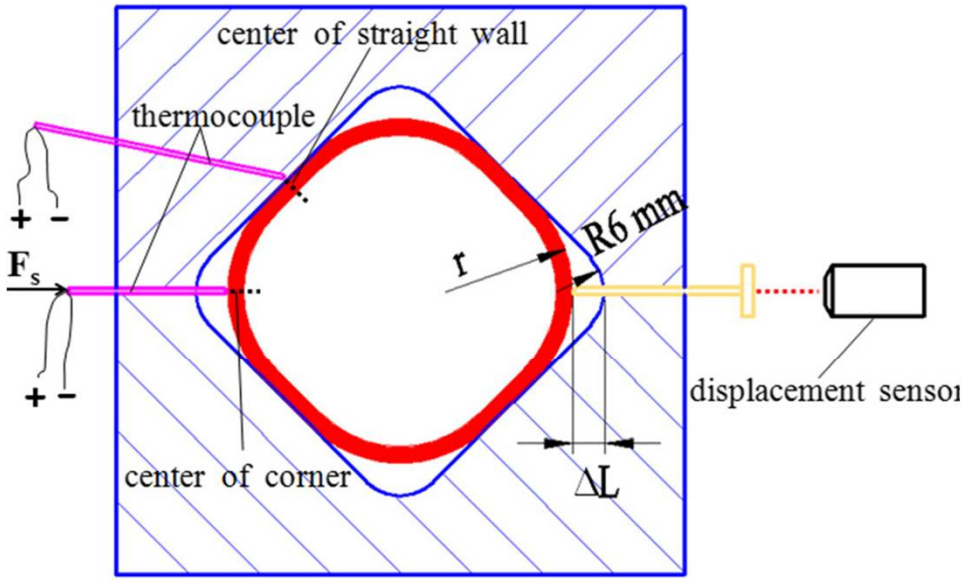
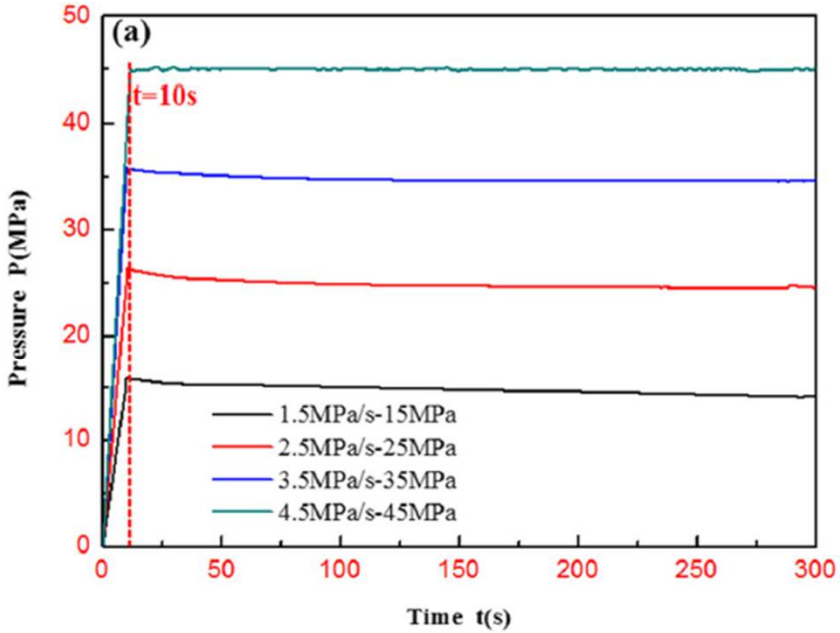
High Pressure Pneumatic Forming

- Material : Ti-3Al-2.5V alloy
- Strain rate sensitive alloy
- Adopting the lower pressurization rate and filling regenerative materials into the tube are effective methods for decreasing or eliminating the temperature difference.

