ADVANCED STEELS FOR WATER COOLED APPLICATIONS

EFPW 2015, SLOVENIA

KARLSRUHE INSTITUTE OF TECHNOLOGY – Campus Nord, INSTITUTE FOR APPLIED MATERIALS – Applied Material Physics (KIT, IAM-AWP)

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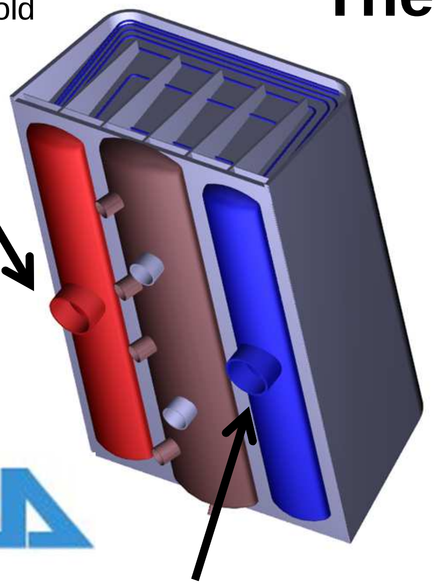
Outline

- **Problems** in **water cooled environement**
- Strategies for improvement of **EUROFER for water cooled application**
- Optimized **new 9%Cr steels**
- **Final conclusion**

Challenge

Steels for water-cooled applications in a Fusion environment

The WCLL Blanket Design



PbLi as **breeder,** neutron **multiplier** and T **carrier.**

Water at PWR conditions as coolant **(285/325 °C at 15.5 MPa)**

Irradiation up to:
Starterblanket: **20 dpa**
2nd blanket: **40-50 dpa**

- Critical temperature regime for **Irradiation hardening (T< 350°C)**
- Need for a combination of **maximum toughness** with **acceptable strength**

P. A. Di Maio et al., "Optimization of the breeder zone cooling tubes of the DEMO water-Cooled Lithium Lead breeding blanket", **P1.038**

Strategies

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Hypothesis: The irradiation shift in DBTT remains unaffacted

A very low DBTT (compared to standard EUROFER) could lead to an **acceptable loss of ductilty**

Can we achieve **improvements with EUROFER** by changing **thermal treatment** to meet our requirements?

What are the limits in **DBTT/Ductility** that can be reached with EUROFER?

EUROFER Optimization

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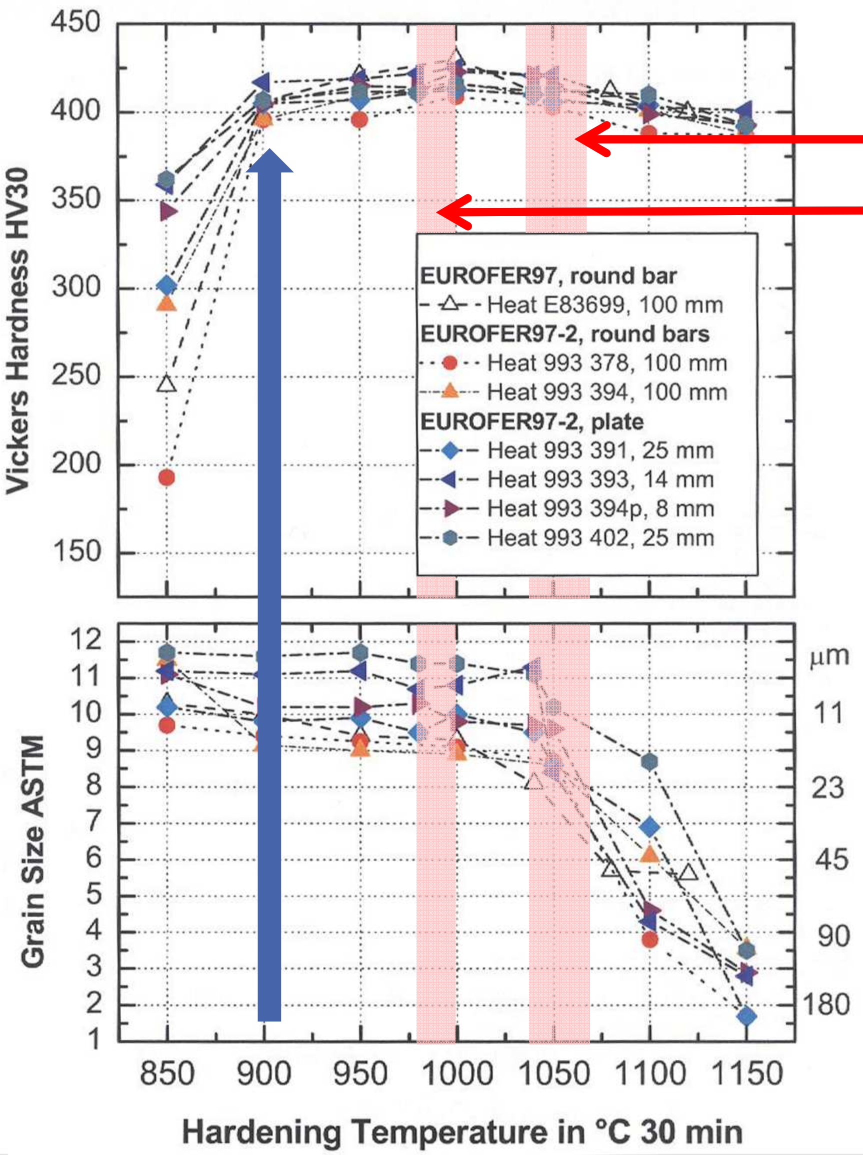


Conventional austenitization:

→ 1040°C / 30 min

→ 980°C / 30 min

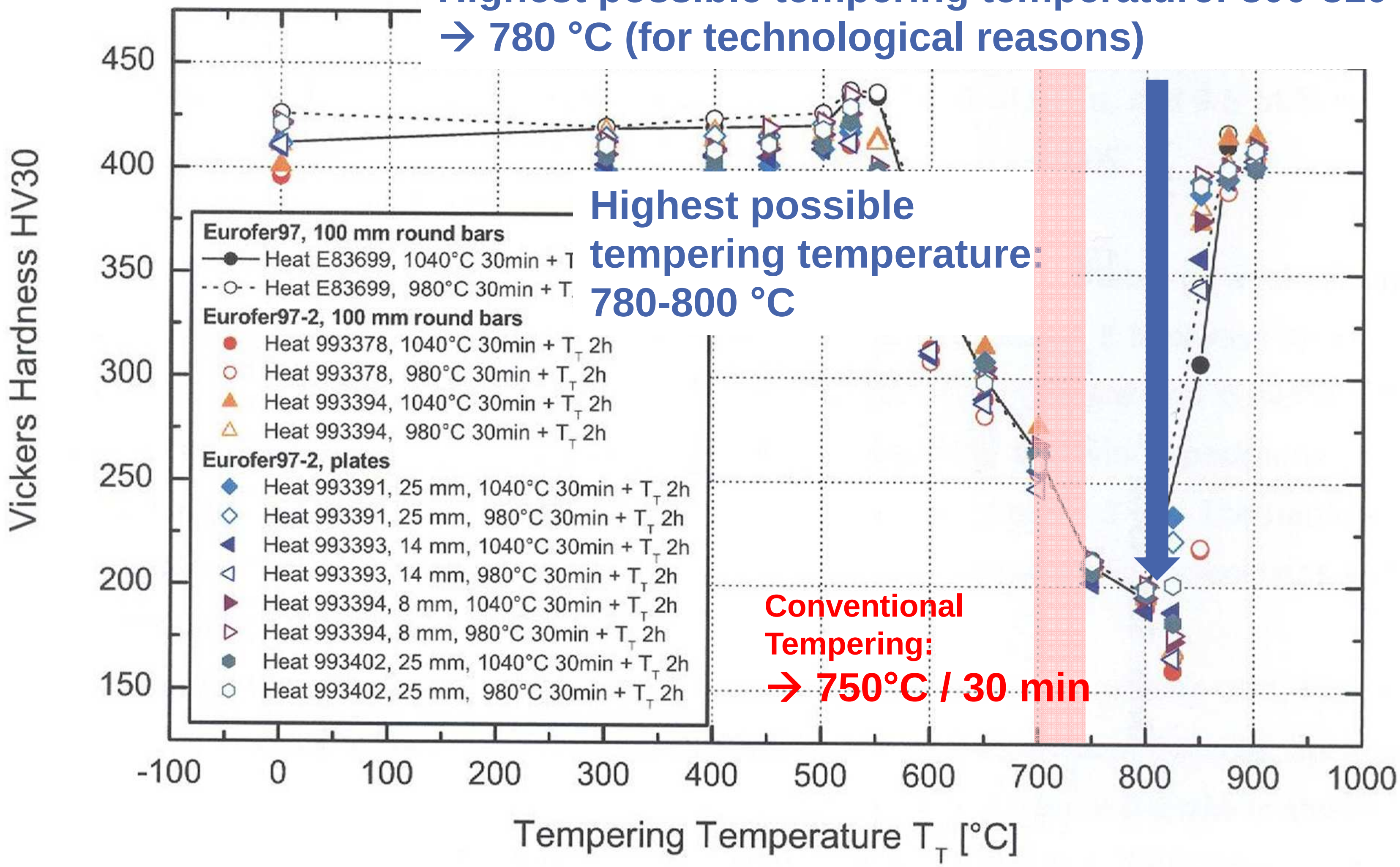
Lowest possible annealing temperature: 900 °C

