HUMAN CAPITAL
NATIONAL COHESION STRATEGY

INSTITUTE OF METALLURGY
AND MATERIALS SCIENCE
Polish Academy of Sciences

EUROPEAN
UNION

Progress in PhD research

Strengthening of hexagonal materials by severe plastic deformation

Titanium for new generation of dental implants

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Interdisciplinary PhD Studies in Materials Engineering with English as the language of instruction
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Introduction: dental implants, titanium grades

Two types of titanium implants available commercially [based on composition of structural material]

Commercial Purity (CP) Grade 4 Ti implants

Ti 6Al-4V (α+β)alloy (Grade 5 Ti) implants

Toxic/harmfull additives

Titanium grades		Grade 2 Ti	Grade 4 Ti		Grade 5 Ti [Ti 6Al-4V]
		Wt [%]	Wt [%]		Wt [%]
composition	C	Max 0.1	Max 0.1		
	Fe	Max 0.3	Max 0.5	Fe	Max 0.25
	H	Max 0.015	Max 0.015	Al	6
	N	Max 0.03	Max 0.05	V	4
	O	Max 0.25	Max 0.4	O	Max 0.2
	Ti	Balance	Balance	Ti	Balance
Mechanical properties	Yield Strength [Mpa]	280-450	480-655		830-930
	Ultimate Tensile Strength [Mpa]	340-430	550-660		895-990
	Elongation at break %	20-28	15-20		10-15

Grade 2 and 4 not strong enough for new generation of [structural] dental implants

Materials for grain refinement strengthening

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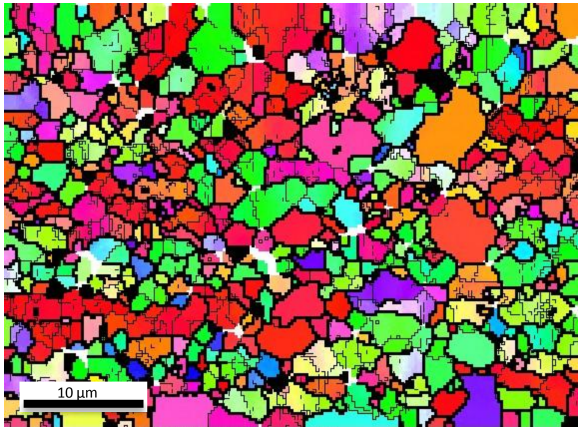
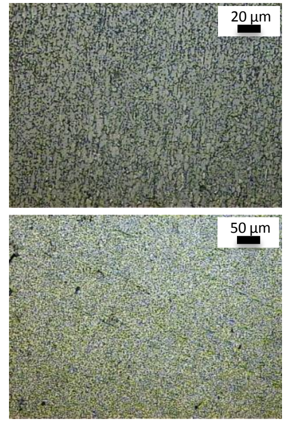
Microstructure of commercially available titanium implants



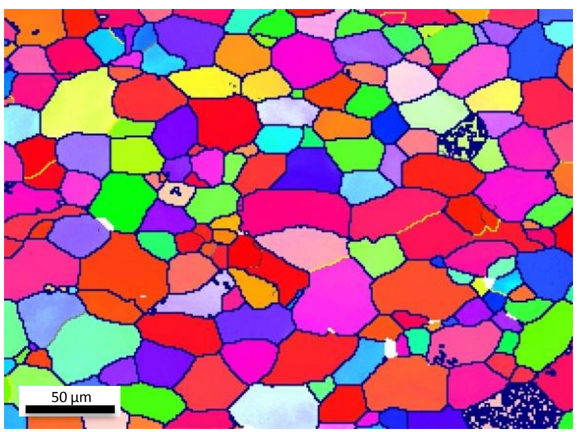
Grade 5 Titanium
IDI commercial implant crystalographic orientations map



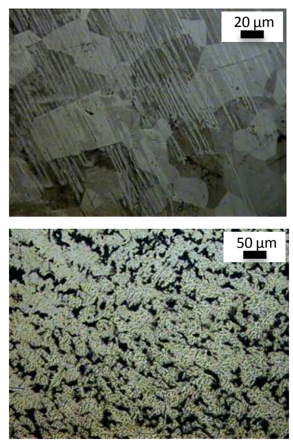
Grade 5 Titanium
IDI commercial implant optical microscopy. Transverse and longitudinal sections

