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TECHNICAL UNIVERSITY OF KOŠICE
Faculty of Metallurgy - Institute of Materials
Faculty of Mechanical Engineering

TECHNICAL UNIVERSITY OF LIBEREC
Institute for Nanomaterials, Advanced Technologies and Innovation

MECHANICAL PROPERTIES OF POWDER CoCrW-ALLOY AND Ti-6Al-4V PREPARED BY AM TECHNOLOGY

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LECTURE LAYOUT

- Introduction
- Material and experiment
- Porosity and mechanical properties of powder CoCrW-alloy and Ti-6Al-4V prepared by AM technology
- Conclusions

Introduction TUKE

- Since 1952
- Faculty of Metallurgy – 3 Institutes:
  Institute of Materials
  Institute of Metallurgy
  Institute od Recycling Technologies

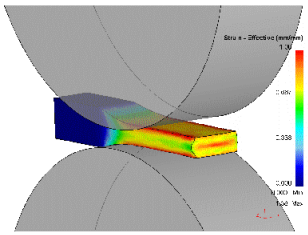
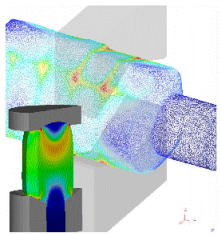
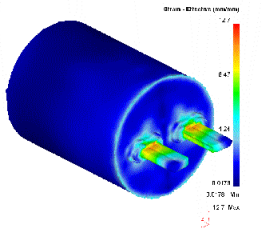
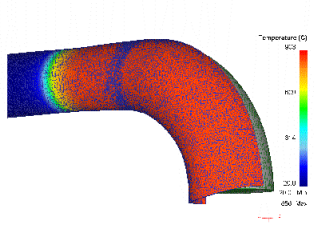
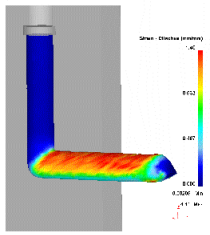
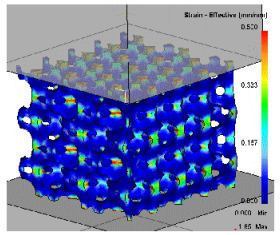
- Experimental part – in cooperation with Faculty of Mechanical Engineering – Institute of Security and Biomedical Engineering – **Department of Biomedical Engineering and Measurement**

Institute of Materials – Deparment of plastic deformations and simulation processes

- Physical simulations:

  experimental rolling – hot/ambient/cryo conditions, ECAP, ECAR,...
- Numerical simulations of metal forming processes:

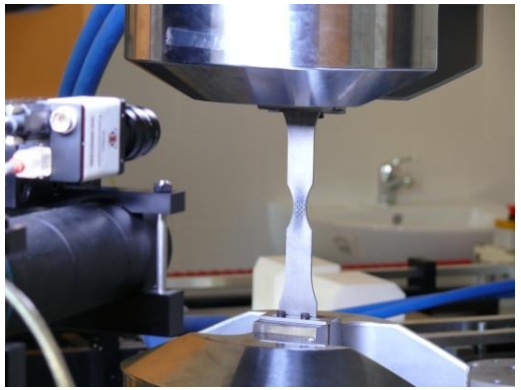
  software Deform 2D/3D

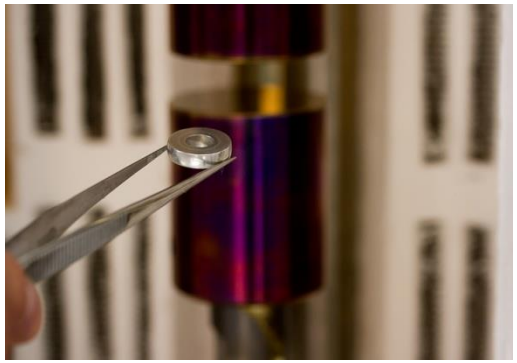







- Laboratory for material identification, mechanical testing, metalograhpy analysis

Institute of Materials – Deparment of plastic deformations and simulation processes

- DEMO Laboratory Tinius Olsen for Central Europe
  - tensile test, compression test, bending test
  - ambient temperute / hot tests up to 1200˚C
  - videoextensometry





