Durable MCrAlX Coatings for demanding applications in gas turbines

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Project team for KME 703

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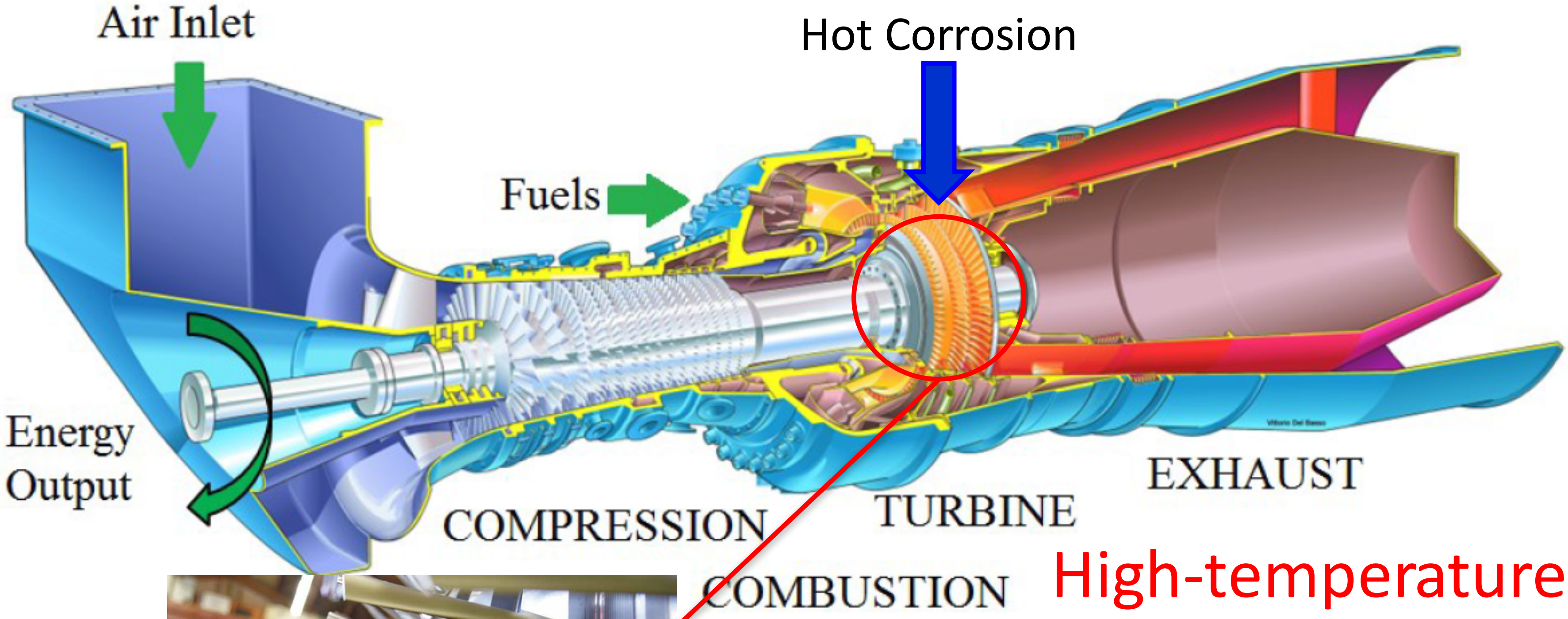
Outline

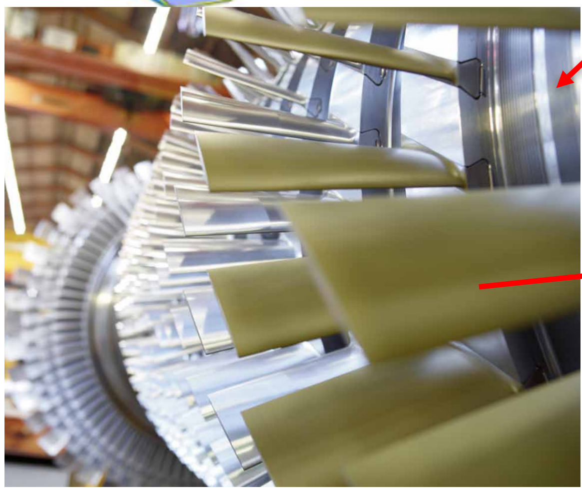
- Background
  - General introduction
  - KME 703
- Project works and results
  - Oxidation test
  - Coating characterization
  - Simulation modelling
- Summary
- Future work

