MECHANICAL PROPERTIES MAPPING OF CAST BIMETALLIC WORK ROLL SHELL MATERIAL BY NANOINDENTATION

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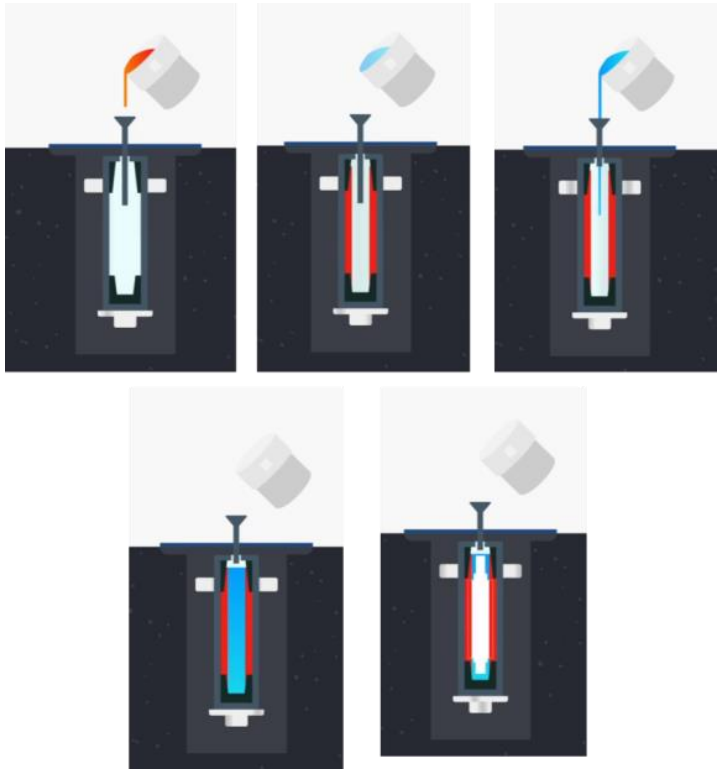
➔ ***BEWARE FELLOWSHIPS programs co-financed by the COFUND program of the European Union (FP7 - Marie Curie Actions).***

Wallonie

Rolls for the hot rolling mill

- **Roll requirements** : Good wear resistance and hardness at high T
- Cast bimetallic work roll material commonly used in hot strip mills.

Hot strip mill



Bimetallic rolls production by vertical spin casting: a) casting of shell material; b) casting of core and barrel material. *(from www.mkb.be)*

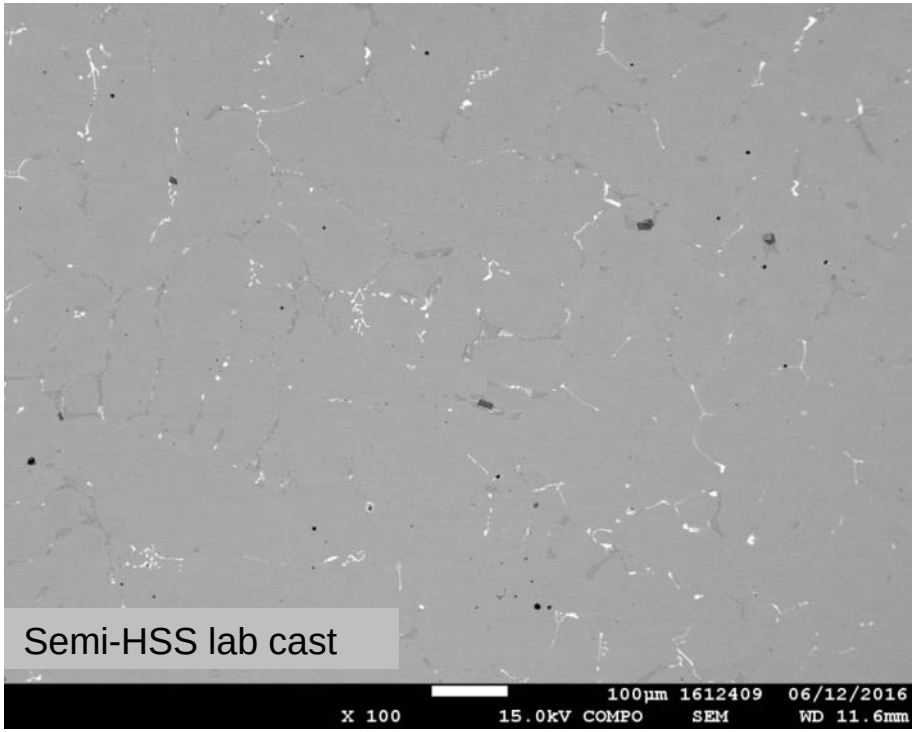
Work rolls development

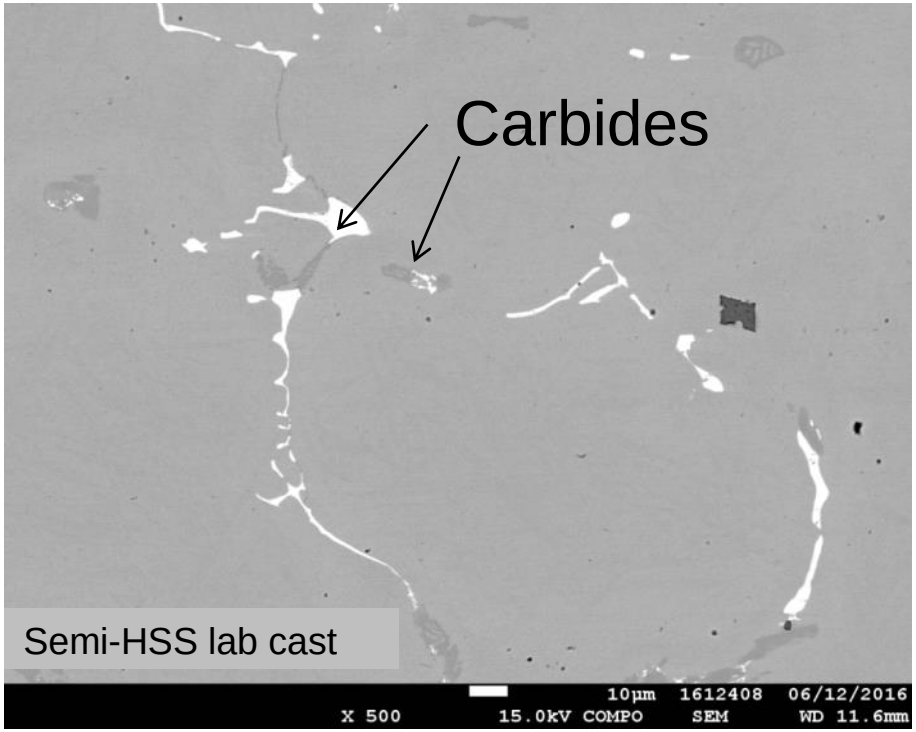
- **Core:** spheroidal graphite
- **Shell materials**

