

High Entropy Alloys reinforced by TaC or HfC carbides



Patrice Berthod

**Institut Jean Lamour & Faculté des Sciences et Technologies,
Université de Lorraine, 2 allée André Guinier, 54000 NANCY, France**

Outlines

Introduction / Objectives

Results:

Elaboration

Microstructures

Oxidation behaviours

Mechanical properties

Conclusions / Outlooks

Introduction

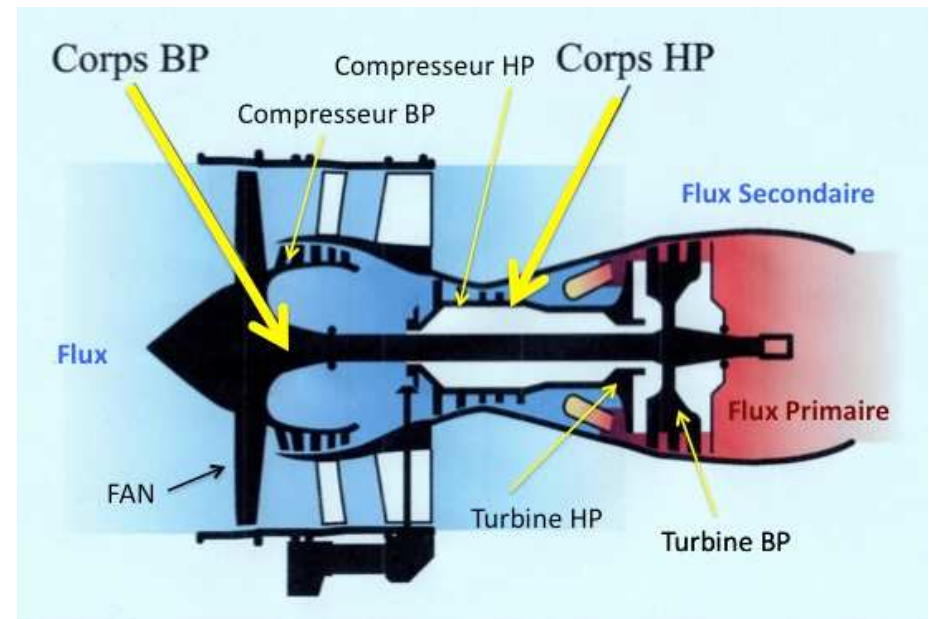


Superalloys: metallic alloys with exceptional properties for hot components:

- * for turbine disks and blades, combustion chamber...
- * to resist against severe mechanical and chemical solicitations at elevated temperature



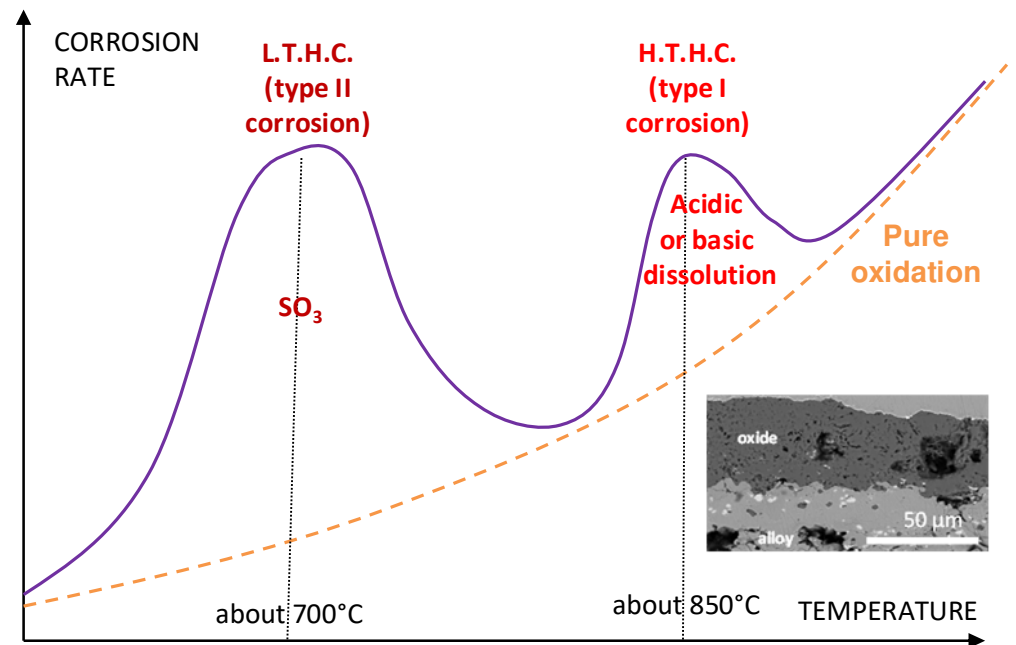
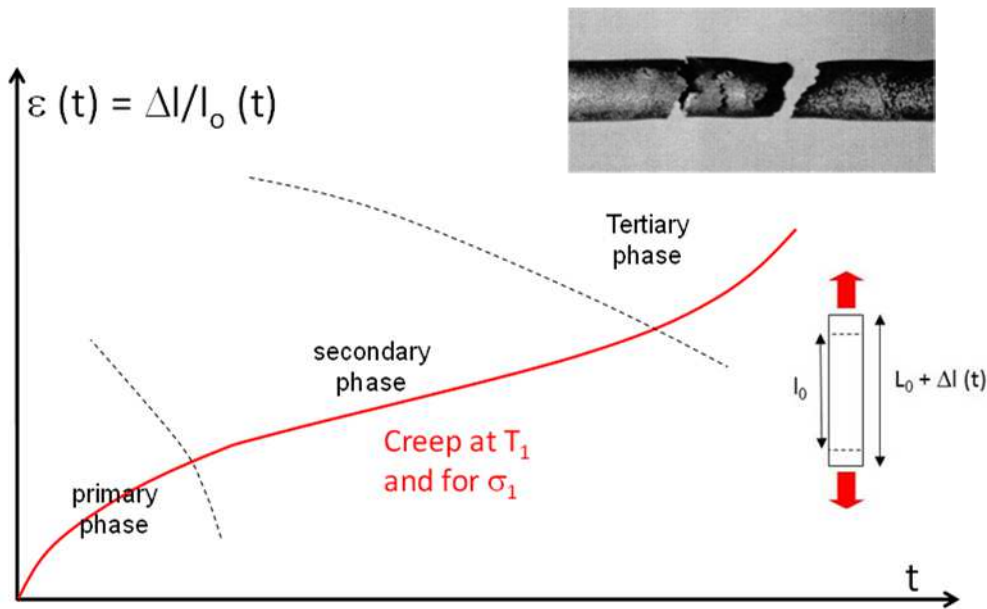
<https://www.publicdomainpictures.net/fr/view-image.php?image=23201&picture=dans-un-moteur-jet>



https://commons.wikimedia.org/wiki/File:Turbor%C3%A9acteur_DC_DF_%C3%A0_Fort_Taux_Dilution.jpg

Properties needed at high temperature ($T > 1000^\circ\text{C}$):

