KME703
Durable MCrAlX Coatings for demanding applications in gas turbines

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Project team for KME 703

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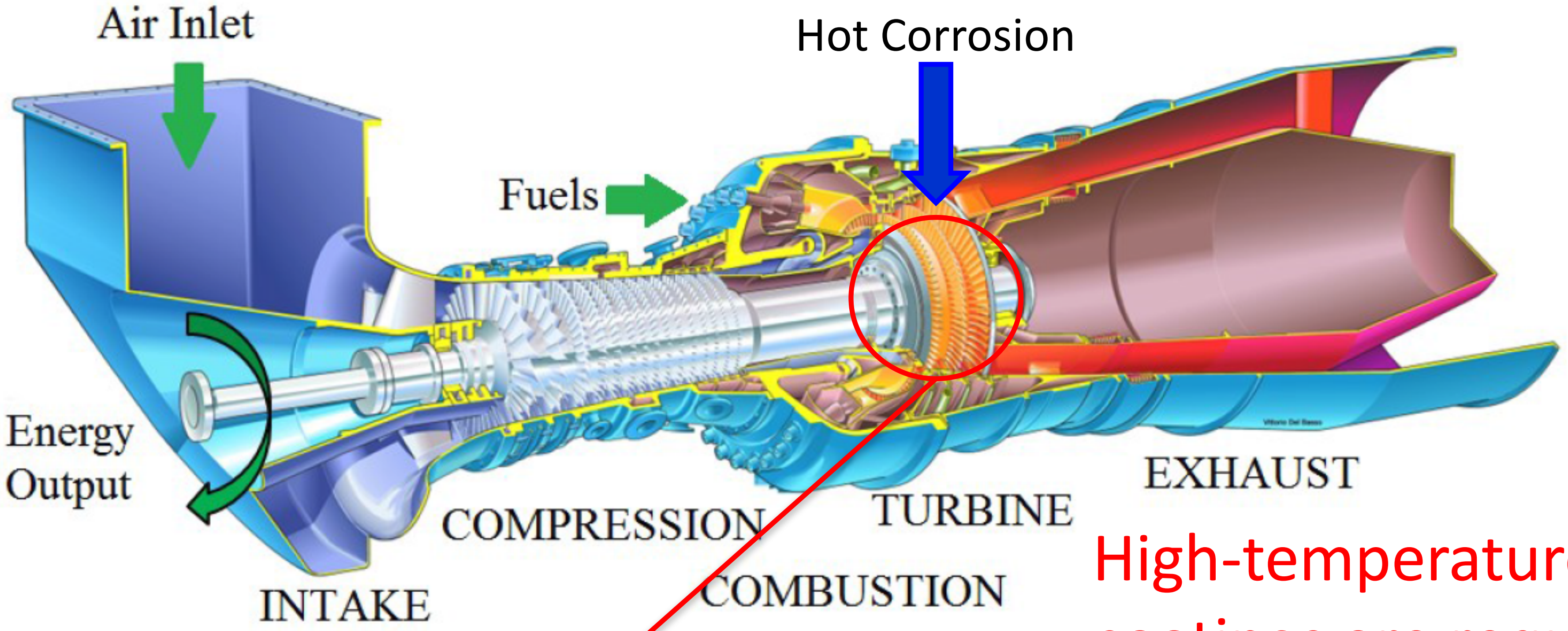
Outline

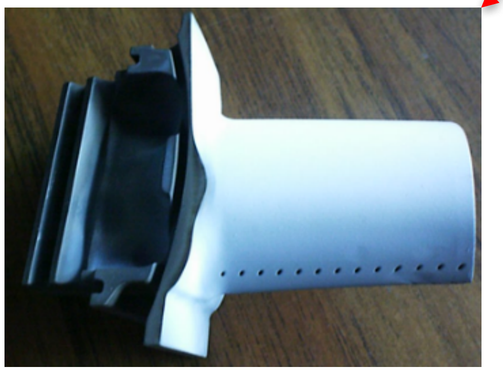
- Background
  - General introduction
  - KME 703
- Project works and results
  - Oxidation
  - Mechanical properties
  - Simulation-Interdiffusion
- Summary
- Future work

Gas turbine

High-temperature exposure:
Oxidation
Hot Corrosion



High-temperature coatings are required!!



High-performance :

- Increase T, high efficiency
- longer life
- resistant against TCF
- optimized mechanical property

MCrAlX High-temperature coatings

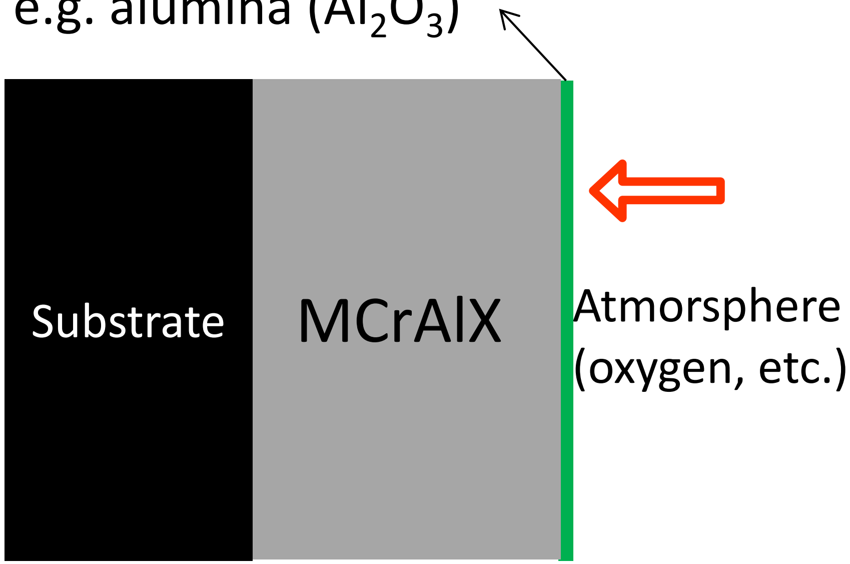
MCrAlX or MCrAlY

- M → Chromium
- Cr → Aluminum
- AlX → Minor element
- Y → Yttrium

Overlay

Bond coat

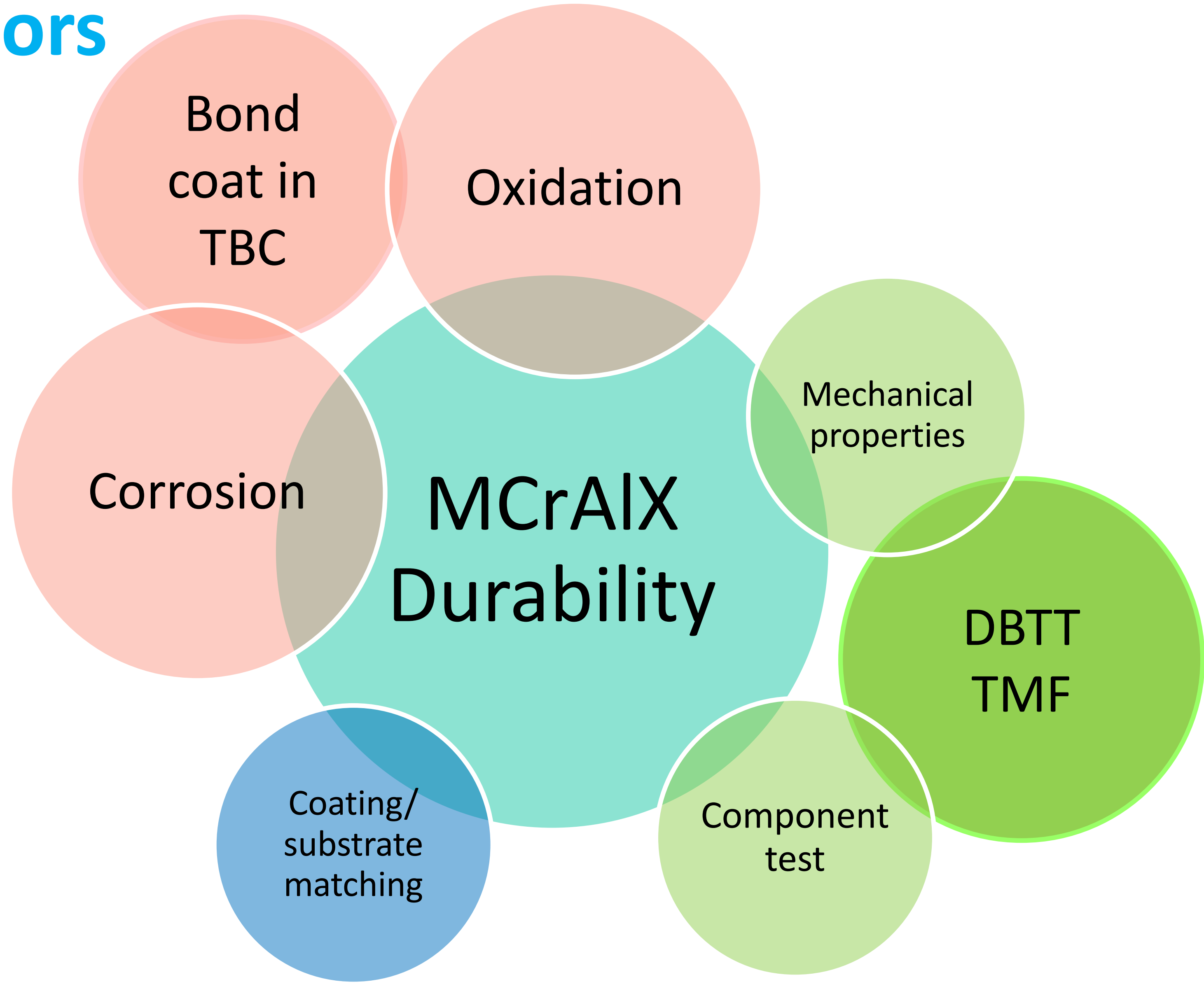
Protective oxide scale (TGO)
e.g. alumina (Al_2O_3)



