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Structural Funds
2007-2013

Romania - Republic of Serbia
IPA Cross-border Cooperation Programme

Toward nanostructuring
via severe plastic deformation

Universitatea Politehnica Timișoara

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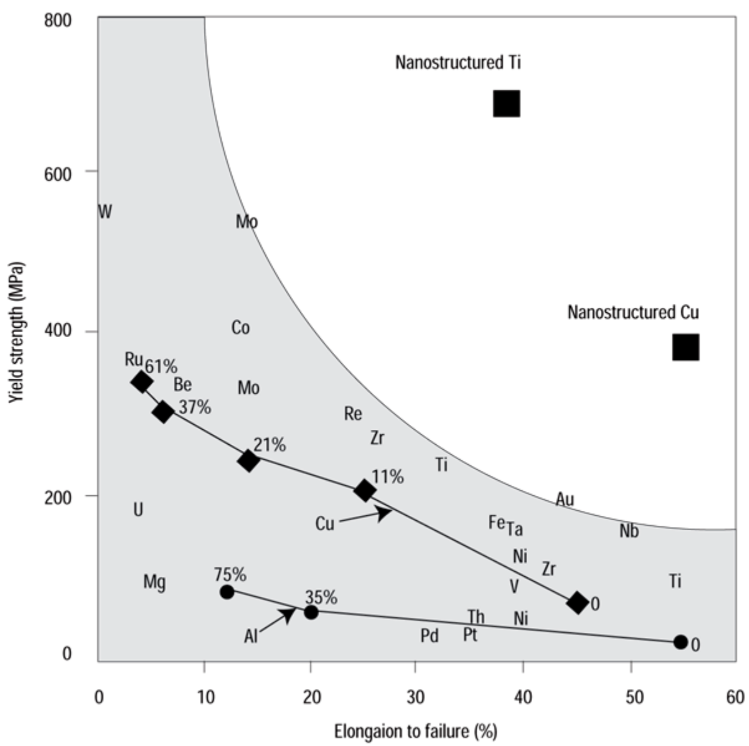
Severe plastic deformation (SPD)

Defined as metal forming processes in which a very large plastic strain is imposed on a bulk process in order to make an ultra-fine grained metal.

Azushima et al.

Using plastic deformation processes one can get workpieces or semifinished parts which possess an ultrafine granulation (ultrafine grained metals), a structure that cannot be obtained by conventional methods.



After R. Valiev

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Characteristic features of SPD:

- plastic deformation → shear process
- cross section of the processed material → often unchanged
- material’s integrity → affected,
- metal exploiting → optimized to obtain substantial refinements of grain,
- the process → permanent change of the mechanical properties.

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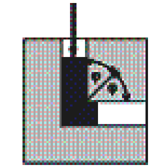
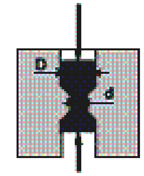
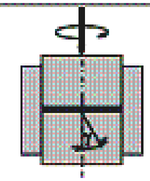
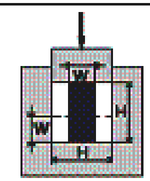
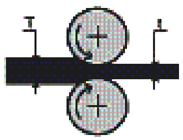
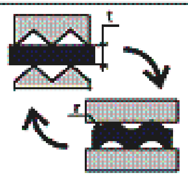
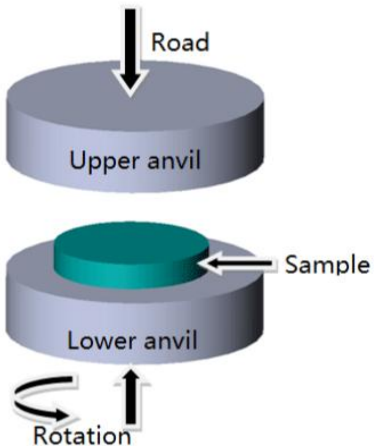
SPD processes:

- equal channel angular pressing (ECAP)
- accumulative roll-bonding (ARB)
- high pressure torsion (HPT)
- repetitive corrugation and straightening (RCS)
- cyclic extrusion compression (CEC)
- torsion extrusion, severe torsion straining (STS)
- cyclic closed-die forging (CCDF)
- super short multi-pass rolling (SSMR)

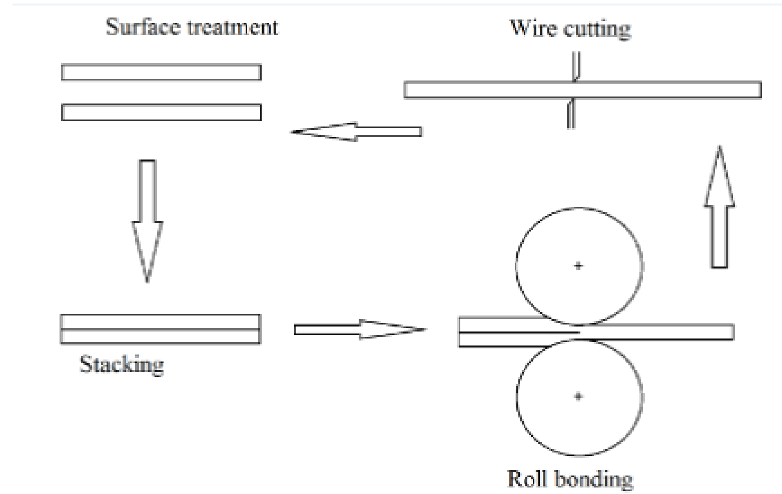
Table 1: Major SPD processes.