Material	Application	Composition (wt %)			
		C	Cr	W eq.(=W+2Mo)	Nb + V
High Chromium Iron	• HSM Roughing Stands • HSM Finishing Stands	2.5 – 3.5	15 - 22	6 - 10	< 0.5
HSS (High Speed Steel)	• HSM Finishing Stands	1.5 - 2	3 - 6	6 - 10	4 - 8
Semi-HSS	• HSM Roughing Stands	0.6 - 1	6 - 10	4 - 8	0.5 - 2

Typical microstructure

- Microstructural characterization by SEM

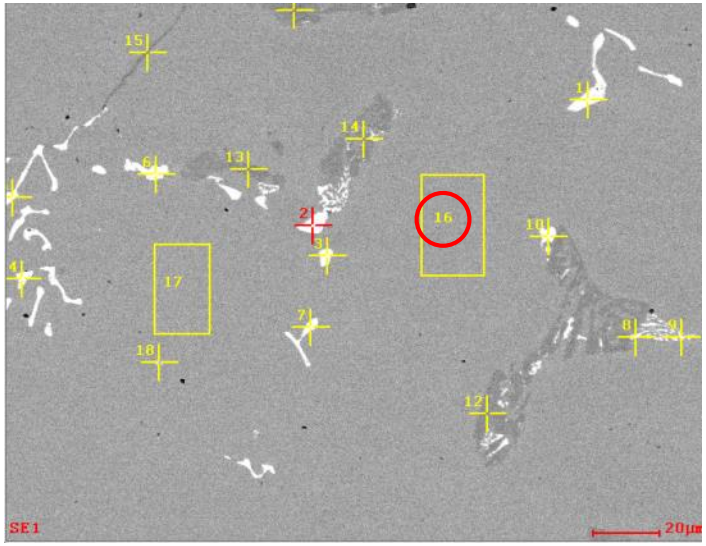




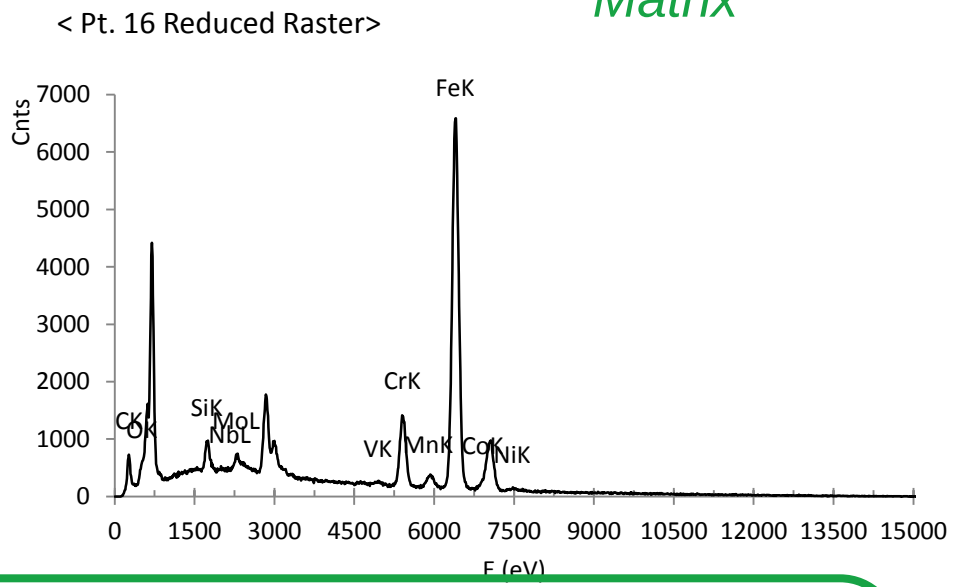
➔ **HSS Steel sample with clusters of micrometric carbides**

