PROPERTIES OF TWIST EXTRUSION AND ITS POTENTIAL FOR SEVERE PLASTIC DEFORMATION

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Twist Extrusion: Why care?

Kinematics of TE is substantially different from that of other SPD processes (like ECAP and HPT).

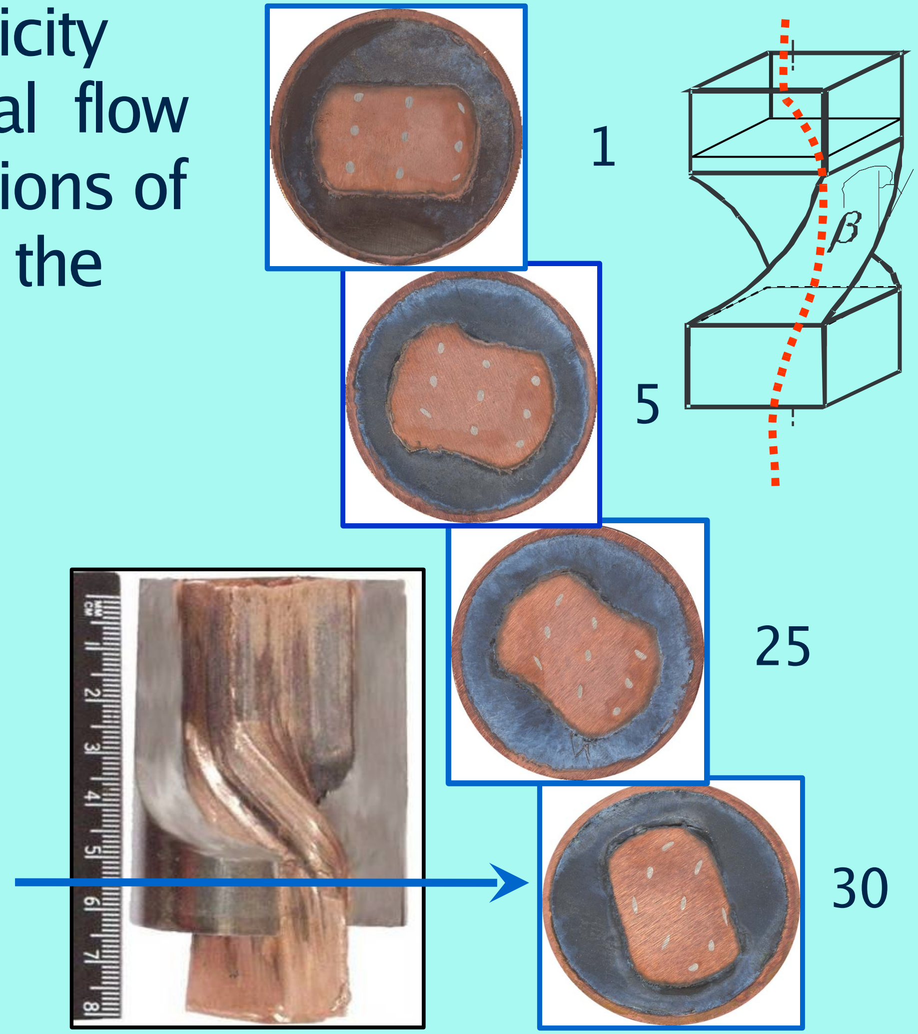
⇩

New potential for investigating and forming new structures with new properties.

Experimental investigation of TE kinematics

1. We used experimental vizioplasticity method (E. G. Thomsen) . Metal flow were reconstructed from cross-sections of the specimen with fibres stopped in the die.

2. We refined this method by incorporating two natural conditions:
-metal volume remains constant;
-metal flow is limited by the surface of the die.



<u>Advantage</u>: method takes into account the actual rheology of metal and real friction conditions.

Main Findings

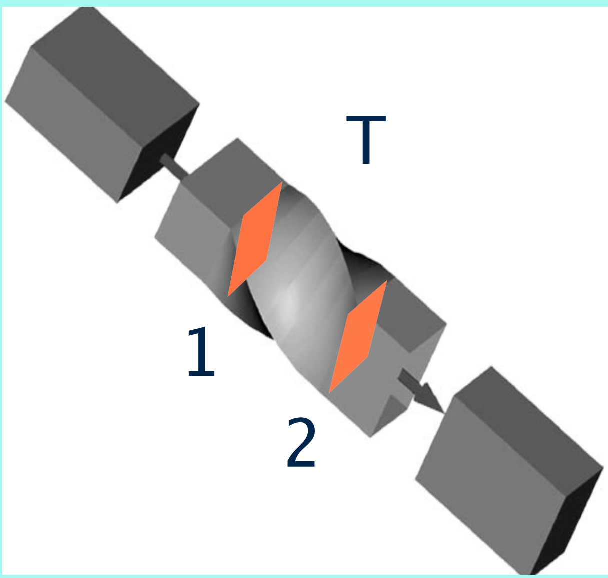
- As in HPT and ECAP, deformation in TE is performed through **simple shear.**
- There are **multiple shear planes**, unlike in HPT and ECAP. These planes are perpendicular and parallel to the specimen axis.
- There are **vortex flow with stretching and mixing** within the deformation centre
- There are **four well defined deformation zones** with different properties of metal flow

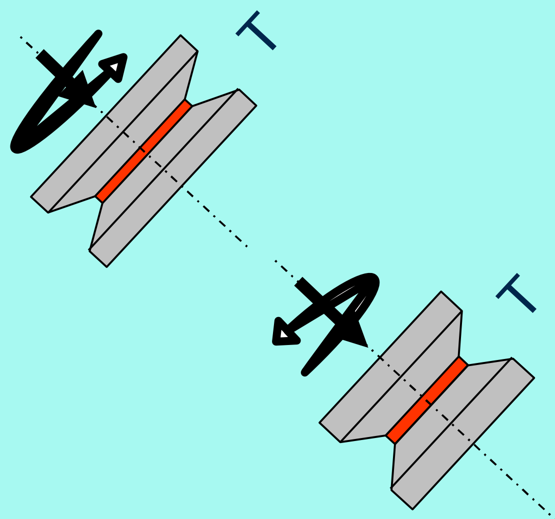
Deformation Zones 1 and 2

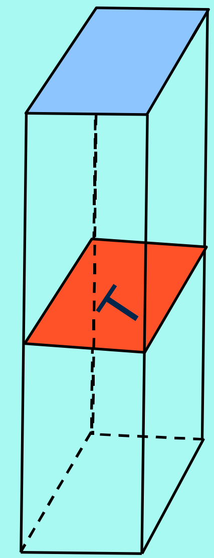
Located at the two ends of the twist part of the die.

Simple shear in the **Transversal plane (T) as in HPT**.

Shears in zones 1 and 2 have opposite direction.

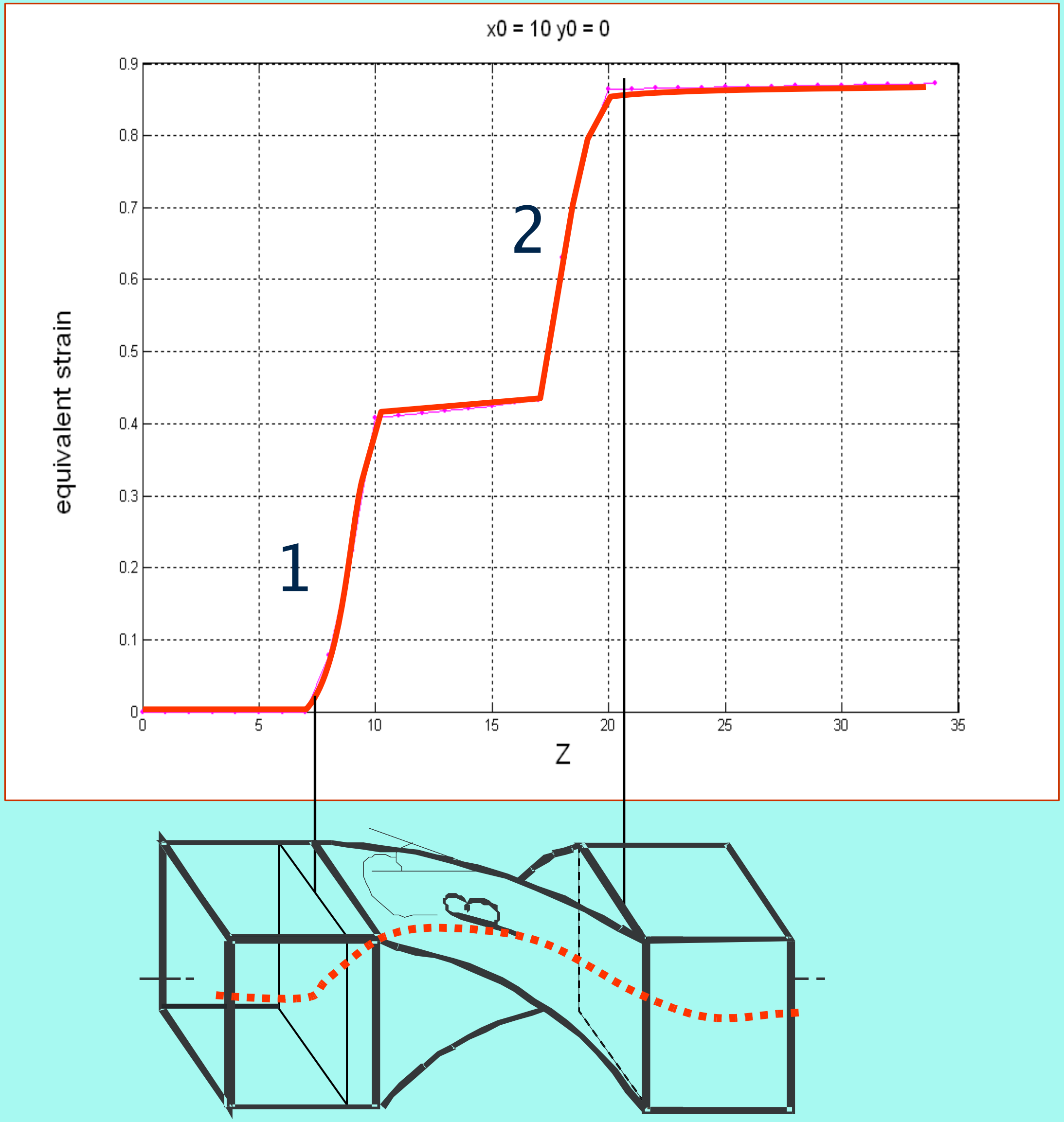


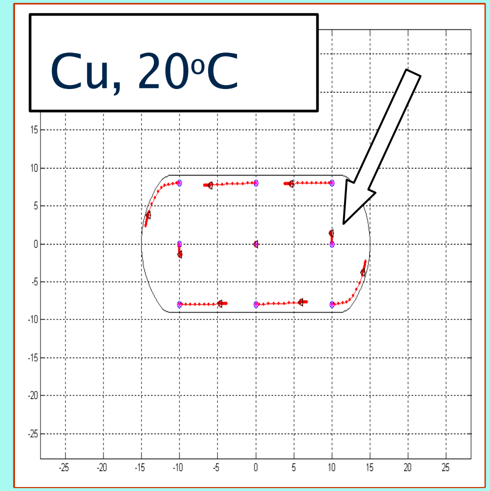




Strain: from e ~ 0.0 on the axis to e ~ 1.0 ÷1.5 on the periphery

Strain accumulation
Zones 1 and 2



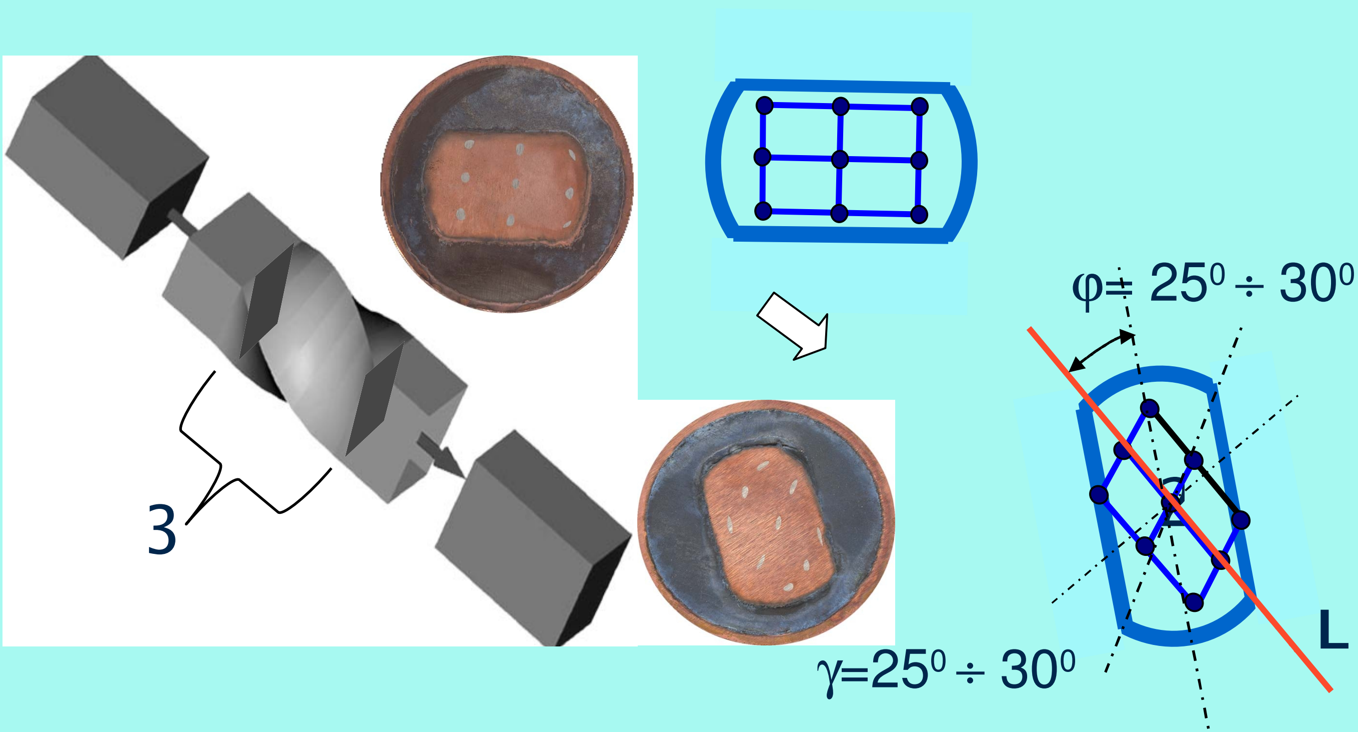


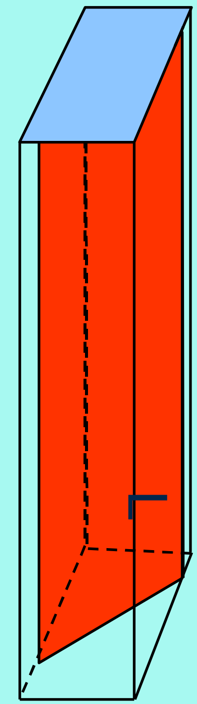
Strain accumulation along the die in a characteristic point where zones 1 and 2 are responsible for most of the deformation.