Project aim

- To develop new MCrAlX-coatings with better performance for use in land based gas turbines of medium size
  - Enhanced resistance against thermal growth and spallation of the protective scale
  - Increased strain tolerance to prevent coating cracking during thermal cycling
- To contribute to the understanding of some important issues in high temperature protection of superalloys
- To study the influence of the applications of such coatings on the behavior of superalloys.
- By thermodynamic/kinetic simulation and experimental studies

Key factors


Bond coat in TBC
Oxidation
Mechanical properties
Corrosion
MCrAlX Durability
DBTT
TMF
Coating/ substrate matching
Component test

Project progress

MCrAlX coating systems:

1. Fe-containing coatings for cost reduction-D7#
2. Miner elements modified (Ru)-D1#
3. Triple phase with enhanced mechanical properties-C#
4. Co base coatings with enhanced corrosion resistance-B#

Ni base

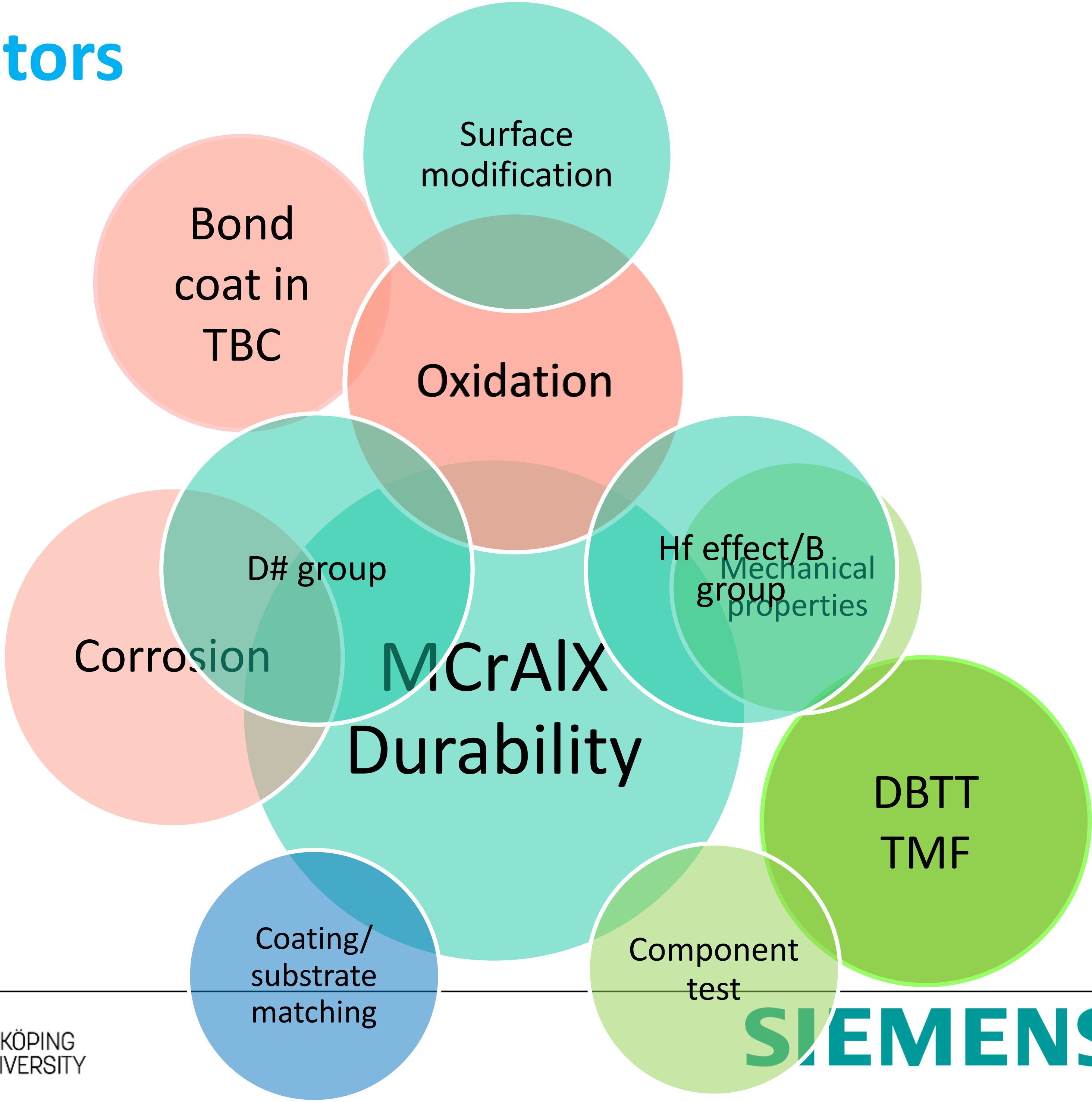
Main test

- Oxidation test
- Cyclic oxidation
- DBTT
- Thermal mechanical fatigue
- Corrosion test
- Oxidation-diffusion model modification and application

Task progress

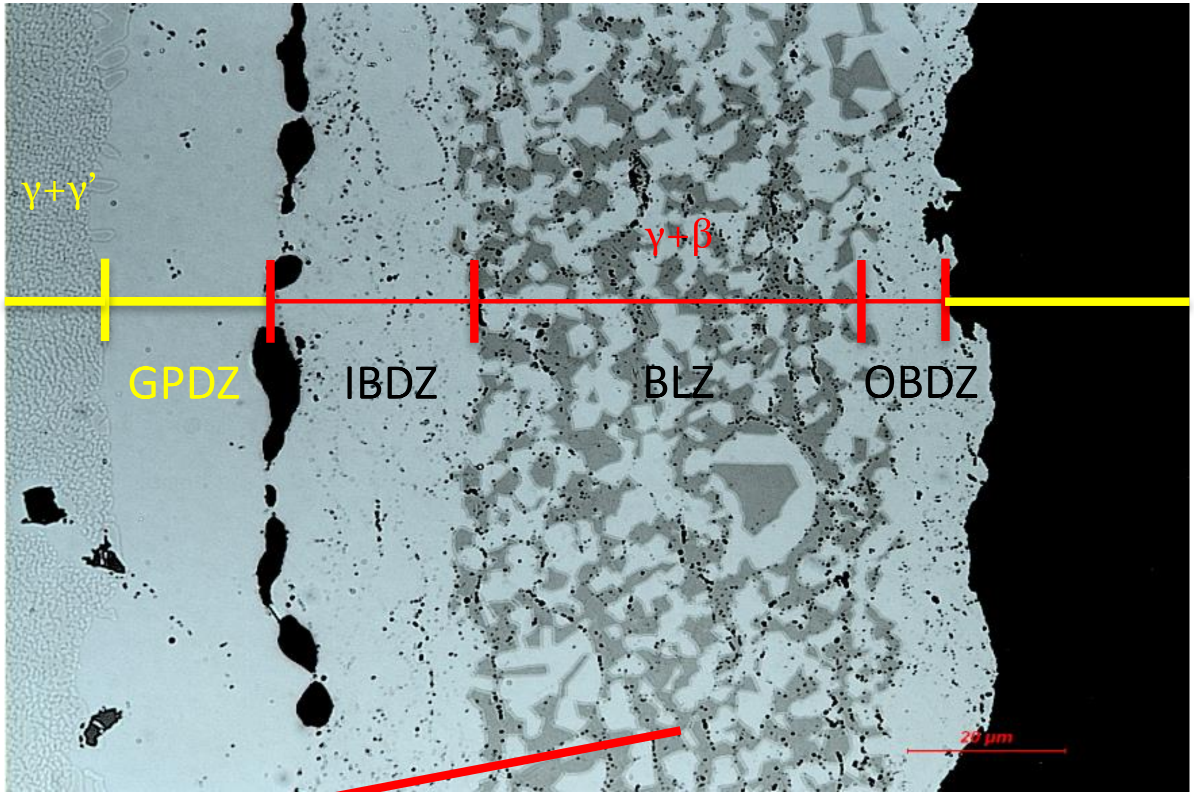
- Cyclic oxidation at 1100 °C
- Oxidation at 900, 1000, 1100 °C
- Simulation
- TMF
- DBTT

Key factors


Surface modification
Bond coat in TBC
Oxidation
D# group
Hf effect/B group
Mechanical properties
Corrosion
MCrAlX Durability
DBTT TMF
Coating/ substrate matching
Component test