Material and experiment

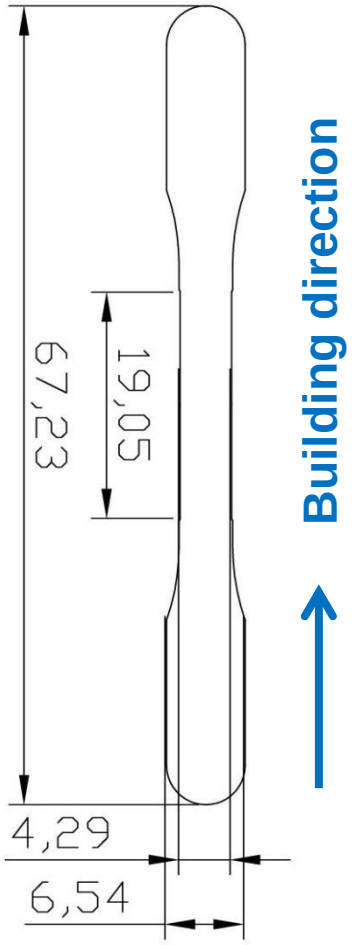
Grade	Co	Cr	W	Si	Mn, N, Nb, Fe	Ni, Be, Ga
CoCrW-alloy*	60,5	28	9	1,5	< 1%	Free from
Grade	**Ti**	**Al**	**V**	**N, C,H, Fe, O**		
Ti-6Al-4V*	90	6	4	< 1%		

Required mechanical properties*	CoCrW-alloy*	Ti-6Al-4V*
Yield Strength YS	635 MPa	950 MPa
Tensile Strenght UTS	1030 MPa	1005 MPa
Elongation at fracture A5	10 %	10 %
Density	8,6 g/cm3	4,5 g/cm3

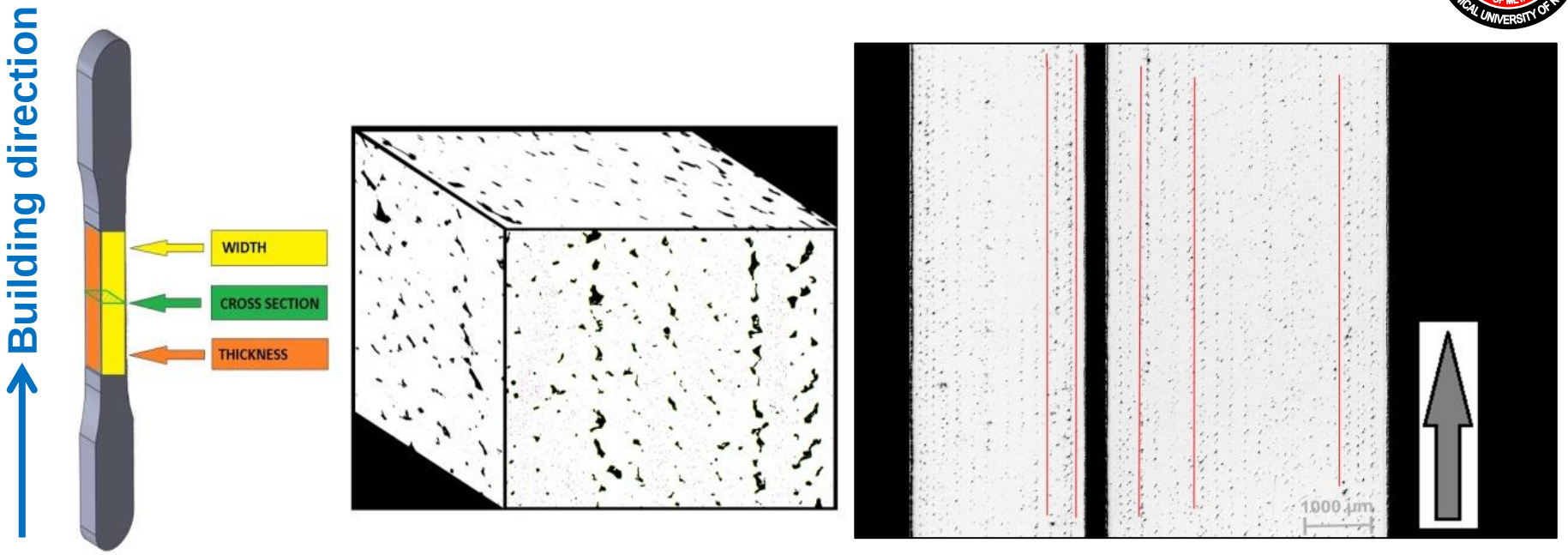
* Remanium® star CL and rematitan® CLR powered by Dentaurum

Experimental methods

- AM technology – **Selective Laser Melting** – **manufactoring of tensile test speciemens** (MPIF Standard Test Methods Edition 2007)
- Microstructure – **evaluation of porosity** – theoretical and graphical method
- **Static tensile test** – strain rate 0,002s^{-1} (Tinius Olsen H300KU) – 15 samples