Deformation Zone 3

Located in the twist part of the die between zones 1 and 2

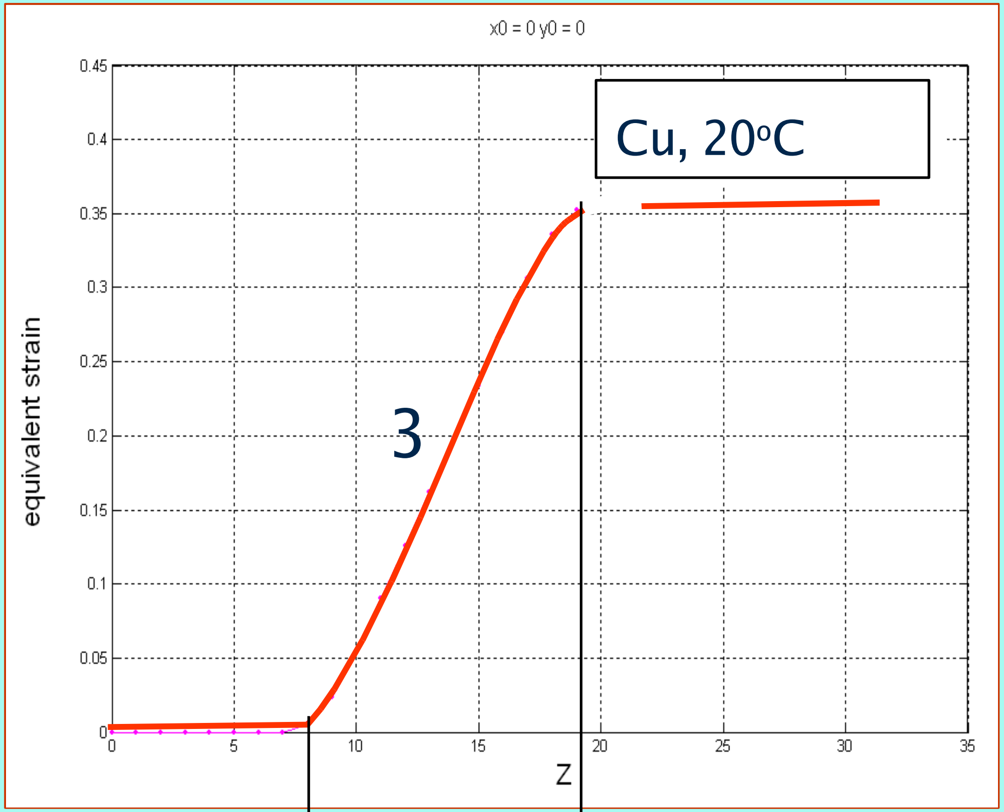
Simple shear in the rotating **Longitudinal plane** (**L**)

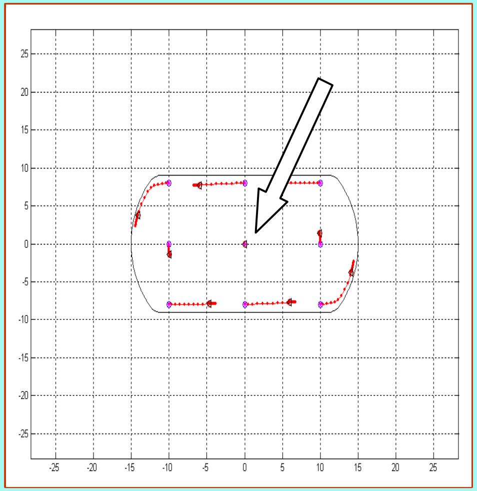


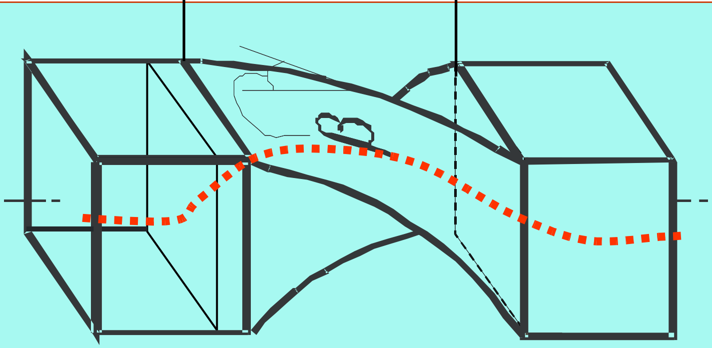


Strain: e ~ 0.4 ÷0.5

Strain accumulation
Zones 3







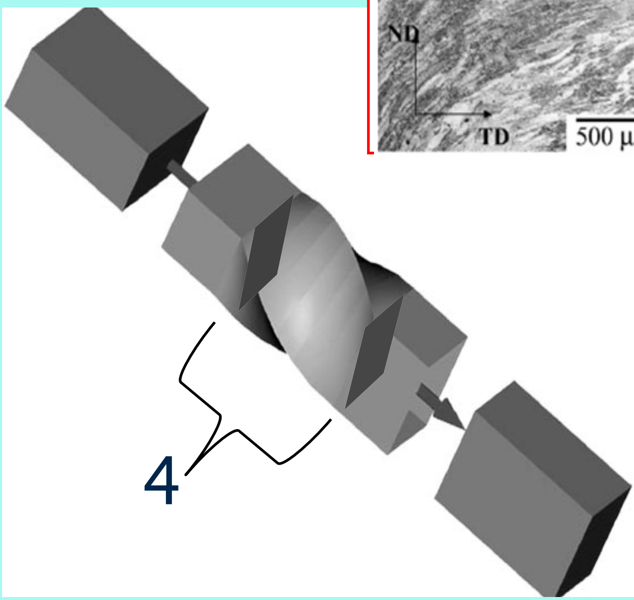
Strain accumulation along the die in central point where zone 3 is responsible for the deformation.

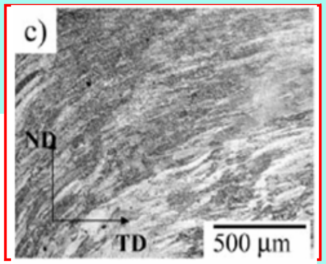
Deformation Zone 4

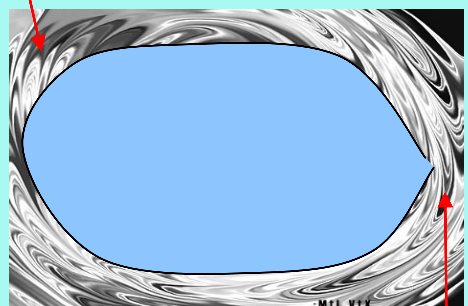
Located in the twist part of the die between zones 1 and 2

Simple shear in the **peripheral layer** (1÷2 mm thick)

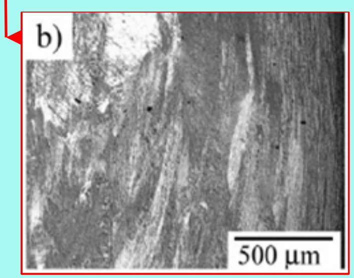
Al-0.13%Mg

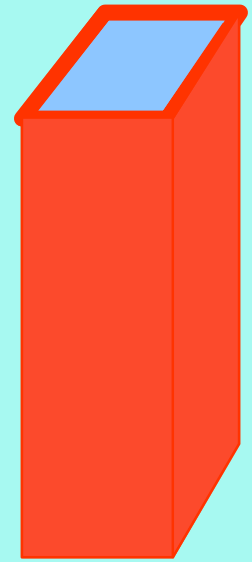






Al-0.13%Mg

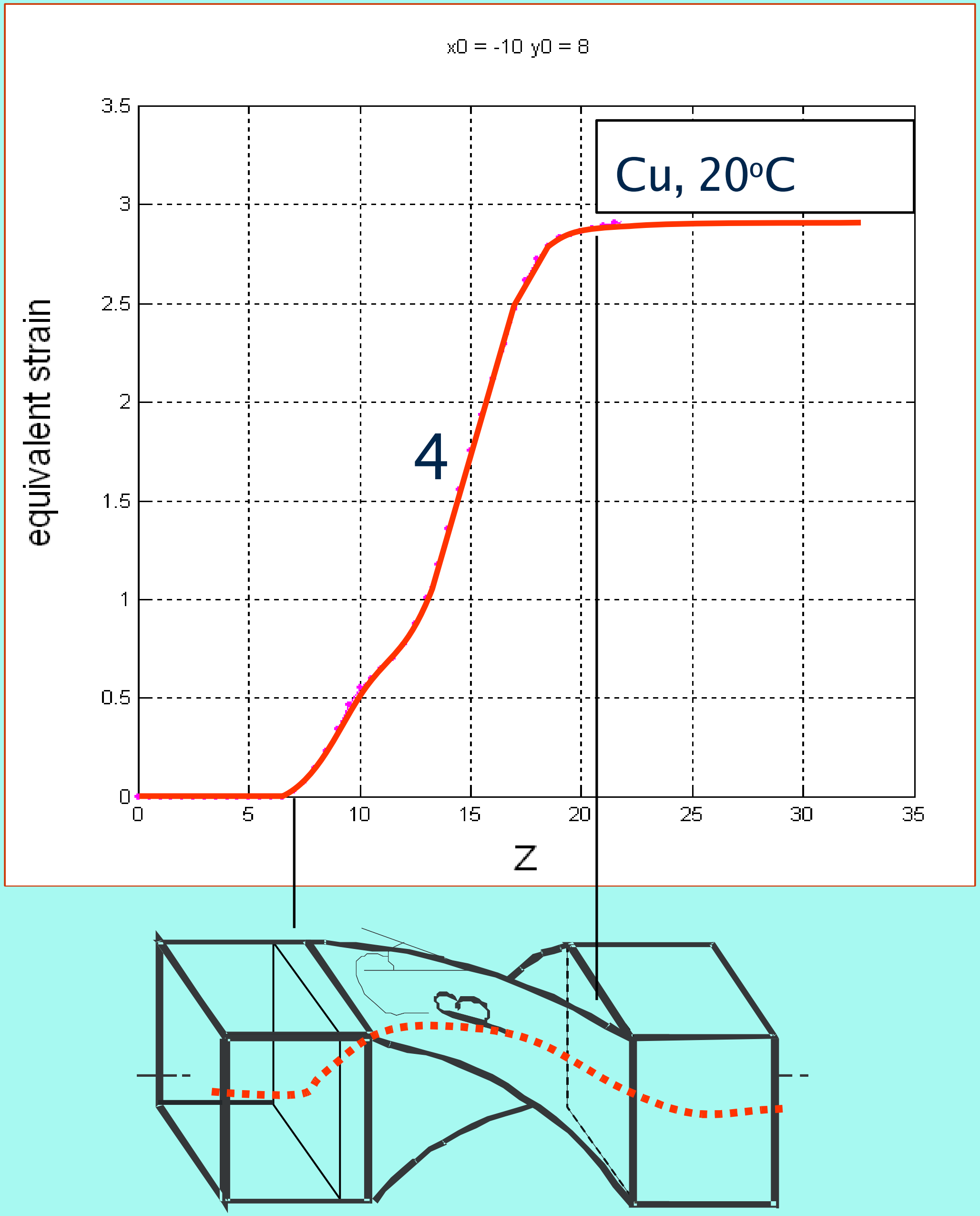


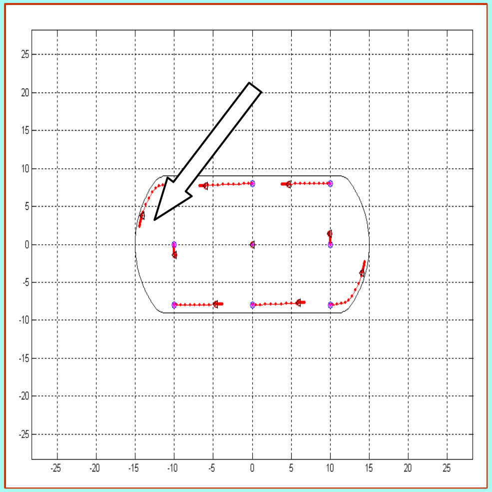


Strain: e ~ 2

We thank Dr. Berta (University of Manchester, UK) for macrostructures b), c)

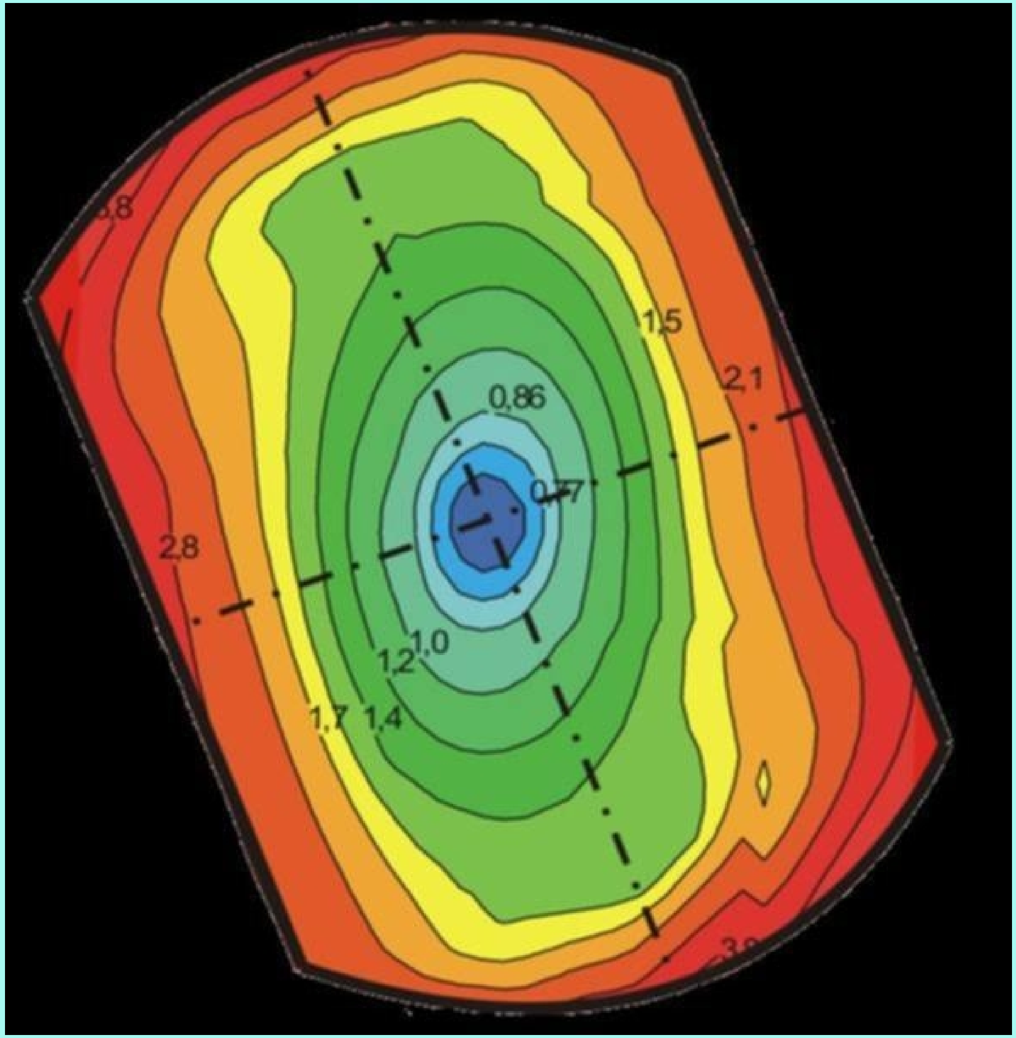
Strain accumulation Zone 4





Strain accumulation along the die in a peripheral point

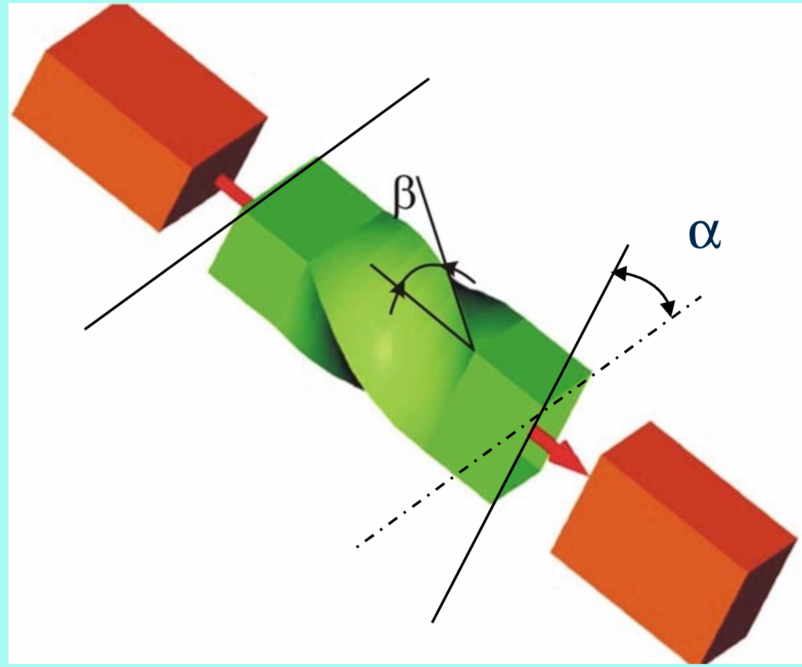
Accumulation Strain at TE (Cu, 20°C)



