MINI – CAS ON MECHANICAL ENGINEERING

METAL FORMING (INSIGHTS ON)

Antonello Astarita, Ph.D.

University of Naples «Federico II», Dept. Of Chemical, Materials and Production Engineering

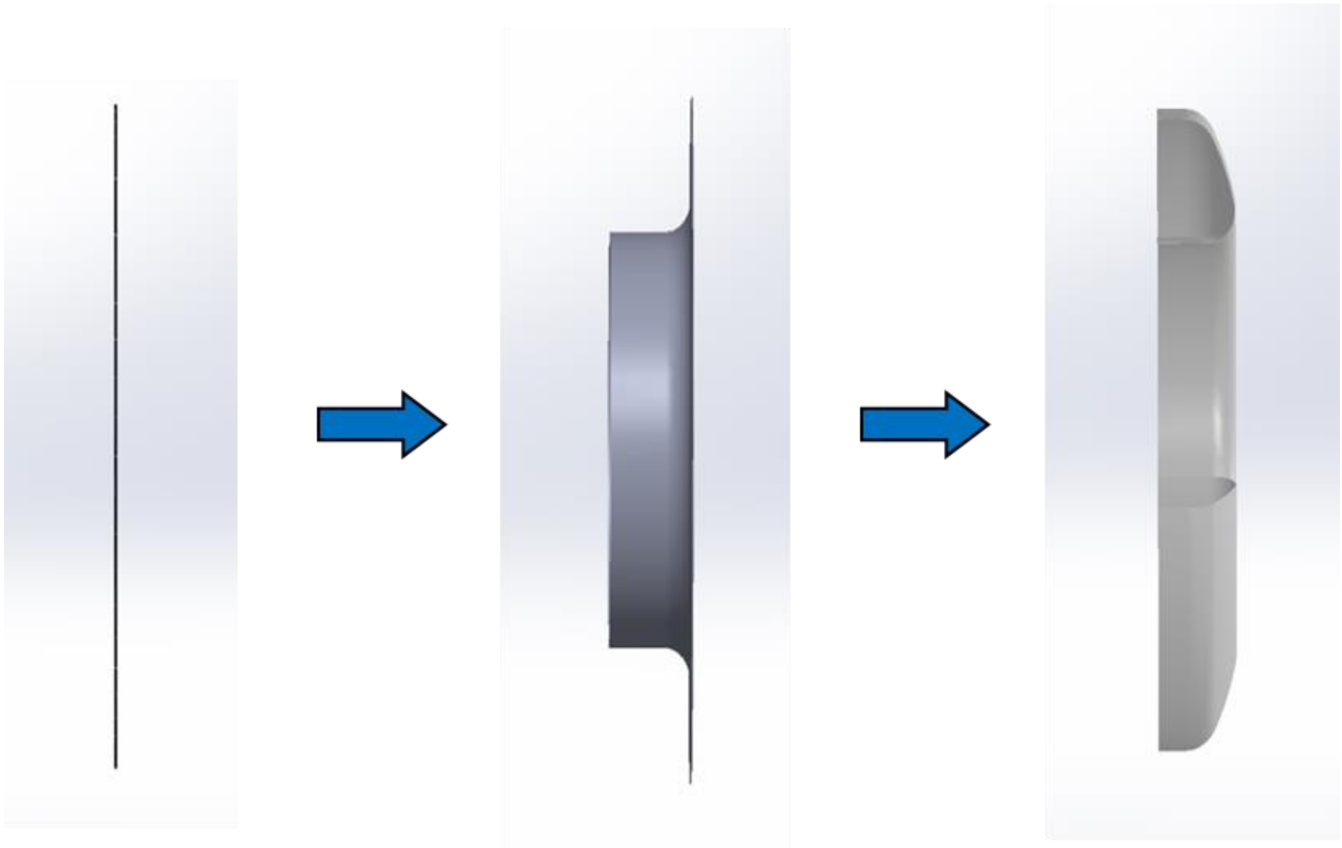
antonello.astarita@gmail.com

antonello.astarita@unina.it

Introduction

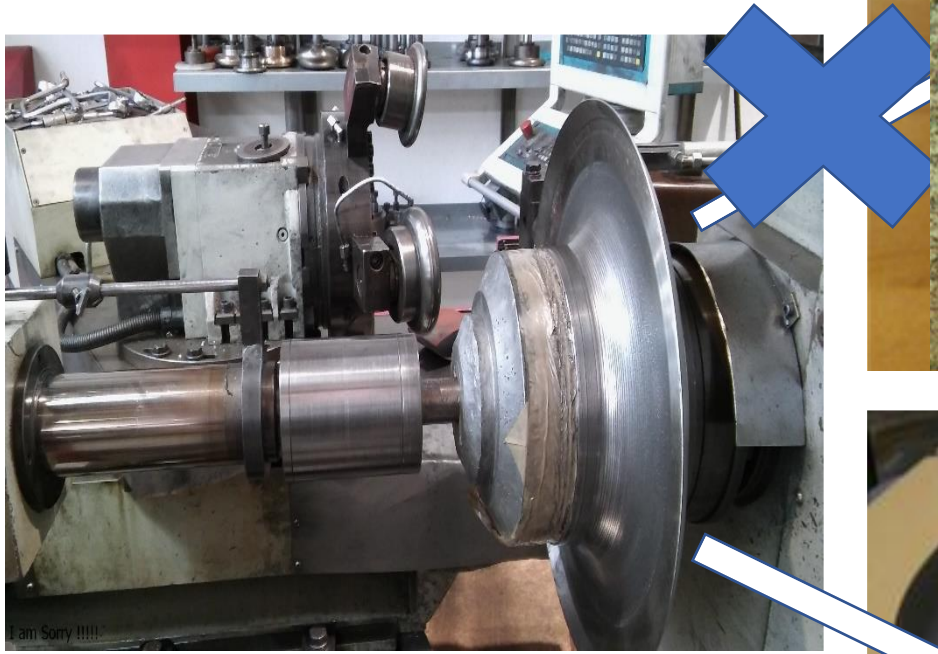
A «process» conceived to produce, starting from a semifinished product, parts with the desired shape and the desired properties (e.g. mechanical properties, corrosion behaviour, roughness and so on).

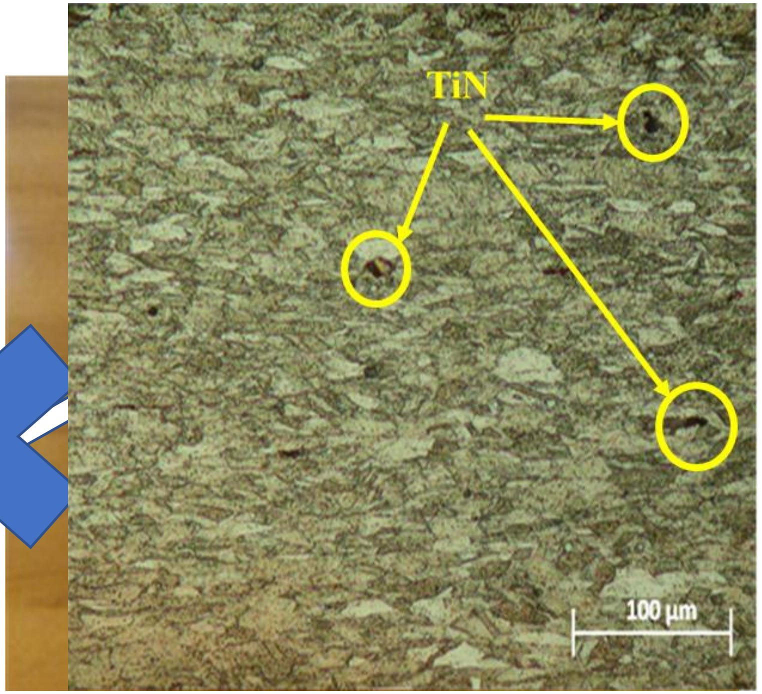
Material forming: the «science» that studies these processes

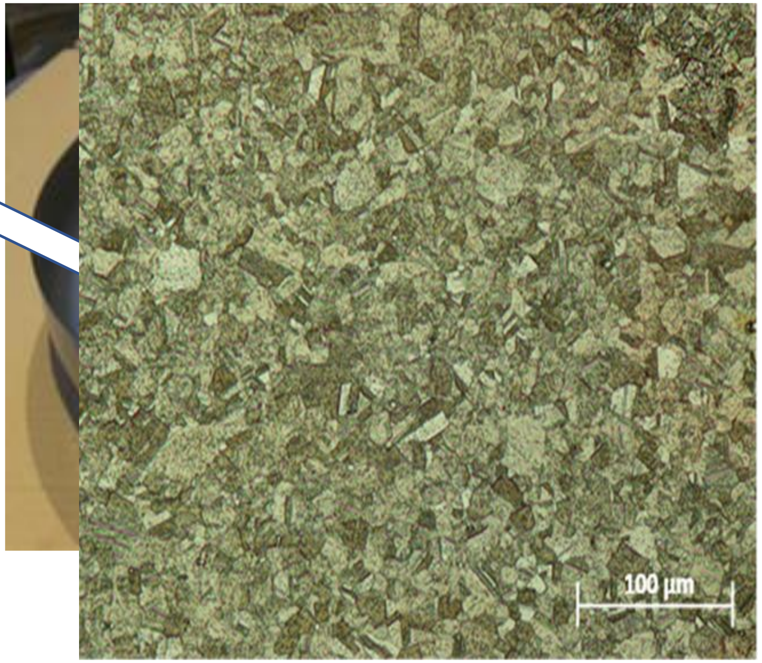


Introduction

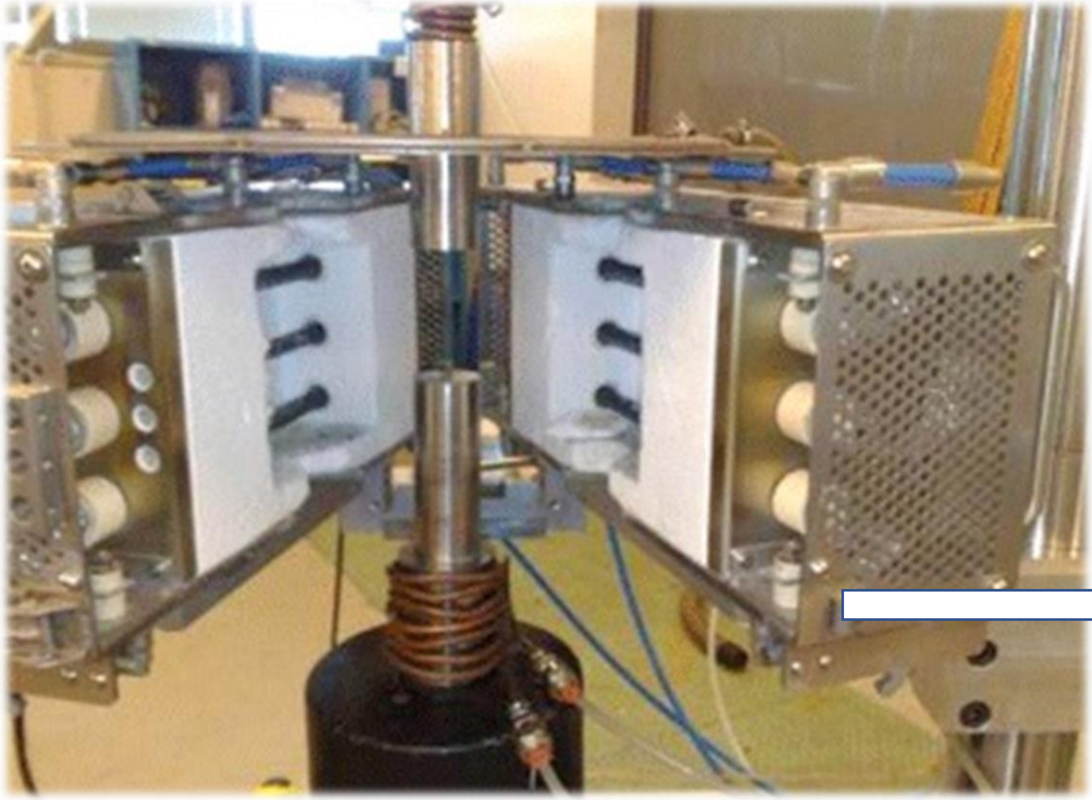
INFLUENCE OF THE BASE MATERIAL ON THE PROCESS EFFECTIVENESS

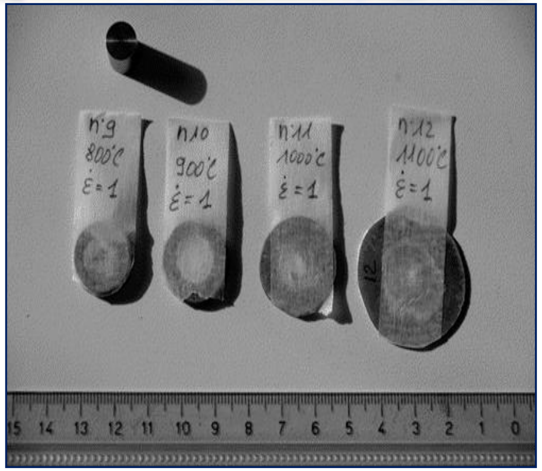


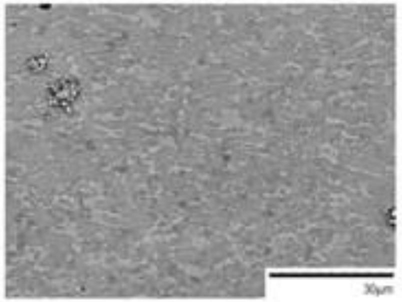
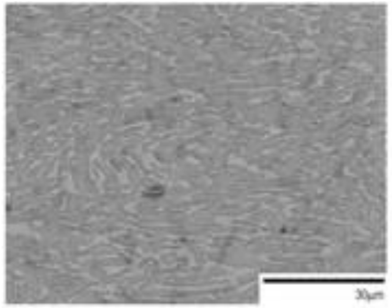
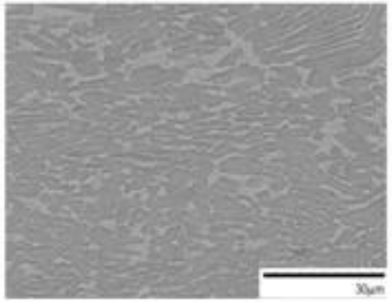
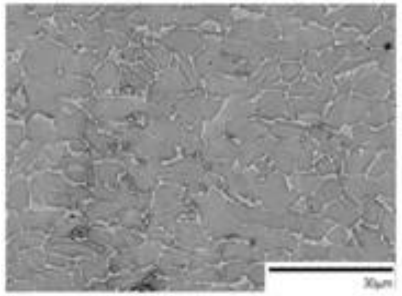
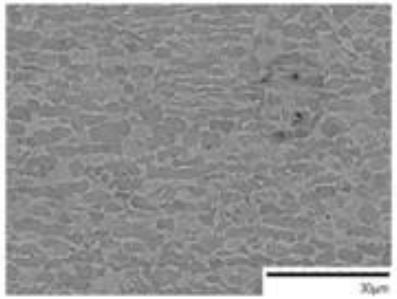
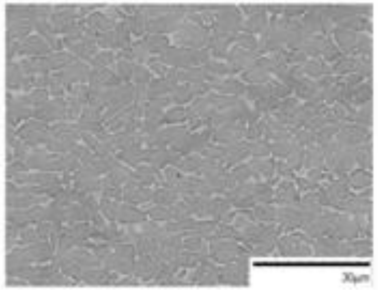
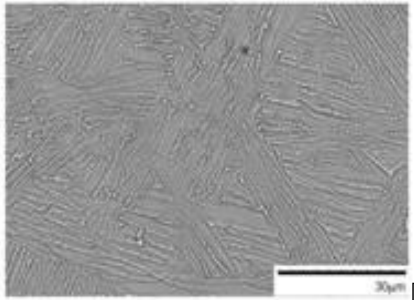
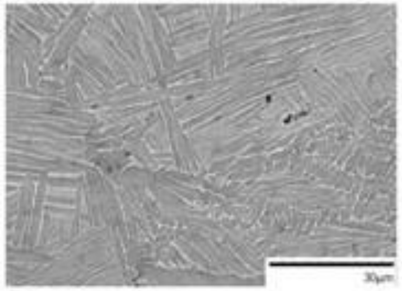
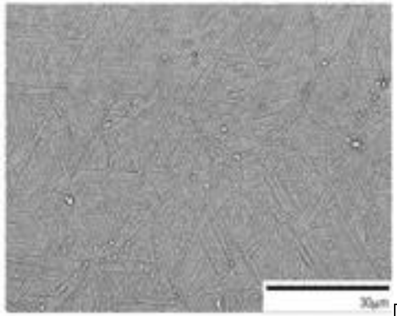




Introduction





	$v = 0{,}01\ s^{-1}$	$v = 0{,}1\ s^{-1}$	$v = 1\ s^{-1}$
900°C			
1000°C			
1100°C			

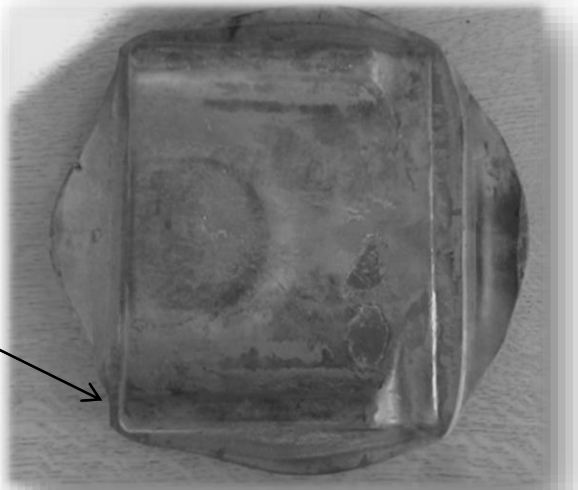
INFLUENCE OF THE PROCESS ON FINAL MICROSTRUCTURE OF THE PART

Experimental: Forging Tests

Test at T=940-960°C: filling defect (corner)