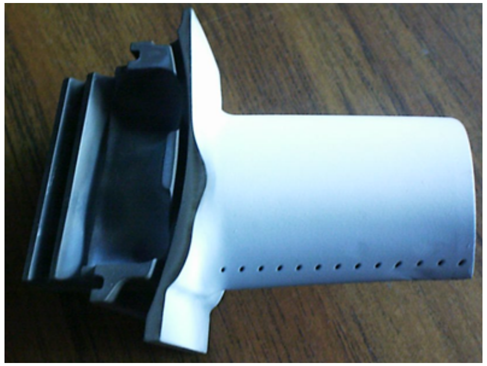
Gas turbine

High-temperature exposure:
Oxidation
Hot Corrosion

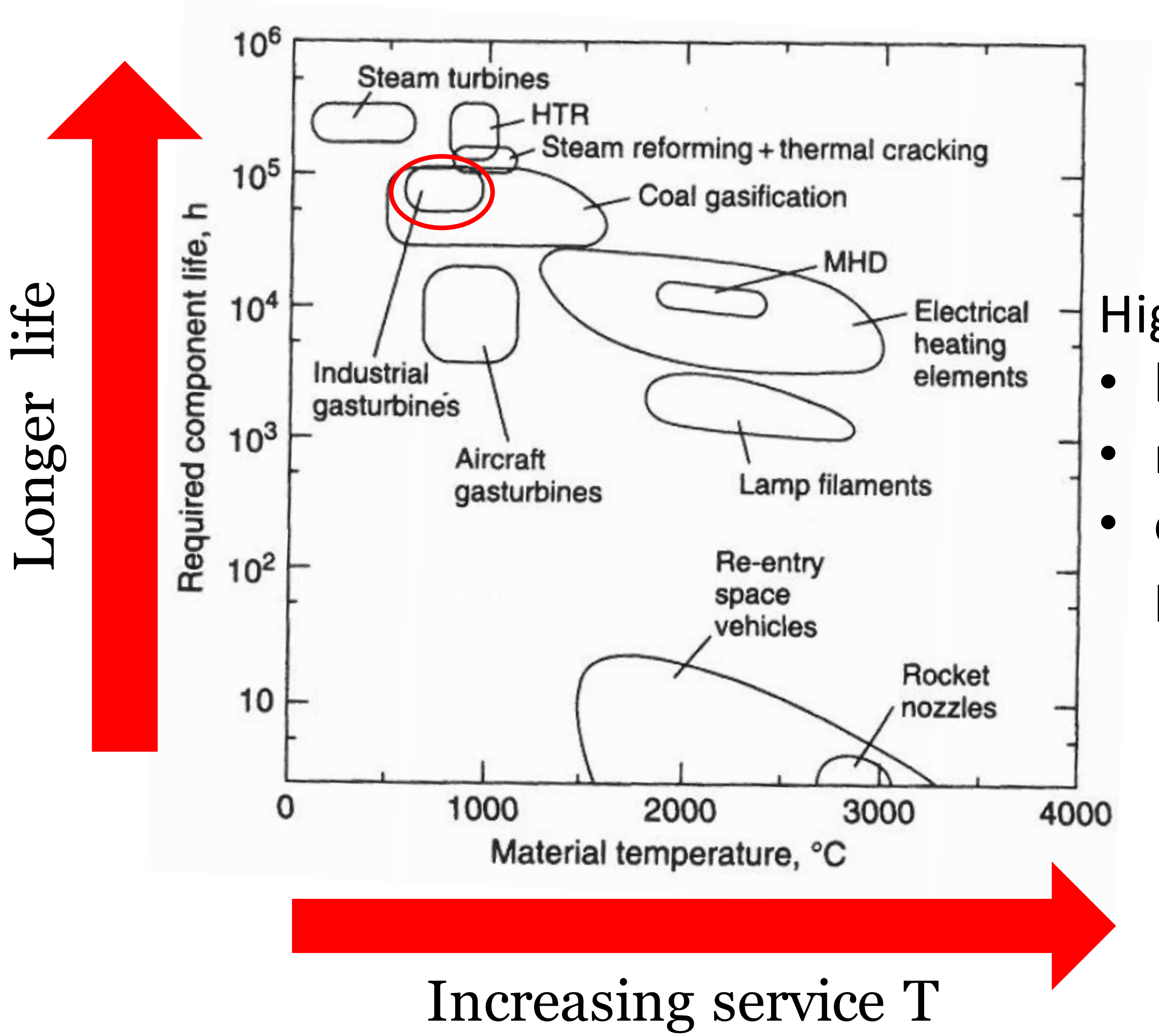


High-temperature coatings are required!!





