Applications of Twist extrusion

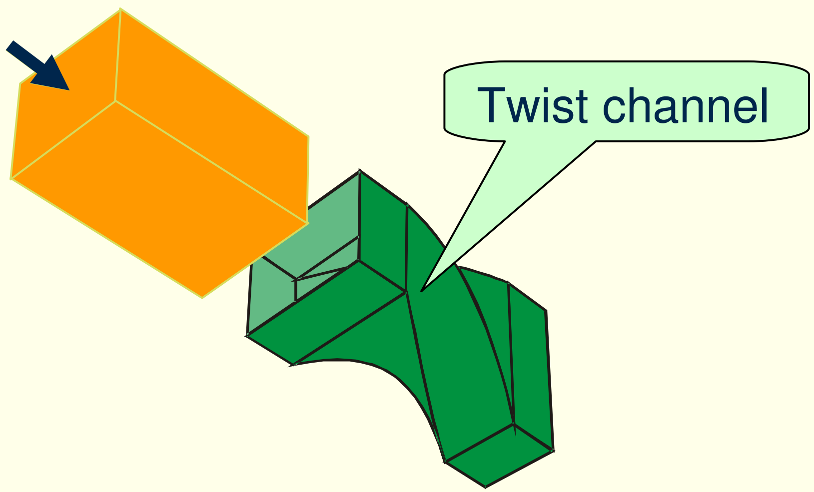
Yan Beygelzimer

Donetsk Institute of Physics and Technology
National Academy of Sciences of Ukraine
Donetsk, UKRAINE

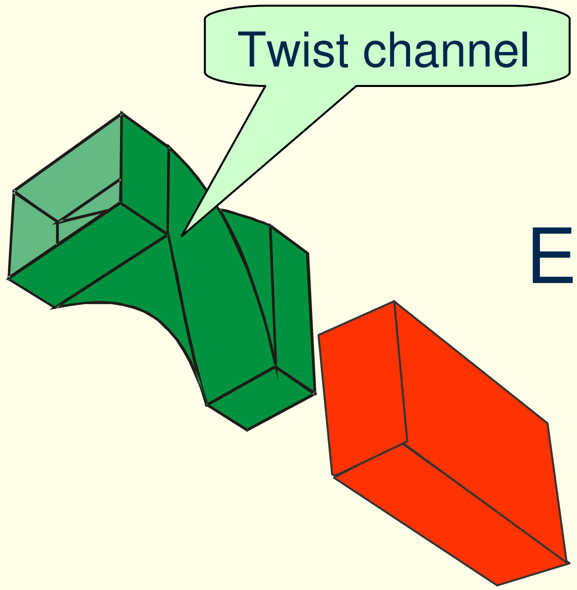
Outline

- TE
- Mechanics of the TE
- Two in one
    - Fragmentation
    - Consolidation
- Rolling with shear
- Main result

The idea of TE:



The idea of TE:

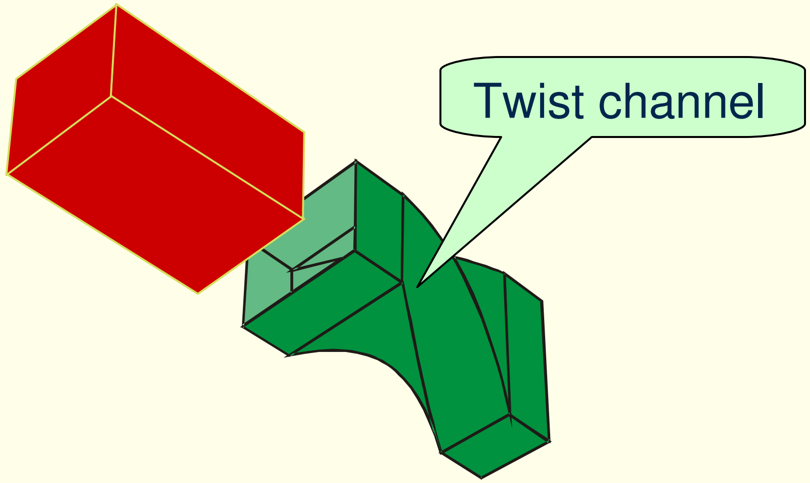


Equivalent strain e~1

The shape and the dimensions of the work-piece do not change!

The idea of TE:

Equivalent strain e~2

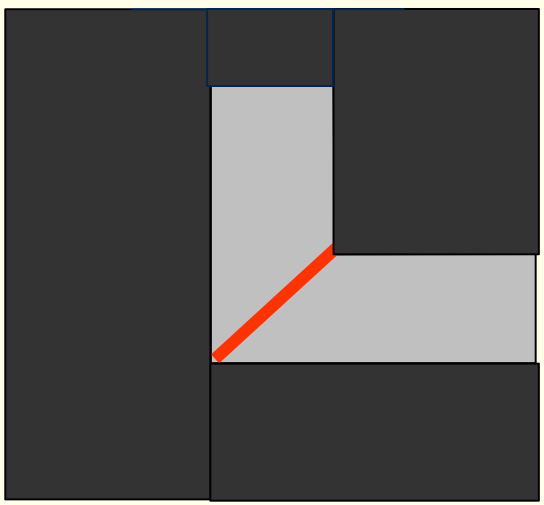


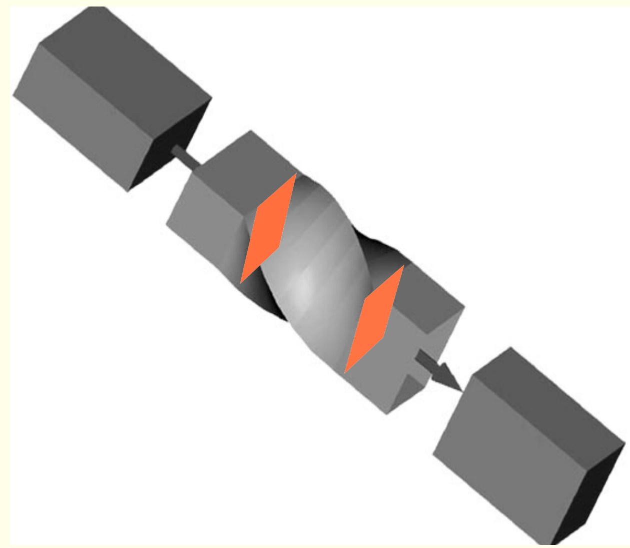
Repeated twist extrusion leads to grain refinement

Peculiarities of the TE

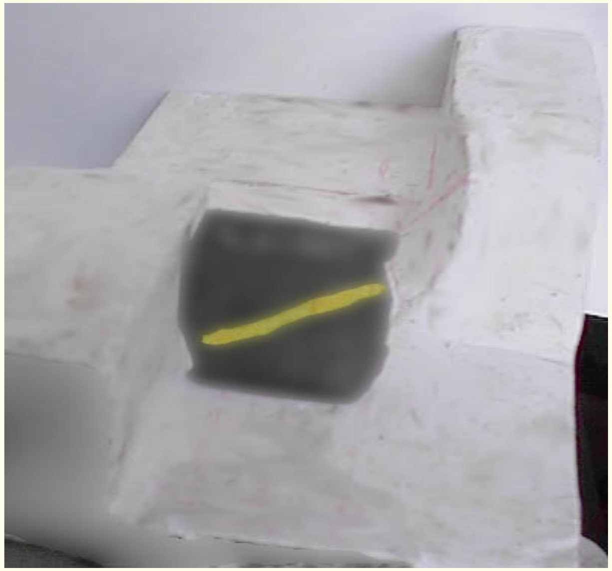
Shear plane

The simple shear plane in TE is perpendicular to the axis of the specimen, instead of being at 45-60 degrees as in ECAE. This allows us to obtain new structures and textures.





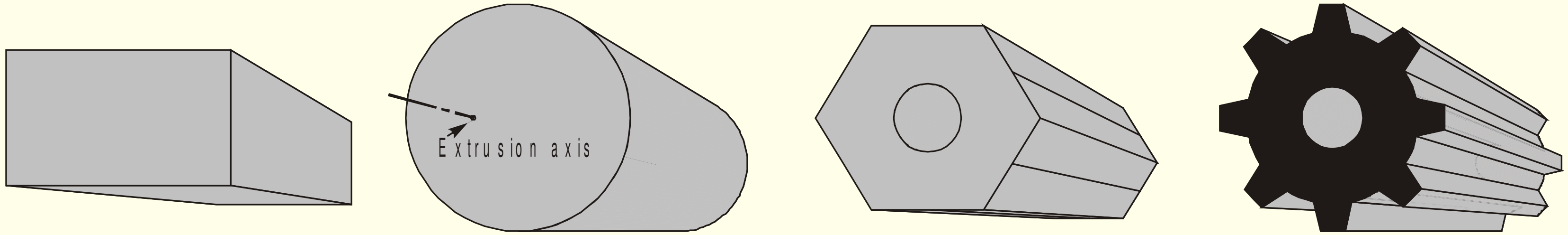
Peculiarities of the material flow



TE is characterized by intense flows of material being deformed within cross-sections of the billet. This is very important when deforming powder materials since it intensifies consolidation processes

Possible cross-sections of final product

•TE can handle profile billets including those with the axial channel.

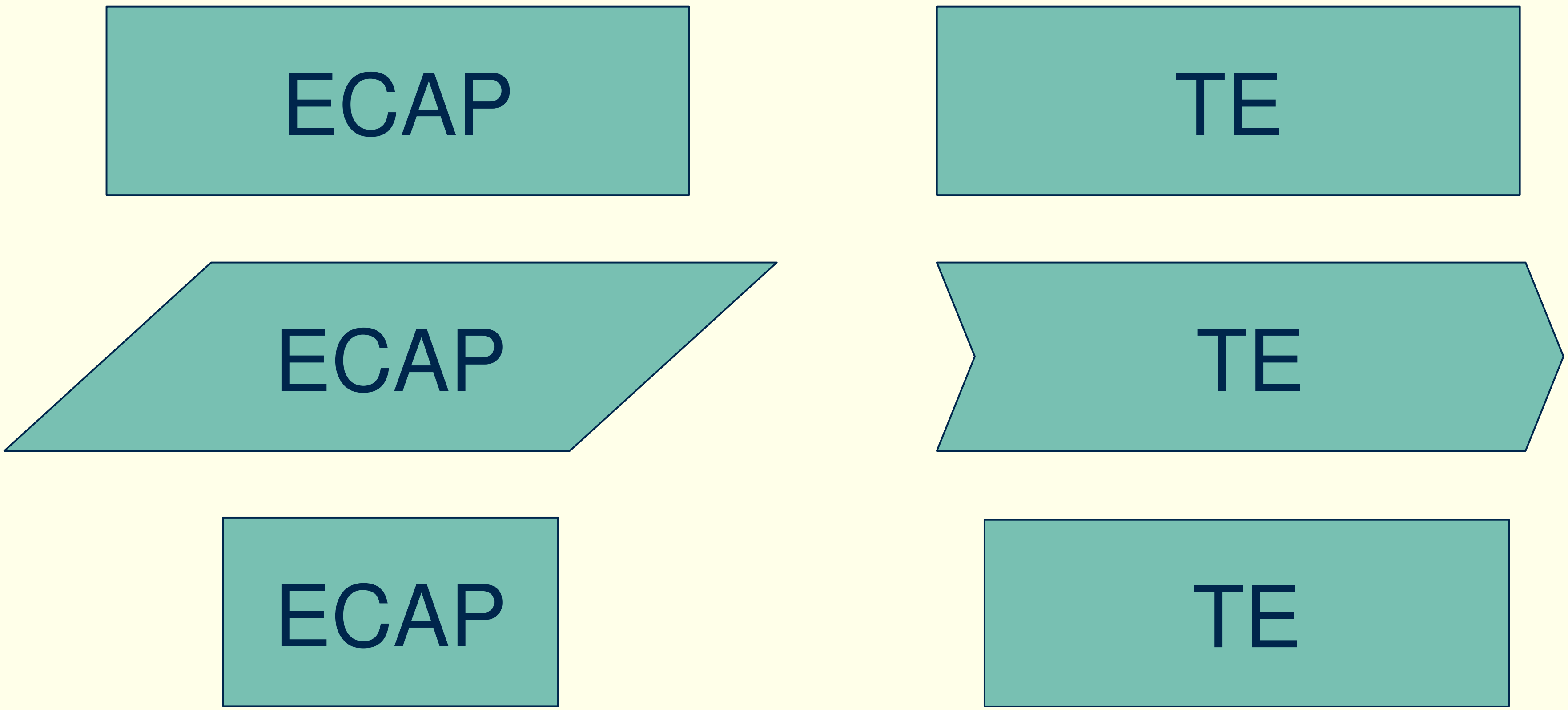


•TE does not change the direction of the billet moving which allows one to embed TE into already existing industrial lines.

•TE can easily be performed on any standard extrusion equipment by putting a twist die in place of the standard die.

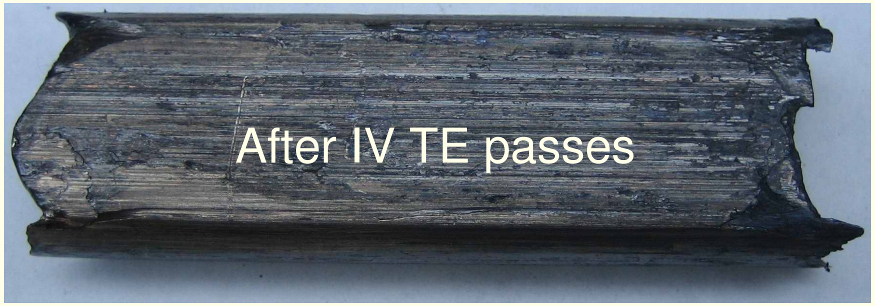
Waste of metal at TE and ECAP

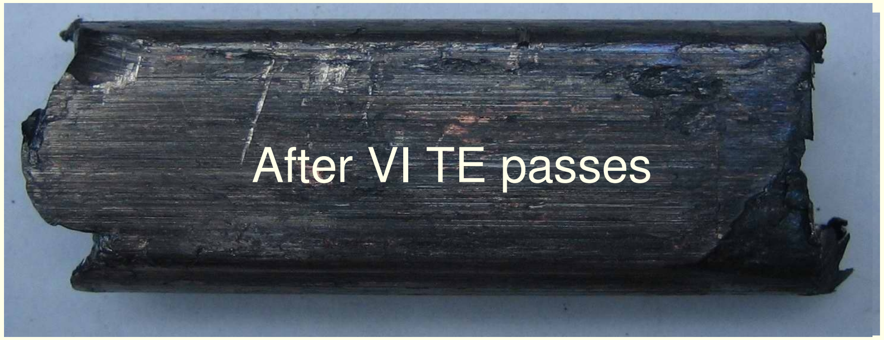
Form of the TE processed billets: amount of waste material