Evalutation of porosity

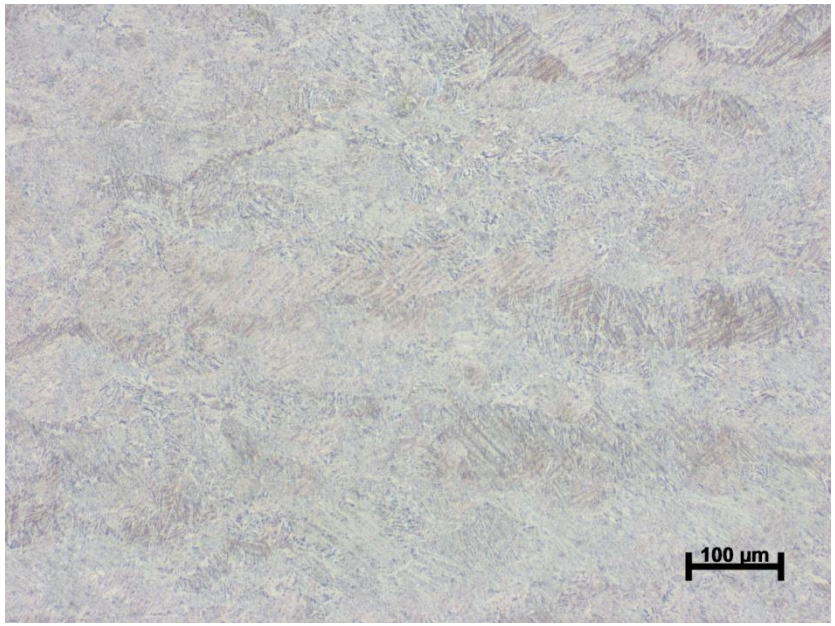


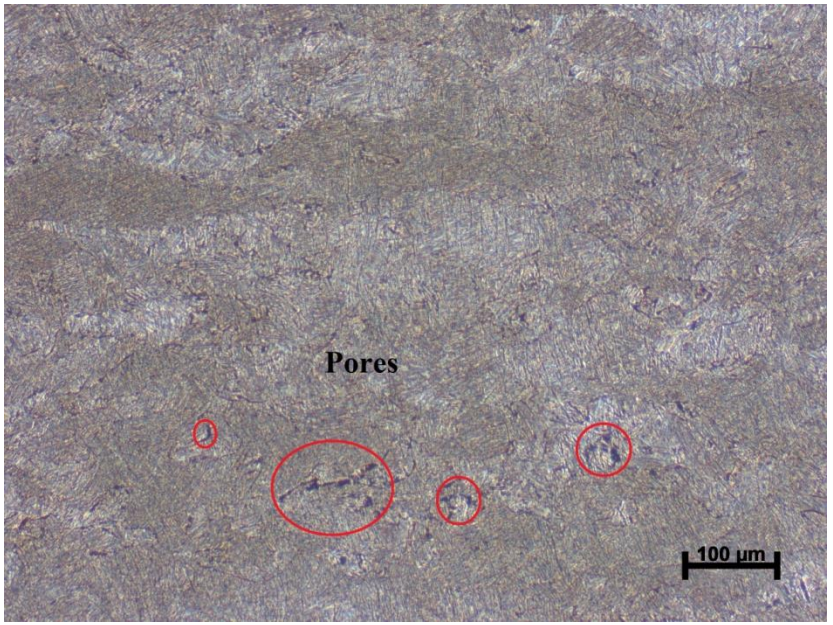
- evaluated in three directions
- **distribution of pores is non-uniform**
- significant **line spacing** is visible - corresponding to building direction of samples

Ti-6Al-4V after etching

- completely martensitic structure (α)
- by using DIC filter – visible individual and continuous pores