Challenge of coating design



High-performance :

- longer life
- resistant against TCF
- optimized mechanical property

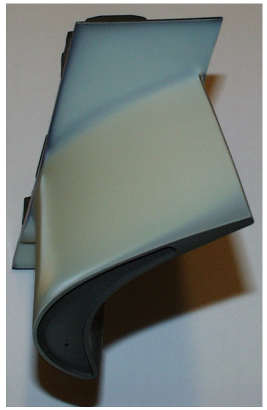
MCrAlX High-temperature coatings

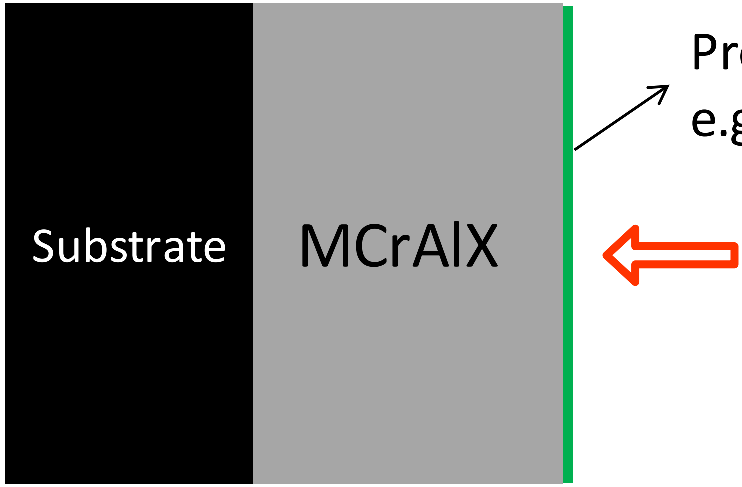
- **Metallic coatings** (oxidation and hot corrosion resistance)
- **Ceramic coatings** (heat insulation)

MCrAlX or MCrAlY

Yttrium

Chromium Aluminum Minor element





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

Atmorsphere
(oxygen, etc.)

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

Project progress

MCrAlX coating systems:

1. Fe-containing coatings for cost reduction-D7#
2. Minor elements modified (Ru, Ce)-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 using oxidation-diffusion model
- Other test is proceeding.

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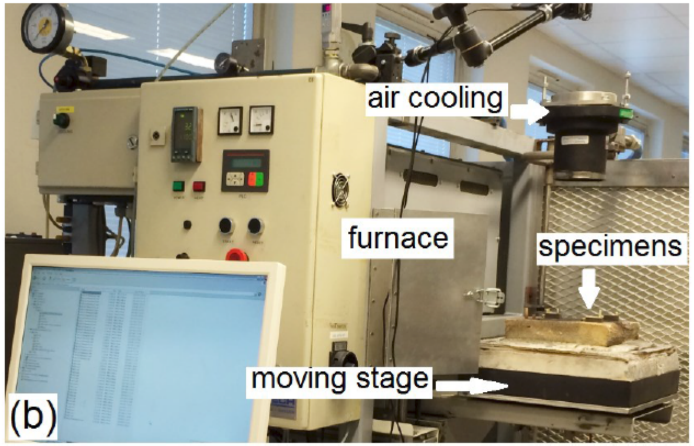
Oxidation test

Isothermal oxidation (in air):

1. 900 °C (0 to 5,000 hours)
2. 1000 °C (0 to 10,000 hours)
3. 1100 °C (0 to 800 hours)



4. Cyclic oxidation (in air):

- One cycle: 1100 °C for 1 hour with 10 min forced-air cooling to 100 °C
- 0 to 800 cycles