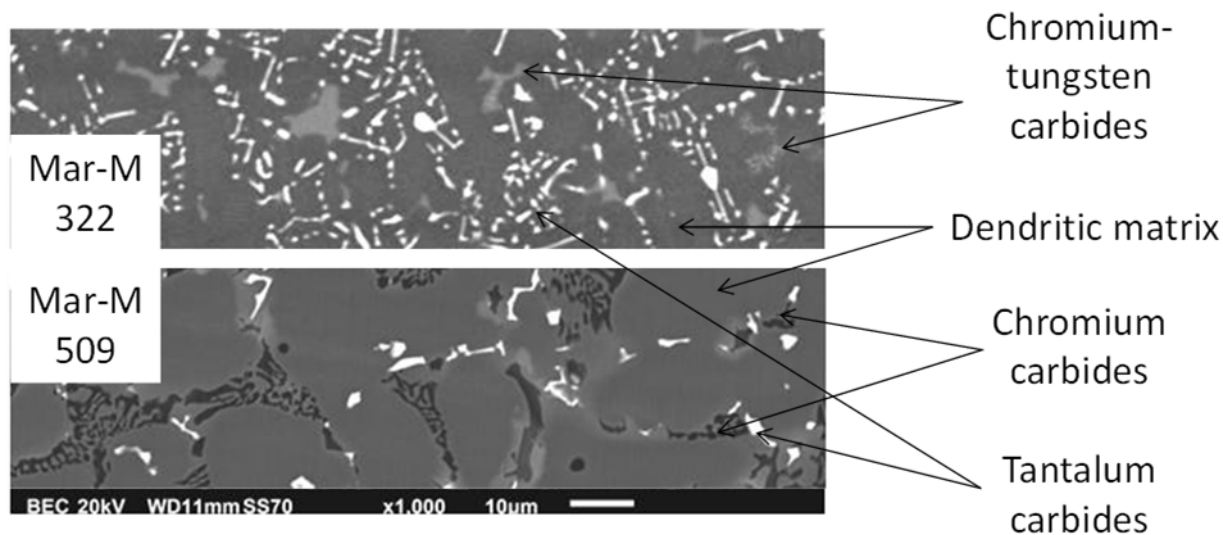
good resistances against thermal fatigue, creep... and corrosion by melts, oxidation by gases at high temperature...



Enhance the specific power and/or the energy efficiency → increase the turbine inlet temperature and the pressure ratio

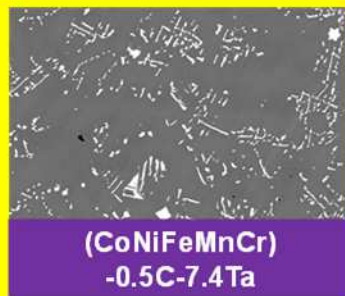
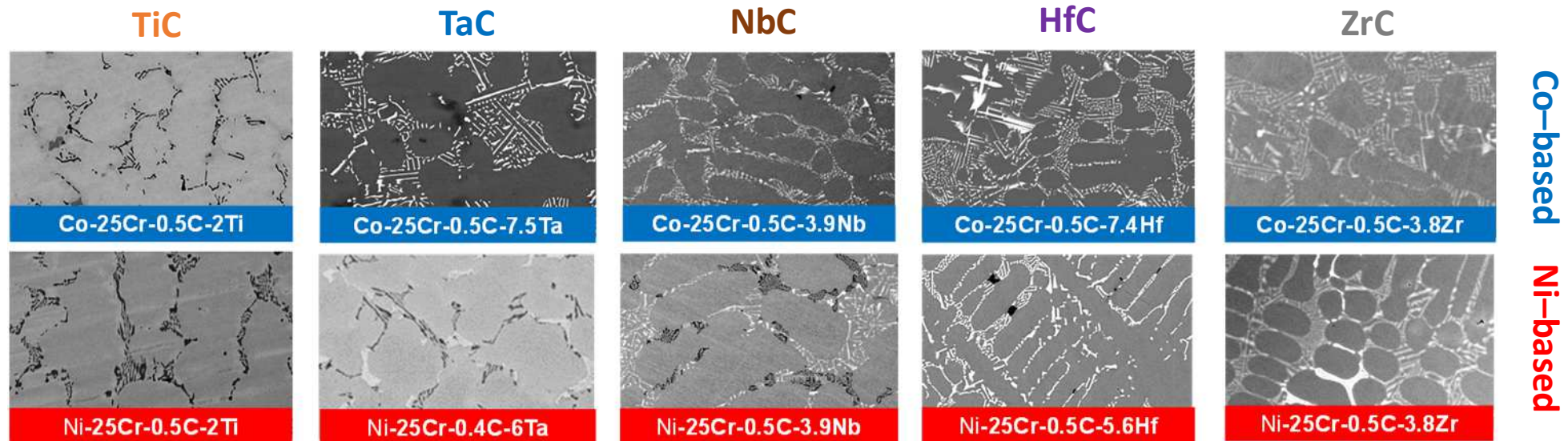
Go beyond γ/γ' single crystalline superalloys (limited to 1100°C because of γ' dissolution problems)

Solutions exist among polycrystalline cast superalloys strengthened by carbides, derived from some rather old ones

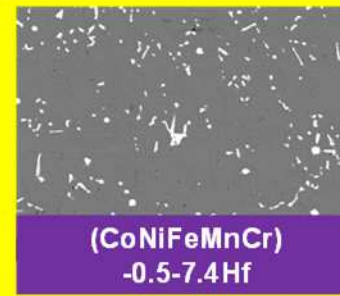


Objectives of this work: to explore new matrix × carbides systems

→ HEA × (TaC or HfC) inspired by the most creep-resistant MC-reinforced Ni-based or Co-based alloys



Model alloys
25 μm



HEA-based

Journal of Metallic Material
Research (2022) 5(2) pp.1–10.

Journal of Engineering Sciences and
Innovation (2022) 7(3) pp.305–314.

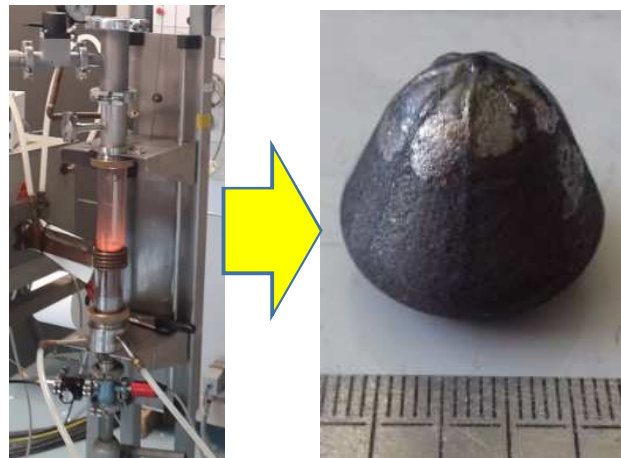
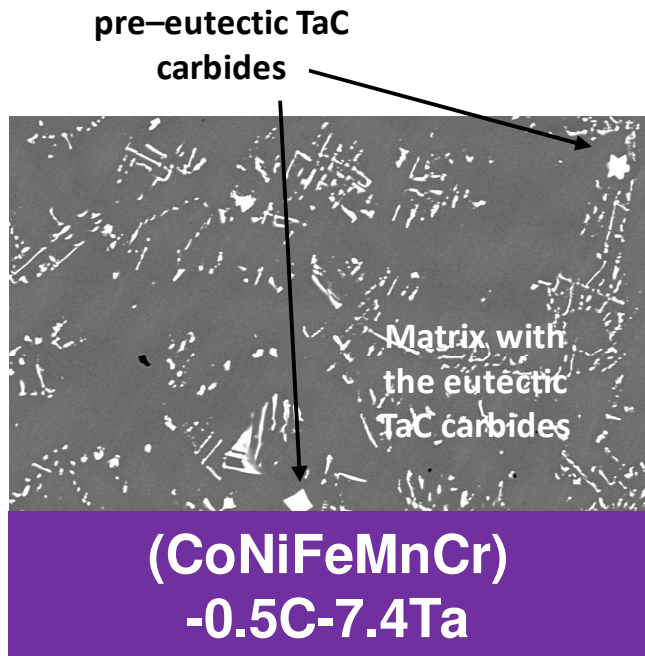
Results: elaboration