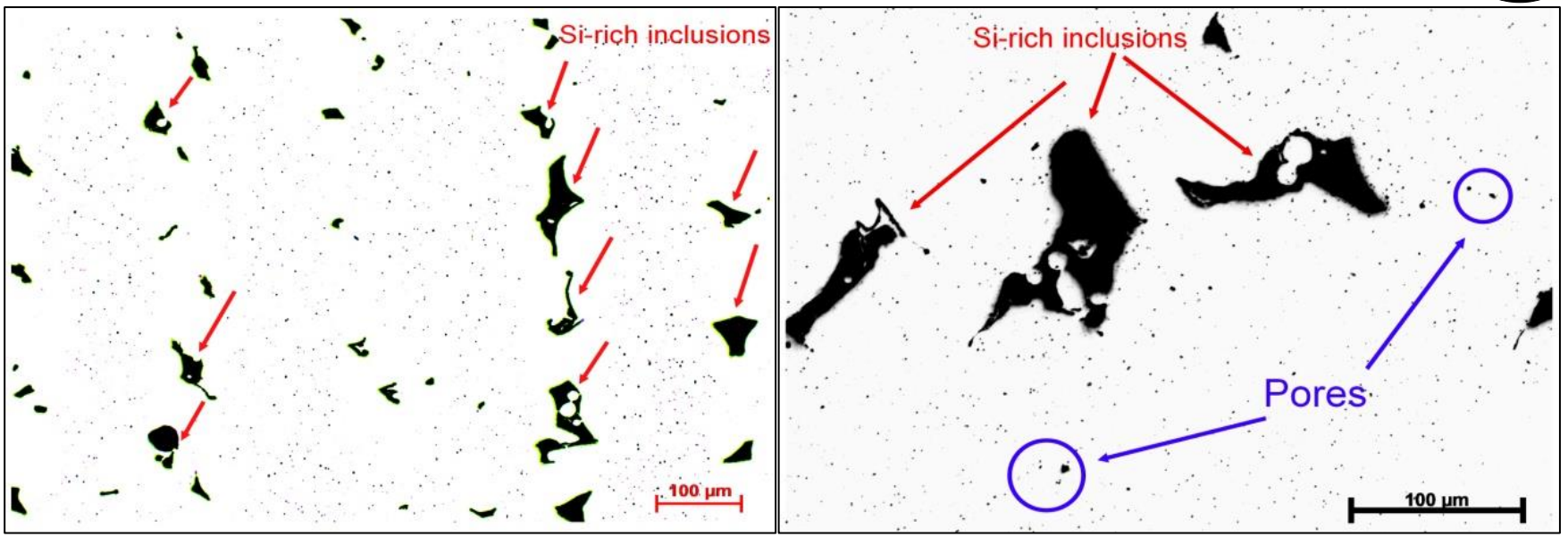
- **Etching in this case causes incorrectly indicating pore**





CoCrW-alloy*

Building direction



- **non-uniformity of porosity** is obvious
- **presence of inclusions –** distribution of inclusions is line spaced also
- inclusions probably plucked during polishing – next analysis are needed

Evaluation of porosity

- **Mathematical:**

$$P = \left(1 - \frac{\rho_g}{\rho_t}\right).100[\%]$$

where P – total porosity,

ρ_g – green density [kg.m^{-3}]

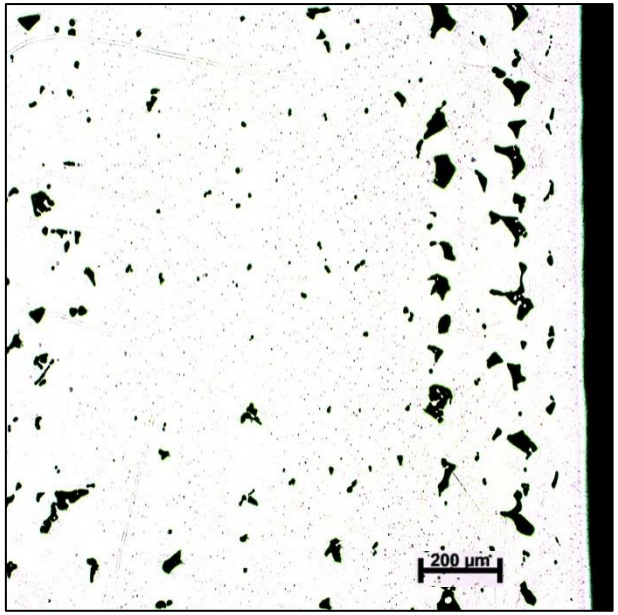
ρ_t – theoretical density [kg.m^{-3}].

- **Archimedes technique:** evaluation of density (reciprocal value of total porosity)
- **Graphical method:** ImagineJ software – Quantitative image analysis of investigatedmaterial treats pores as isolated plane two-dimensional objectsin solid surroundings.