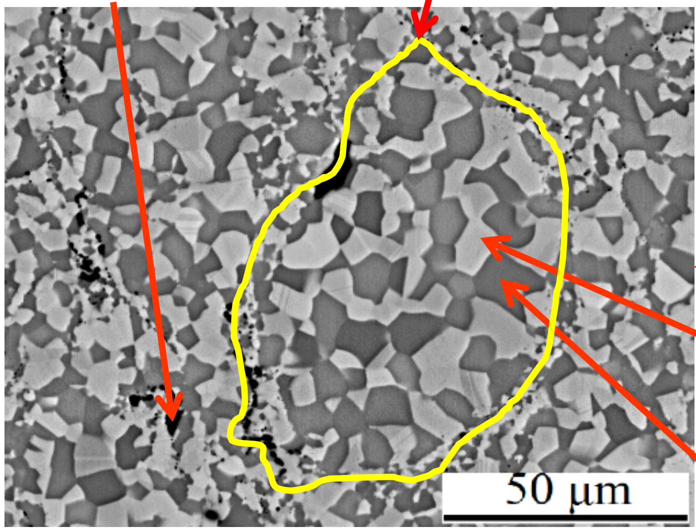
Characterization of coating behavior

OBDZ: Outer-β-depletion zone
BLZ: β-left zone
IBDZ: Inner-β-depletion zone
GPDZ: γ'-depletion zone



splat-on-splat structure

Y-rich

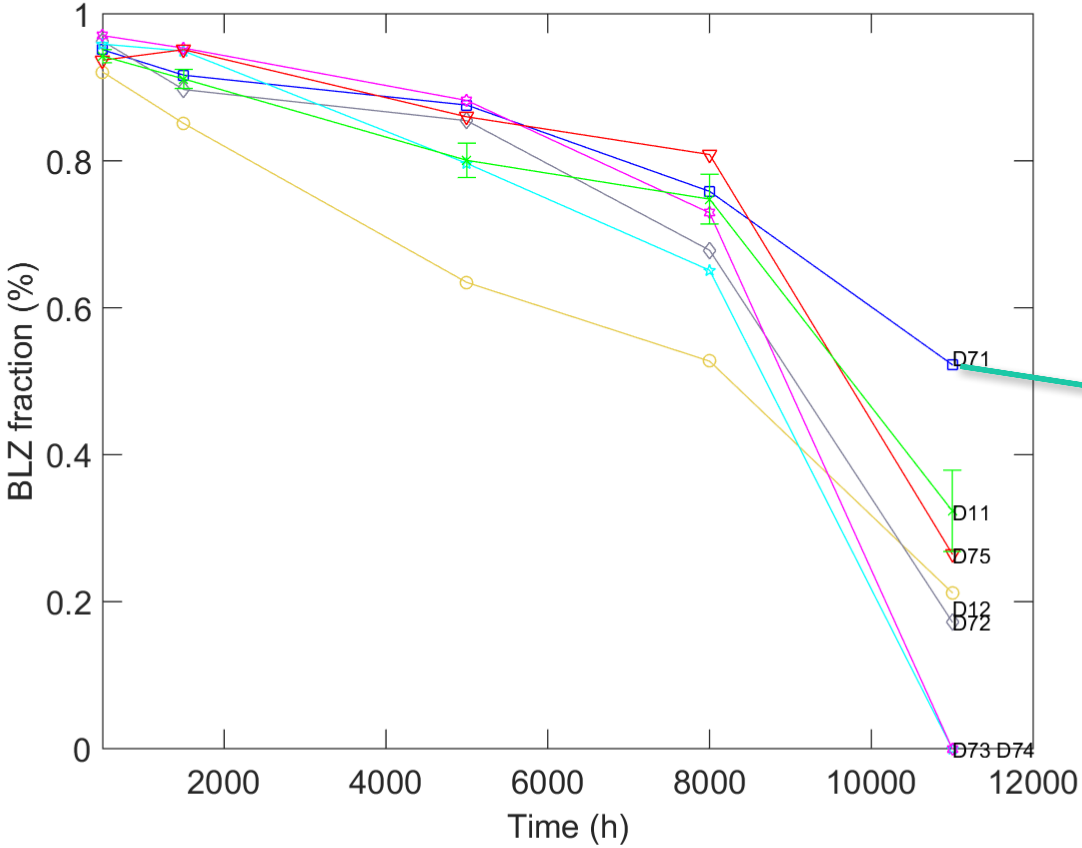


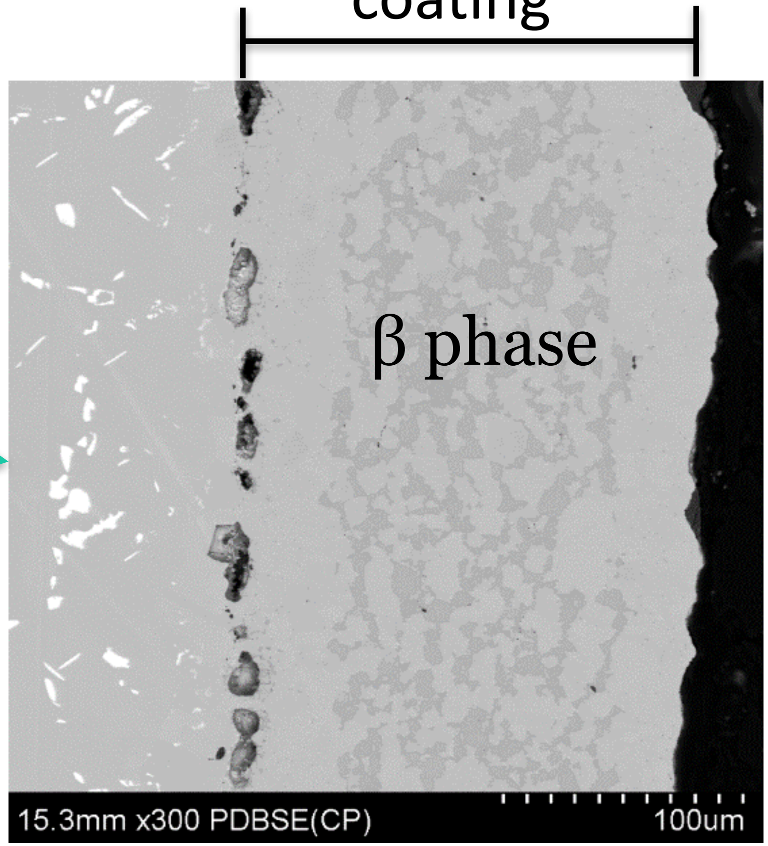
γ-(Co,Cr,Ni, …)