Dental implant produced from Ti 6Al-4V alloy (Grade 5 Ti)

Microstructure consists of small (diameter under 10 µm) equiaxed α phase grains with smaller (around 1 µm) β phase grains



Grade 4 Titanium
Neoplant commercial implant crystalographic orientations map



Grade 4 Titanium
Neoplant commercial implant optical microscopy. Transverse andlongitudinal sections.

Dental implant produced from Commercial Purity Grade 4 titanium

Microstructure consists of single phase, big, equiaxed grains.
Mean grain diameter ~ 30 µm

Next generation of implants might be produced from refined titanium with nano/micrometer grains.

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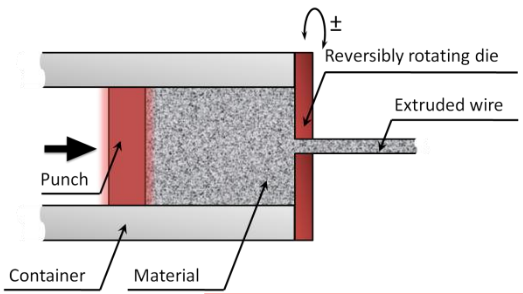
Microstructural investigation of hexagonal metallic materials after KoBo type extrusion:

Commercial Purity Titanium



- KoBo – technique for cost and energy saving metal forming
- Method consists of standard extrusion combined with oscillation twisting of die.
- The result is substantially decreased hardening rate and decrease in extrusion force.

No quantitative microstructure description; no KoBo titanium reports

Extrusion parameters/properties	Extruded samples		
Extrusion temperature T=400 °C billet pre heated to T=450 °C angle of rotation +/- 6°; frequency of die oscillations 5Hz	Grade 2 Titanium	Grade 4 Titanium	Grade 5 Titanium Ti 6Al-4V (comparison)
Die/product diameter	6 mm	10 mm	
Extrusion speed	0,5 mm/s	-	
extrusion force	~ 70T	100T	
Yield Strength initial [Mpa]	280-450	480-655	830-930
Yield Strength KoBo [Mpa]	675	-	-

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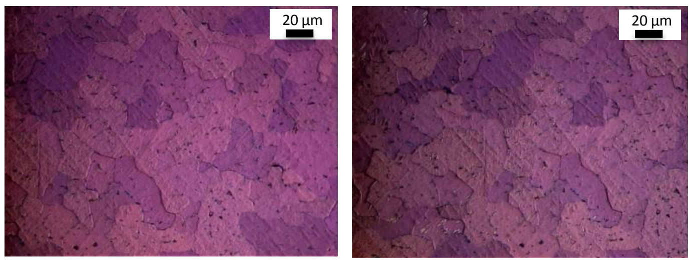
Commercial Purity Titanium

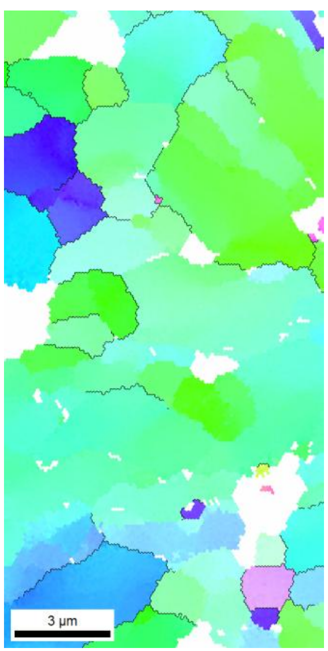


Grade 4 Titanium

(state before KoBo extrusion)
Optical micrographs
(polarized light)

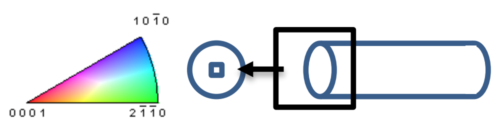
Microstructure of non-deformed Grade 4 Ti