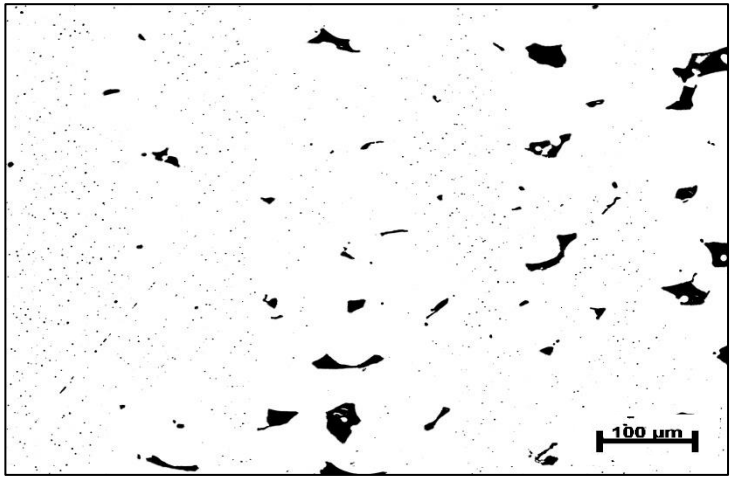
[Bidulska 2010]Bidulska, J., et al. ActaMetallurgicaSlovaca, 2010, Vol.16, No.1., pp 4-11. ISSN 13351532

[Bidulska 2014]Bidulska, J., et al. Advanced Materials Research, 2014, Vol.783-786, pp 108-113. ISSN 10226680

CoCrW-alloy*

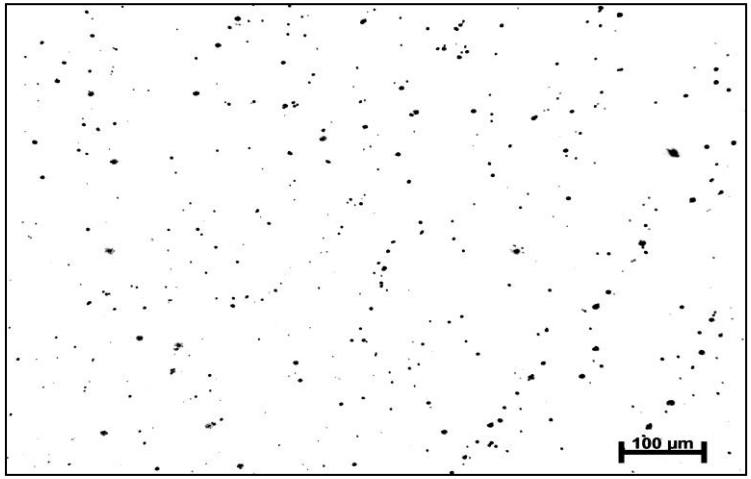


POROSITY
2,28%



Ti-6Al-4V*

POROSITY
5%



Description of the pores parameters

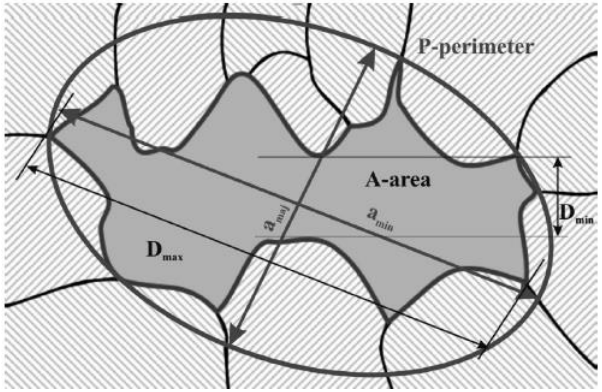
- **Morphological characteristics:**

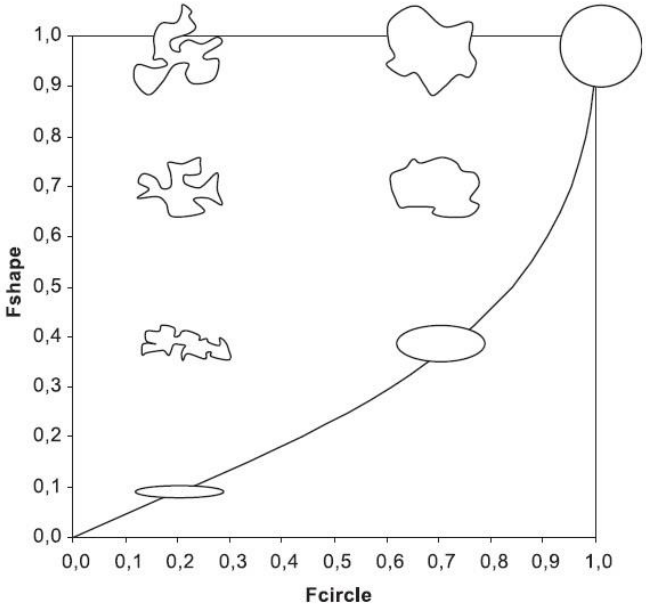
f_{circle}, f_{shape} – the morphological characteristics that show the shape of the pores with a major impact on the mechanical properties