Sample description

- Chemical analysis by EDS



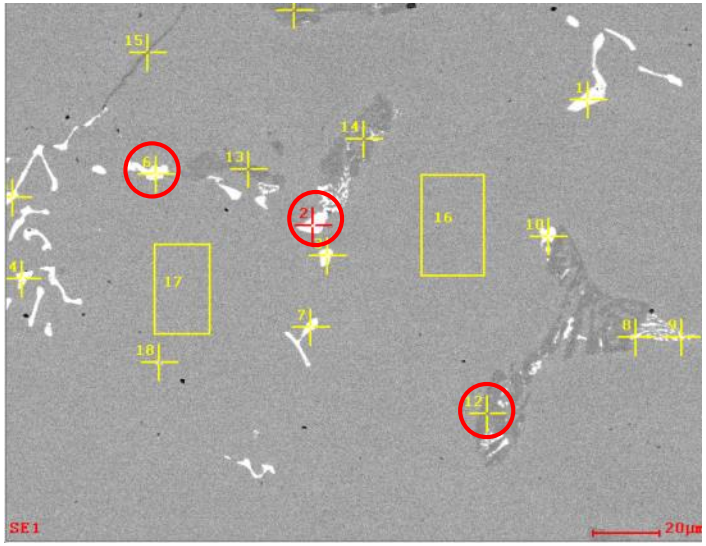
Matrix

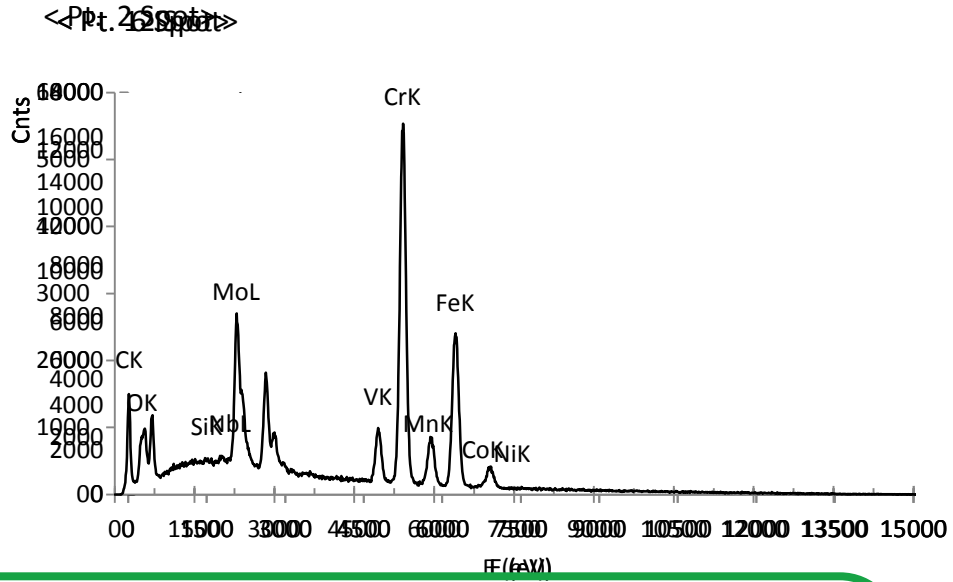


➔ **Micrometric and complex shaped carbides**

Sample description

- Chemical analysis by EDS





➔ **Micrometric and complex shaped carbides**

➔ **Cr rich (dark grey)**

➔ **Mo rich (white)**

➔ **Nb rich (white)**

Problematic and Objectives

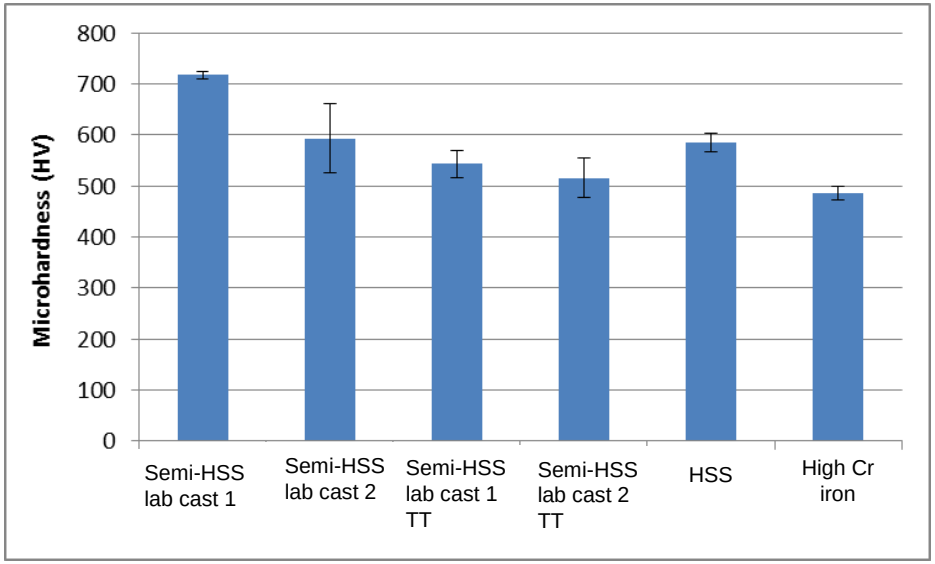
- ***Roll performance influenced by carbides (type, size, chemical composition..)***
  - *Ex. Too hard carbides comparing to matrix may act as spikes making scratches on the roll matrix*
- *Importance of characterization of carbides distribution and mechanical properties*

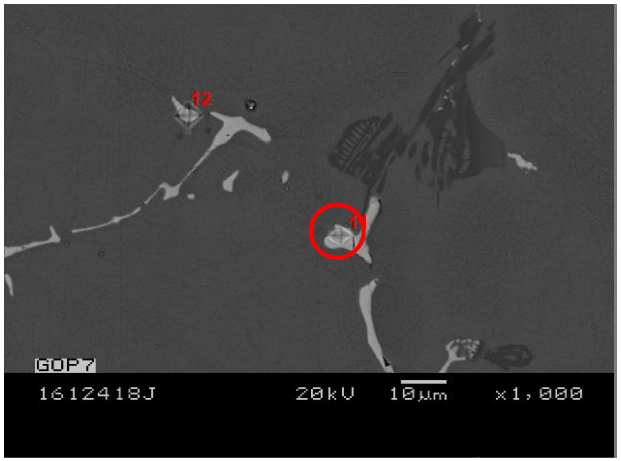
STRATEGY

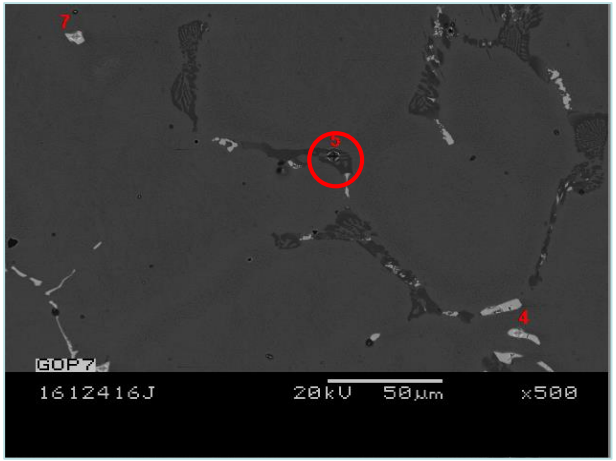
- ***Microhardness experiments***
- ***Nanoindentation maps***
  - ***Mechanical property mapping***
  - ***Mechanical property histograms***
- ***Quantitative correlation of the mechanical maps with the microstructural map***