Figure. Furnaces for (a) isothermal oxidation; (b) Cyclic oxidation

Oxidation test

Temperature effect

Growth of alumina scale

Scale thickness

time

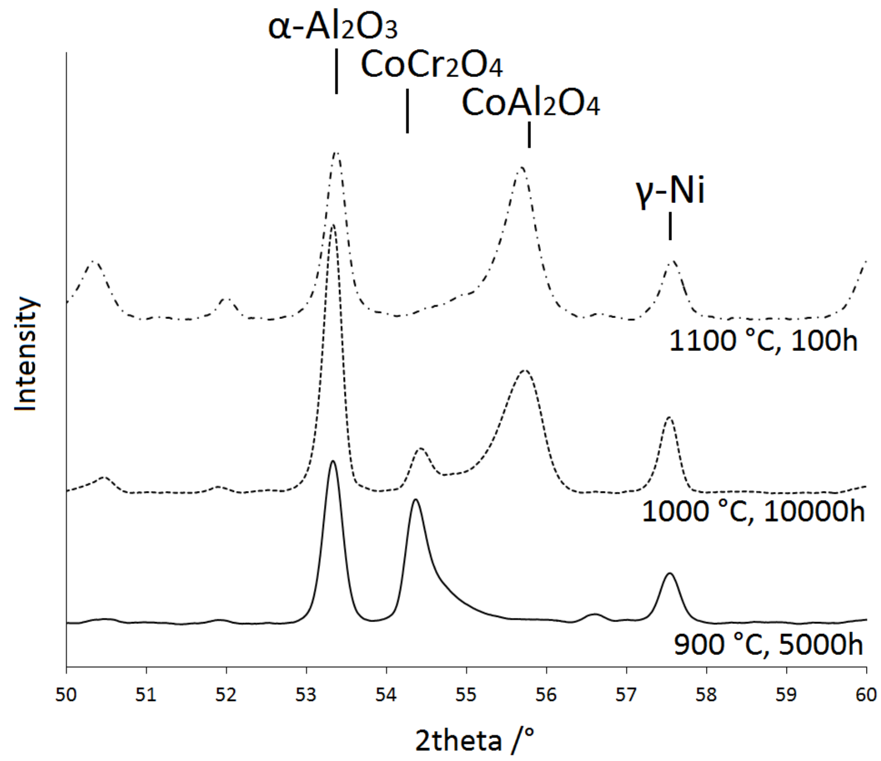
$$h = (k_p t)^{1/2}$$

$$k_p = k_0 e^{-\frac{Q}{RT}}$$