Waste of metal at TE

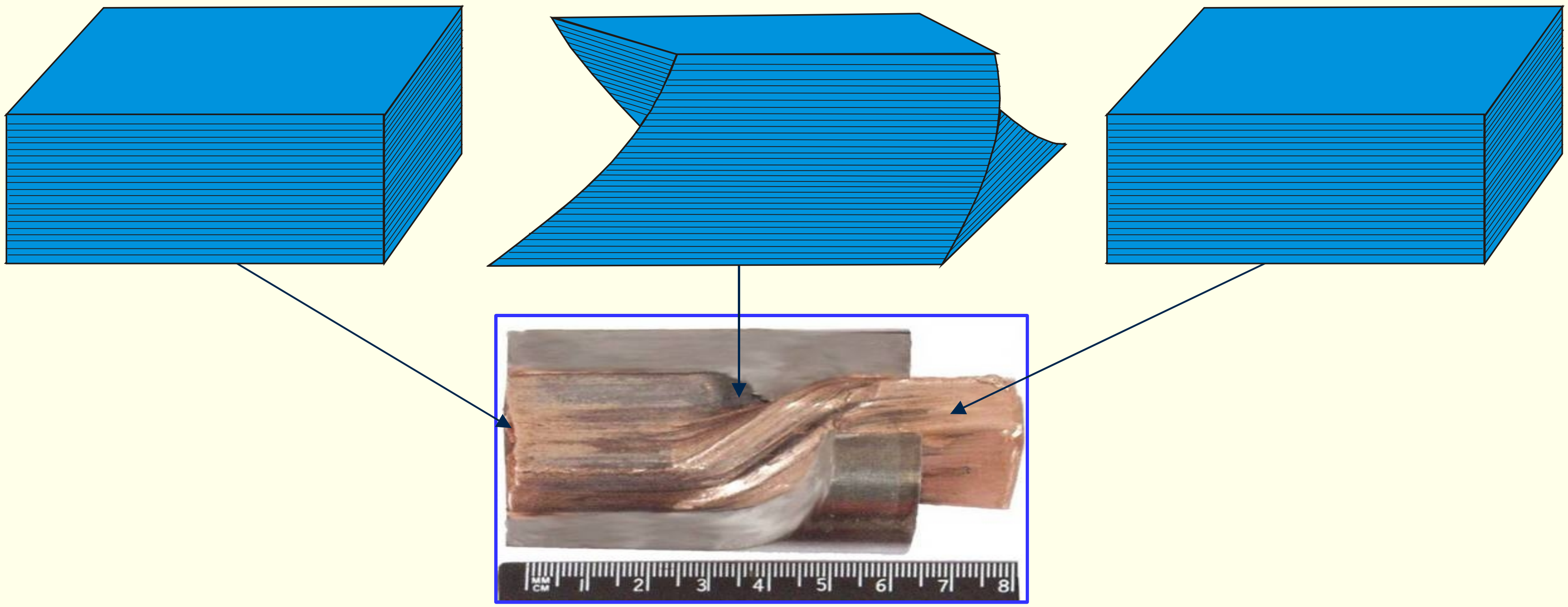
Form of the TE processed billets (Cp Ti Grade 2)



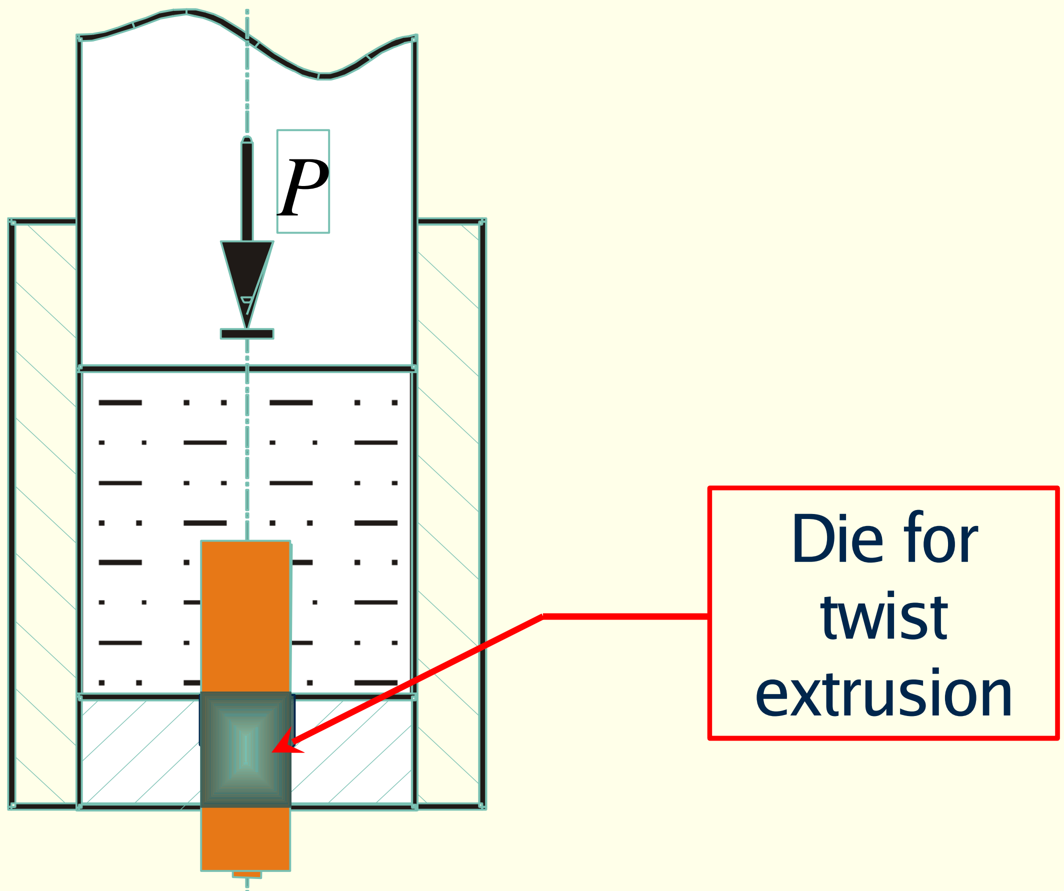


Change of specimen surface

TE is characterized by a significant nonmonotone change of specimen surface while the specimen goes through the die. Such changes affect metal structure and could allow one to insert various alloying elements into surface layers of the billet.

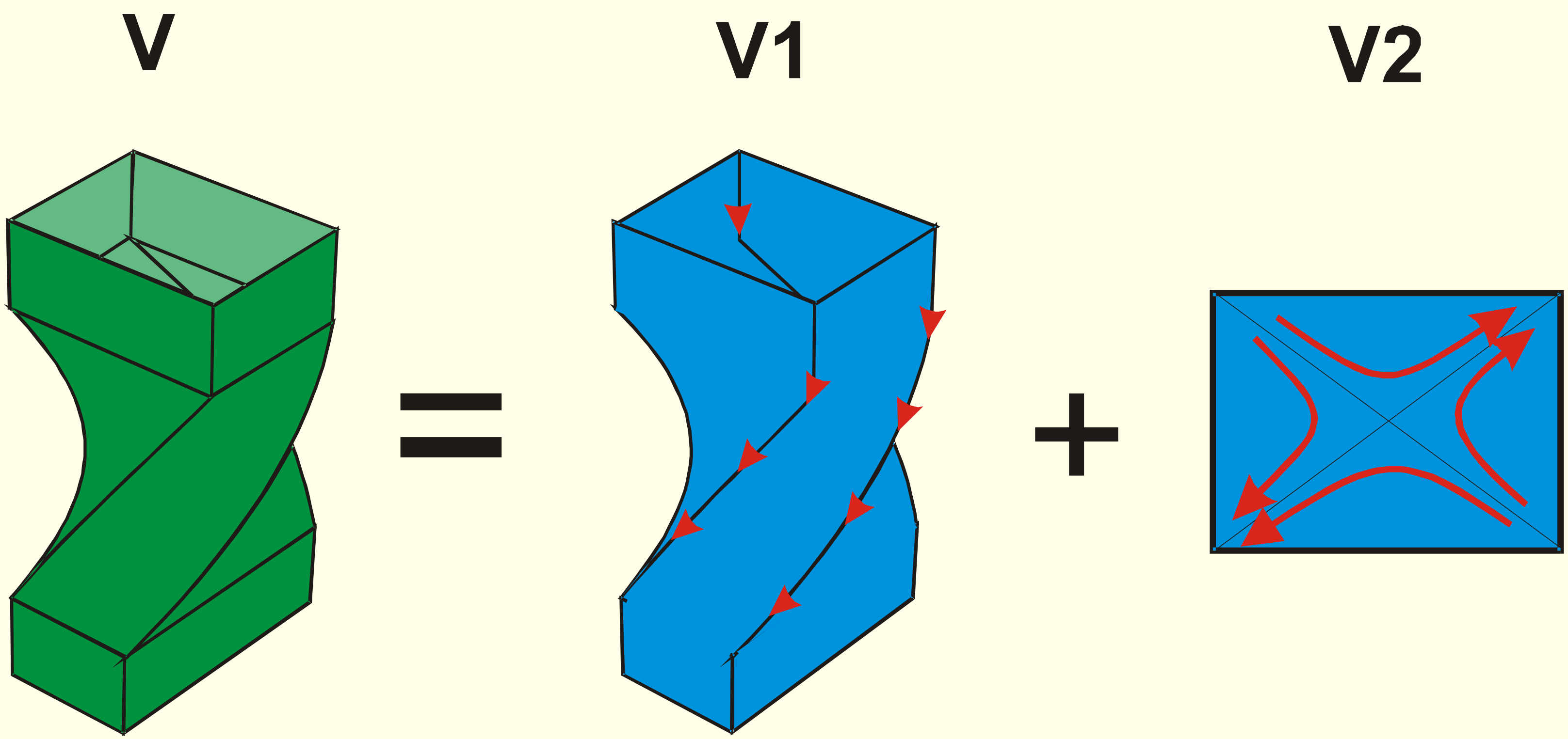


Twist extrusion easy to install on the standard installation for direct extrusion



Mechanics of the TE

VELOCITY FIELD



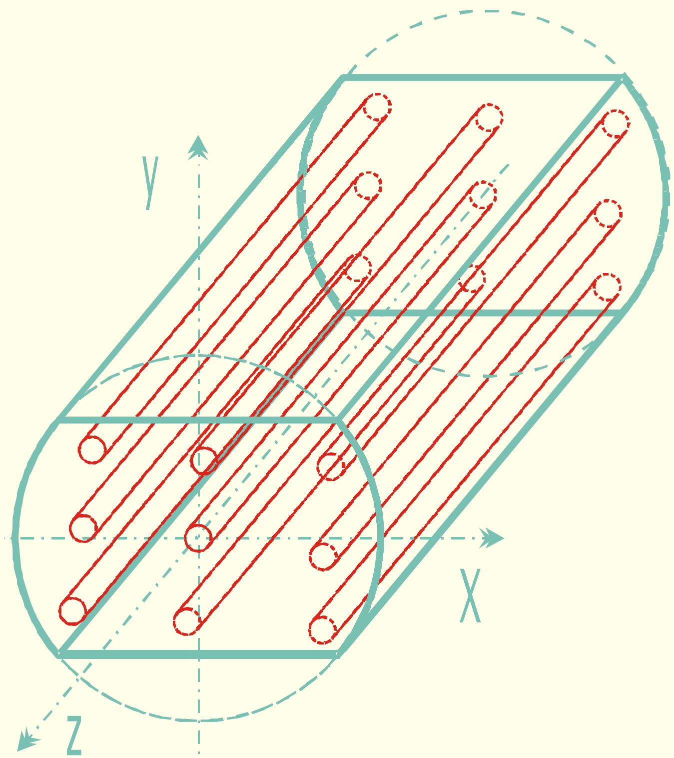
Velocity field

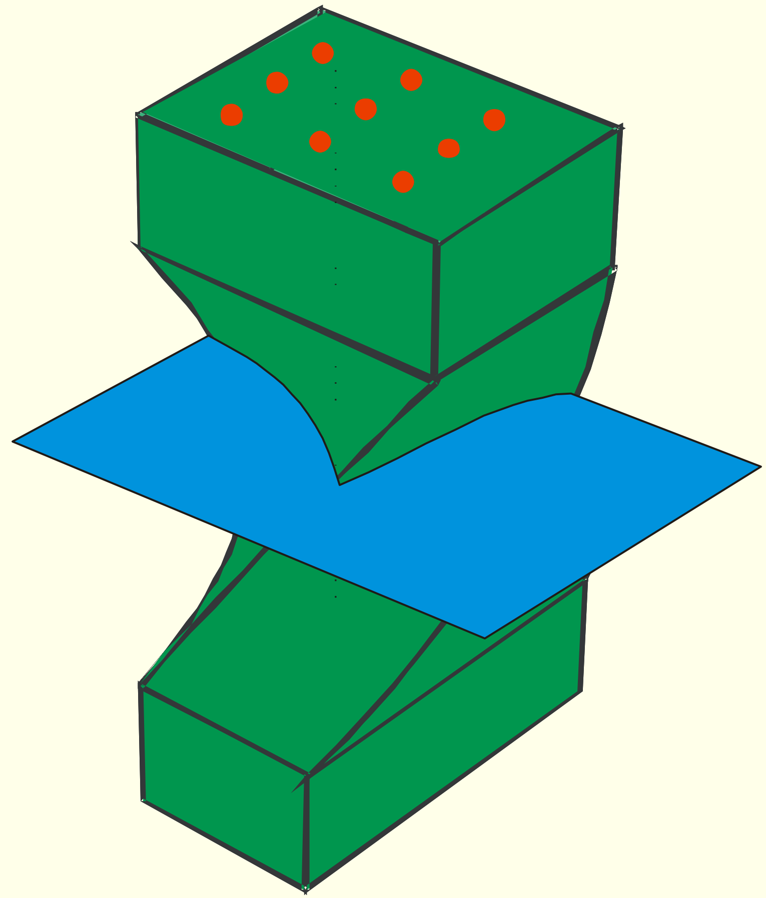
Twist flow

Flow within the Specimen cross-section

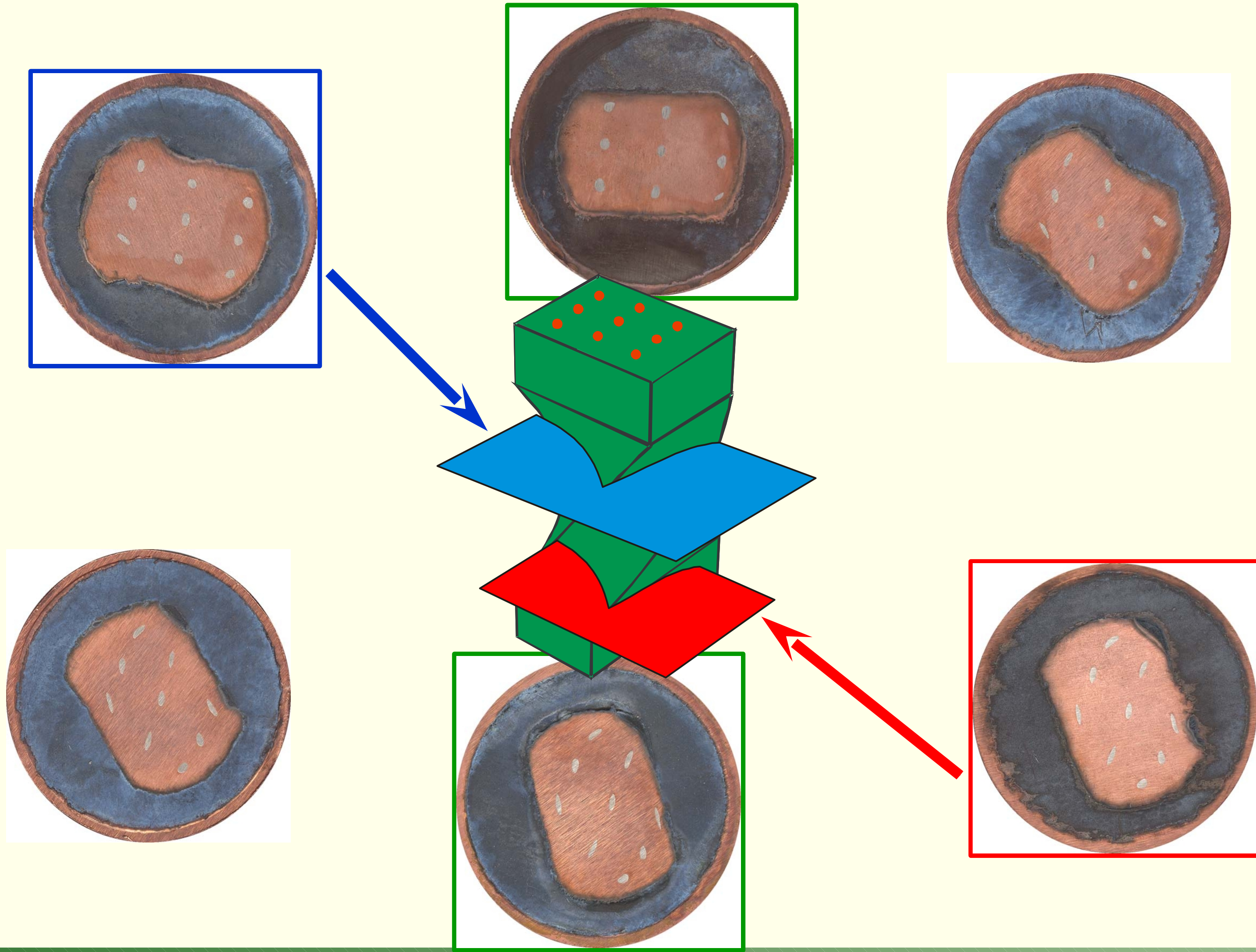
Experimental investigation of the process's mechanics