Test at T=1100°C, better material flow - flash;

«Buy to Fly» Ratio: R_f= 4

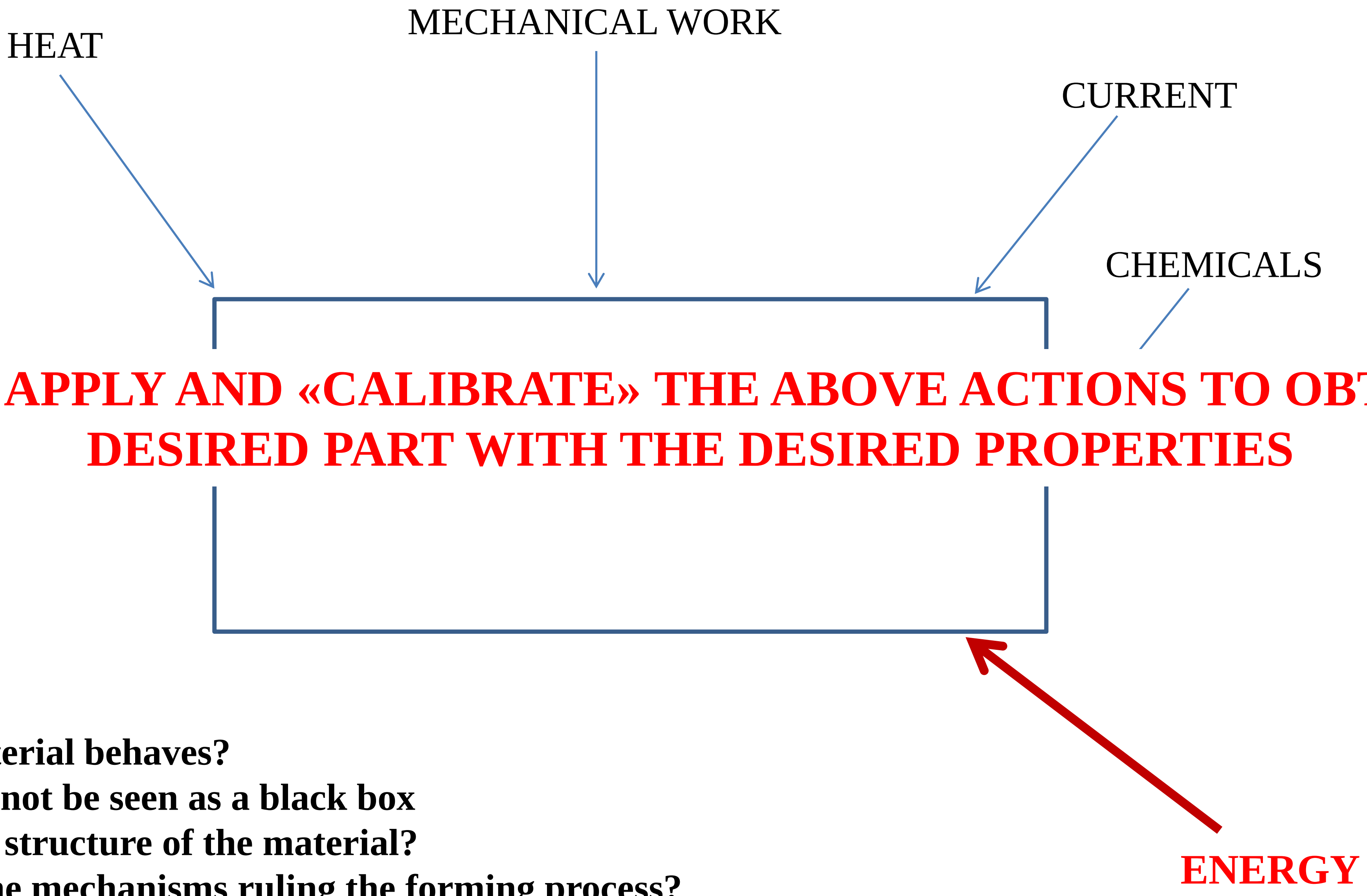


Introduction

FORGED IN ALPHA FIELD

FORGED IN BETA FIELD

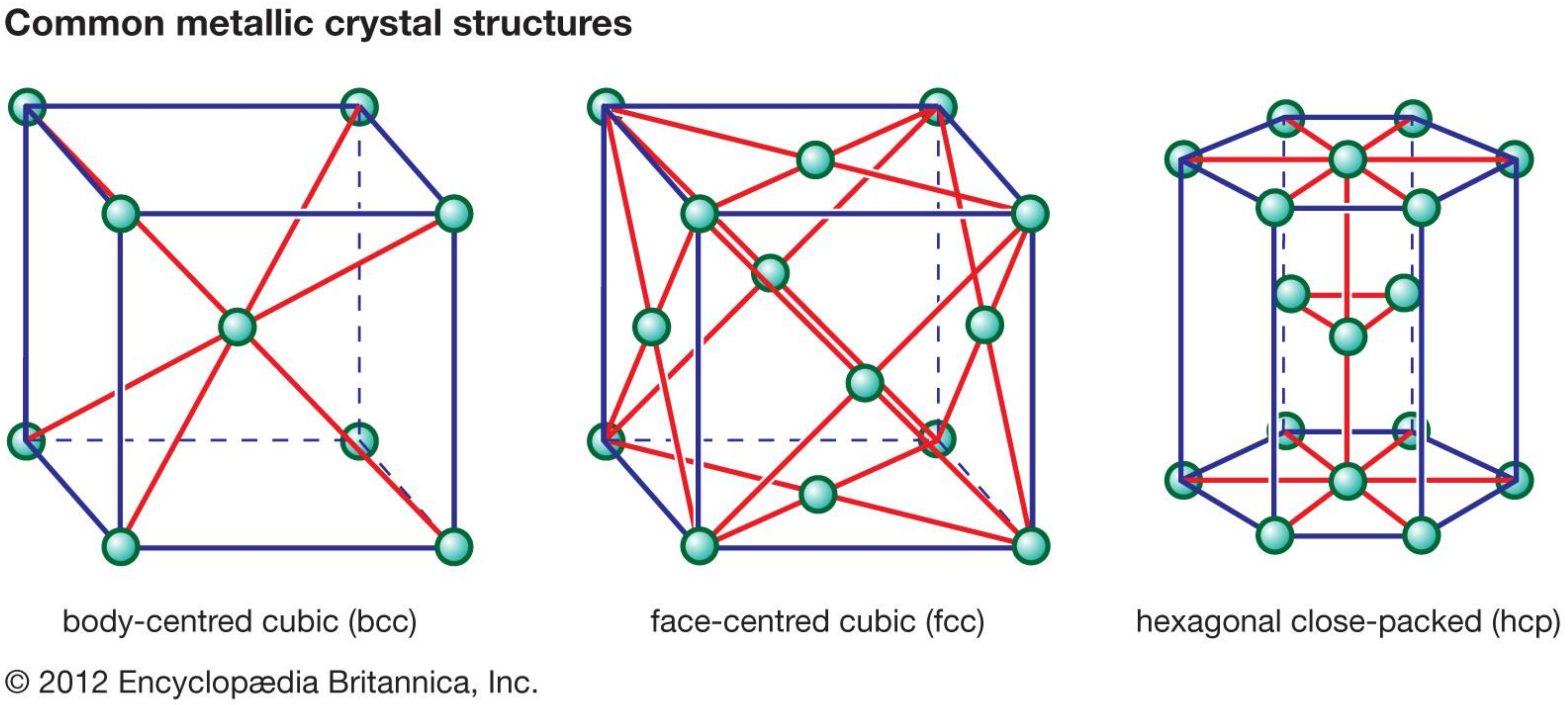
Introduction



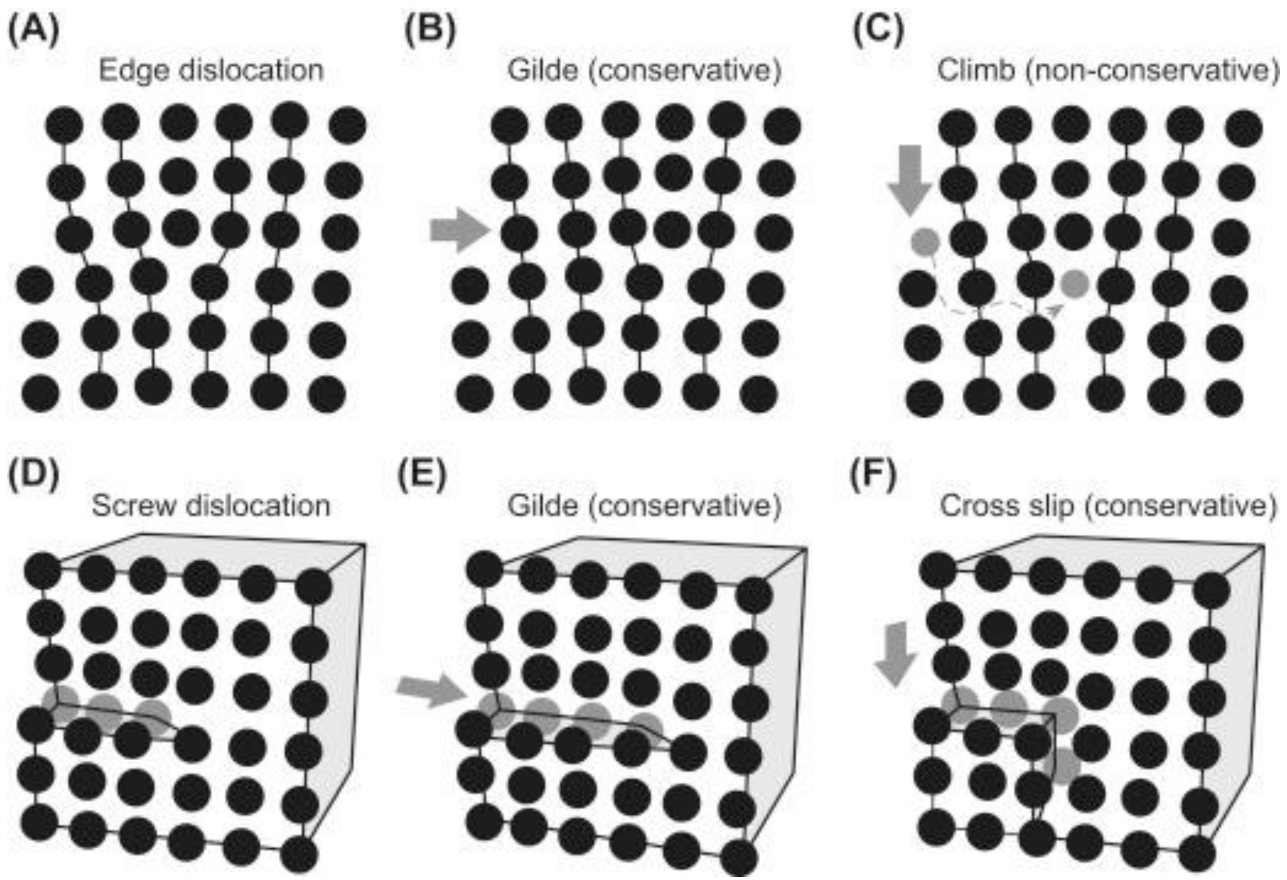
HOW TO APPLY AND «CALIBRATE» THE ABOVE ACTIONS TO OBTAIN THE DESIRED PART WITH THE DESIRED PROPERTIES

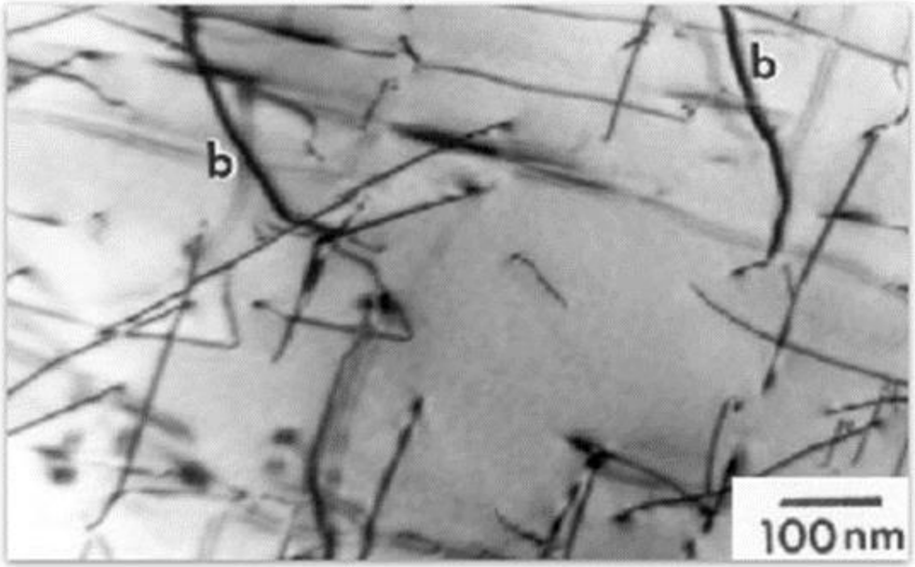
1. **How the material behaves?**
2. **Material cannot be seen as a black box**
3. **Which is the structure of the material?**
4. **Which are the mechanisms ruling the forming process?**