Controlling metal flow in TE

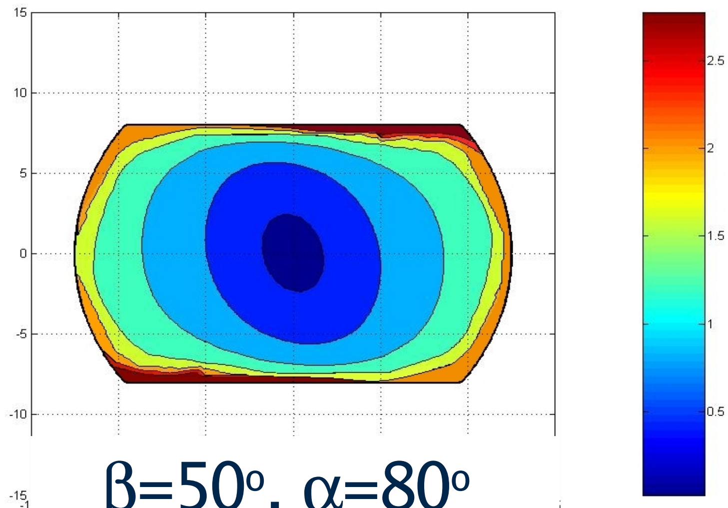
Strain distribution and deformation zones boundaries strongly depend on

- the geometry of die's cross-section,
- inclination angle **β**
- rotation angle **α**

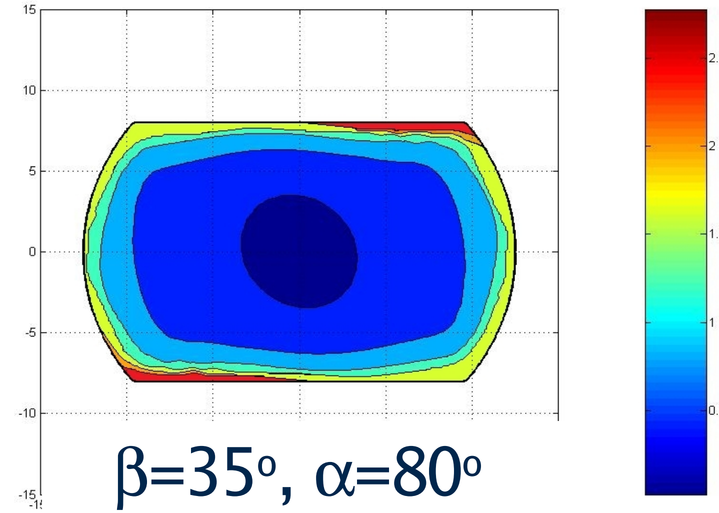


By varying these parameters, one can obtain given inhomogeneous strain. <u>This is of interest for</u> (1) investigating the effects of strain gradient on the evolution of material structure, as well as (2) obtaining gradient structures.

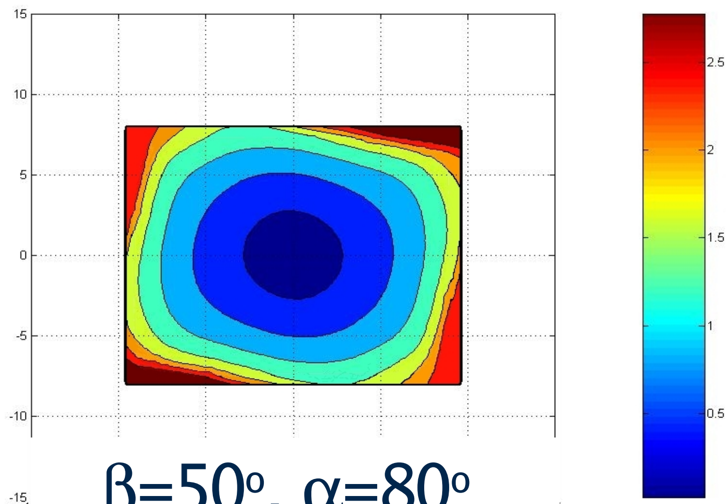
Accumulation strain for **1 pass TE** (Cu, 20^{o}C)



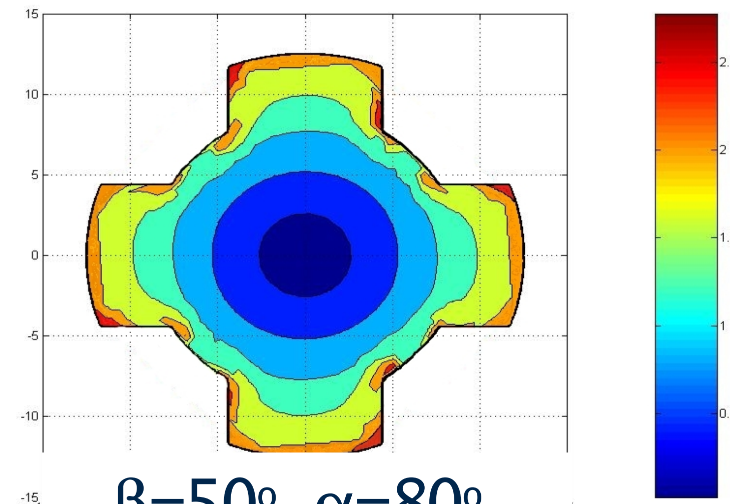
β=50^o, α=80^o



β=35^o, α=80^o



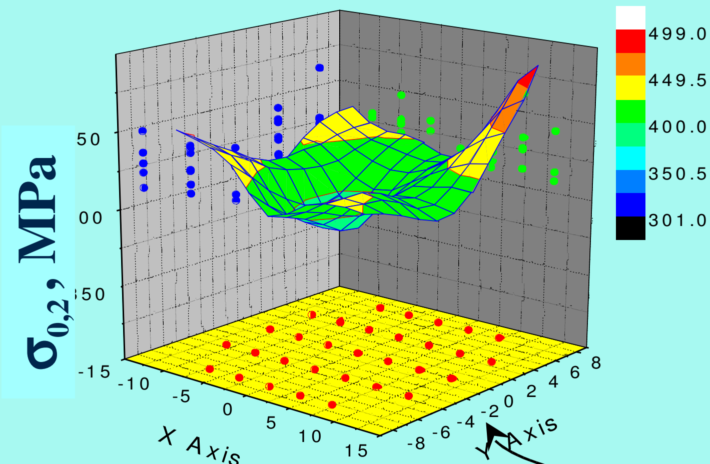
β=50^o, α=80^o



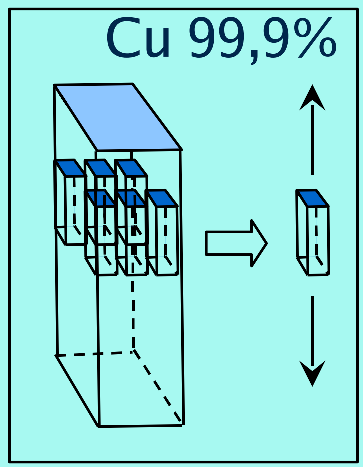
β=50^o, α=80^o

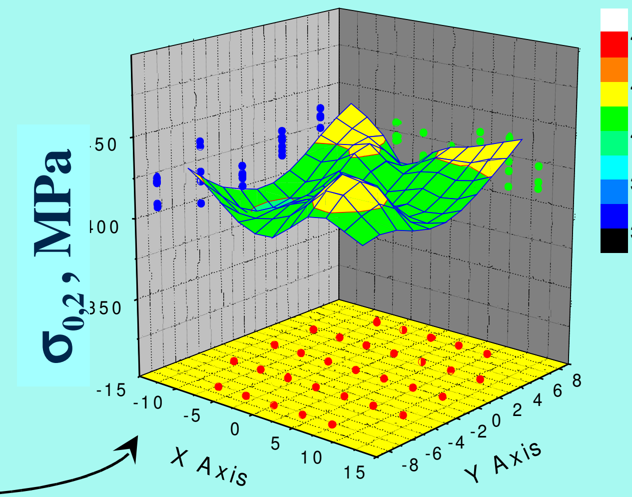
Smoothing of structure and properties during maltipass TE

Despite the nonuniformity of deformation, subsequent TE typically leads to uniform structure and properties. This is due to (1) mixing of metal and (2) stabilization of structure and saturation of properties if strain becomes greater than saturation level e_s



After 2 passes





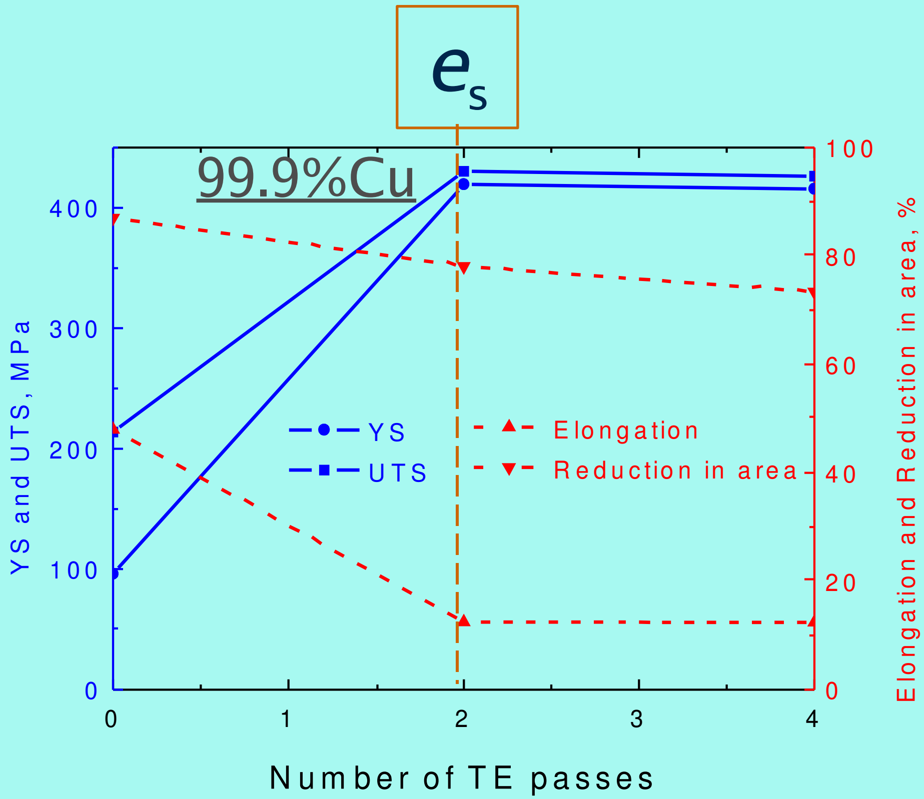
After 4 passes

Mean	Min	Max	Range
419	**385**	**462**	**77 (18%)**

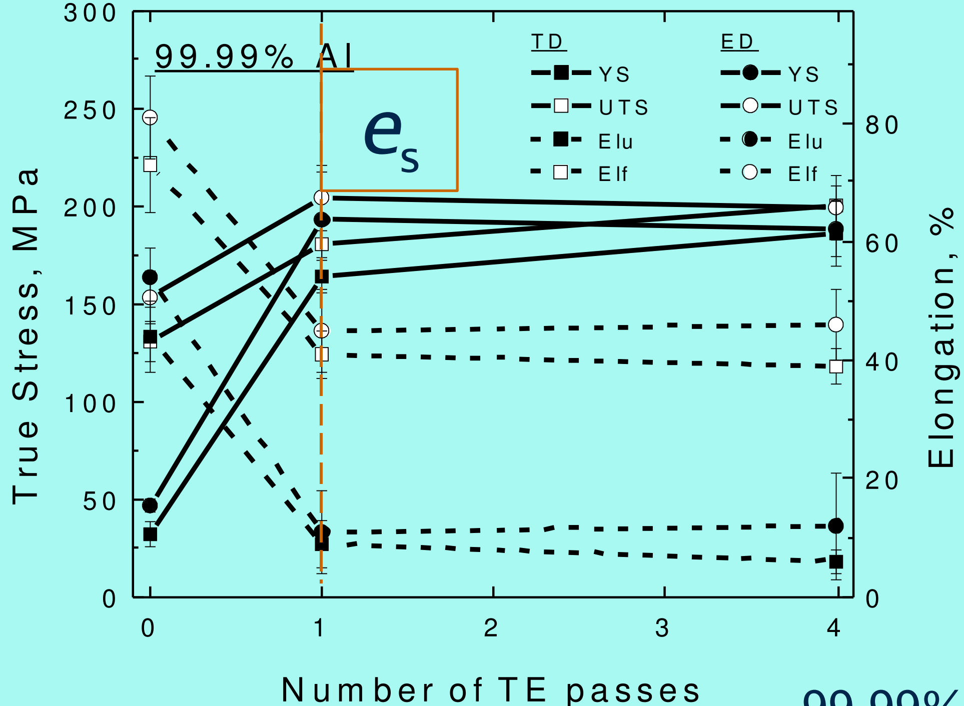
Mean	Min	Max	Range
426	**403**	**450**	**47 (11%)**

Joint work with Dr. Korshunov, Sarov, Russia

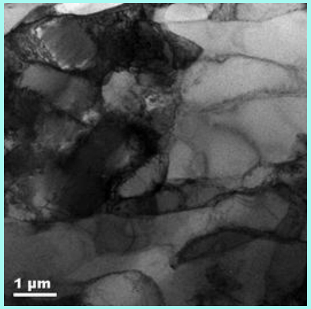
Stabilization of structure and saturation of properties during TE



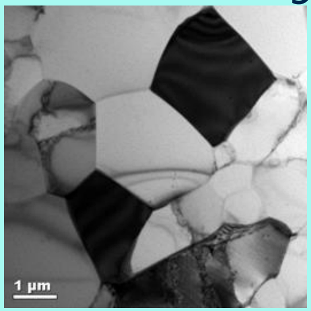
Joint work with Dr. Korshunov, Sarov, Russia