Specimen with the fibers

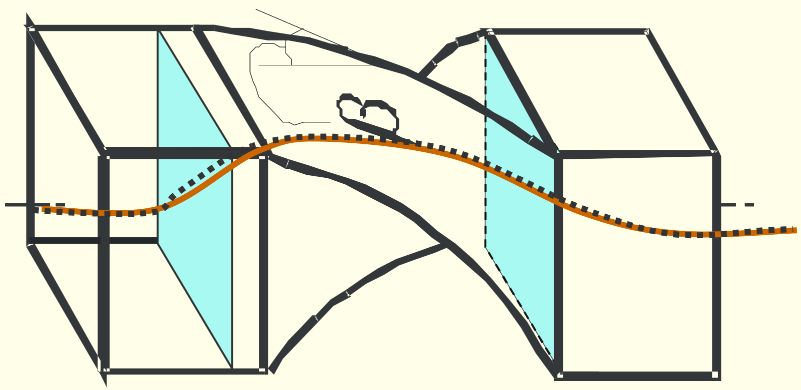




Experimental investigation of the process's mechanics



Finding of the velocity field from the experimental stream lines



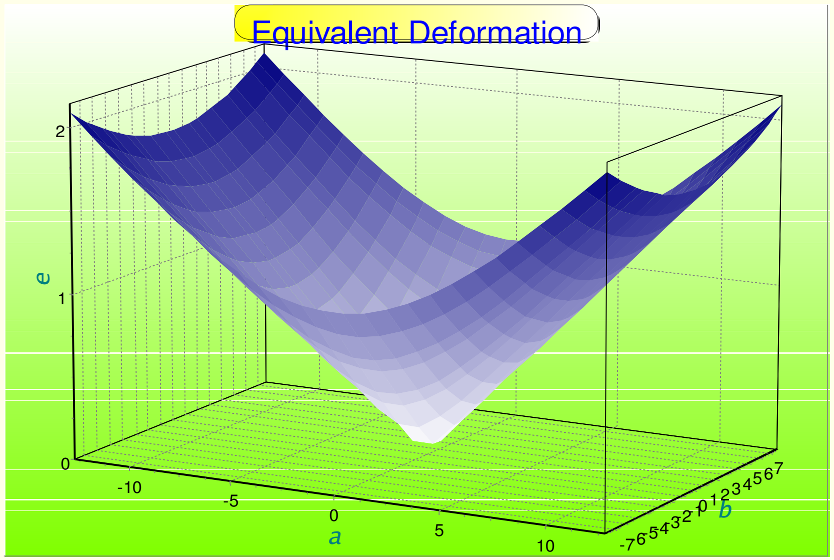
Experimental stream line

Theoretical stream line

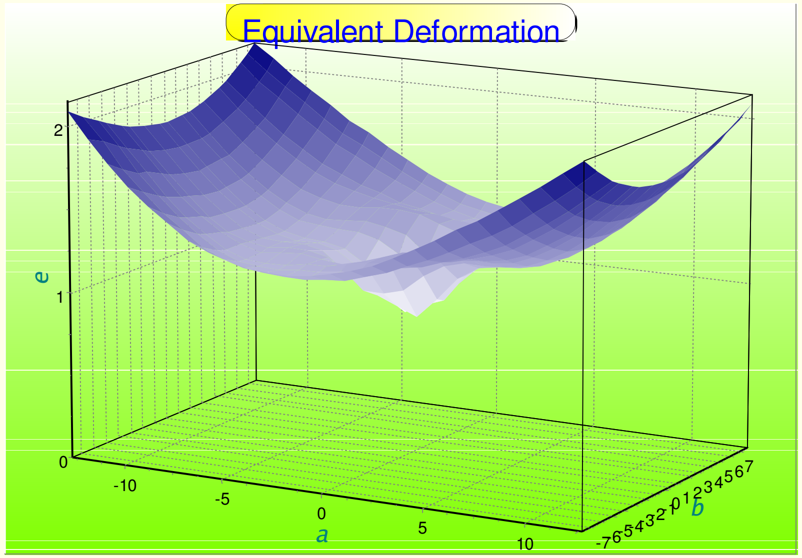
Strain distribution

$$\varepsilon_{i\max} = tg\beta_{\max};$$
$$\Lambda_{\max} = \sqrt{3}tg\beta_{\max};$$

$$\varepsilon_{i\min} = 0.4 + 0.1tg\beta_{\max};$$
$$\Lambda_{\min} = \sqrt{3}(0.4 + 0.1tg\beta_{\max});$$



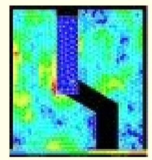
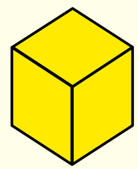
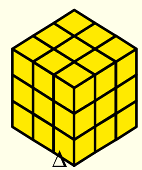
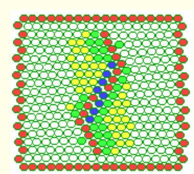
Without V2



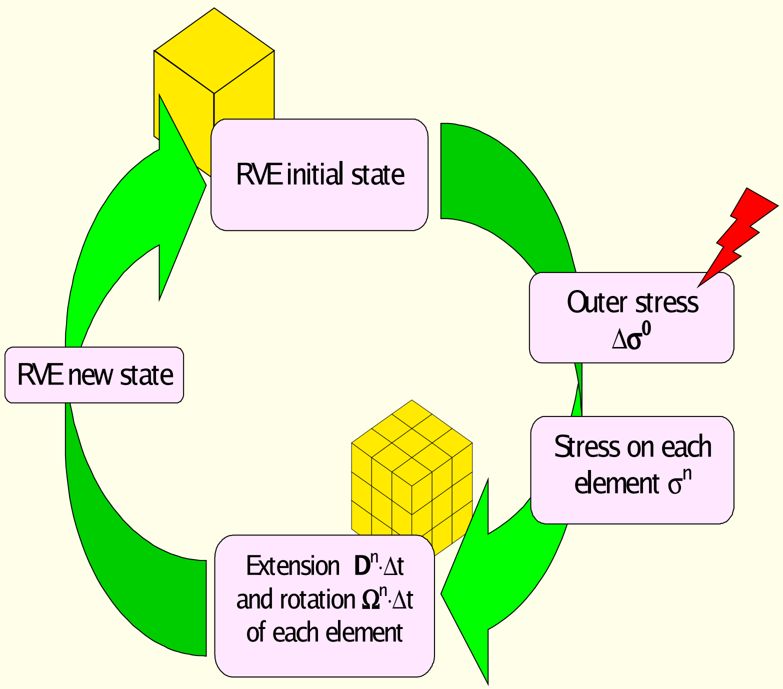
With V2

Mathematical simulation

Methods

FEM 	*Physics and technique of high pressure (2003), №4*
Continual model with inner parameters  S Θ	*Eng. Fracture Mech.*, ***48***, *N5. (1994), Mech. of Mat. 2005 V.37. P.753-767*
Micromechanical model based on cellular automata 	*Phil. Mag.* A, **79**, N10, (1999)
Molecular dynamics 	*V International Conference Metallurgy Refrectories and Enviromen, Stara Lesna, High Tatras, Slovakia, 2002, May 13-16, 289-292*

Simulation of grained refinement. Cellular model

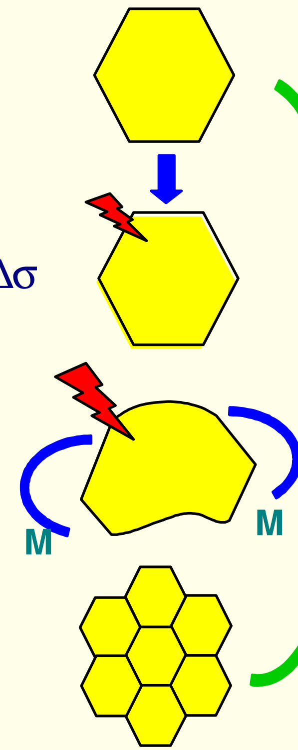


Initial grain

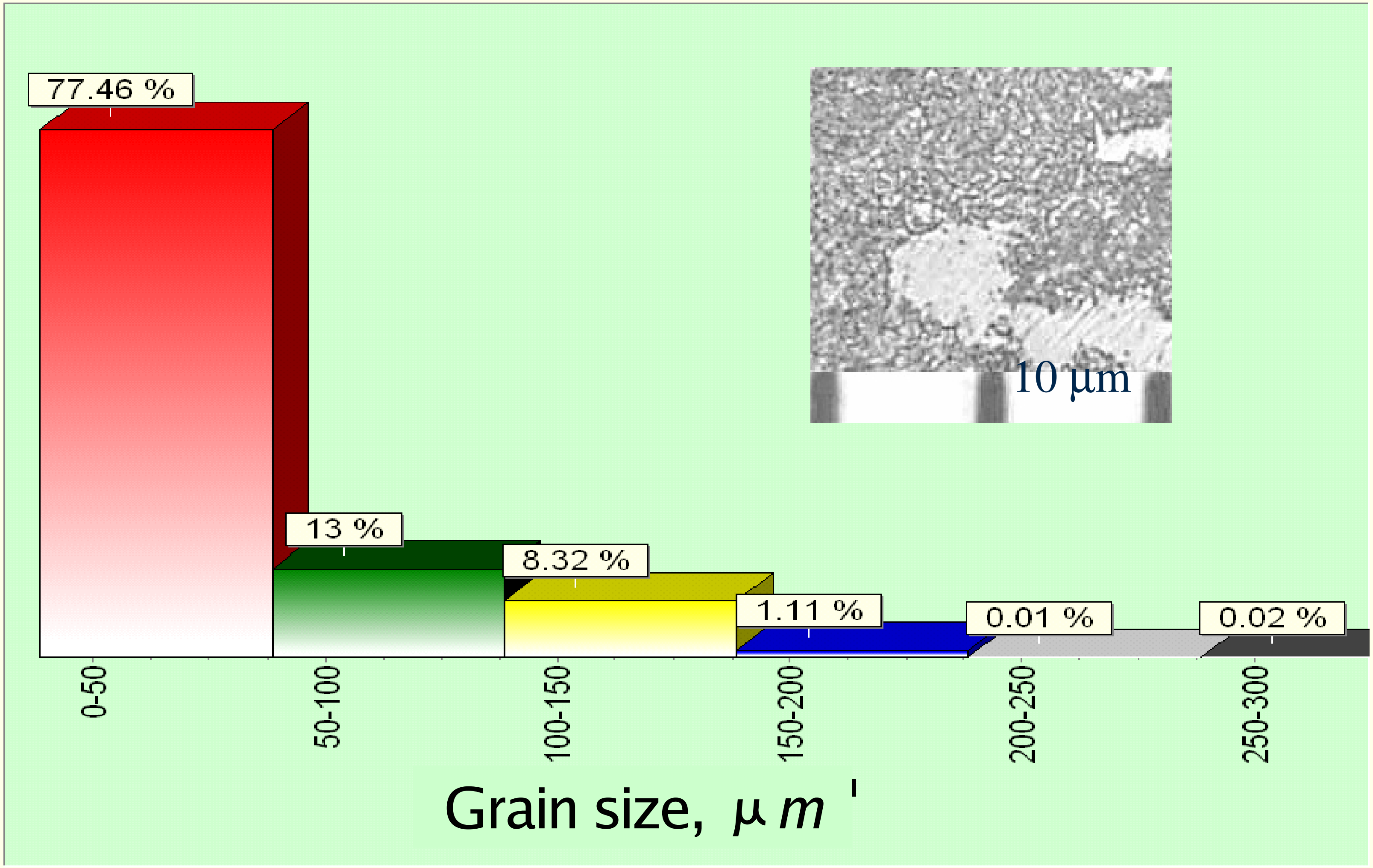
Plastic deformation $\Delta\sigma$

Deformation continues Rotation moments appear

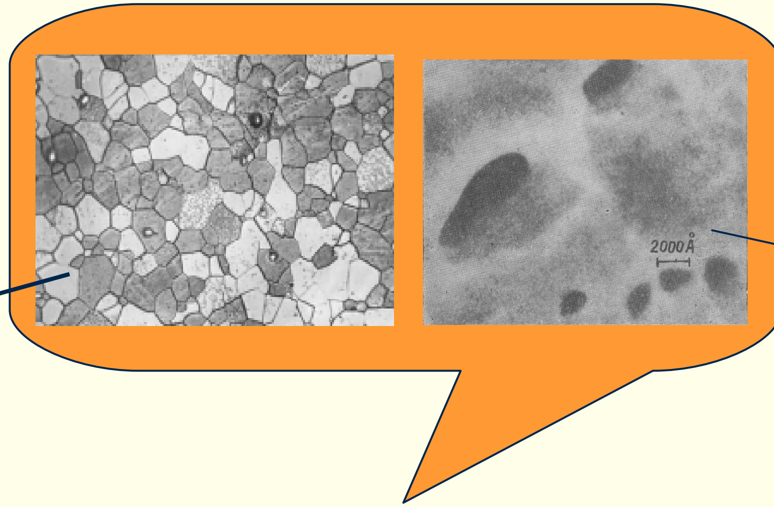
Moment stresses relax through grain splitting



Simulation of grained refinement. Cellular model



Continuum approach



Specific fragment boundary area

S

Continuum model of material

Porosity

Θ

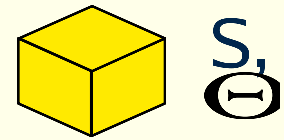
Kinetic equations of the model.

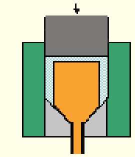
$$\begin{cases} \dfrac{d\bar{N}}{d\gamma} = \left(C_1 + C_2 C_5 \bar{N}_b\right) F\left(\bar{S}\right) - \left(C_3 + C_4\right) \bar{N} \\ \dfrac{d\bar{N}_b}{d\gamma} = C_4 \bar{N} - C_5 \bar{N}_b \\ \dfrac{d\bar{S}}{d\gamma} = \dfrac{C_5 \bar{N}_b}{\bar{S} + \bar{S}_0} \\ \dfrac{d\Theta}{d\gamma} = C_3 \bar{N}^{\frac{3}{2}} d_c^{-3} v - C_6 \Theta \end{cases}$$

- N - number of AZ per unit of the cross section area
- S - total length of the high-angle boundaries per unit of the cross section area
- N_b - number of embryo of the high-angle boundary per unit of the cross section area
- N_p - number of voids per unit of the cross section area
- Θ - porosity

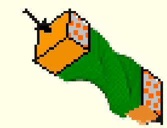
$$d = \frac{1}{S}$$

Simple shear provide the most intensive grain refinement process.

