Metal injection molding of W components for extreme loads

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Eindhoven

23/01/2013

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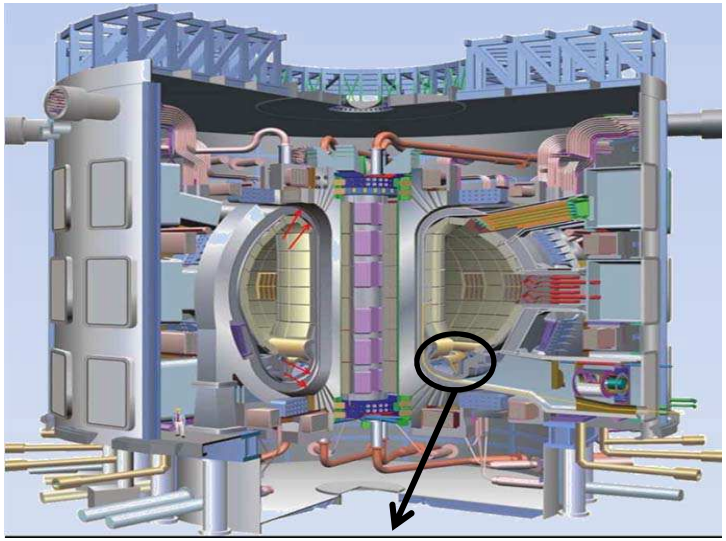
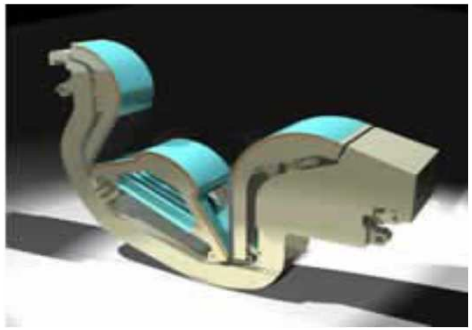
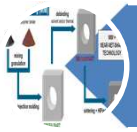
Scope





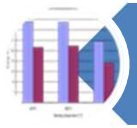
- To develop suitable W materials to be used in the divertor area of the future DEMO reactor
- To show the potential of the MIM technique as reliable method capable to produce good materials and to be easily scalable to mass production
- Demonstrate the feasibility of using MIM method for joining W components without welding/joining technique

Overview



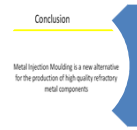
MIM: the process

Why high performance Tungsten components by MIM



Characterisation of MIM Tungsten metal

“2K” Demo component

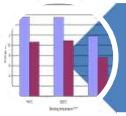


Conclusions

MIM: the process (1)


MIM: the process


Why high performance Tungsten components by MIM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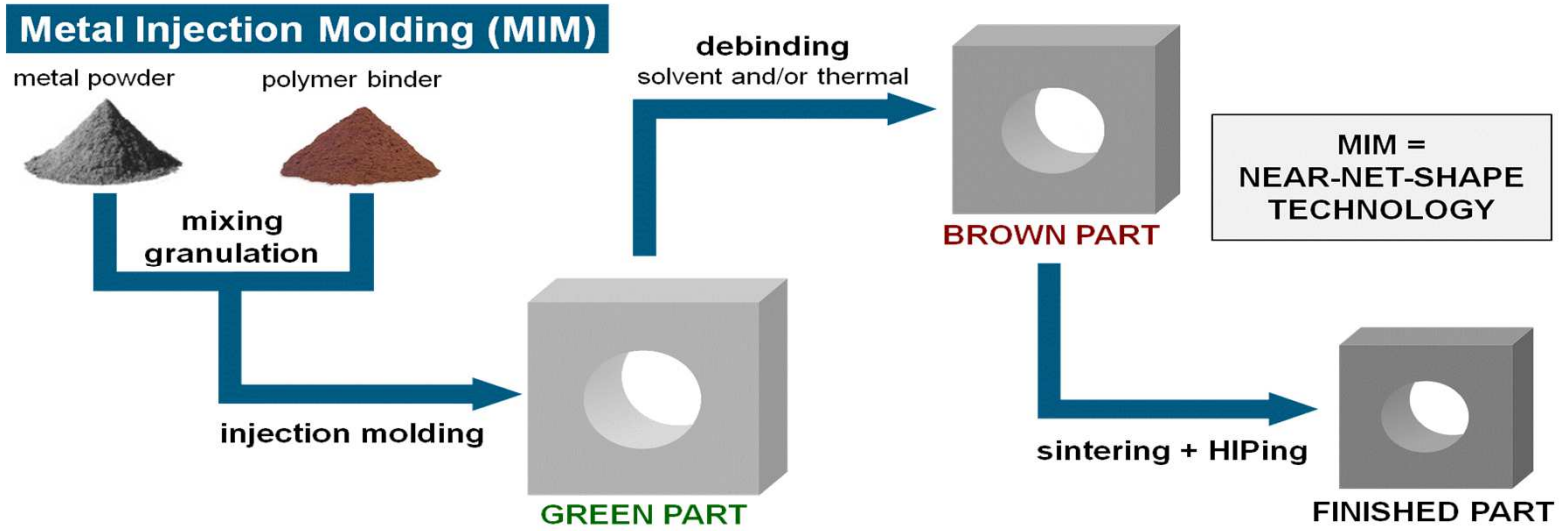
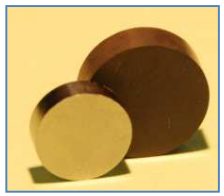
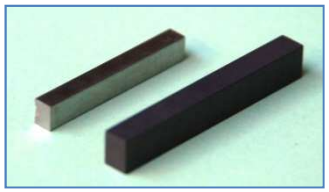


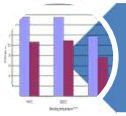




MIM: the process (2)


MIM: the process


Why high performance Tungsten components by MIM


Characterisation of MIM Tungsten metal


"2K" Demo component


Conclusions


Powder & Binder mixing


Metal injection molding

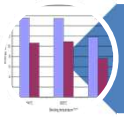

Pre-sintering


Sintering to end density

Net shaped components


MIM: the process


Why high performance Tungsten components by MIM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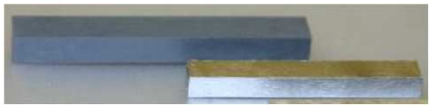
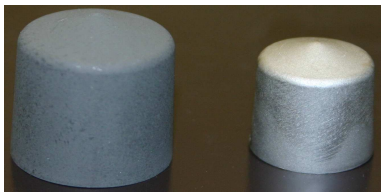
"2K" Demo component

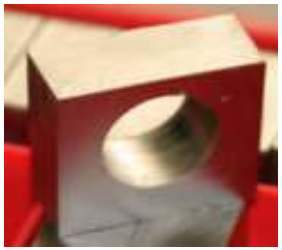

Conclusions


Green & as sintered Standard Charpy test sample

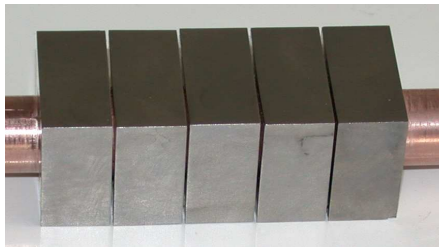

As sintered Standard Tensile test sample


Green & as sintered thimble for HEMJ divertor design

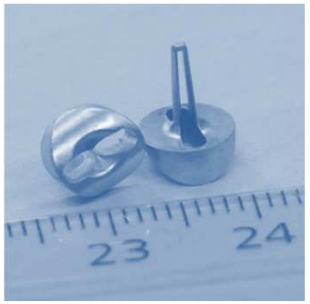

Internal voids e.g. cooling channels possible



Mockup manufactured By Ansaldo


As sintered monoblocks and mock up for ITER divertor target

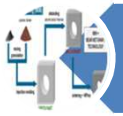

As sintered bolts



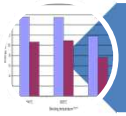
Fine structures possible

Why high performance components by MIM:

the product


MIM: the process


Why high performance Tungsten components by MIM


Characterisation of MIM Tungsten metal

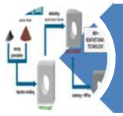

"2K" Demo component


Conclusions

- Isotropic properties and microstructure ➔ homogeneity
- Ultra high purity materials ➔ homogeneity and predictability
- Free from re-crystallization and recovery ➔ reliability
- Improved properties by unique alloying/doping ➔ performance and predictability
- Free Shaping, avoiding machining ➔ reliability and performance
- MIM technology, having tight control on geometry and appropriate for high volume production ➔ reliability