Experiments at
→ 900-920-940 °C

E. Materna-Morris et al.: Final Report on the EFDA Task TW4-TTMS-005-D2

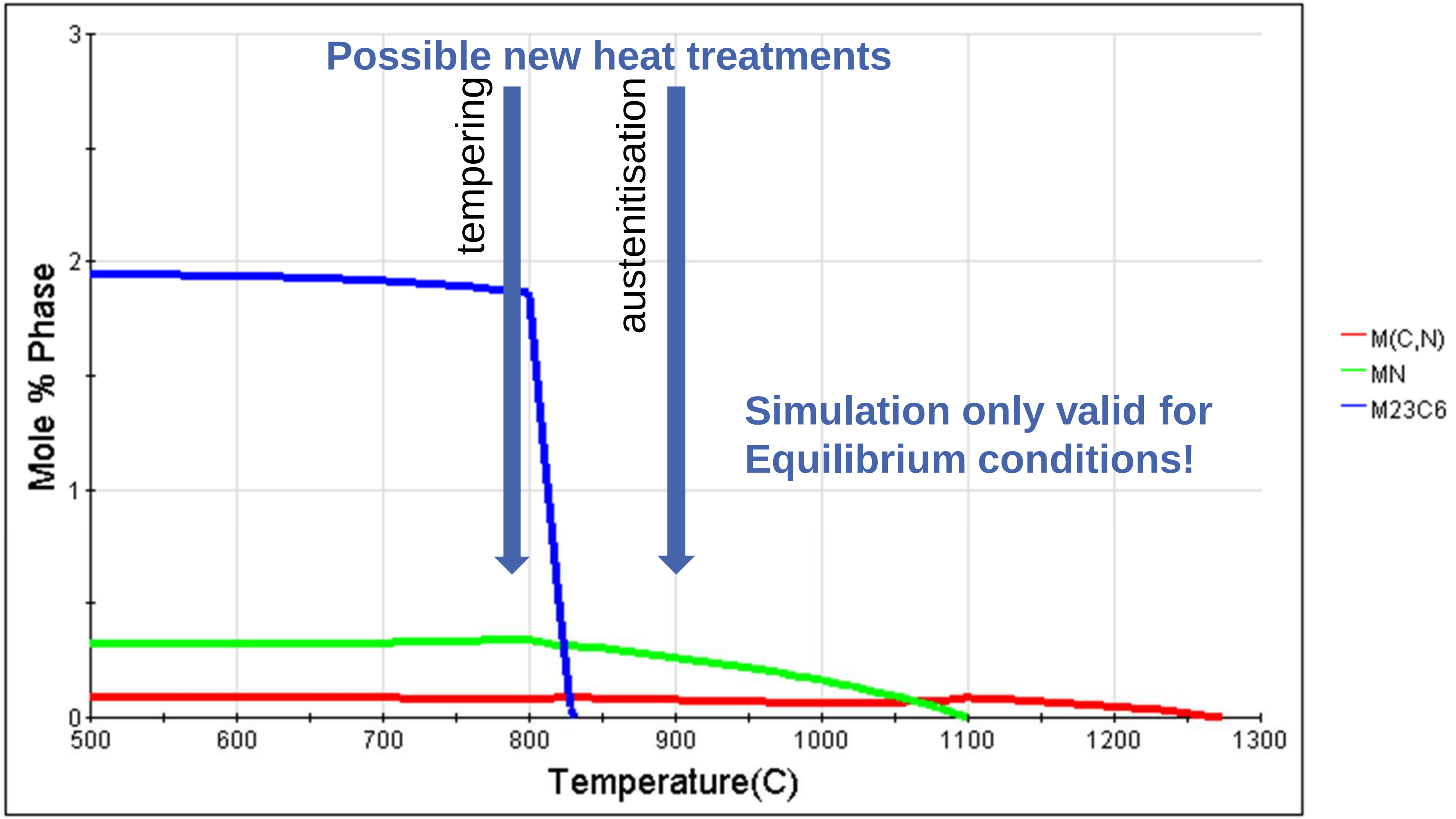
EUROFER Optimization

Highest possible tempering temperature: 800-810 °C
→ 780 °C (for technological reasons)



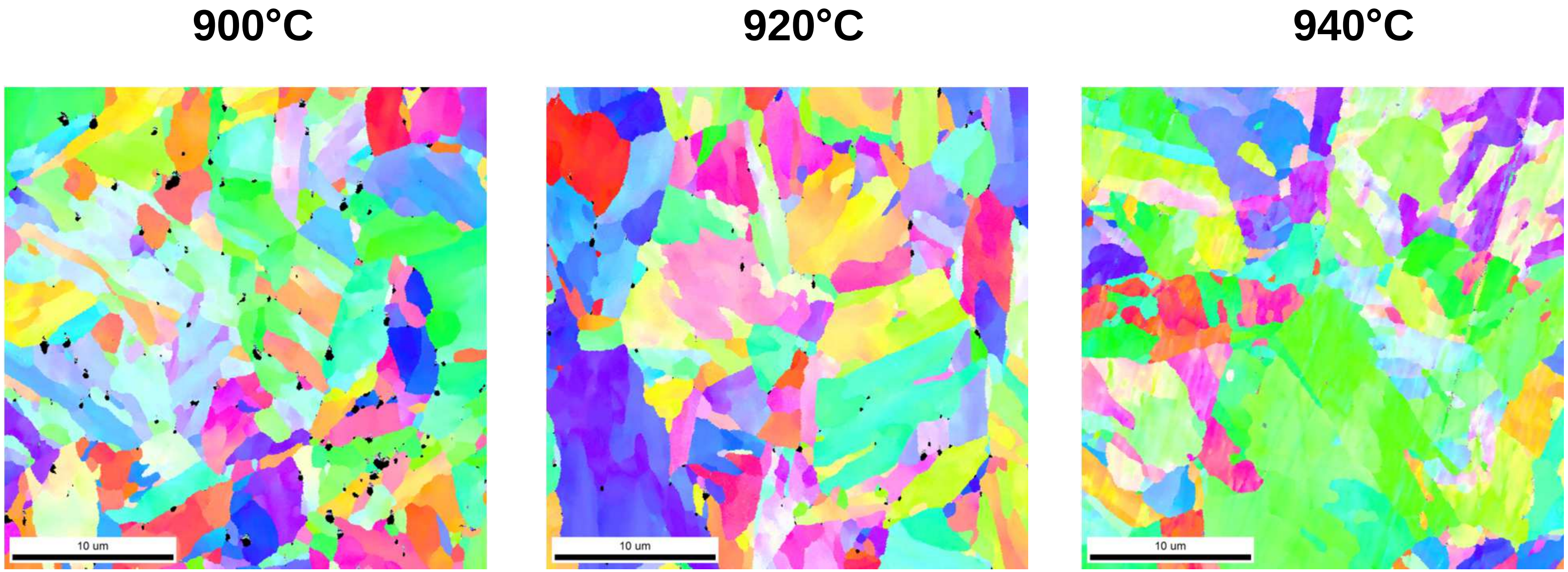
EUROFER Optimization

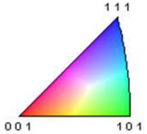
Fe-8.89Cr-0.53Mn-0.148Ta-0.18V-1.059W-0.096C-0.037N wt(%)