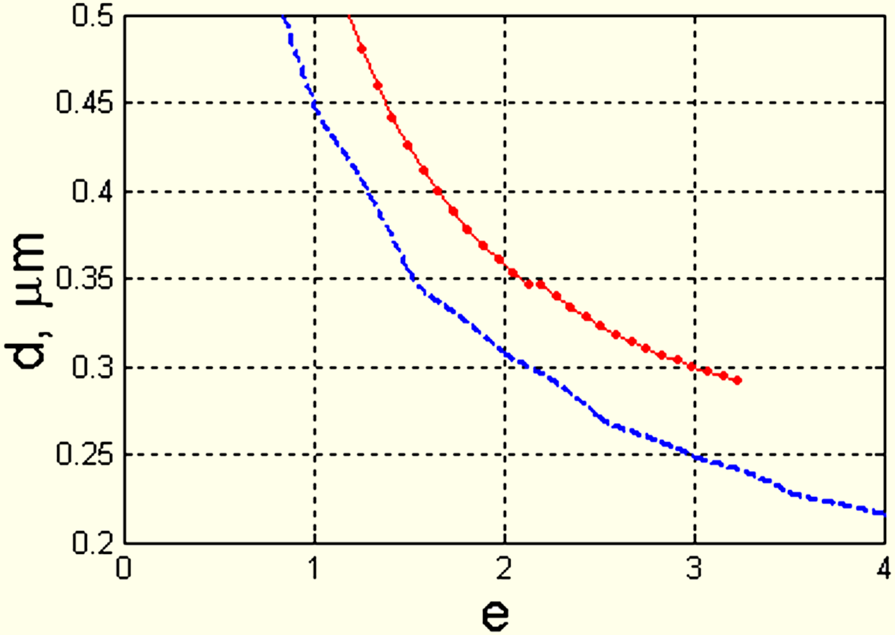


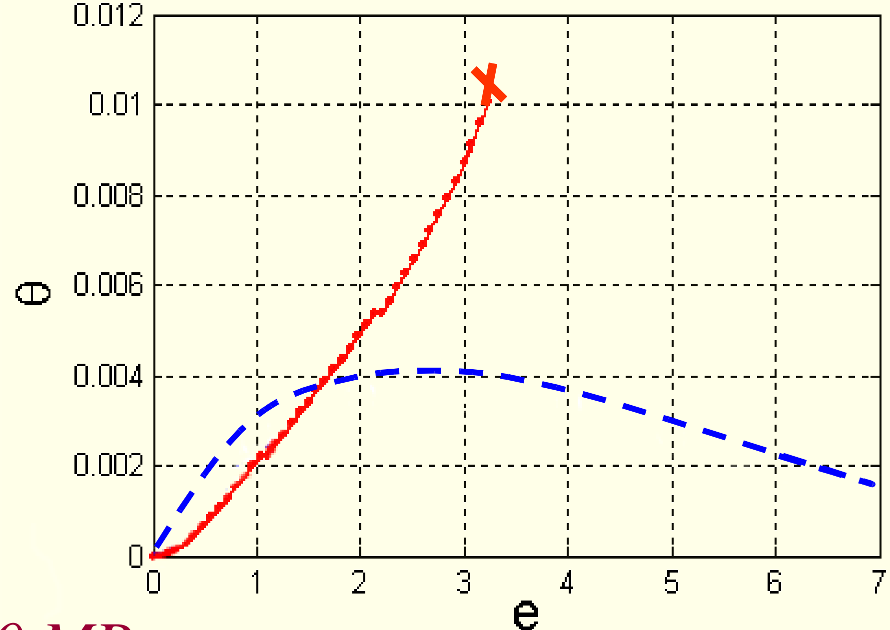


– direct extrusion



– twist extrusion



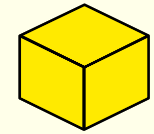


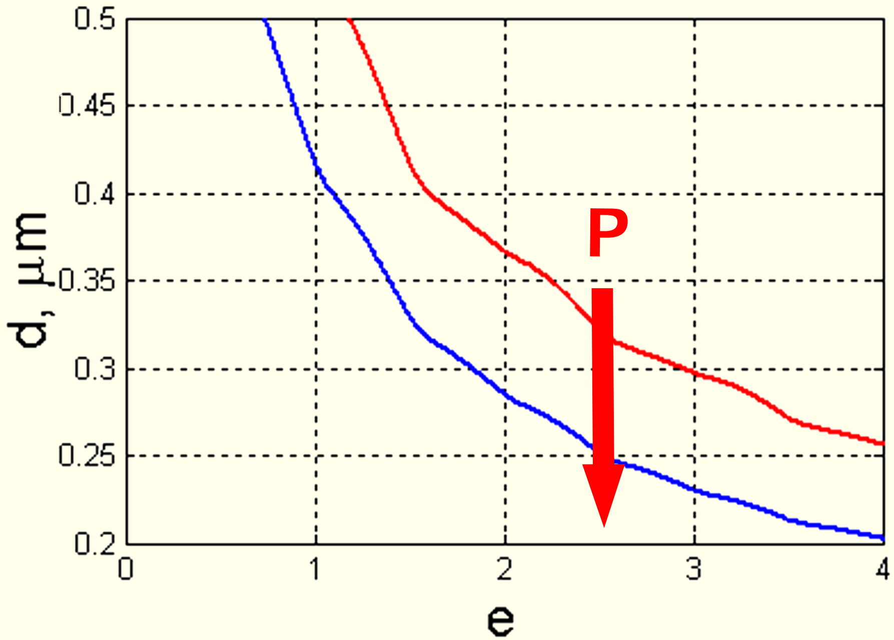
θ – porosity

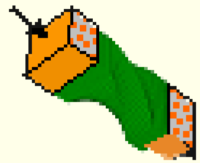
d – average grain size

$P_{n\partial} = 600\ MPa$

Pressure leads to increasing the intensity of grain refinement and repression microporosity formation

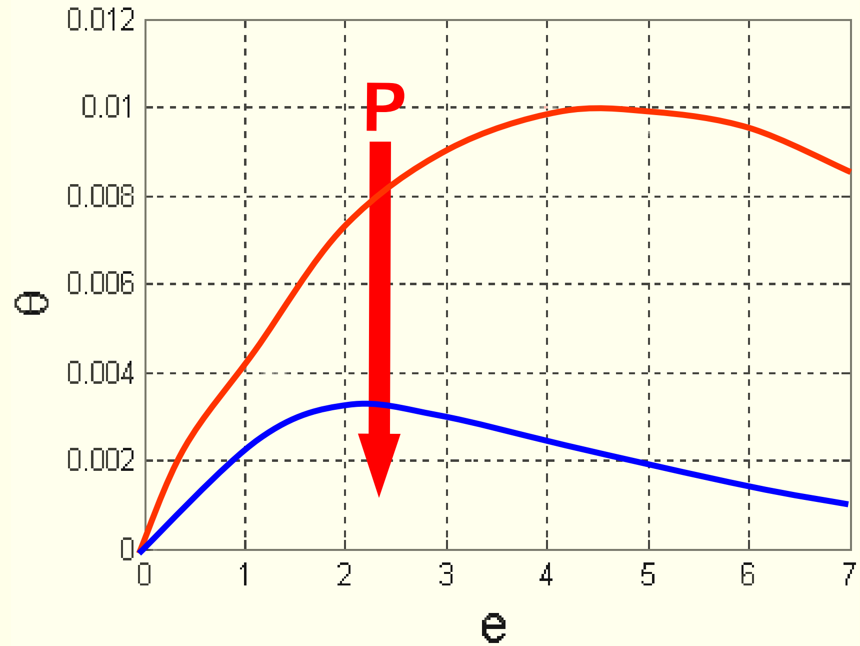






— $P_{n\partial} \approx 0.1$ MPa

— $P_{n\partial} = 1000$ MPa

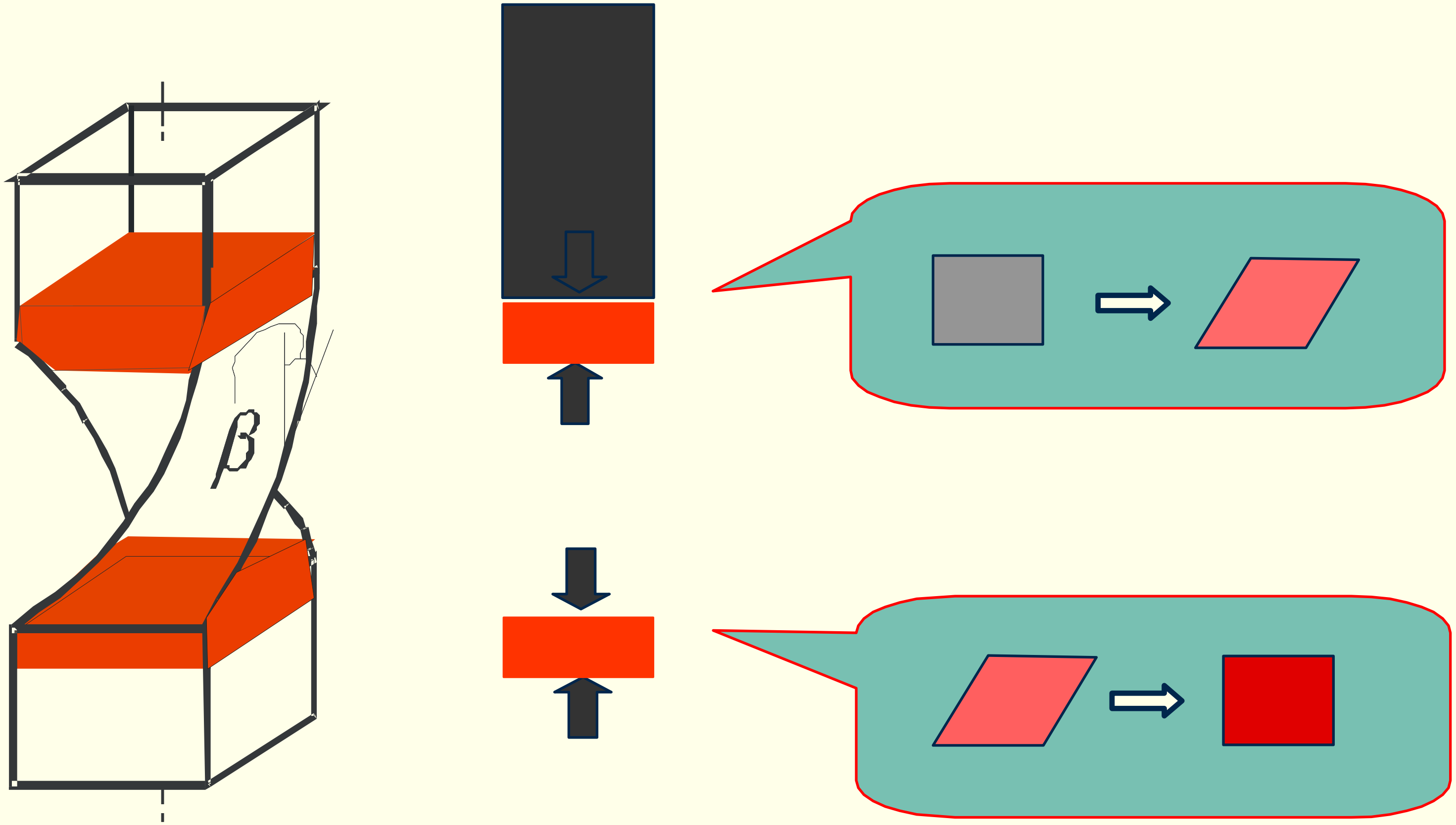


θ – porosity

d – average grain size

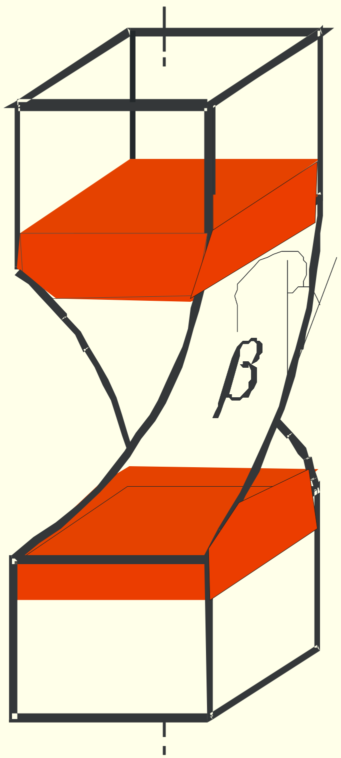
Resume

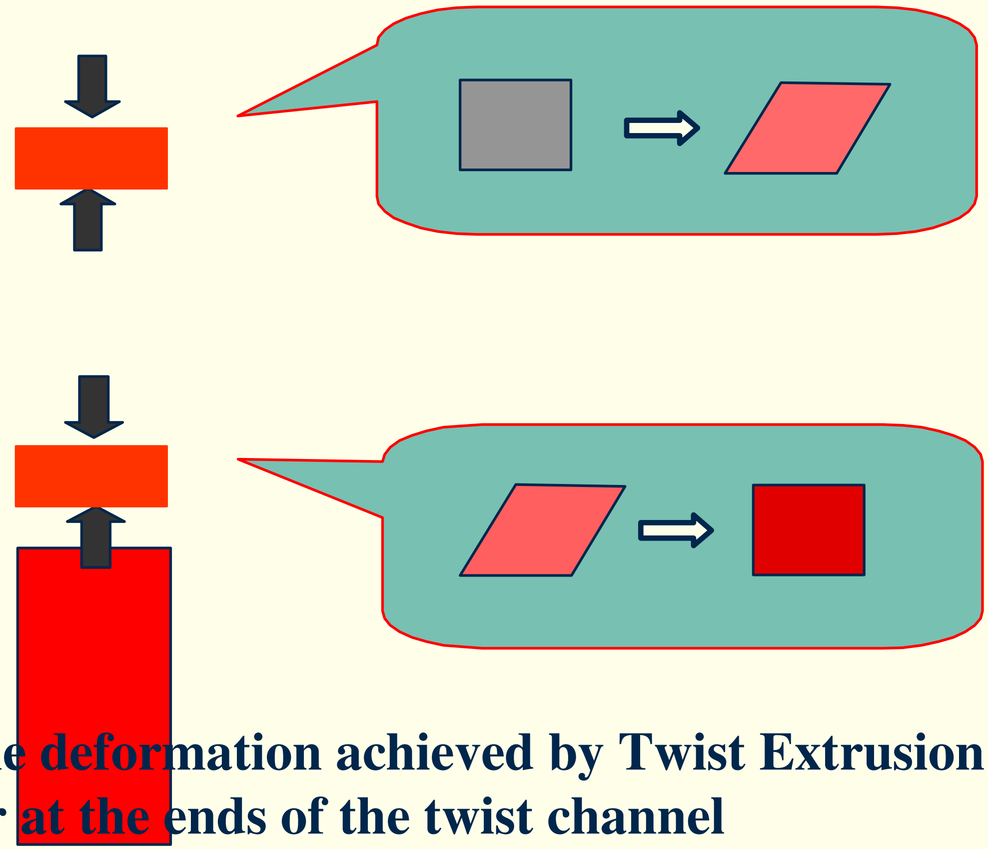
Metal Deformation under Twist Extrusion



We showed that most of the deformation achieved by Twist Extrusion is Simple Shear at the ends of the twist channel