99.99% Al



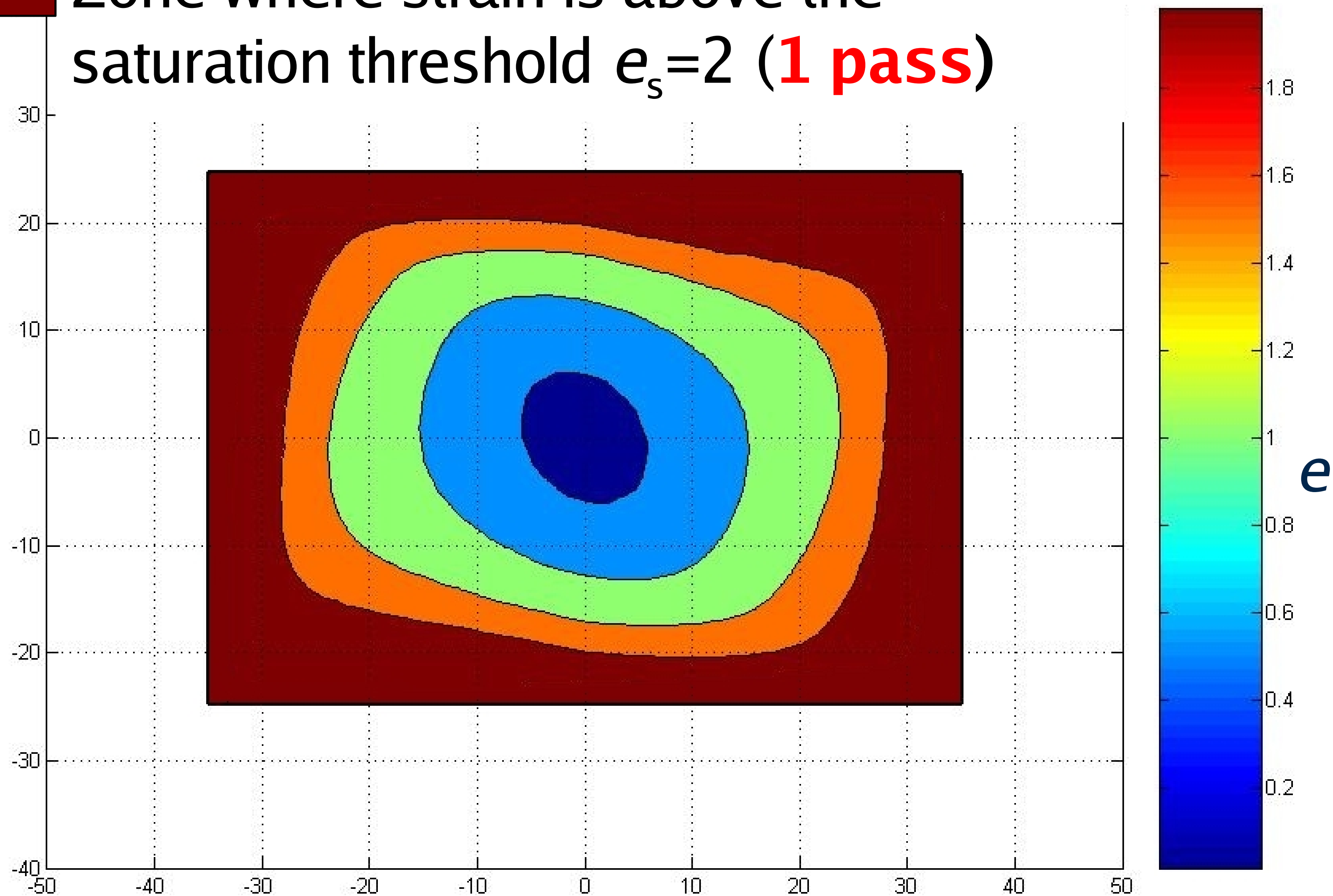
1 TE pass



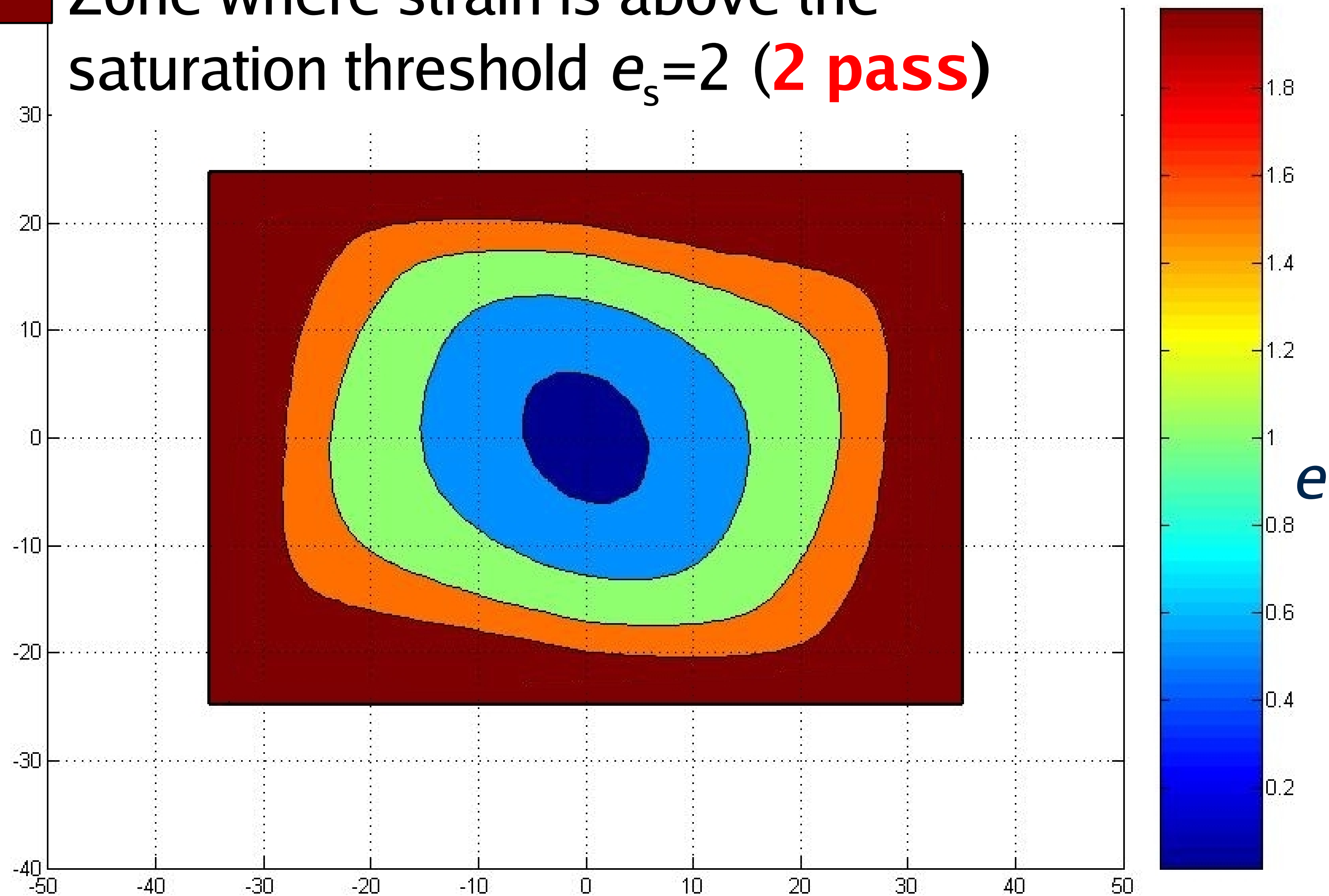
4 TE passes

Joint work with Prof. Horita, Kyushu University, Fukuoka, Japan

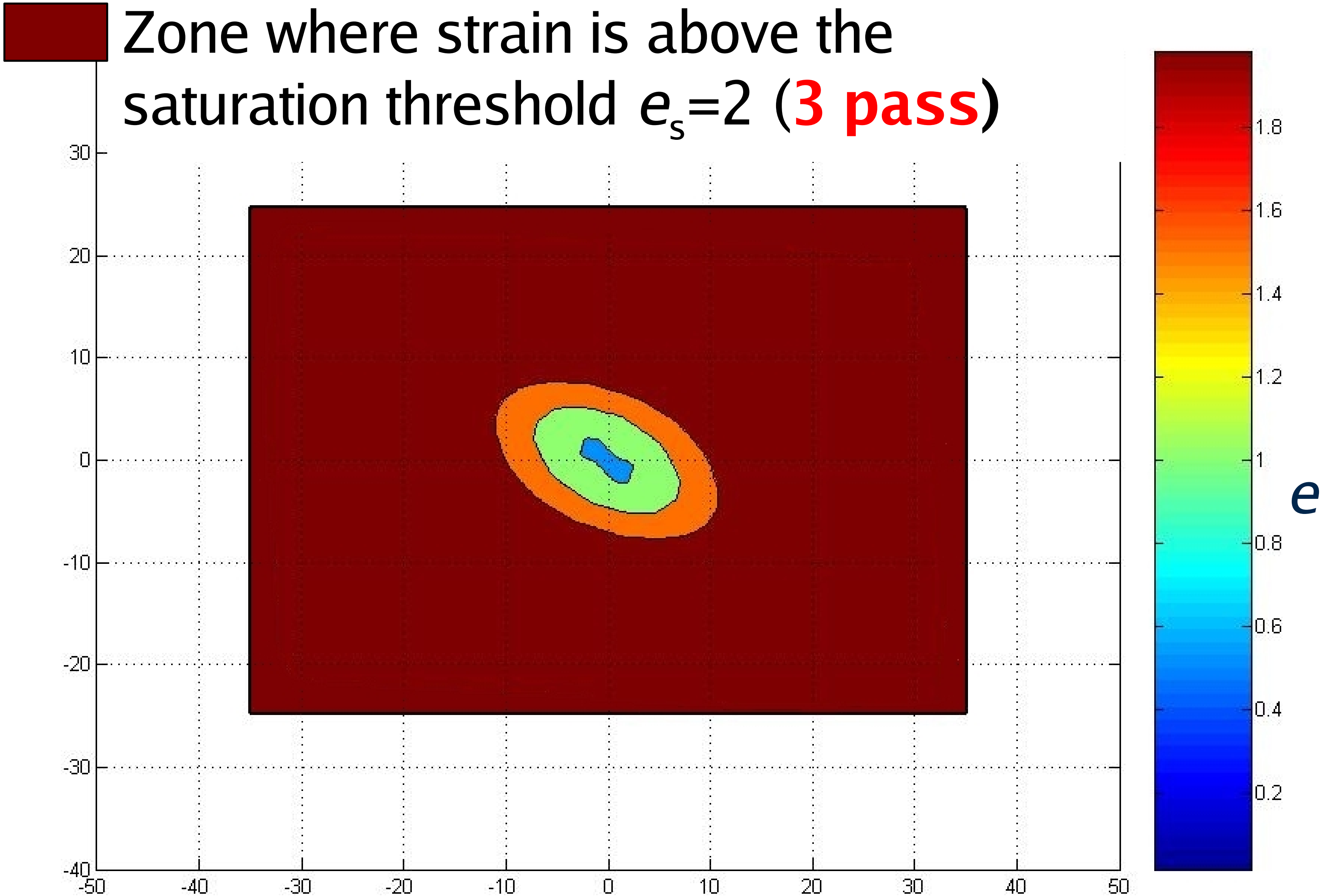
Zone where strain is above the saturation threshold e_s=2 (**1 pass**)



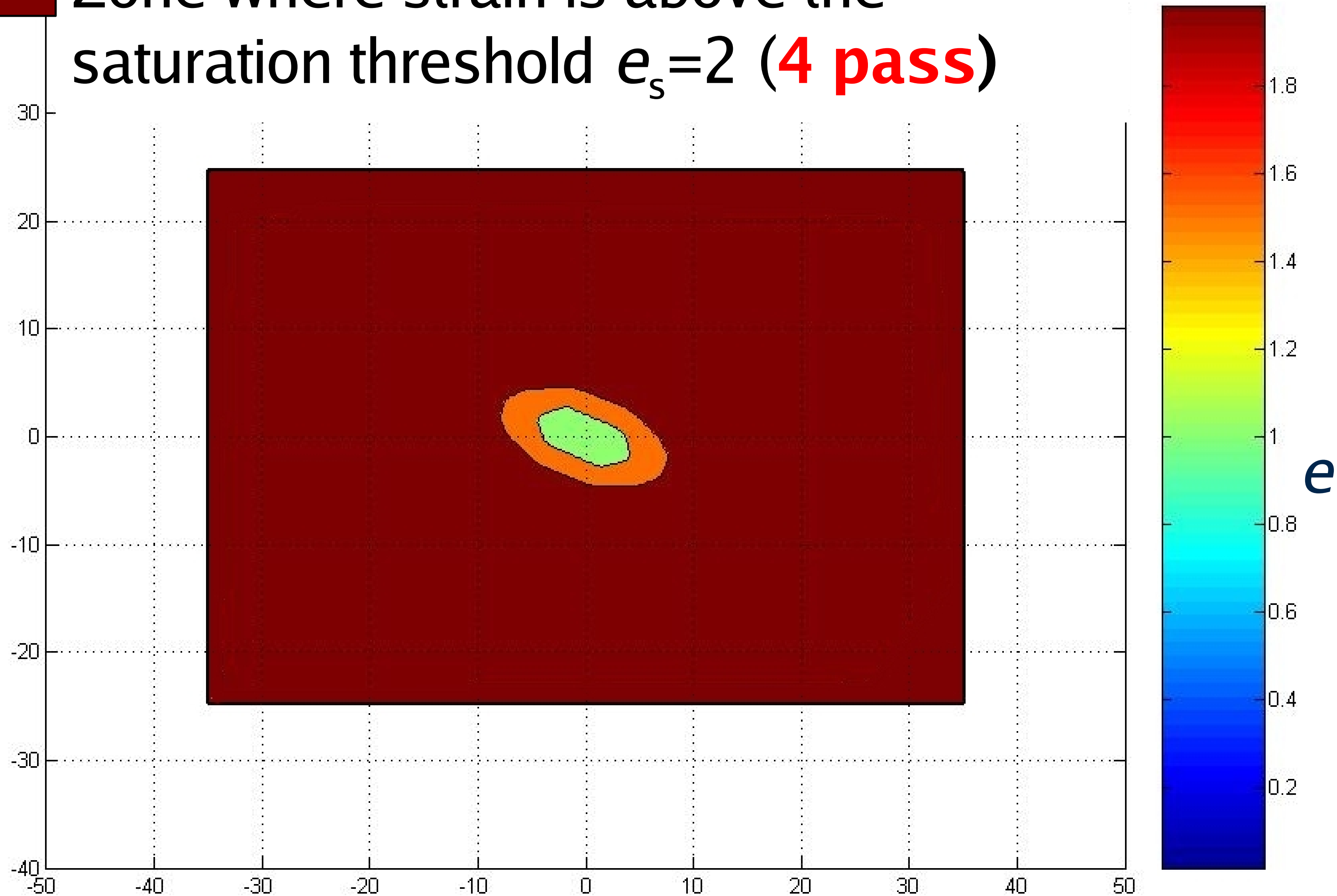
Zone where strain is above the saturation threshold e_s=2 (**2 pass**)

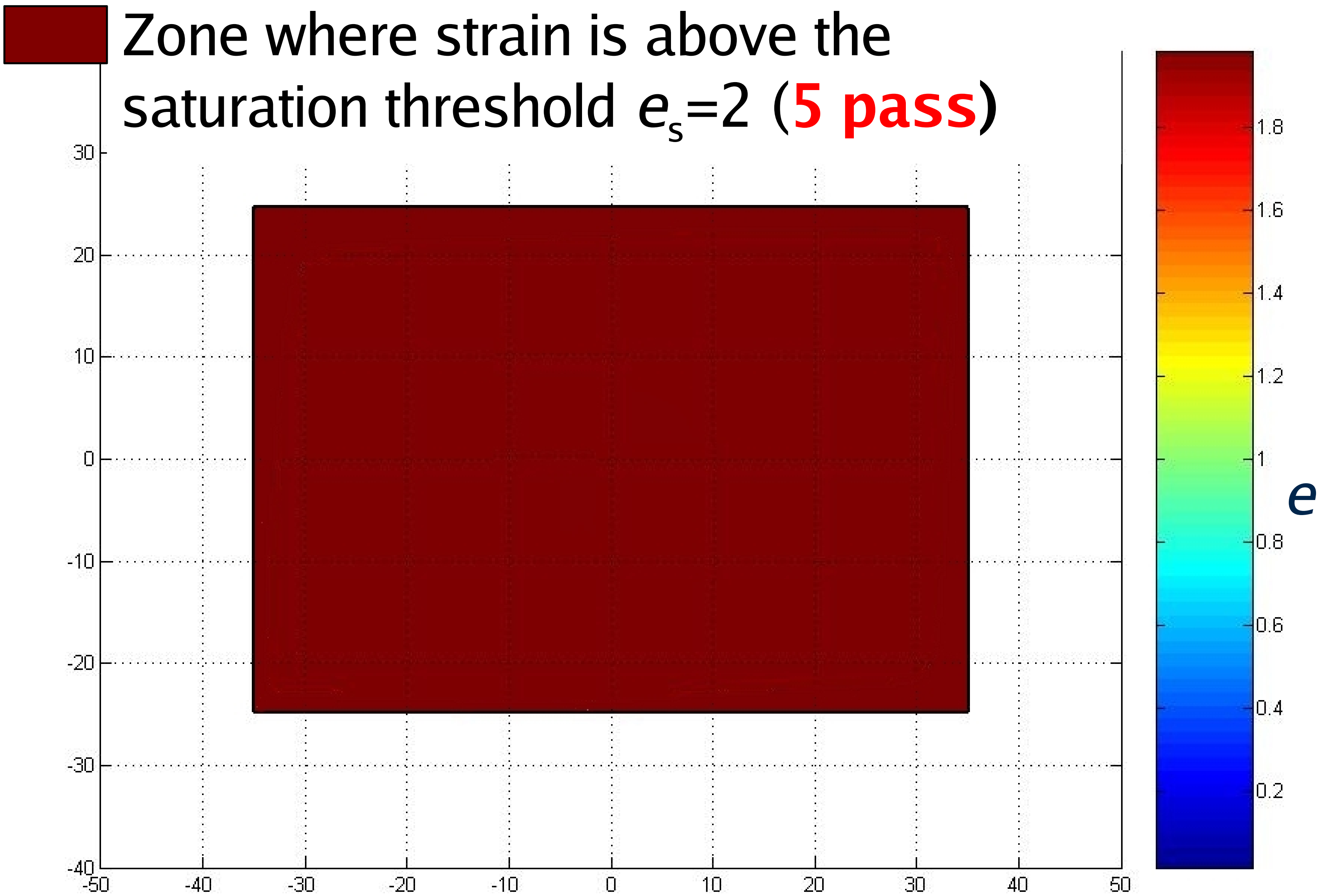


Zone where strain is above the saturation threshold e_s=2 (**3 pass**)