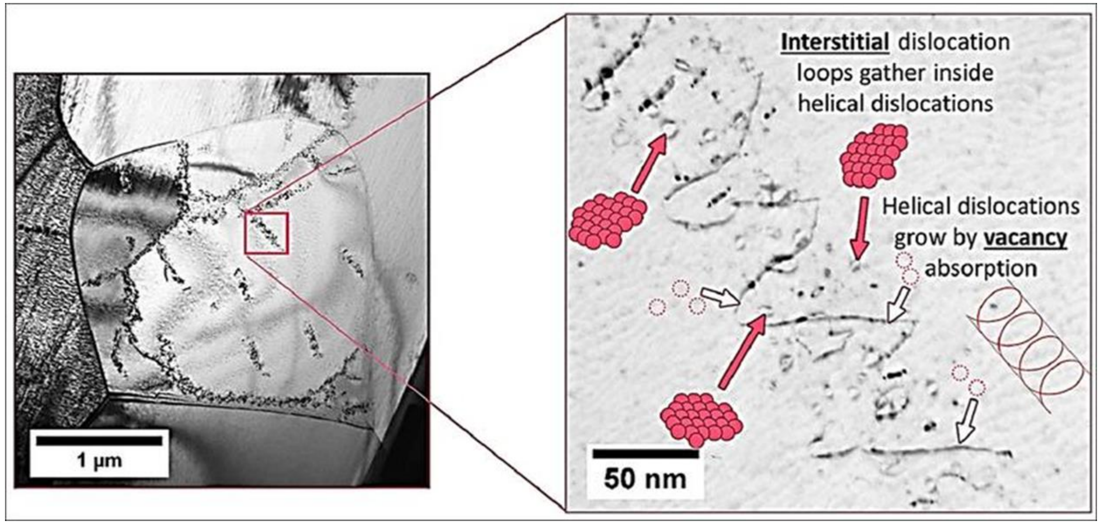
Cold Plastic Deformation Basic



Cold Plastic Deformation Basic

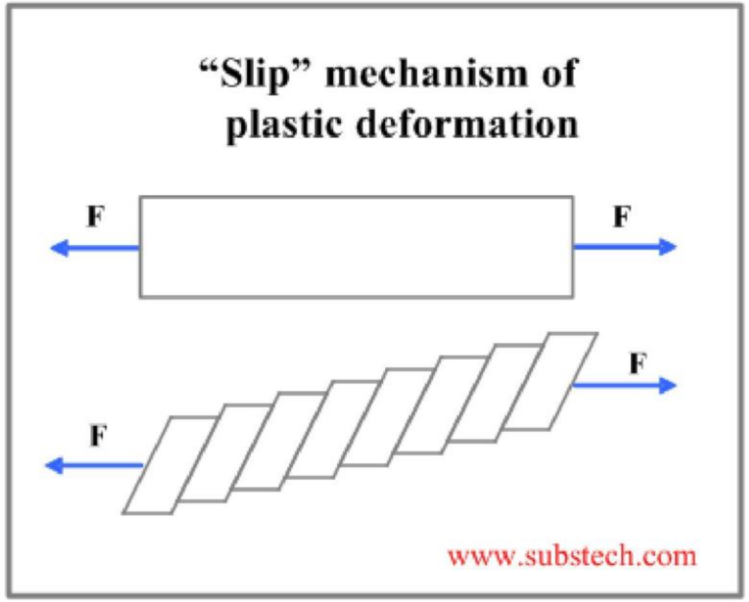


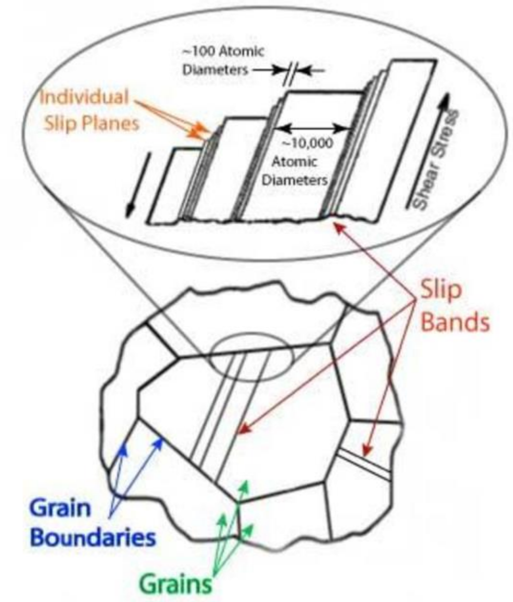




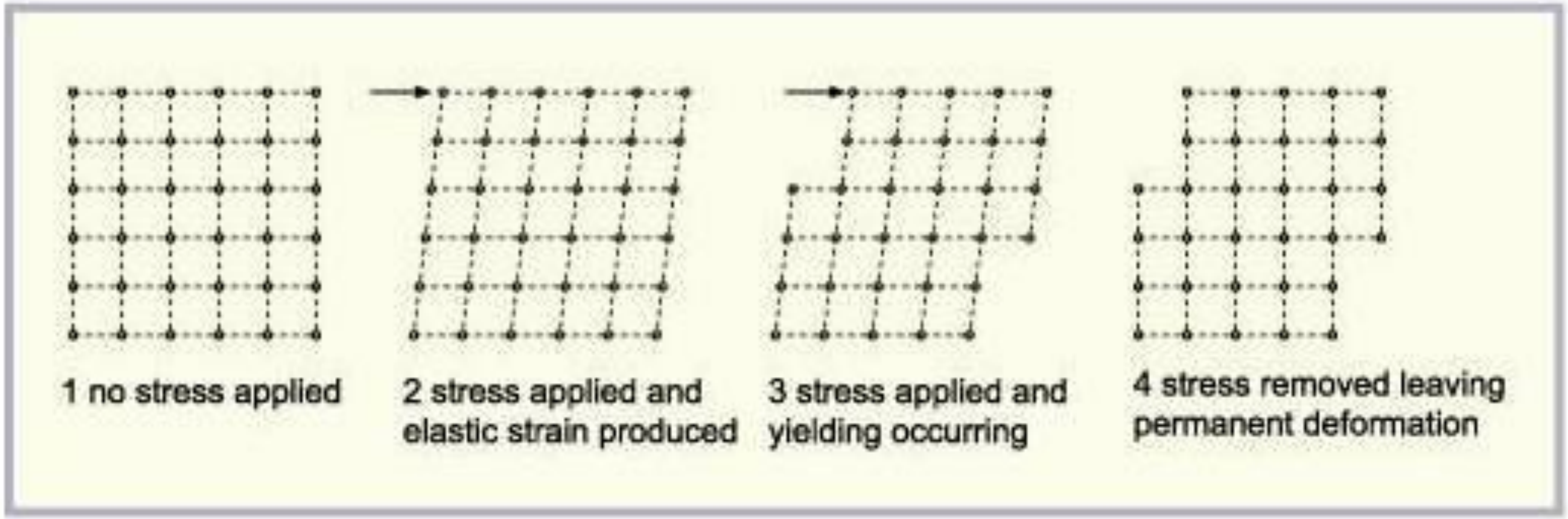
Plastic Deformation

- Slip forms small steps of crystal resulting from large dislocations along same plane
- Schmidt law – stress reqd to initiate slip in a Pure single crystal is constant at a given temp
    - All planes don't have same RSS for given load. Deformation to start on plane having max RSS



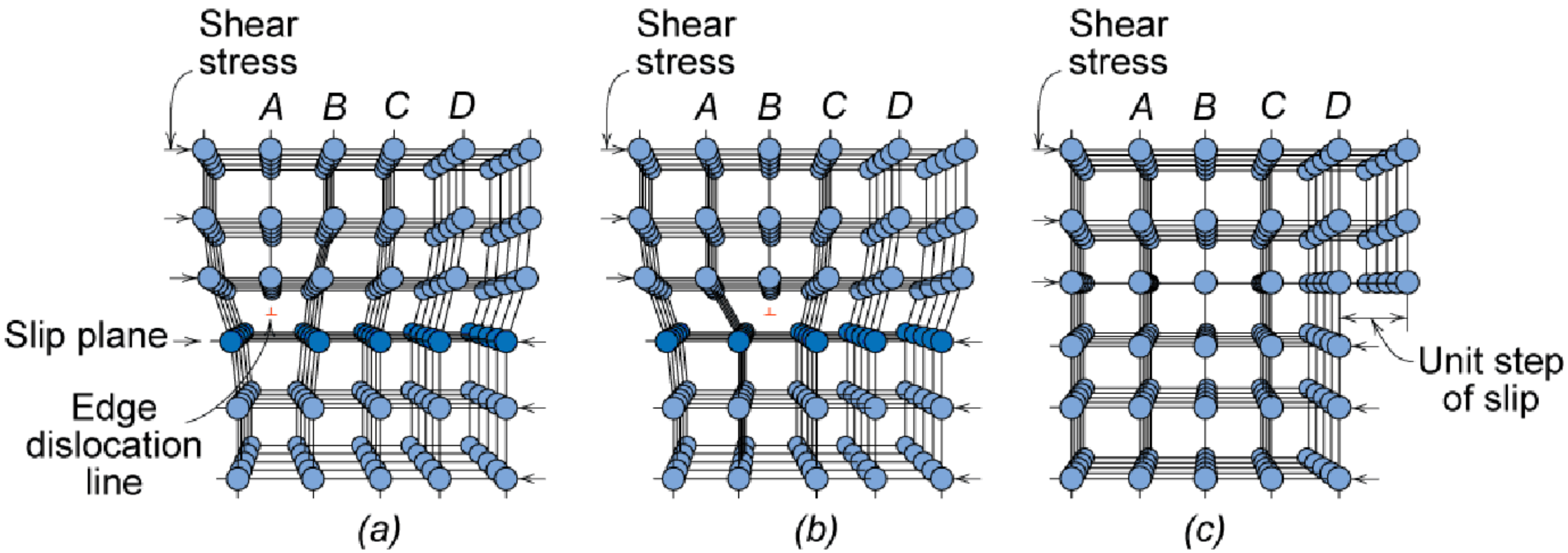


Cold Plastic Deformation Basic

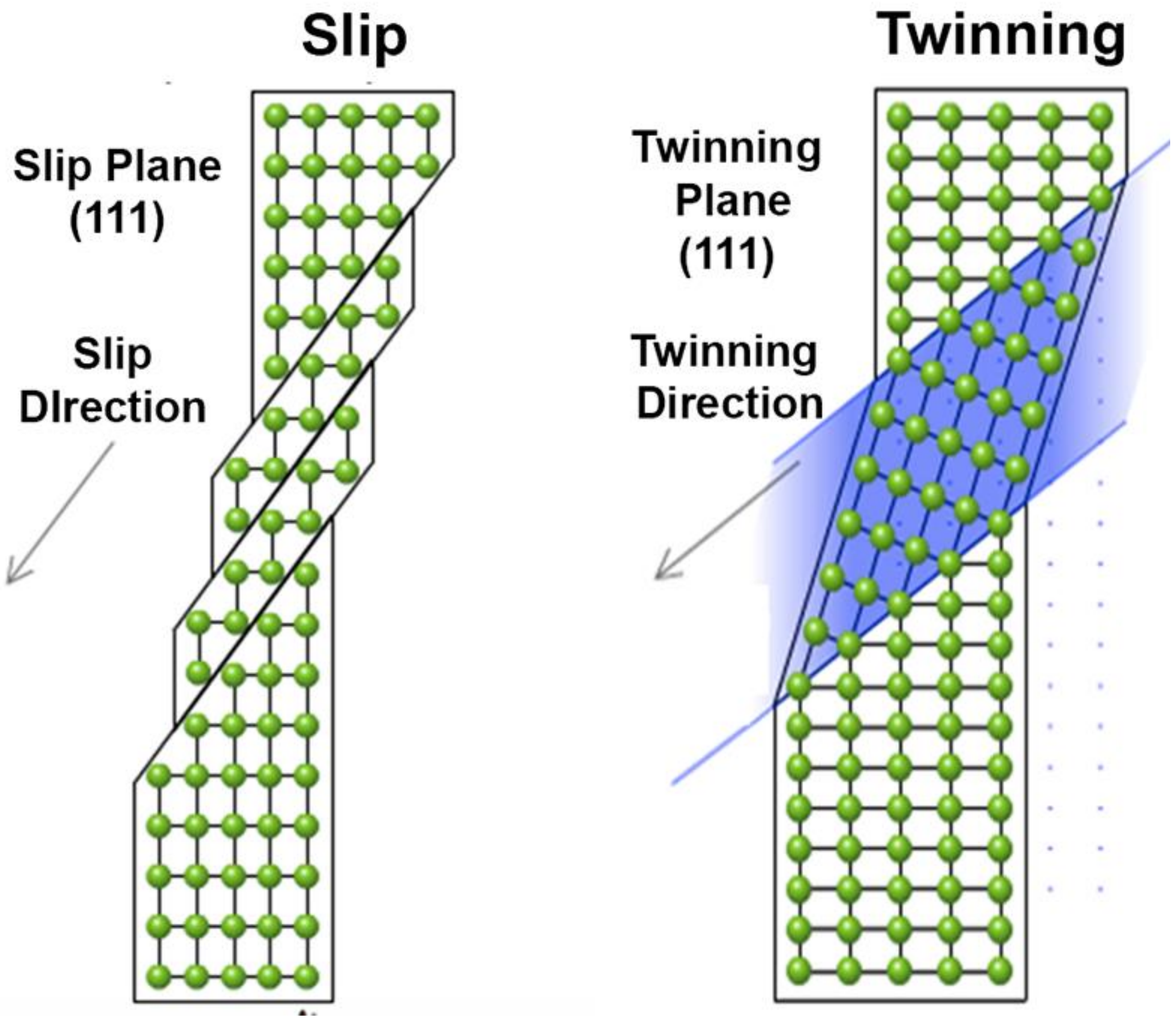


Stages of Plastic Deformation

Adapted from Fig. 7.1, *Callister 7e.*

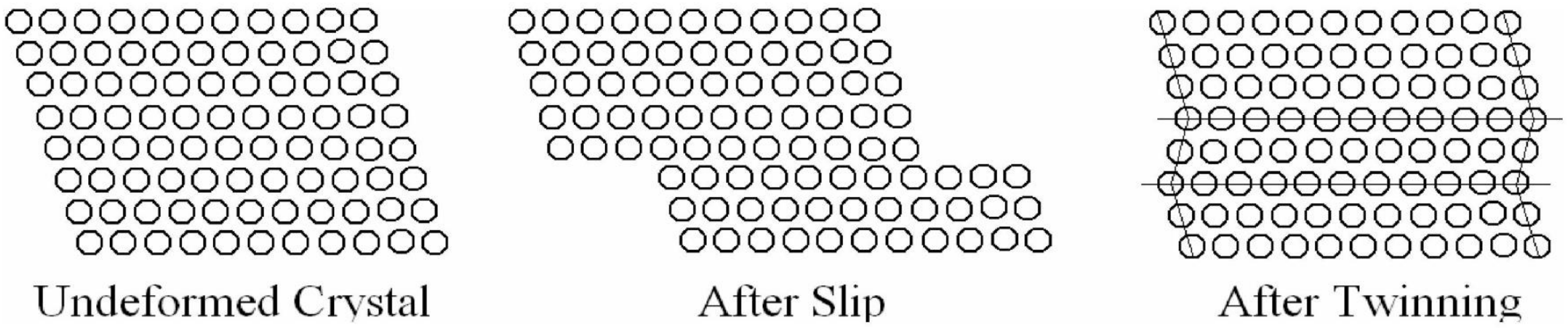


Cold Plastic Deformation Basic

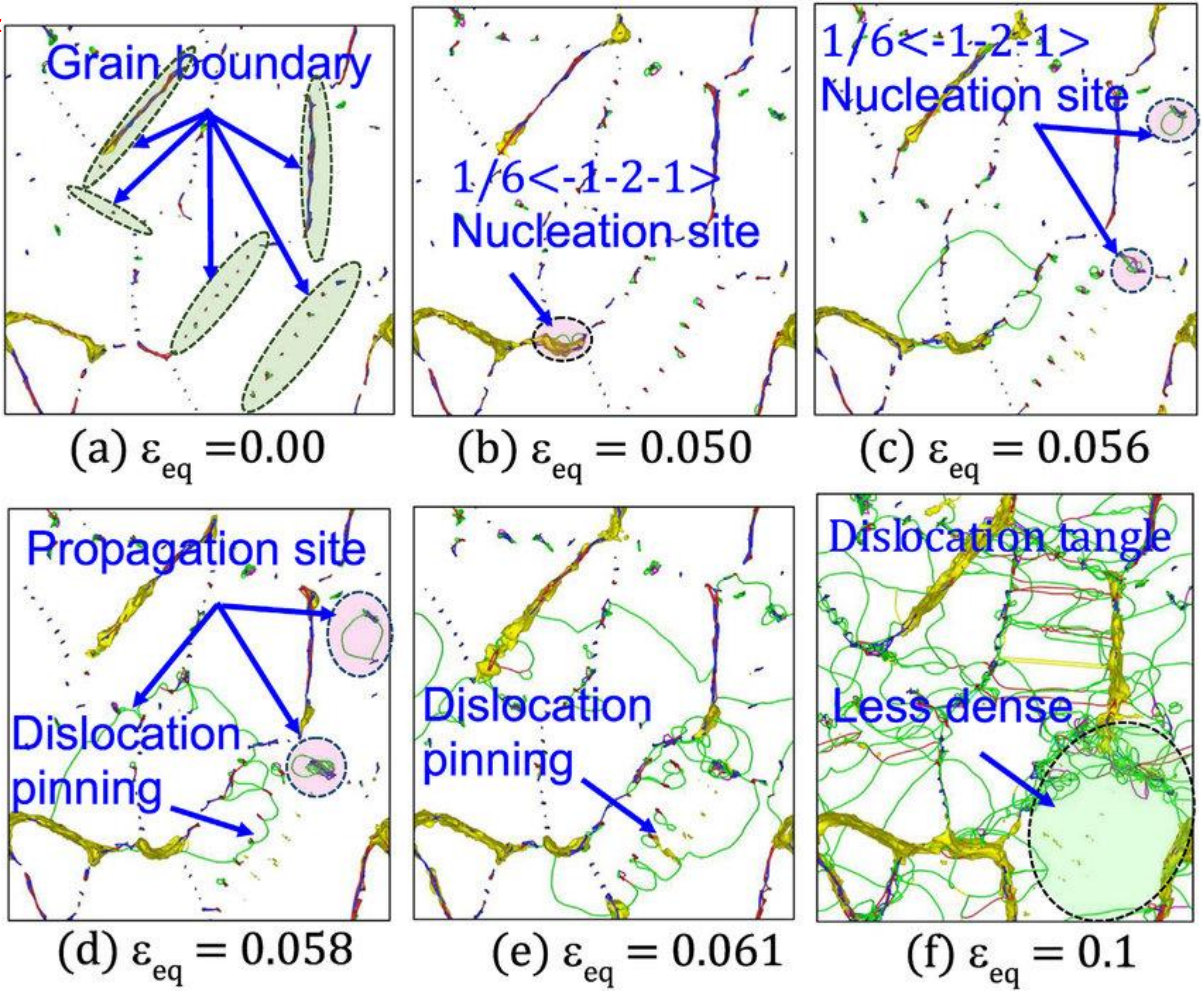


Slip v/s Twinning

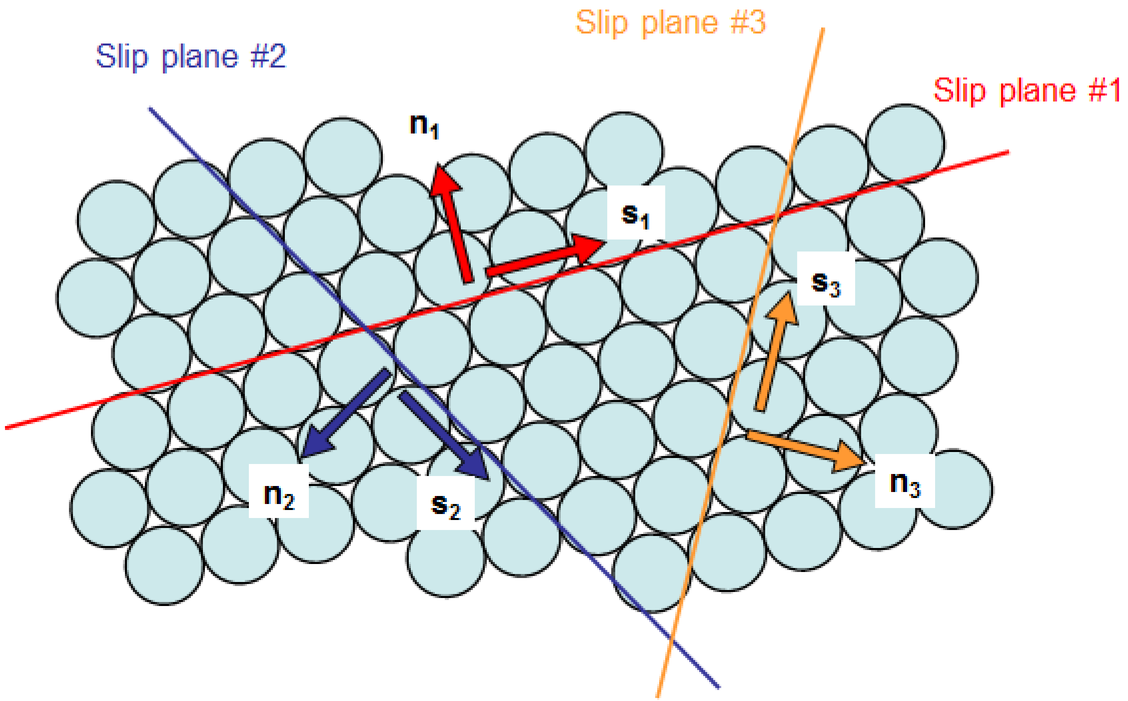
	Slip	Twinning
• Atomic movement		
	whole number of atomic spacing	fractional atomic spacing..
• Microscopic appearance		
	Thin lines	Wide bands or broad lines
• Lattice orientation		
	No change in lattice orientation	Lattice orientation changes
• Time		
	many milli sec	few micro sec
• RSS		no role