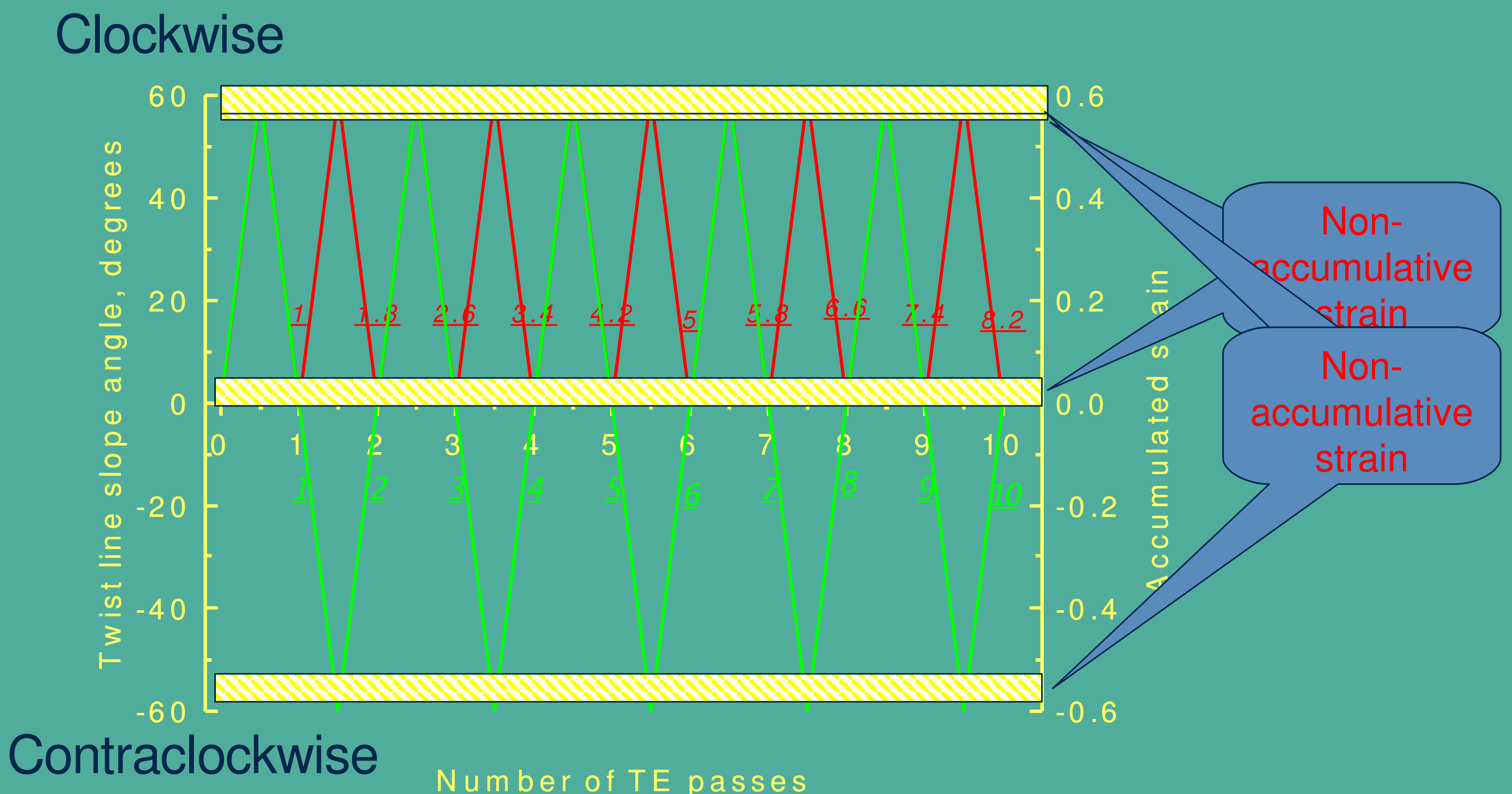
Metal Deformation under Twist Extrusion





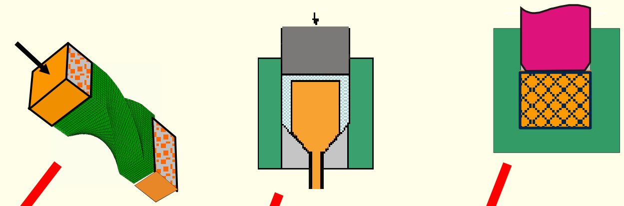
We showed that most of the deformation achieved by Twist Extrusion is Simple Shear at the ends of the twist channel

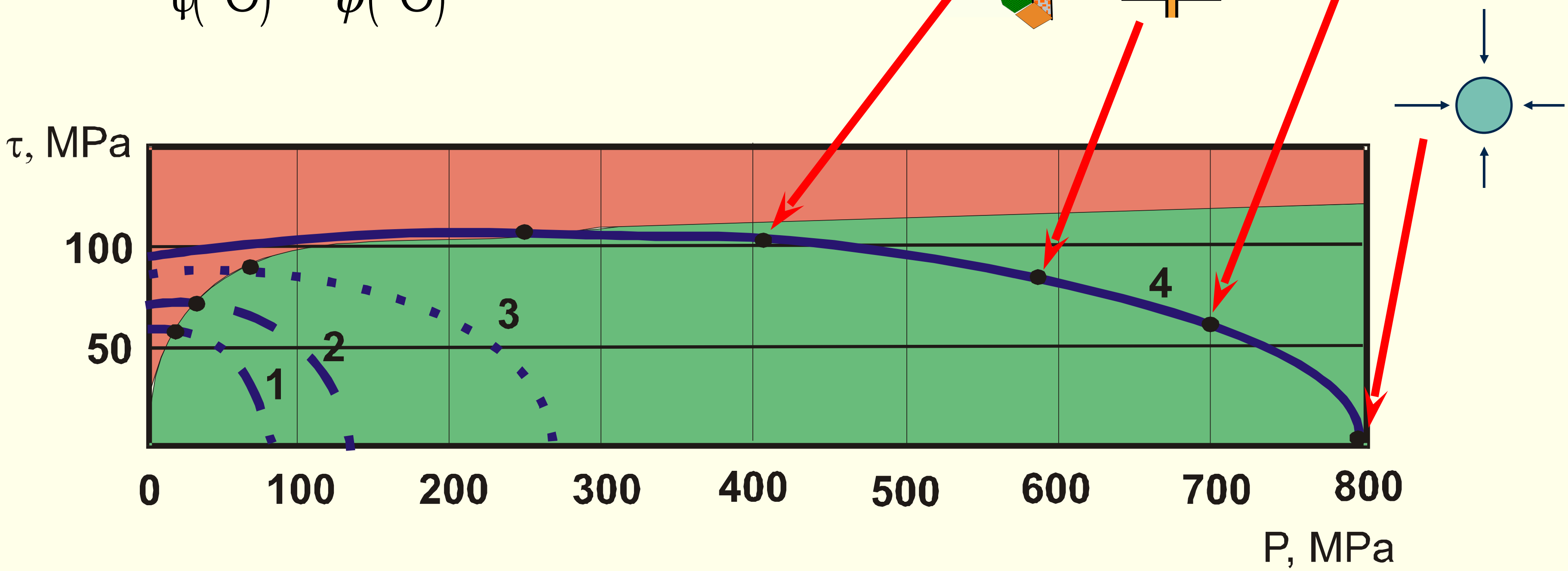
Influence of TE path



Powder consolidation

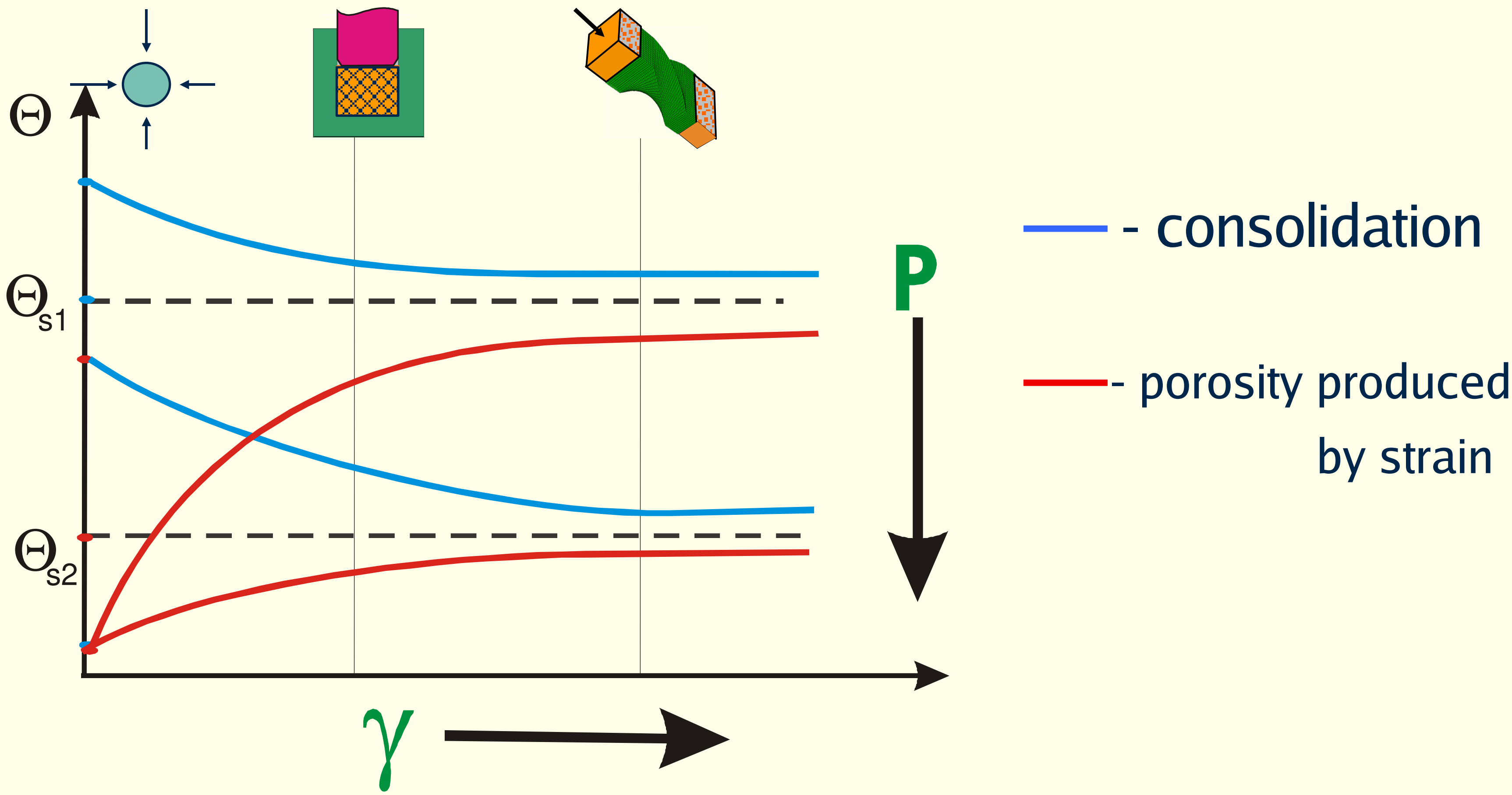
$$\frac{p^2}{\psi(\Theta)} + \frac{\tau^2}{\varphi(\Theta)} = (1-\Theta)\left(k_0 + \alpha p\right)^2$$



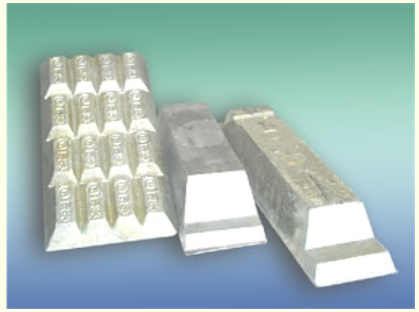


Yield surfaces for the powder at the various level of porosity:
1-30%, 2-20%, 3-10%, 4-3%.

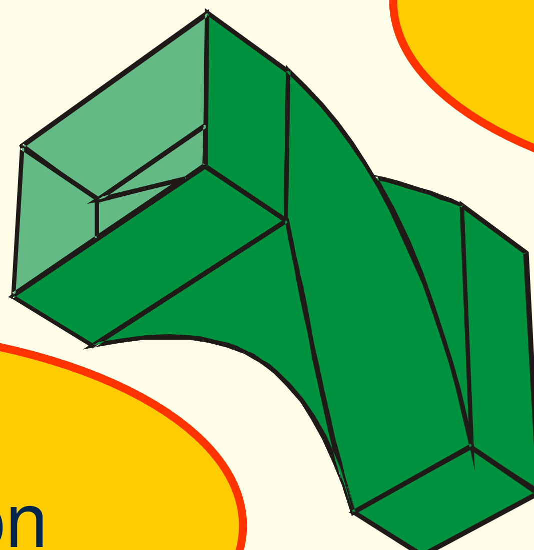
Porosity produced by strain and consolidation by strain under pressure