EUROFER Optimization

Microstructure characterized by
Electron Backscatter Diffraction (EBSD)

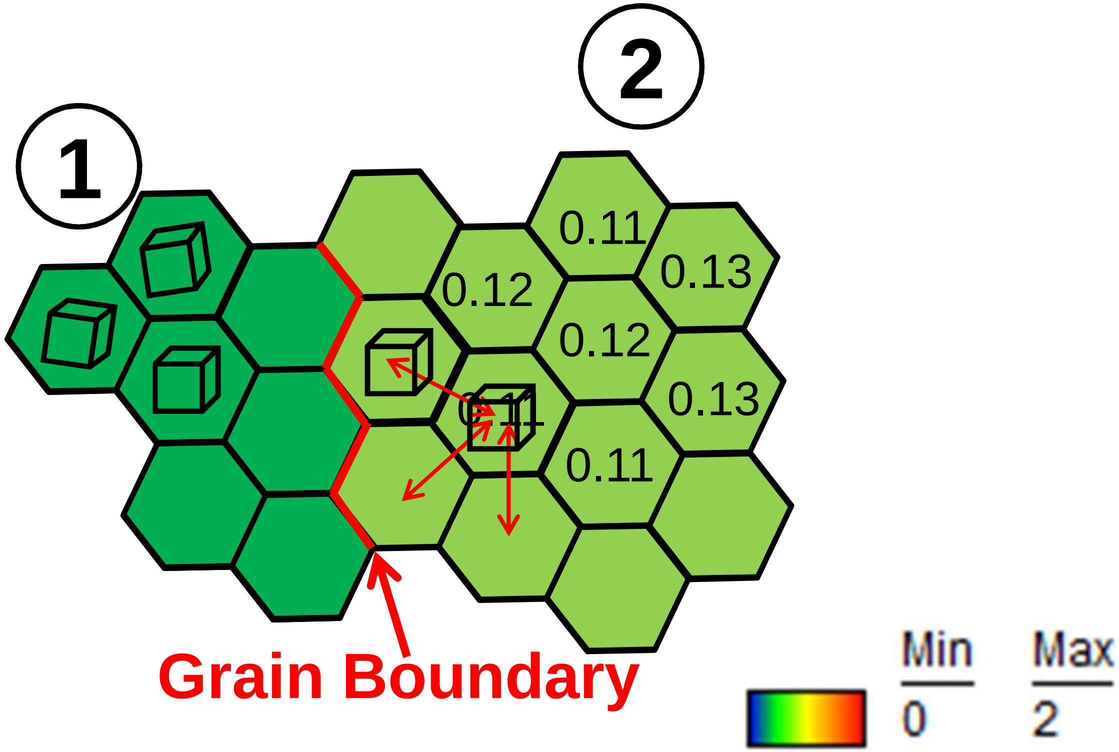




Invers Pole Figure Maps (after little cleanup)
$M_{23}C_6$ carbides visible as black (unindexed) spots

EUROFER Optimization

Microstructure characterized by
Electron Backscatter Diffraction (EBSD)

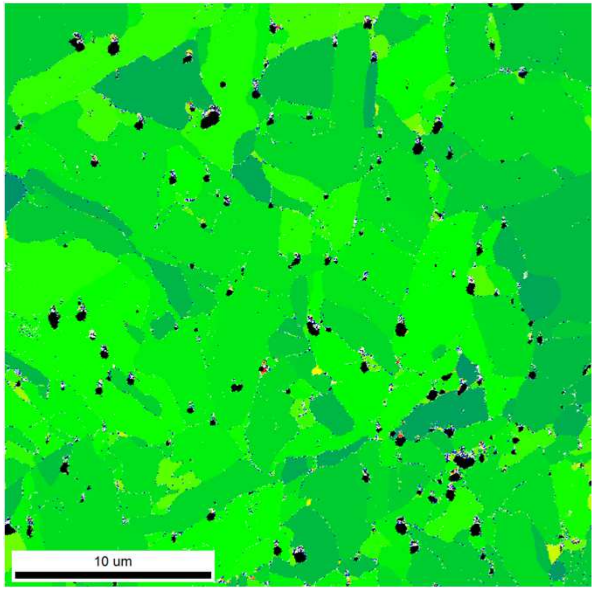


Grain average misorientation Map

EUROFER Optimization

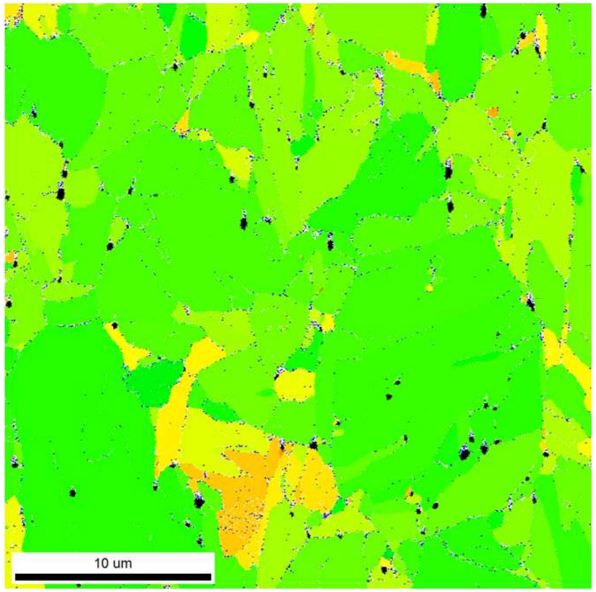
Microstructure characterized by
Electron Backscatter Diffraction (EBSD)

900°C



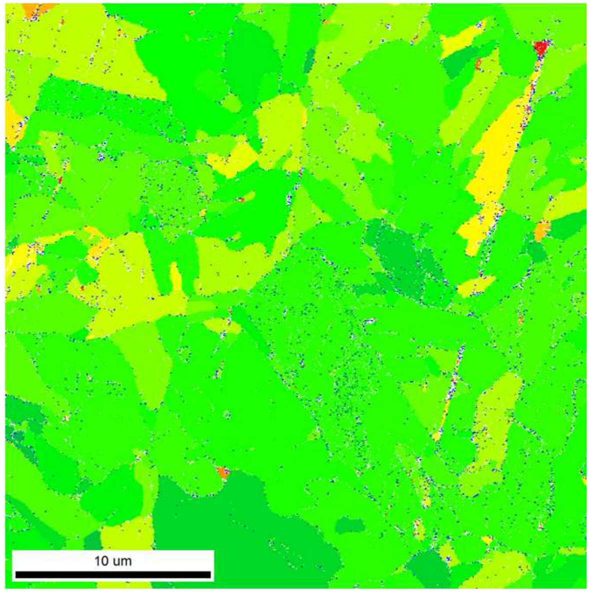
0,39°

920°C

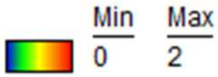


0,34°

940°C



0,37°



Grain average misorientation Maps
Showing the state of the microstructure (recovered)