Why high performance components by MIM:

the process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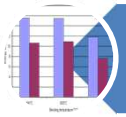

Characterisation of MIM Tungsten metal


"2K" Demo component


Conclusions

Advantages MIM process

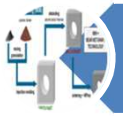
➔Less contamination

➔Less energy consumption

➔Less loss of material

➔Less process steps

Materials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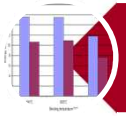

Characterisation of MIM Tungsten metal


"2K" Demo component

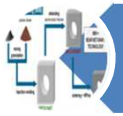

Conclusions

Pure W

W + 1 vol. %Y_2O_3 (0.26 wt.%)

Microstructure
Density
Hardness (HV)
Thermal diffusivity / conductivity
3 P Bending testing
Impact KLST testing
High Heat Flux testing

Microstructure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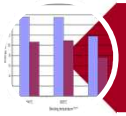
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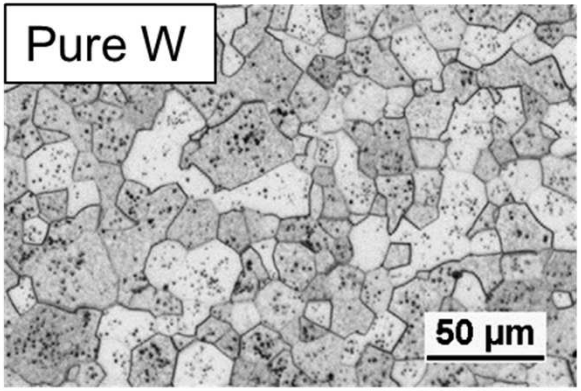

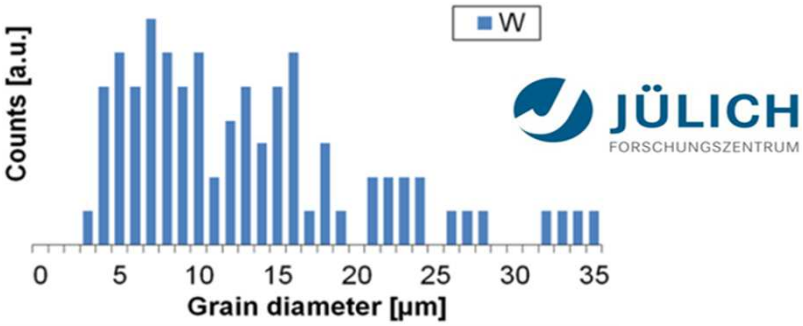

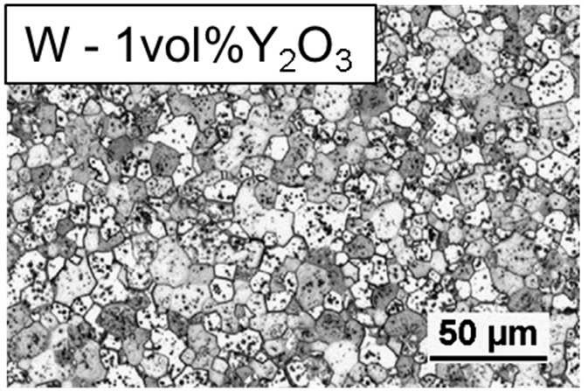

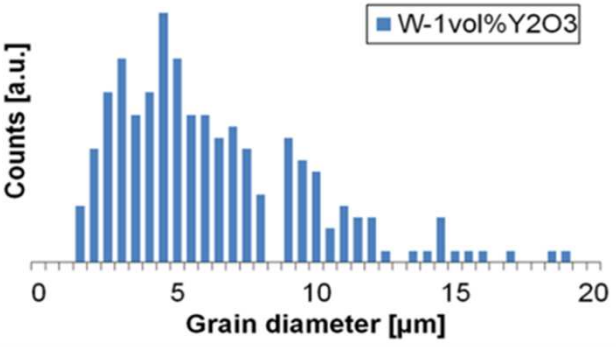

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Microstructure


MIM: the process


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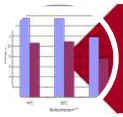
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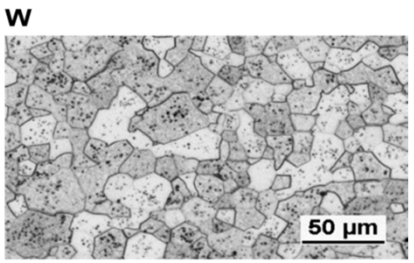
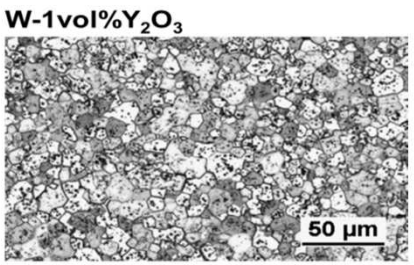
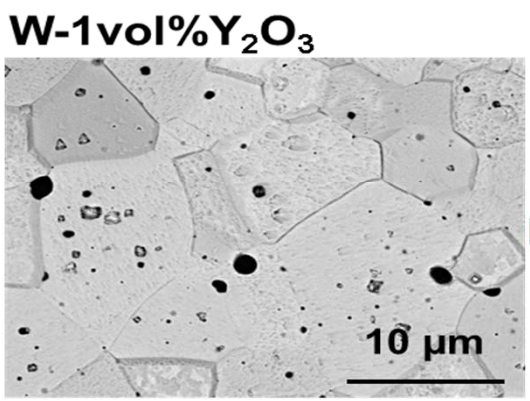




SEM



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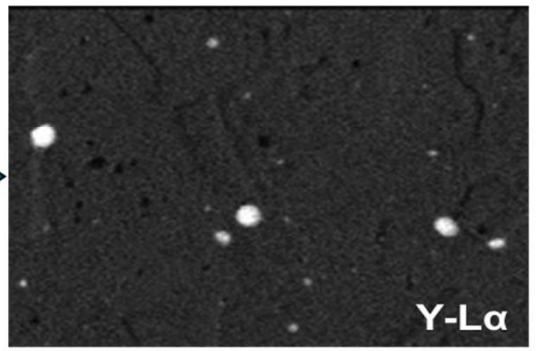
Element mapping