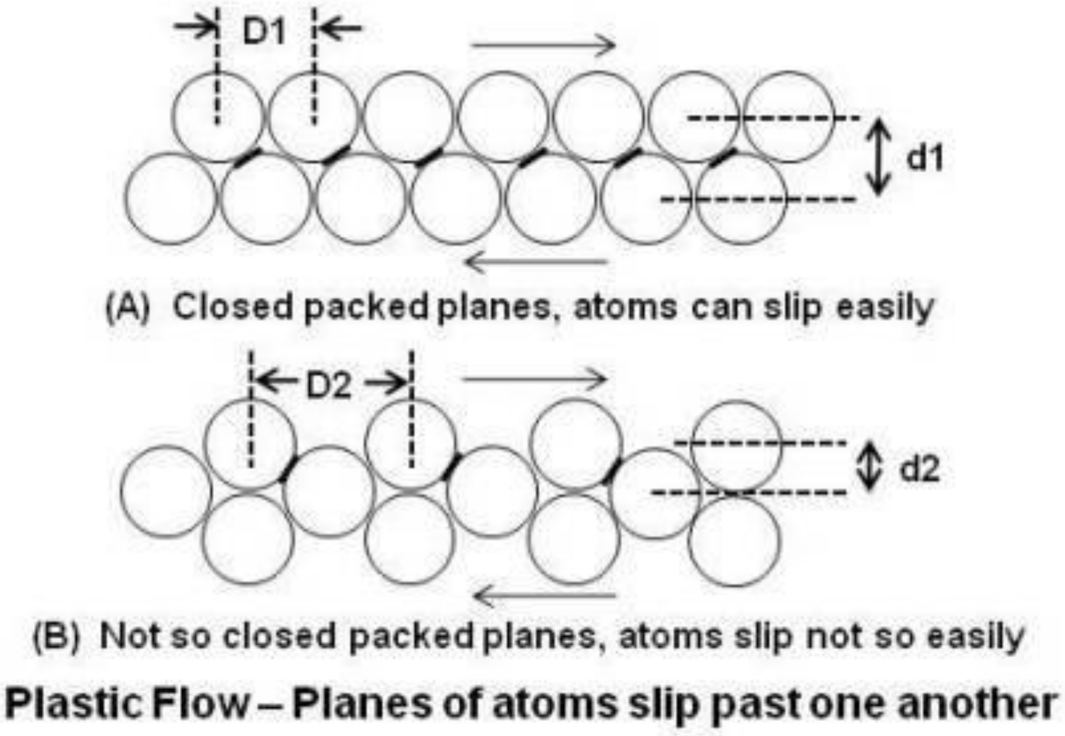


Cold Plastic Def

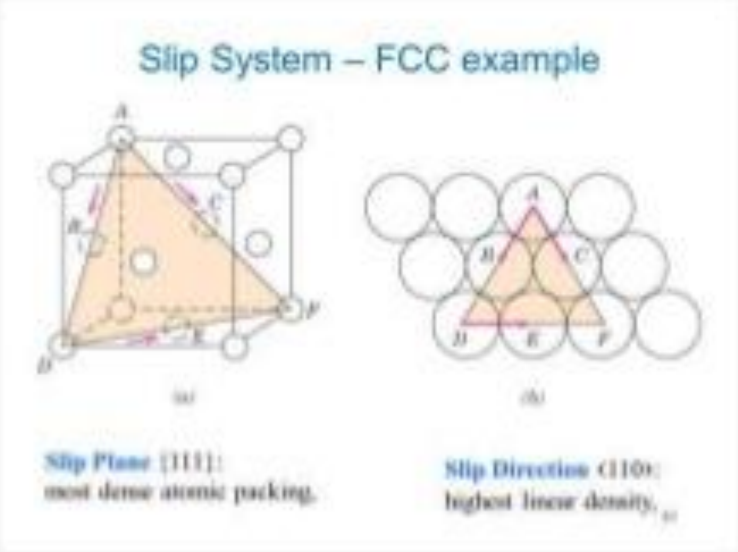


Cold Plastic Deformation Basic





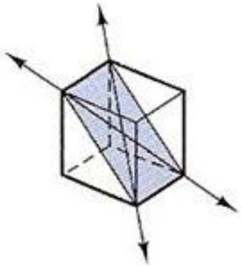
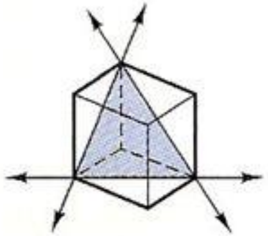
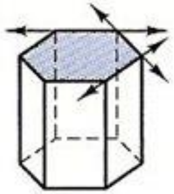
FCC SLIP SYSTEM



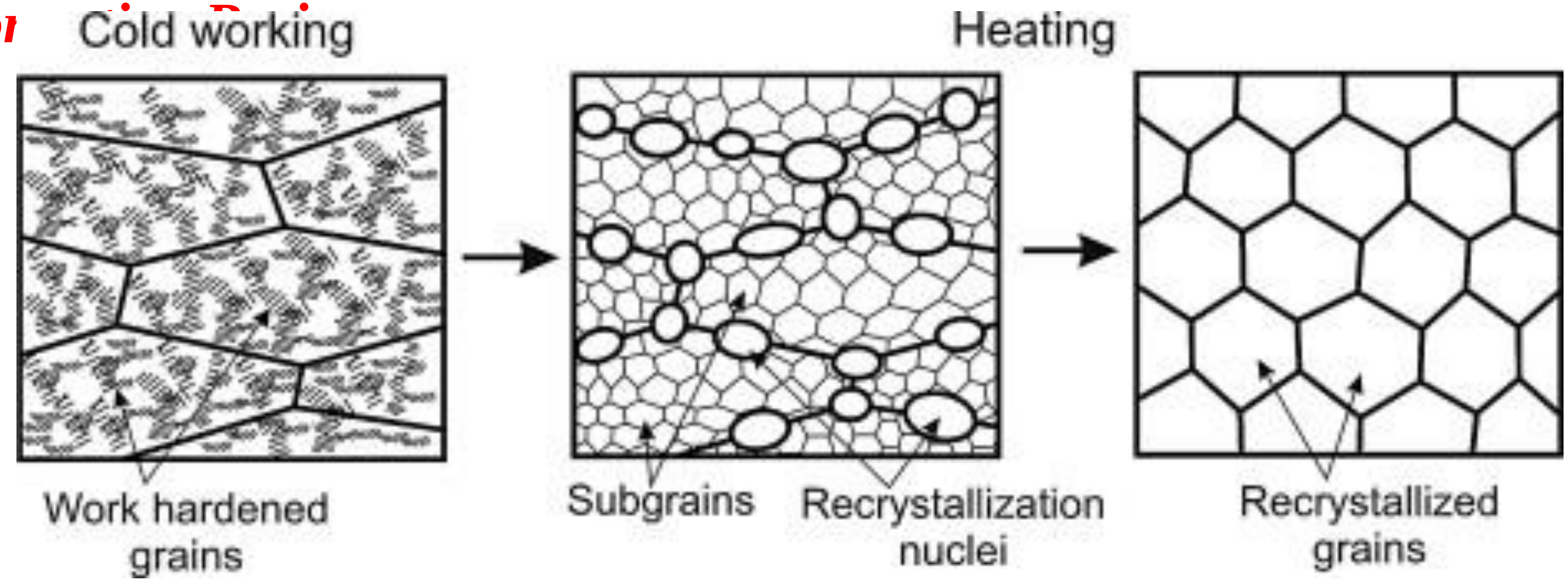
- The slip plane belongs to the {111} family
- Slips occur at <110> -type direction, within {111} planes
- There are several slips direction for a slip plane, forming different possible combination of slip system
- For FCC, 4 unique {111} planes and 3 independent <110> directions, results in 12 slips system.

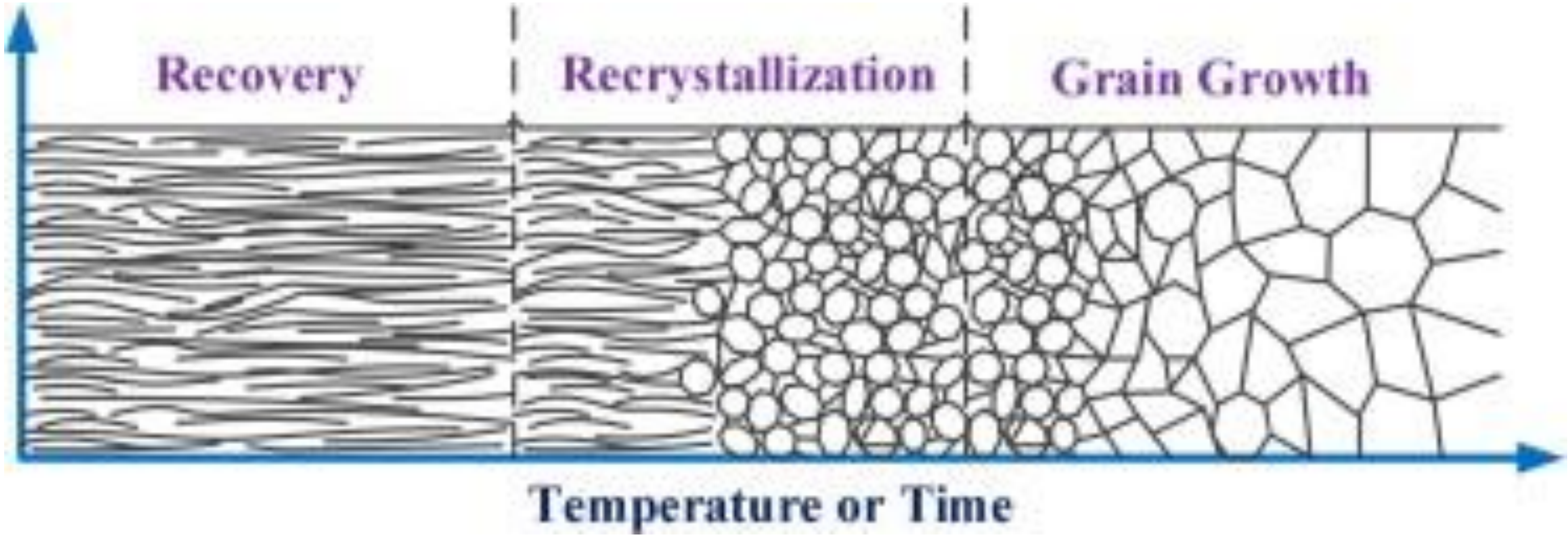
Major Slip Systems

Table 6.9 *Major Slip Systems in the Common Metal Structures*

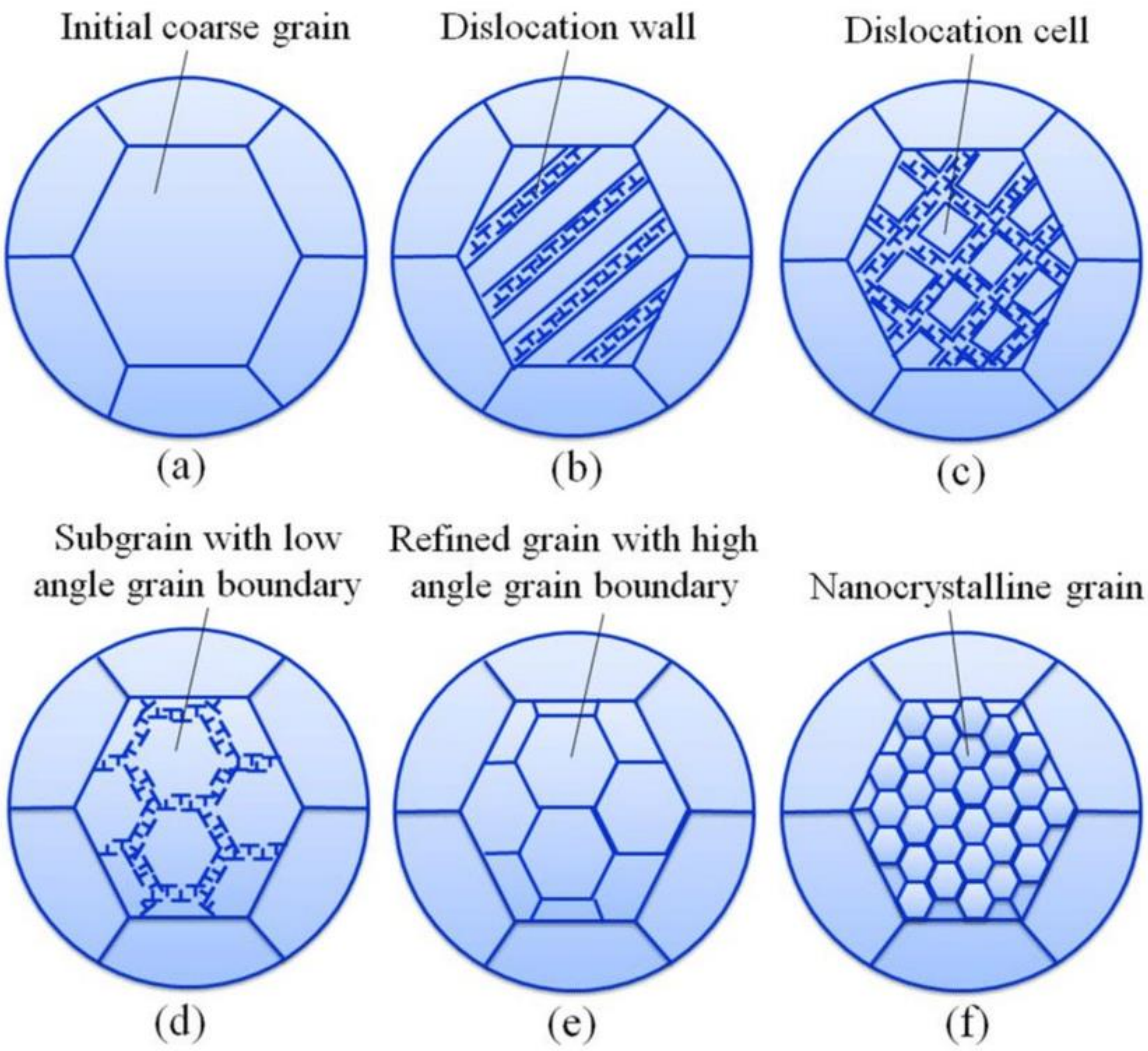
Crystal structure	Slip plane	Slip direction	Number of slip systems	Unit-cell geometry	Examples
bcc	{110}	$\langle\bar{1}11\rangle$	$6 \times 2 = 12$		α-Fe, Mo, W
fcc	{111}	$\langle 1\bar{1}0\rangle$	$4 \times 3 = 12$		Al, Cu, γ-Fe, Ni
hcp	(0001)	$\langle 11\bar{2}0\rangle$	$1 \times 3 = 3$		Cd, Mg, α-Ti, Zn