Vickers microhardness

- Matrix (100g) ~ 500-700HV





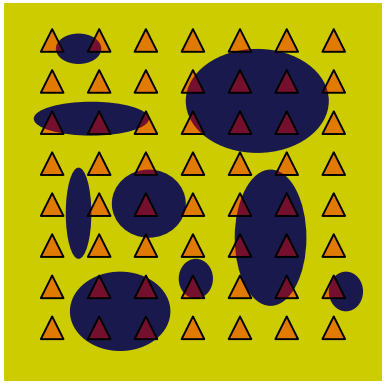


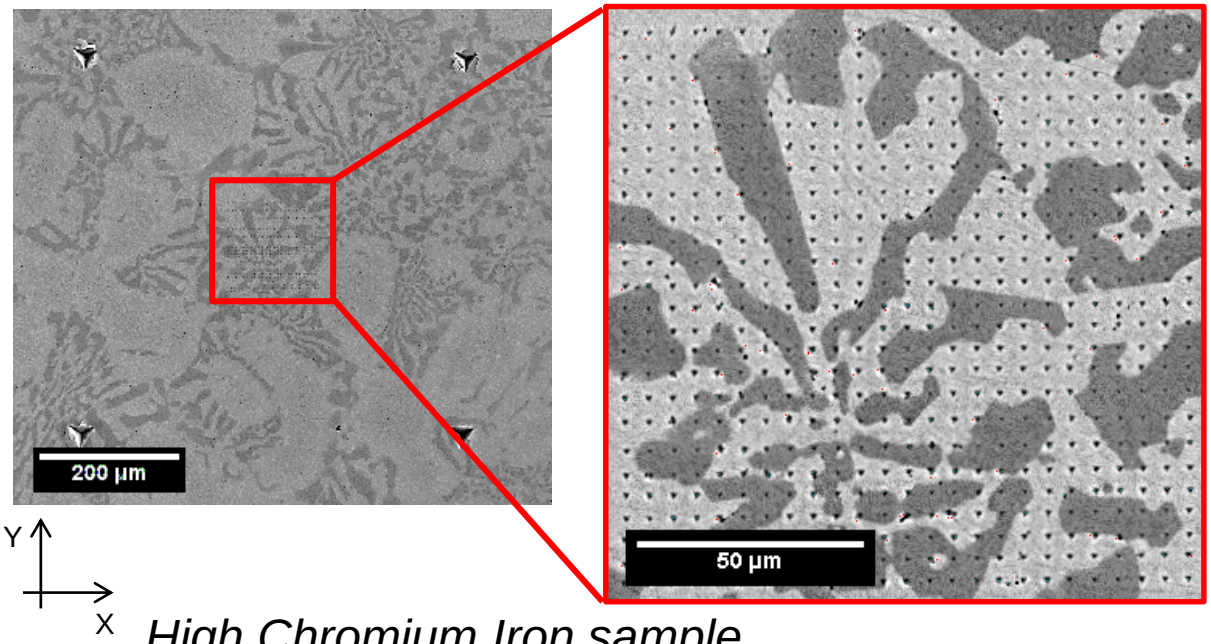
- Carbides (20g)
  - White ~ 800-1000HV
  - Dark grey ~ 900-1000HV

➔ **Use of nanoindentation?**

Nanoindentation mapping

- Grid technique[1,2]
  - MTS G200 - XP Berkovich (CSM mode)
  - 25x25 = 625 indents / $\Delta X = \Delta Y = 2\mu m$
  - Maximum indentation depth = 100nm
  - @ room T and strain rate = $0.05s^{-1}$





High Chromium Iron sample

Indent Size ~0.7µm
→ Much lower than carbides size…

→ *Phase constituents*

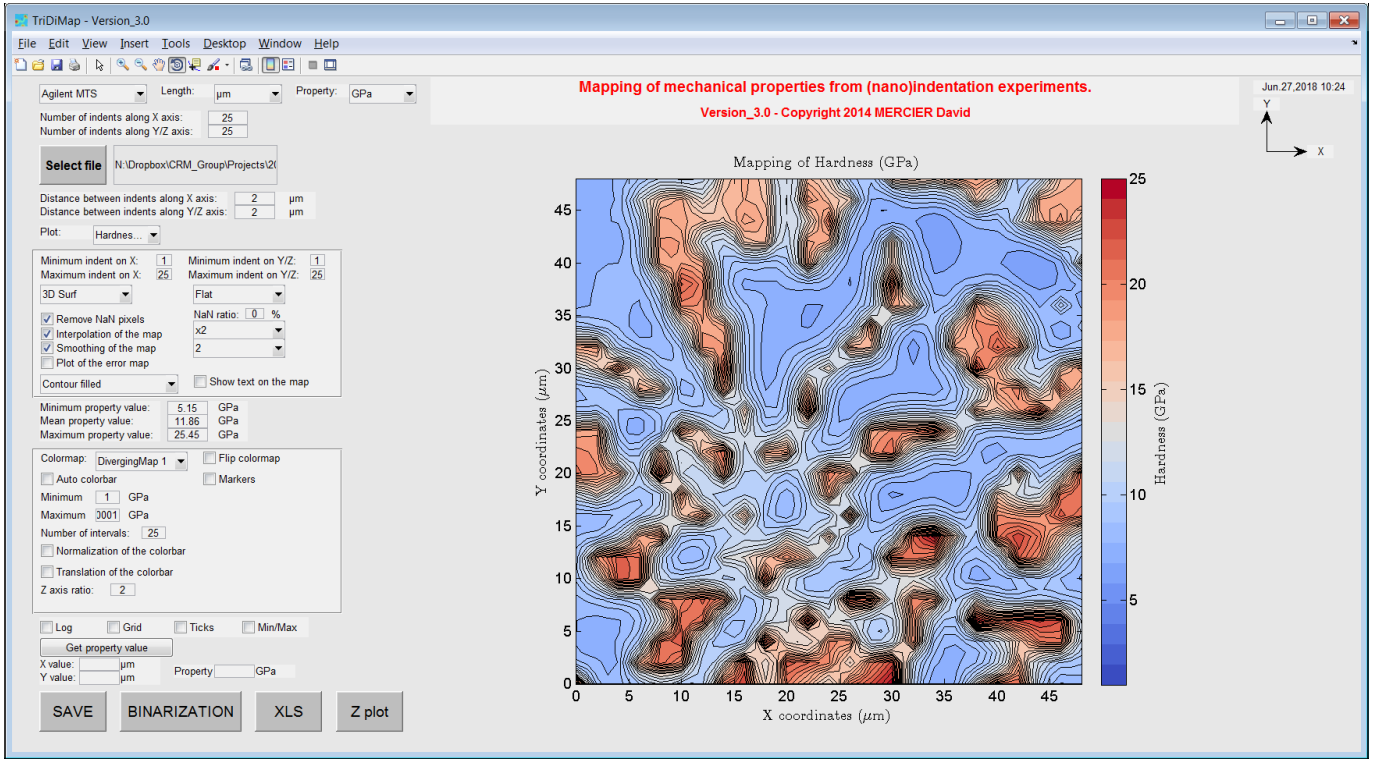
[1]Constantinides G. et al., Materials Science and Engineering: A, 430(1-2), 2006.
[2]Randall N. X. et al., J. Mater. Res., 24(3), 2009.