/

Microstructures in the as-cast state & obtained chemical compositions

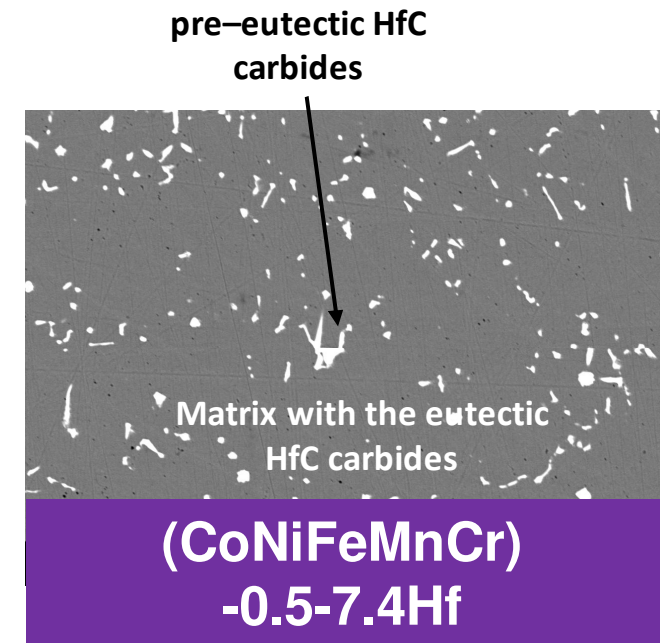
Equimolar CoNiFeMnCr + TaC or HfC

Elaborated by high frequency induction foundry under inert atmosphere (Ar) from pure elements



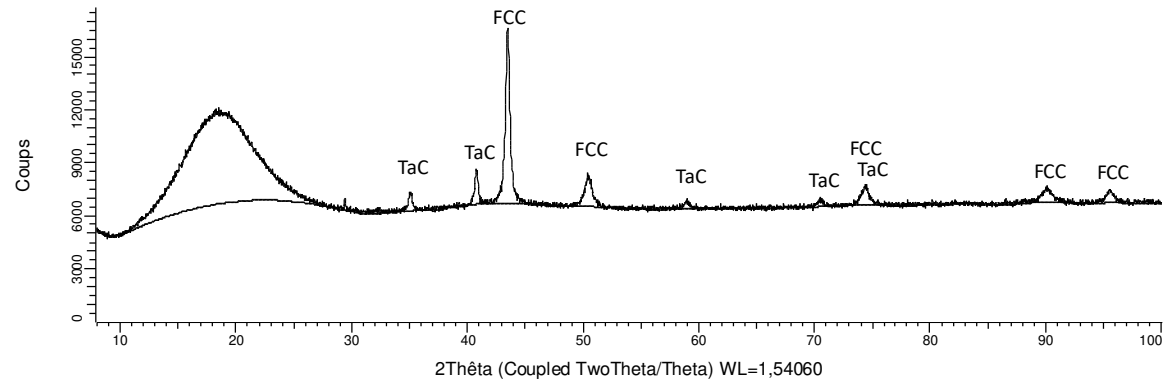
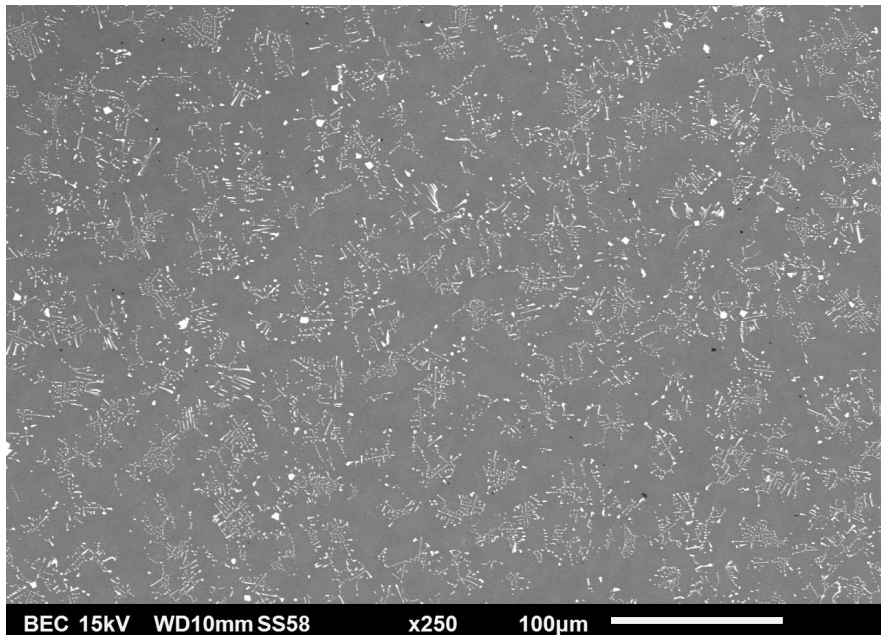
Model alloys

25 μm



Equimolar CoNiFeMnCr + TaC

Matrix: FCC, rather homogeneous (Mn segregation), containing 2wt.%Ta; Carbides: TaC (pre-eutectic and eutectic)