TEM of W doped with 1 vol.%Y_2O_3


MIM: the process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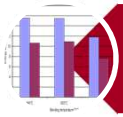
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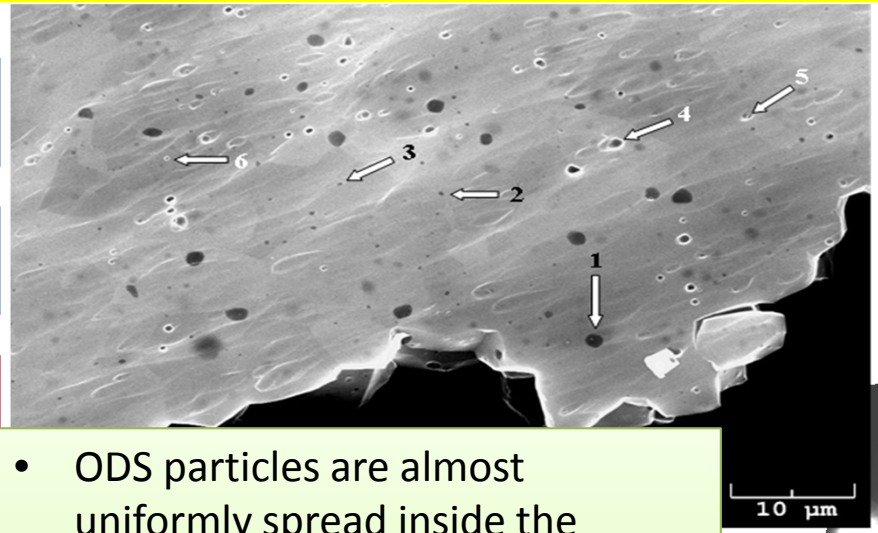
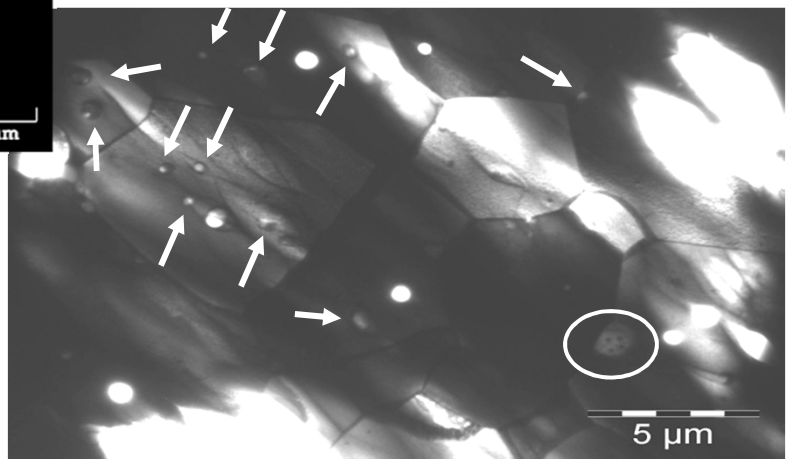
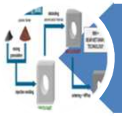


1,2,3 => ODS particles
4,5,6 => pre-existing pores

- ODS particles are almost uniformly spread inside the material volume, mainly as inclusions in the W grains
- W grains containing more than one oxide inclusion are observed everywhere



HRTEM of pure W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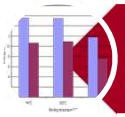
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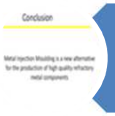
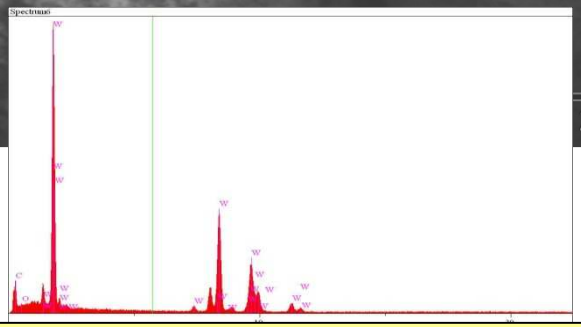
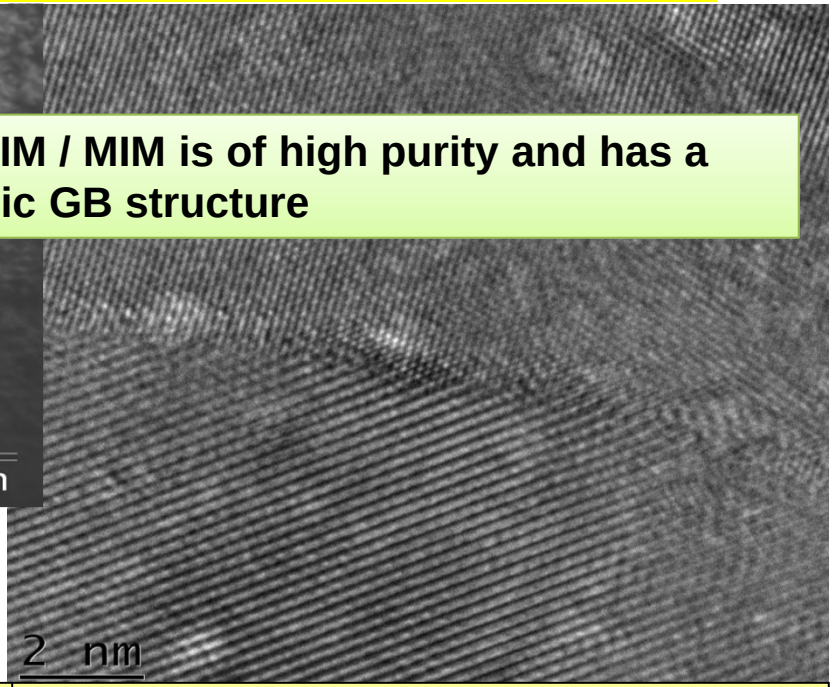

Conclusions

Pure W material, fabricated by PIM / MIM is of high purity and has a perfect atomic GB structure

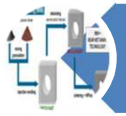




Triple junctions (TJs) and grain boundaries (GBs) analysed by contrast in HRTEM and by X-EDS.

representative observed atomic structure of a GB in the material. No impurity atoms or amorphous phase are seen on these GBs.

Density and Hardness (HV)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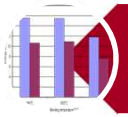
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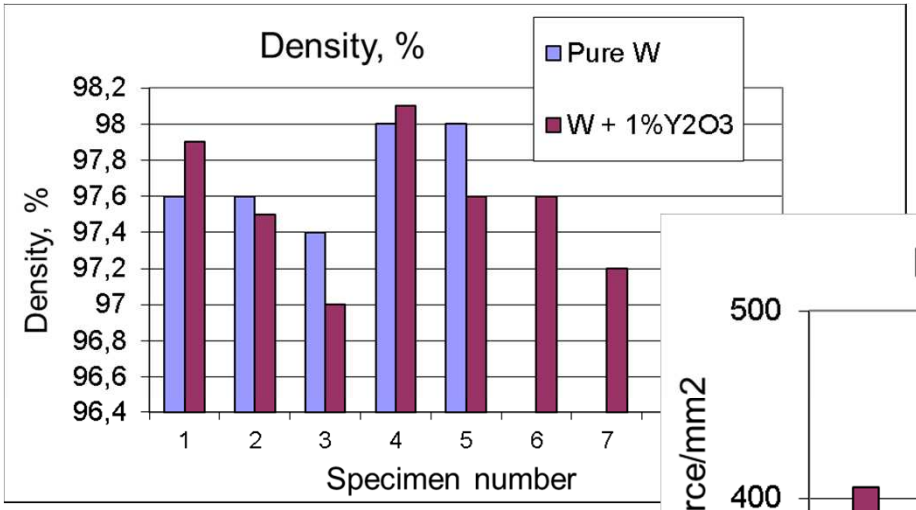
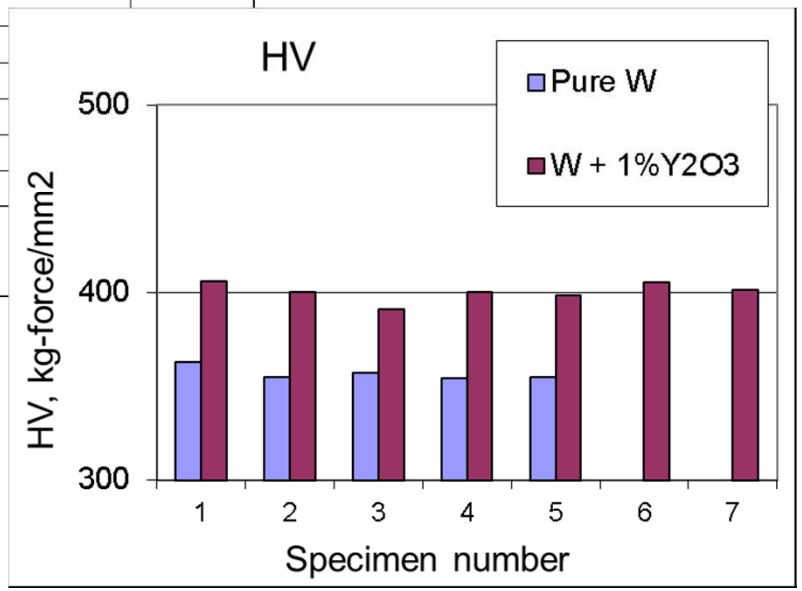
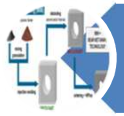