Zone where strain is above the saturation threshold e_s=2 (**4 pass**)



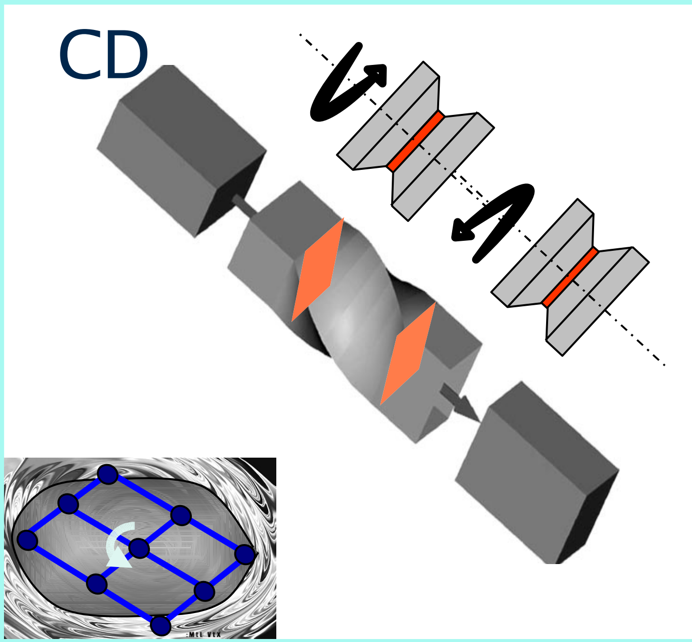


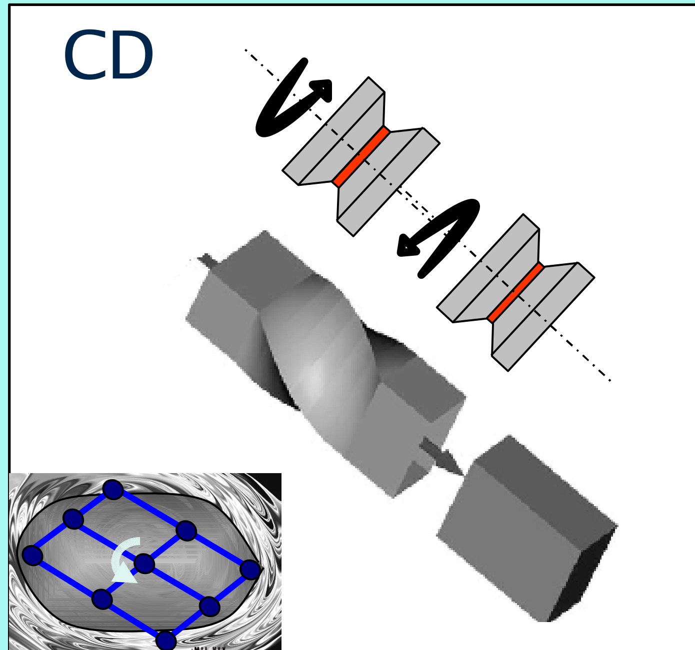
Zone where strain is above the
saturation threshold e_s=2 (5 pass)
30
20
10
0
-10
-20
-30
-40
-50
-40
-30
-20
-10
0
10
20
30
40
50
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
e

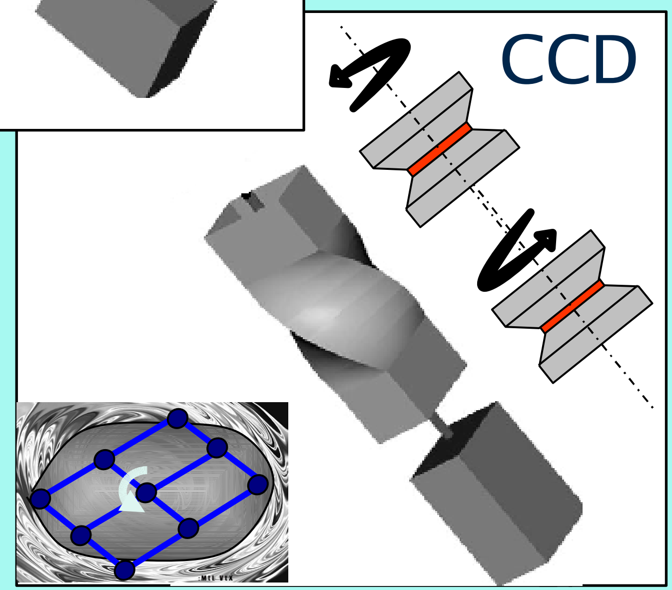
Two main routes of TE

Two orientations of the die (,) lead to two main routes of TE

Route I: CD+CD



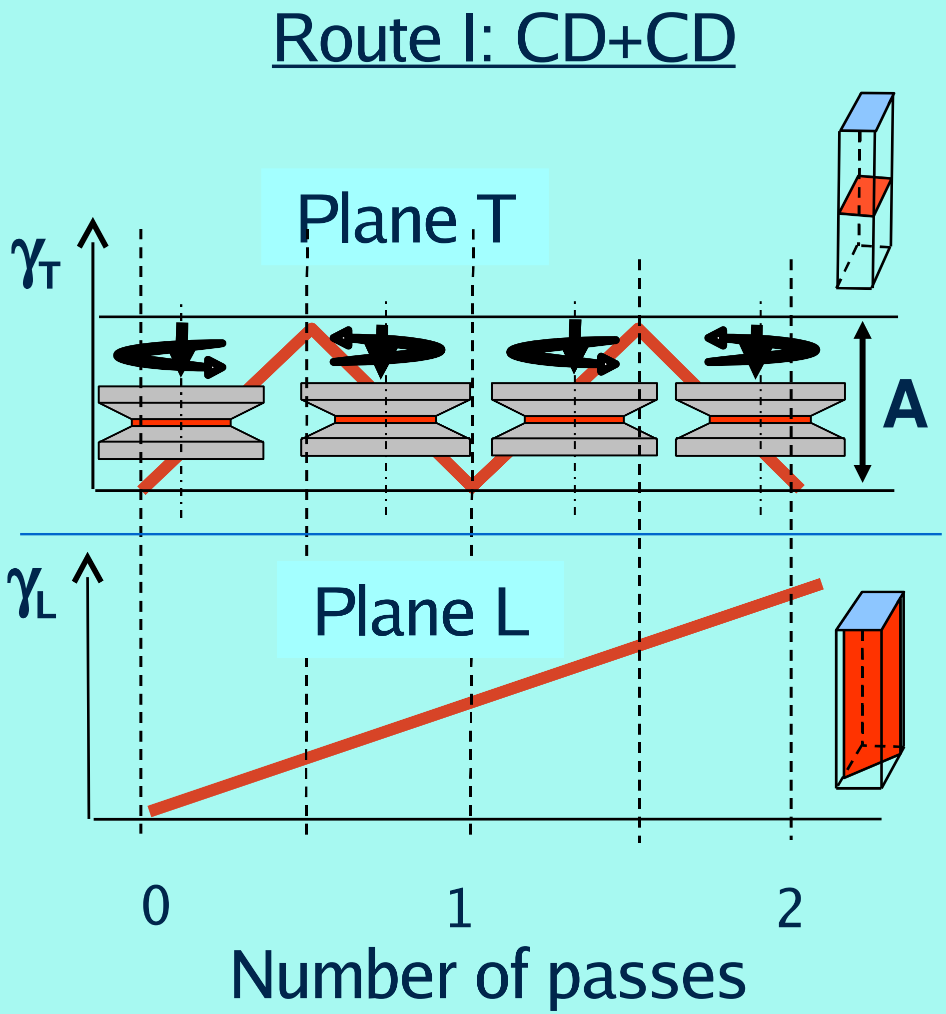


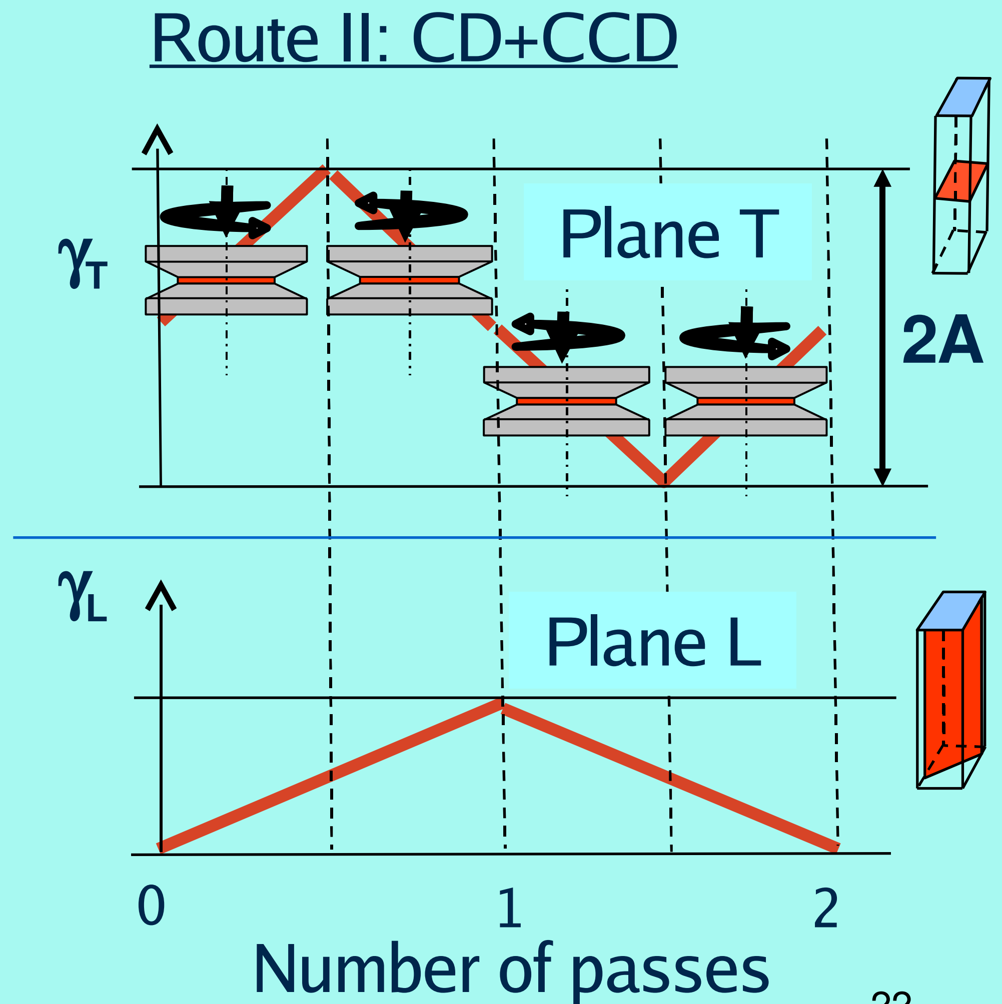


Route II: CD+CCD

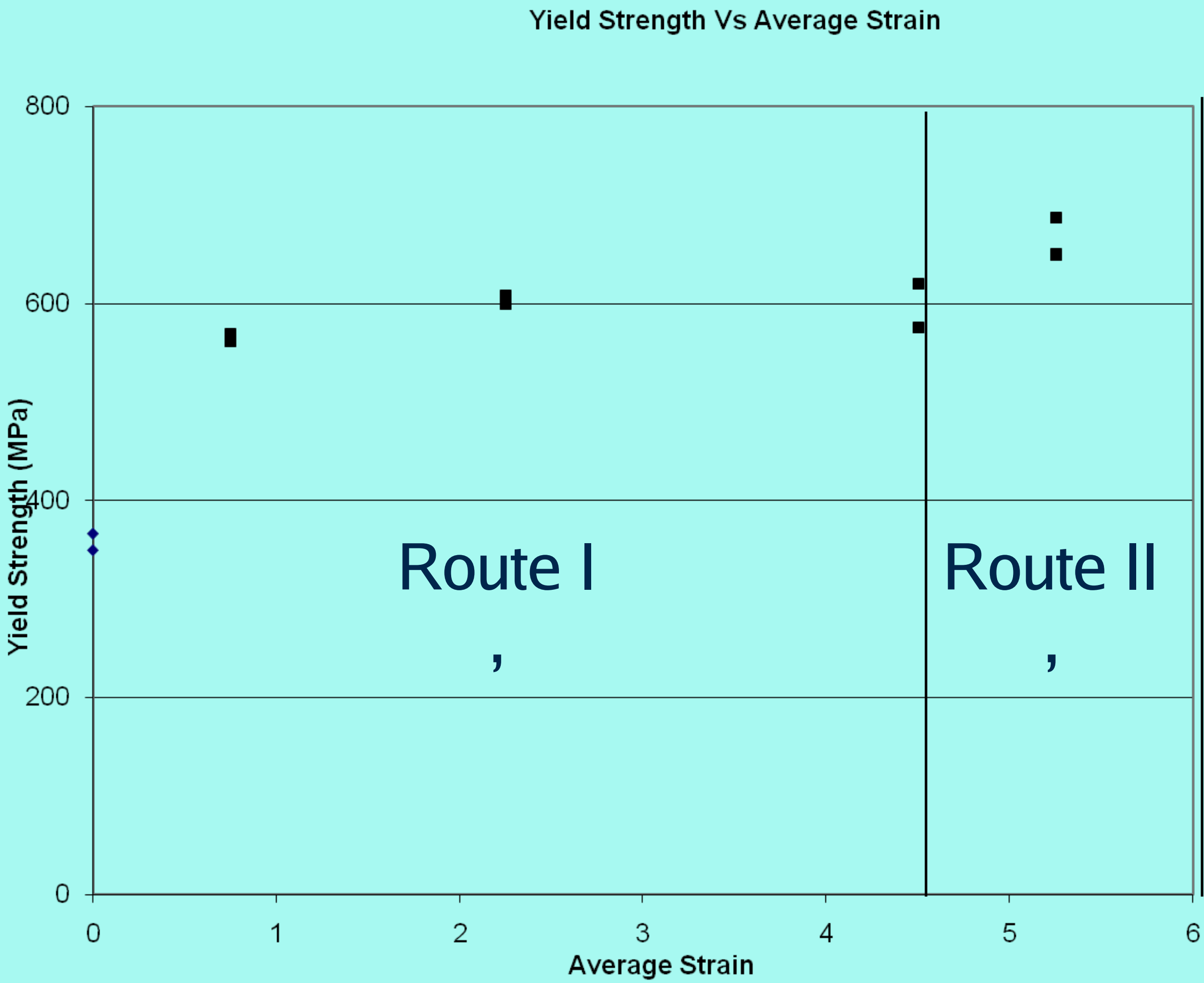
CD-clockwise die
CCD- counterclockwise die