Process name	Schematic representation	Equivalent plastic strain
Equal channel angular extrusion (ECAE), Segal, 1977		$\varepsilon = n\frac{2}{\sqrt{3}}\cot\varphi$
Cyclic extrusion-compression (CEC), J. and M Richert, Zasadzinski, Korbel, 1979		$\varepsilon = n4\ln\left(\frac{D}{d}\right)$
High-pressure torsion (HPT), Valiev et al., 1989		$\varepsilon = \frac{tg\gamma}{\sqrt{3}}$
Cyclic closed-die forging (CCDF), Ghosh, 1988		$\varepsilon = n\frac{2}{\sqrt{3}}\ln\left(\frac{H}{W}\right)$
Accumulative roll-bonding (ARB), Saito, Tsuji, Utsunomiya, Sakai, 1998		$\varepsilon = n\frac{2}{\sqrt{3}}\ln\left(\frac{T}{t}\right)$
Repetitive corrugation and straightening (RCS), Zhu, Lowe, Jiang, Huang, 2001		$\varepsilon = n\frac{4}{\sqrt{3}}\ln\left(\frac{r+t}{r+0.5t}\right)$

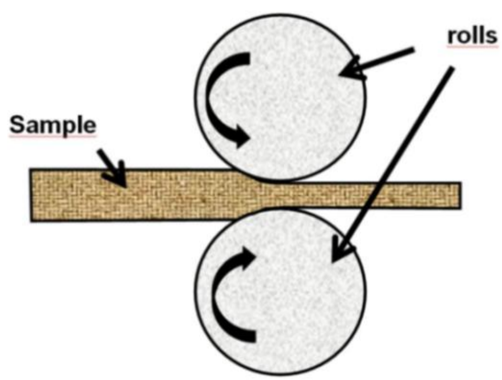
after A. Rosochowski, Solid State Phenomena vols. 101-102 (2005) pp 13-22



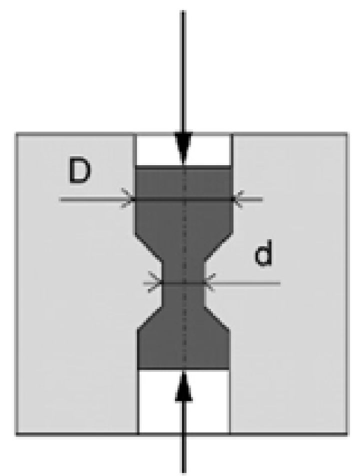
HPT process



ARB process



Cold rolling technique



CEC process

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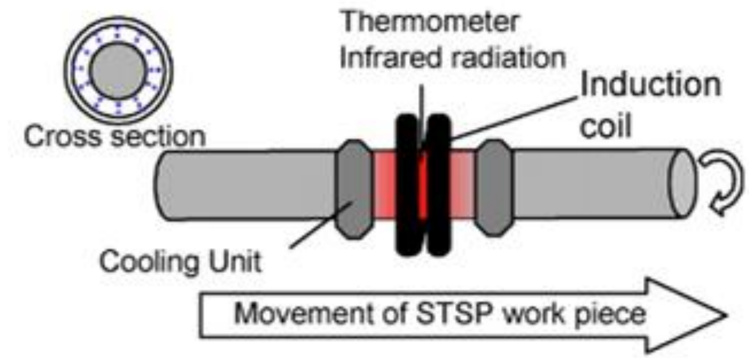
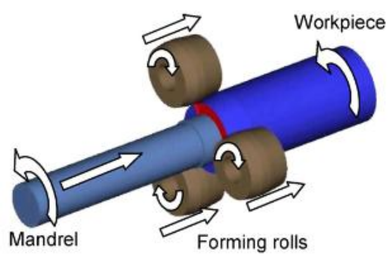
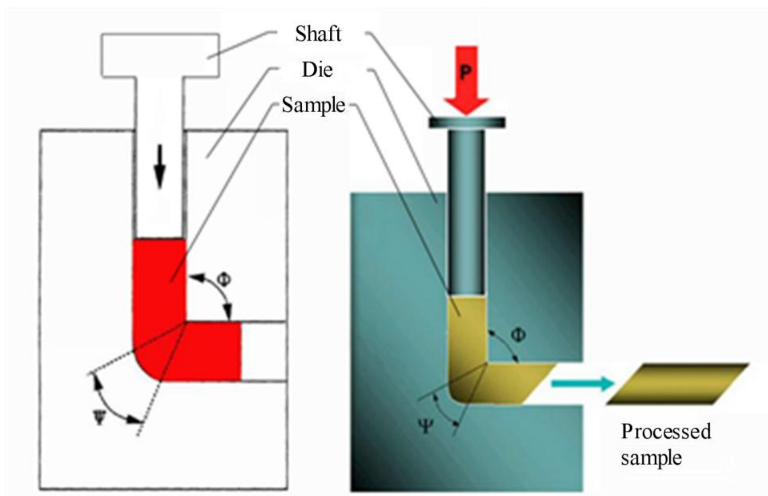