Thermal conductivity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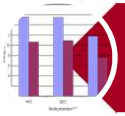
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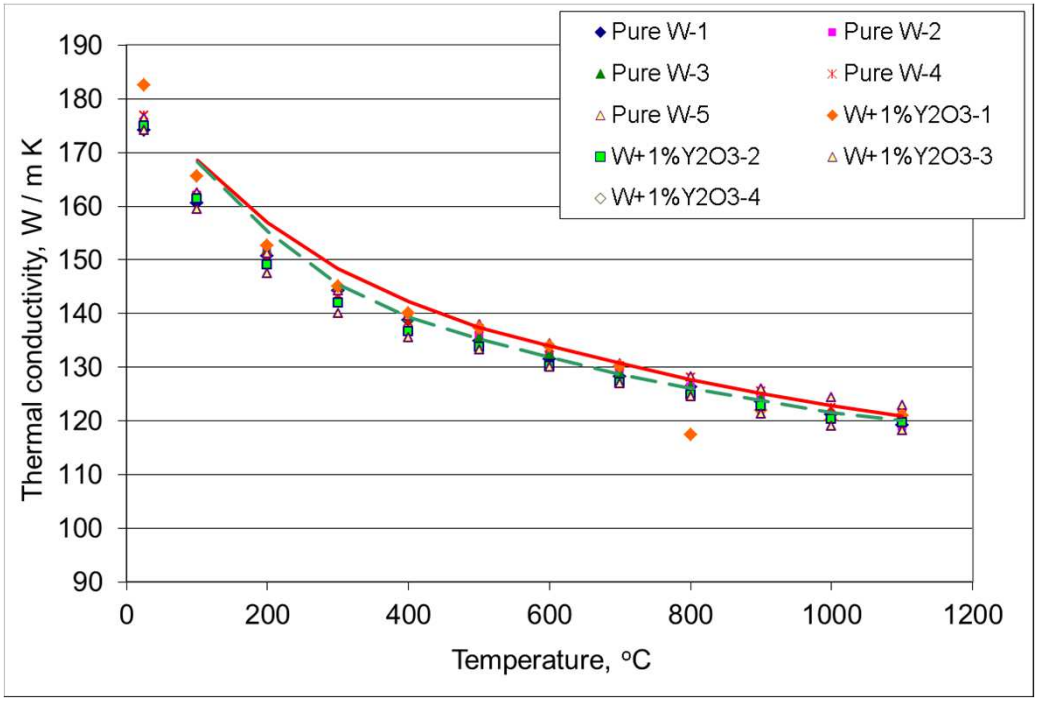
Conclusions

Thermal diffusivity α [mm^2/s] was measured by laser flash method



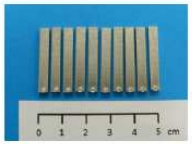
Thermal conductivity K [W/mK] :

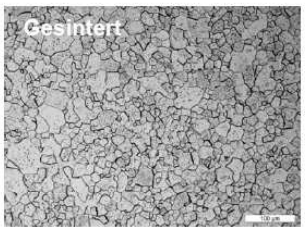
$K = \alpha * \rho * Cp$

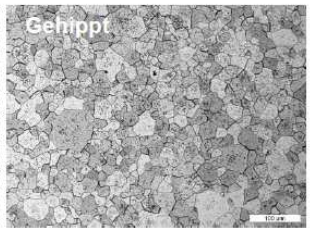
Measured by Plansee

Rein W (ECN)

Gesintertes W







	C [µg/g]	Fe [µg/g]	Mo[µg/g]	Si [µg/g]
Gesintert	15	< 5	204	20
Gehippt	6	11	240	20
Spezifikation	30	30	100	20

Alle übrigen Elemente unterhalb der Nachweisgrenze

Eigenschaft	Messwert		
	Gesintert	Gehippt	Std. W
Dichte Bars	19,060 (98,76%)	19,076 (98,84%)	
Dichte Squares	19,106 (99,00%)	19,102 (98,97%)	
Wärmeleitfähigkeit 25°C	177,2 $Wm^{-1}K^{-1}$	176,9 $Wm^{-1}K^{-1}$	164 $Wm^{-1}K^{-1}$
Härte	376 HV_{30}	378,6 HV_{30}	SR 425 HV_{30} Rxx 366 HV_{30}
Korngröße	17,2 µm	18,8 µm	

* WLF Literatur High purity W 174 $Wm^{-1}K^{-1}$

- ECN – Niederländisches Institut für Energie Innovation
- Hauptkompetenzen – Anlagenentwicklung für Energietechnik und Wärmebehandlungen
- MIM-Entwicklung (inkl. Mitarbeiter) von Philips Lighting übernommen
  - Extrem hohe Reinheit
  - DBTT vergleichbar mit umgeformten Material
  - Dichte nach Sintern ~ 99% der theoretischen Dichte
  - Hohe Biegefestigkeit
  - WLF besser als Literaturwerte

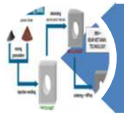
Auch im gesinterten Zustand extrem gute Eigenschaften erreicht.

A Step ahead in Technology.

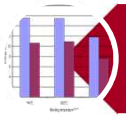
PLANSEE

High temperature tensile tests

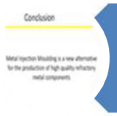
high purity tungsten

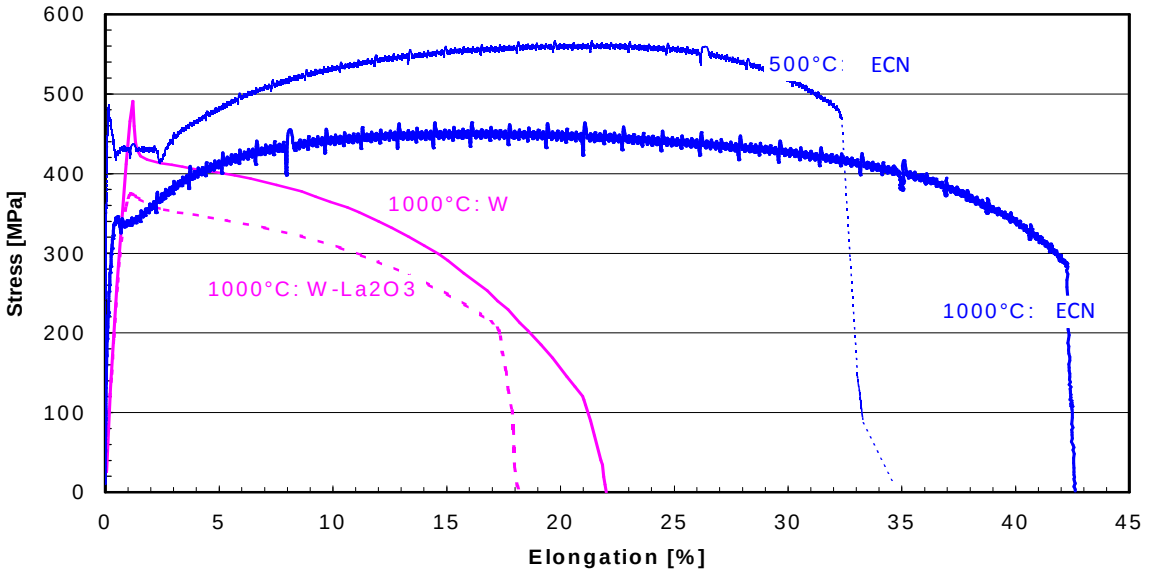

MIM: the process

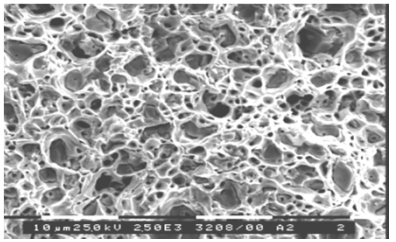

Why high performance Tungsten components by MIM


Characterisation of MIM Tungsten metal


"2K" Demo component


Conclusions





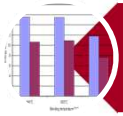
Fracture at 500 °C

High temperature tensile tests show good high temperature strength, plasticity, and ductility.