β-NiAl

Oxidation- D group

Isothermal 1000 ^{0}C

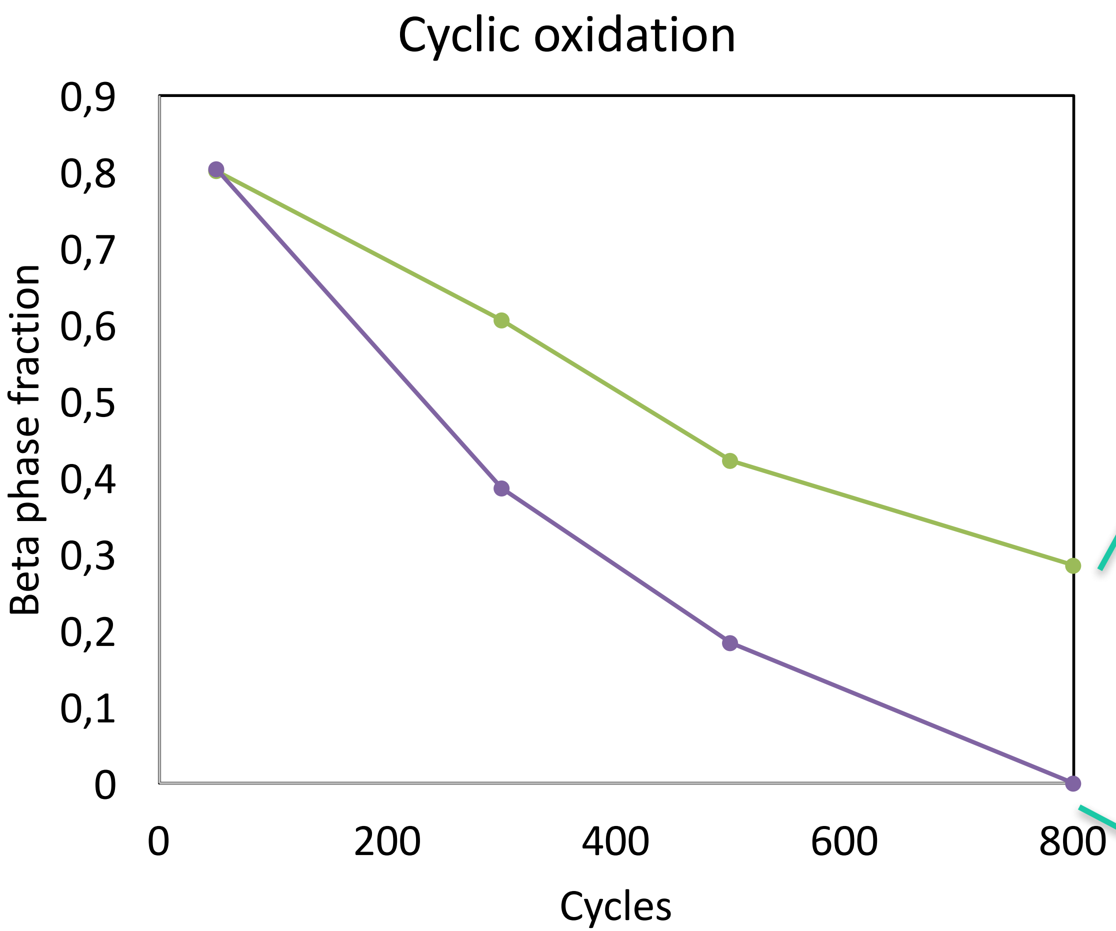




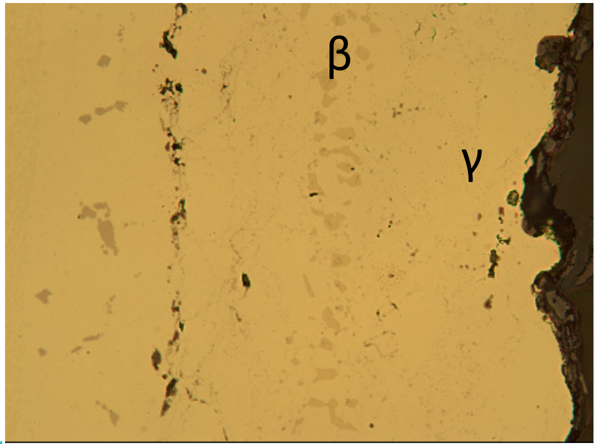
Oxidation resistance

D71(Fe)>D11(Ru), D75>D72 D12, D73, D74

Oxidation- B group/Hf effect

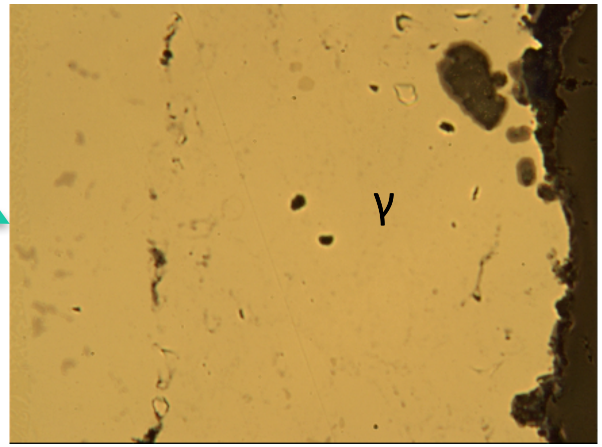


IN792 Coating



B11 : MCrAlY

B12 : MCrAlY+0.2Hf



Hf: negative effect on oxidation

Oxidation- Coating surface treatment

HVAF sprayed MCrAlX coating

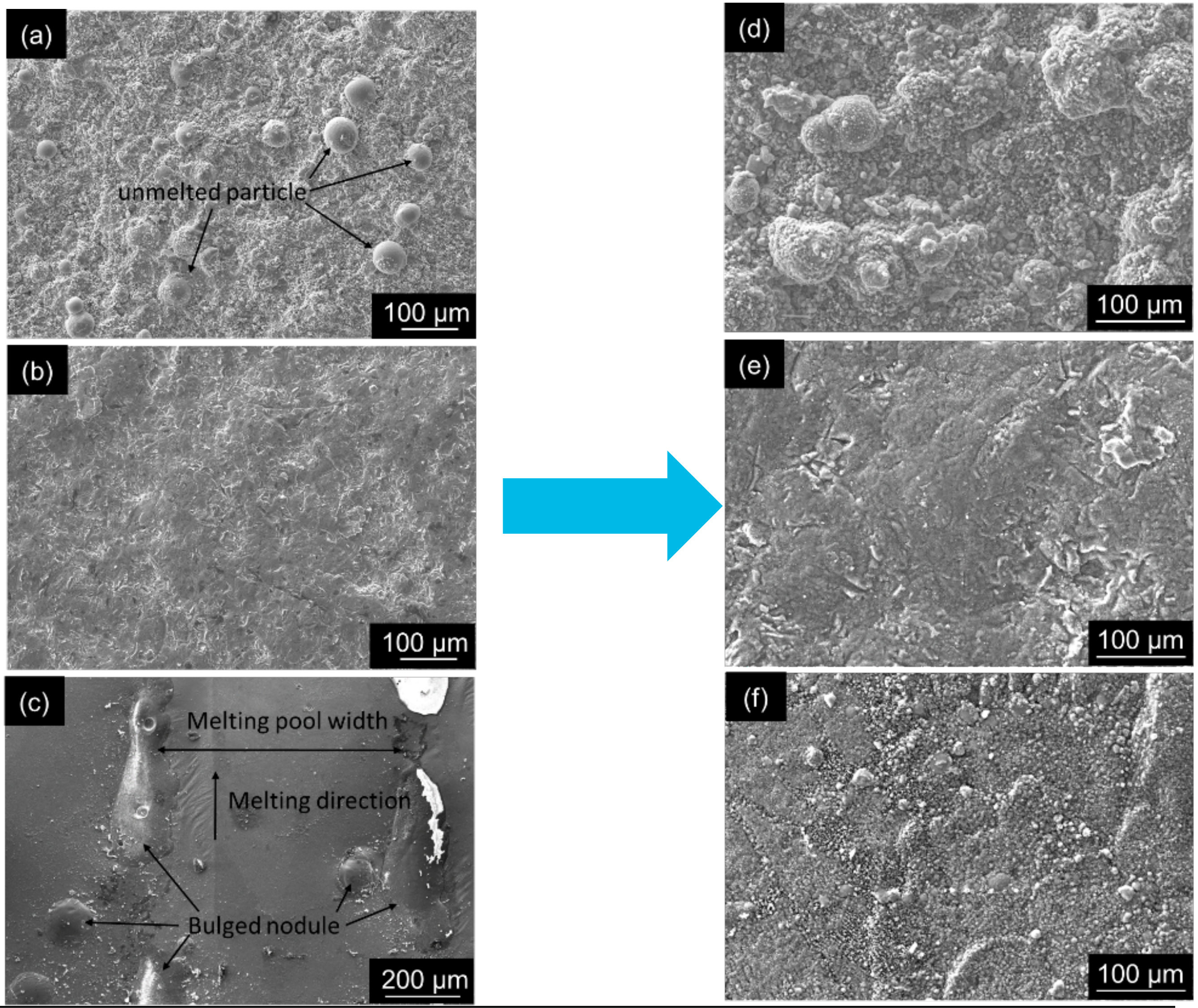
Before oxidation

1000 C_1000 h

1. Not-treated

2. Shot-peened

3. Laser surface melting



Coating surface treatment

1000 C_1000 h

1. Not-treated

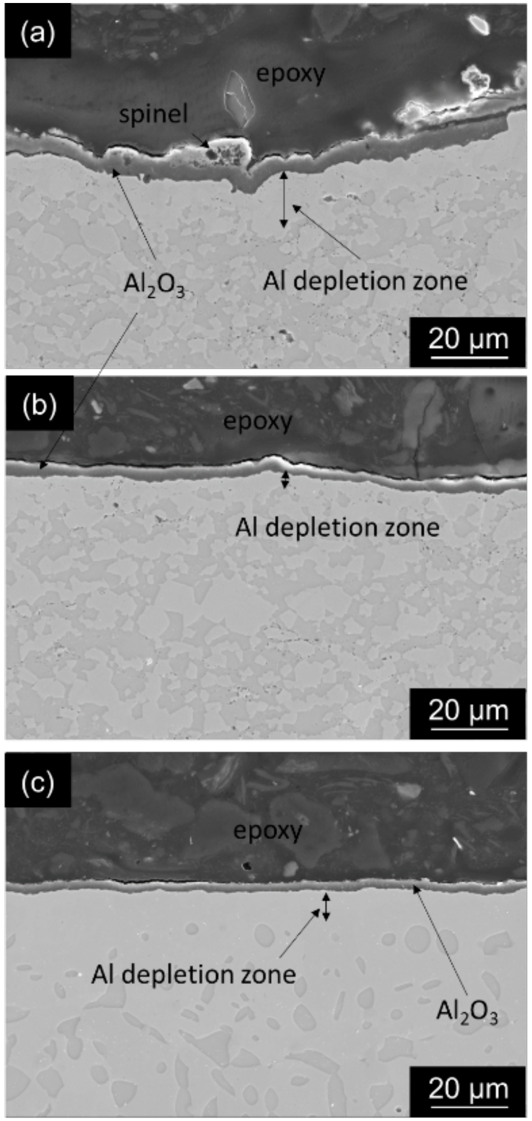
   Spinel
   Al2O3 thickness: 4 µm

2. Shot-peened

   No spinel
   Al2O3 thickness: 3 µm

3. Laser surface melting

   No spinel