Severe torsion straining



Spin extrusion



Equal Channel Angular Pressing

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Current experiments

Materials (Rolled band):
- Aluminium
- Copper
- Brass
- CuZnAl shape memory alloys

ECAP
• Extrusion of a workpiece through a set of intersecting channels of identical cross-section
• Inlet and outlet channels intersect at an angle of 90 degrees or more
• Intersection of channels can be sharp or include "fan angles"
• Easy multipass processing because workpiece retains shape
• Workpiece must have sufficient ductility

ARB
• Easy to implement
• Surface material needs to be cleann
• Successive passes
• Workpiece must have sufficient ductility

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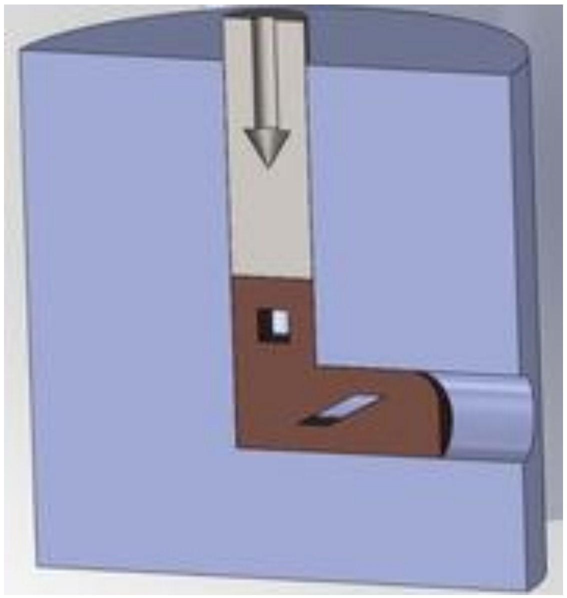
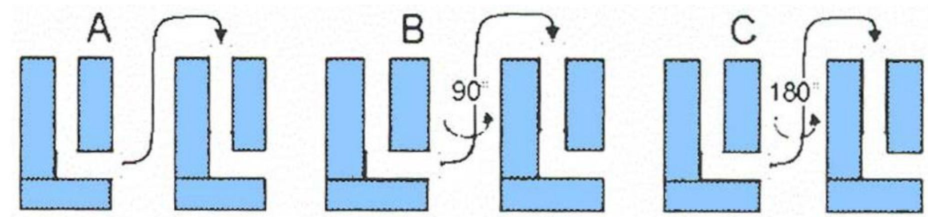
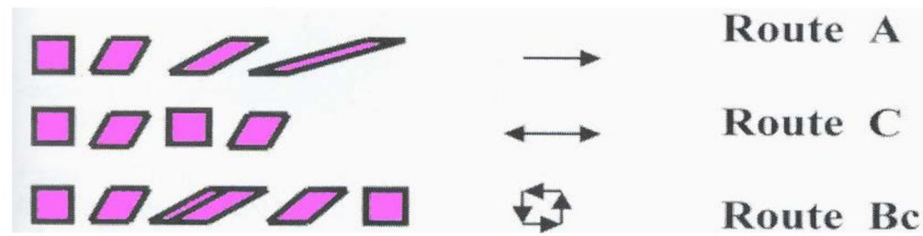
ECAP - imparts a large strain on the workpiece without the need to change its cross section.





(A)



(B)

Nearly simple shear in the intersection zone of the inlet and outlet channels

Process Characteristics
Nearly simple shear in the intersection zone of the inlet and outlet channels
Strain is relatively uniform for the majority of the workpiece cross section
Low to mild texture depending on route

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ECAP

Benefits

- Little change in work piece geometry
- Nearly uniform plastic strain
- Relatively low extrusion loads
- Nearly unlimited strain space
- Alternative product microstructures (filamentary, lamellar, and equiaxed)
- Alternative product textures
- Scalable to large and small size workpiece
- Can be applied to all materials (metals, ceramics, polymers, and composites)

Limitations

- Material ductility needs to be sufficient
- Level of strain per pass (dependent on die angle)
- Level of texture produced
- Level of microstructure refinement
- Microstructural uniformity (depends on tool design, die geometry, billet geometry, and material characteristics)

Applications

- Work hardening (strain hardening)
- Microstructure refinement to:
    - ➢Heal of cast defects
    - ➢Increase strength
    - ➢Increase ductility
    - ➢Increase toughness
- Texture development, conversion or, elimination
- Powder consolidation