Pressurisation and Corner filling



$$r = R + 0.414\Delta L$$



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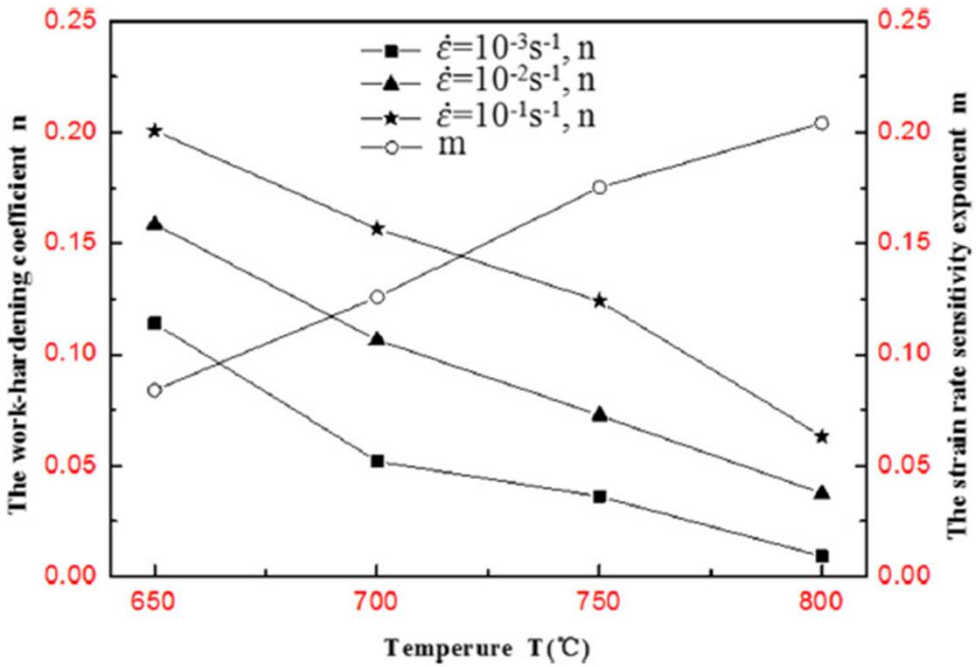
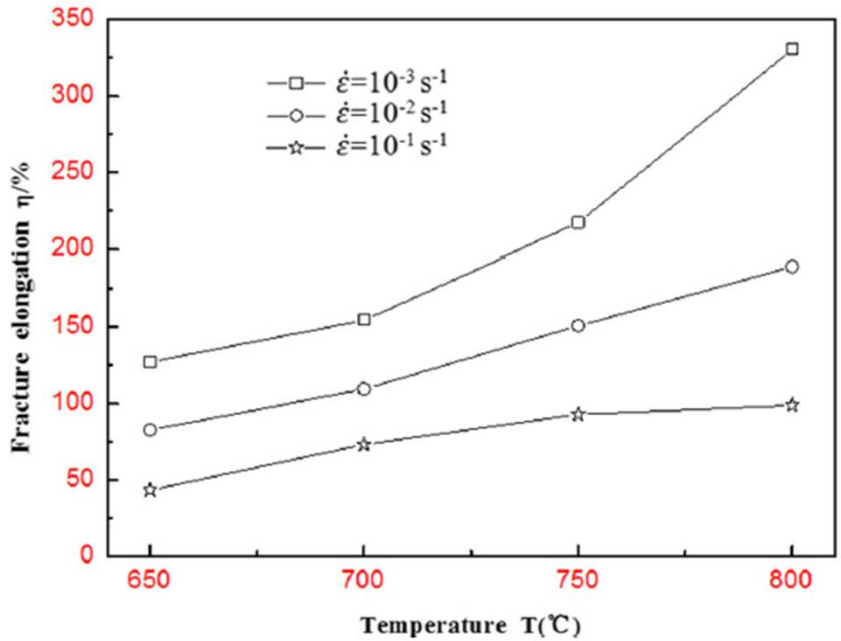
Tensile behaviour