Nanoindentation mapping

- 3D mechanical properties maps

➔ Automatic and parametrized Matlab toolbox/GUI. Full access on Github → “TriDiMap”[1]

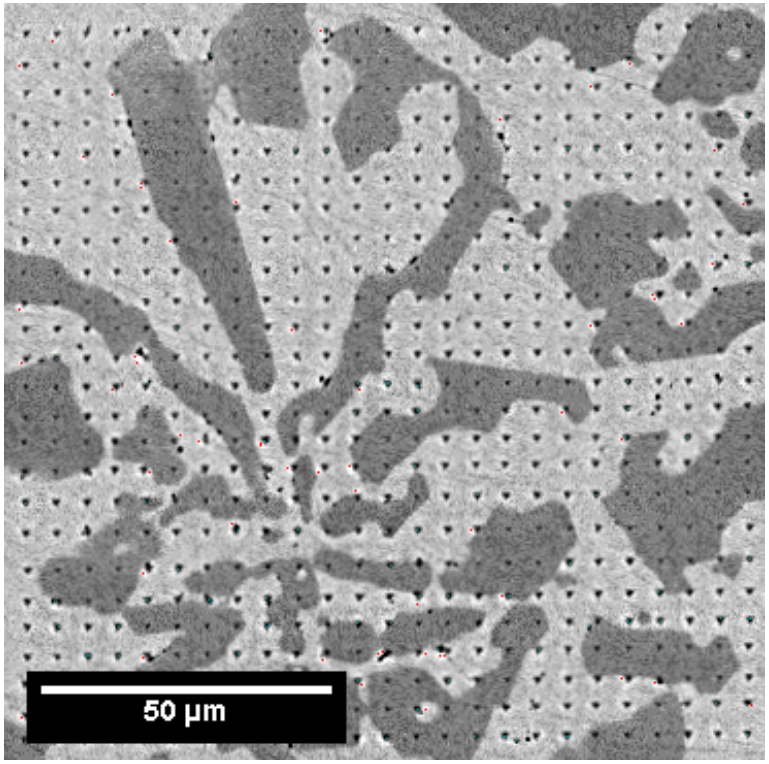
➔ Interpolation and smoothing steps…. Different types of plots (surface, isocontour…)

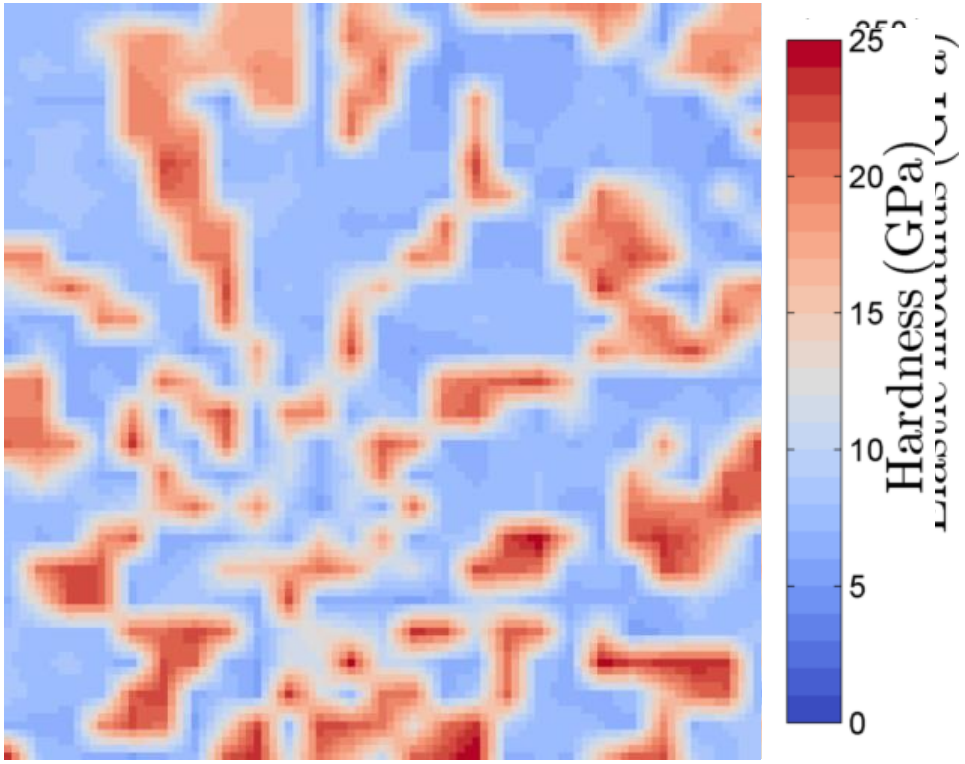


[1]**Mercier D. et al, “Microstructural and mechanical characterisation of electroplated nickel matrix composite coatings”, Surface Engineering (2018).**

Nanoindentation mapping

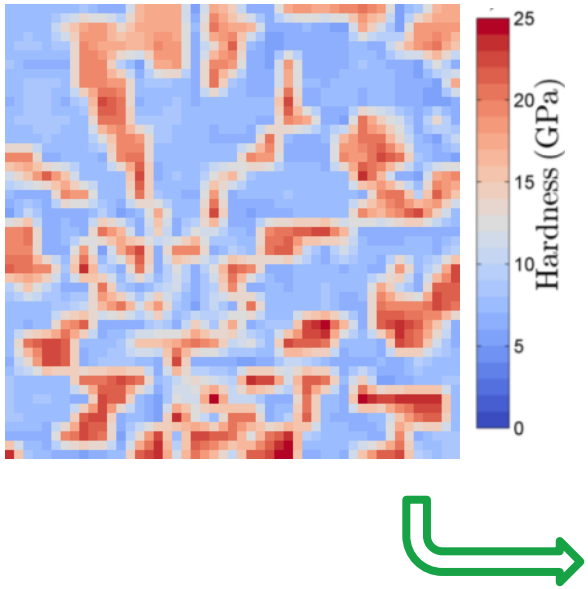
- Qualitative comparison
  - ➔ Mechanical properties calculated at max indentation depth.
  - ➔ Interpolated (x2 or x4) maps = better resolution