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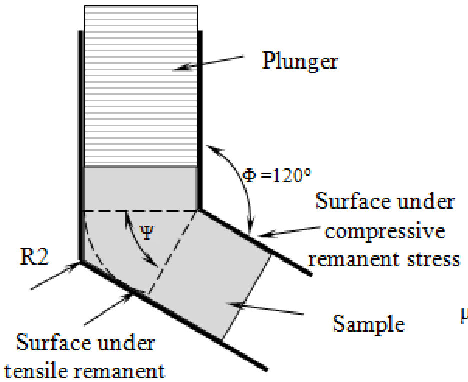
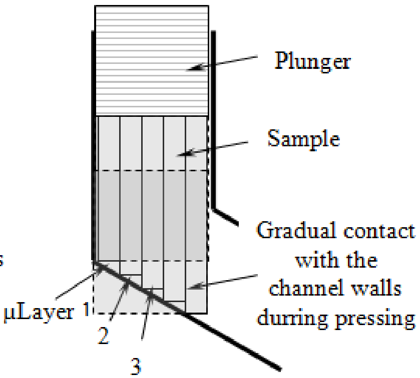
Our results

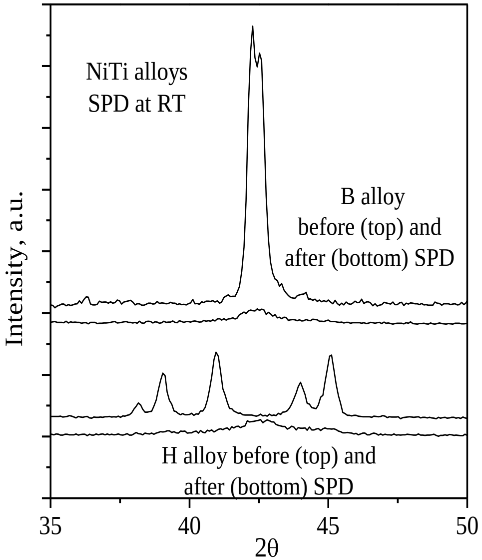
a. Picture of the device in the press

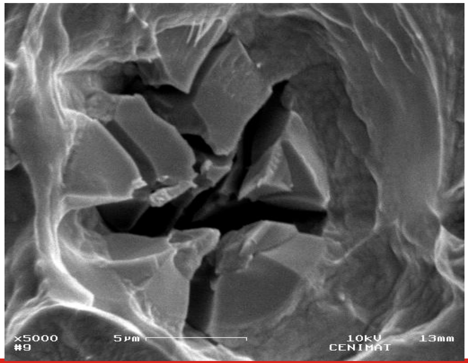
b. 90 ° dye

c.120 ° dye









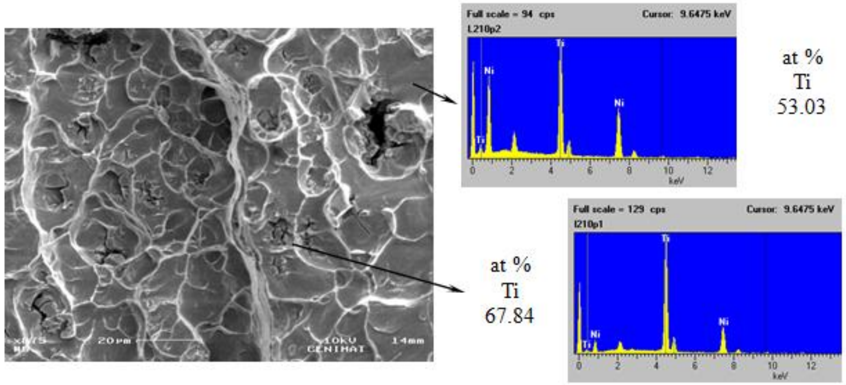
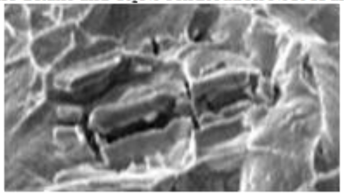


Fig. 2.54 Fracture details and Ti_2Ni contribution NiTi H alloy SPD sample deformed at RT



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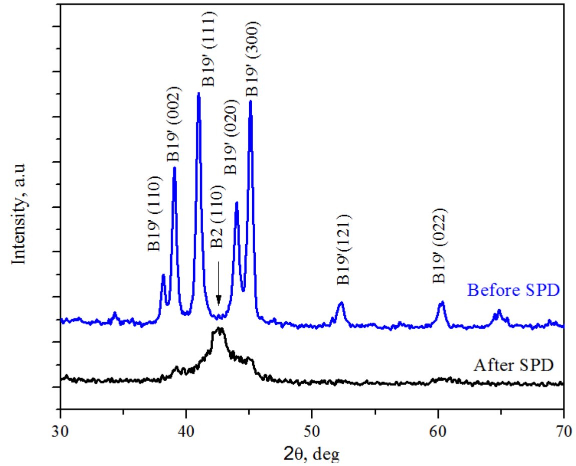