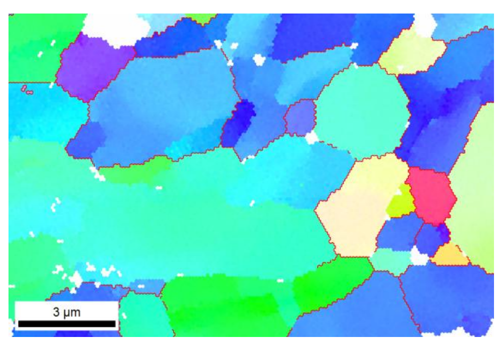
Equiaxed grains with mean diameter of 30 µm



Grade 4 Titanium

KoBo Extruded IPF orientation maps
(transverse sections)





First attempts at Grade 4 titanium plastic deformation by means of KoBo method

Microstructure is significantly refined

Mean grain diameter reduced to 10 µm

Strong texture, crystallites aligning around two main orientations [10$\bar{1}$0] (blue) and [2$\bar{1}\bar{1}$0] (green)

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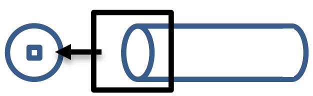
Microstructural investigation of hexagonal metallic materials after KoBo type extrusion:

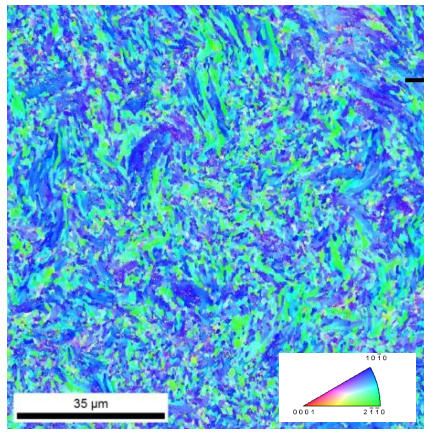
Commercial Purity Titanium

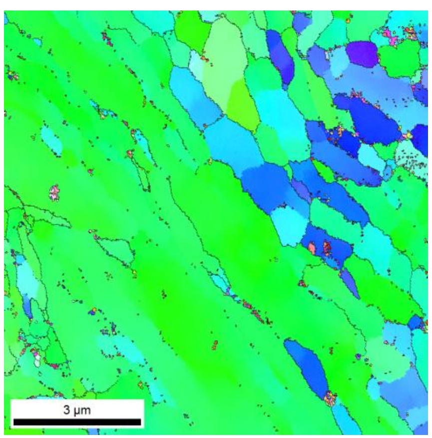
Grade 2 Titanium

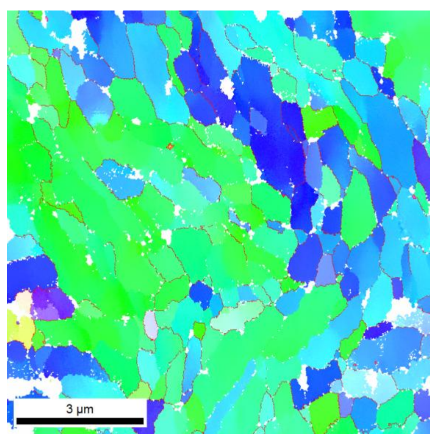
KoBo Extruded IPF orientation maps

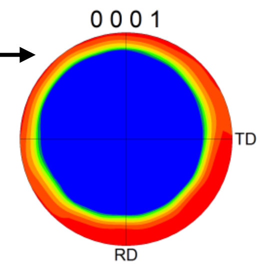
Highly refined microstructure
Characteristic ‘twisted’ grains
Strong texture











KoBo Extruded Ti Grade2 Inversed pole figure

calculated form discrete orientations measurements (EBSD orientation map)

Sample with axial texture – basal crystallographic planes are aligned parallel to the extrusion direction

Plans for nearest future:

- Mechanical strength testing
- Microhardness measurements
- Preparation of new samples of KoBo extruded titanium

Further plans:

- Orientation Microscopy in TEM
- Calorimetry
- Wetability measurements

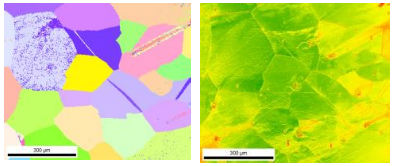
Microstructural investigation of hexagonal metallic materials after KoBo type extrusion: High purity polycrystalline zinc

- EBSD measurements/Image Quality Factor analysis

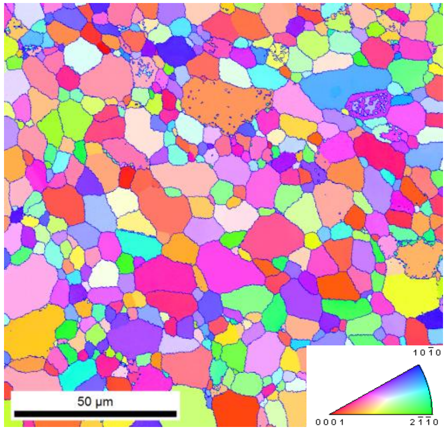
Material	Initial diameter [mm]	Product diameter [mm]	Extrusion temperature	Frequency of die oscillations [Hz]	Extrusion speed [mm/s]	Initial yield strength [MPa]	Product yield strength [MPa]
Zn 99,995%	40	2	24 C	3	0,5	45,9	113

- Yield strength of product is more than doubled compared to initial state
- Microstructure with characteristic composite-like arrangement of features
- Thick areas of deformed crystalline lattice along the grain boundaries
- Composite-like structure of material: soft grain interior and hard „shell" – grain boundaries

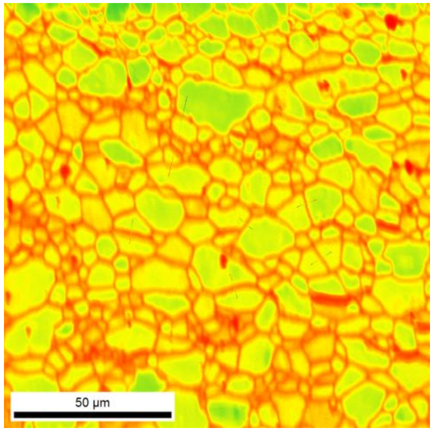
Ipf and IQ maps of transverse section of initial state sample



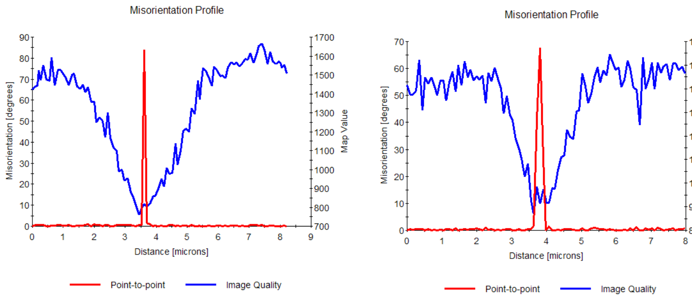
IQ (image quality) and misorientaion profiles: parameter variations across grain boundaries in initial state zinc



Ipf map of transverse section of KoBo extruded sample (center of sample)



IQ (image quality) map of transverse section of KoBo extruded sample red – low IQ; green – high IQ



IQ image quality (blue line) and misorientaion (red line) profiles: parameter variations across grain boundaries in KoBo extruded zinc – wide dip in image quality profile corresponds to thick areas of distorted crystalline lattice streatched along grain boundaries.