Oxidation constant

temperature

Spinel type



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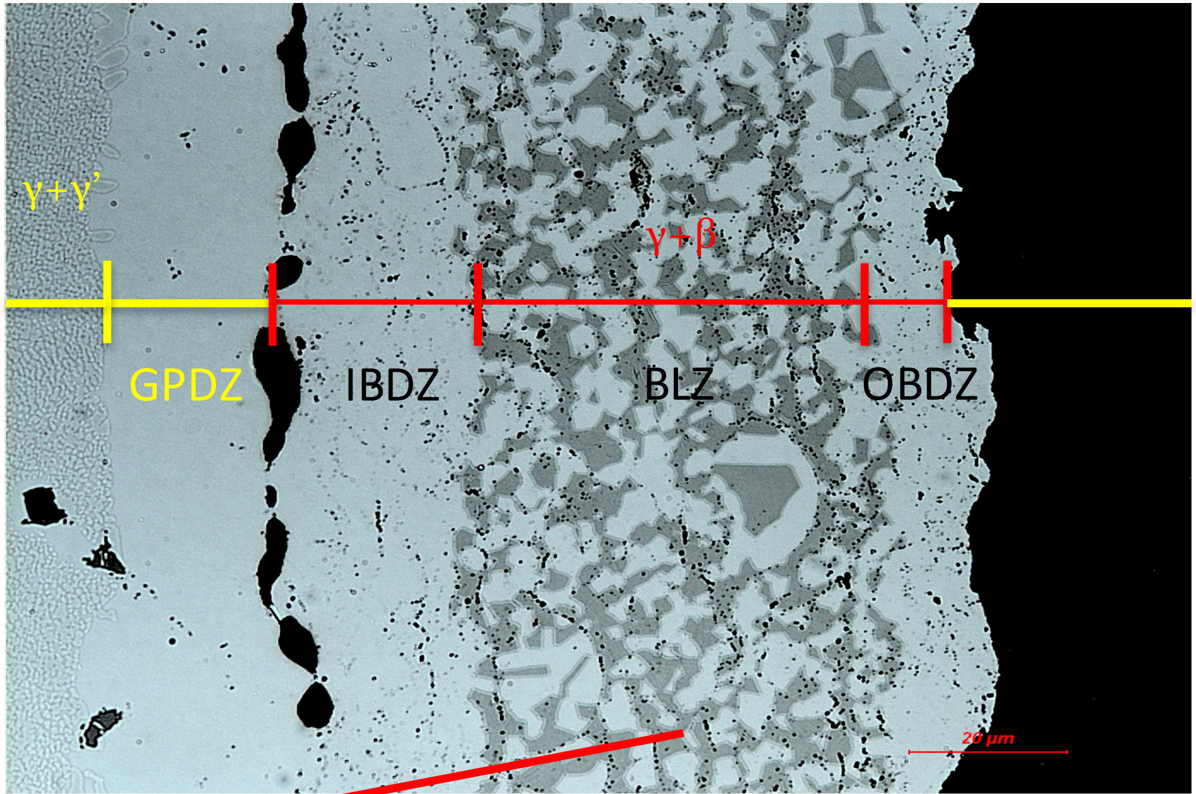
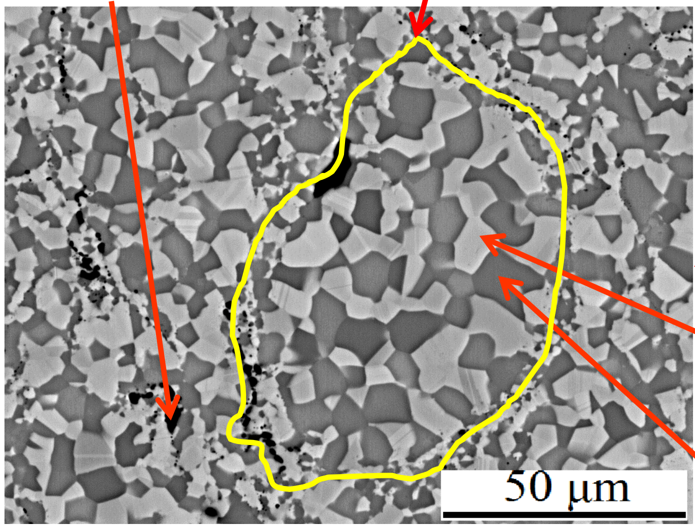
Characterization of coating behavior