Ductility in Uniaxial tension

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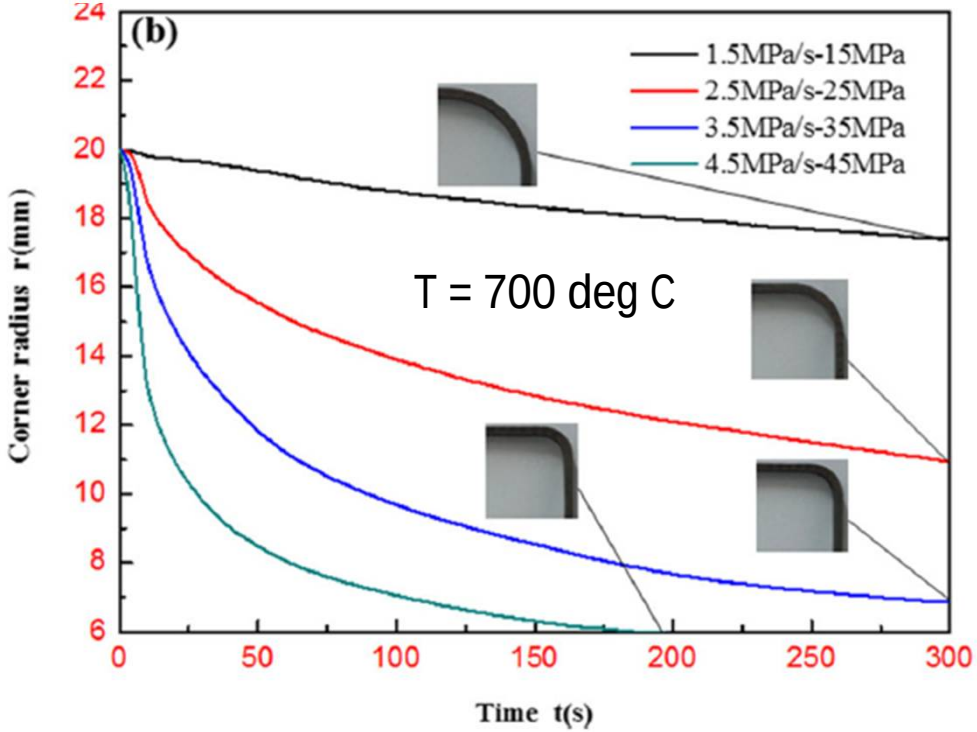
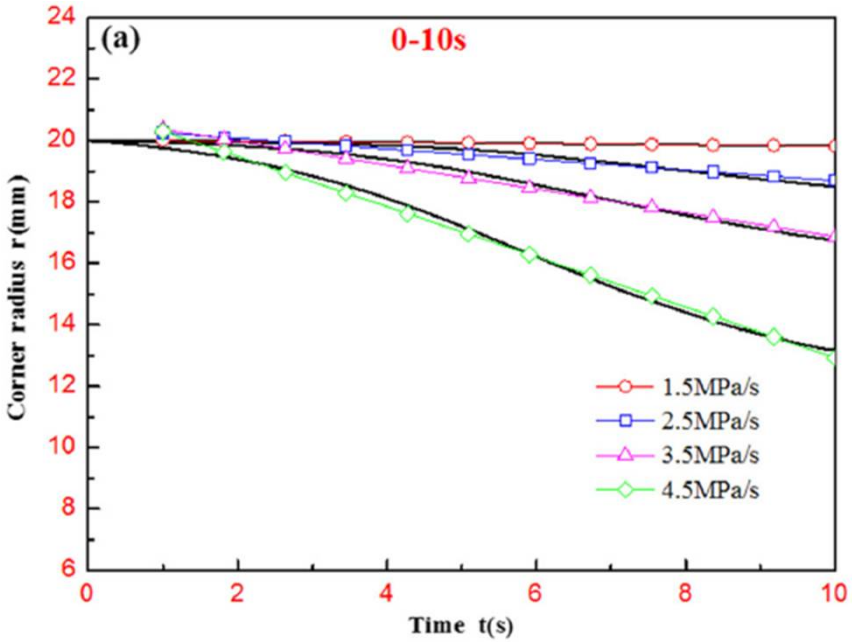
Corner filling