Influence on Microstructure

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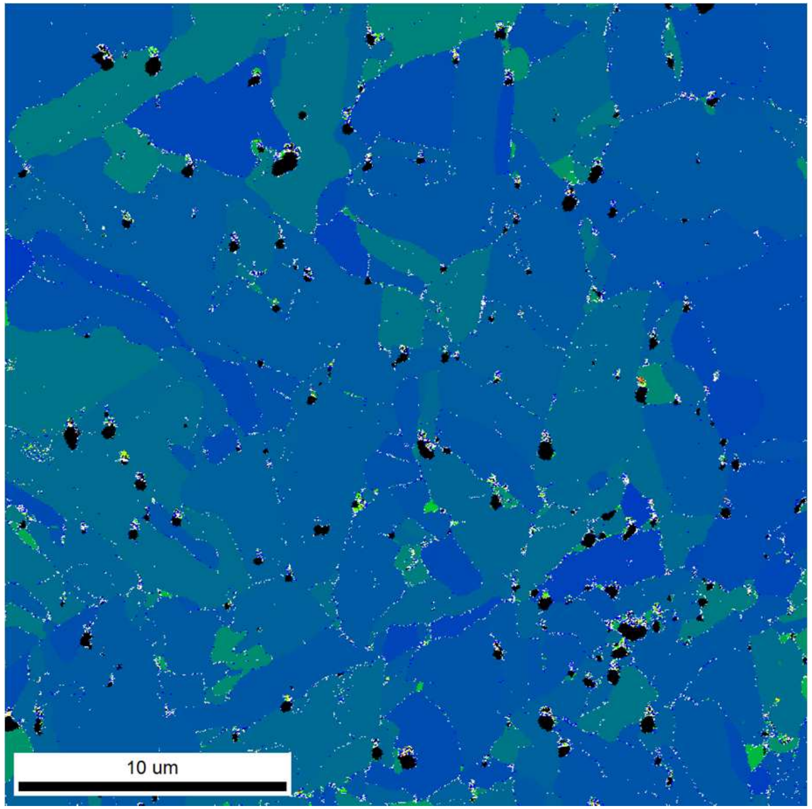
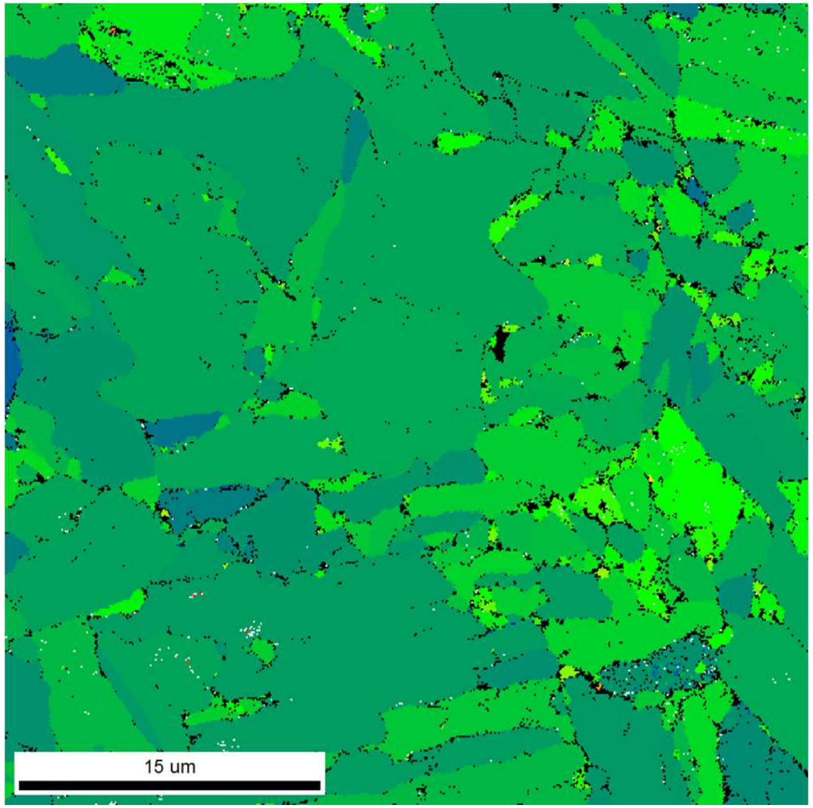
900°C