Twist Extrusion: Two in One



Fragmentation



Twist Extrusion

Consolidation

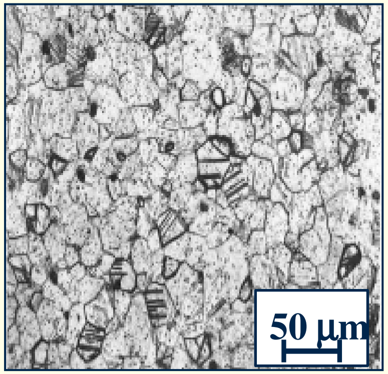
Fragmentation

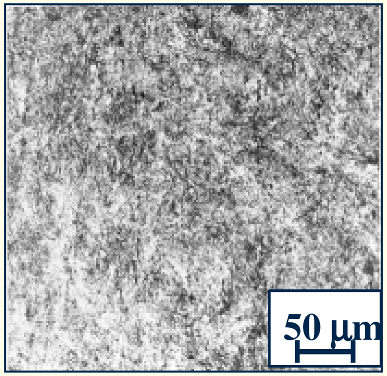
- Grains refinement. UFG materials

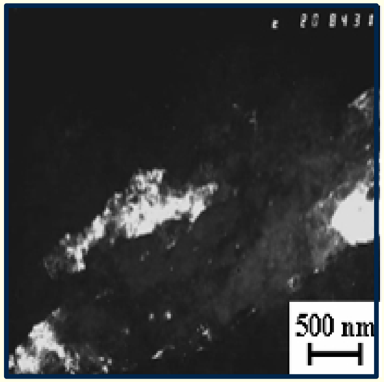
- Breaking of a brittle particles

TE processing of *Cp*Ti and Ti alloys

Twist extrusion of the Ti







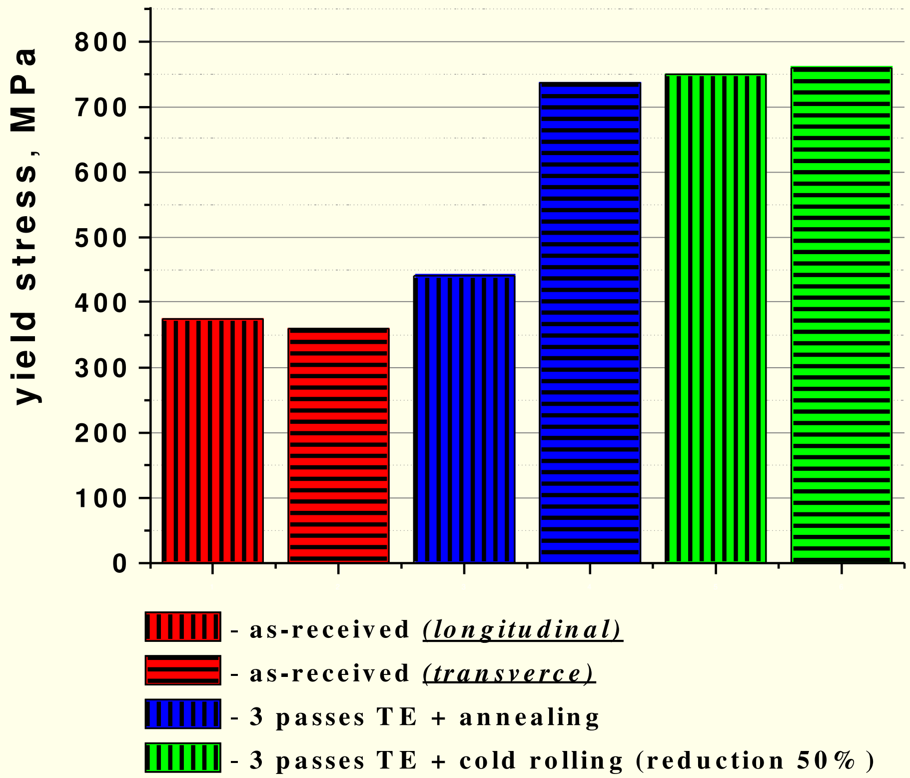
Initial state

After 3 passes

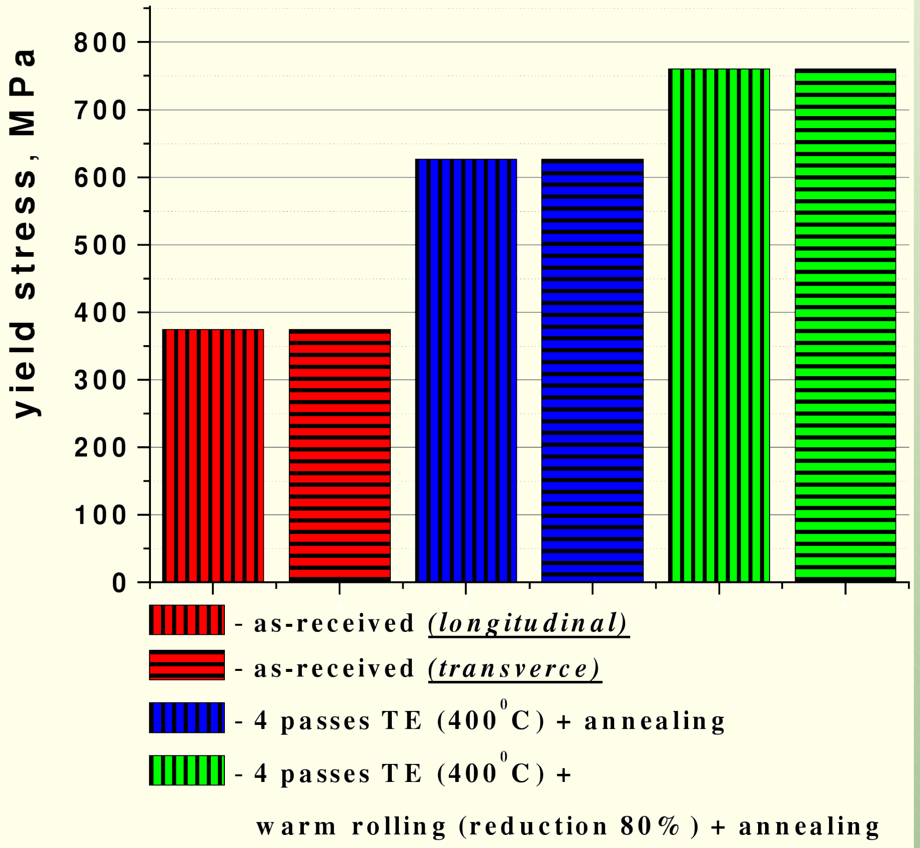
Results are obtained with Professor V.Stolyarov, IPSM UGATU, Russia

Yield strength data

Cold TE under pressure 700 MPa



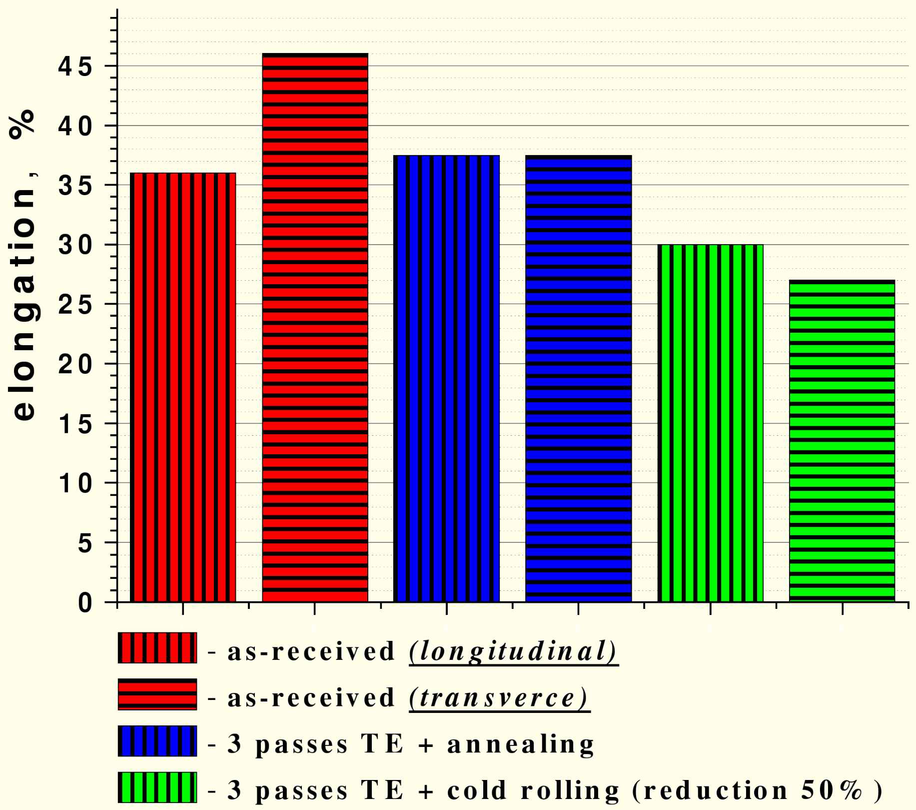
Warm TE



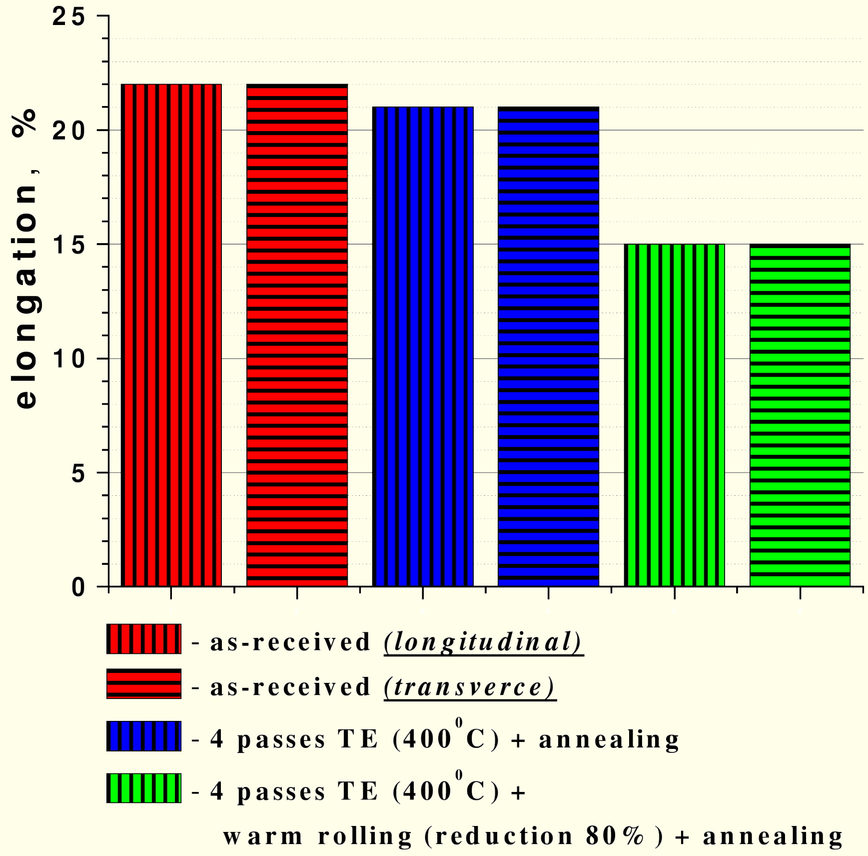
Obtained with Prof. V.Stolyarov, IPAM UGATU, Russia

Uniform elongation

Cold TE under pressure 700 MPa



Warm TE



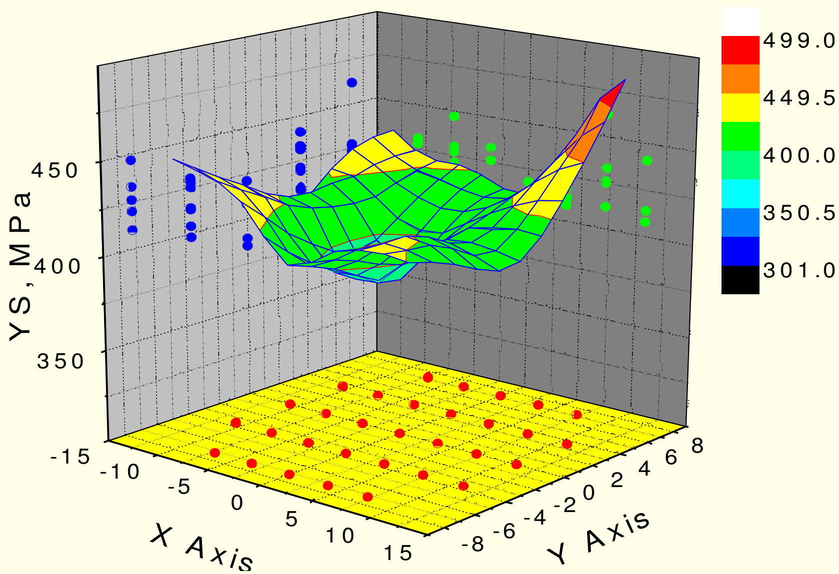
Obtained with Prof. V.Stolyarov, IPSM UGATU, Russia

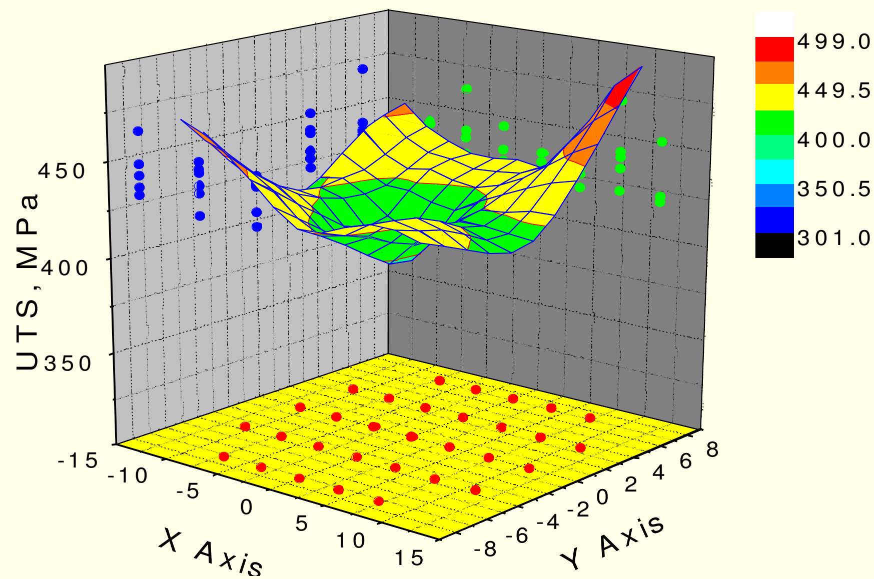
Plates for traumatology and orthopedic are made from UFG titanium

Properties	CpTi	CpTi After treated.	Ti6-4
Yield stress , MPa	**375**	**760**	**850**
Uniform elongation , %	**22**	**15**	**12**

TE processing of Cu alloys

Cu, 2 TE passes through 60 deg. die





Mean	Min	Max	Range
419.32	385	462	77

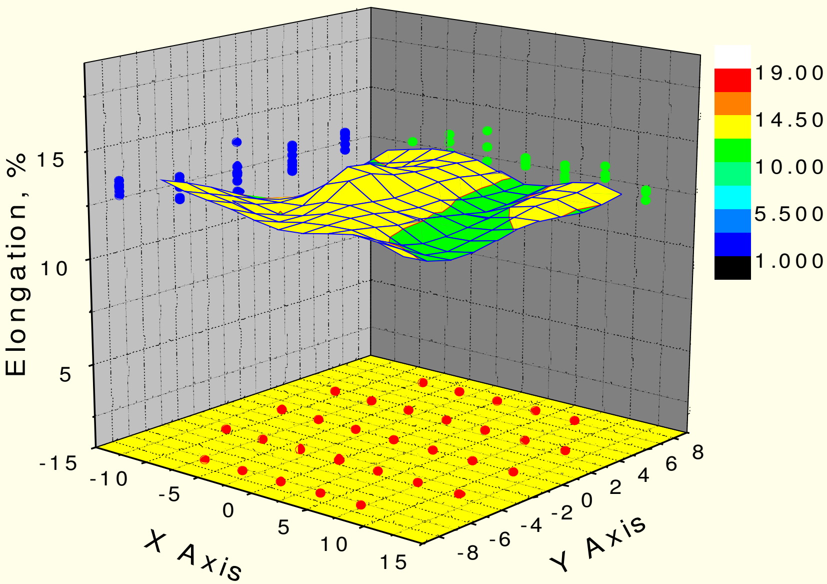
- YS distribution

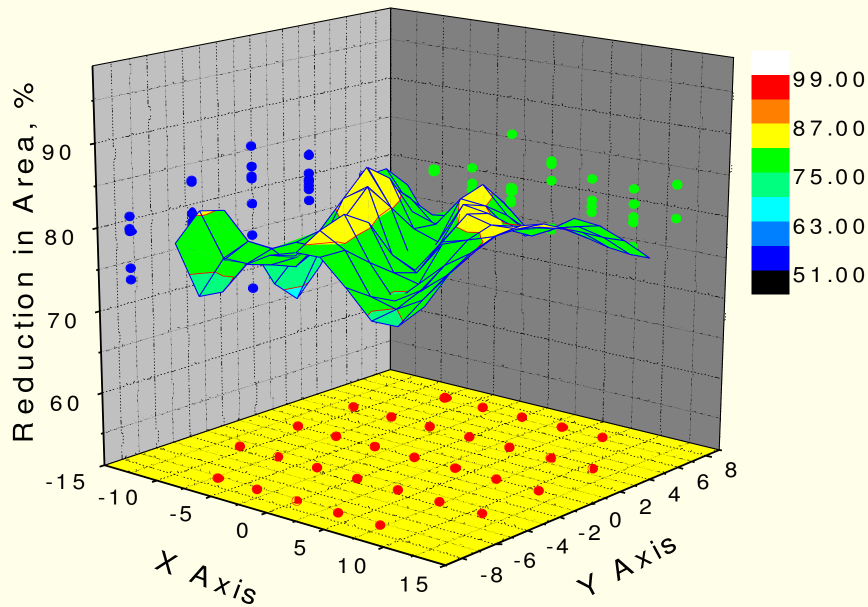
Mean	Min	Max	Range
430.35	396	469	73

- UTS distribution

Obtained with Dr.A.I.Korshunov, Russian Federal Nuclear Center VNIIEF, Sarov, Russia