Two main routes of TE





Route II overcomes saturation

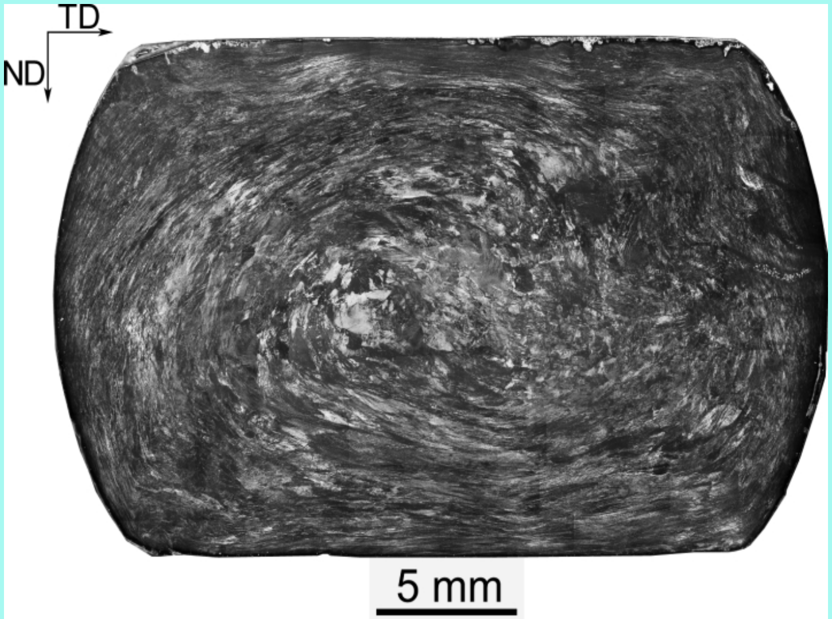


CP-Ti
(grade 2)
300°C
β=45°

Different loading paths can lead to different structures and properties. In particular, using route II allows one to increase the yield threshold of Ti after it saturates in route I

Joint work with Prof. Rack, Clemson University, USA

Vortex and Mixing

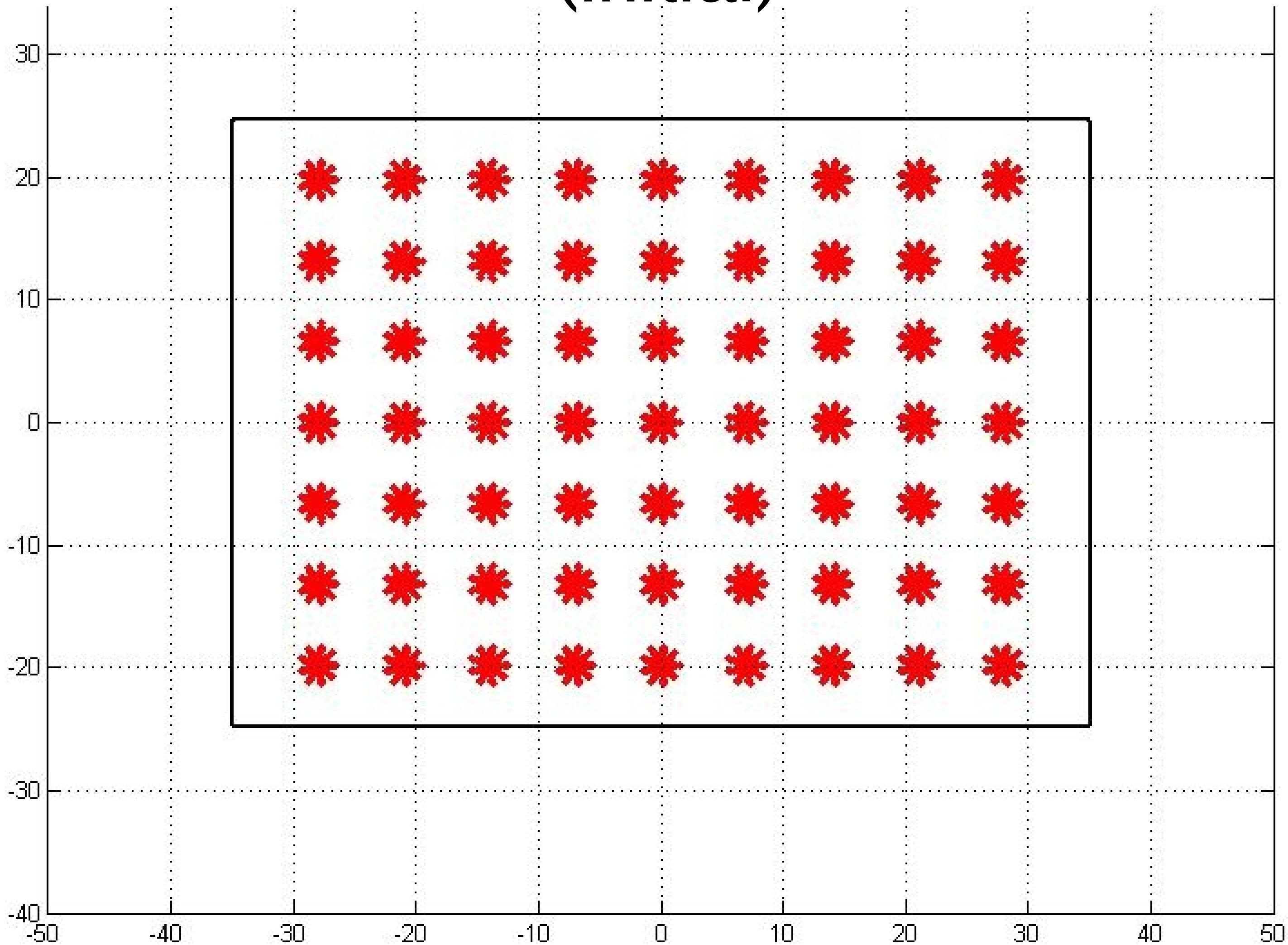


perpendicular cross-section

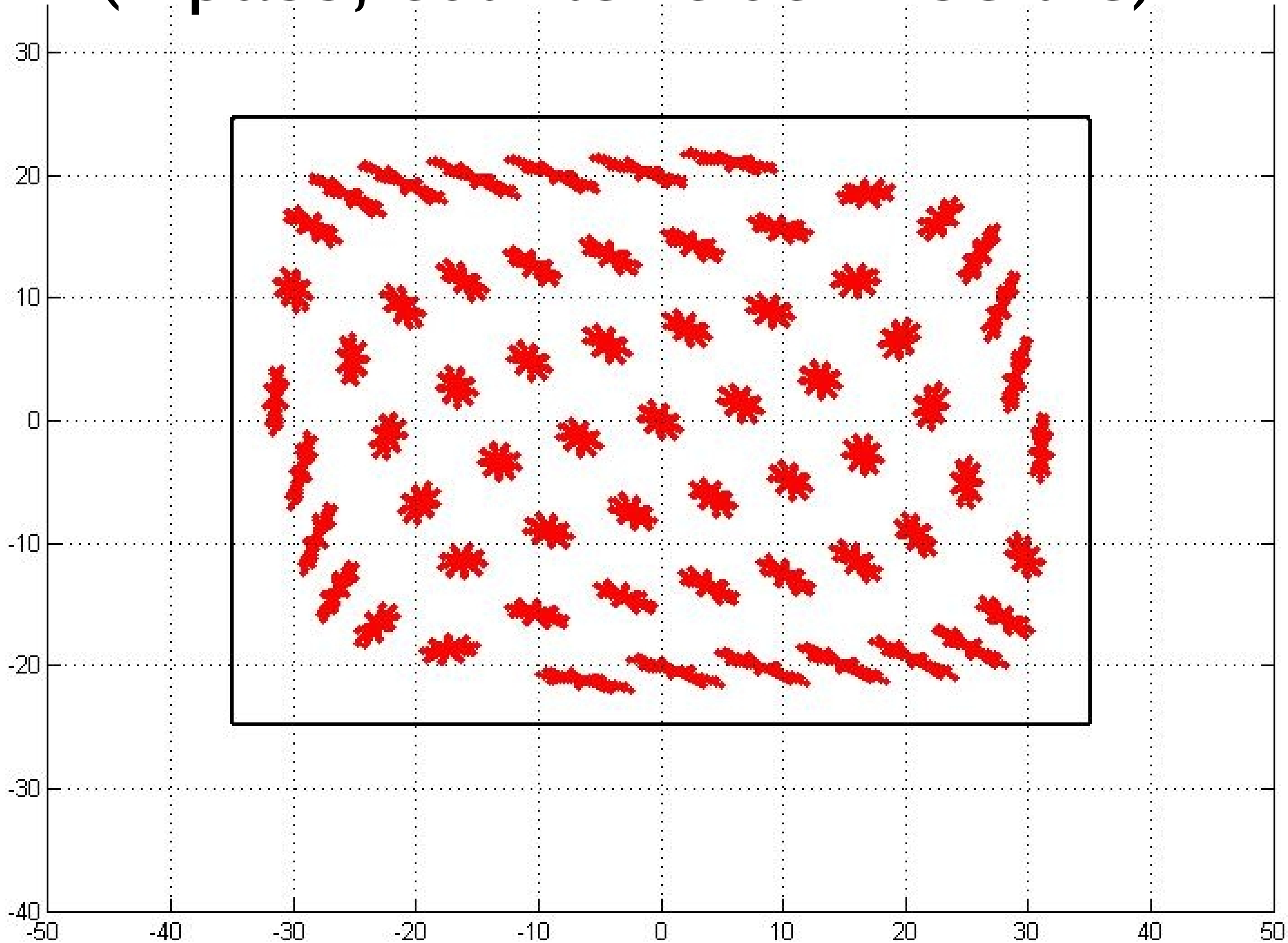
Deformation Zones 3 and 4 form a vortex-like flow which stretches metal particles.

The stretching increases with subsequent TE passes as long as the dies have a constant direction (all clockwise or all counter-clockwise)

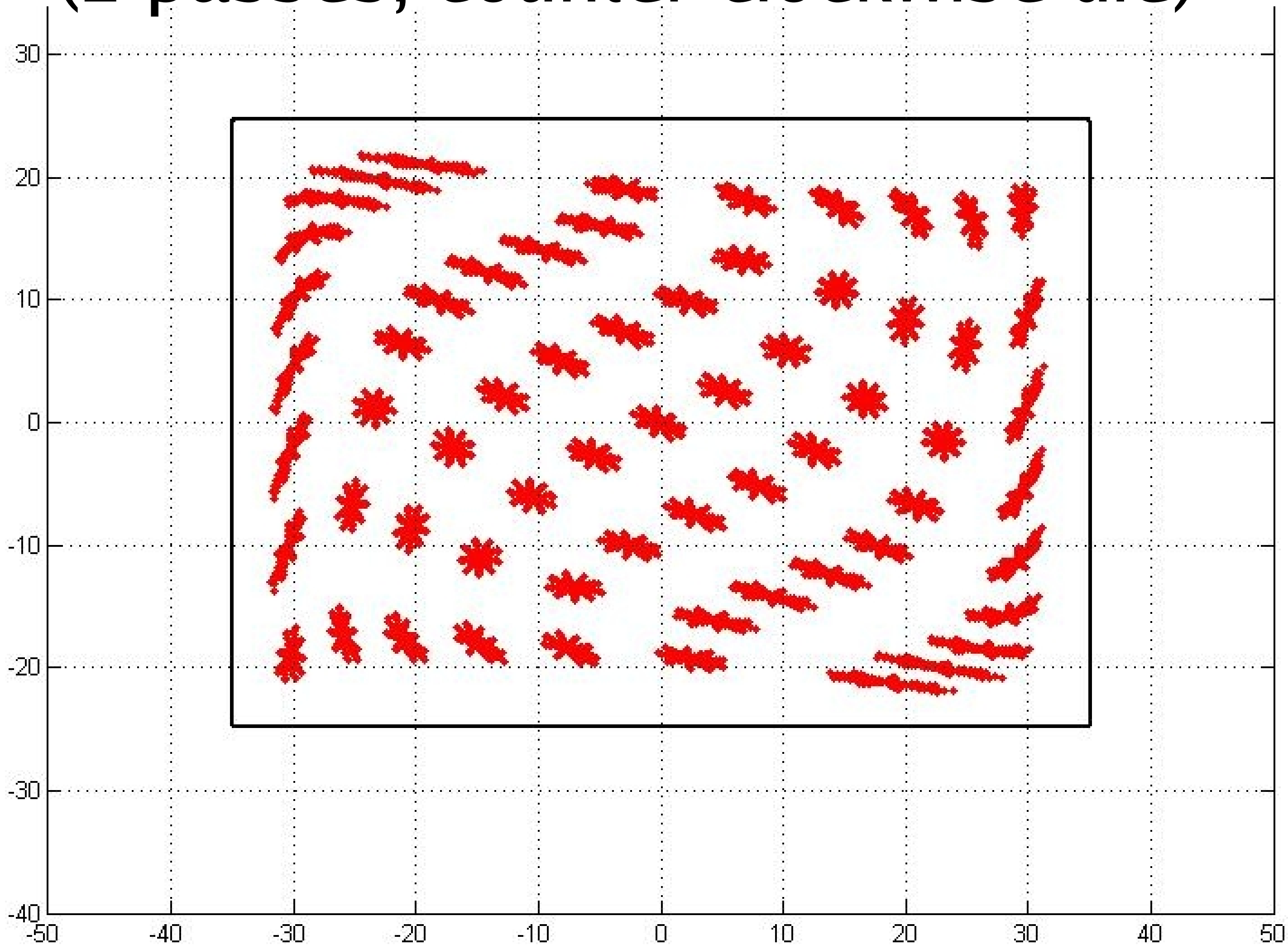
Stretching (initial)