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



splat-on-splat structure

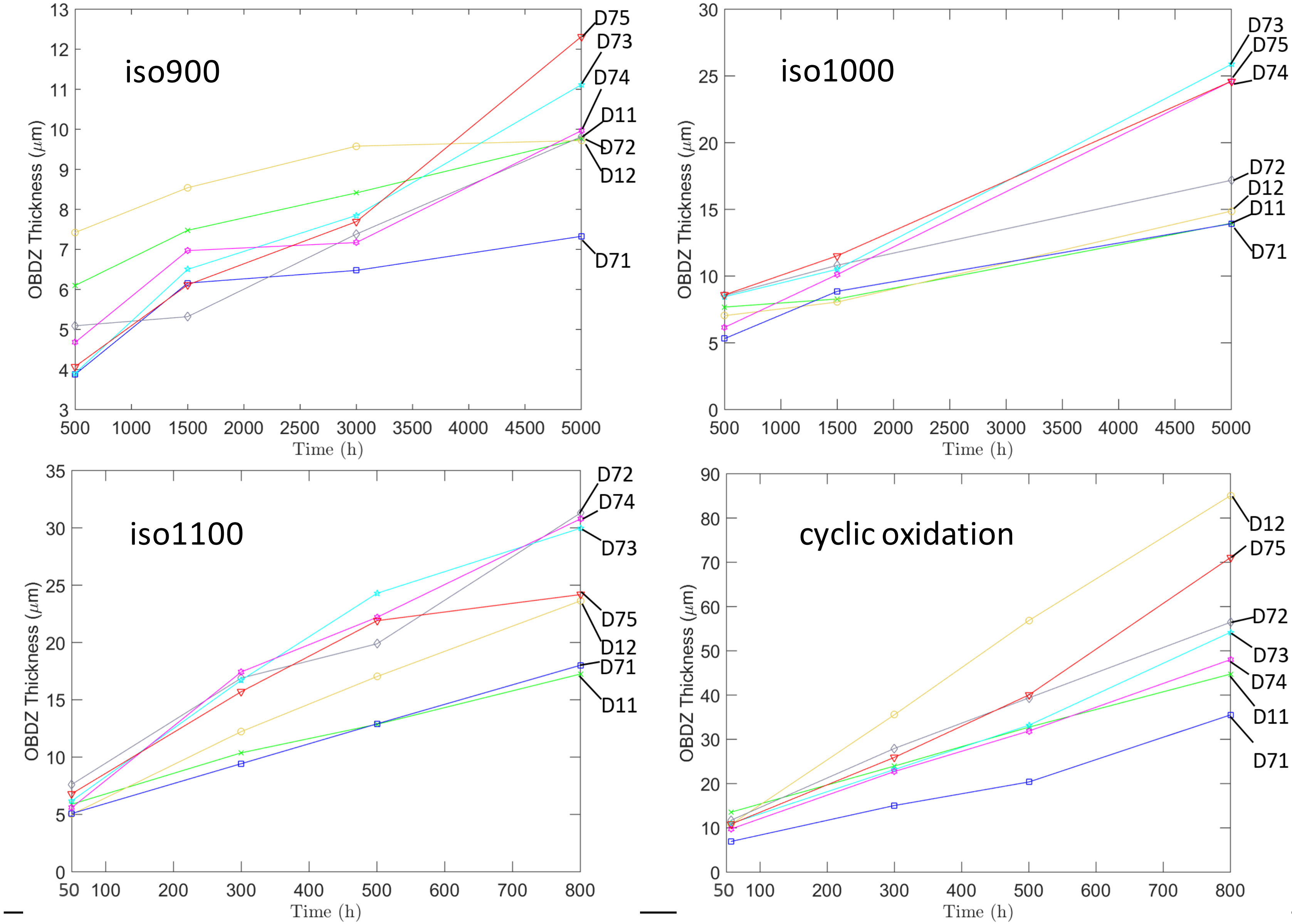
Y-rich



γ-(Co,Cr,Ni, …)

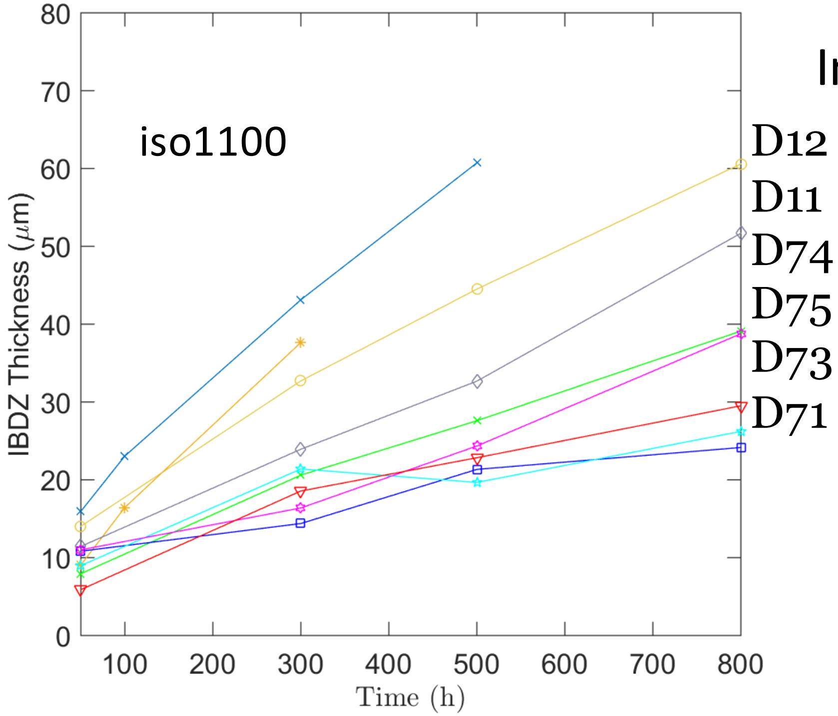
β-NiAl

Outer beta depletion zone (OBDZ)



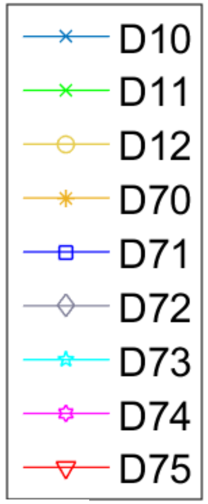
Stand deviation: 1-3 µm (short time), 10-15 µm (long time)