Cu, 2 TE passes through 60 deg. die





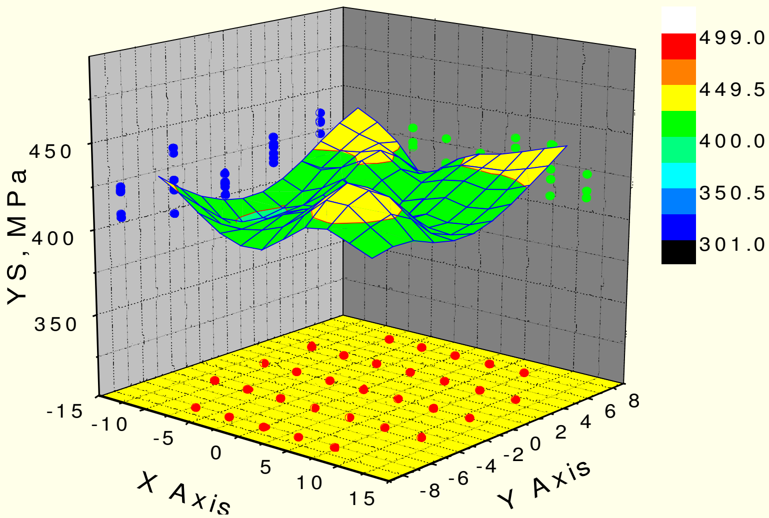
Mean	Min	Max	Range
12.47	11.4	13.8	2.4

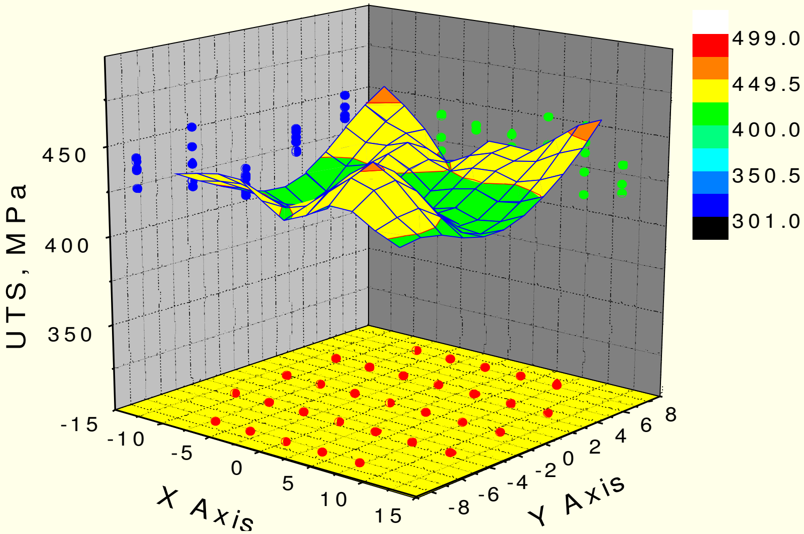
Mean	Min	Max	Range
78.11	67.4	85.4	18

- Elongation distribution
- Reduction in area distribution

Obtained with Dr.A.I.Korshunov, Russian Federal Nuclear Center VNIIEF, Sarov, Russia

Cu, 4 TE passes through 60 deg. die





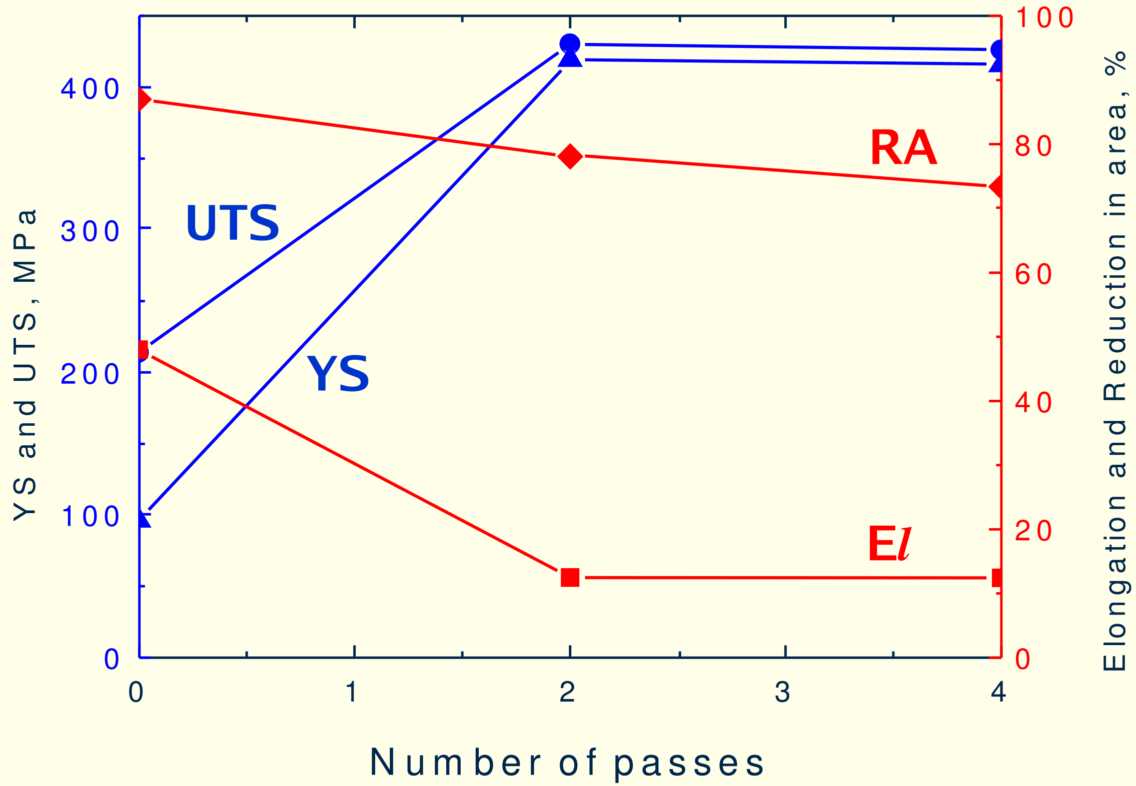
Mean	Min	Max	Range
415.68	393	436	43

Mean	Min	Max	Range
426.13	403	450	47

- YS distribution
- UTS distribution

Obtained with Dr.A.I.Korshunov, Russian Federal Nuclear Center VNIIEF, Sarov, Russia

Cu, summary of mechanical properties after TE processing



- **Mean values of tensile tests data**

Obtained with Dr.A.I.Korshunov, Russian Federal Nuclear Center VNIIEF, Sarov, Russia

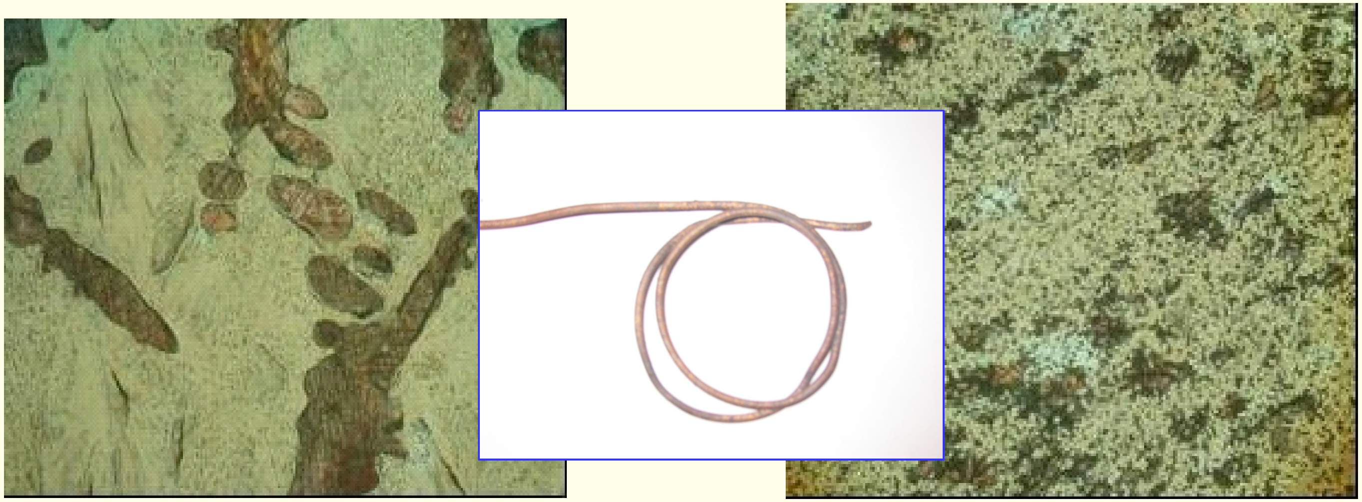
Twist extrusion+Cold rolling of the Cu

State	Section	H_μ, MPa	Minimal grain size b, μm	Maximal grain size l, μm	k=l/b
THE	normal to THE axis	1080	0,26	0,64	2.5
	parallel to THE axis	1040	0,18	1,01	5.6
Rolling normal to THE axis	parallel to rolling axis	1270	0,13	0,24	1.9
	normal to rolling axis	1230	0,12	0,82	6.8
Rolling in parallel to THE axis, centre	parallel to rolling axis	1300	0,09	0,24	2.7
	normal to rolling axis	1230	0,13	0,79	6.1
Rolling in parallel to THE axis, edge	parallel to rolling axis	1320	0,11	0,26	2.4
	normal to rolling axis	1280	0,12	0,74	6.2

Twist Extrusion of phosphorous Cu (9% P)

Initial state

1 pass



Treatment	YS, MPa	δ , %
Direct Extrusion, μ=4.5	360	4
Twist Extrusion	420	11

Back pressure = 200 MPa, T= 623 K

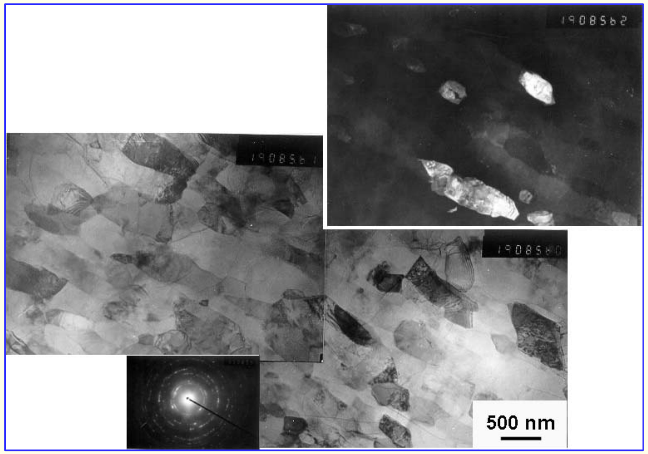
TE processing of Al alloys

Twist extrusion of the Al-Mg-Sc-Zr alloy

Chemical composition:
Al - 3 wt.%Mg - 0,3 wt.%Sc – 0,10 wt.%Zr

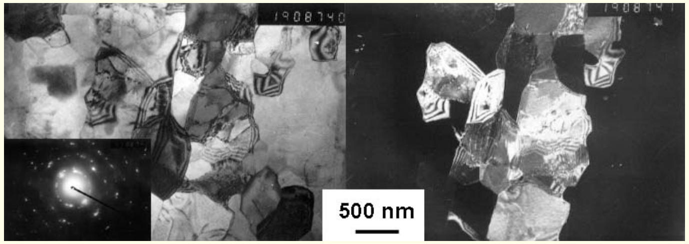
Initial grain size d_{av}=100 μm

Twist extrusion: T=280-300ºC
5 passes CW + 1 pass CCW



d_{av}=0.325 μm
d_{min}= 0.077μm
d_{max}=0.671 μm

Standard direct extrusion:
T=280-300ºC



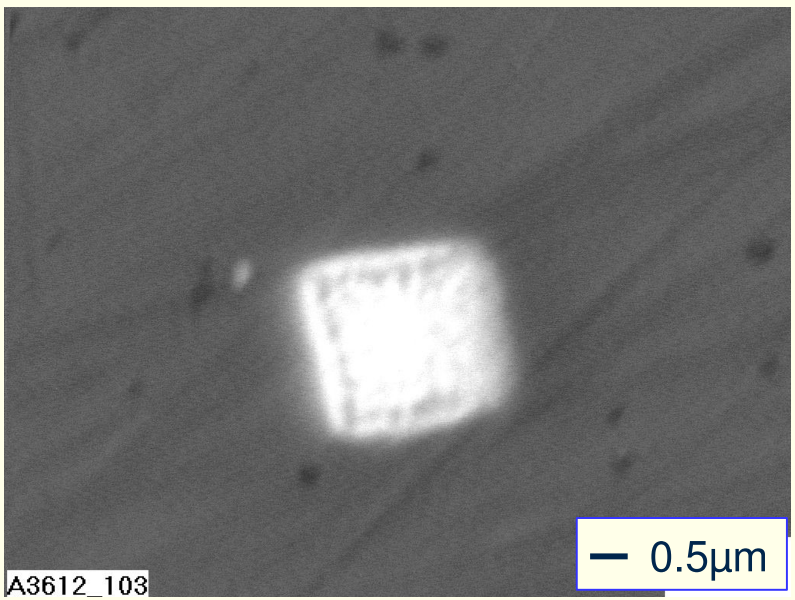
d_{av}= 0.455 μm
d_{min}= 0.129μm
d_{max}=1.032 μm

Results are obtained with Professor Y.Mil’man, IPM NASU, Ukraine

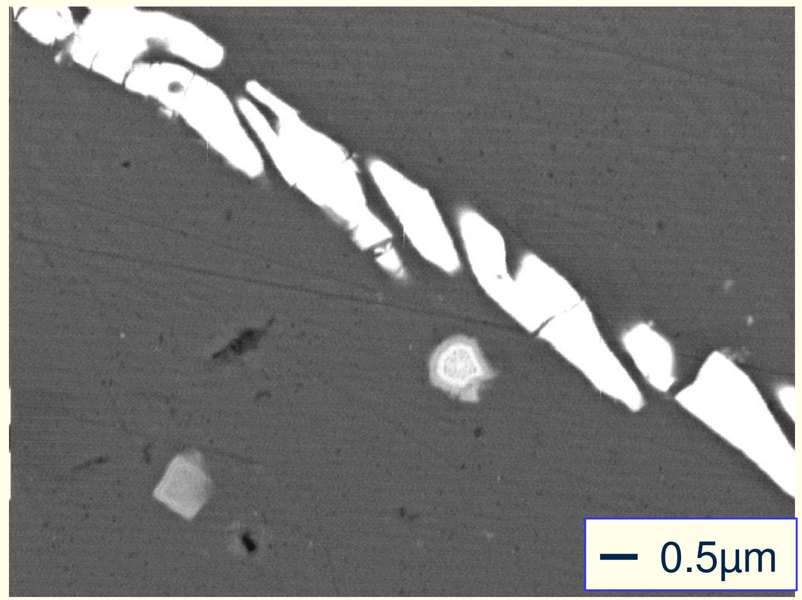
Twist extrusion of the Al-Mg-Sc-ZR alloys

Chemical composition:
Al – 3 wt.%Mg - 0,3 wt.%Sc – 0,15 wt.%Zr

SEM, As-cast structure
Cross-section



SEM, As-deformed structure,
TE – 5 passes, T_{def}=280-300ºC
Longitudinal section

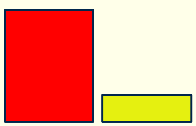


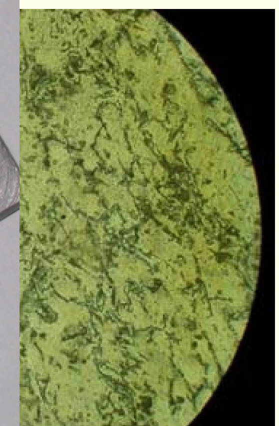
Results are obtained with Professor Y.Mil'man, IPM NASU, Ukraine

TE of recycle Al alloy

Al-88% ; Si 9.5%

ass



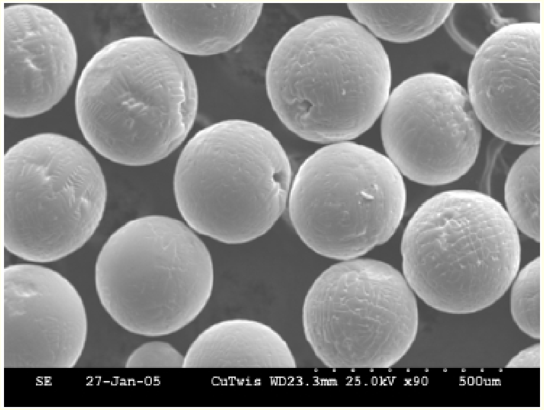


σ $_y$=50MPa δ =1% σ $_y$=205MP δ =14%

a

Consolidation

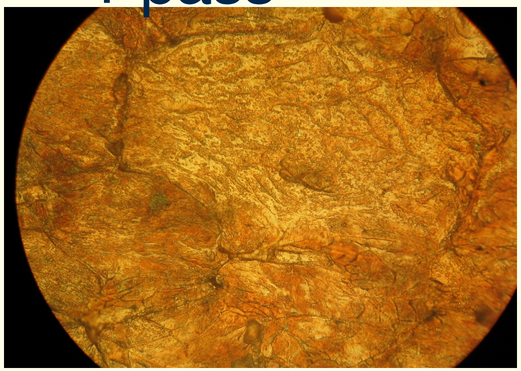
Consolidation of nanostructural Cu powder by Twist Extrusion