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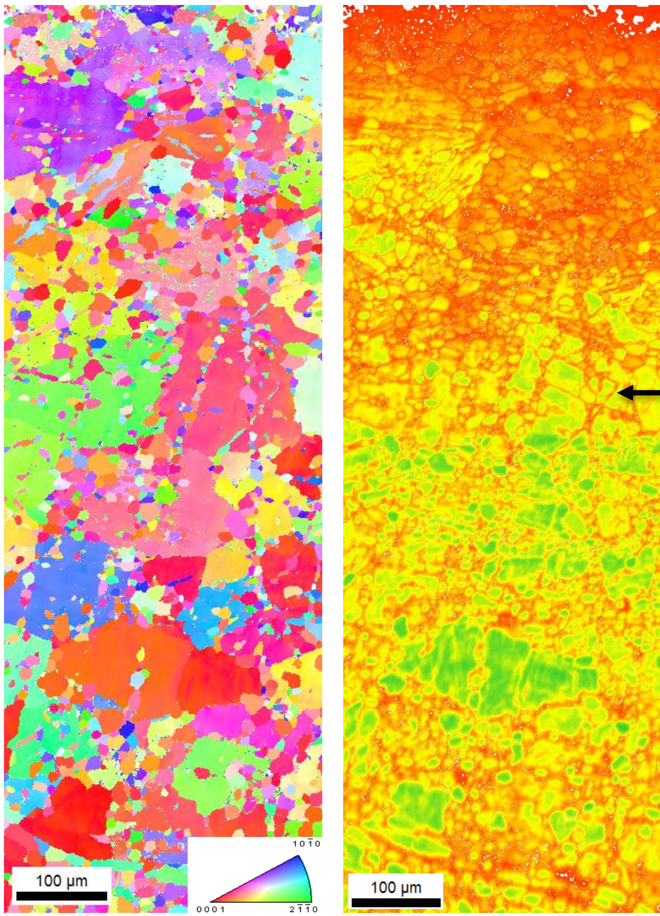
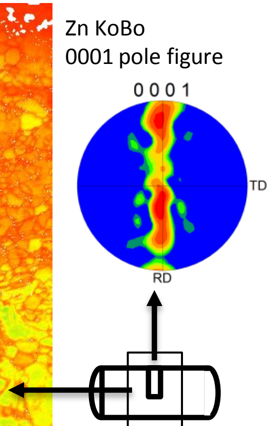
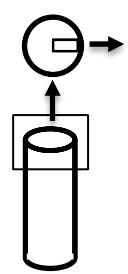
Microstructural investigation of hexagonal metallic materials after KoBo type extrusion: High purity polycrystalline zinc

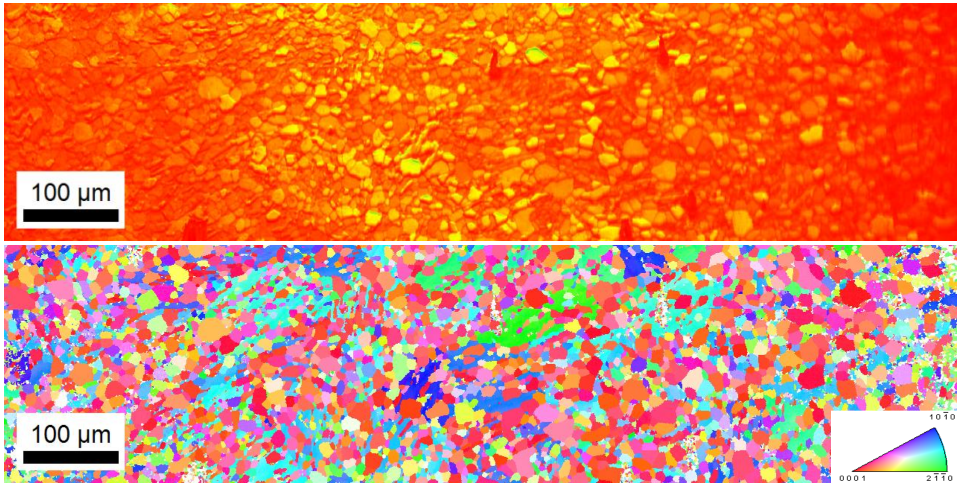
- No visible changes of grain diameter along radius of sample
- Sample is highly deformed (high defects density) in areas close to the surface
- Microstructure consists of small grains (up to 20 μm) embedded into bigger, partly elongated grains (above 100 μm)
- Visible small grains ordered in straight lines
- Strong axial texture – basal 0001 planes (part of basal slip system) aligned parallel to the extrusion direction





Ipf and IQ maps of longitudinal section of KoBo extruded sample. Map taken along the radius of sample





Ipf and IQ map of transverse section of KoBo extruded sample. Map taken along the radius of sample

Thank you for your attention

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