Cold Plastic Defor

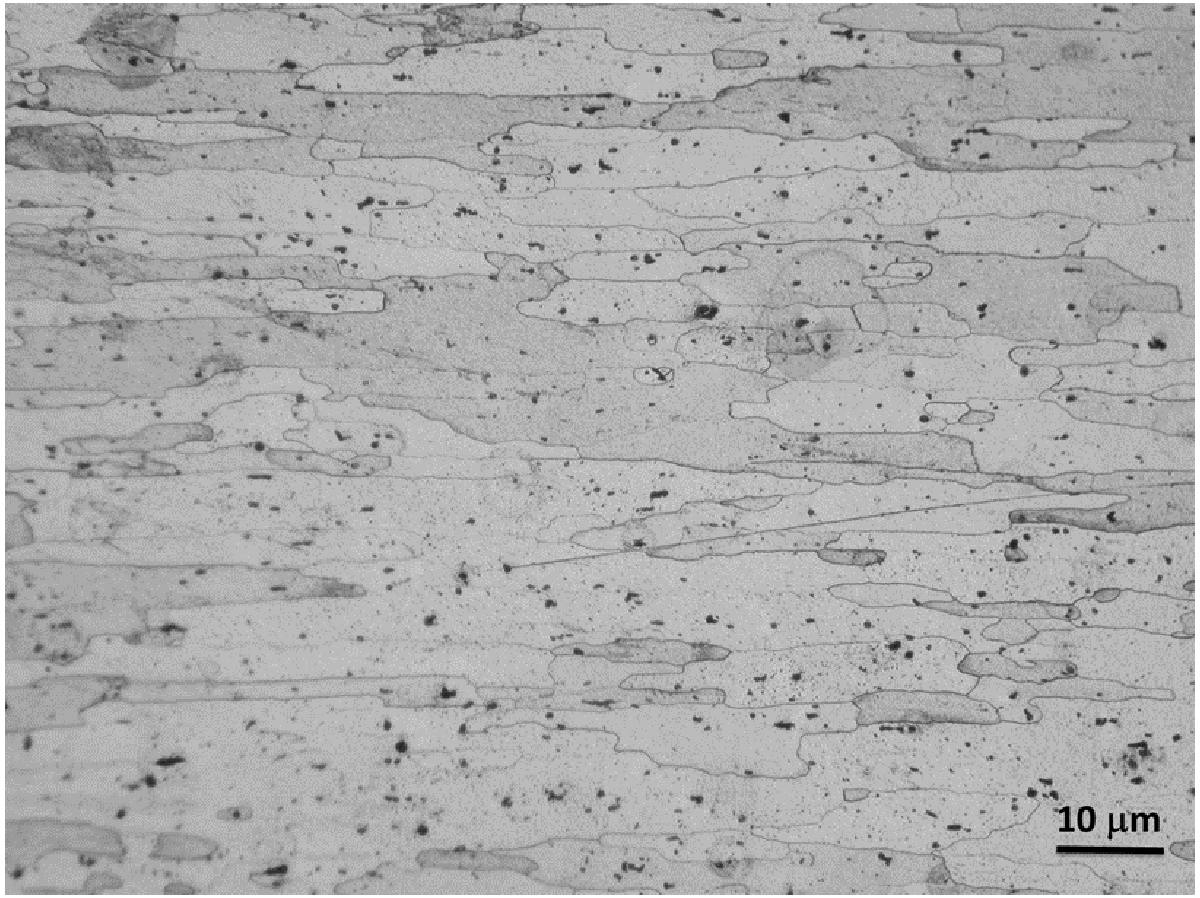


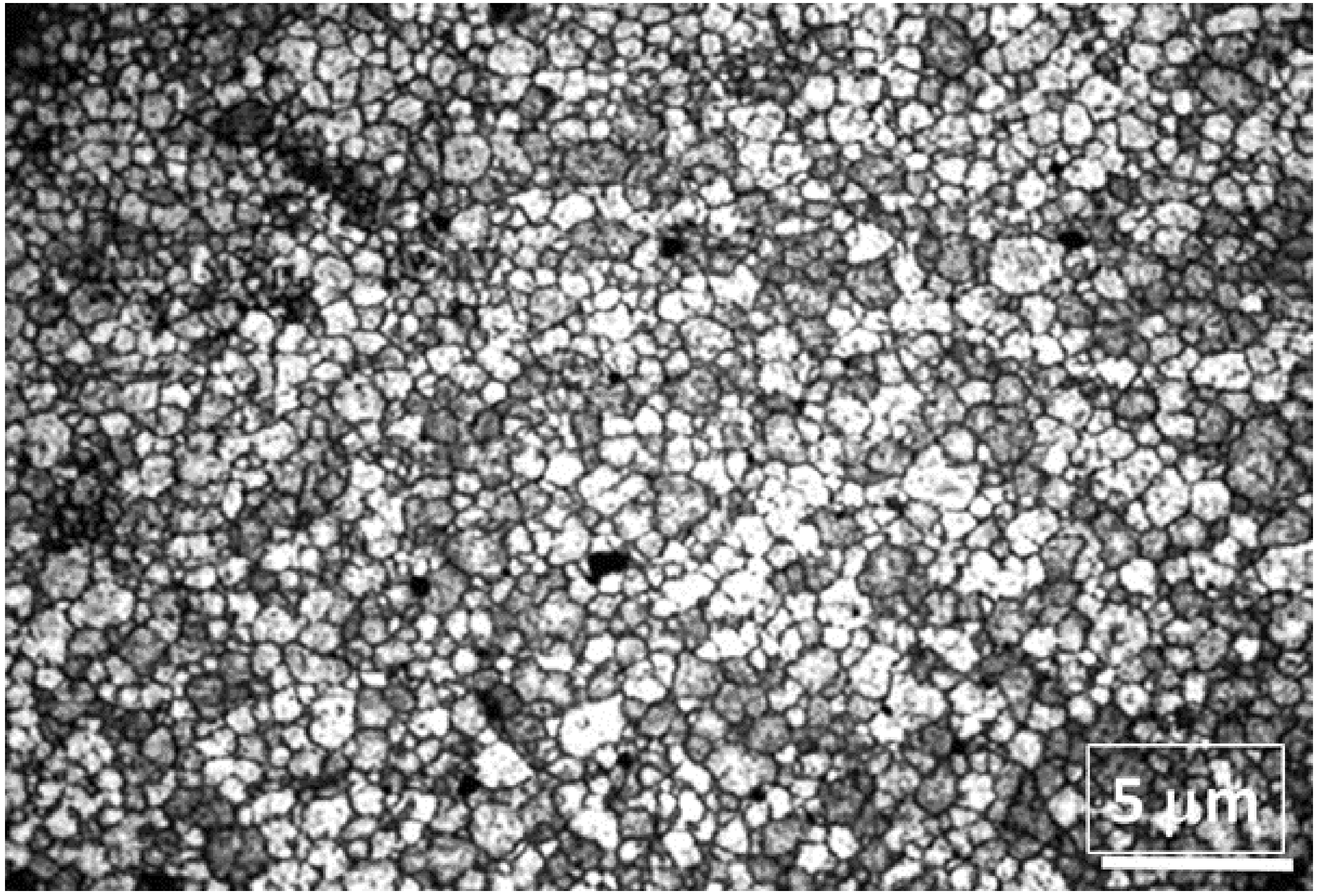


Cold Plastic Deforn

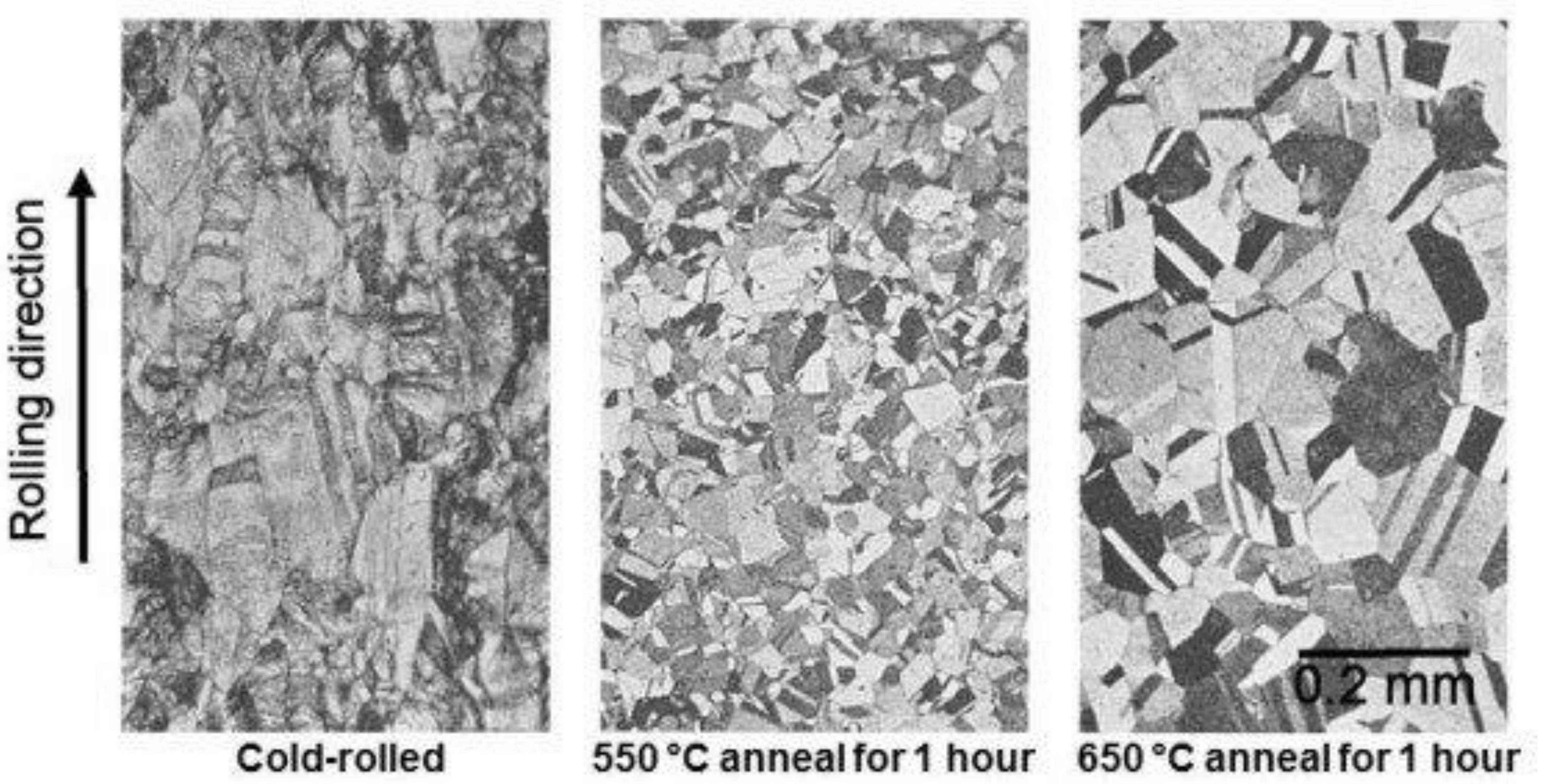


Cold Plastic Deformation Basic

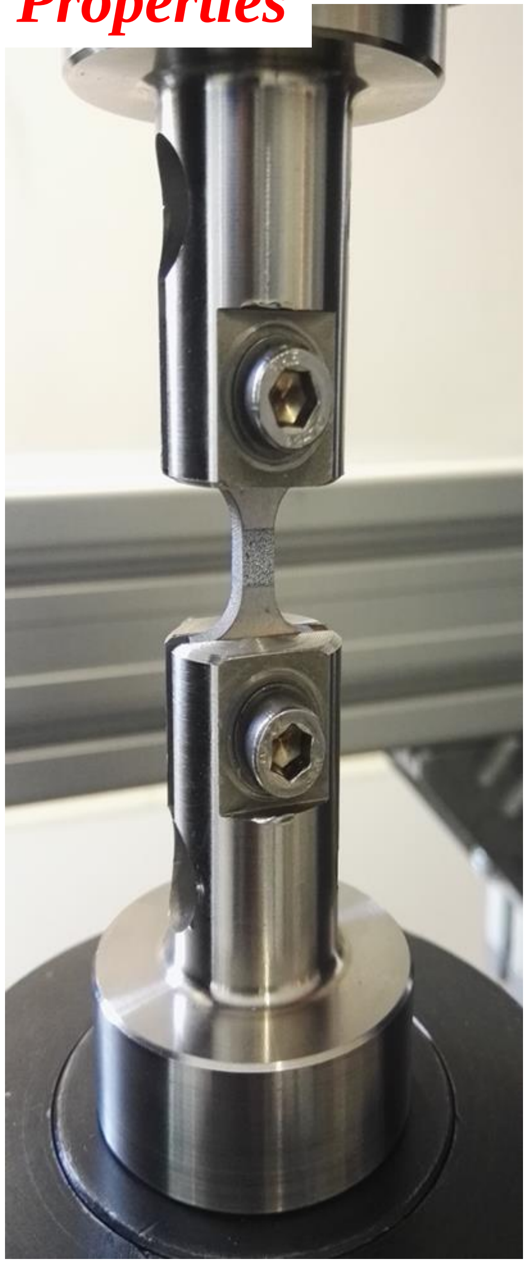


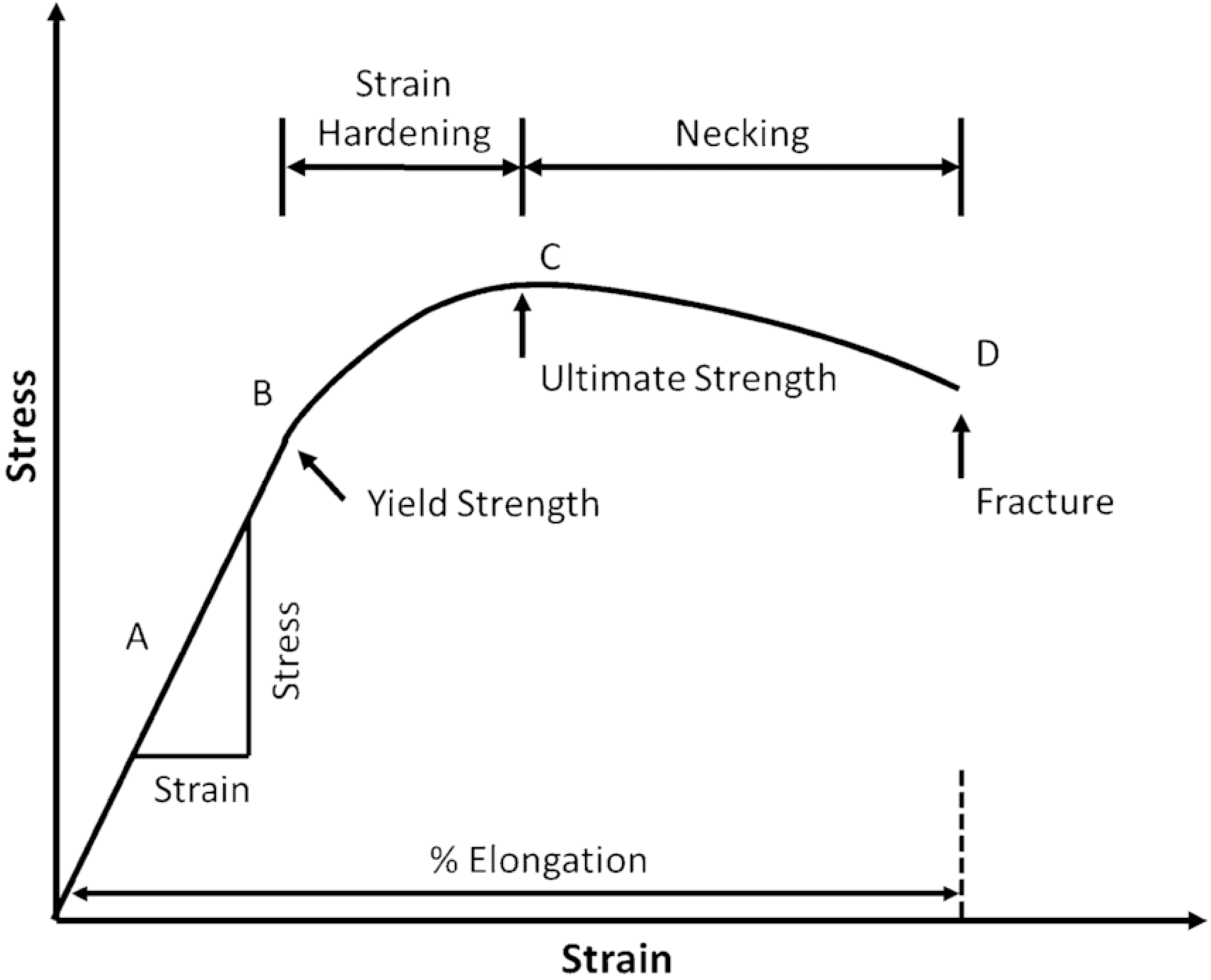


Cold Plastic Deformation Basic



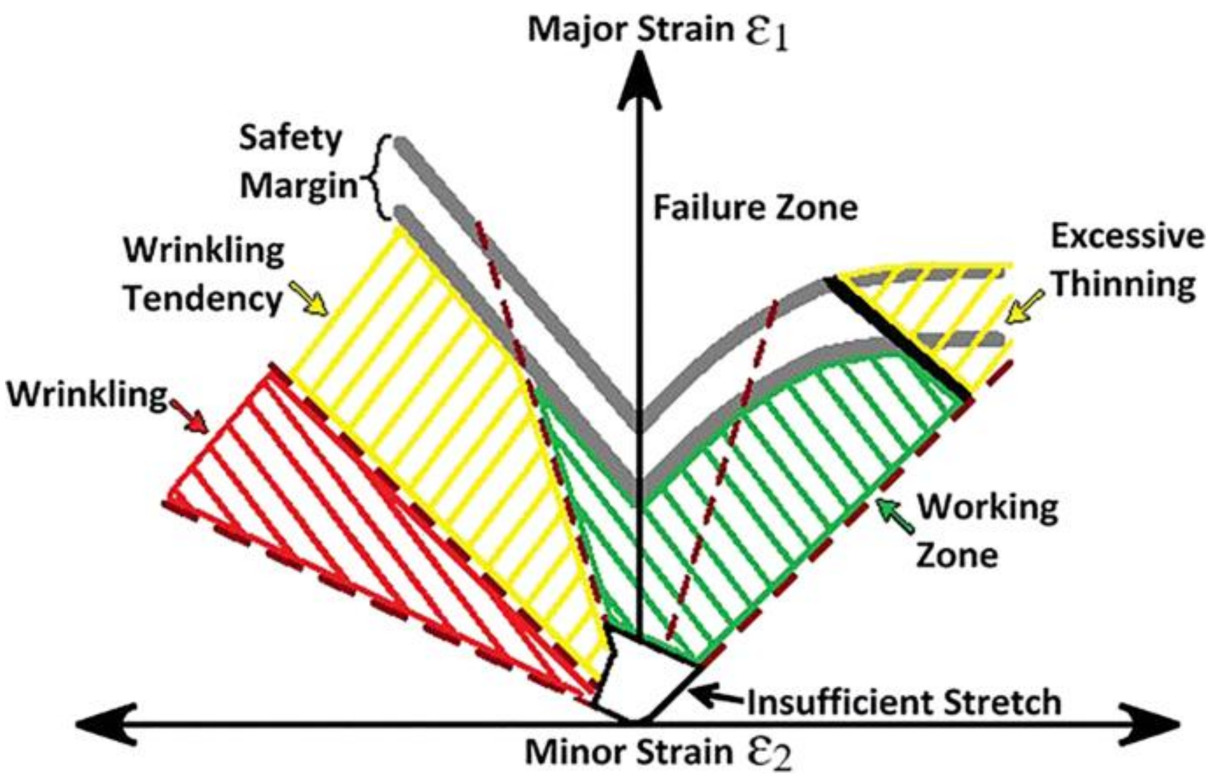
Material Properties

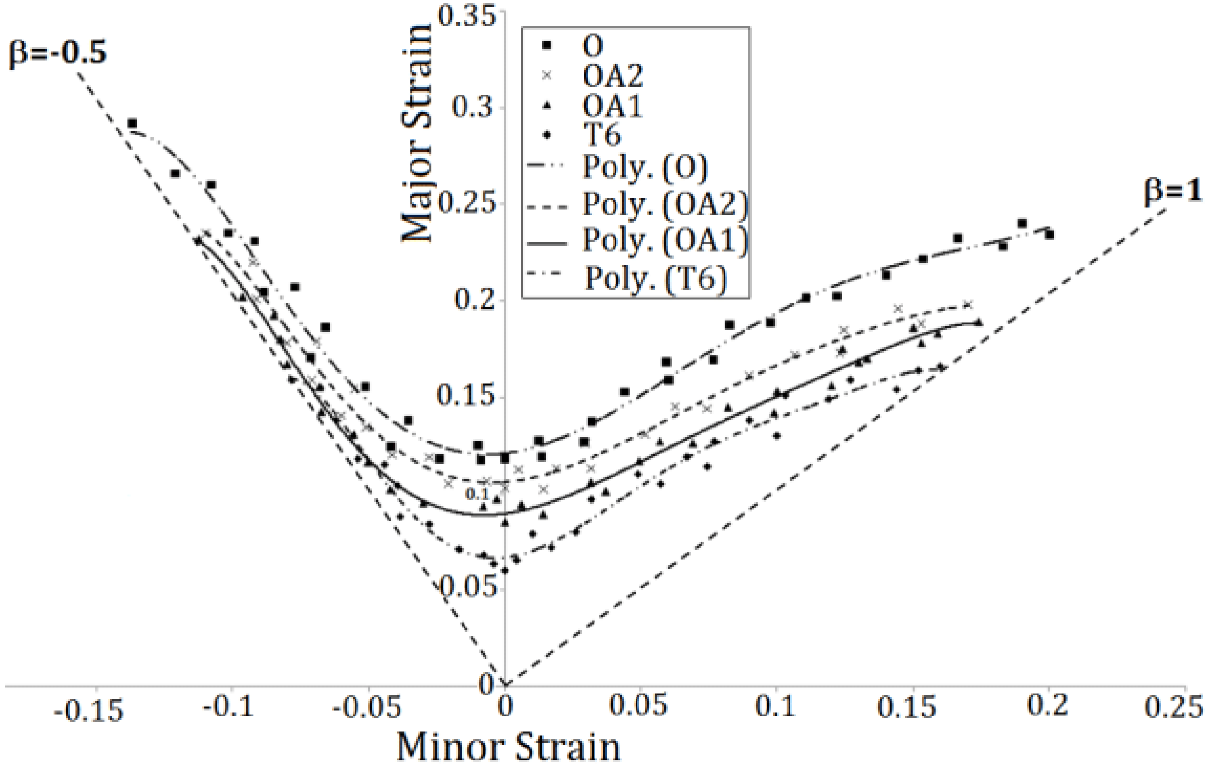




Material Properties