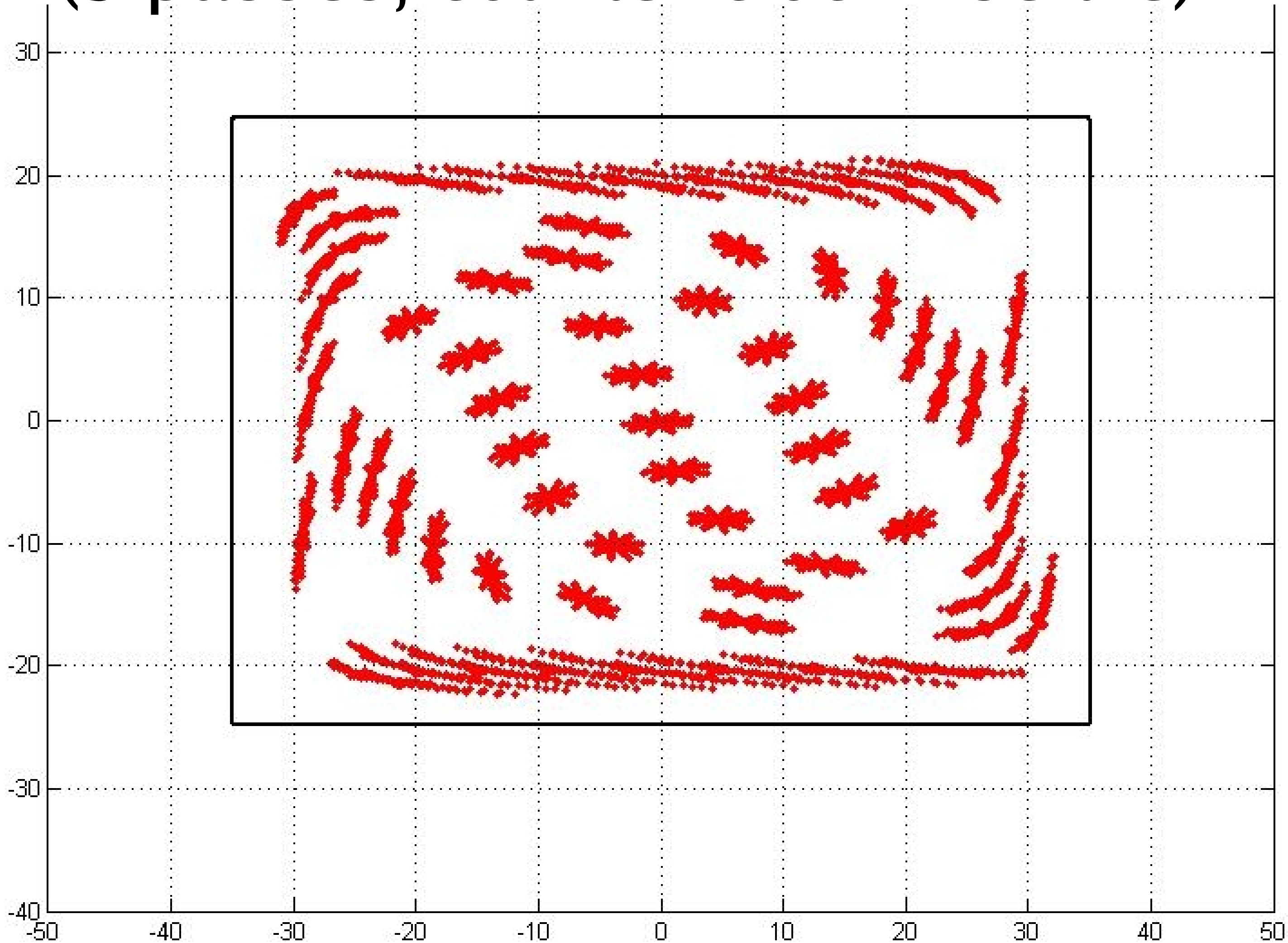
Stretching
(1 pass, counter-clockwise die)



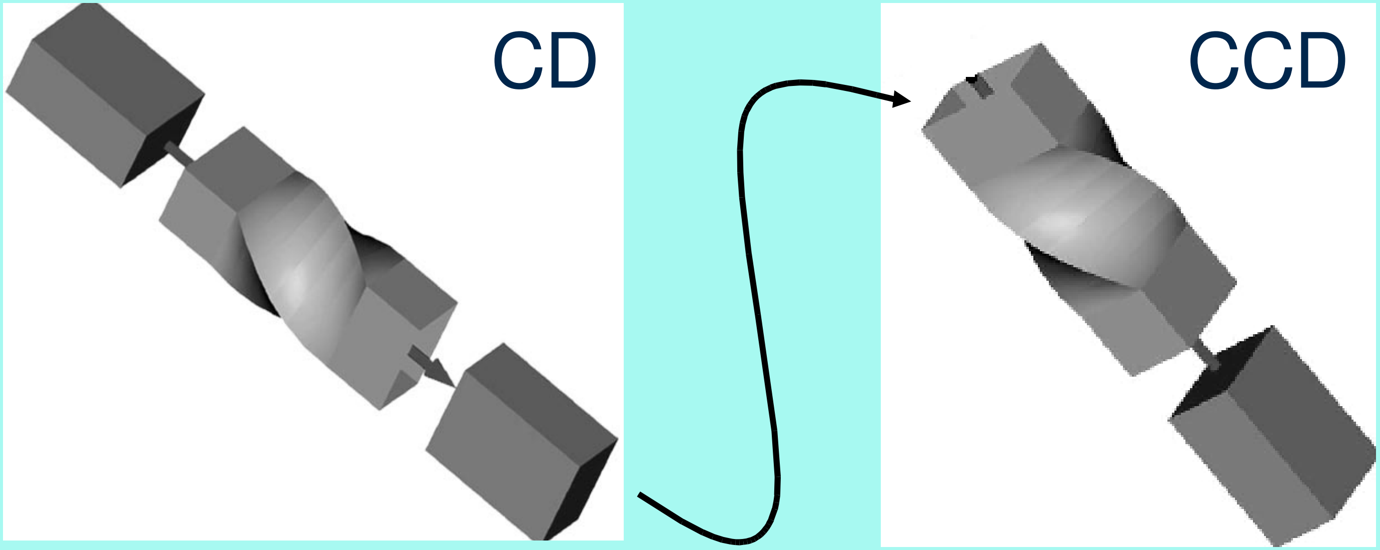
Stretching
(2 passes, counter-clockwise die)

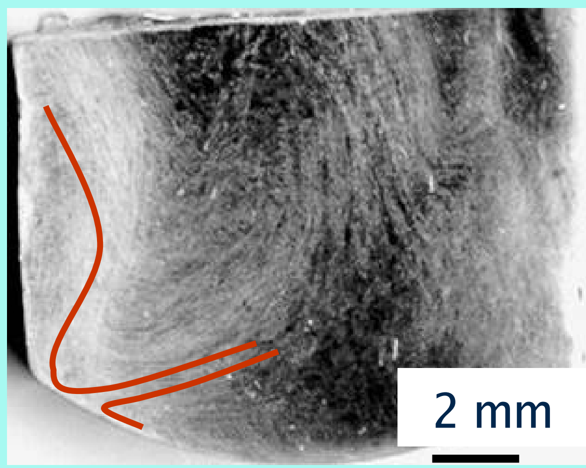


Stretching
(3 passes, counter-clockwise die)



Passes with alternating directions create folds





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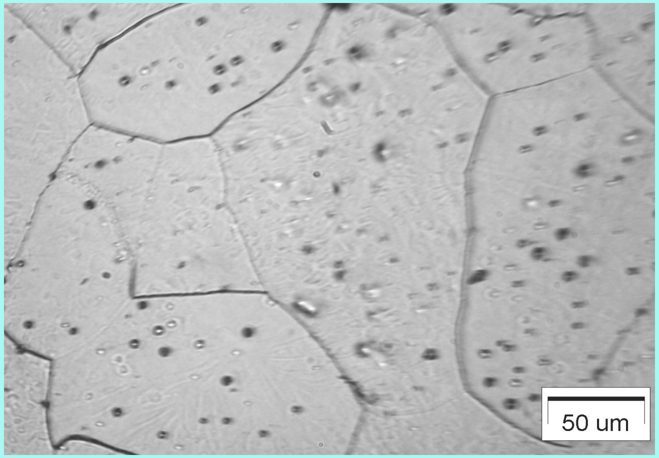
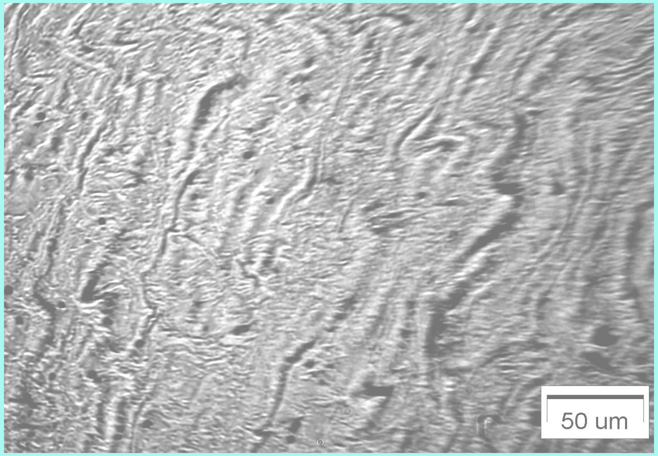
We thank Dr. Milman for sharing the microstructure.

At a finer scale, folds form due to instability of shear planes

Initial



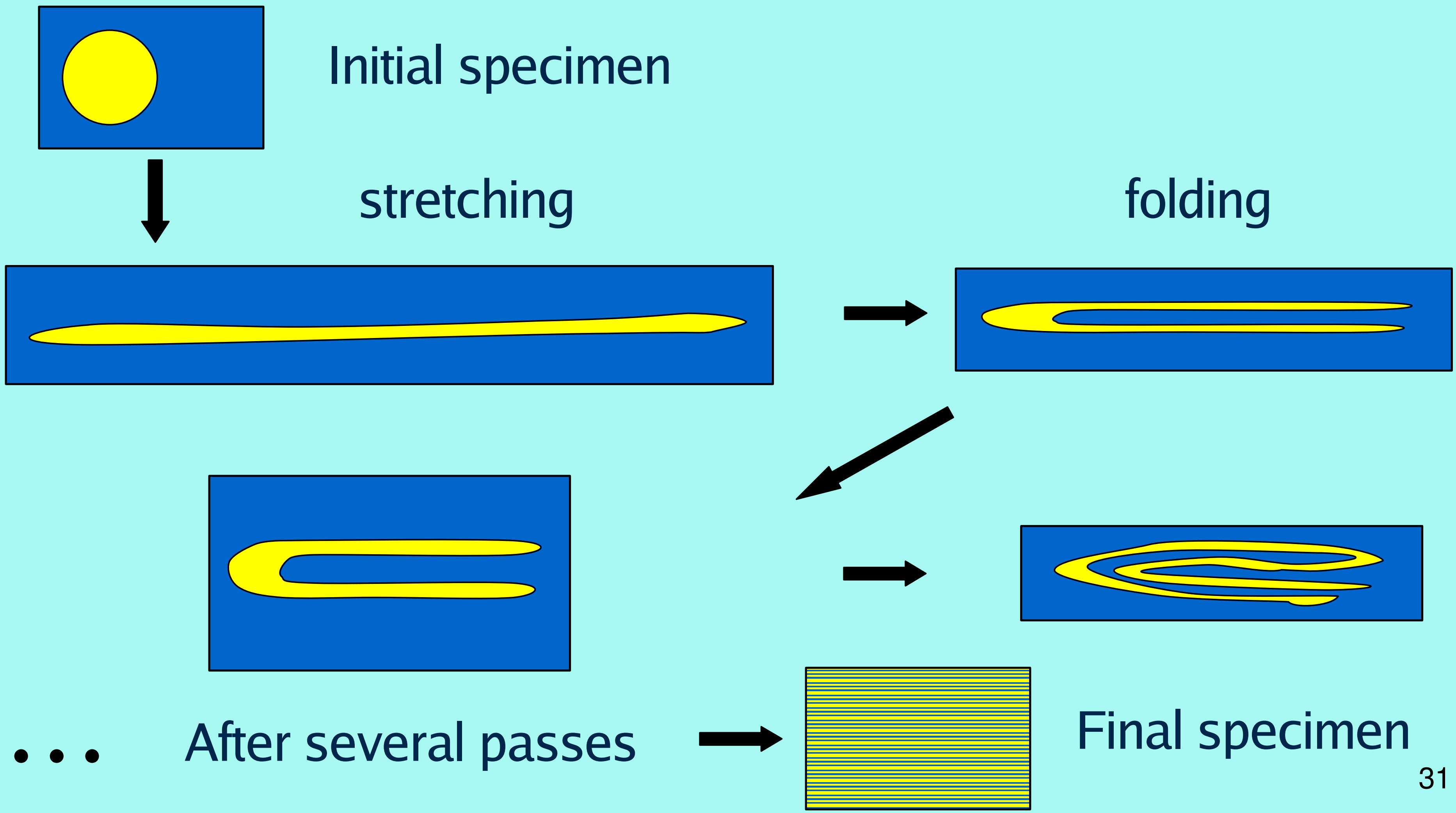
After one pass TE



Aluminum

Joint work with Prof. Milman, Kiev, Ukraine

Alternating stretching and folding leads to mixing, as in Smale's horseshoe

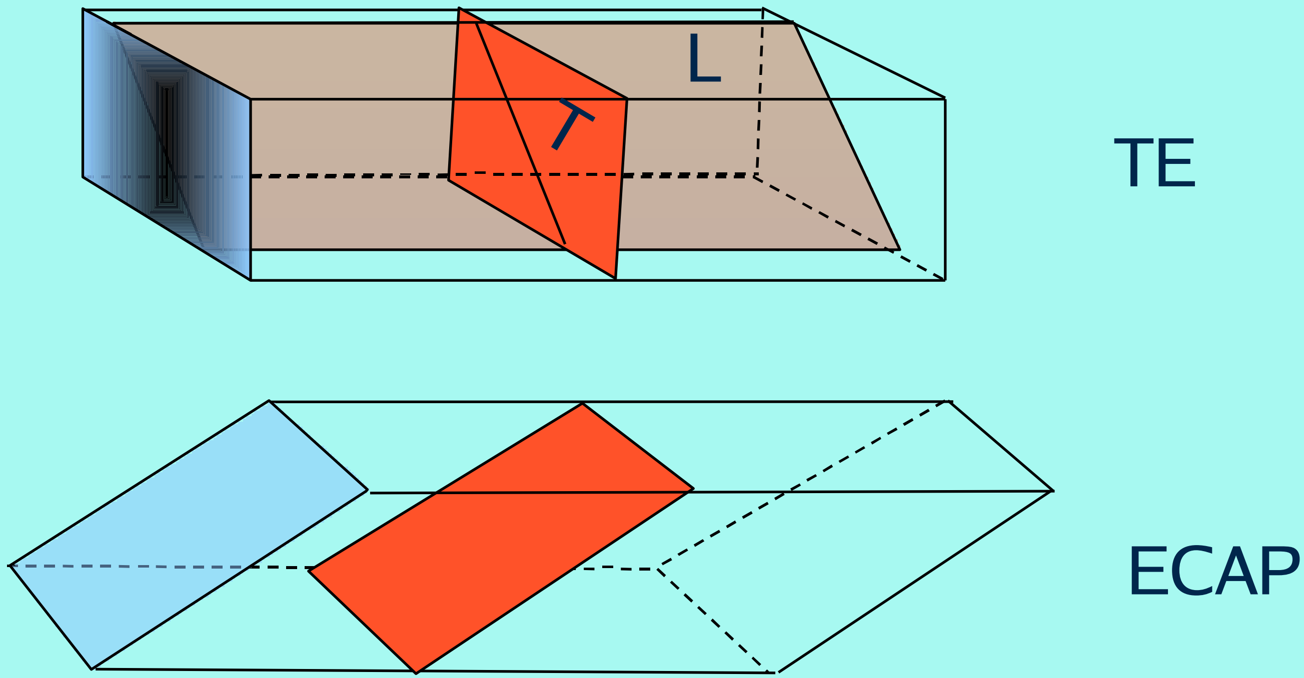


So why should we care about Twist Extrusion?

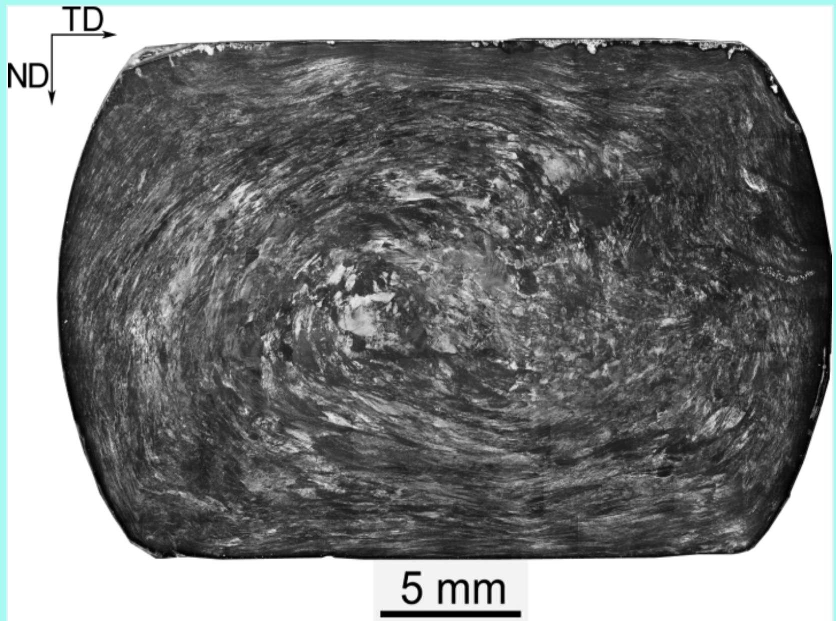
- TE has already been successfully used to obtain UFG structure with good properties in Al, Cu, Ni and Ti alloys (more at http://hunch.net/~yan).