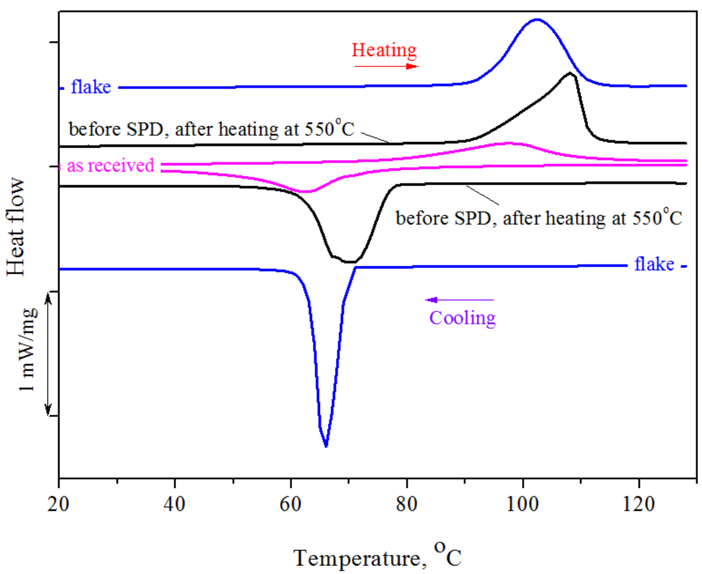

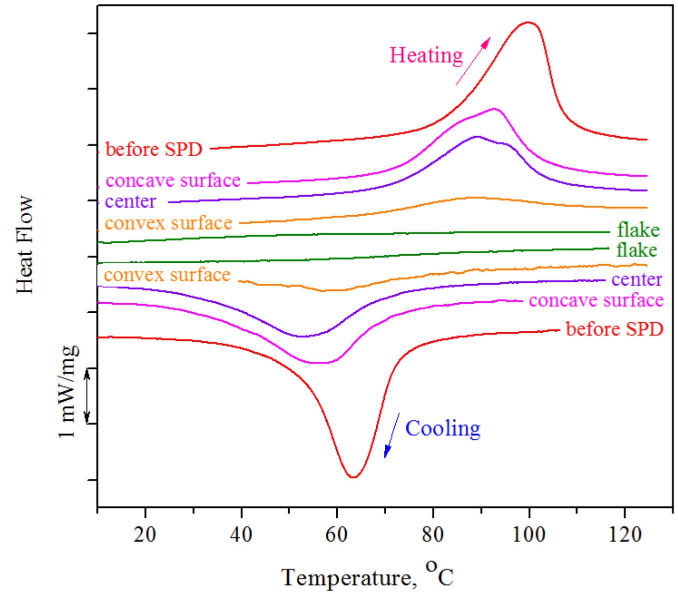

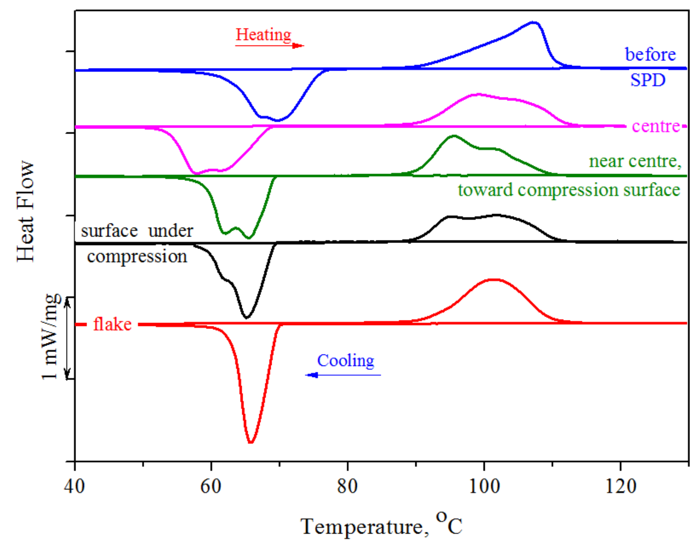

C.M. Craciunescu, F.M. Braz Fernandes - Functional Materials Letters

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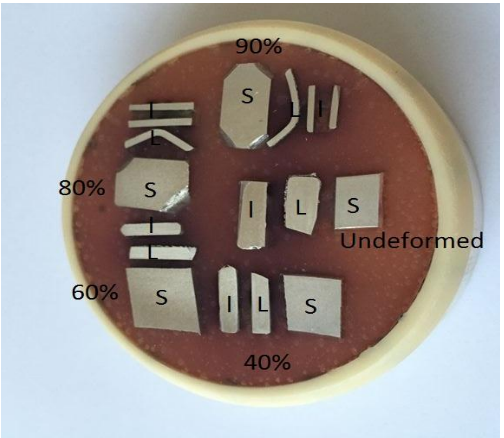
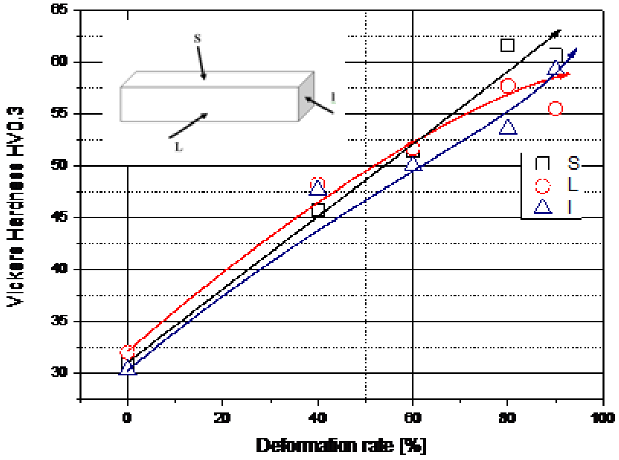
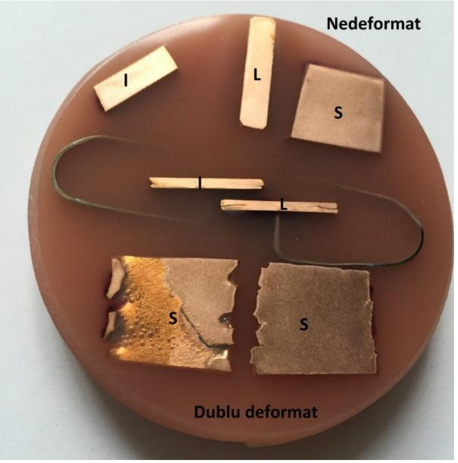
ARB results

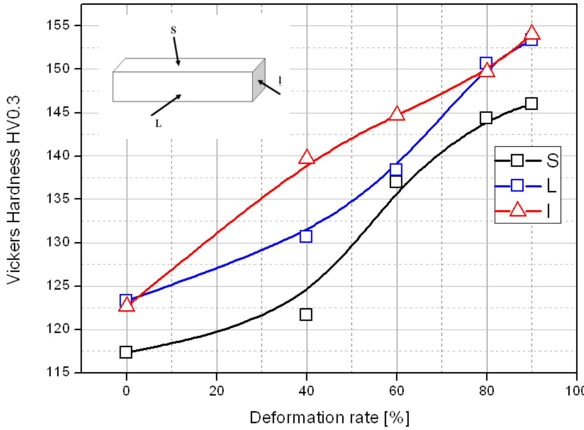
Aluminum 99,94 % - Rolled band 5 x 150 mm
Deformation: 40%, 60%, 80% and 90 %