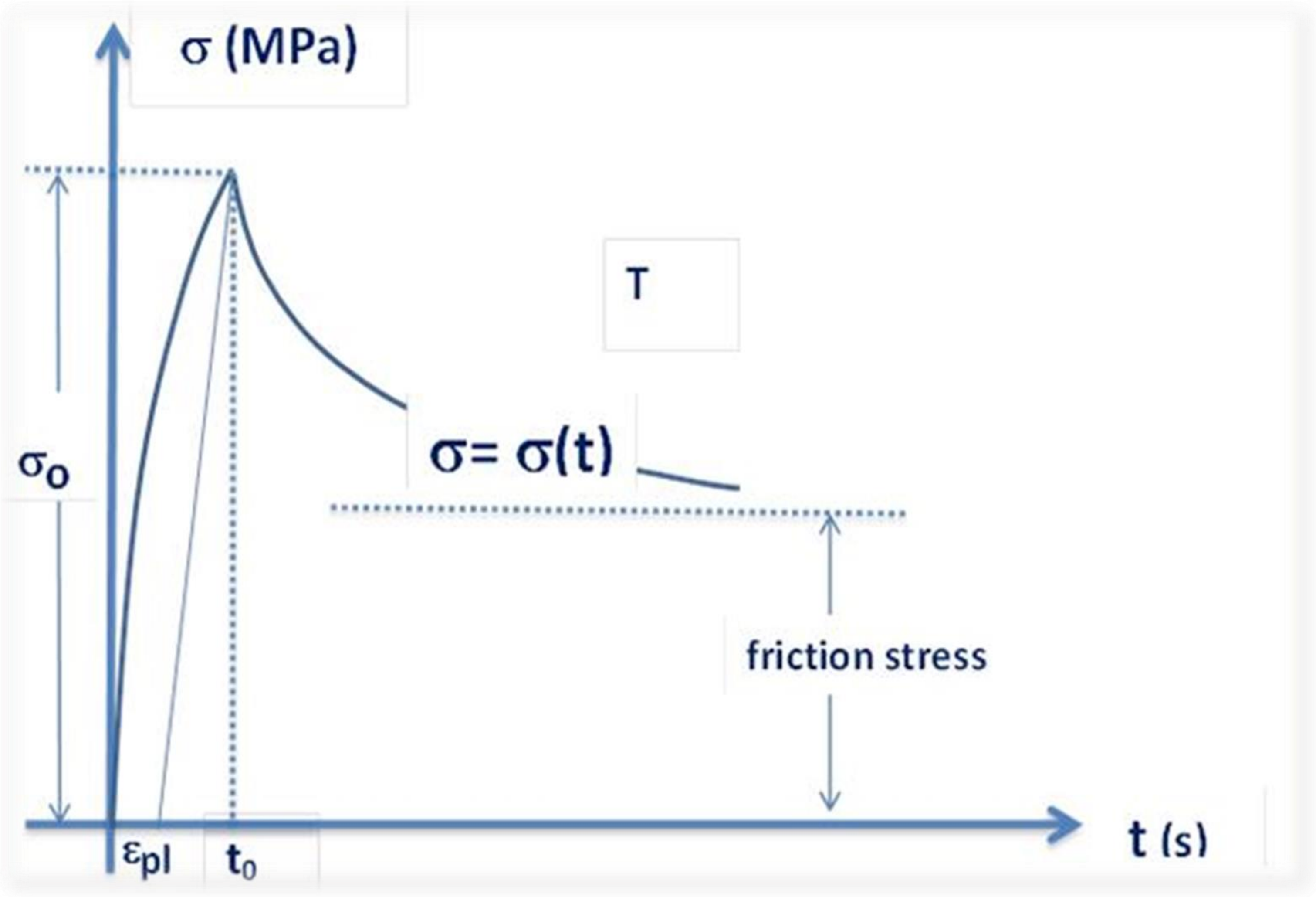
Forming Limit Diagram





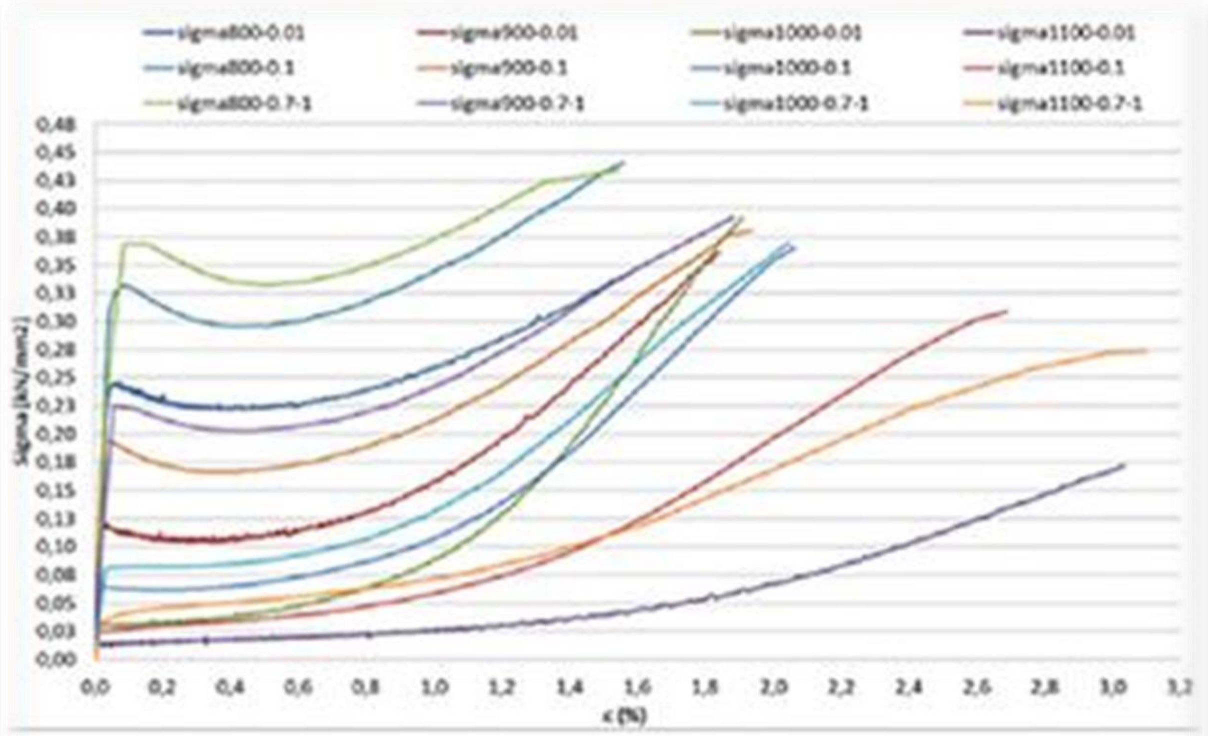
Material Properties

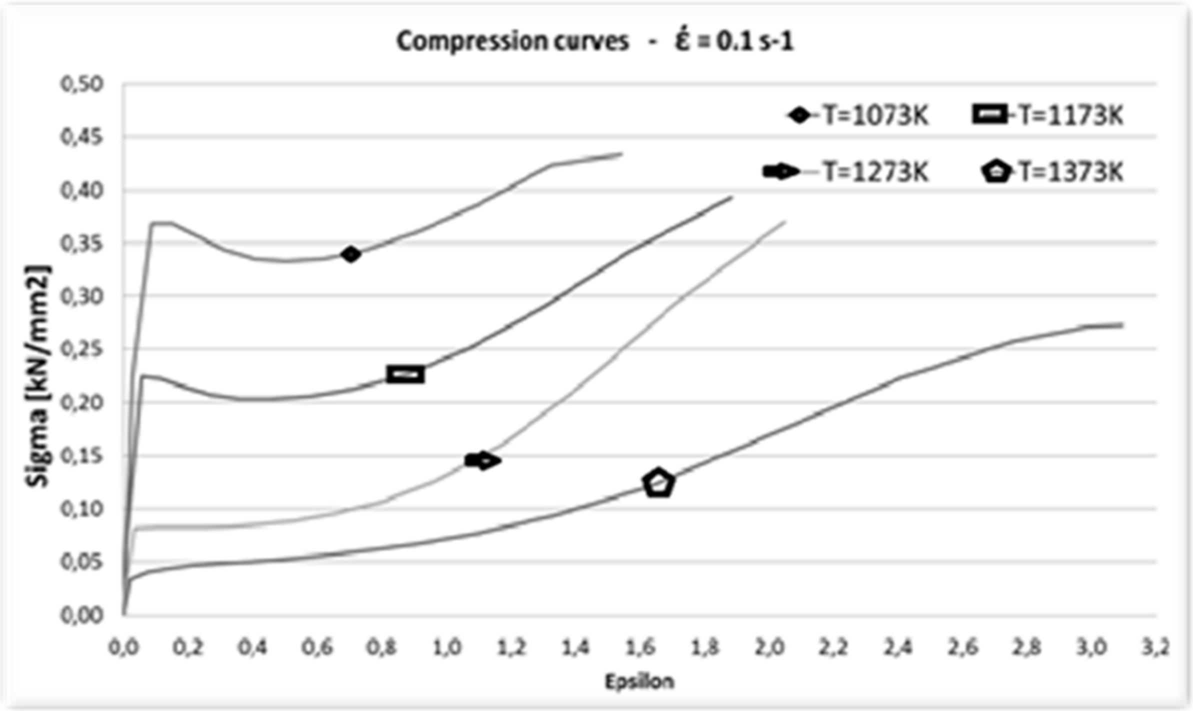
Relaxation test



Material Properties

Compression test





Material Properties

Jhonson Cook Model – a constitutive equation for metals

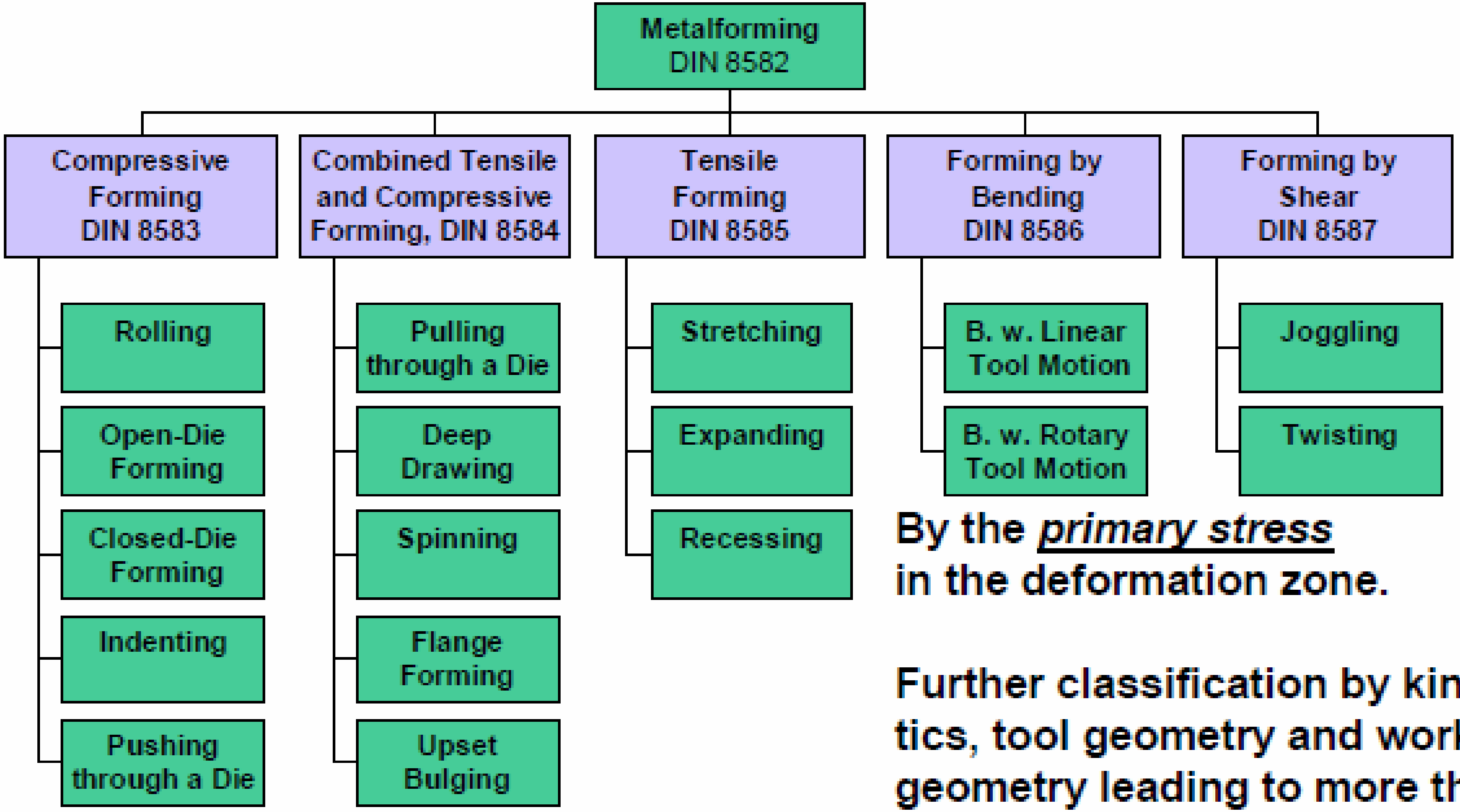
$$\sigma = (A + B\varepsilon^n)(1 + C \ln \dot{\varepsilon}^*)(1 - T^{*m})$$