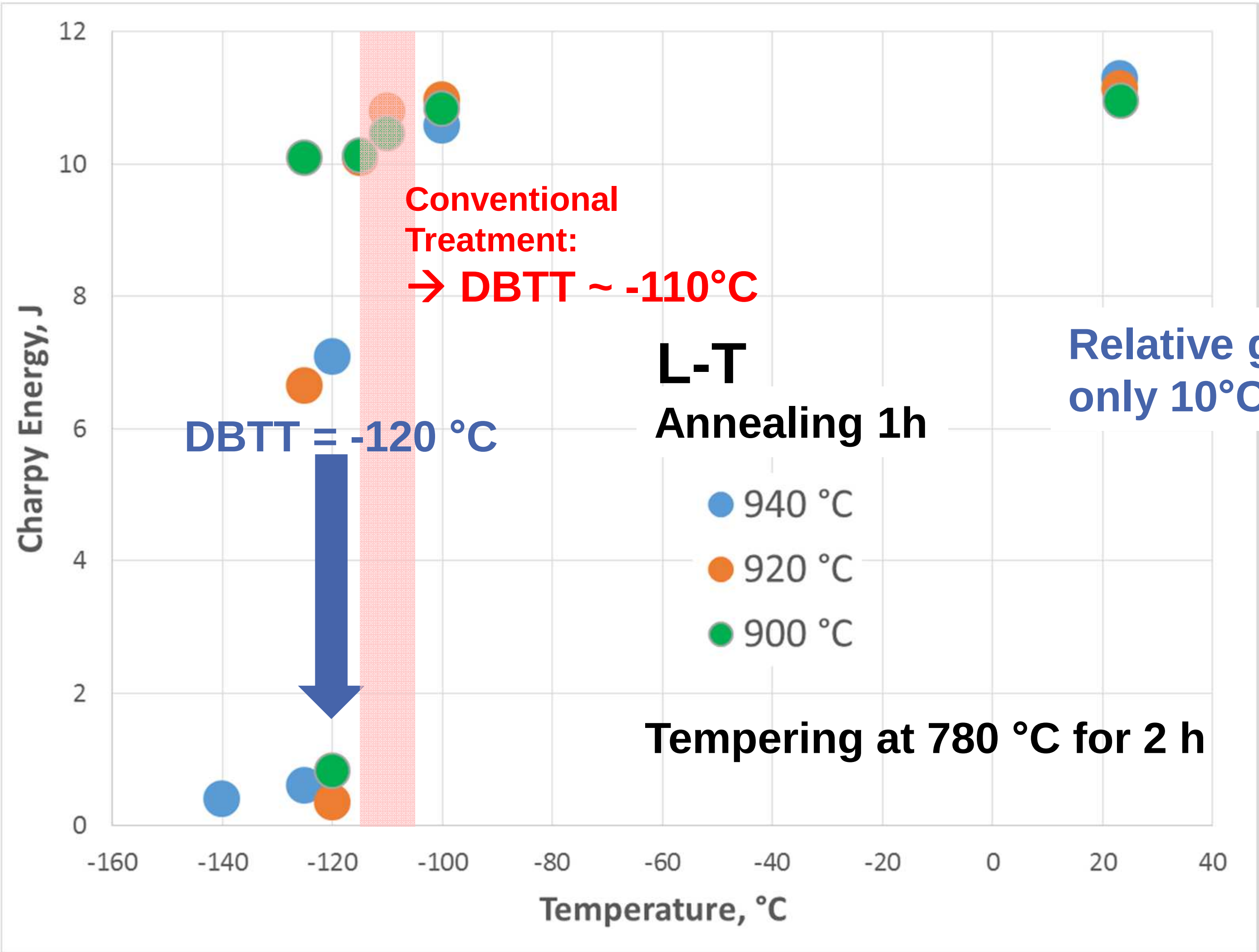
Conventional



Minor changes between microstructure

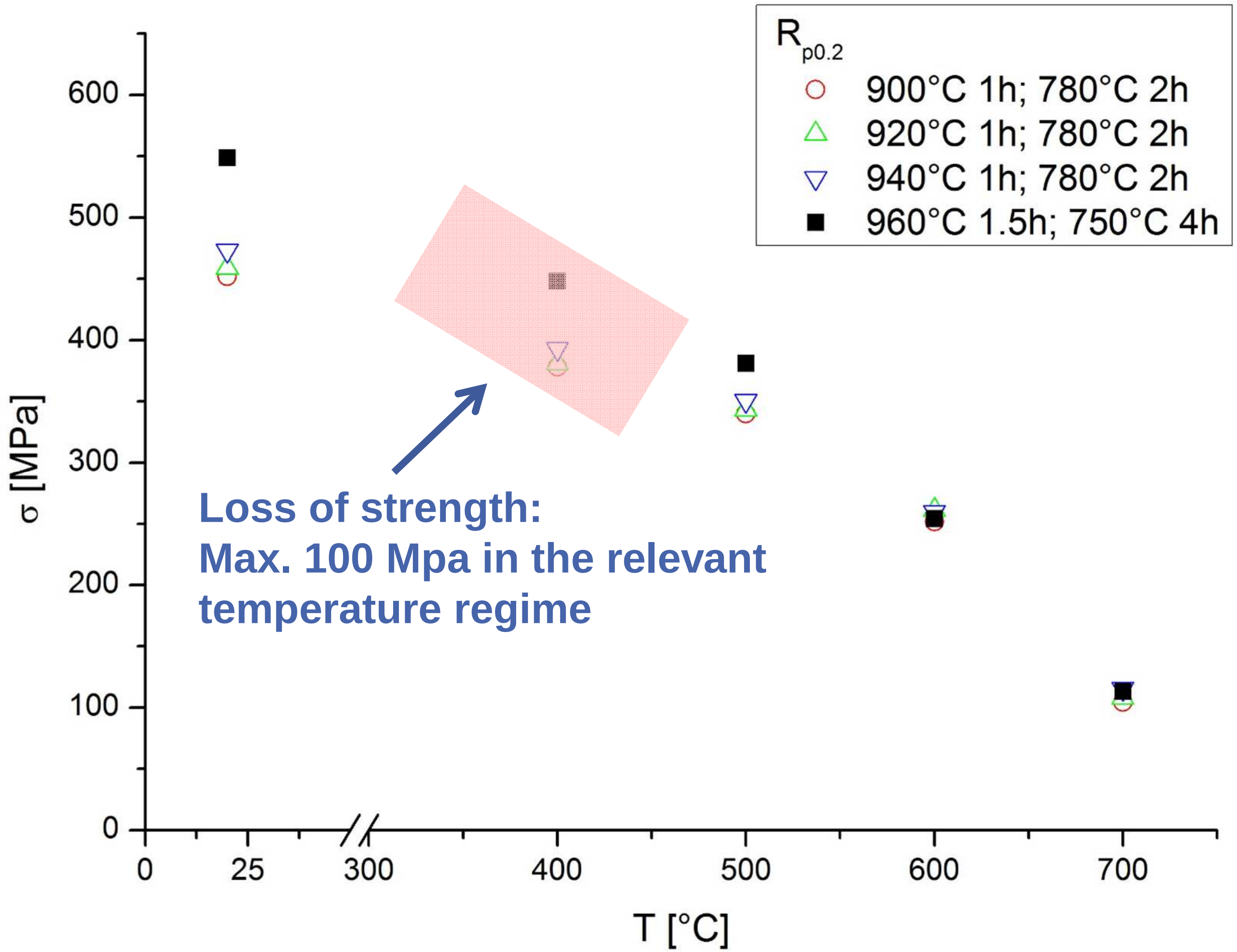
Additional recovery after 900°C tempering

Influence on Mechanical Properties



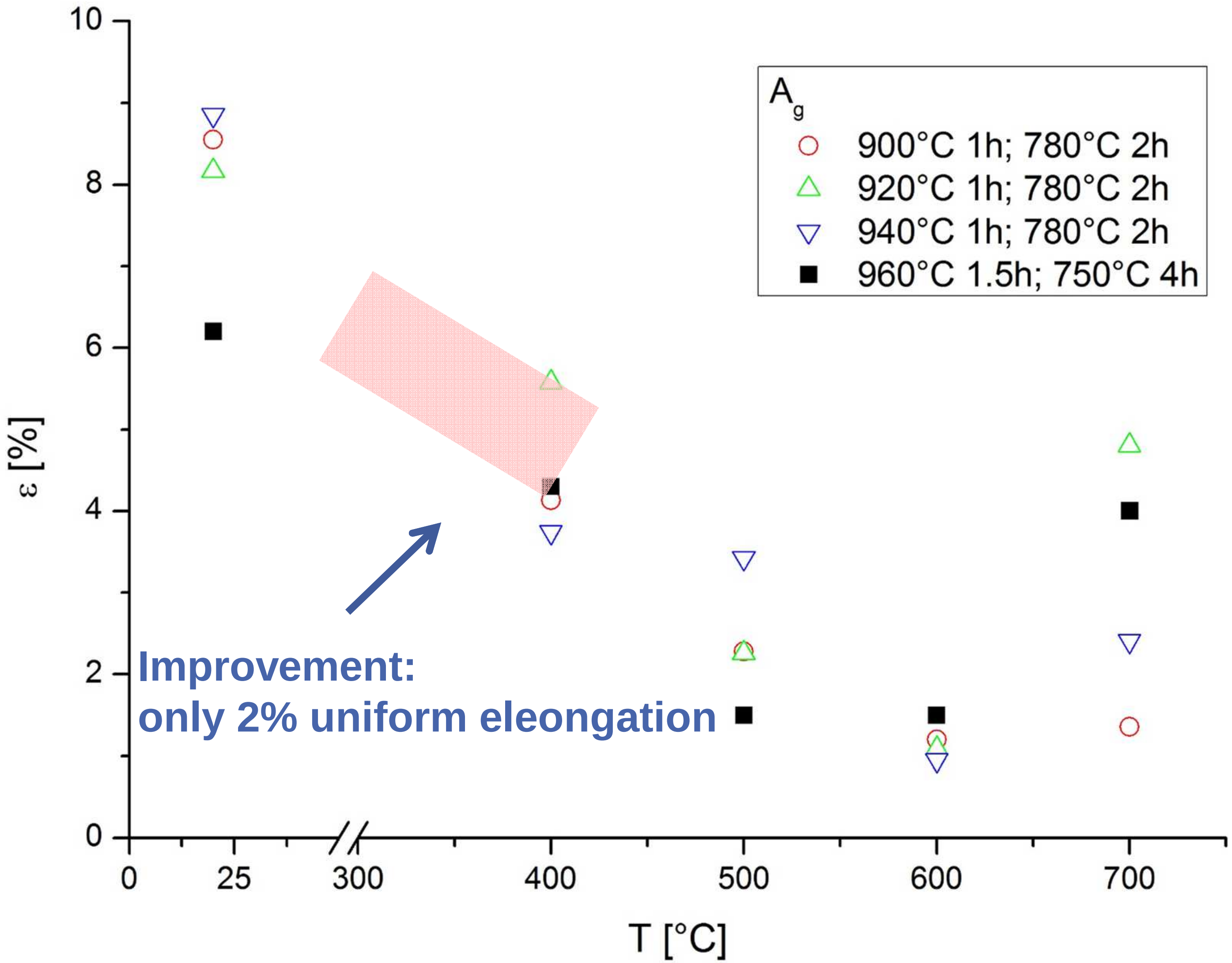
Relative gain in ΔDBTT: only 10°C!

Yield Strength



Loss of strength:
Max. 100 Mpa in the relevant temperature regime

Uniform Elongation



Optimization of EUROFER

Performing extreme heat treatments, i.e. lowest possible austenitisation and highest possible (conservatively reasonable) tempering temperature on EUROFER-2 (993402) leads to:

- **Improvement in DBTT by only -5 °C** (-120 °C absolute)
- **Loss of LT yield strength** by 100 MPa (RT – 400 °C)
- An improvement in LT ductility **by +2 % (uniform elongation at RT – 400 °C)**
- The differences compared to the state as delivered are due to a **slightly refined martensitic lath/package formation** and to softening due to the **higher tempering treatment** (stress relief by C diffusion)

Need for special Optimized 9%Cr steels!