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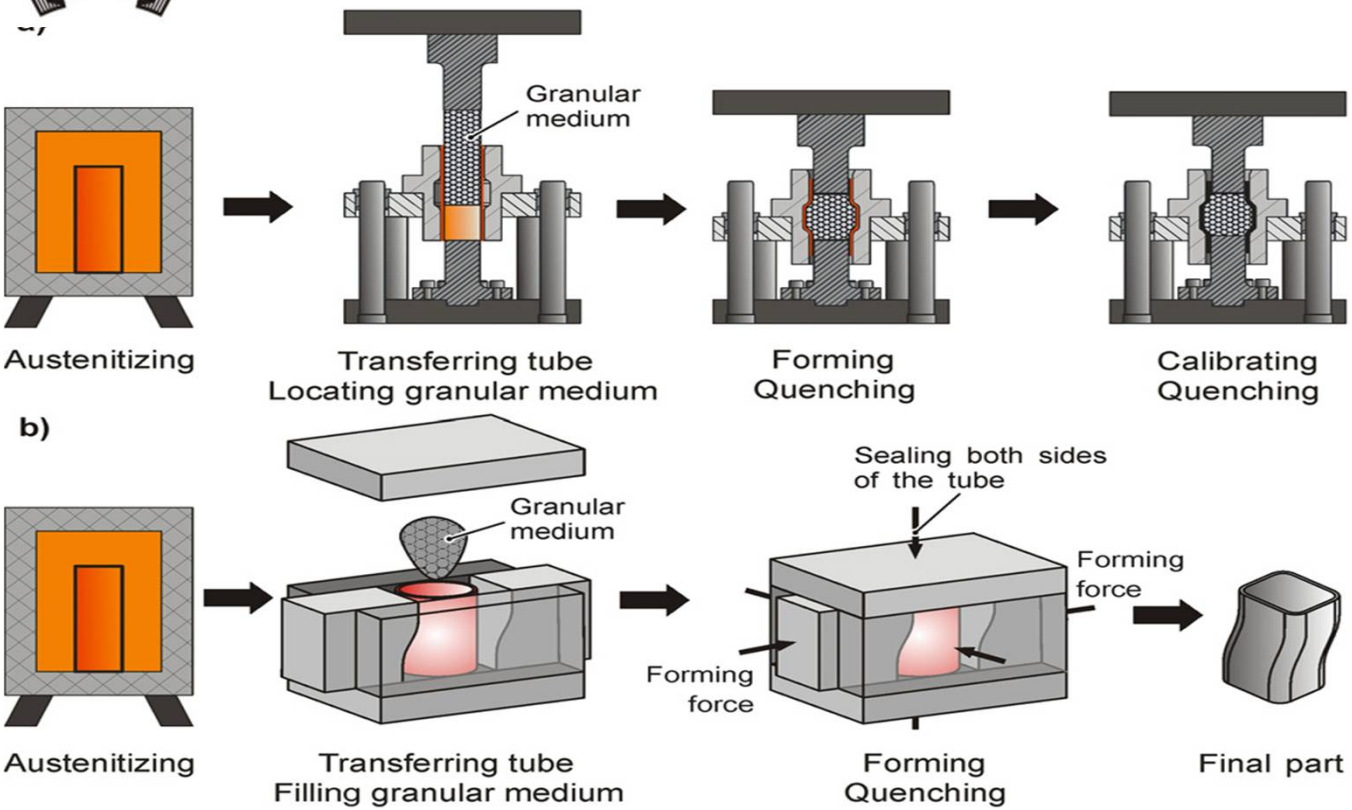
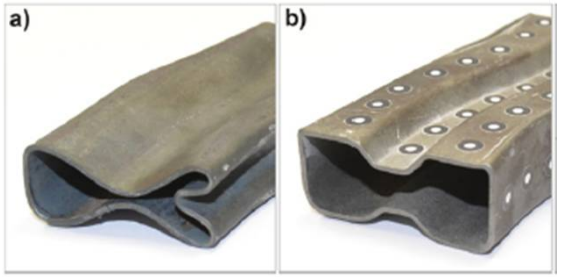
Other means of Hydroforming