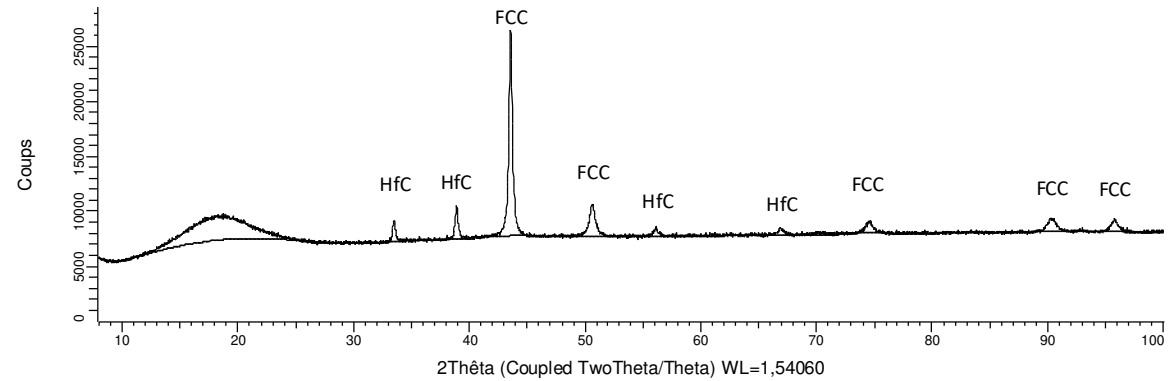
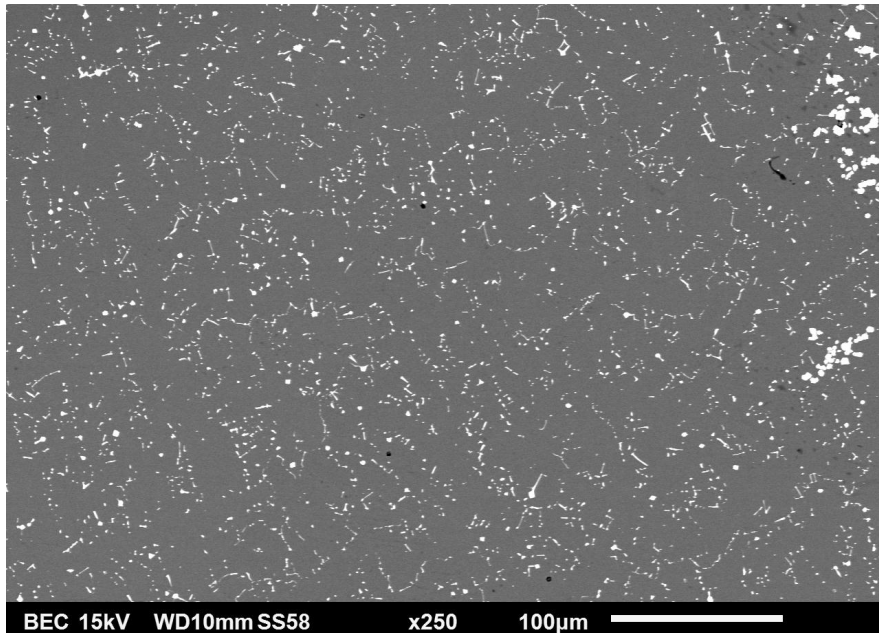


Whole alloy	Wt.% Co	Wt.% Ni	Wt.% Fe	Wt.% Mn	Wt.% Cr	Wt.Ta
Average content	18.5	20.0	17.9	18.1	19.1	6.3
Standard deviation	0.5	0.2	0.5	0.2	0.3	0.7

Matrix	Wt.% Co	Wt.% Ni	Wt.% Fe	Wt.% Mn	Wt.% Cr	Wt.%Ta
Average content	18.2	22.8	16.2	22.1	18.9	1.9
Standard deviation	0.5	1.2	2.1	2.0	0.3	0.4

Equimolar CoNiFeMnCr + HfC

Matrix: FCC, rather homogeneous (Mn segregation), Hf-free;
Carbides: HfC (pre-eutectic and eutectic)



Whole alloy	Wt.% Co	Wt.% Ni	Wt.% Fe	Wt.% Mn	Wt.% Cr	Wt.% Hf
Average content	19.0	19.9	18.1	17.0	19.1	7.0
Standard deviation	0.4	0.5	0.3	0.3	0.2	0.8

Matrix	Wt.% Co	Wt.% Ni	Wt.% Fe	Wt.% Mn	Wt.% Cr	Wt.% Hf
Average content	18.9	23.2	16.6	22.7	18.6	0.0
Standard deviation	2.7	3.6	4.4	6.0	2.5	0.0

Results: properties

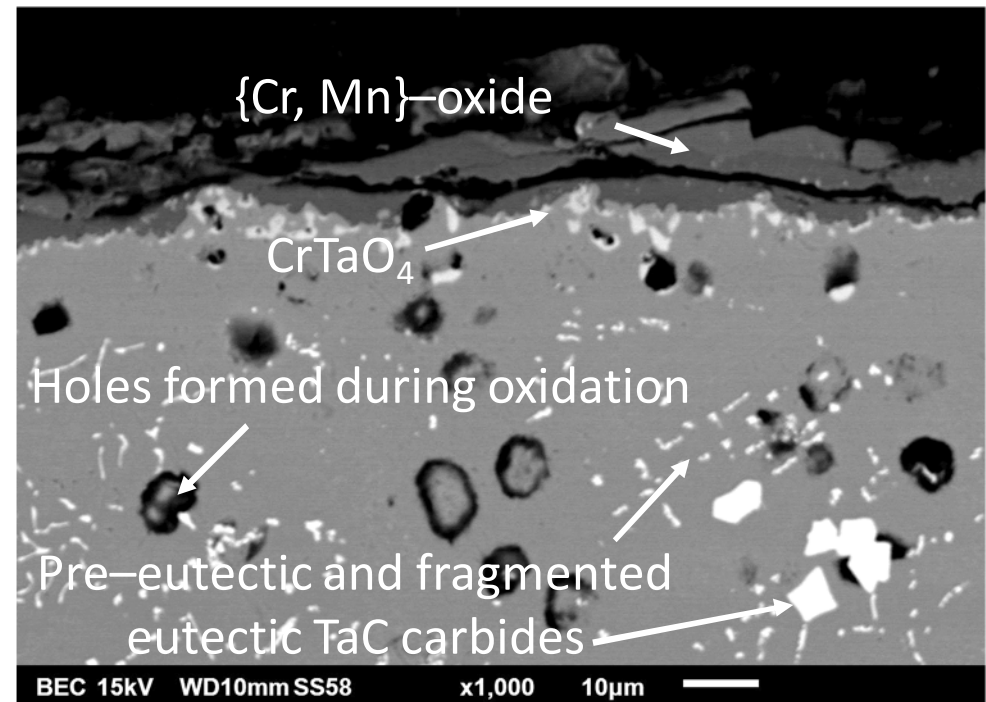
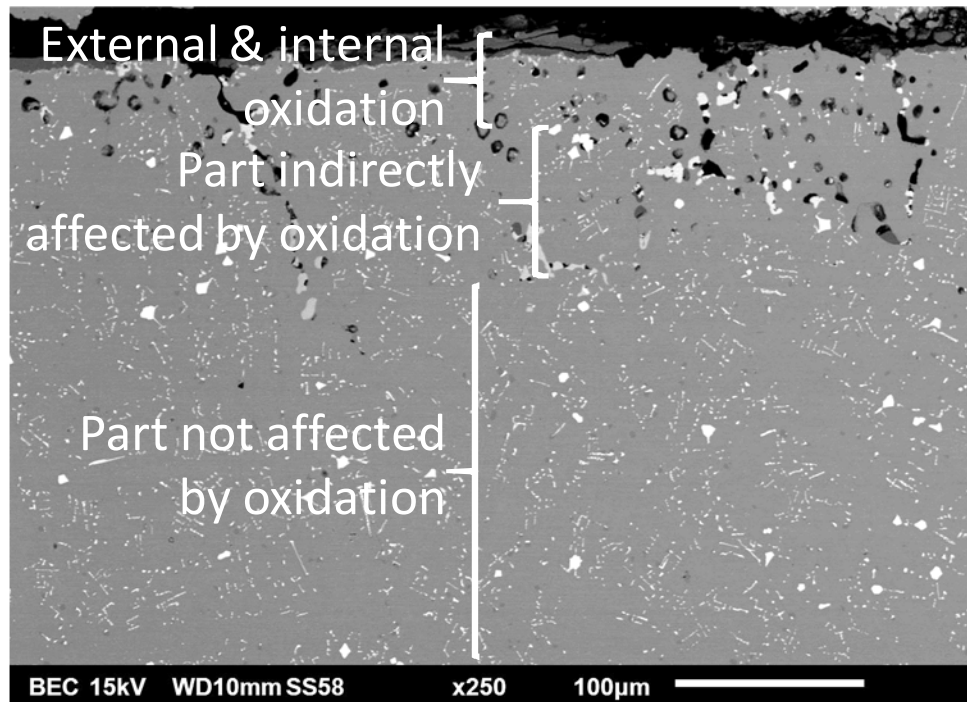
/