Aspect – represents the ratio between major axis and minor axis of ellipse equivalent to pore

- **Dimensional characteristics:**

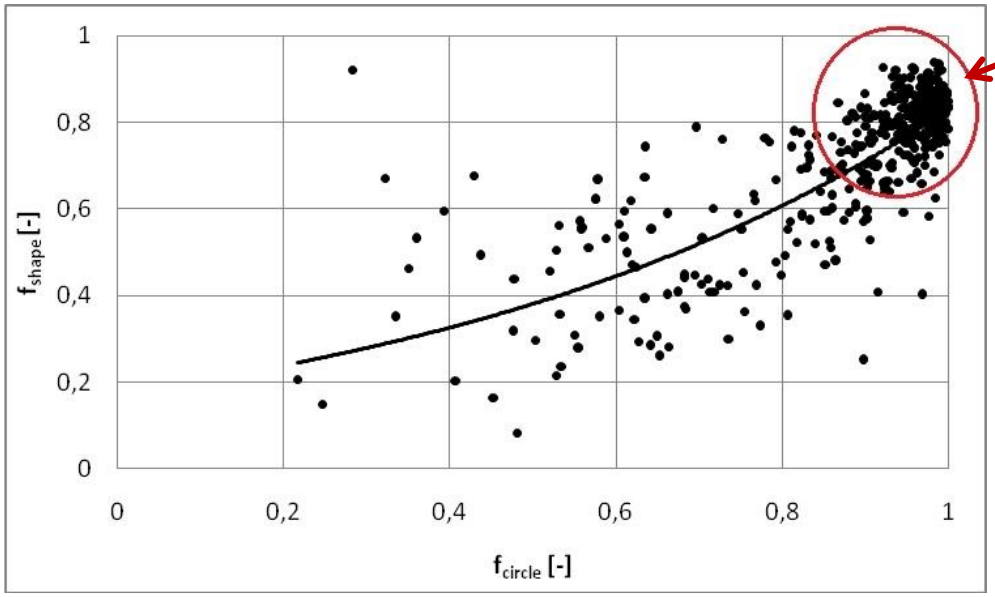
D_{circle} – average length of diameters measured at 2 degree intervals and passing through object‘s centoid)





[Bidulska 2014] Bidulska, J., et al. Advanced Materials Research, 2014, Vol.783-786, pp 108-113. ISSN 10226680
[Puscas 2003] Puscas, T.M., et al. Materials Characterization, Vol. 50, N.1, pp. 1-10. ISSN:

Evalutation of porosity – shape of pores – Ti-6Al-4V

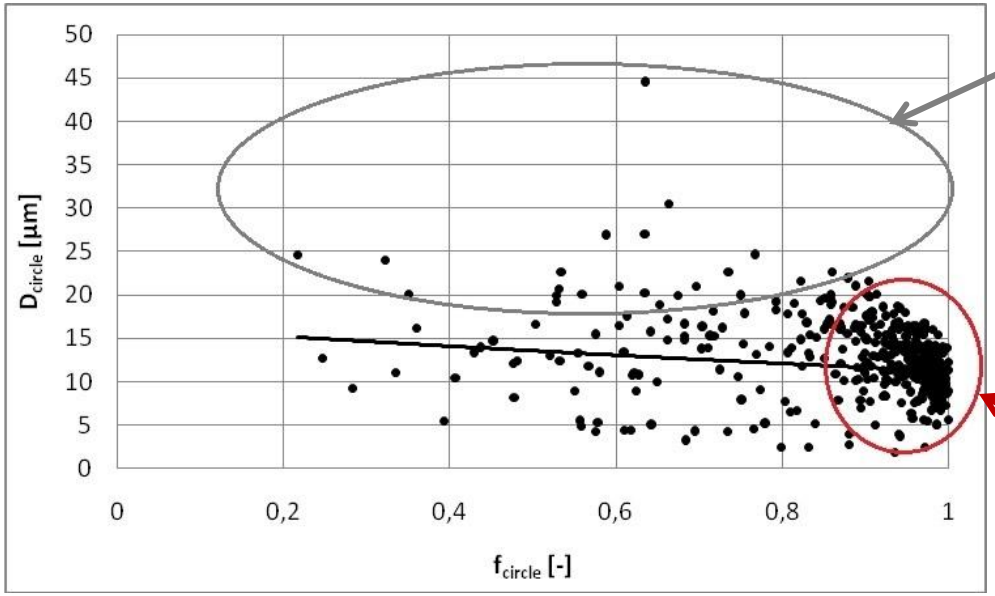


ideal shape of pores – 94%

Dependence f_{circle} vs. f_{shape}

- The **shape of the pore is important for initiation cracking** in static tensile test but also in the further mechanical processing. Pores with sharp edges is more prone to cracking. This factor is multiplied with the pore size.