Granular medium based hydroforming



$$\epsilon_{vol} = 0.0634(1-e^{-0.01274p_h}),\ p_h \text{ in MPa.}$$



Hot formed Without working medium

Hot formed With working medium

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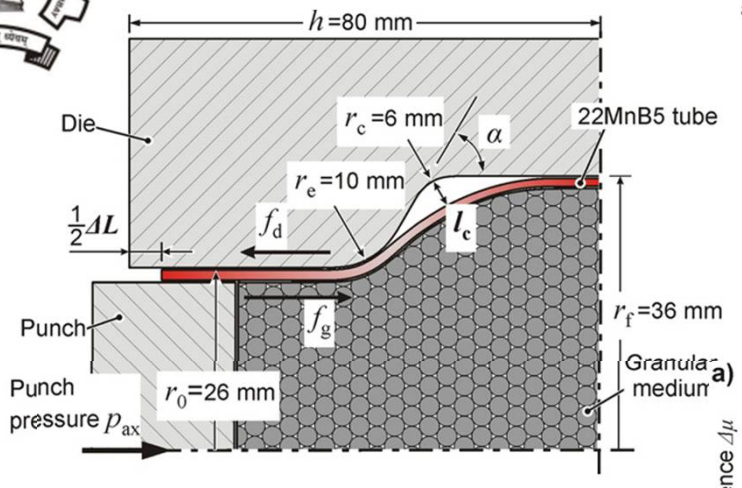
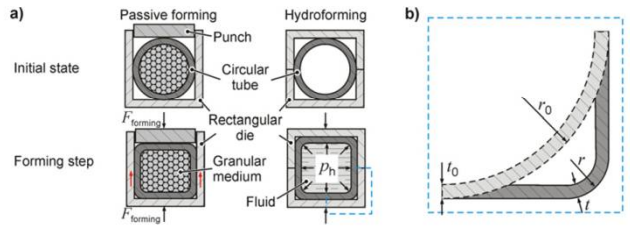
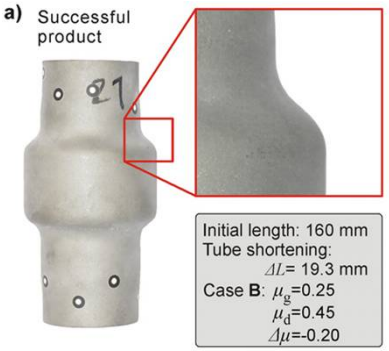
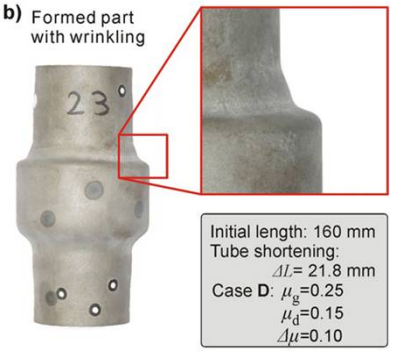
Formability in hot hydroforming

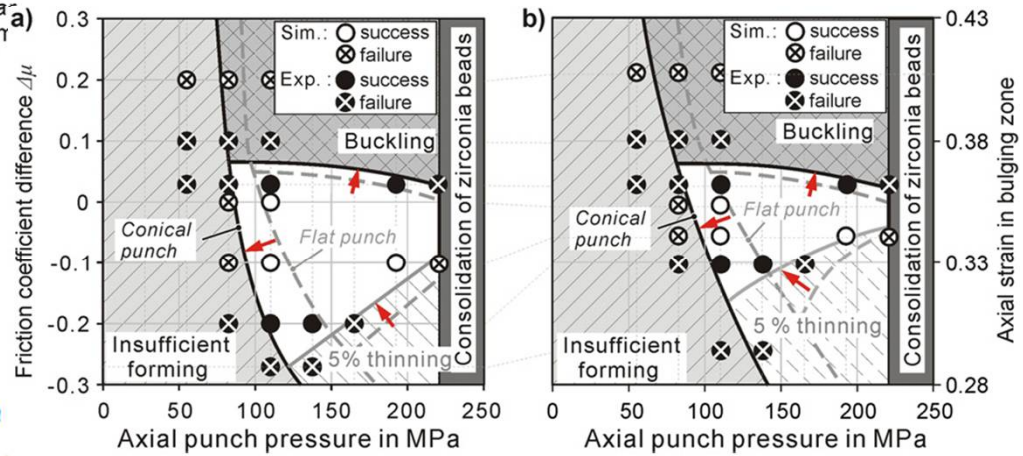




$$p_h = \frac{2t_0}{\sqrt{3}r} K \left(\frac{r}{r_0}\right)^{\left(\frac{4}{\pi}-1\right)} \left[\frac{2}{\sqrt{3}}\left(\frac{4}{\pi}-1\right)\ln\left(\frac{r_0}{r}\right)\right]^n$$







H. Chen et. Al., CIRP Annals, Manufacturing Technology, 65(2016)273-276

Hot Hydroforming Stainless Steel

- Ferritic stainless steels
- Better corrosion resistance (esp. SCC)
- Lower coeff. Of thermal expansion
- High thermal conductivity
- Poor formability in warm working; better above 700 deg C
- Quartz / Zirconia beads are safe forming media
- Inherent friction between granules and tube aids axial feeding

Hot forming stainless steel & Media

Chemical composition	C	Cr	Mn	Ni	Ti+Nb	Fe
Amount (wt-%)	0.02	18	-	-	0.6	Bal.