IBDZ vs. GPDZ

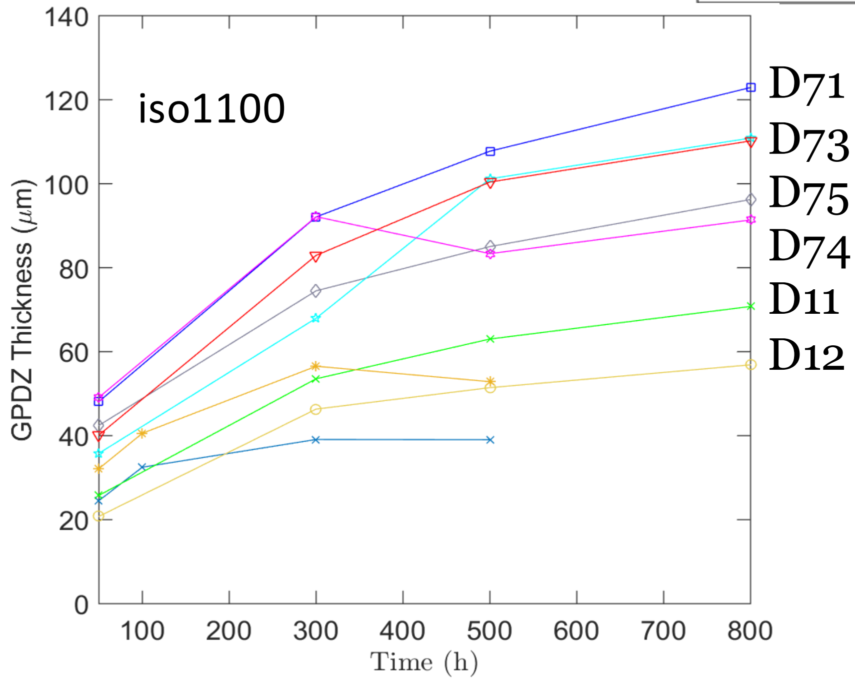


Inner beta depletion zone (IBDZ)

Fe-containing coatings



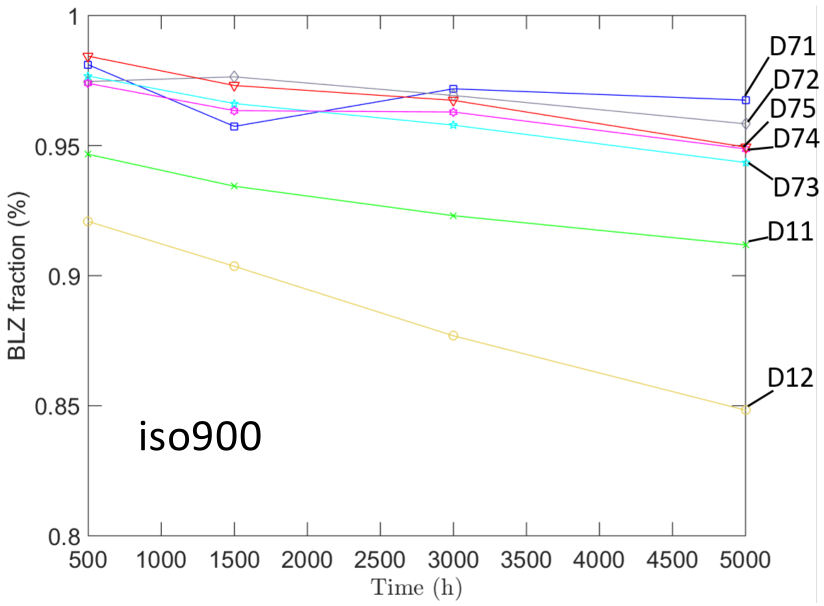
Gamma prime depletion zone (GPDZ)