   Al2O3 thickness: 2 µm



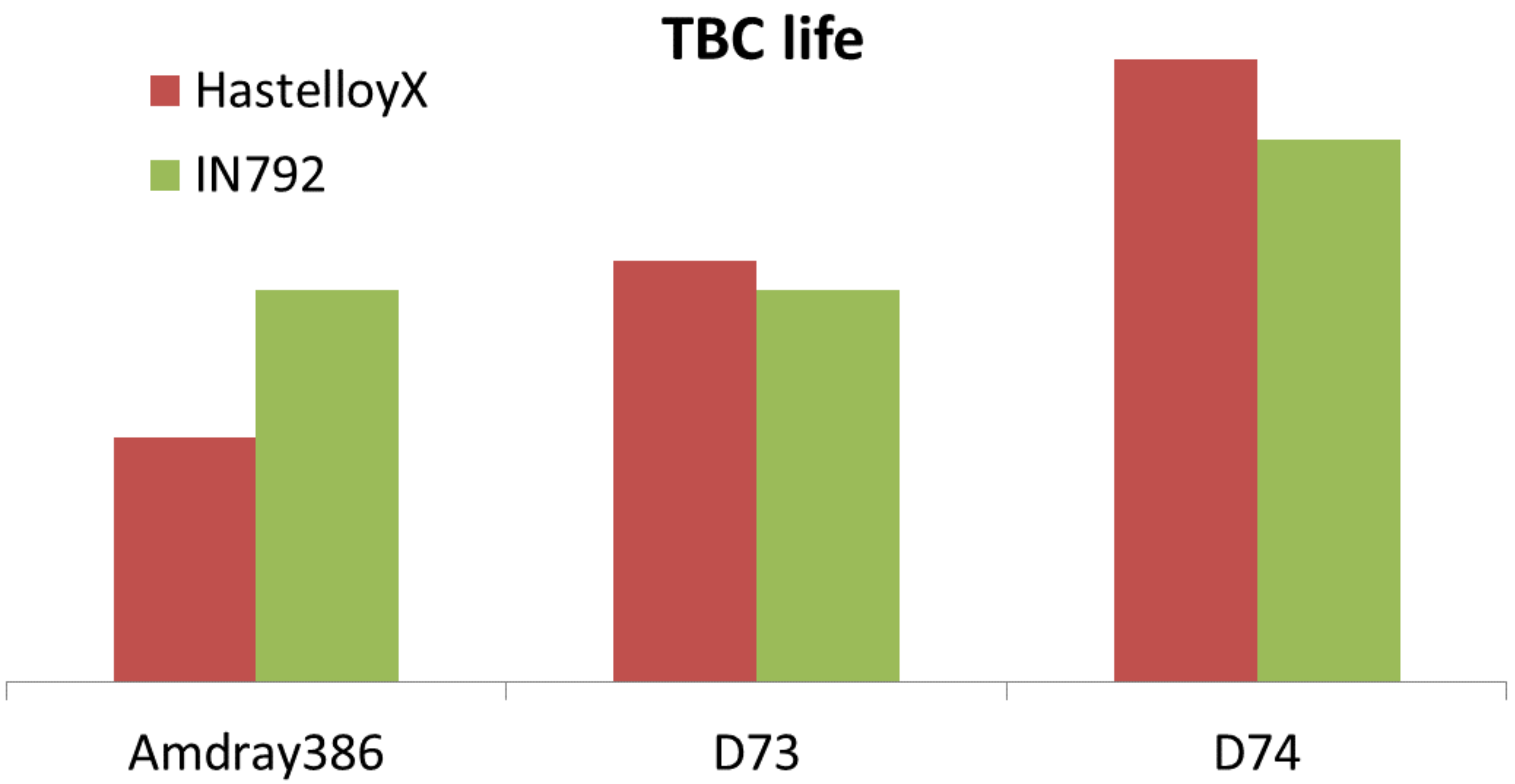
Surface treatment effect:

- Reduce surface roughness
- Remove unmelted particles

- Reduce Al consumption
- Increase Al diffusion to form a uniform Al2O3 layer
- Suppress spinel formation

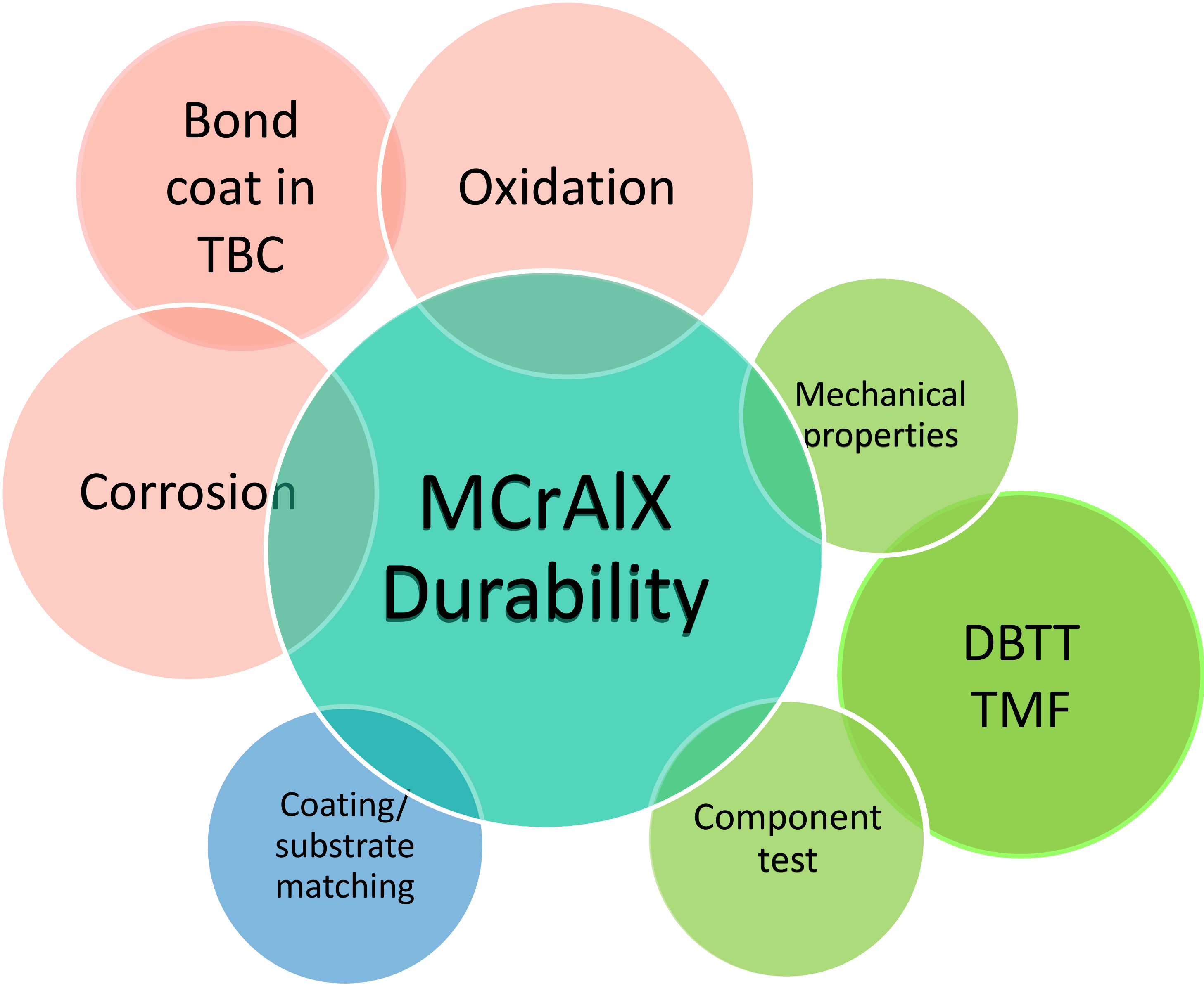
SP and LSM treatments: improve oxidation resistance

Bond coat in TBC



TBC life: D74, D73 (KME703)>Amdry 386 (commercial)

Key factors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Mechanical properties

1. DBTT

Sample	DBTT
CMSX-4+D71	400 C
IN792+D71	500-550 C
CM247LC+D71	300-400 C
IN792+D10	Good ductility
CM247LC+D10	Good ductility
IN792+D11	400 C

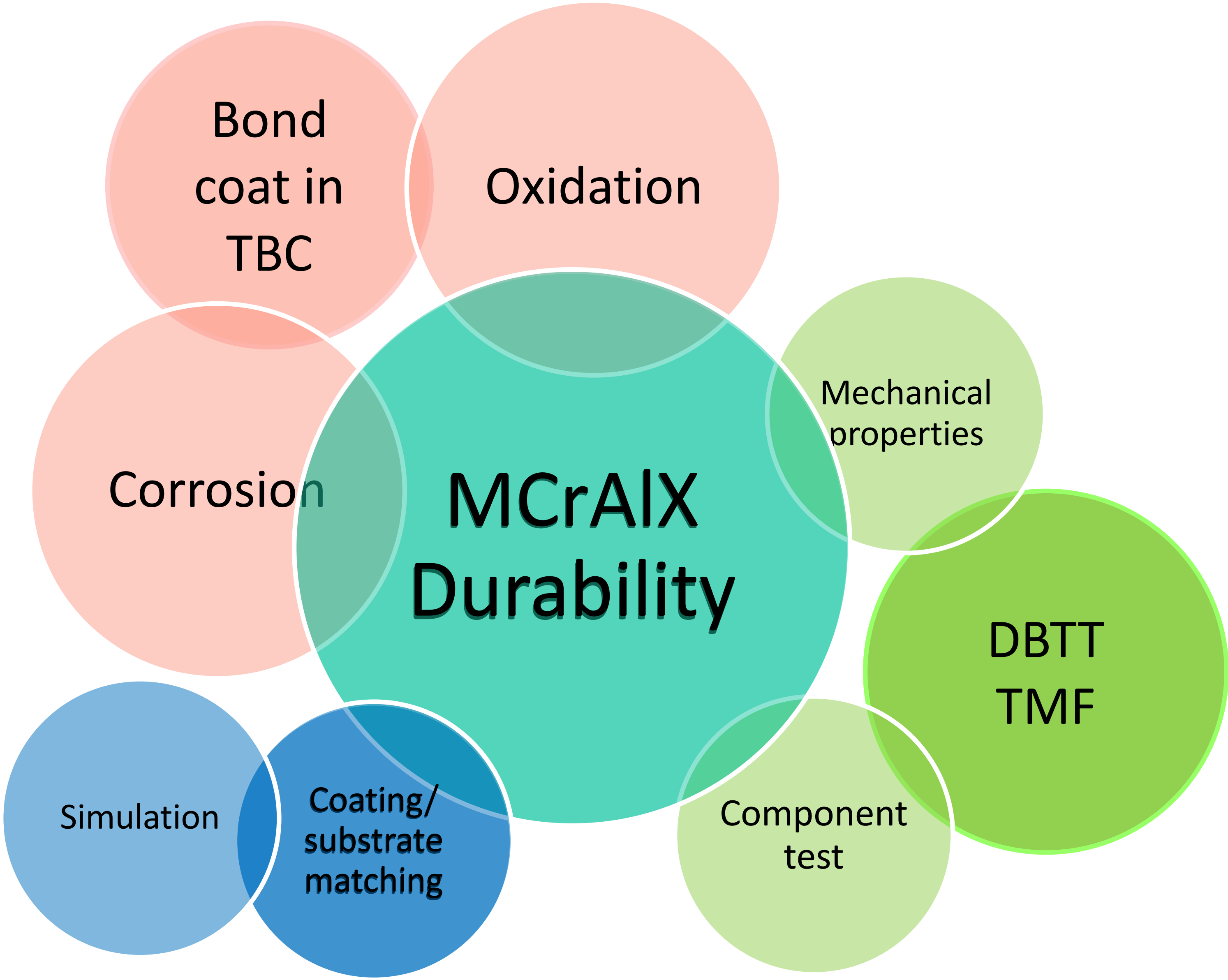
- Coating DBTT: D10>D11>D71
- Substrate effect: single crystal> polycrystalline