Density (g/cm^3)	7.7
Young´s modulus (GPa)	220
Heat capacity (J/kg·K)	460
Coefficient of thermal expansion (/K)	10×10^{-6}
Thermal conductivity at 20 °C (W/m·K)	25

Granular material	Particle size (mm)	Hardness	Melting point (°C)
Zirconia beads	0.4-0.6	>1180 HV	2715
Steel balls	1.0	60~66 HRC	1505

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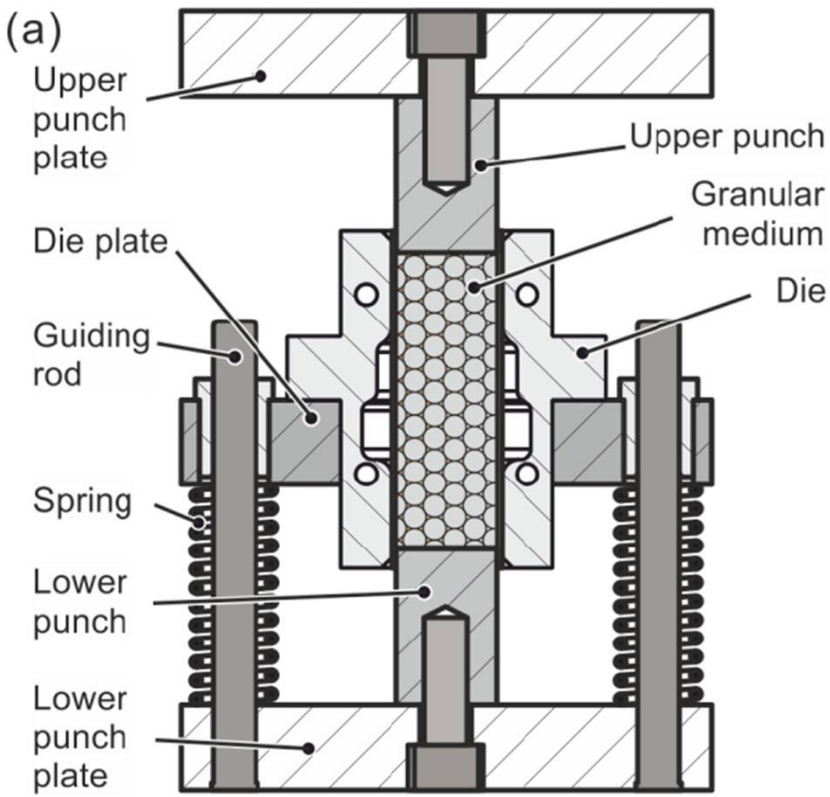