New strategies

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Optimized 9%Cr steels

Lower **CARBON** content	→	Decrease amount of (coarse) **$M_{23}C_6$ carbides**
Higher **VANADIUM** content	→	Increase number of (fine) **MX precipitates**
No **TUNGSTEN**	→	Decrease solid solution strengthening

Strategies

Simplified base alloy for comparison

		Cr	W	V	Ta	N	C
1	EUROFER-						
	J361	9	1				0,1
2	EUROFER-LV						
				0,35	0,1	0,04	0,06
3	EUROFER-V						
	J363				0,1	0,04	0,1
4	OPTIFER						
			1	0,35	-	0,04	0,06
5							
	J365	9	-	0,35	0,1	0,04	0,06
6	OPTIFER-vLvVTwW						
	J366	9	-	0,62	0,14	0,04	0,03

Lower carbon content

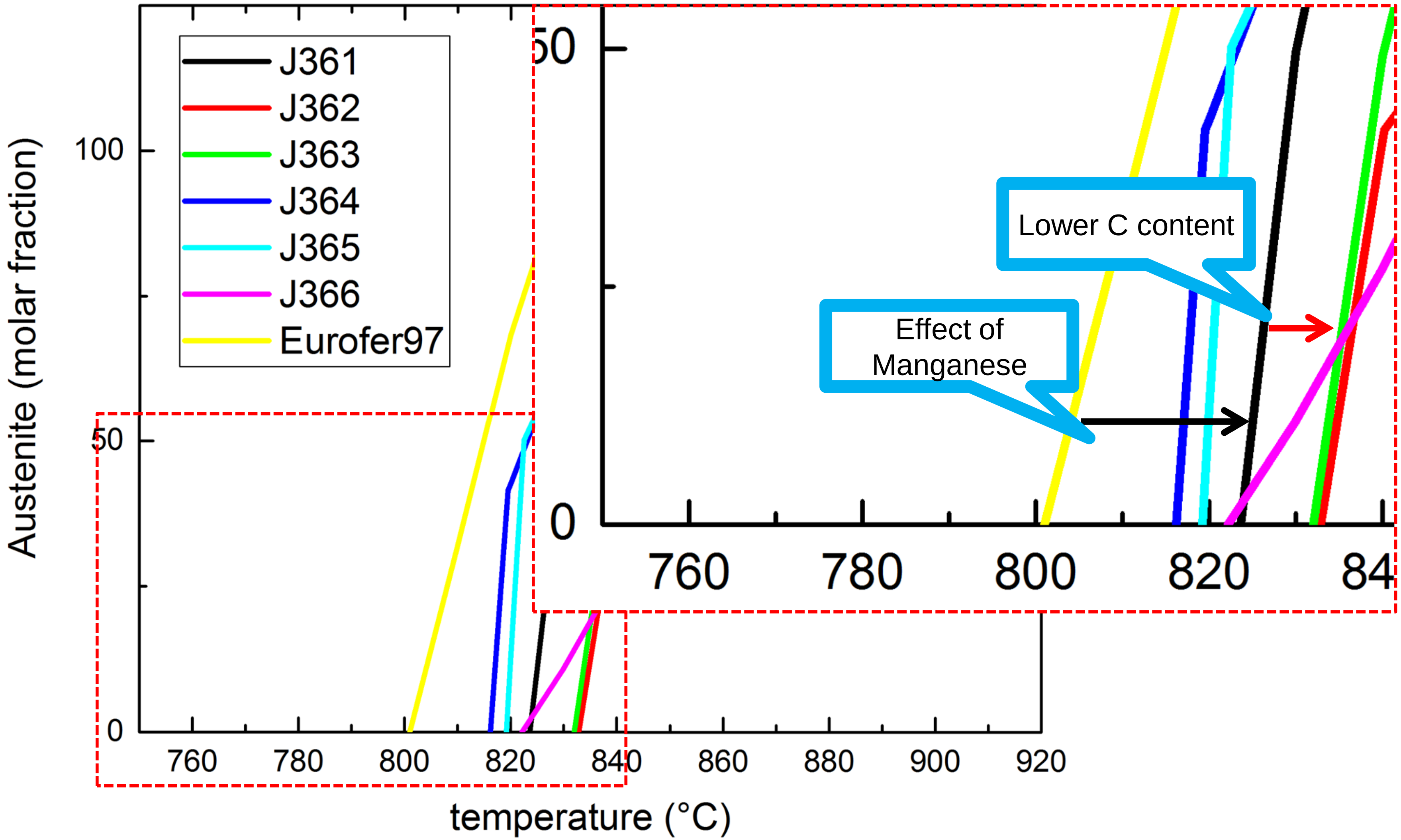
High V content (compared to 1)

No Ta (effect of tantalum)

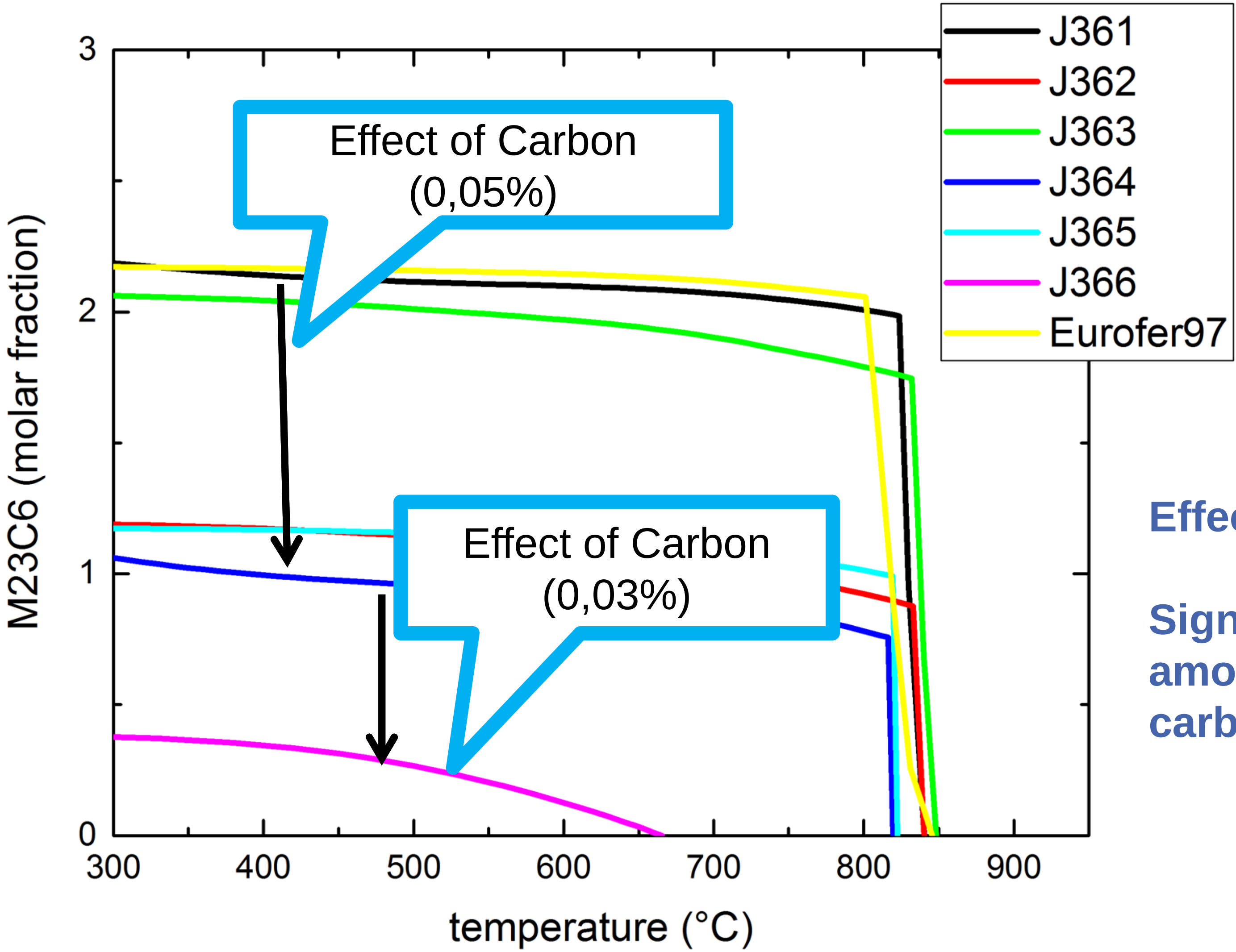
No W (effect of tungsten)

Various modifactions of alloying elements

Phase calculations (Austenite)