3P Bending results

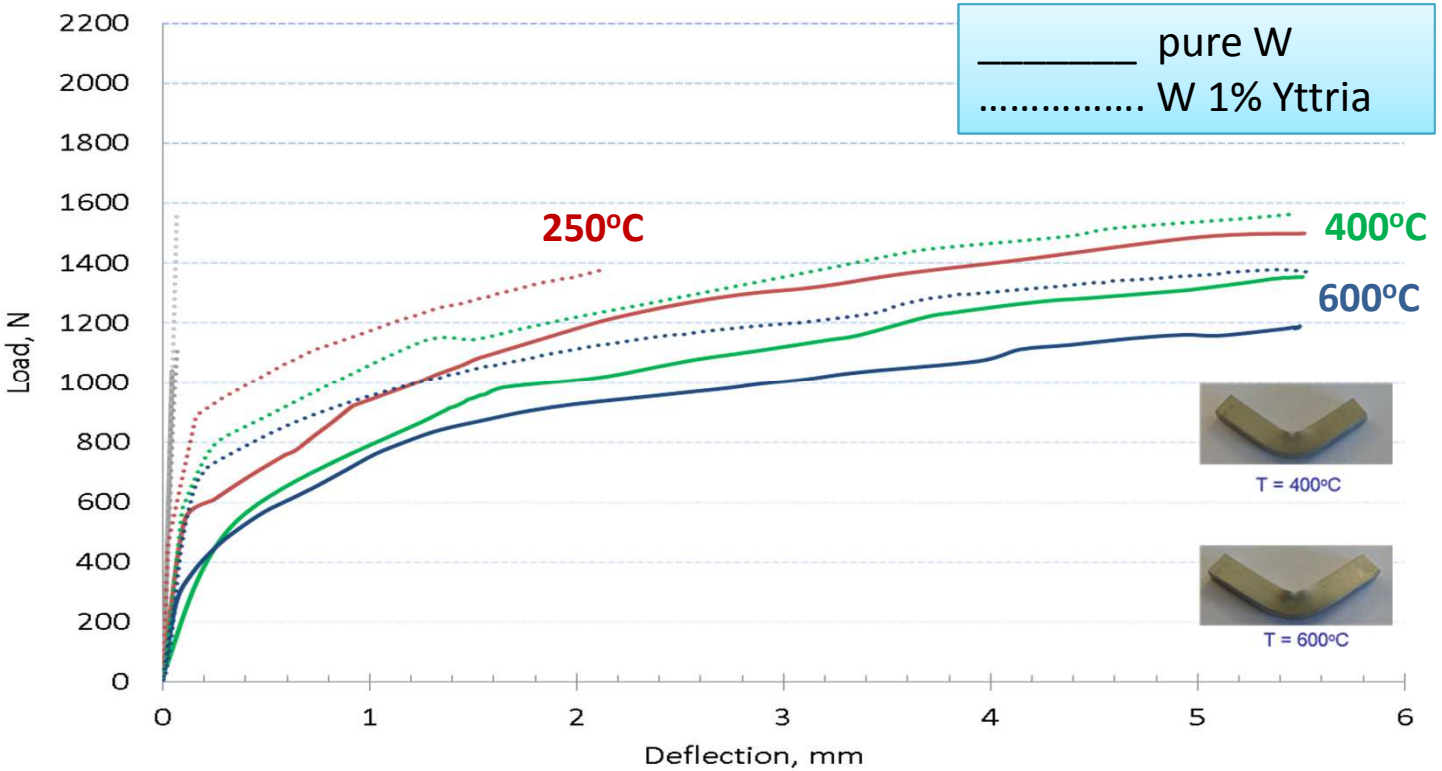

MIM: the process


Why high performance Tungsten components by MIM

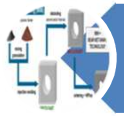

Characterisation of MIM Tungsten metal


"2K" Demo component


Conclusions



Charpy impact results


MIM: the process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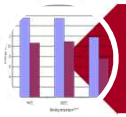
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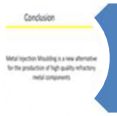
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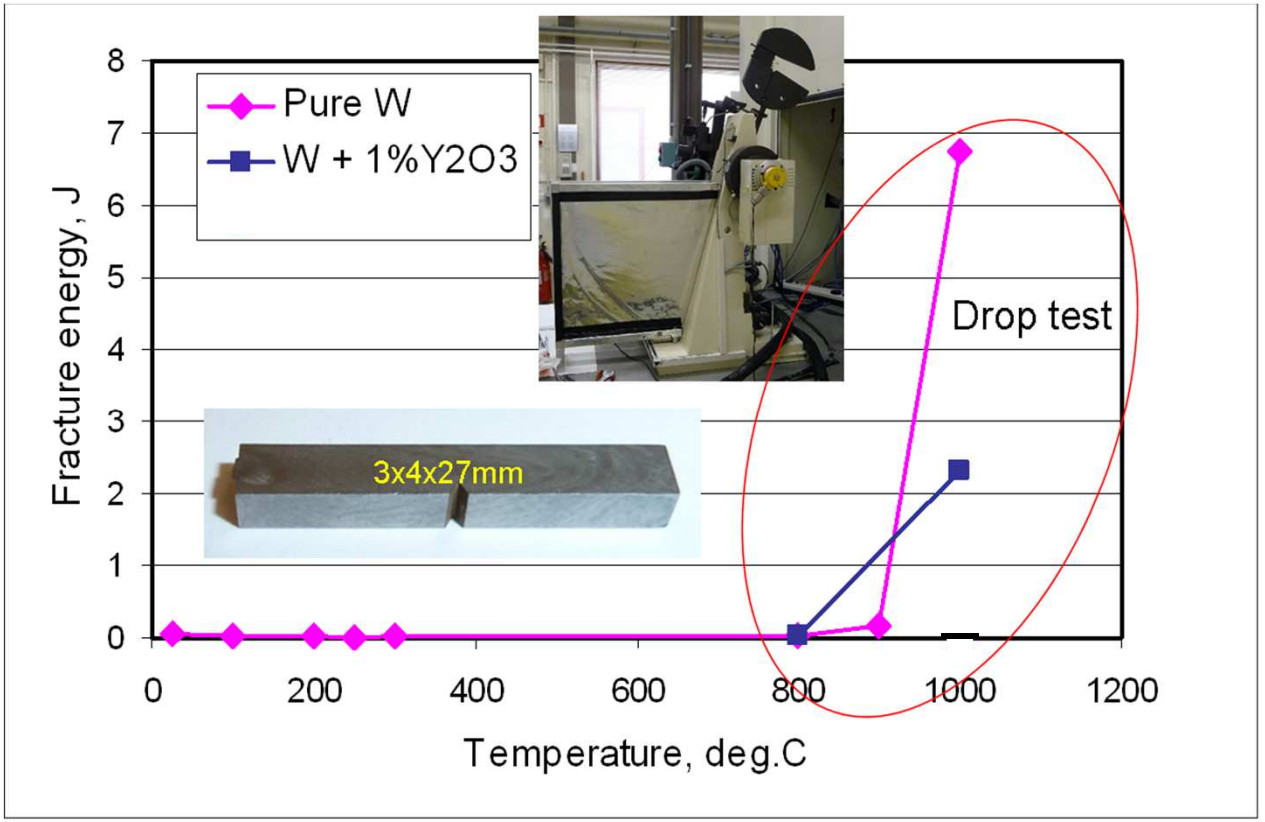