Oxidation behaviours at 1000 and 1100°C



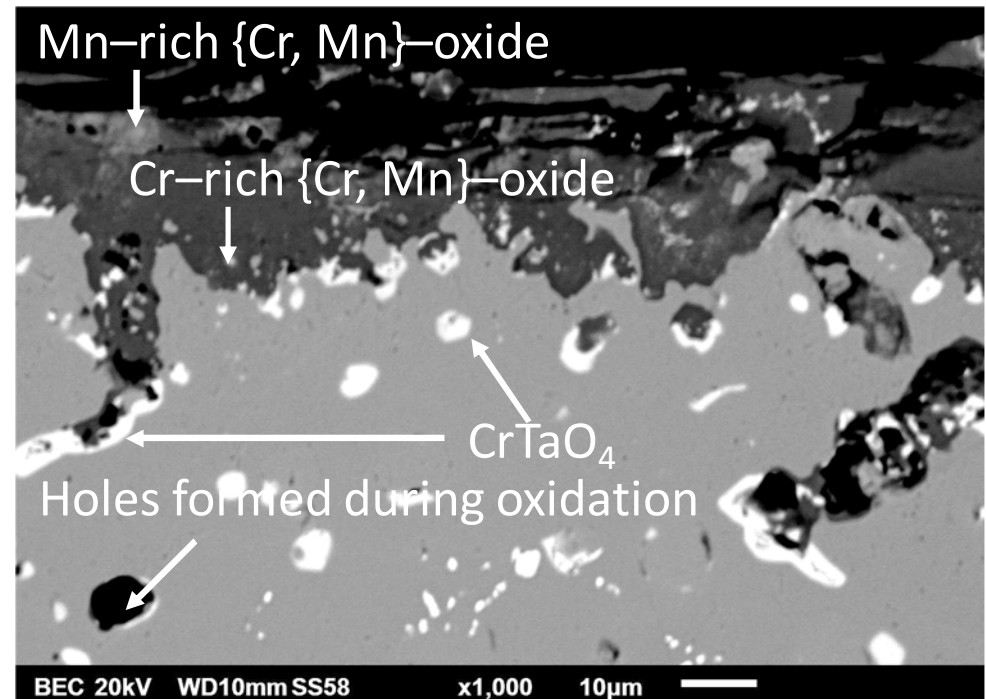
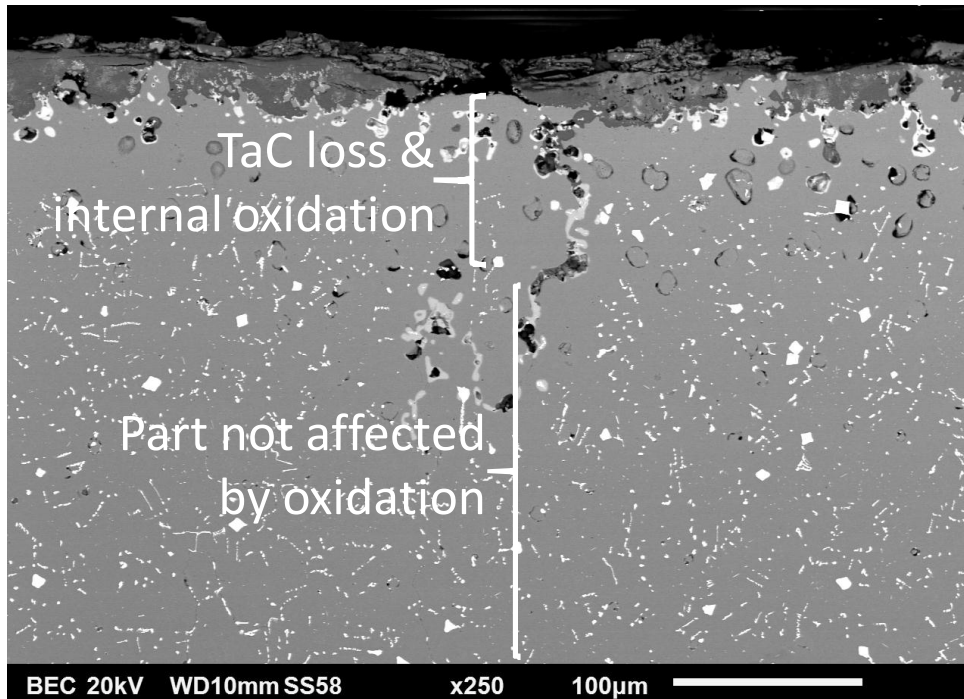
CoNiFeMnCr + TaC after 50 h at 1000°C

Oxides: external mixed of Mn and Cr, internal mixed of Cr and Ta; TaC disappearance (ext.) and fragmentation (int.); holes due to oxidation (Kirkendall effect possibly)