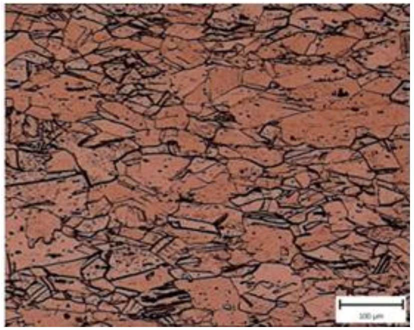


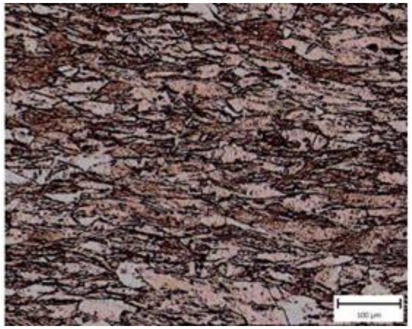


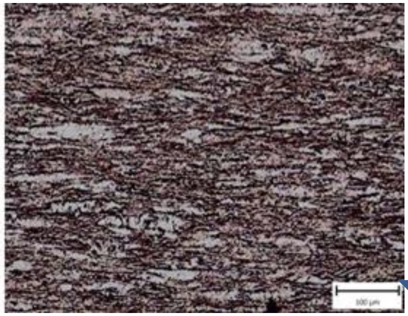
Copper 98,75 %
Deformation: 40%, 60%, 80% and 90 %.

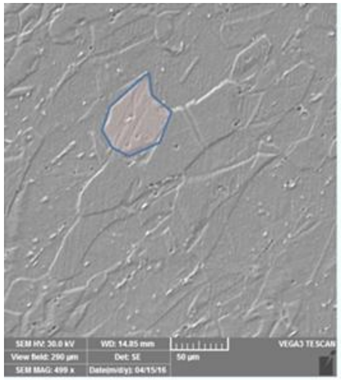


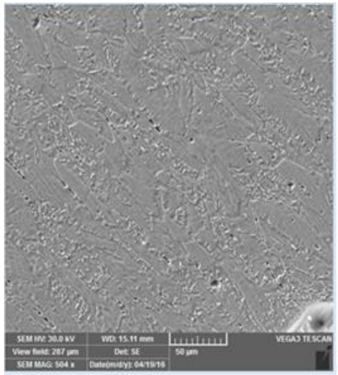


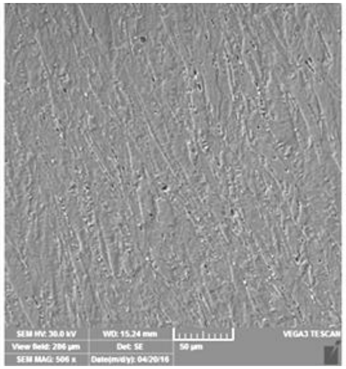


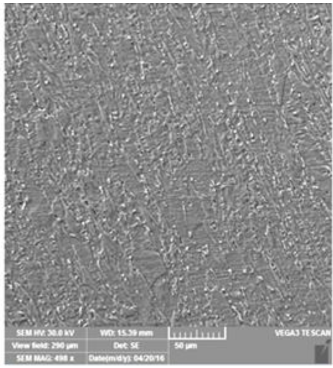












Microscopic images of the samples double deformed

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Chemical composition of brass