High Heat Flux (HHF) test results


MIM: the process


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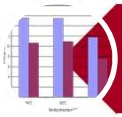
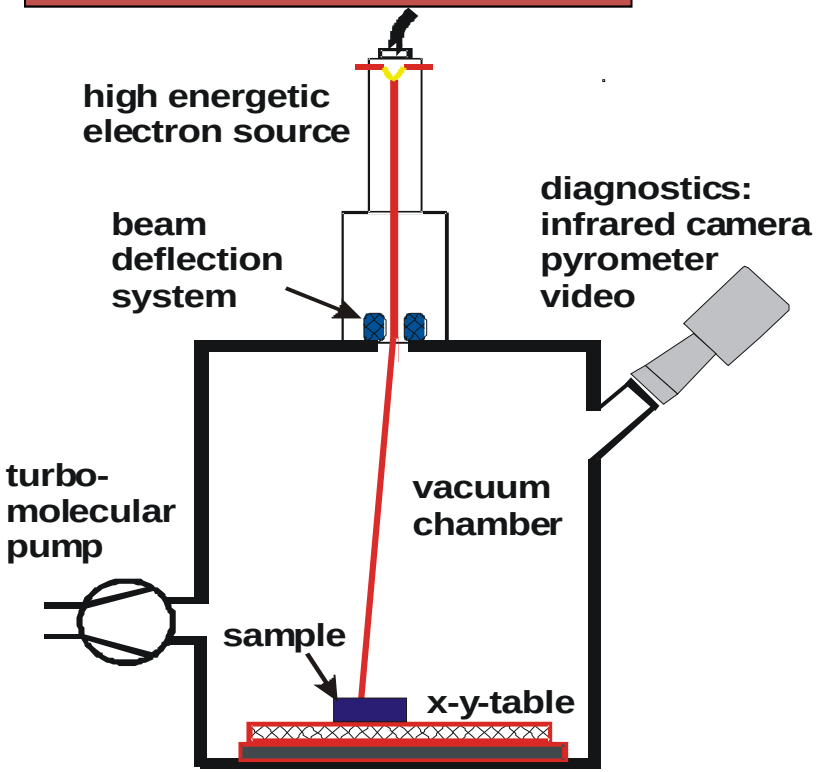

Characterisation of MIM Tungsten metal


"2K" Demo component


Conclusions

JUDITH I e-beam facility



Loading: 100 & 1000 pulses

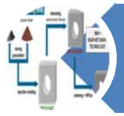
Duration: 1 ms

Loaded area: 4 x 4 mm²

Power Density: 0.19; 0.38 and 1.13 GW/m²

T = RT – 1000°C

High Heat Flux (HHF) test results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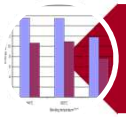
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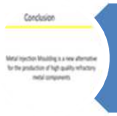
"2K" Demo component


Conclusions

Surface analyses: SEM of pure W

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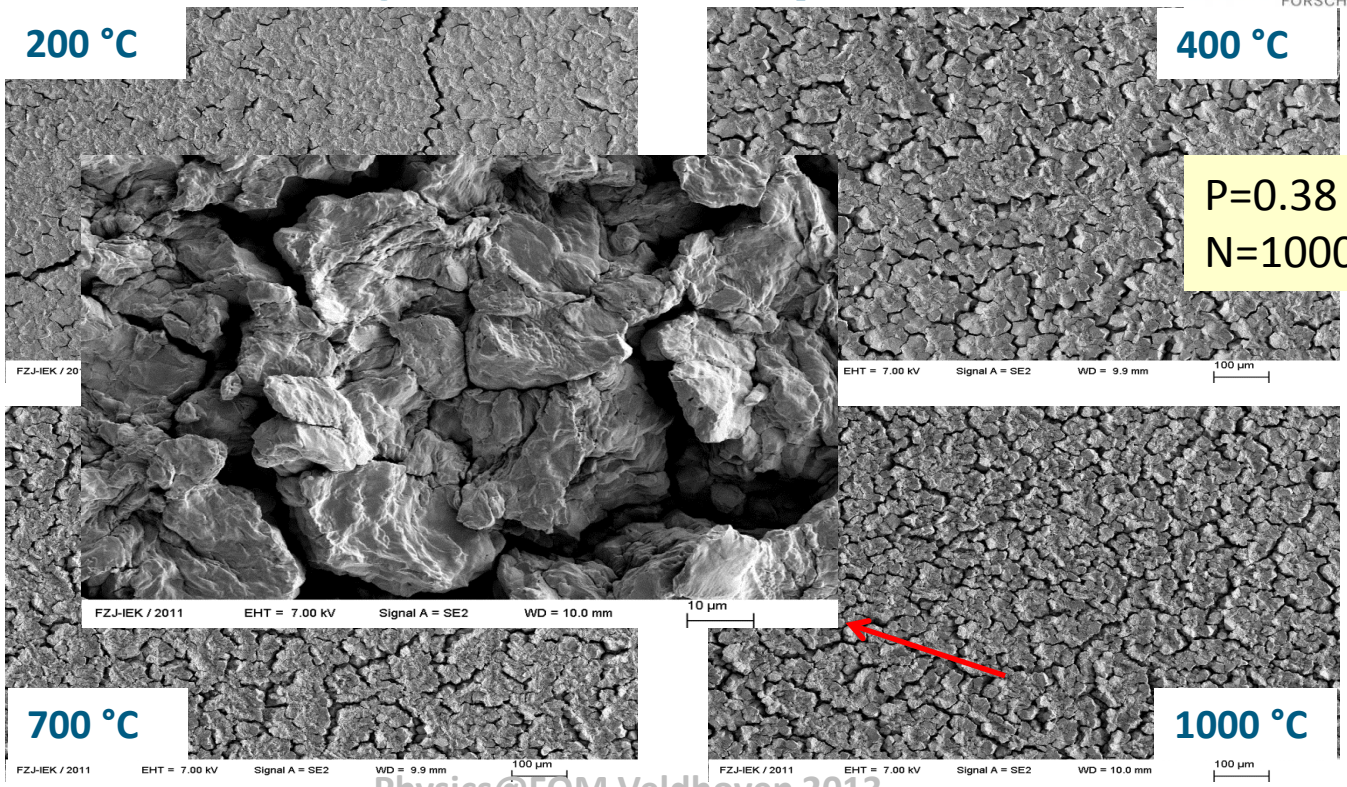
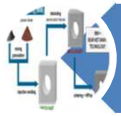
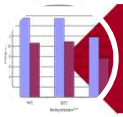