- Most importantly, TE opens new possibilities for investigating and forming new structures with new properties, mainly due to four factors.

Factor 1: Two new shear planes in the volume of the specimen



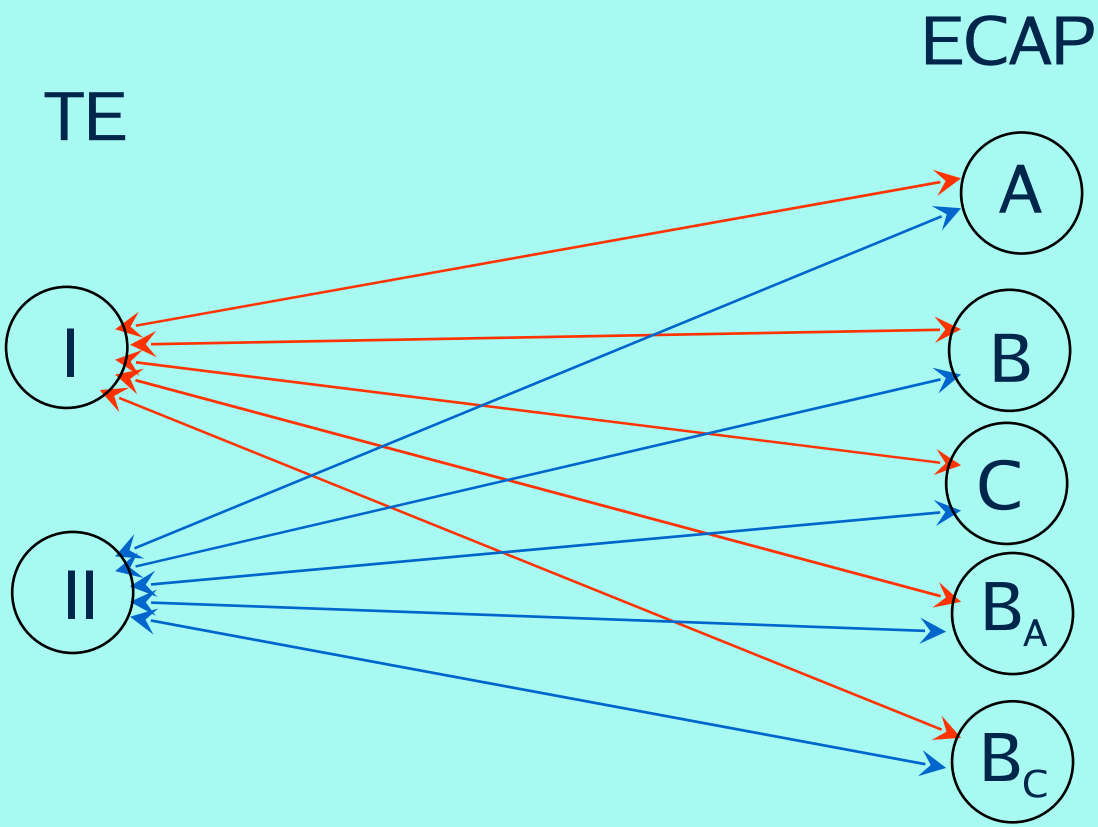
Factor 2: Vortex-like flow with stretching and mixing of metal particles



This is of interest for
(1) homogenization (2) mechanochemical reactions

Factor 3: Two main routes of TE

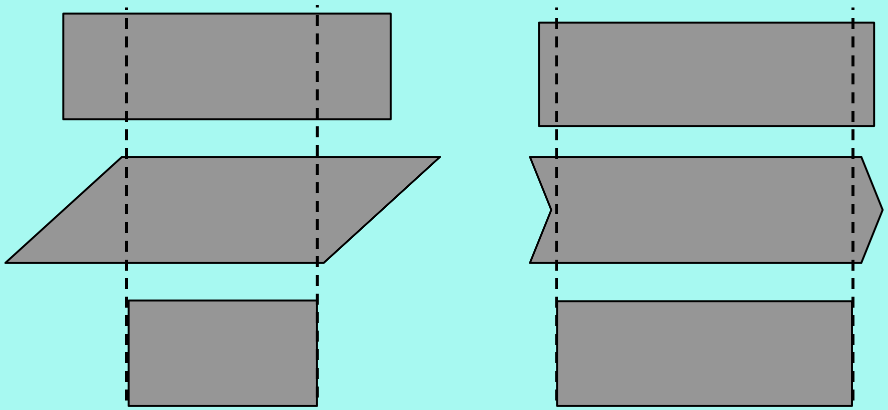
which can be combined with any SPD or metal forming processes (for example: ECAP, rolling, extrusion) to broaden the space of possible loading paths.



Factor 4: New technological possibilities

ECAP

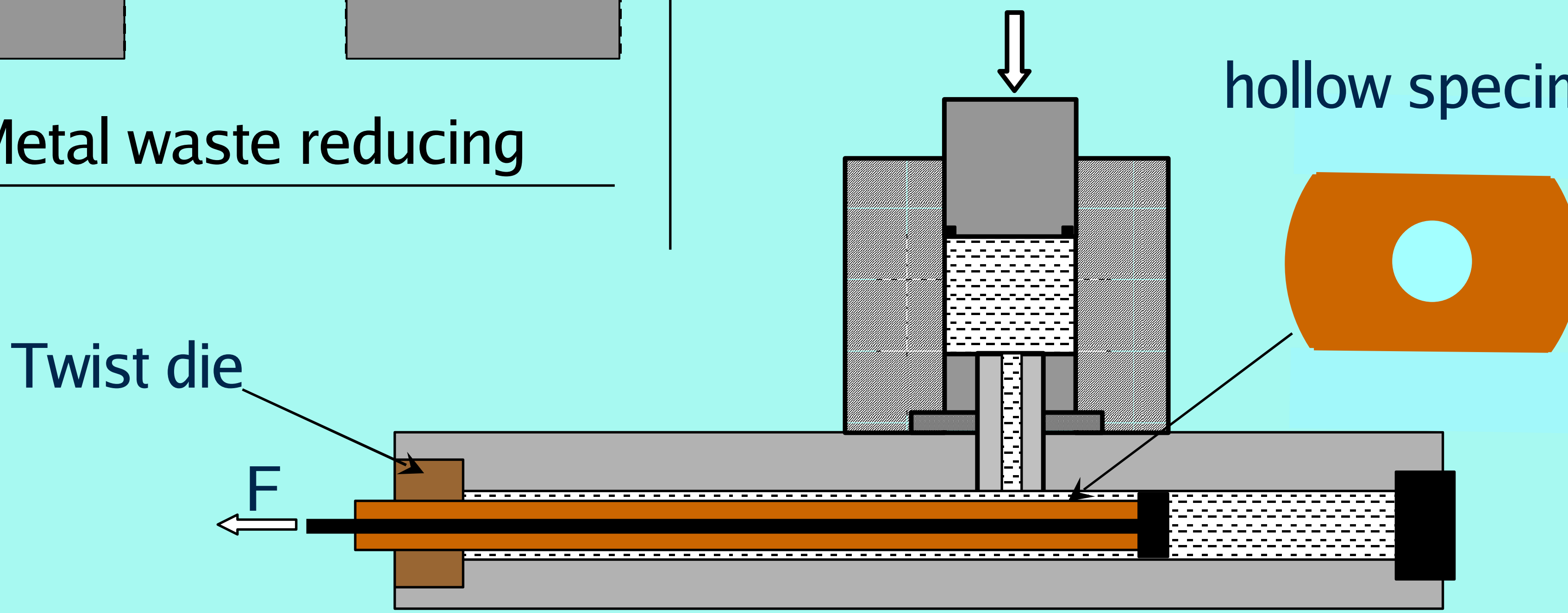
TE

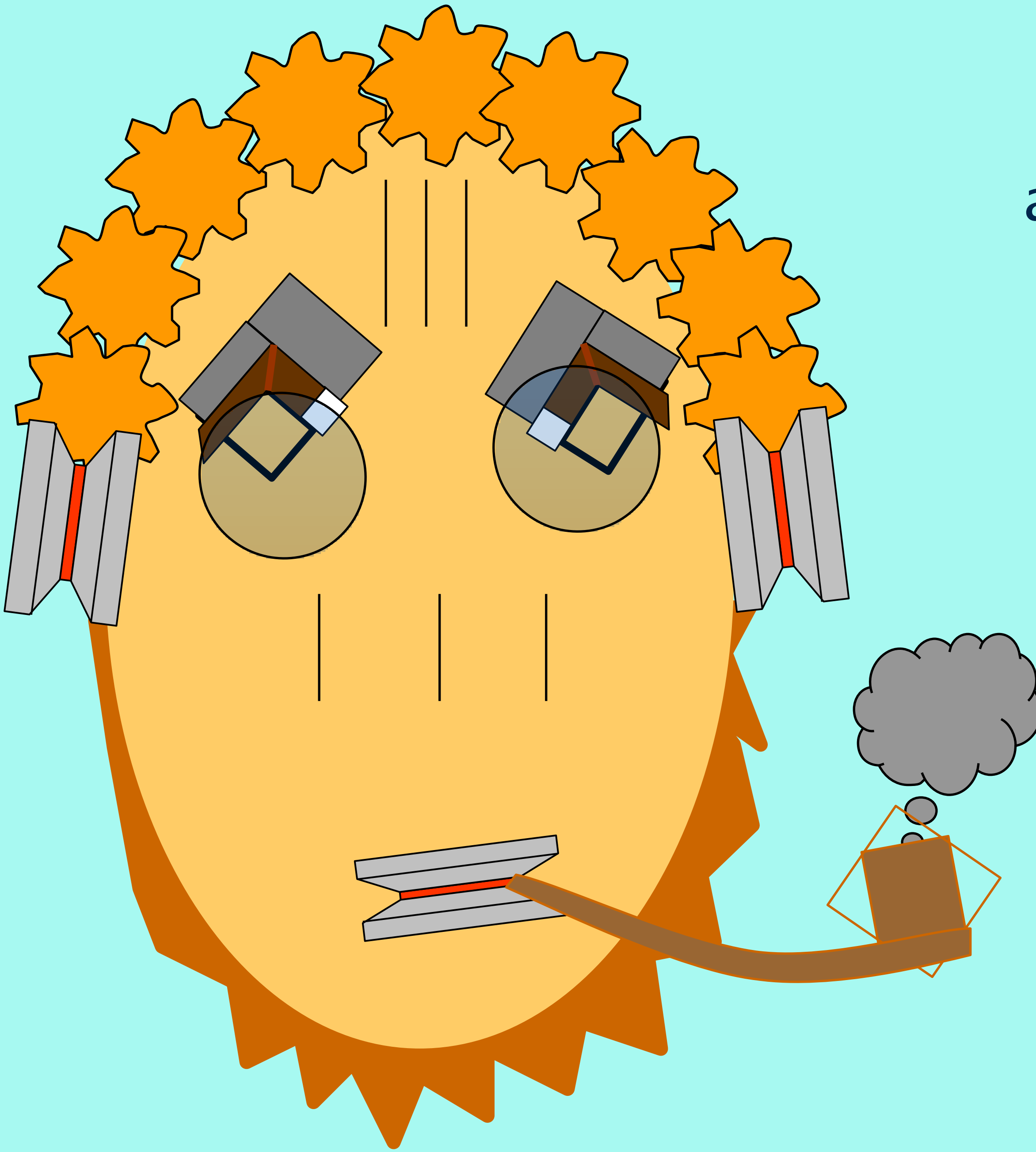


Metal waste reducing

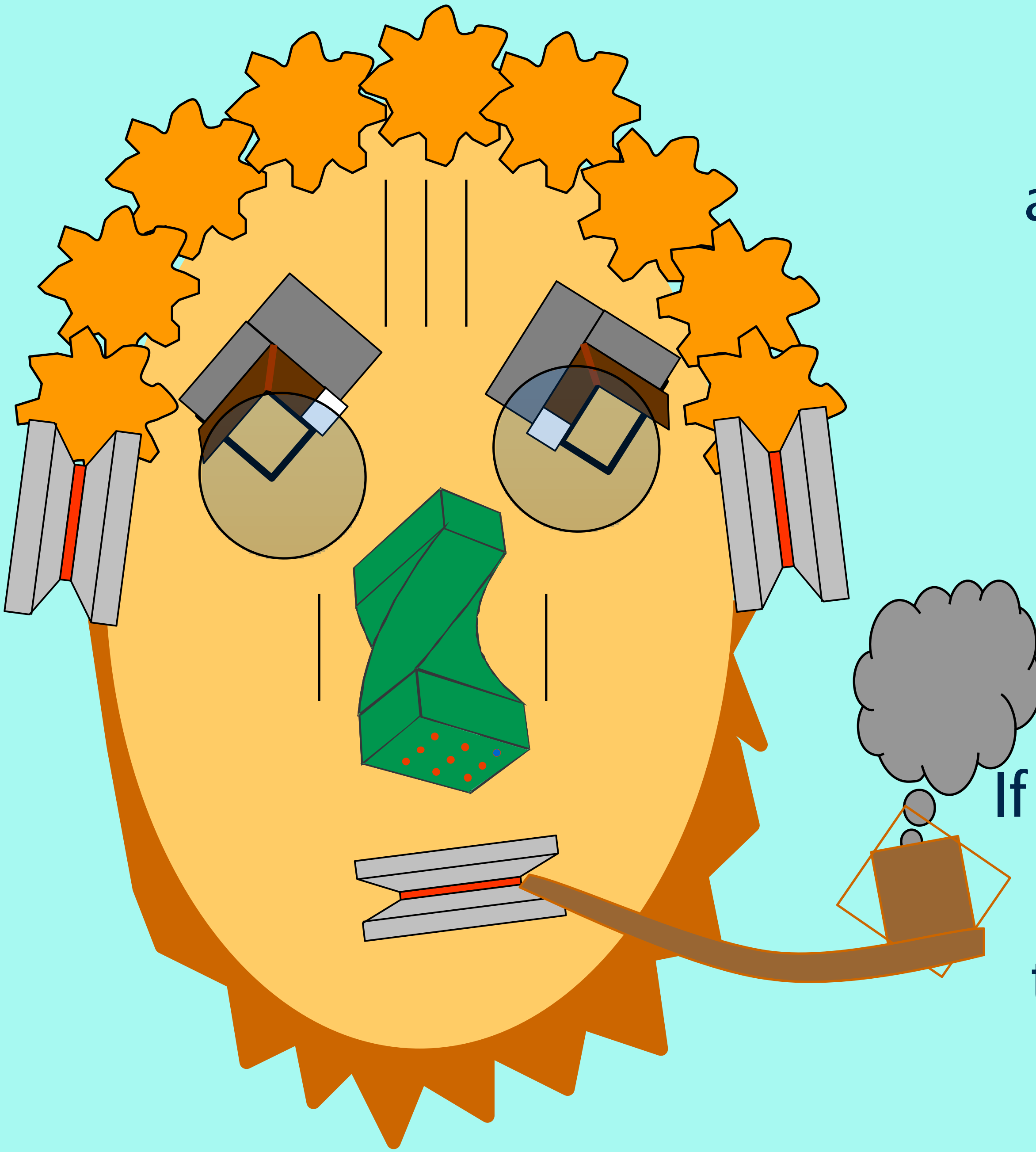
Obtaining profile

or





We hope that TE will find its place among other SPD techniques



We hope that TE will find its place among other SPD techniques

If anyone wants to talk about TE,

tean@an.dn.ua