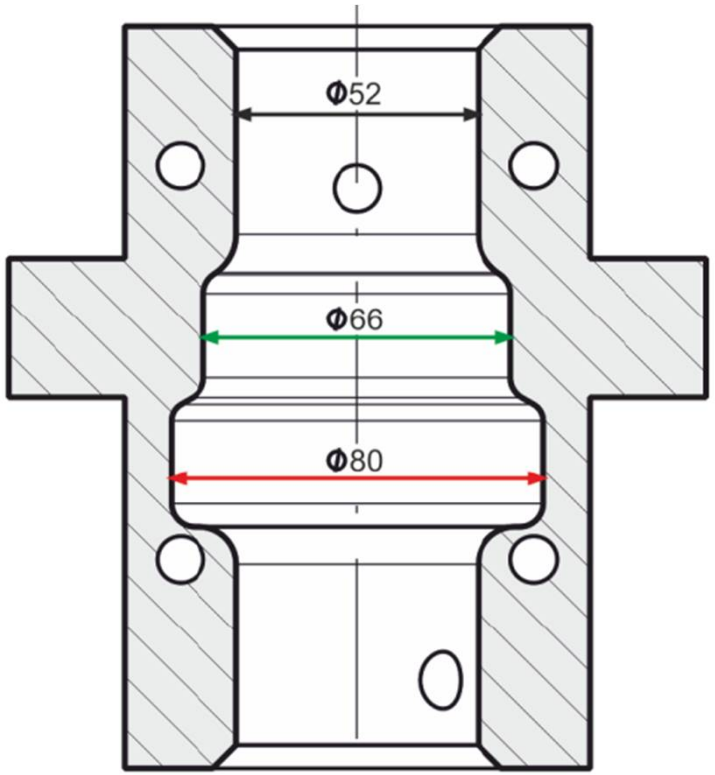

Tube OD = 50mm, wall thk = 1.5mm

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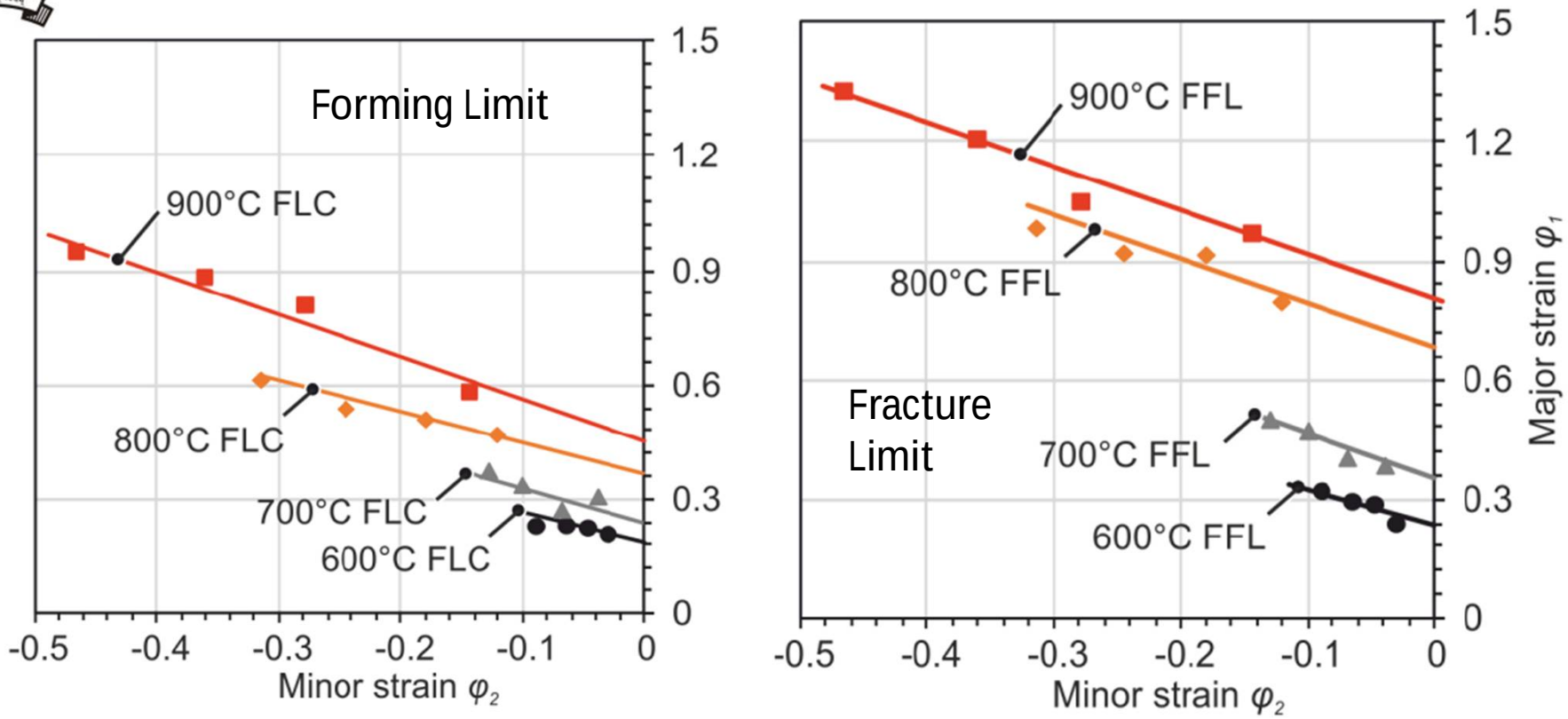
Forming limits & Fracture Limits