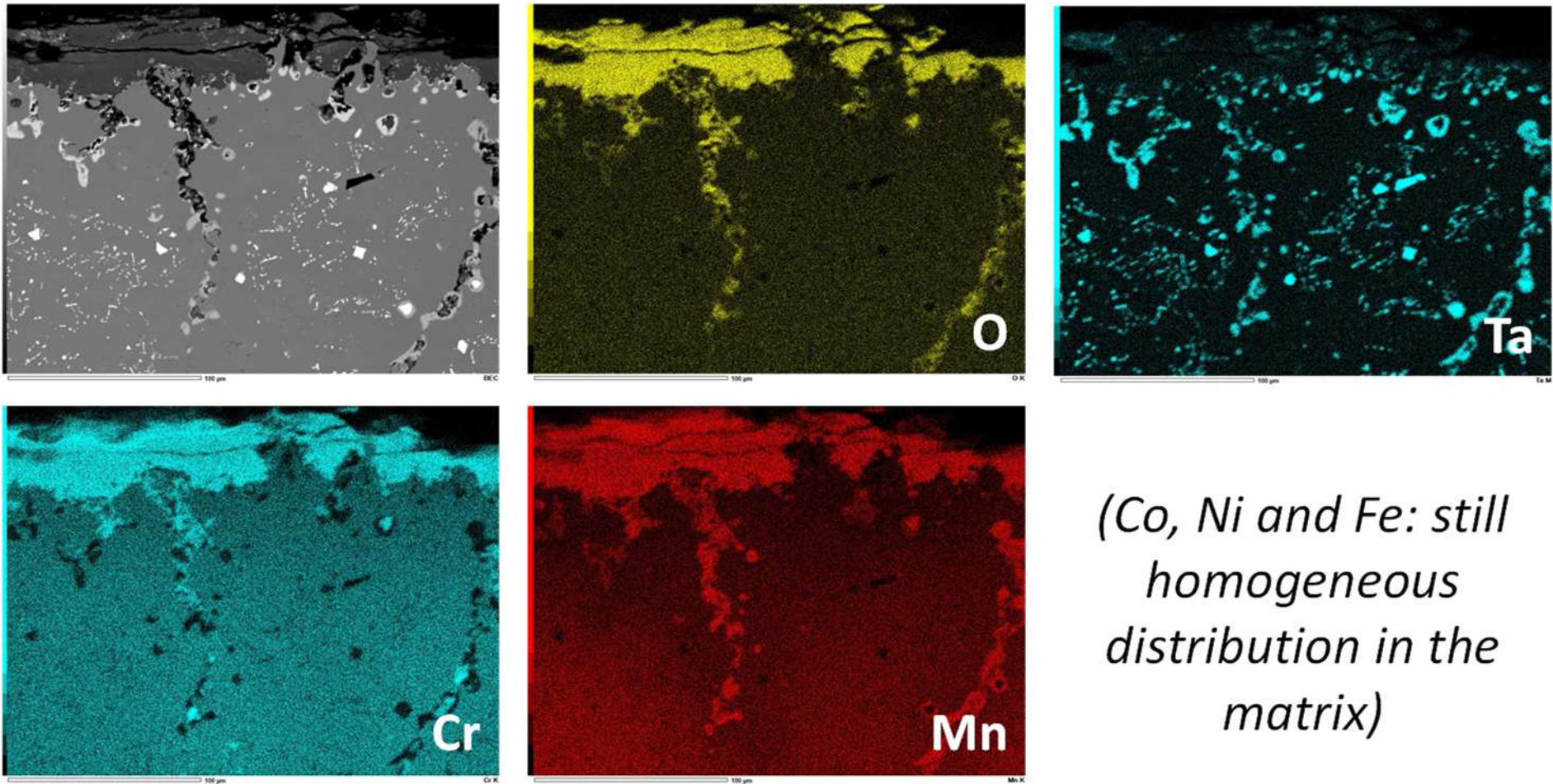
CoNiFeMnCr + TaC after 50 h at 1100°C

Globally the same phenomena as at 1000°C but more extended depths



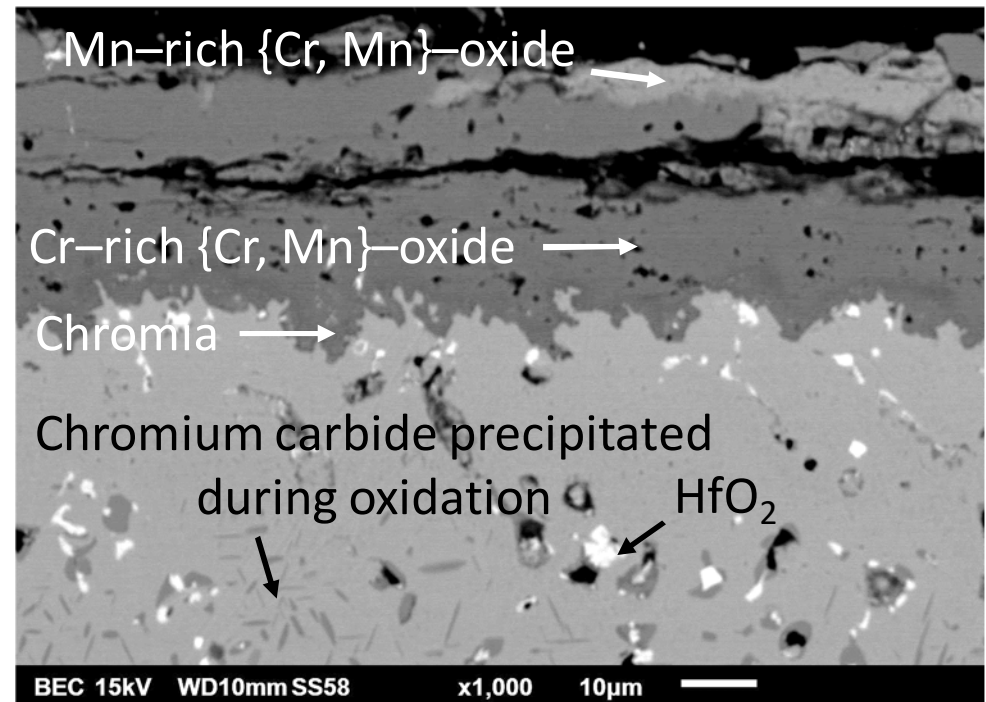
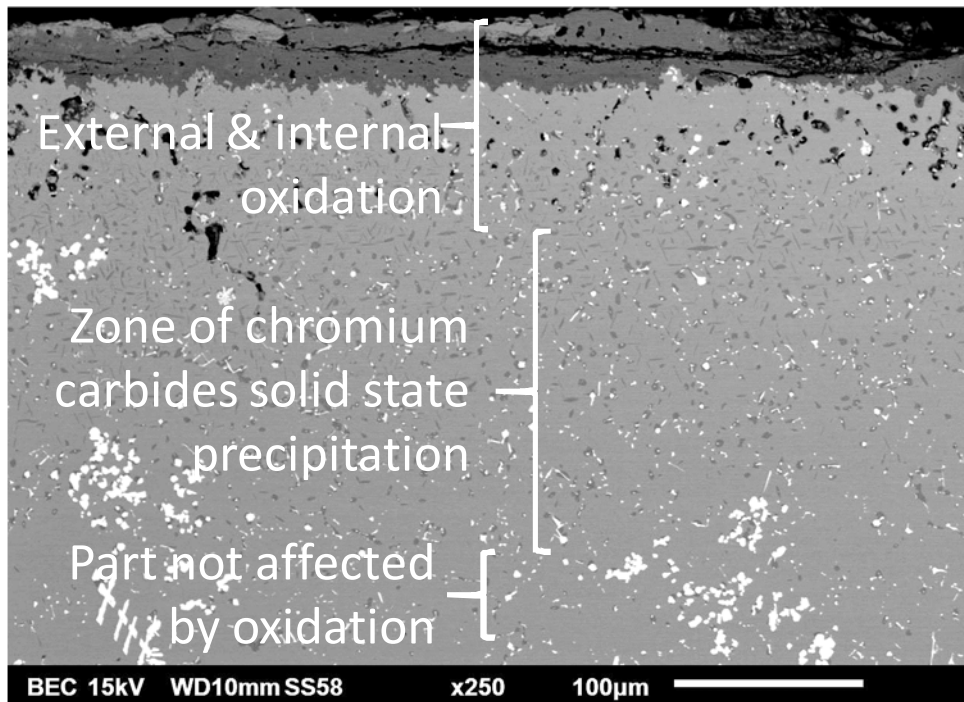
CoNiFeMnCr + TaC after 50 h at 1100°C