- Cu – 68.57 %
- Zn – 27.35 %
- Al – 3.86 %

Metallographic sample

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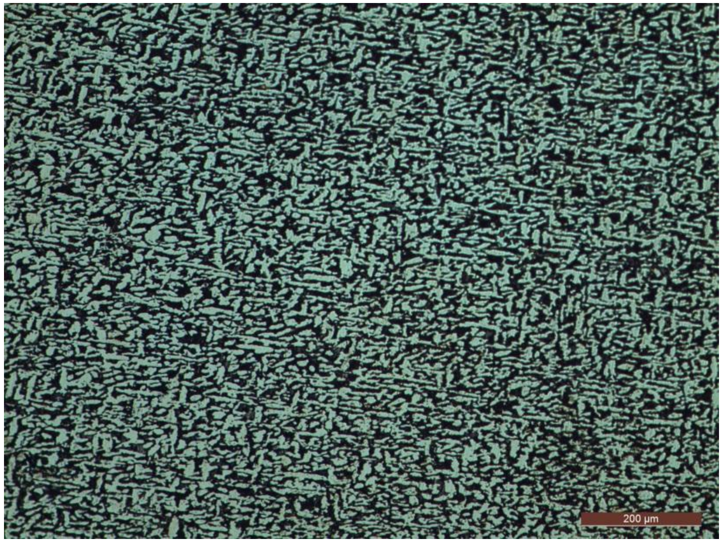
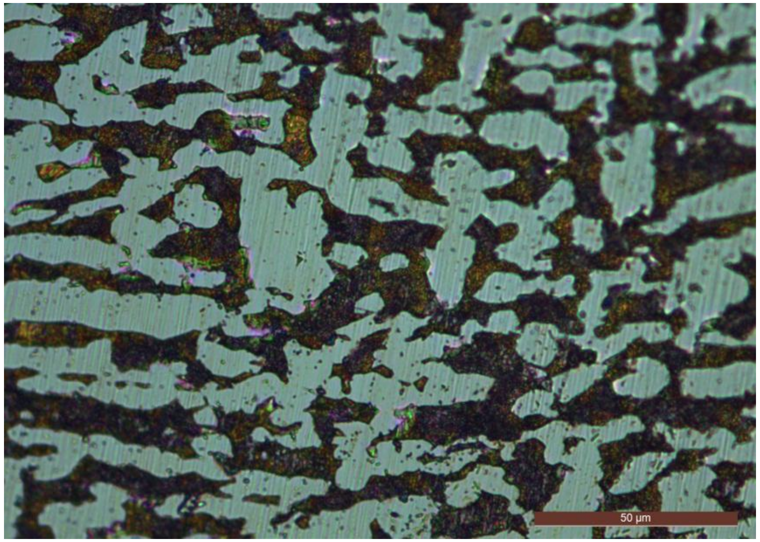
Microstructure