2. TMF

- TMF life: D10>D11>D71
- Crack propagation: D71>D11>D10

D71: good oxidation resistance, brittle

Key factors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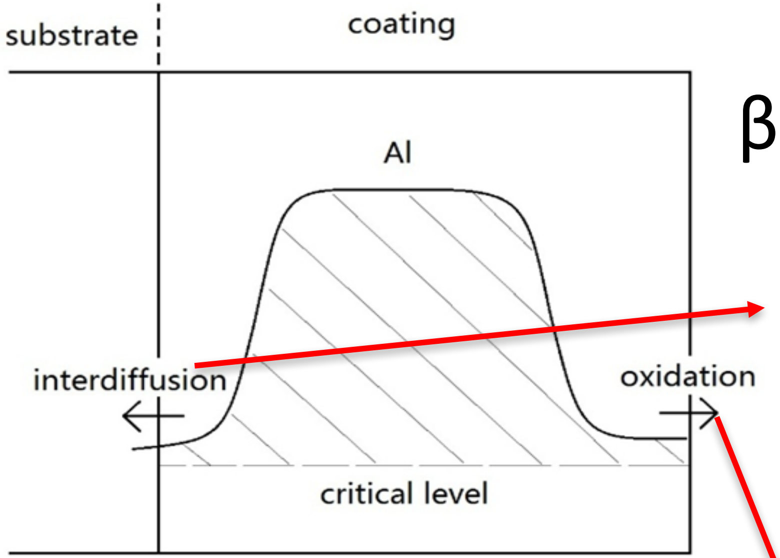
Oxidation-diffusion model

Model

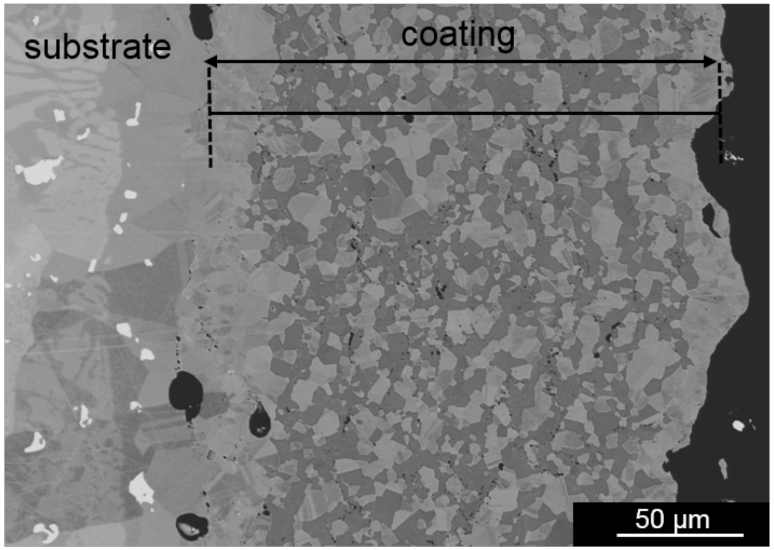


β phase depletion in coating

- Interdiffusion:

Thermodynamics and kinetics (diffusion, microstructures)
– DICTRA

Exp

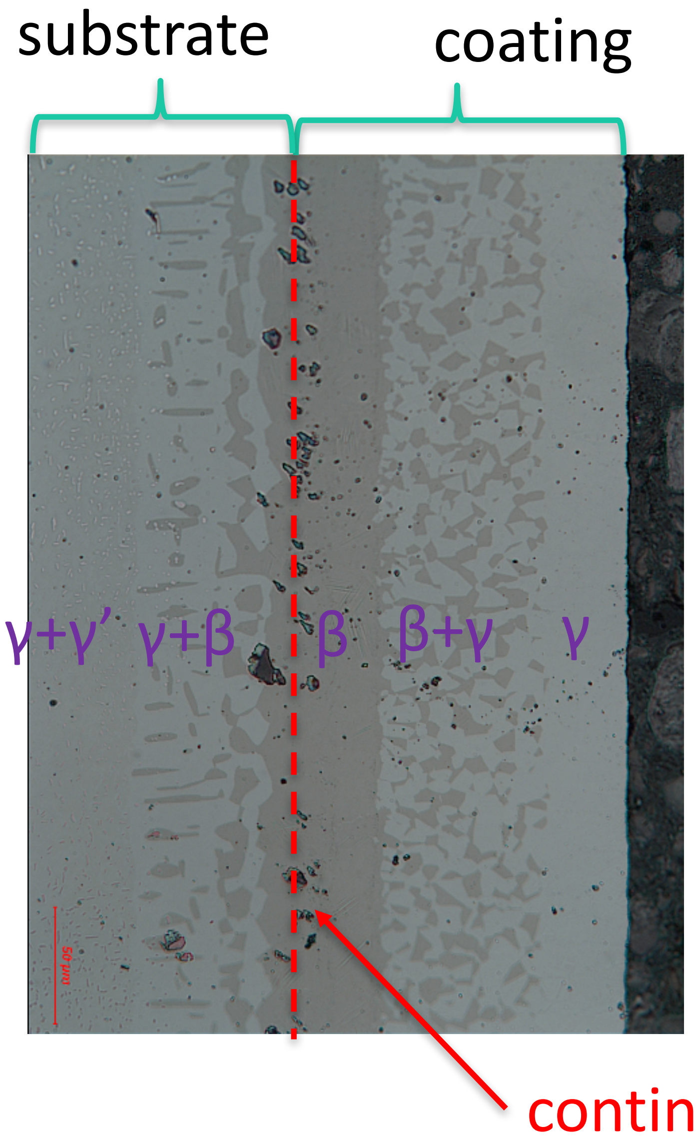


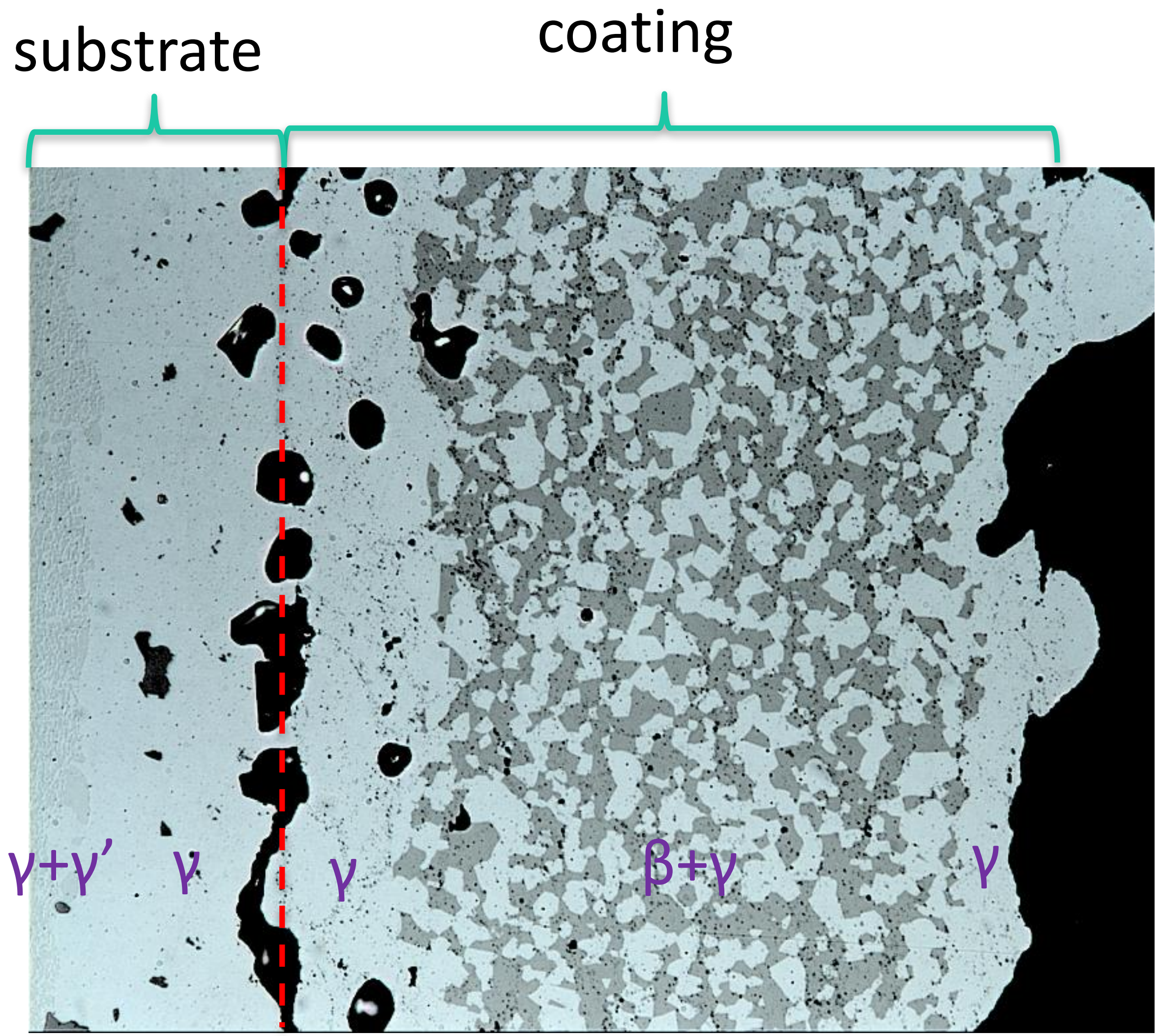
- Oxidation:

Oxidation law ($h = h_0 + (kt)^{1/n}$, $e.g.\ h = (kt)^{1/2}$)
– experimental fitting, Matlab