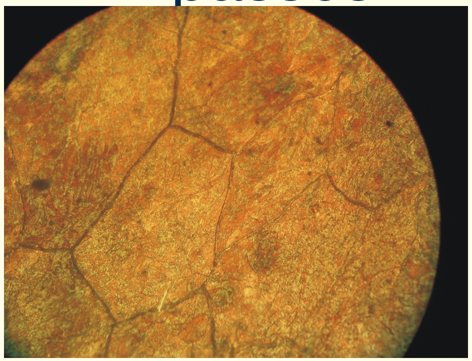
Back pressure = 200 MPa, T= 473 K

Initial powder, D=250 μm

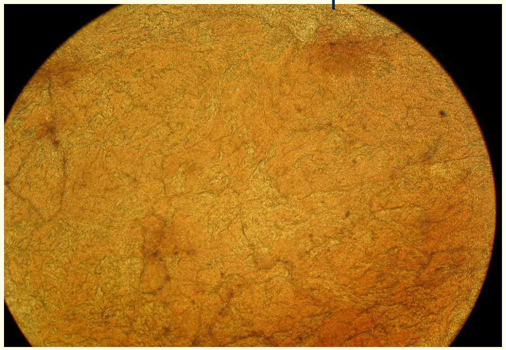
1 pass



2 passes



3 passes+
deformation ϕ12мм



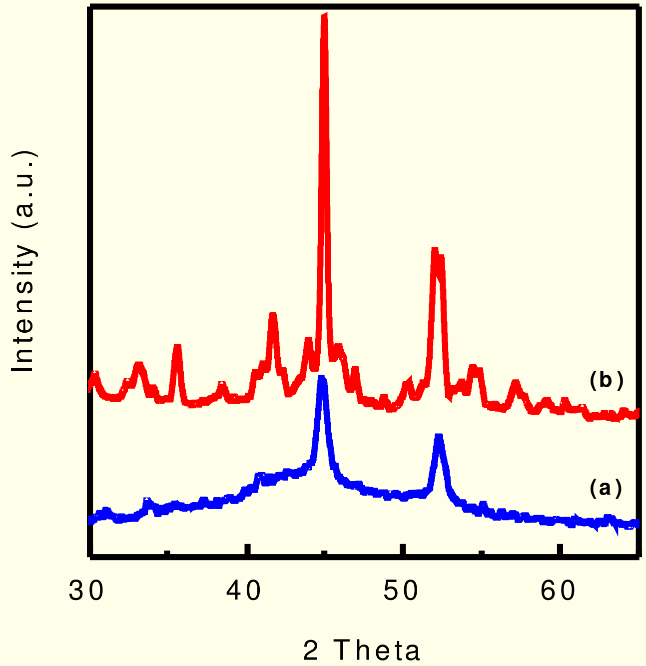
Density

1 pass	2 passes	3 passes+ deformation ϕ12мм
99,2%	99,6%	99,2%

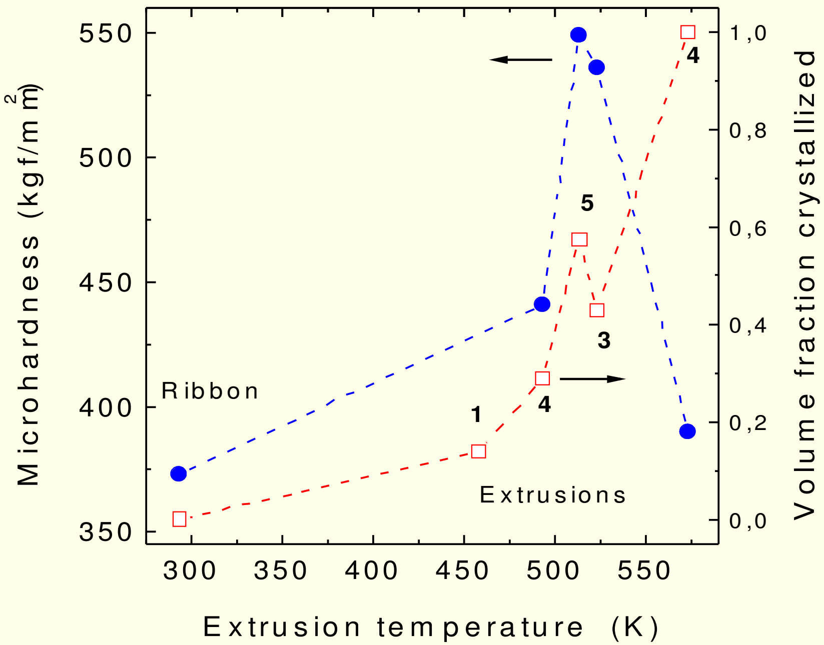
Consolidation of nanostructural Cu powder by Twist Extrusion

State	Density, %	Diameter of the coherent-scattering region L, nm
powder	-	100
TE, 1 path	99.2	36
TE, 2 paths	99.6	55

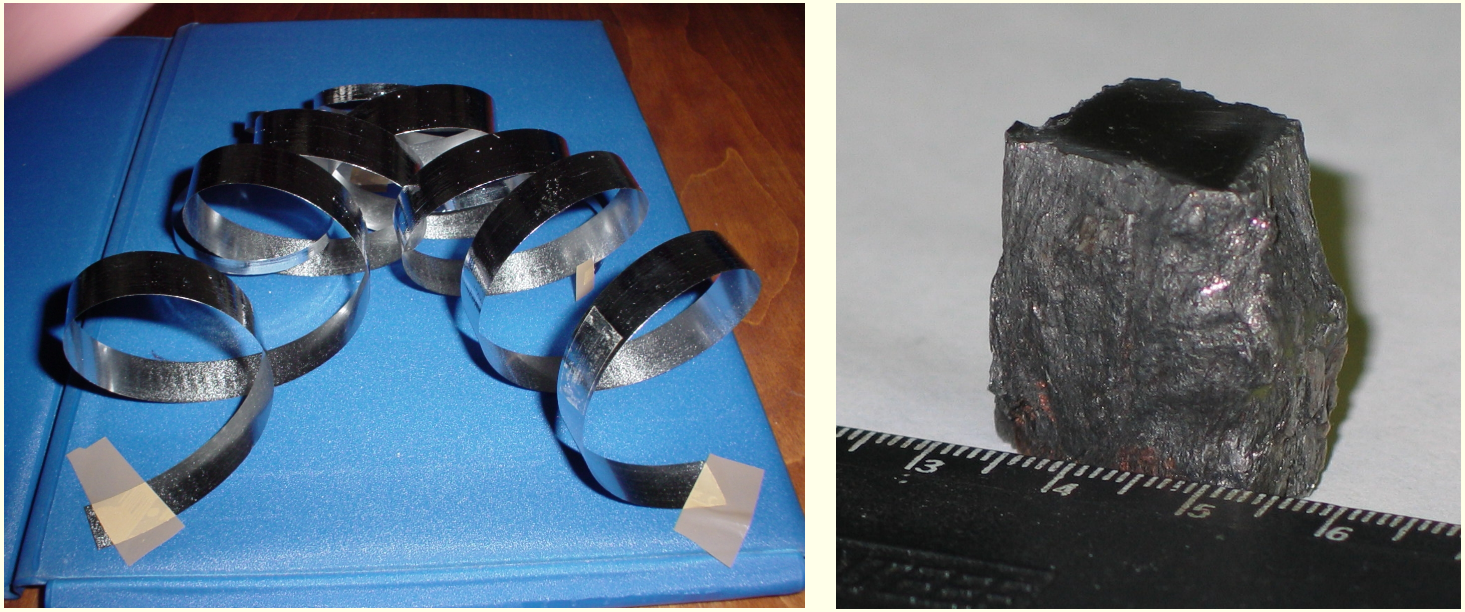
Consolidation of amorphous $Al_{86}Ni_6Co_2Gd_6$ melt-spun ribbons by Twist Extrusion



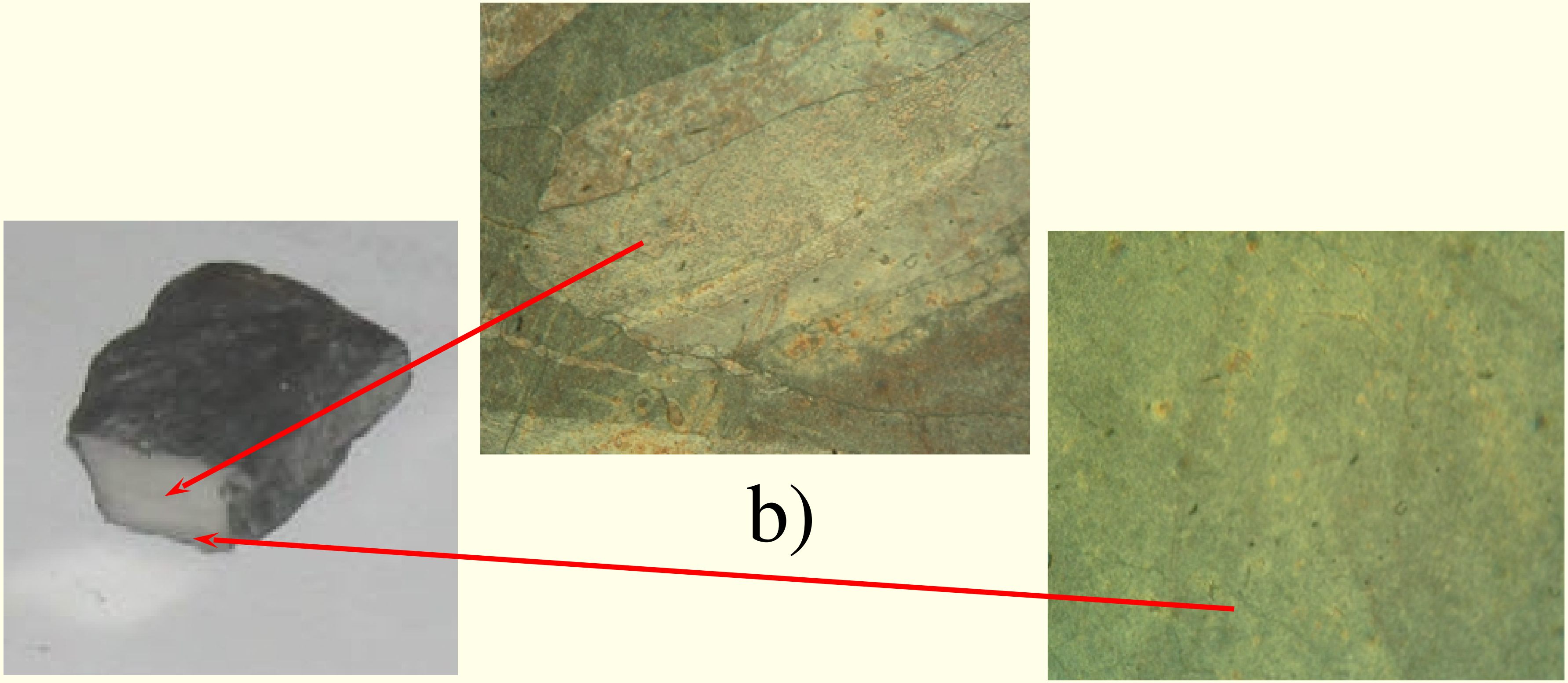
XRD traces from consolidates produced by TE: (a) at 523 K (3 passes) and (b) at 573 K (4 passes).



Microhardness of the amorphous ribbons before and after consolidation (left axis) and the volume fraction crystallized in the compacted samples (right axis) as function of the extrusion temperature. Numbers represent the number of TE passes.



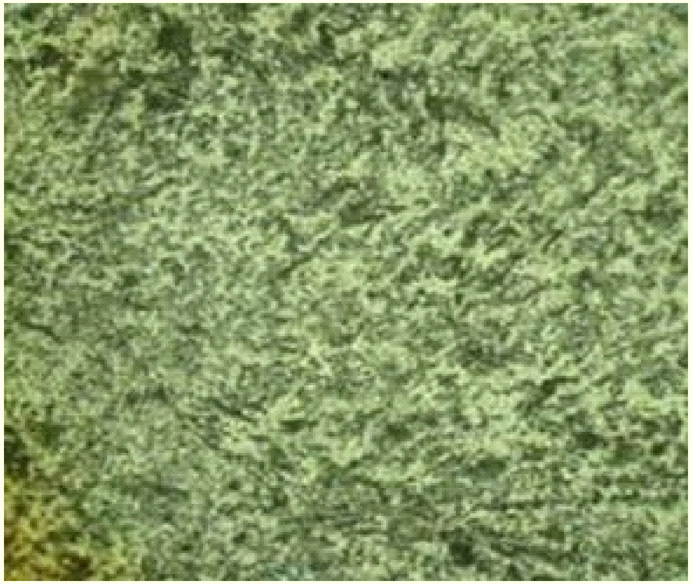
As-prepared melt-spun amorphous $Al_{86}Gd_6Ni_6Co_2$ ribbon (a) and TE-processed billet (b) compacted at 523 K.



a) b) c)

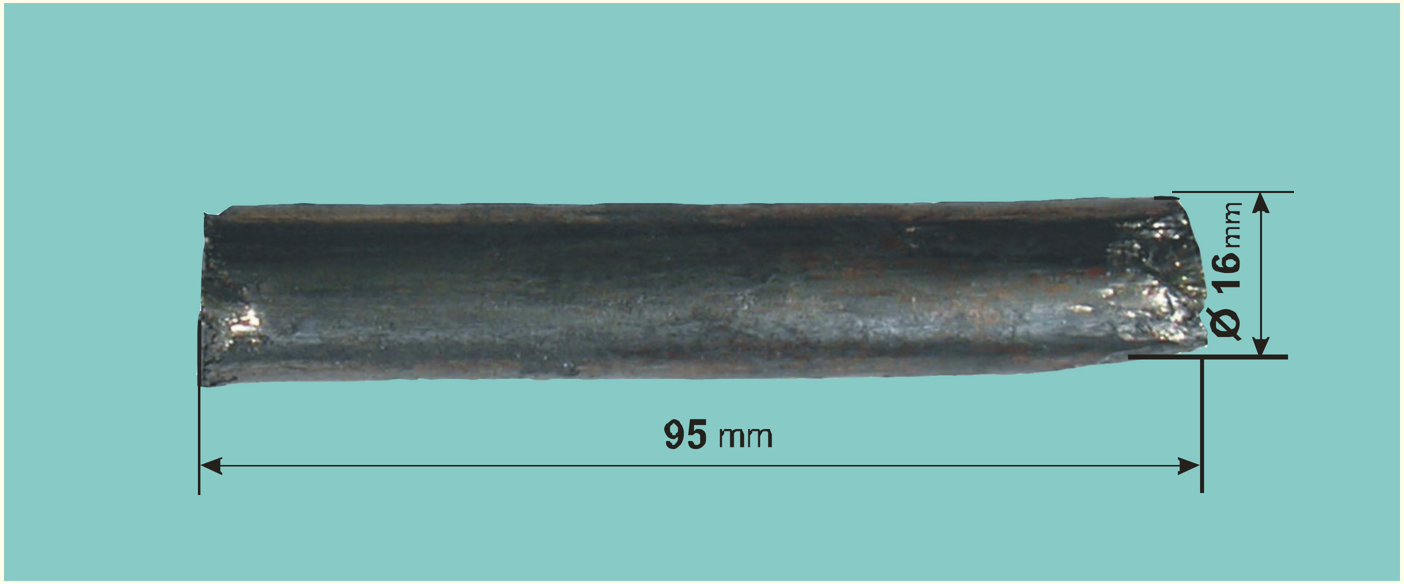
Compacted specimen (a), macrostructure of central part (b) peripheric part (c).

Consolidation of the cutting of the recycled Al alloy by Twist Extrusion



Yield stress =180-220 MPa;   El= 20-24%

Consolidation of the cutting of the recycled Mg alloy by Twist Extrusion



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