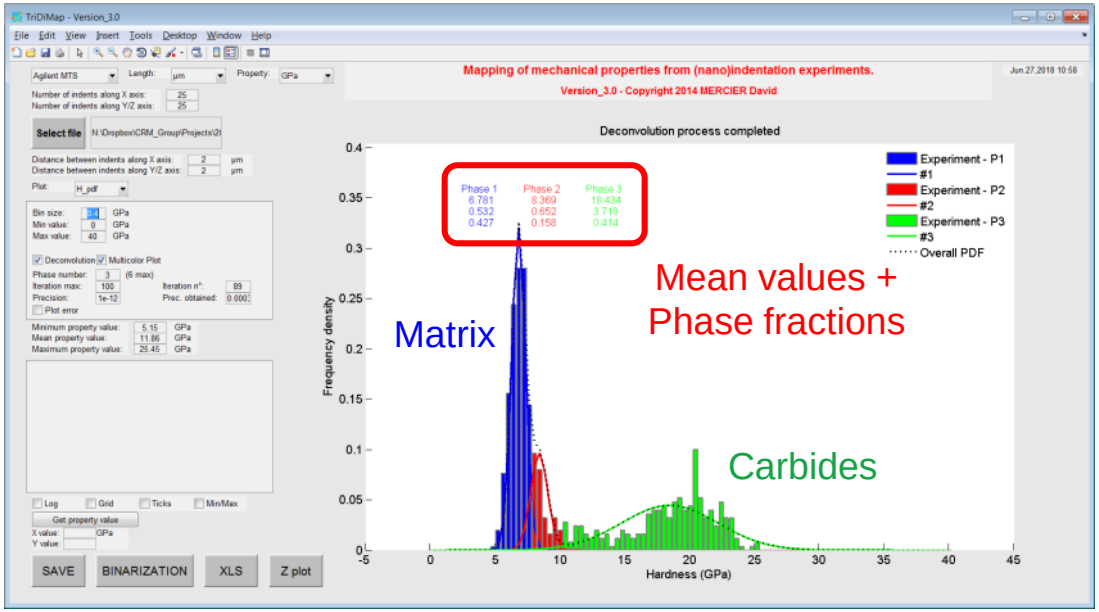




Mechanical properties distribution

- Generation and fit of histograms.
  - ➔ Automatic and parametrized Matlab toolbox/GUI. Full access on Github ➔ “TriDiMap”[1]
  - ➔ Based on code of J. Němeček[2,3] = Multi-modal Gaussian distribution + deconvolution.
  - ➔ Minimization process of the error between experimental and theoretical PDFs





- **Choice of distribution function ➔ Gaussian[4,5]**
- **Estimation of bin size ? ➔ No specific rule…**
- **Bi-modal or tri-modal statistical distribution ? Interface properties[6] ?**

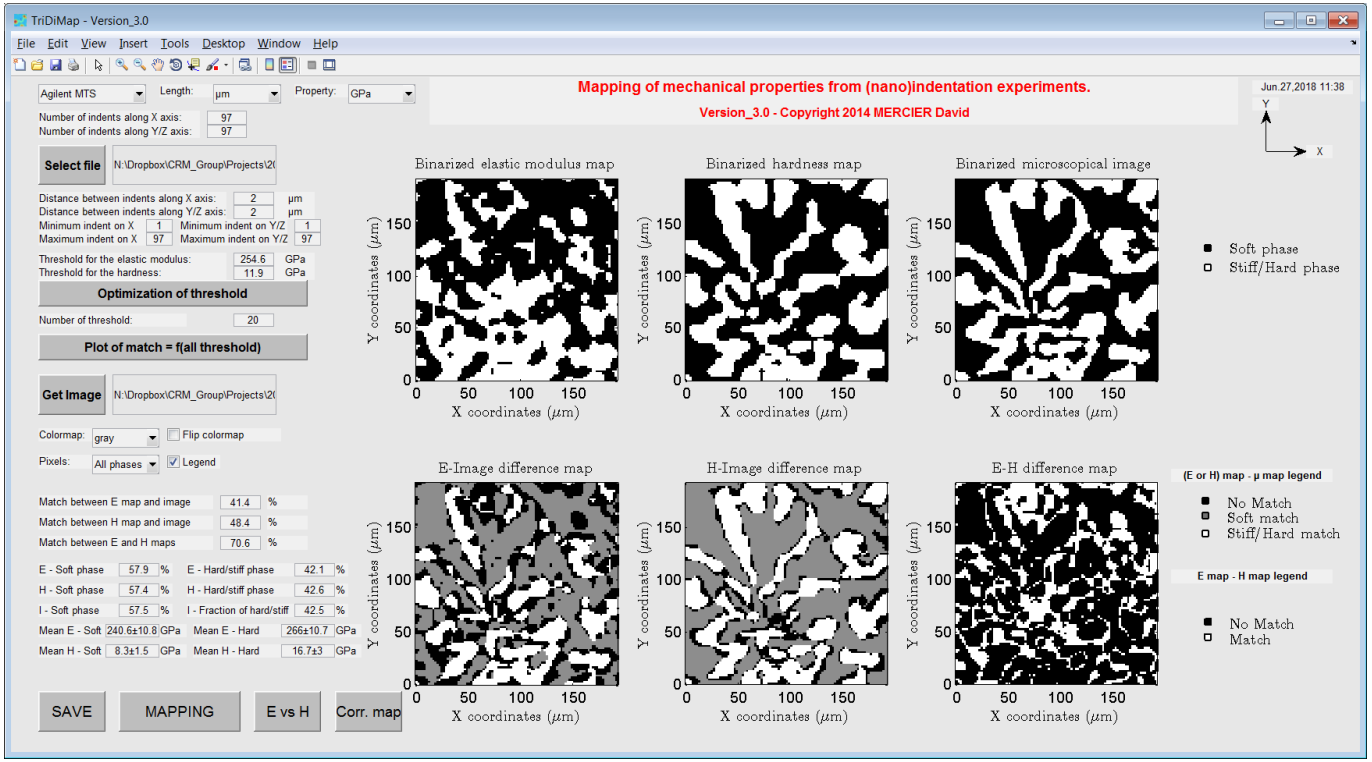
[1]Mercier D. et al, “Microstructural and mechanical characterisation of electroplated nickel matrix composite coatings”, Surface Engineering (2018).
[2]Němeček J., PhD thesis, , Czech Technical University, 2009.
[3]Personal webpage of J. Němeček.
[4]Vandamme M., PhD thesis, MIT, 2008.
[5]Randall N. X. et al., Journal of Materials Research, 24(3), 2009, pp. 679-690.
[6]de Vasconcelos, L. S. et al., Extreme Mechanics Letters, 2016.