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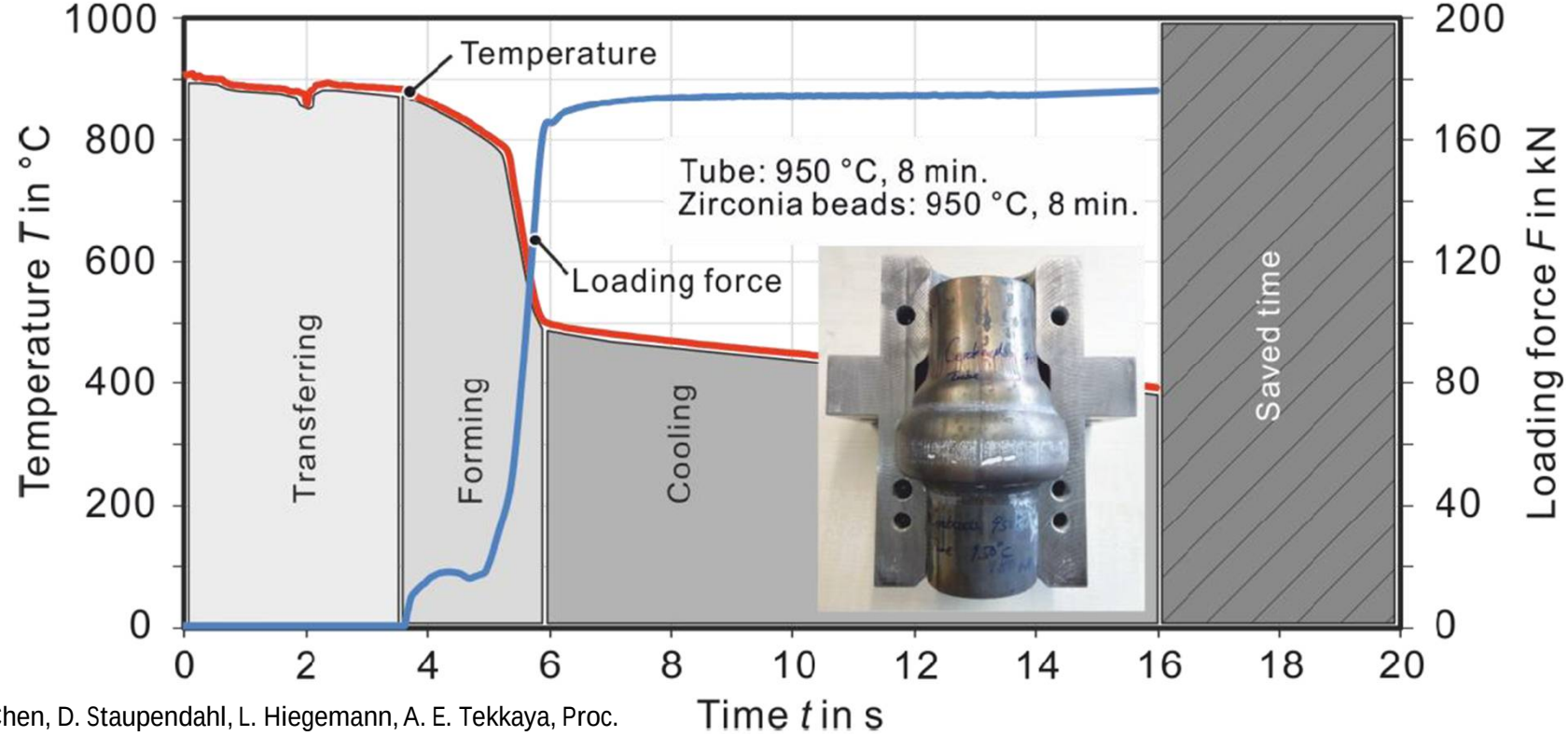
Forming with hot granular media



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In Summary

- Hot hydroforming is needed for sheets & tubes of high temperature materials
- The working medium depends upon the temperature capability of each.
- Hot gas forming, granular media are viable options
- Gas and granular media have their own advantages in hot forming
- Pulsating pressure works better than monotonic pressure of the working fluid / media

Thank you