P=0.38 GW/m^2
N=1000

High Heat Flux (HHF) test results


MIM: the process

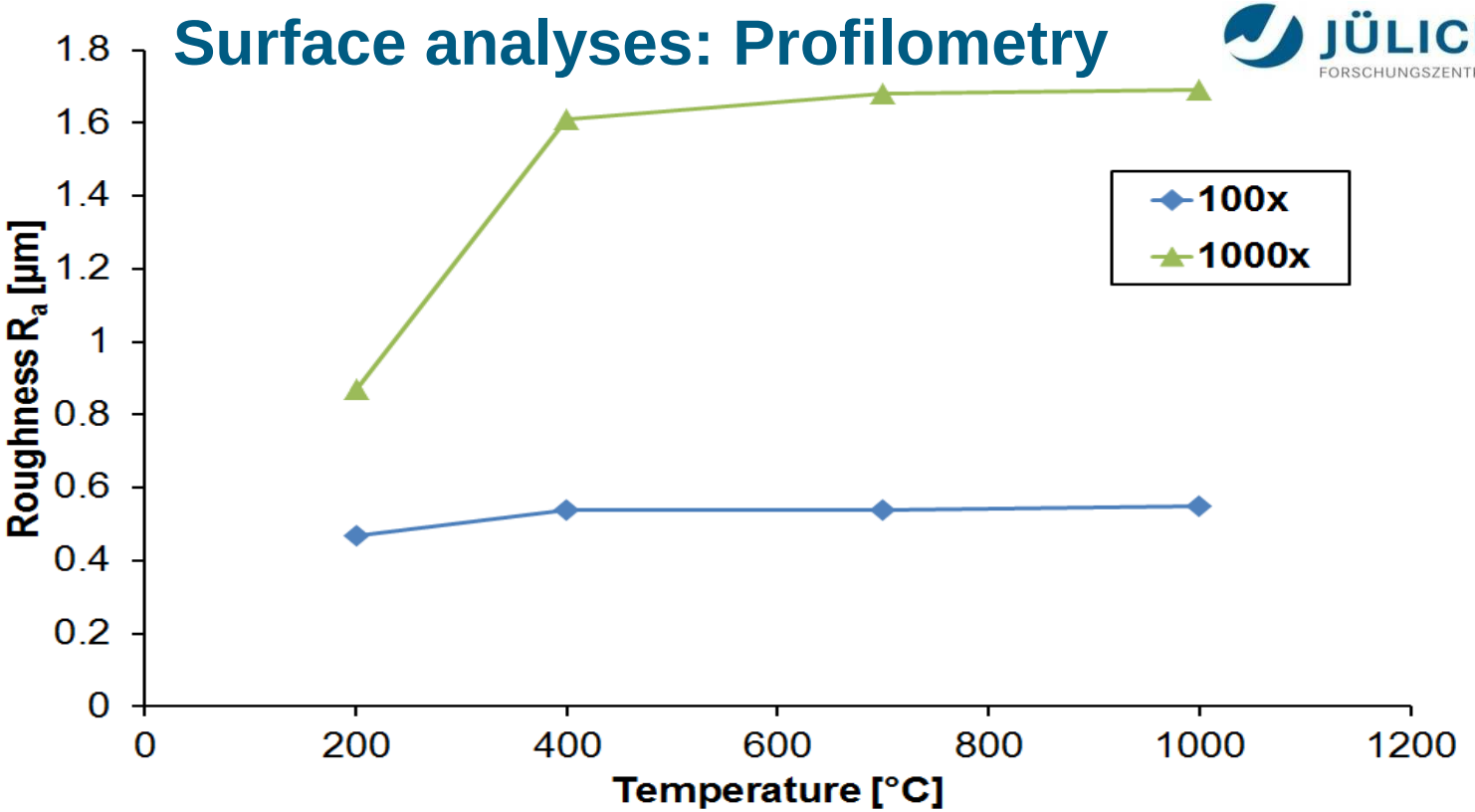

Why high performance Tungsten components by MIM


Characterisation of MIM Tungsten metal


"2K" Demo component

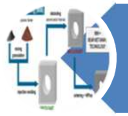

Conclusions

Surface analyses: Profilometry

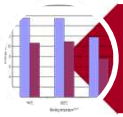


High Heat Flux (HHF) test results

W-1vol.%Y_2O_3: P_{abs} = 0.38 GW/m^2, t = 1 ms, n = 1000, T = 1000 °C

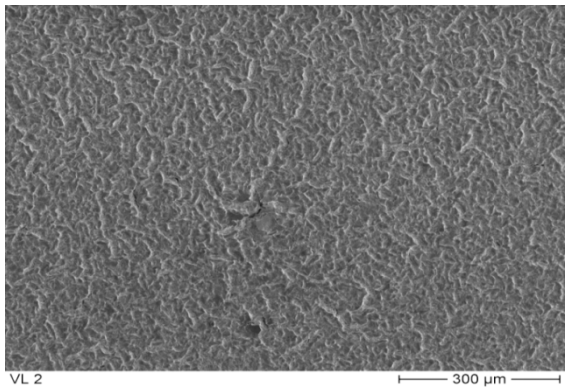

MIM: the process

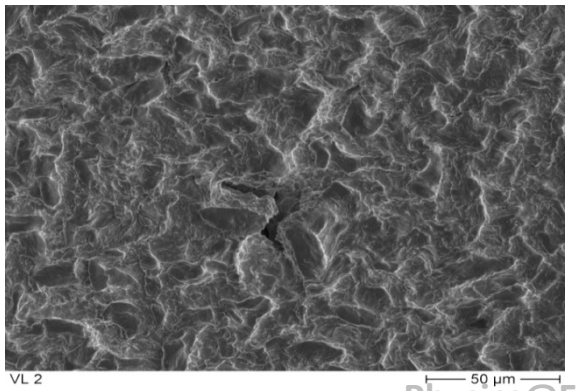

Why high performance Tungsten components by MIM

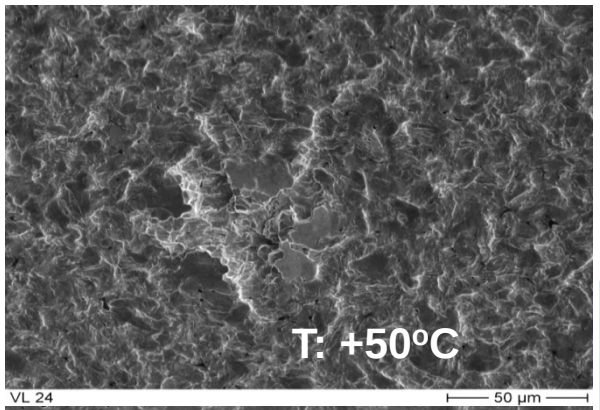

Characterisation of MIM Tungsten metal

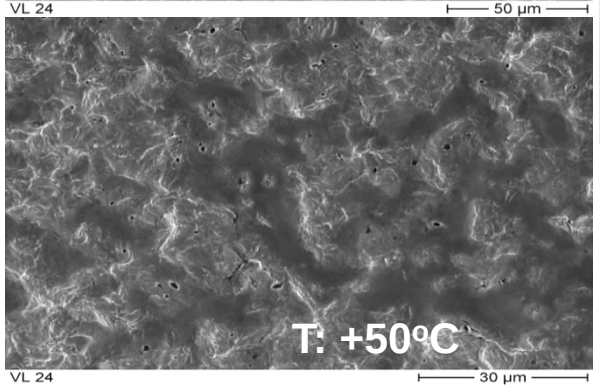

"2K" Demo component


Conclusions









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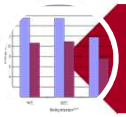
Surface analyses : SEM

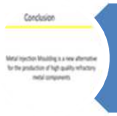
High Heat Flux (HHF) test results


MIM: the process


Why high performance Tungsten components by MIM


Characterisation of MIM Tungsten metal


"2K" Demo component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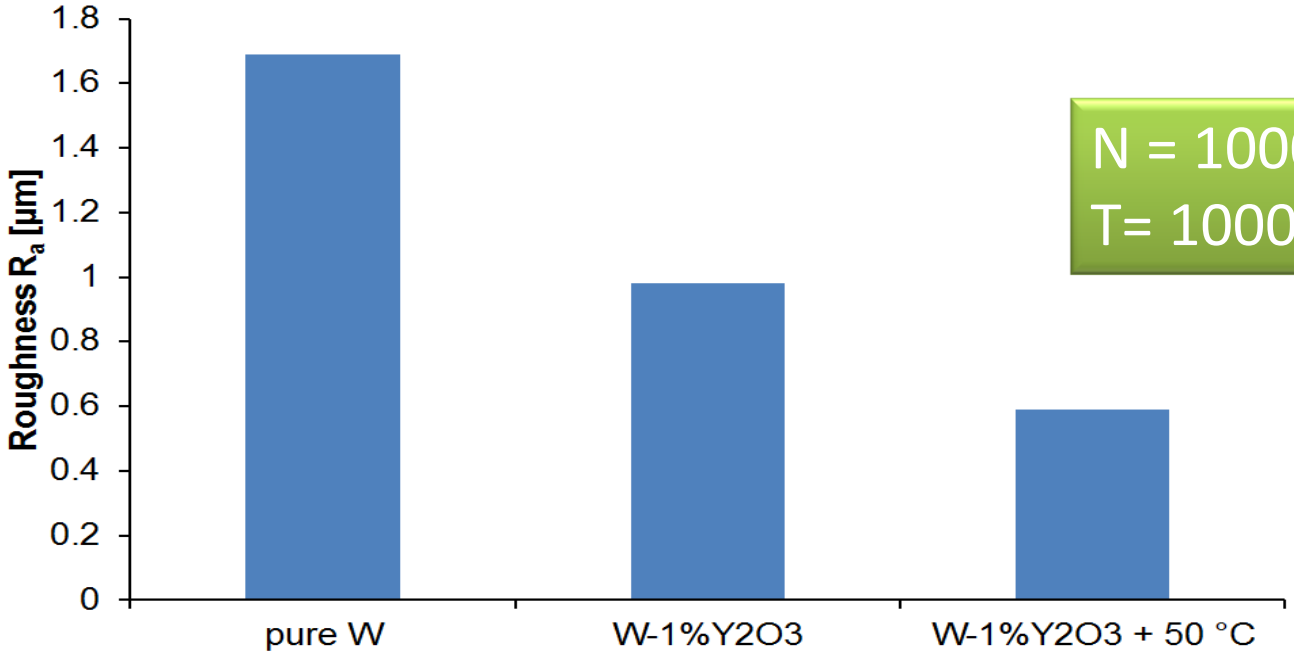
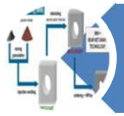