Microstructure

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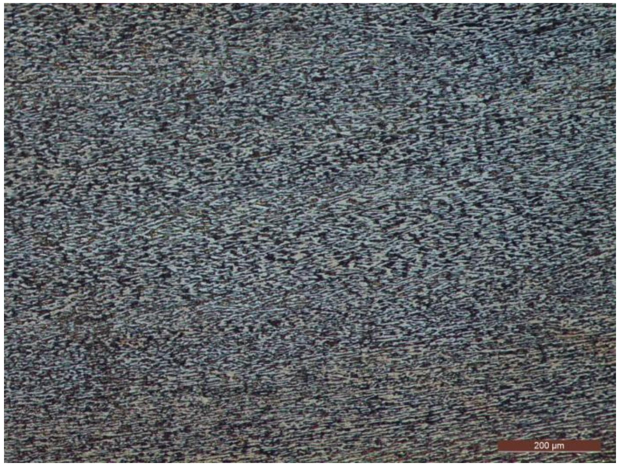
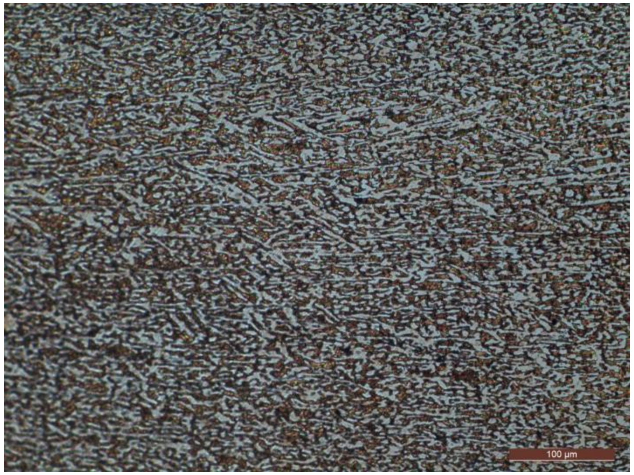
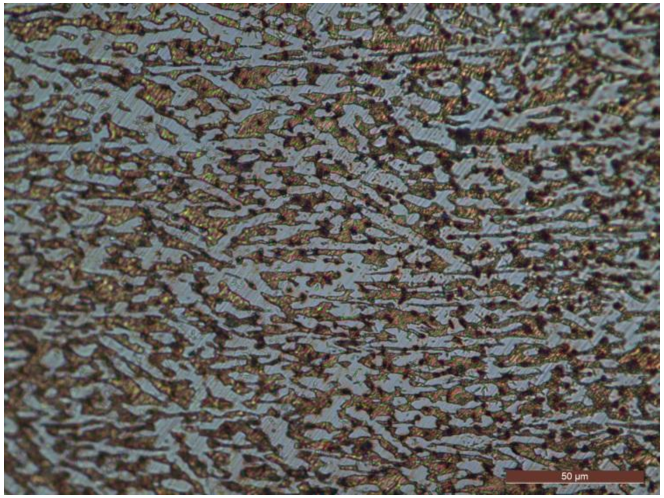
- After 50% deformation

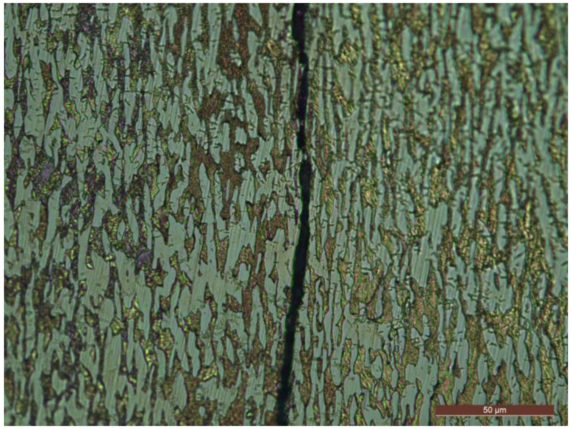




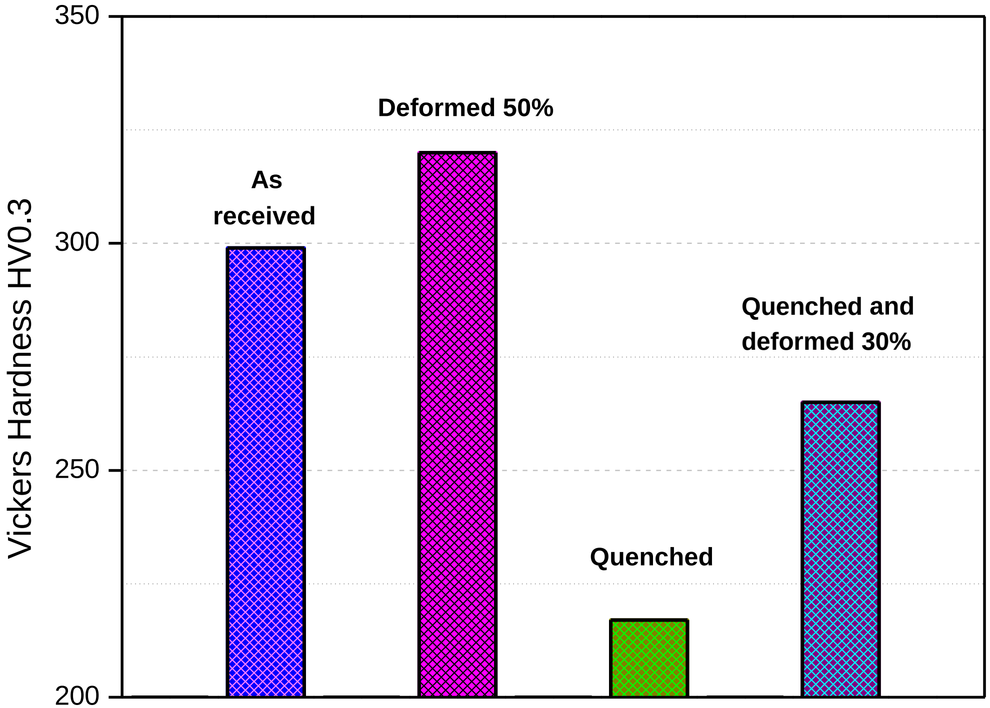


Microstructure

- Deformation area with cracks



Microhardness



Conclusions

For all investigated samples it has been observed:

- as the deformation grade increases the granulation became smaller and a grains stretching and fragmentation took places
- there is a correlation between the mechanical characteristics and the structural analysis results

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