Evalutation of porosity – dimensions – Ti-6Al-4V



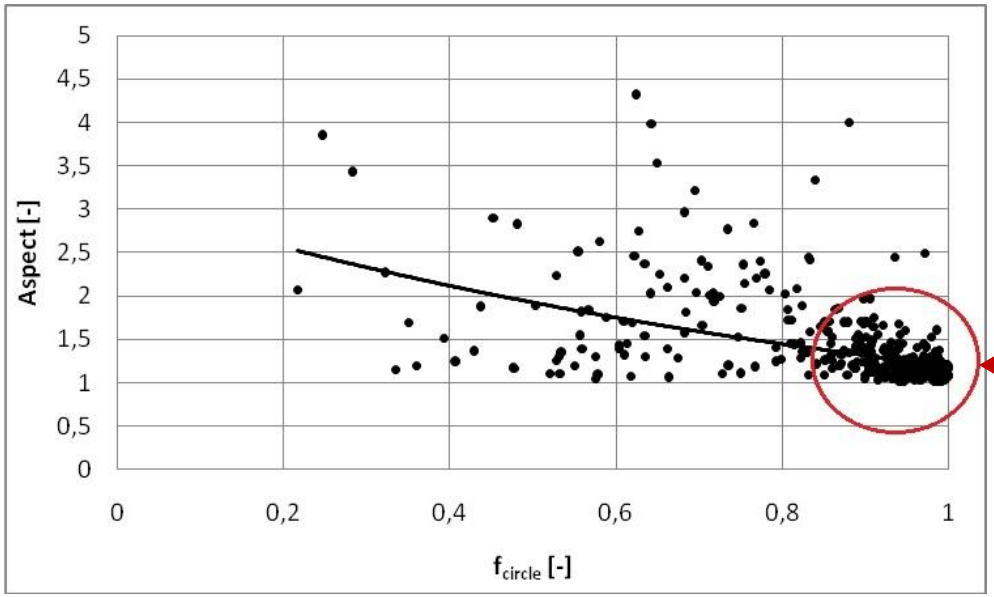
pores in **excess of 20 µm** - **cracks initiation (0,1%)**

the **average pore** size – **no significant affect on mechanical properties**

Dependence f_{circle} vs. D_{circle}

- In terms of pore dimension, **small pores** evolve easily to a **circular form**, while **large pores** are very **irregular** and have a significant internal notch effect on mechanical properties.
- The average pore size was **15 µm**.