N = 1000
T= 1000 °C

2-component MIM mock-ups production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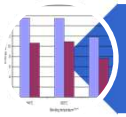
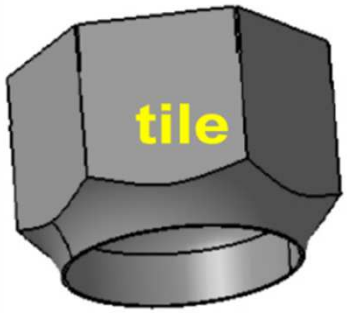

Characterisation of MIM Tungsten metal


"2K" Demo component

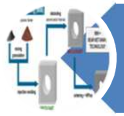

Conclusions



+

= one part

2-component MIM mock-up production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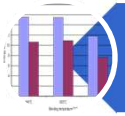
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"2K" Demo component

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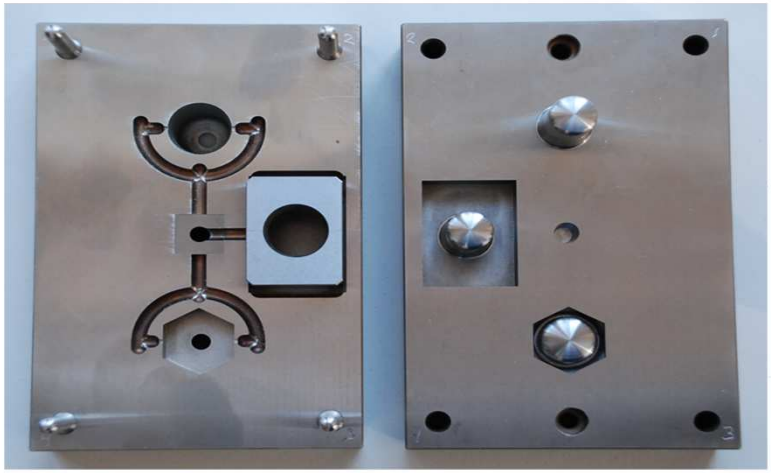

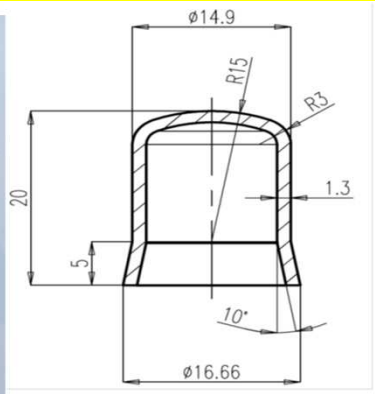

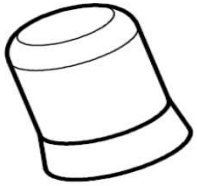

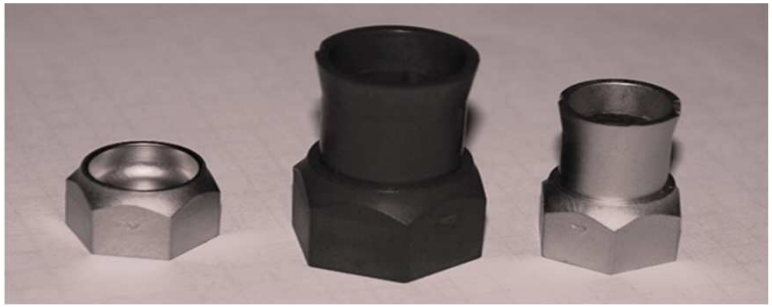

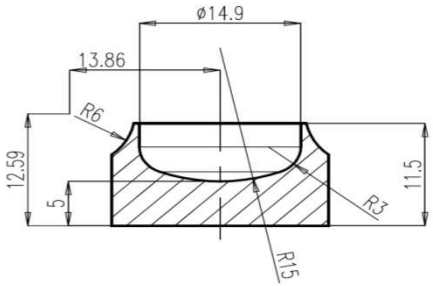

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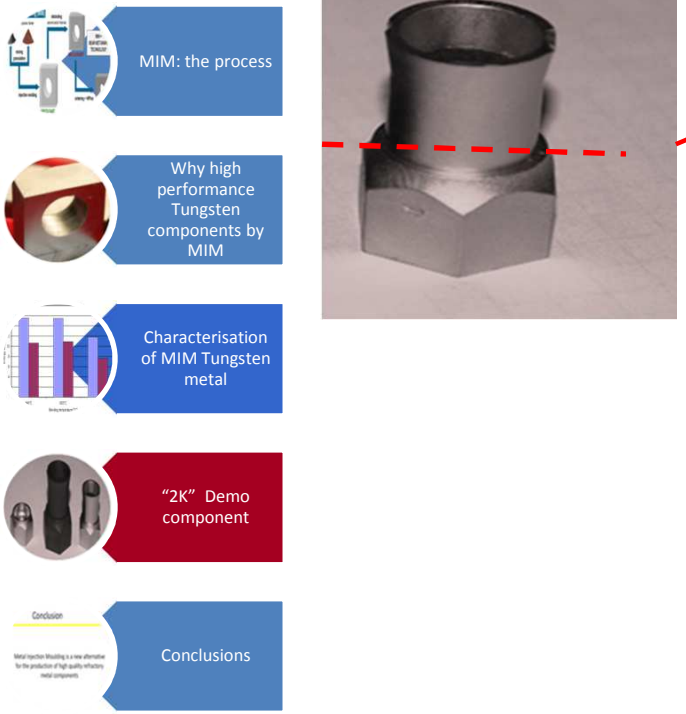
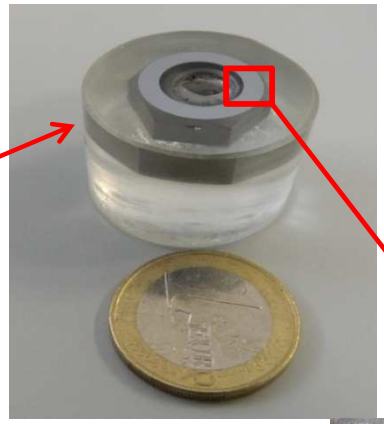
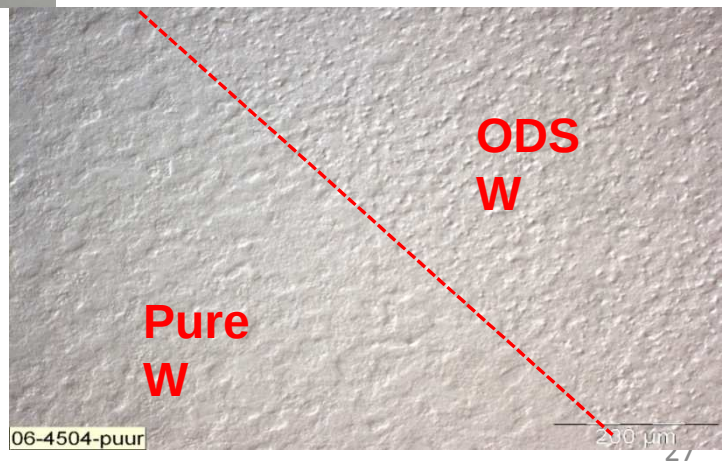
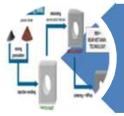
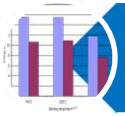


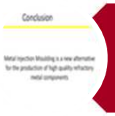




Conclusion







- MIM technology is capable to produce clean isotropic net-shape components with good material properties
- Yttria doped (ODS) MIM Tungsten shows best behaviour as potential armour material
- Metal Injection Moulding is an alternative for the production of high quality refractory metal components

Thanks for your attention

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