Work hardening

Strain rate

Thermal softening

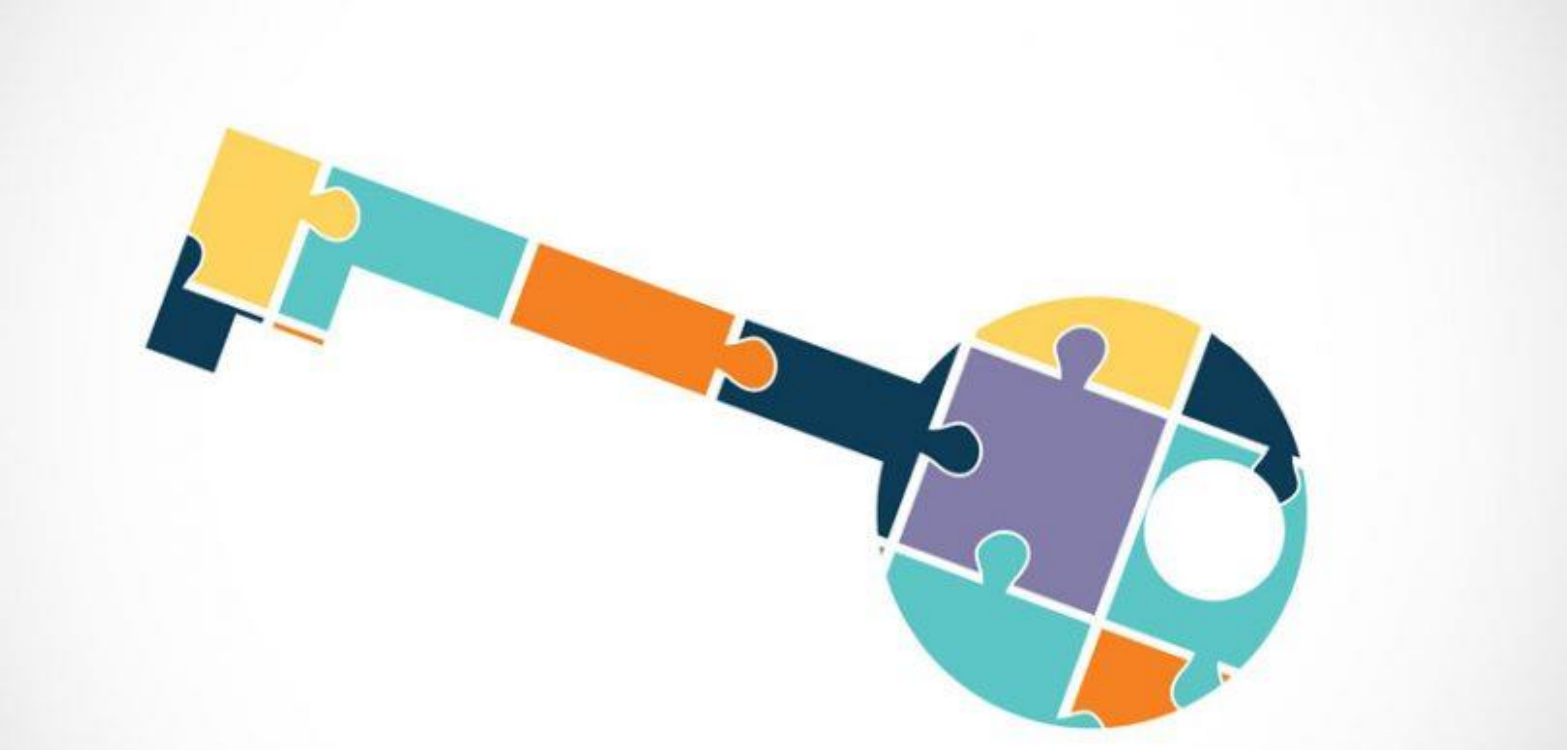
Forming Processes



By the ***primary stress*** in the deformation zone.

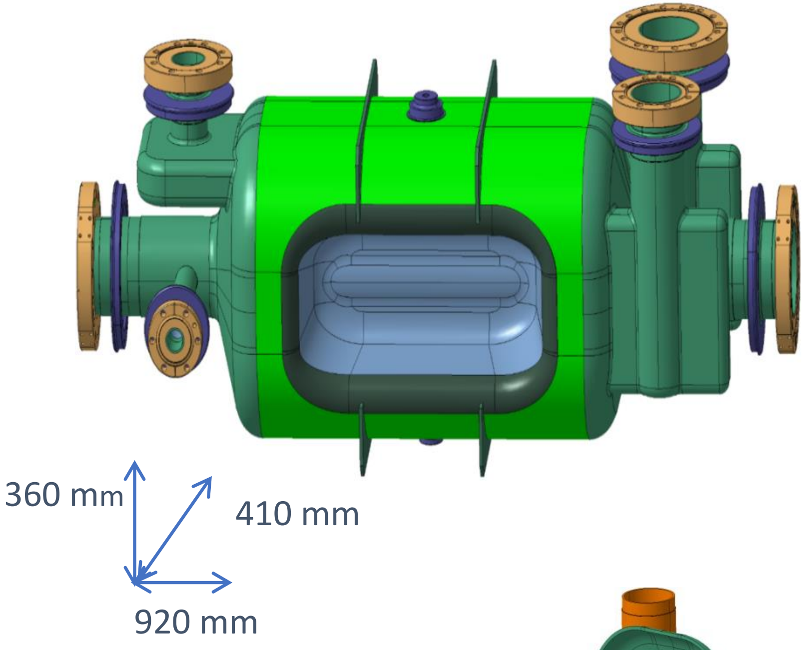
Further classification by kinematics, tool geometry and workpiece geometry leading to more than 200 basic processes!

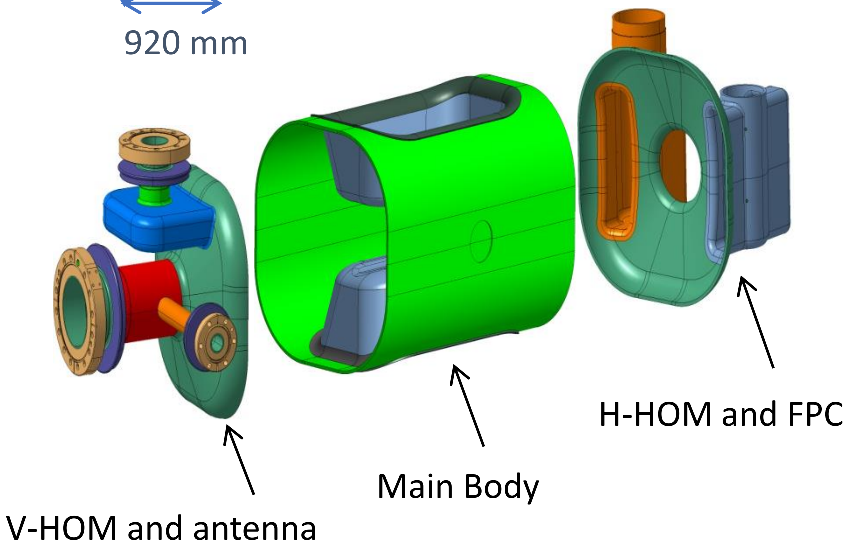
Metal Forming Processes



A KEY MADE OF DIFFERENT PIECES, MADE OF DIFFERENT DISCIPLINES

Radio Frequency Dipole Cavity: why F.E.?





Shaping + **Electron beam welding** of the sub-components

Manufacturing Challenges:

1.Large deformation processes (deep drawing, hole extrusion..)

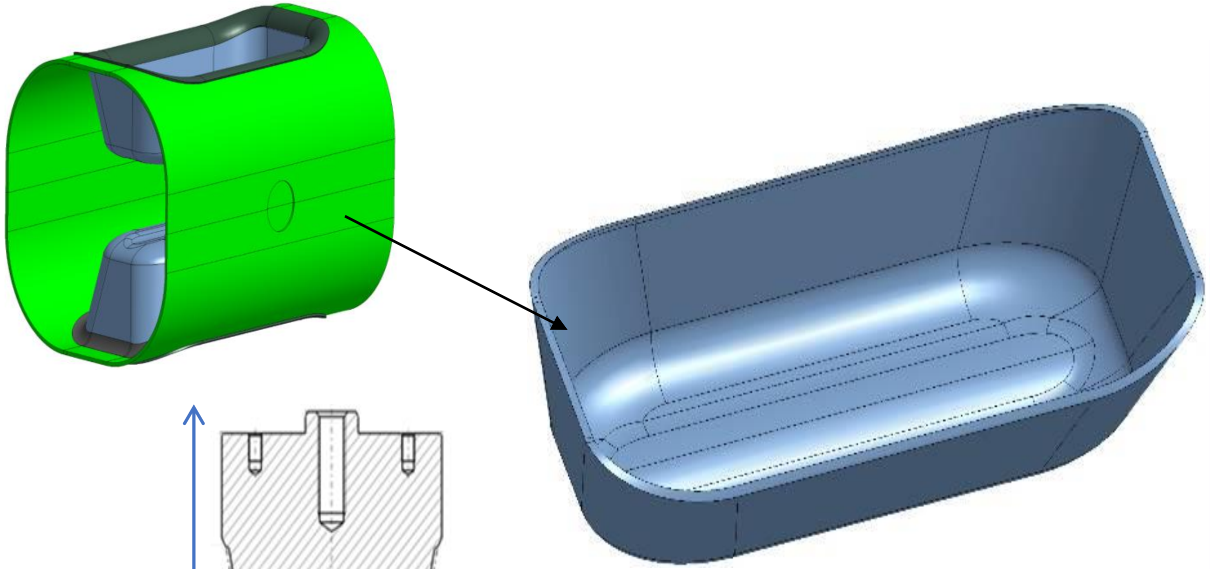
2.Multiple shaping processes on 4mm thick Niobium sheets

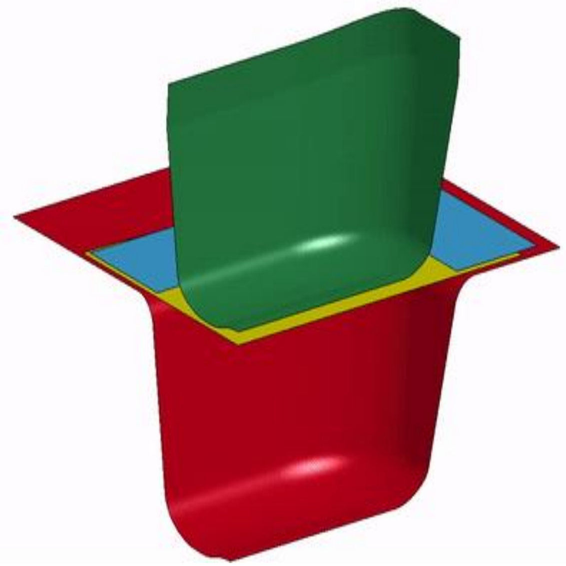
3.Tight geometrical tolerances ($\pm$0.1mm)

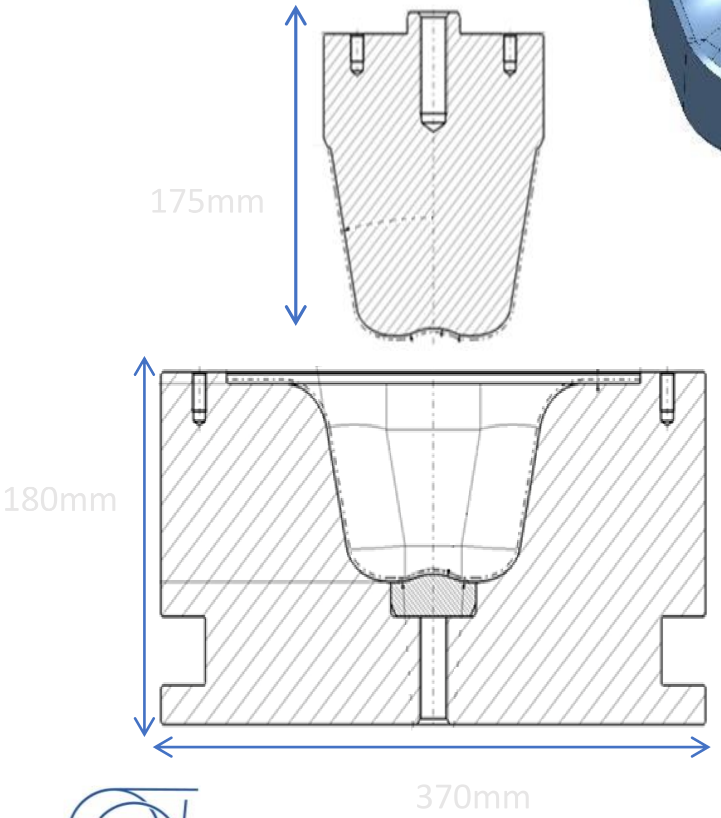
FEM analyses

- Better understanding of the physical phenomena involved in the process
  - ❖ Determining process feasibility
- Faster iteration on the design of the fabrication tools