Chemical changes in the oxidation-affected subsurface (X-maps): Mn empoverishment (Mn has more diffused than Cr)



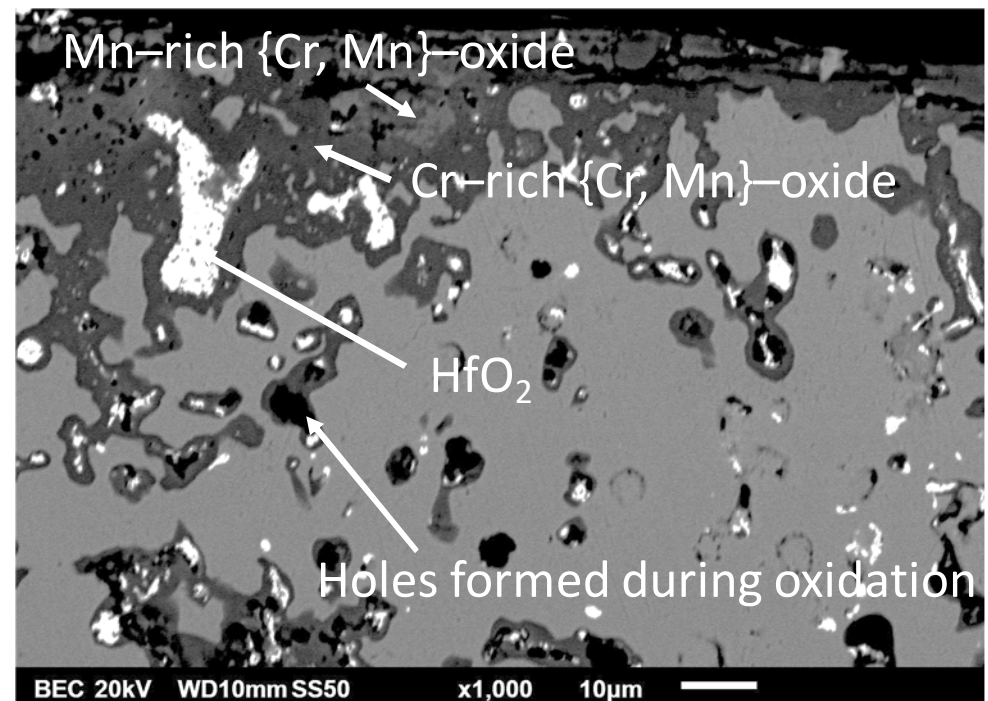
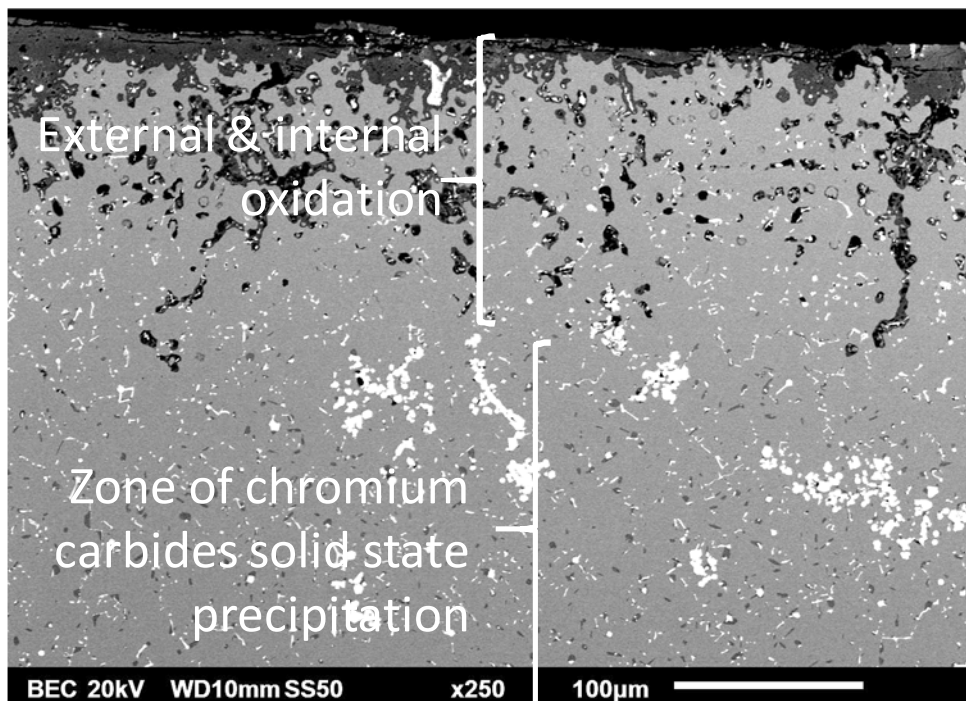
CoNiFeMnCr + HfC after 50 h at 1000°C

Oxides: external mixed of Mn and Cr with various ratio, internal oxidation of Hf; HfC oxidized in situ; rare small holes due to oxidation