Mechanical property-microstructure correlation

- Image correlation analysis

➔ Automatic and parametrized Matlab toolbox/GUI. Full access on Github → "TriDiMap"[1]

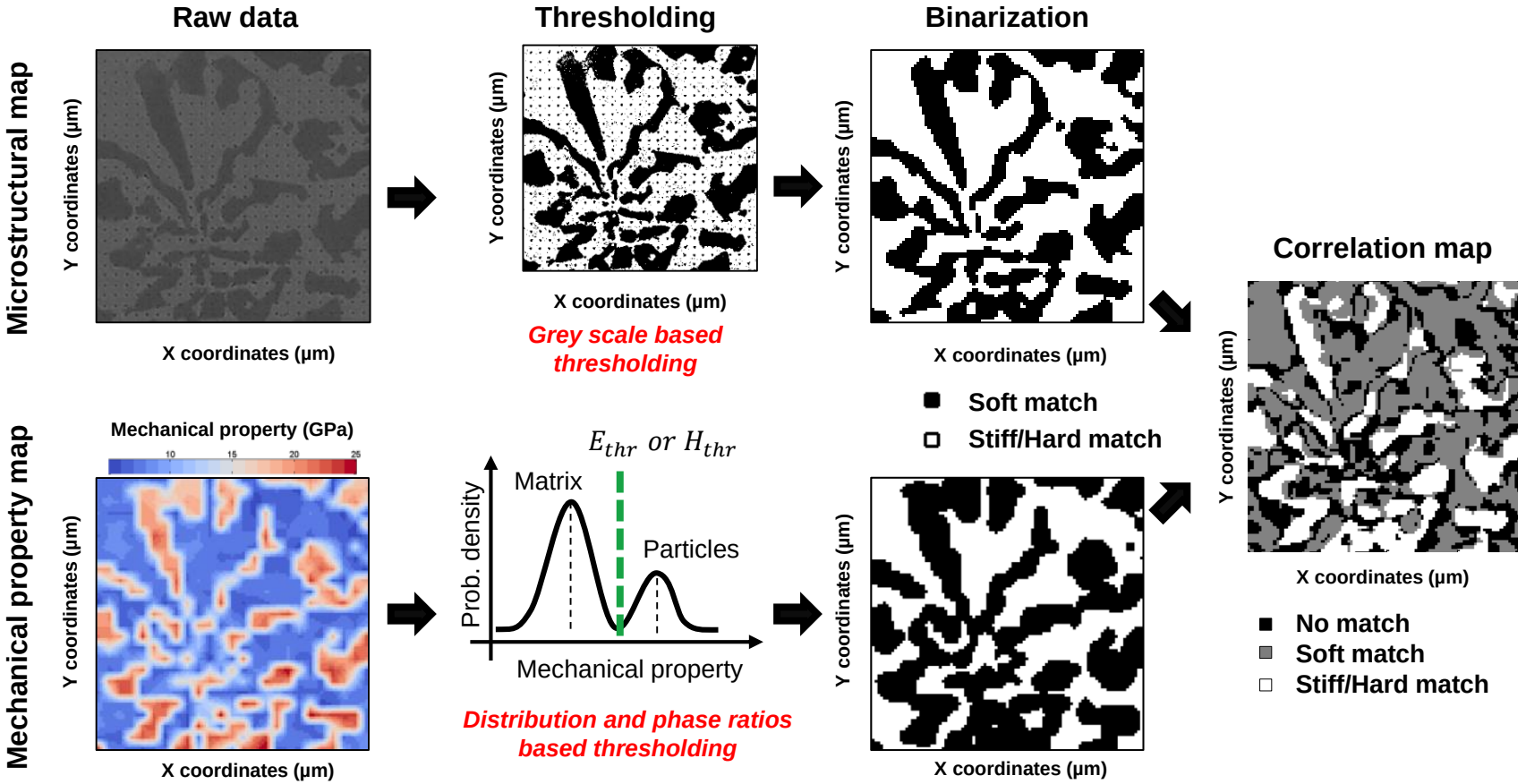
➔ Loading and comparison of binarized mechanical and microstructural maps



[1]Mercier D. et al, "Microstructural and mechanical characterisation of electroplated nickel matrix composite coatings", Surface Engineering (2018).

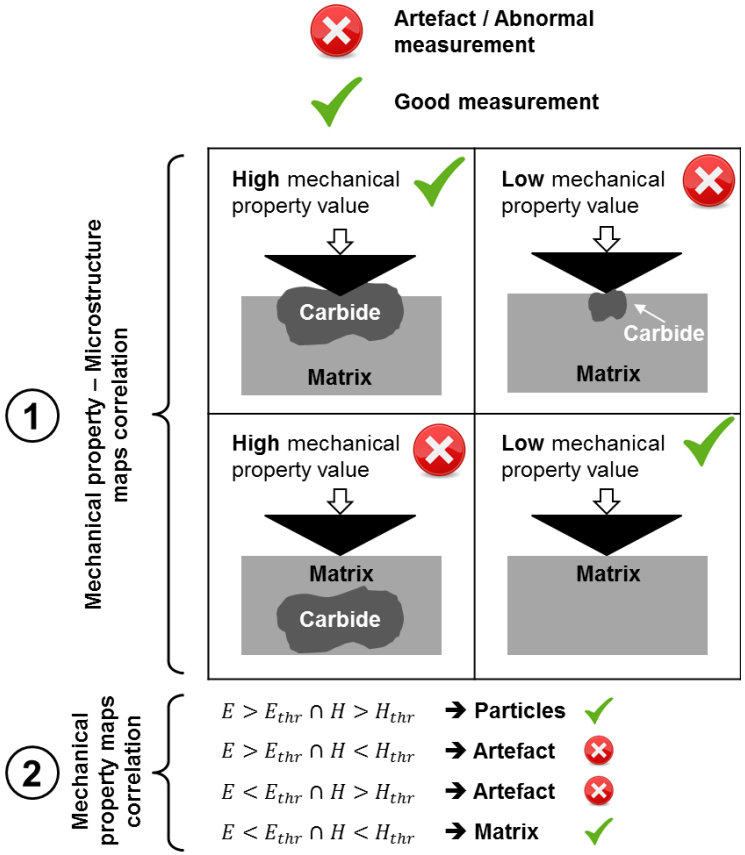
Mechanical property-microstructure correlation

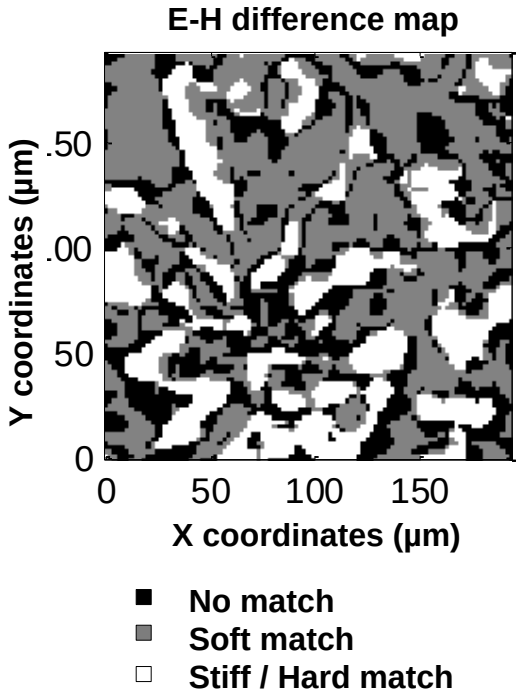
- Principle of the **image correlation analysis**, with **thresholding** and **binarization** steps.