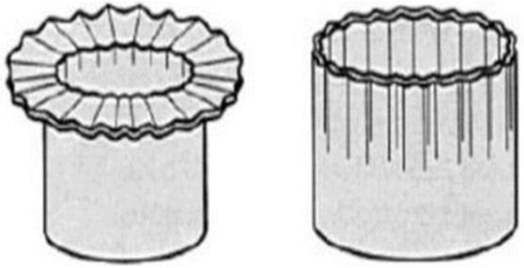
Bowl Case Study: Deep drawing







- High straining of material
- High compressions
- Wrinkles and Puckering

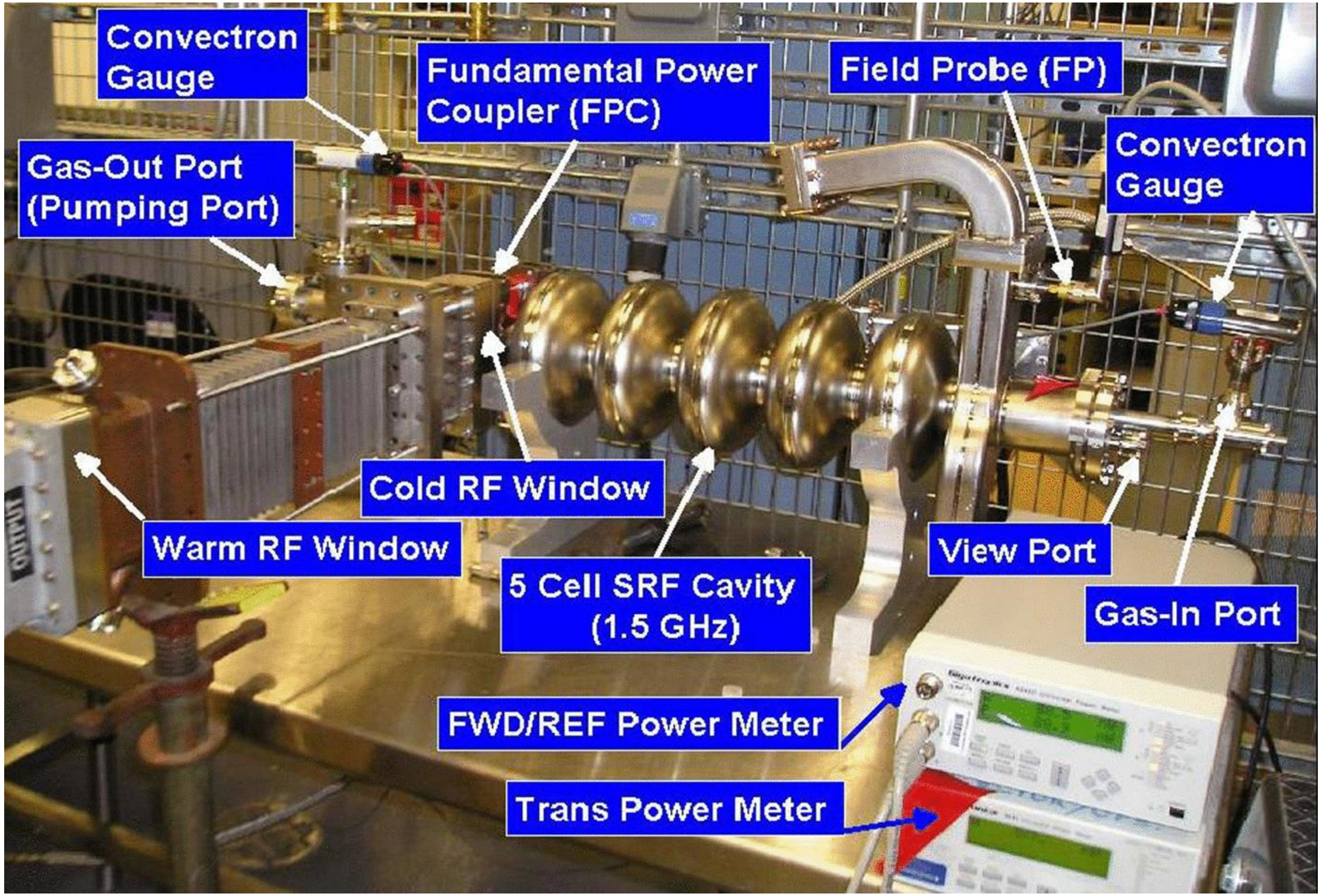


FEM analyses to

- Speed up **tool design**
- Steer **manufacturing choices**

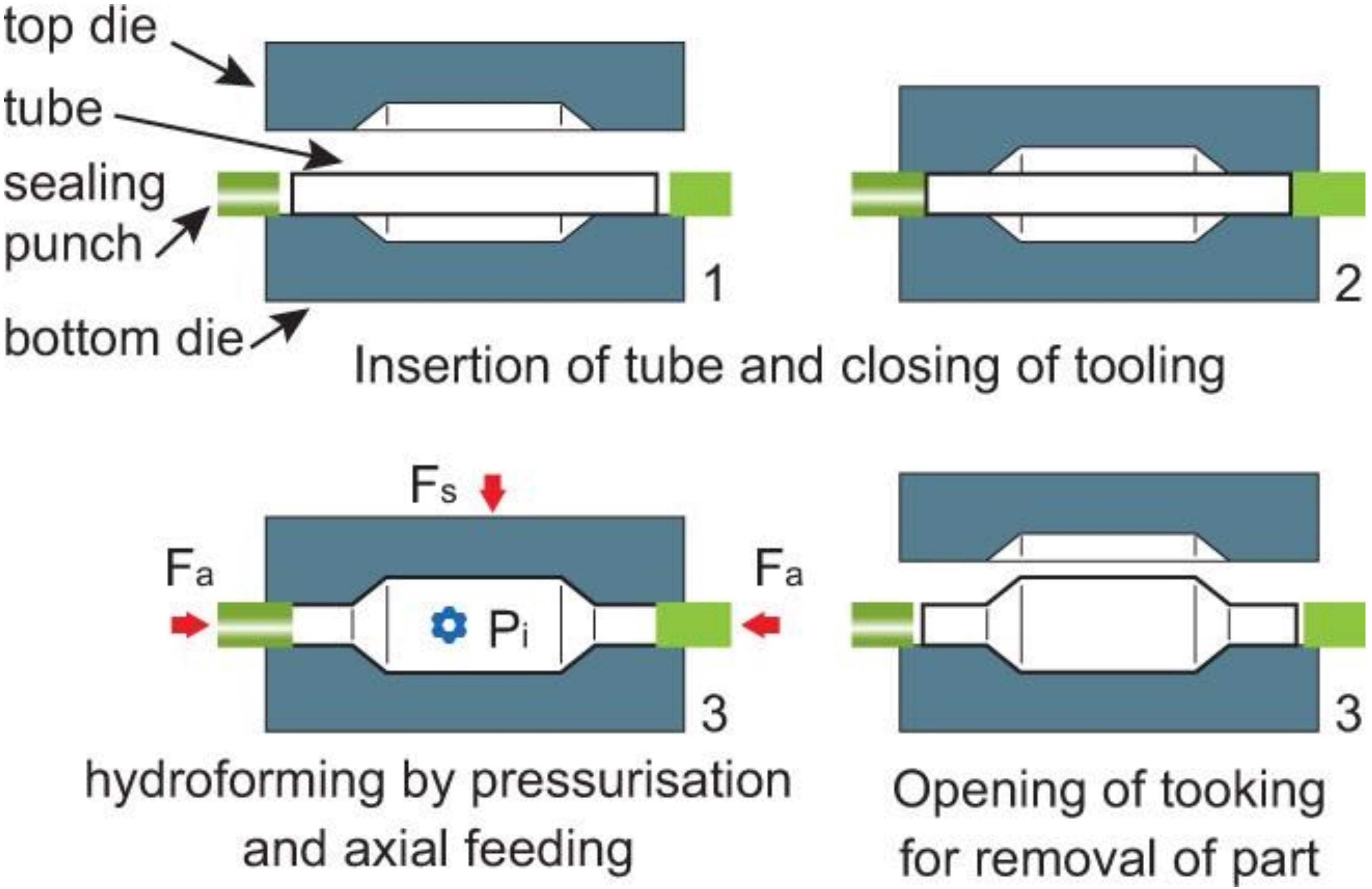
CERN Applications

Multicell RF cavity



CERN Applications

Hydroforming of tubes



CERN Applications

Hydroforming of tubes

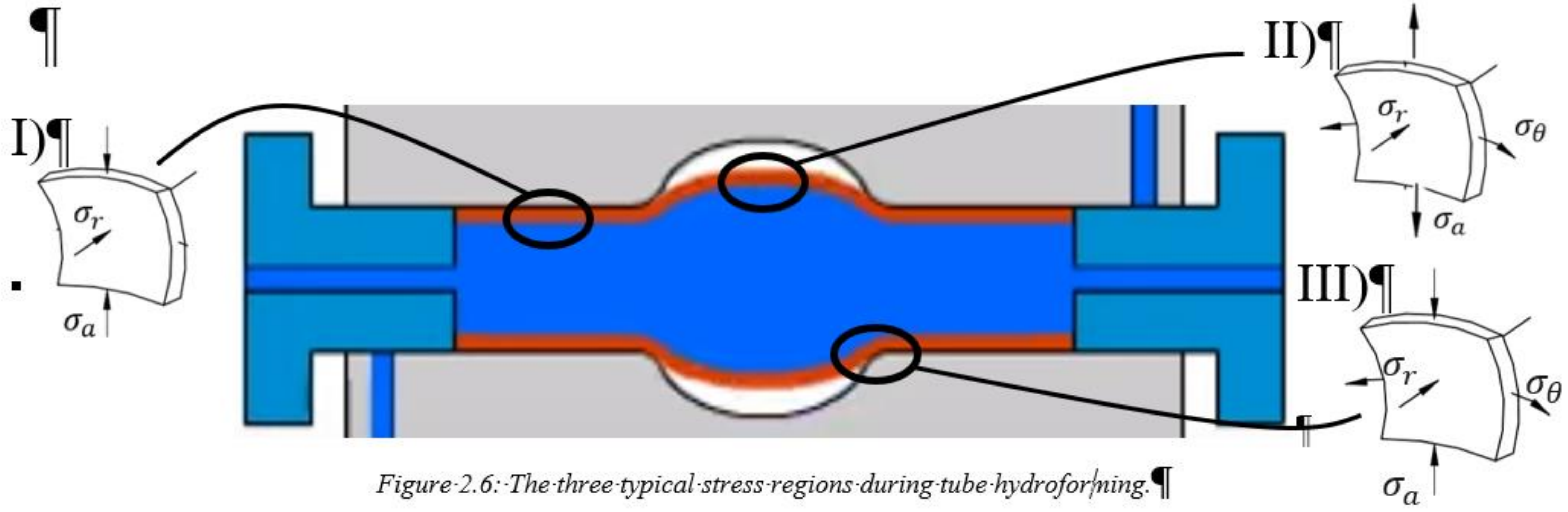
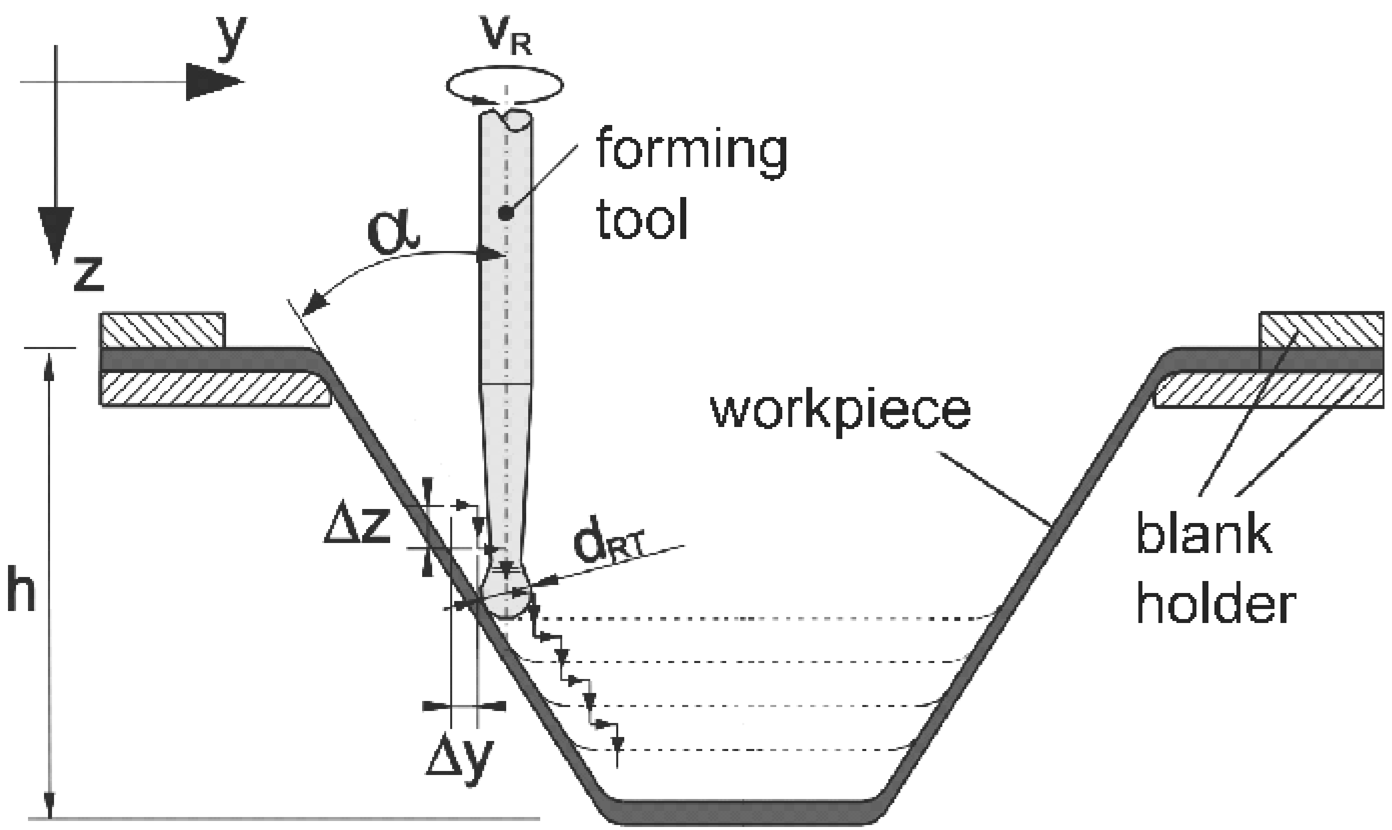


Figure 2.6: The three typical stress regions during tube hydroforming.

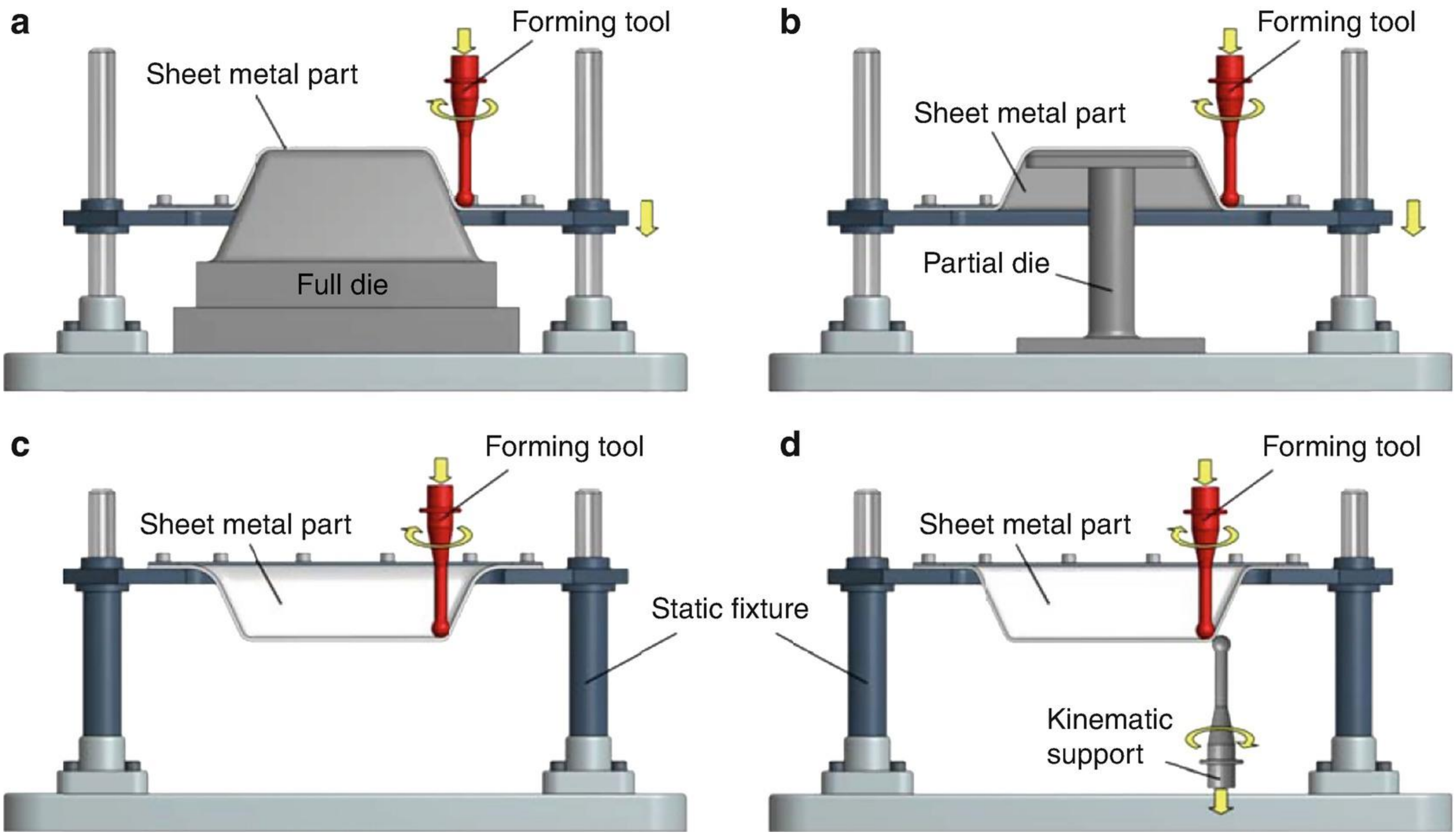
CERN Applications

Hydroforming of tubes

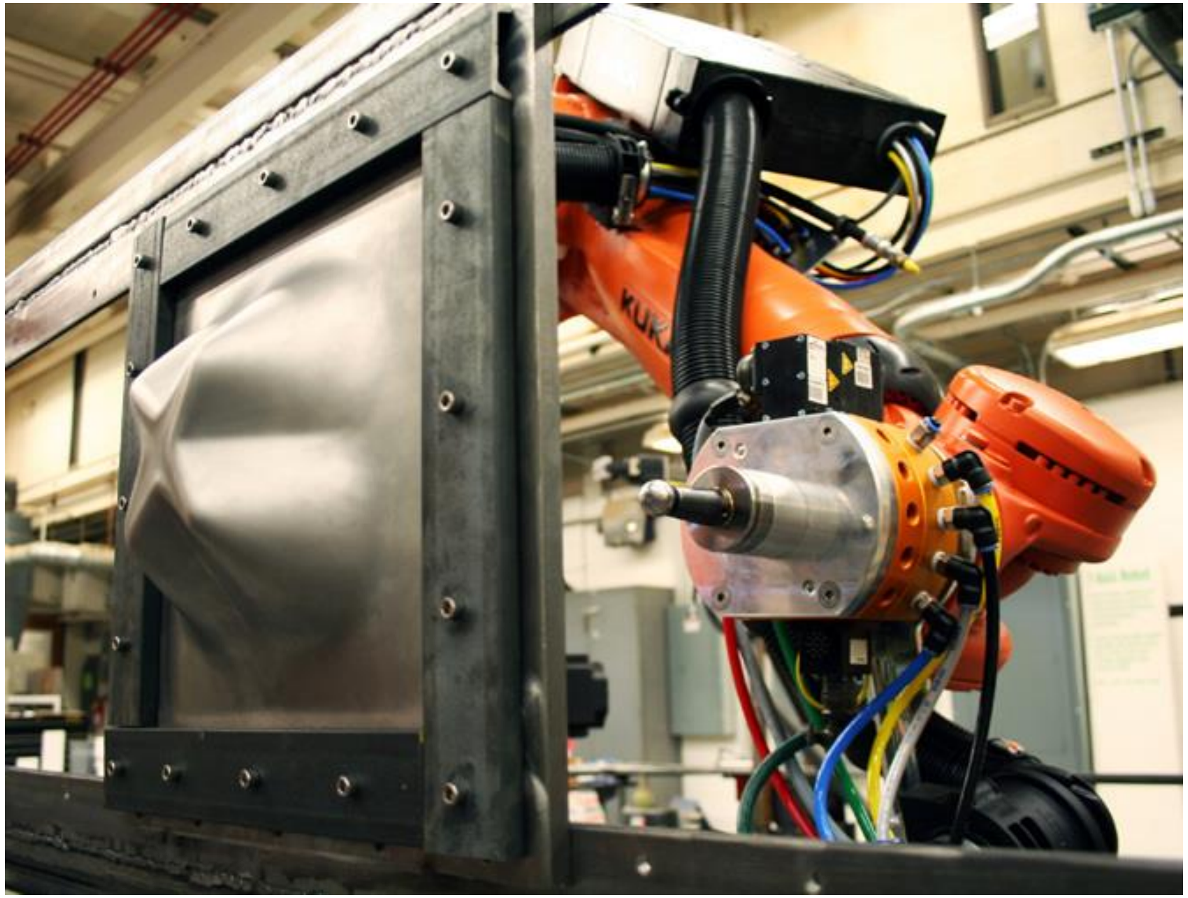
Interesting processes: single point incremental forming



Interesting processes: single point incremental forming



Interesting processes: single point incremental forming



CONCLUDING REMARKS

- **KNOW THE MATERIAL YOU ARE USING**
- **KNOW THE MECHANISMS RULING FORMING**
- **CHARACTERIZE THE PROPERTIES OF THE SPECIFIC RAW MATERIAL YOU ARE USING**
- **KNOW THE PROPERTIES YOU WANT IN THE FINAL PART**
- **FIND OUT A CONSTITUTIVE LAW**
- **CAREFULLY CHOSE THE FORMING PROCESS**
- **MORE THAN CAREFULLY CALIBRATE YOUR PROCESS**
- **(OFF) TOPIC: KNOW TOOLS AND FACILITIES USED AND REQUIRED**

antonello.astarita@gmail.com

antonello.astarita@unina.it

SUGGESTED READINGS

Cahn, Physical Metallurgy
Cottrell, Dislocations and Plastic Flow in Crystals
Dieter, Mechanical Metallurgy