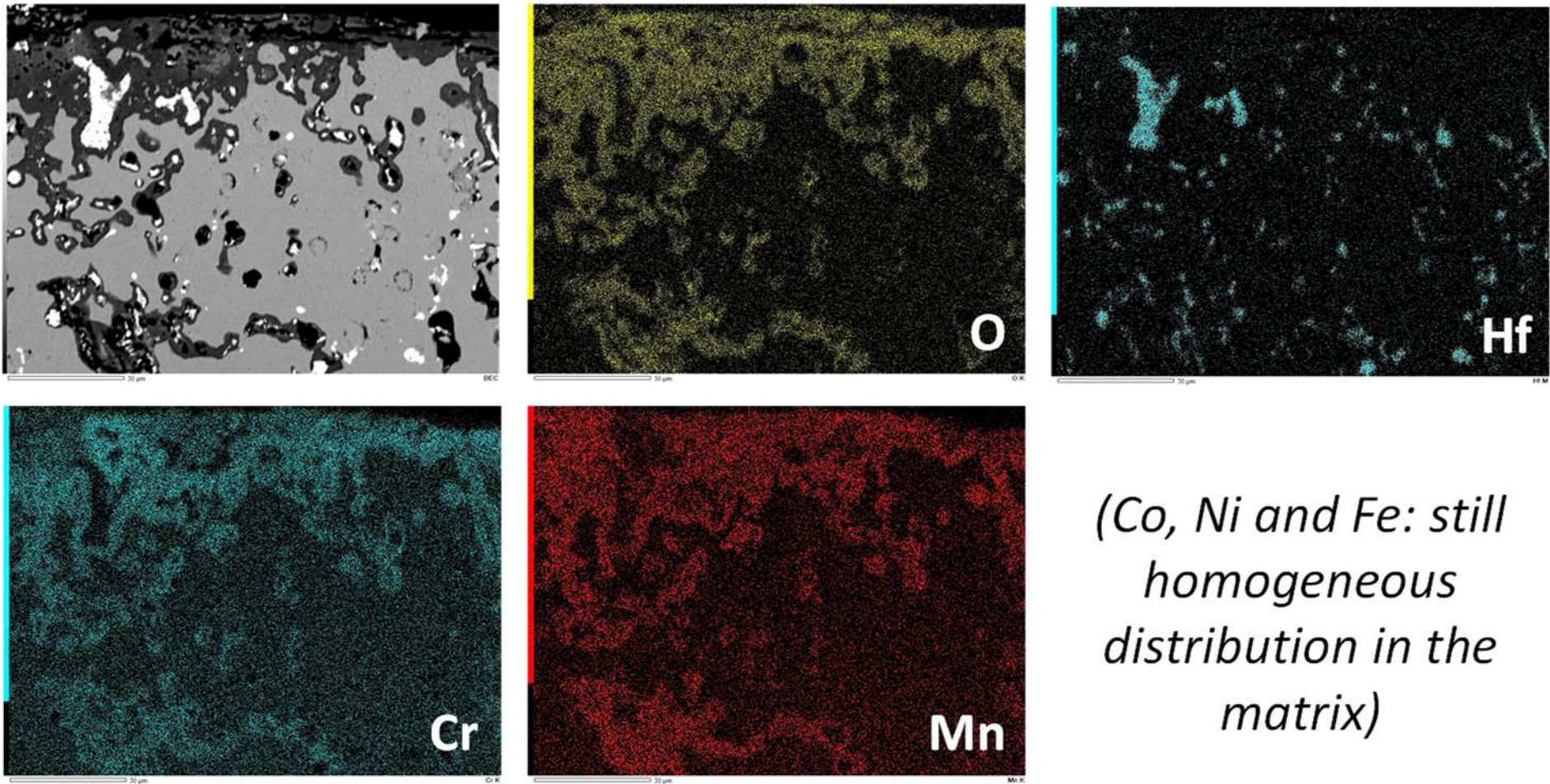
CoNiFeMnCr + HfC after 50 h at 1100°C

Globally the same phenomena as at 1000°C but more extended depths



CoNiFeMnCr + HfC after 50 h at 1100°C

Chemical changes in the oxidation-affected subsurface (X-maps): Oxidation of Mn, Cr and Hf only



(Co, Ni and Fe: still homogeneous distribution in the matrix)

Results: properties

/

Room temperature hardness



Vickers indentation (load 10kg)

5 tests → average ± standard deviation

Hardness higher than for the carbides-free HEA alloy

And low enough to allow machining easiness

Hv _{10kg}	CoNiFeMnCr	CoNiFeMnCr + TaC	CoNiFeMnCr + HfC
Av. value	121	194	162
Std dev	2	5	5

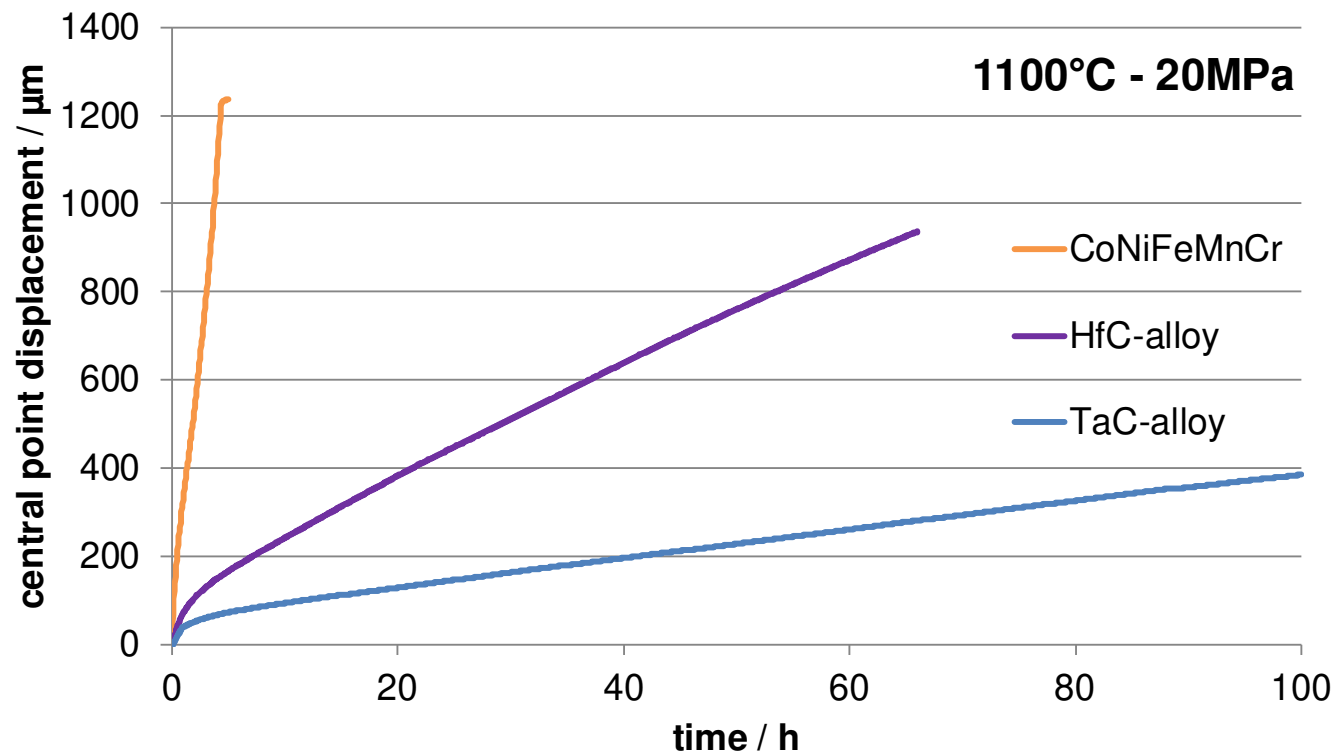
Results: properties

/

High temperature creep: in progress

First promising results with other HEA+MC alloys (with two times less MC carbides)

CoNiFeMnCr +TaC (0.25C-3.7Ta) and CoNiFeMnCr +HfC (0.25C-3.7Hf) → significant strengthening due to MC carbides



Conclusions / Outlooks



Conclusions

Interesting matrix & MC associations

Correct high temperature oxidation behaviors

Hardness maintained at an acceptable level

Promising creep behavior at 1100°C

Outlooks

Kinetic of H.T. oxidation (thermogravimetry) *in progress*

Complementary creep tests (alloys, T, σ) *in progress*

Other HEAs & other MC (e.g. CoNiFeCuCr/Al, ZrC) *in progress*

Fabrication, Structures and Properties of High Entropy Alloys and Refractory High Entropy Alloys

Guest Editor
Prof. Dr. Patrice Berthod

Deadline
~~31 December 2022~~ Extended to
30 June 2023

Special Issue

Invitation to submit

mdpi.com/si/125455

Thank you for your attention!



<https://www.comune.fianoromano.rm.it/la-storia-del-paese/>