Evalutation of porosity – Ti-6Al-4V

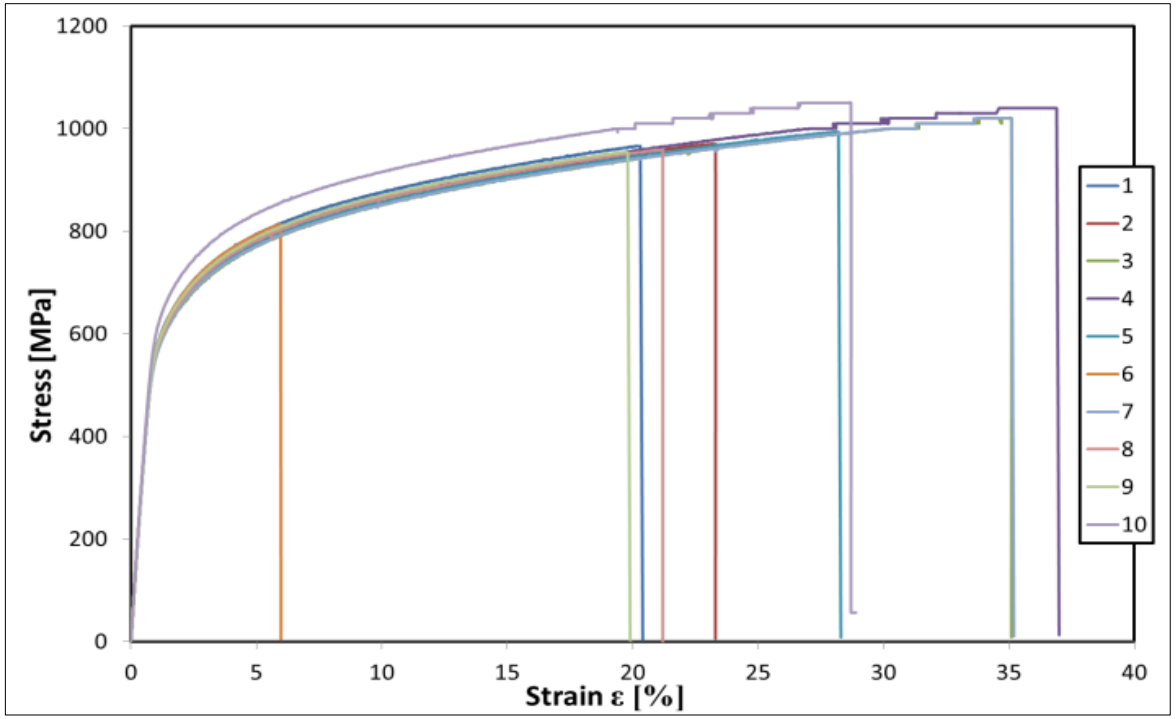


Ideal pores – close to the ratio „1“

Dependence between f_{circle} and aspect

- If the ratio is **„1"** it points out that technology is appropriate on the fact that there will be **no merging of pores**

Mechanical properties of CoCrW-alloy - results

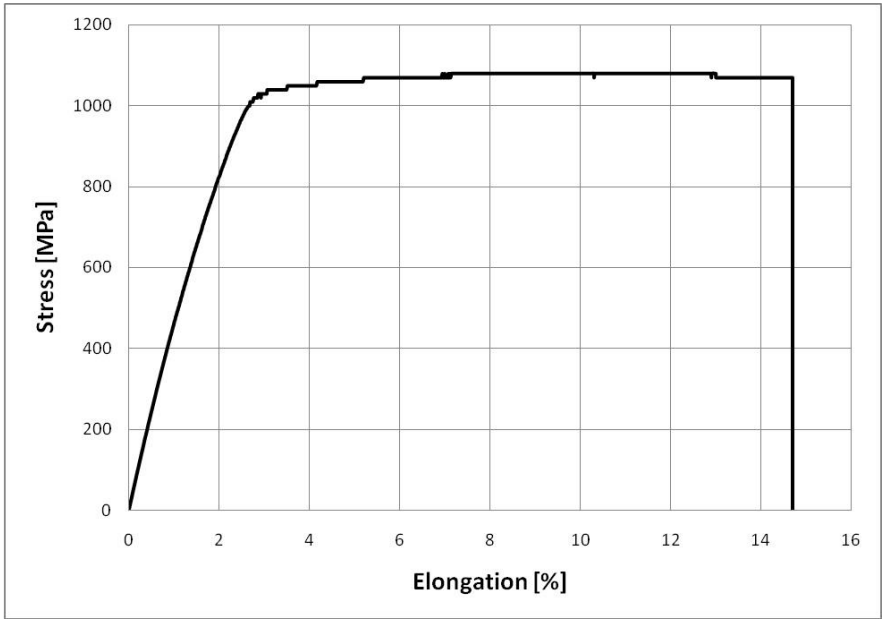


	YS [MPa]	UTS [MPa]
1	564	966
2	556	970
3	550	1020
4	558	1040
5	553	994
6	556	813
7	538	1020
8	555	959
9	563	954
10	598	1050

- Representative strain-stress curves- differences in mechanical properties.
- The variations range of measured UTS values is 237 MPa –

  non-uniformity porosity and presence of inclusions

Mechanical properties of Ti-6Al-4V - results



	YS [MPa]	UTS [MPa]
1	<600; 745>	1080

- The mechanical properties are **only slightly changed – corresponds to evaluated porosity** (UTS for all samples was **1080 MPa**)
- The course of uniform deformation is the same in all samples
- **Brittle fracture** was observed

Conclusions

CoCrW-alloy:

- However, additive manufacturing technology (SLM) is suitable for powder CoCrW-alloy, it is necessary to pay more attention to properties such as mechanical and plastic properties, microhardness, machinability, etc.
- Porosity is inhomogeneous and has influence on mechanical properties. This was reflected on different values of UTS and location of fracture during tensile test.

Ti-6Al-4V-alloy:

- Up to 94% of pores have a ideal shape.
- Porosity distribution is homogenous and it does not affect on the mechanical properties.

Thank you for your attention

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