Mechanical property-microstructure correlation

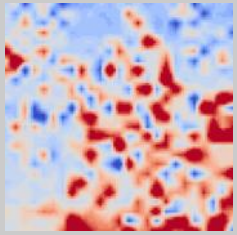
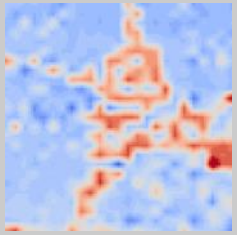
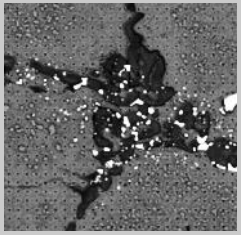
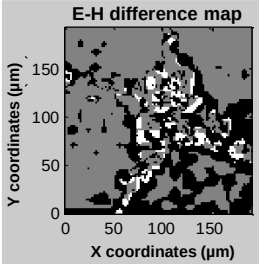
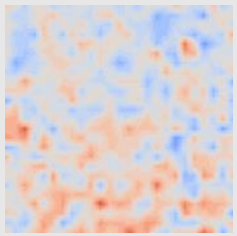
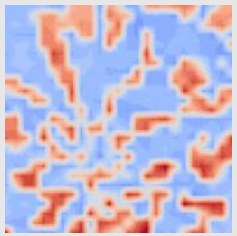
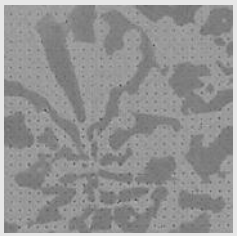
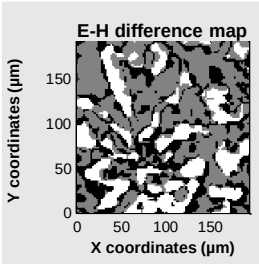
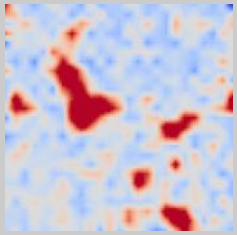
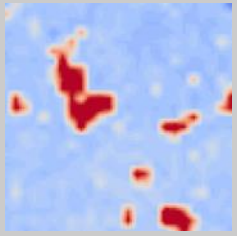
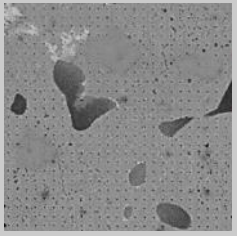
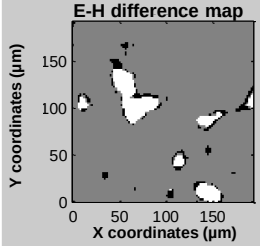
- Principle of the **image correlation analysis**, with **thresholding** and **binarization** steps.

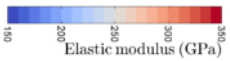


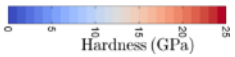


➔ Extraction of corrected average hardness and elastic modulus of carbides and matrix

Application of the image correlation analysis

Sample	E map	H map	µstruct map	Correlation map	Mean E	Mean H
Semi-HSS					E(matrix) = (252 ± 32)GPa E(carbides) = (380 ± 84)GPa	H(matrix) = (9.5 ± 2.0)GPa H(carbides) = (17.6 ± 2.1)GPa
High Cr Iron					E(matrix) = (241 ± 11)GPa E(carbides) = (266 ± 11)GPa	H(matrix) = (8.3 ± 1.5)GPa H(carbides) = (16.7 ± 3.0)GPa
HSS					E(matrix) = (243 ± 19)GPa E(carbides) = (348 ± 27)GPa	H(matrix) = (9.1 ± 1.6)GPa H(carbides) = (22.8 ± 3.5)GPa





- No match
- Soft match
- Stiff/Hard match

Hardness values 1.5 to 3x higher than those obtained by Vickers tests

Conclusion

- Microstructural and mechanical characterization of cast bimetallic work roll with a high-speed steel (HSS) shell material
- Use of nanoindentation mapping
- Development of Matlab toolbox / GUI = TriDiMap (free on Github)
- Extraction of mean mechanical properties of matrix and carbides based on image correlation analysis

Outlook

→ Perform image correlation analysis between mechanical property maps with EDS maps…

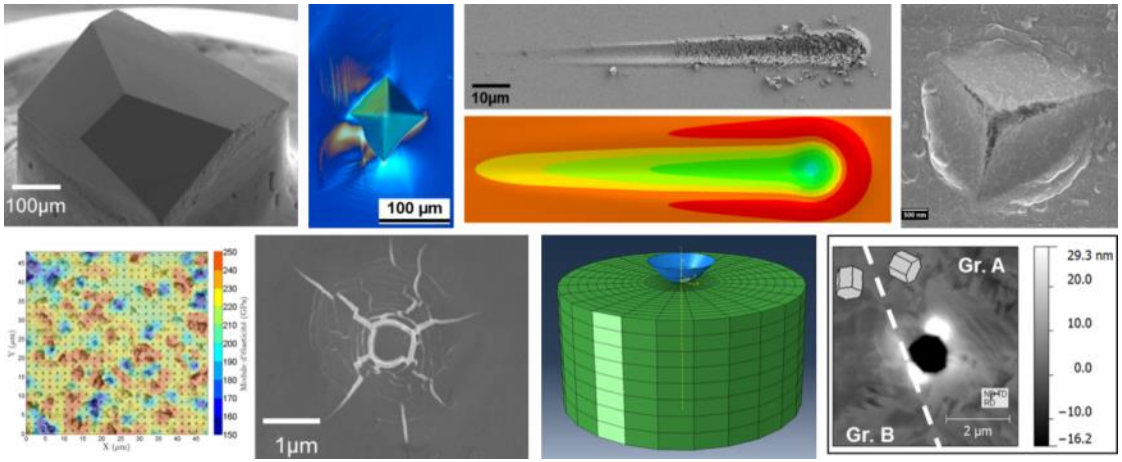
Wallonie

Thanks for you attention.
Question ?

Author would like to thank for the financial support of the BEWARE FELLOWSHIPS programs co-financed by the COFUND program of the European Union (FP7 - Marie Curie Actions).

Indentation 2018 in Liège

Indentation 2018



http://www.aimontefiore.org/INDENTATION2018/

September 11-14 2018

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