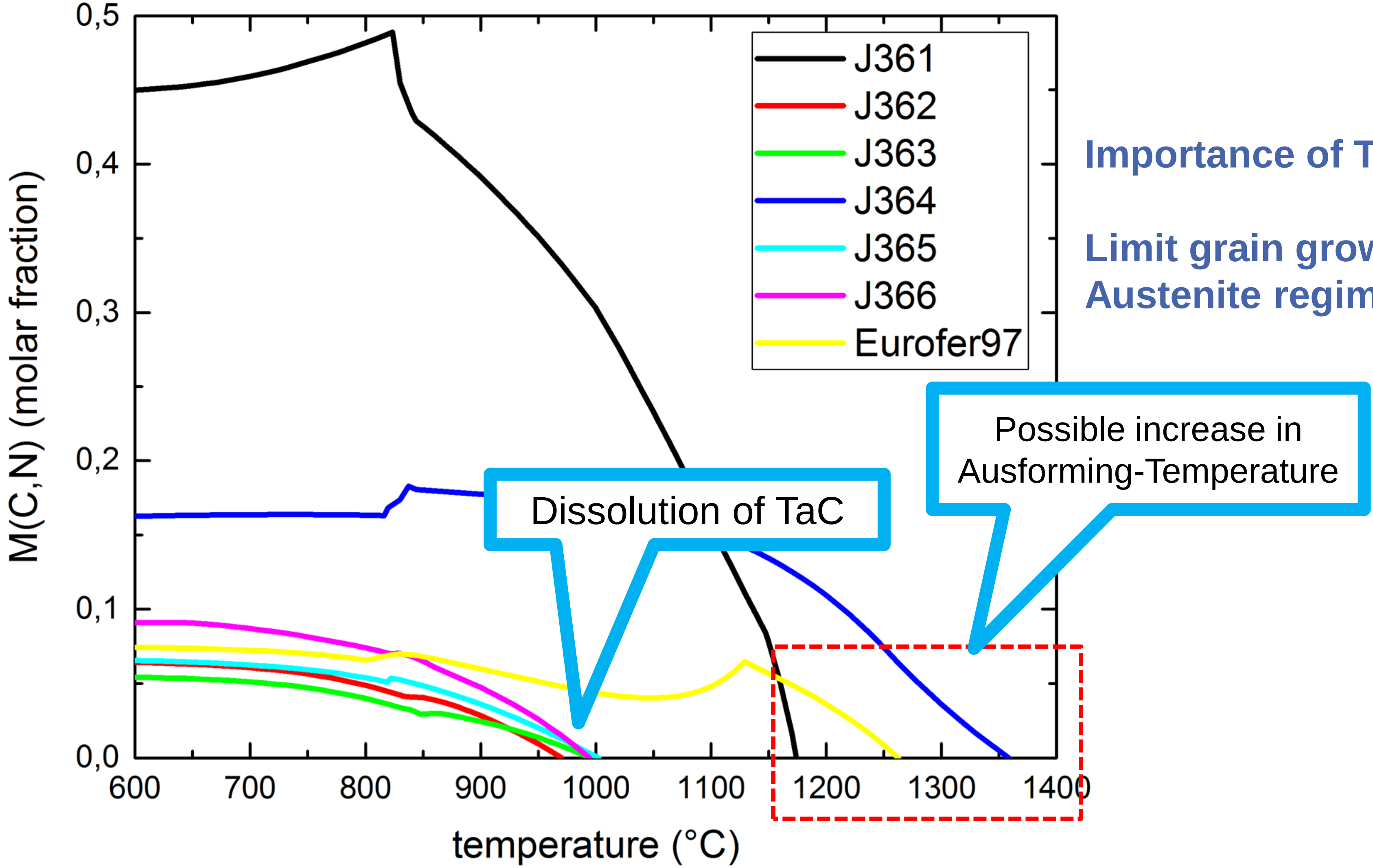
Phase calculations (M23C6)



Effect of carbon:

Significantly lower amount of $M_{23}C_6$ carbides

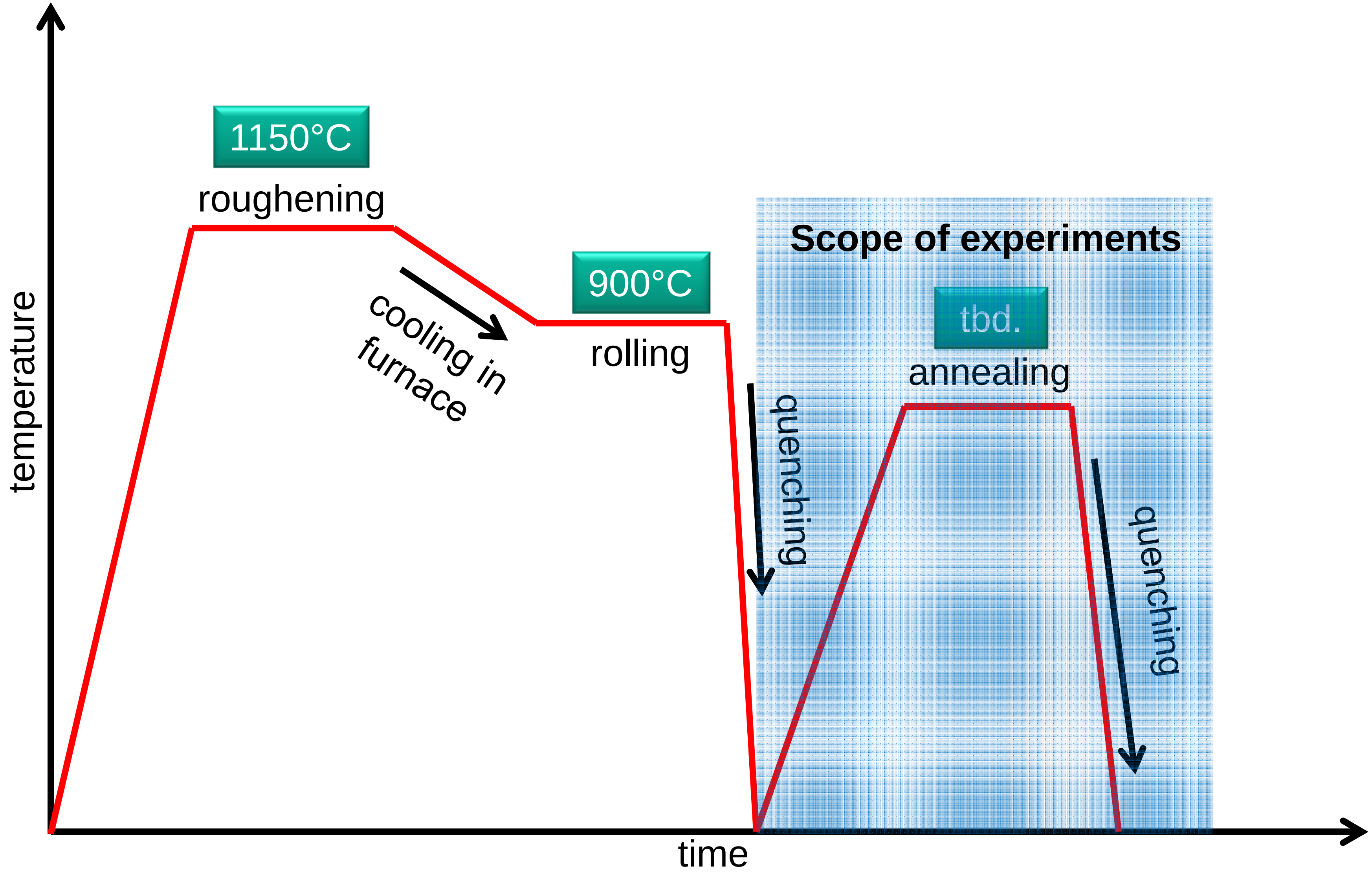
Phase calculations (M(C,N) = TaC)



Importance of TaC:

Limit grain growth in Austenite regime

Production and TMT



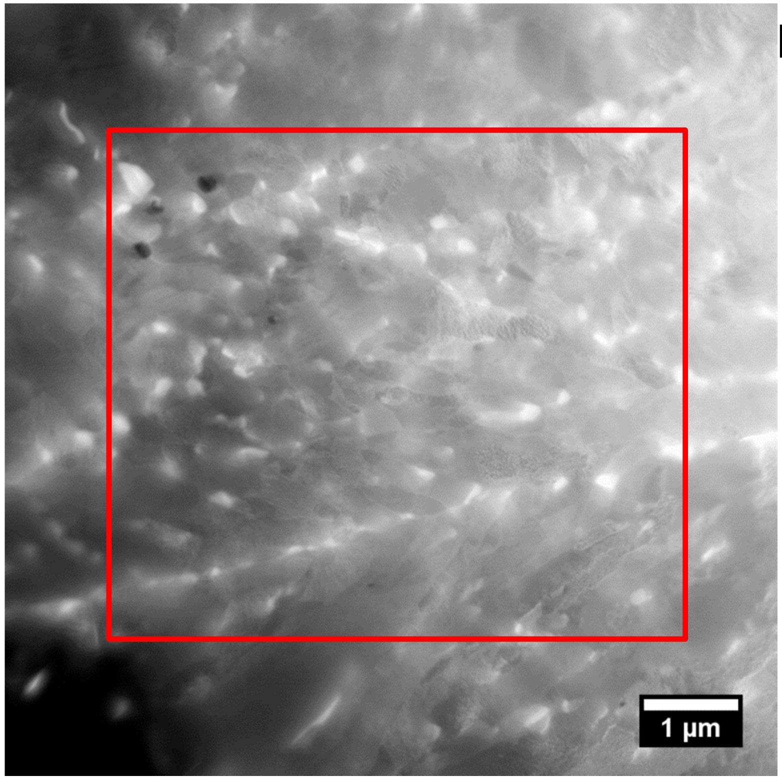
Production and TMT at OCAS

Materials in as-received state

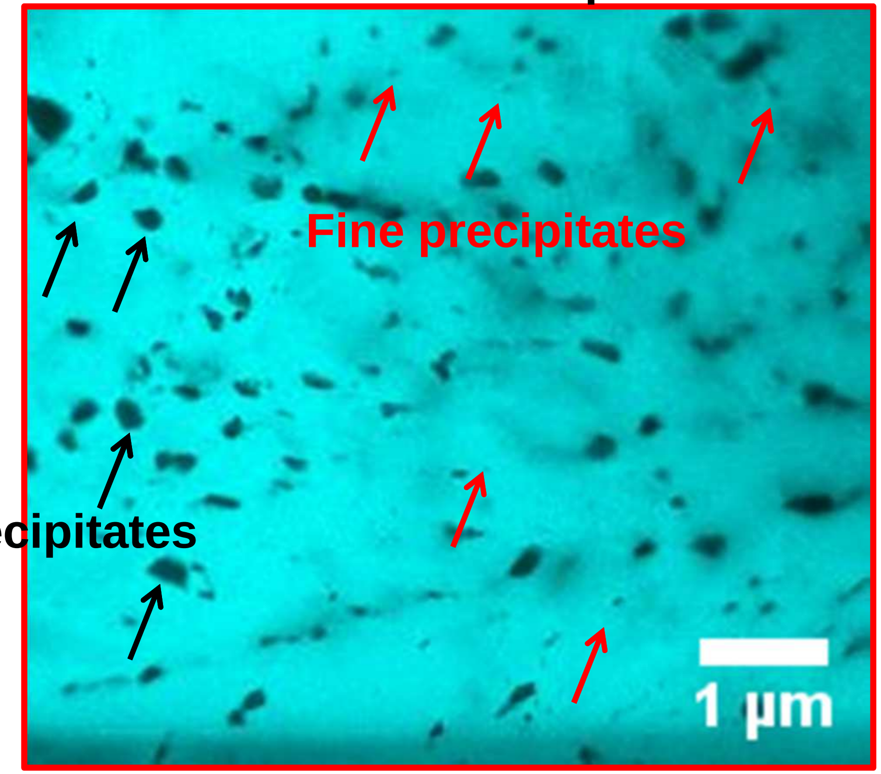
Water quenched after rolling and TMT

TEM images

HAADF STEM Image



Fe-K EDS Map

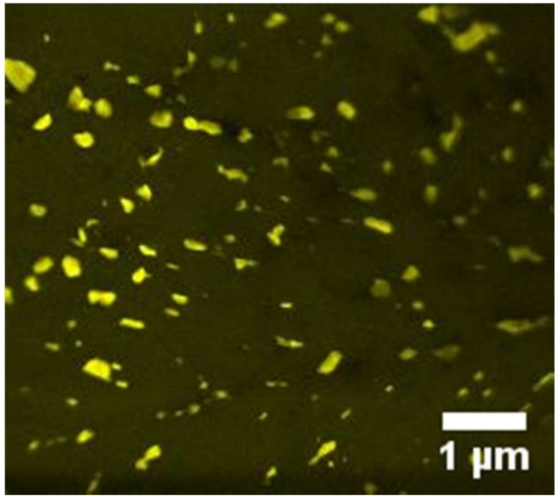


Coarse precipitates

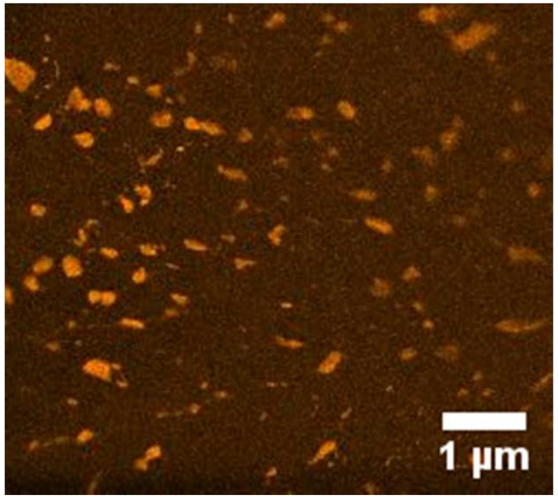
EDS Map of Fe-K reveals secondary phases in different sizes

TEM images

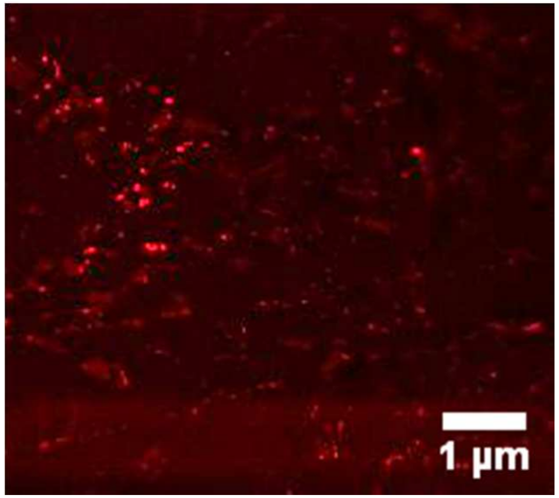
Chromium (K)



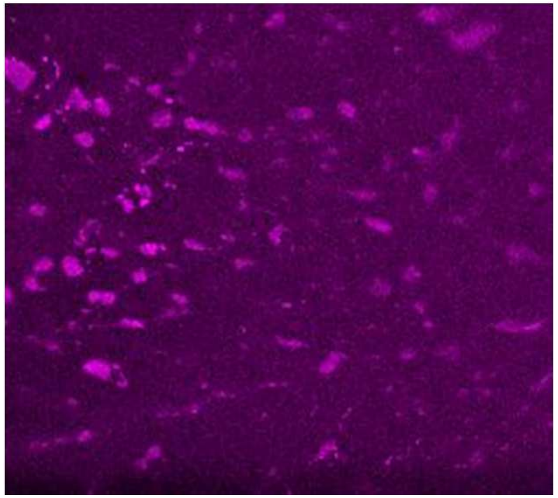
Tungsten (L)



Vanadium (K)



Tantalum (L)

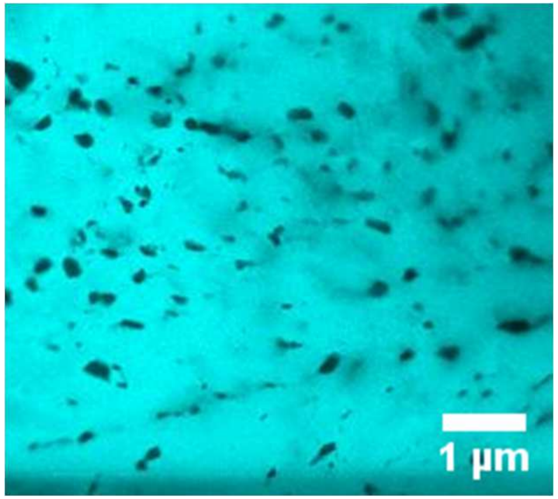


Coarse precipitates

- rich in Cr, W, Ta

M23C6 carbides

Iron (K)



Fine precipitates

- rich in V, Ta

V nitrides/carbides

Conclusions

Improvement of 9%Cr steels for water-cooled applications is **not trivial and challengeing.**

An improvement of **EUROFER-type** steels w.r.t. low temperature applications (water cooling) by thermal treatment is **NOT PROMISING**.

Specially designed **new 9%Cr steels** for LT are one of the scopes of the EUROFUSION programme and **final results / conclusions are still pending.**

THANK YOU FOR YOUR ATTENTION!