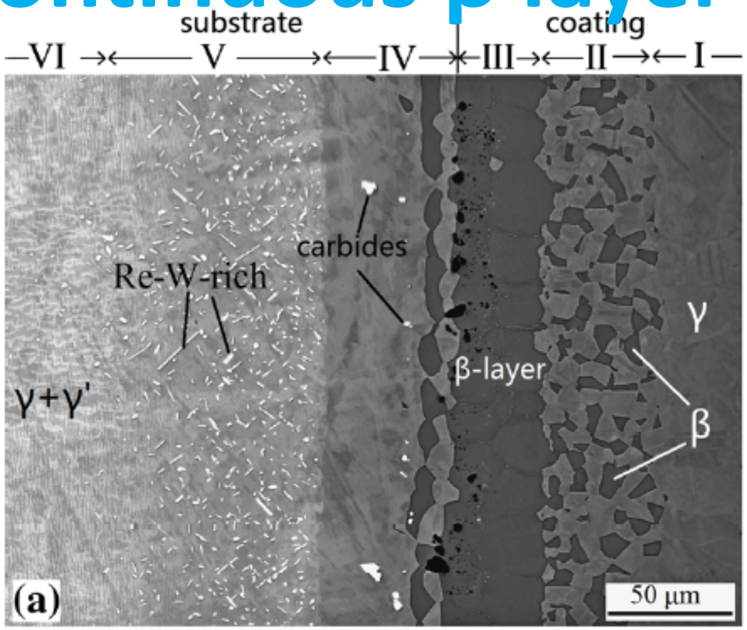
Coating 1:
continuous β layer

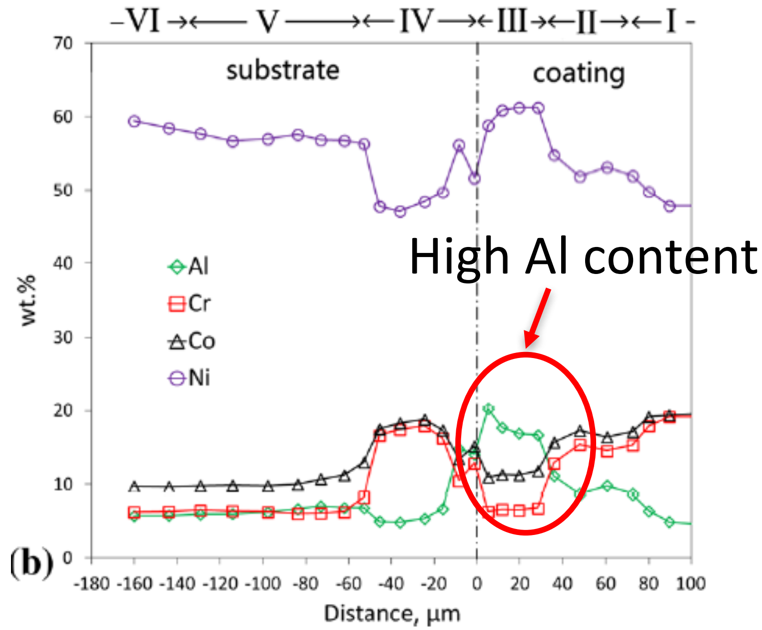
Coating 2:
ordinary MCrAlX



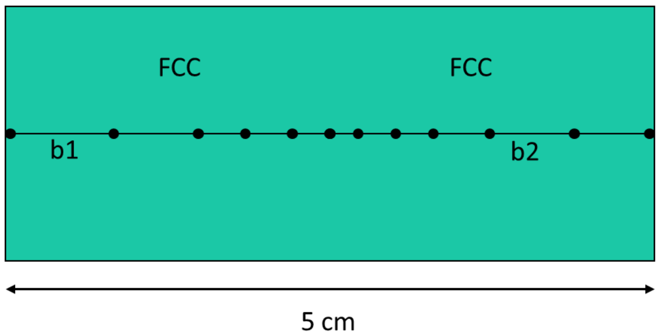


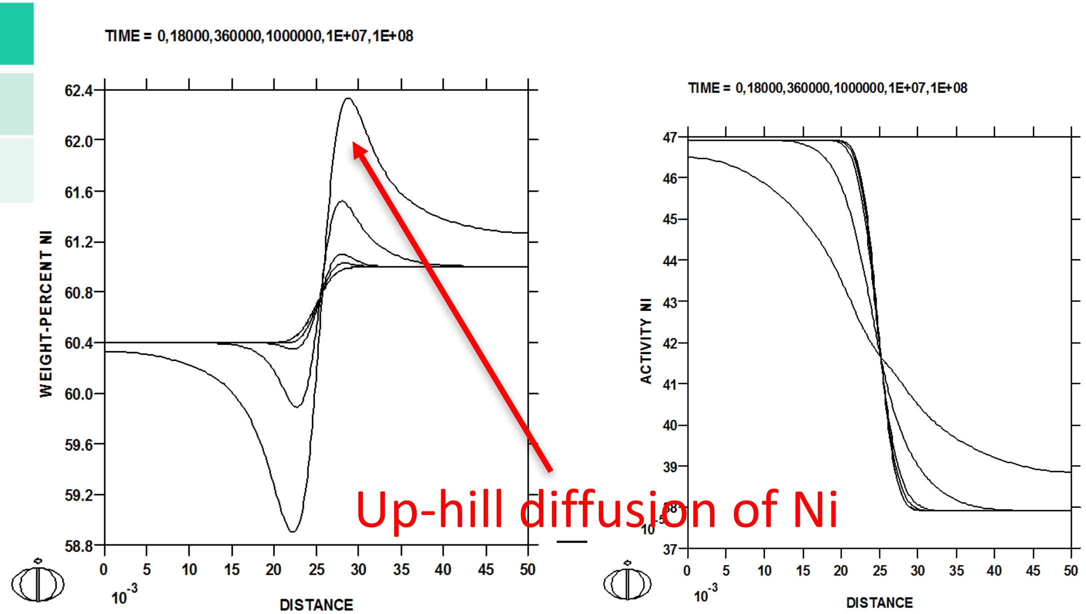
Continuous β layer



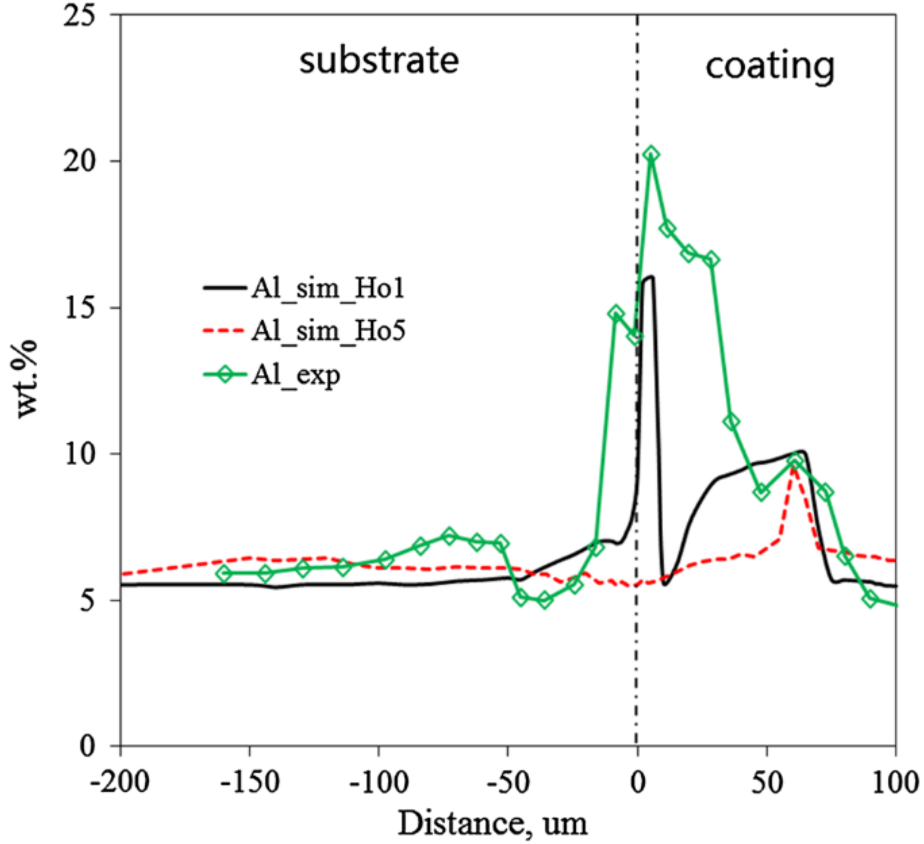


	Ni	Co	Cr	Al	Ta	W	Re
b1	60.2	9.6	6.3	5.5	7	7.2	4
b2	61	18	12	8	1	0	0

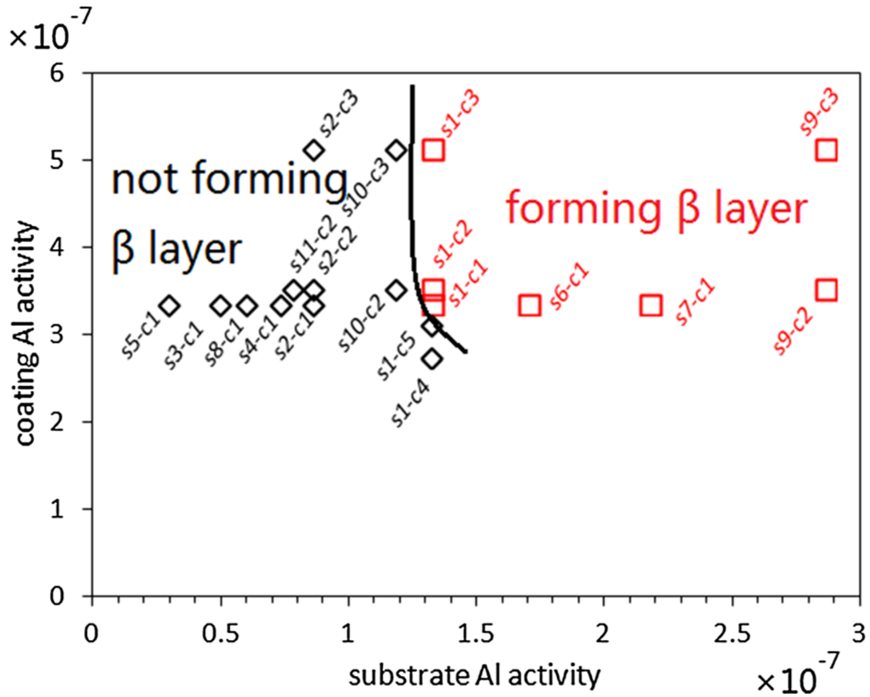




Continuous β layer



Homogenization model 1>model 5:
Calculation of effective elemental diffusivity



Continuous β layer:

- High Al activity in coating and substrate
- Ni uphill diffusion

Modelling of matching between different substrate and MCrAlY coating

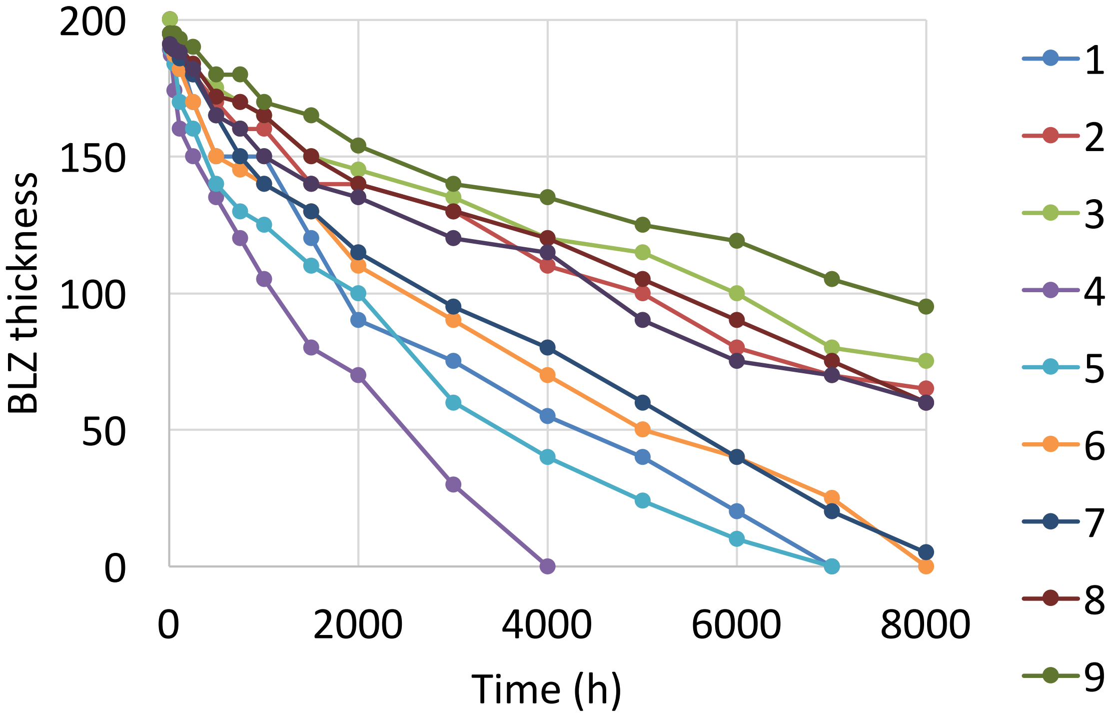
Low c(Al)_sub = low ac(Al)
Low c(Al)_coat ≠ low ac(Al)

No	COAT	SUB	c(Al)_sub	c(Al)_coat
1	high c(Al) Armdry365	Rene 41	1.5	12.5
2		In-792	3.4	12.5
3		CMSX-4	5.6	12.5
4	low c(Al) Armdry997	Rene 41	1.5	8.5
5		In-792	3.4	8.5
6		CMSX-4	5.6	8.5
7	Medium c(Al) high ac(Al)	Rene 41	1.5	10.5
8		In-792	3.4	10.5
9		CMSX-4	5.6	10.5

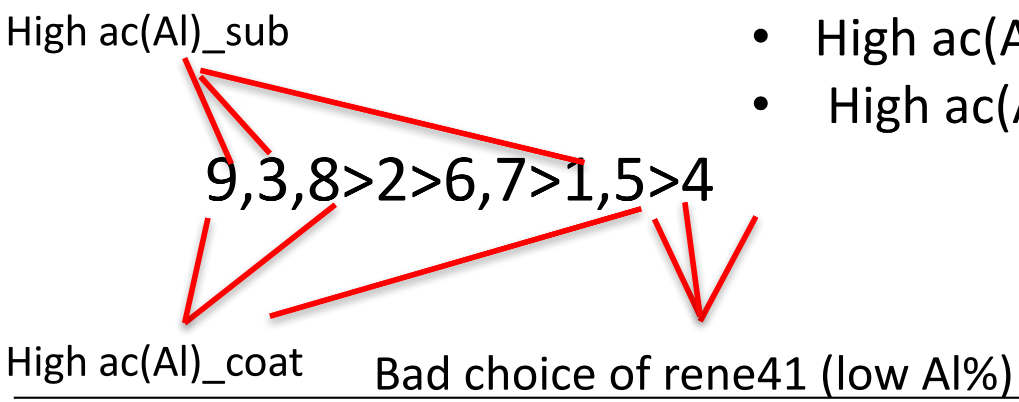
Simulation set-up:

- TCNI5&MOBI2
- 950 C
- 200 micron coating thickness
- Oxidation rate Kp=0.02
- Time step: run till no beta left

BLZ thickness



BLZ thickness order:



- High ac(Al)_sub & coat is a good match.
- High ac(Al)_sub decrease IBDZ depletion

Summary

- New refined MCrAlX Ni-based coatings were tested and shown good long term oxidation resistance.
- Surface treatments by SP or LSM: improve oxidation resistance
- Hf: significant increases oxidation rate, negative effects
- D74 as Bond coat in TBC: improve TBC life
- DBTT&TMF: D10>D11>D71 for coating ductility
- Oxidation diffusion model:
  - Explain the formation of continuous beta layer
  - Coating and substratet matching: Al activity is important
- Good progress in the project as planned

Future work

- Selected coatings from previous work
  - Corrosion testing
  - Ductility testing
  - TMF testing
  - Creep testing
- Simulation to help understanding the degradation mechanisms and validation of the oxidation-diffusion model for alloy design and life modelling

Acknowledgment

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Energiforsk

KME
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Thank you for your attention!

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