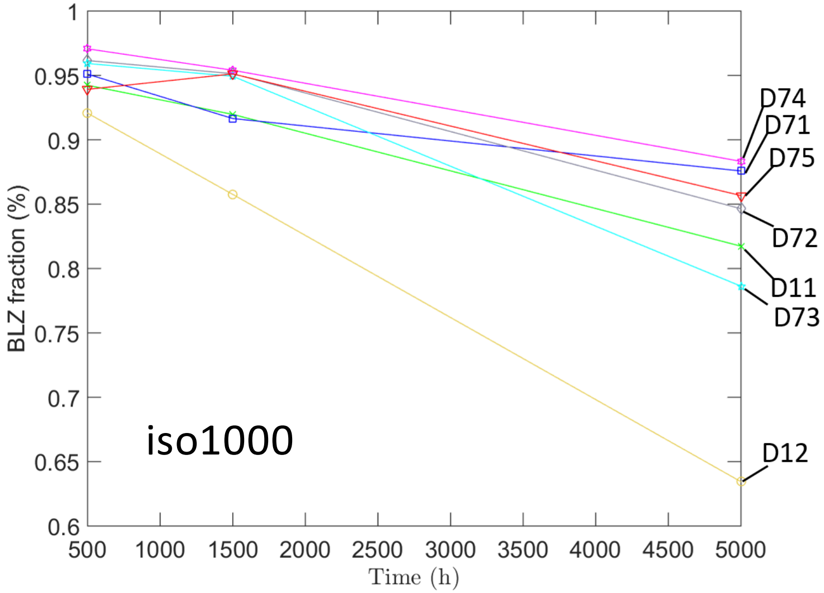


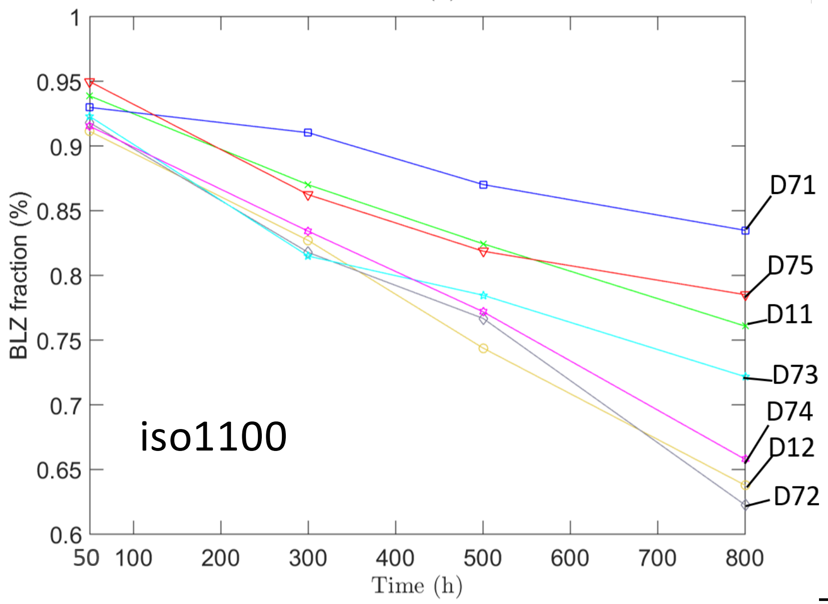
D7#:

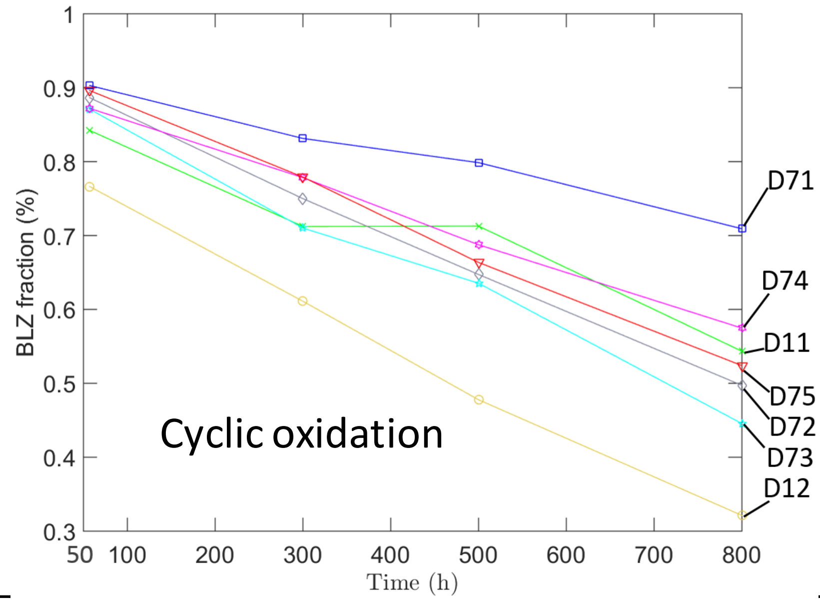
- Coating: decrease IBDZ
- Substrate: increase GPDZ

Beta left zone fraction (BLZ)









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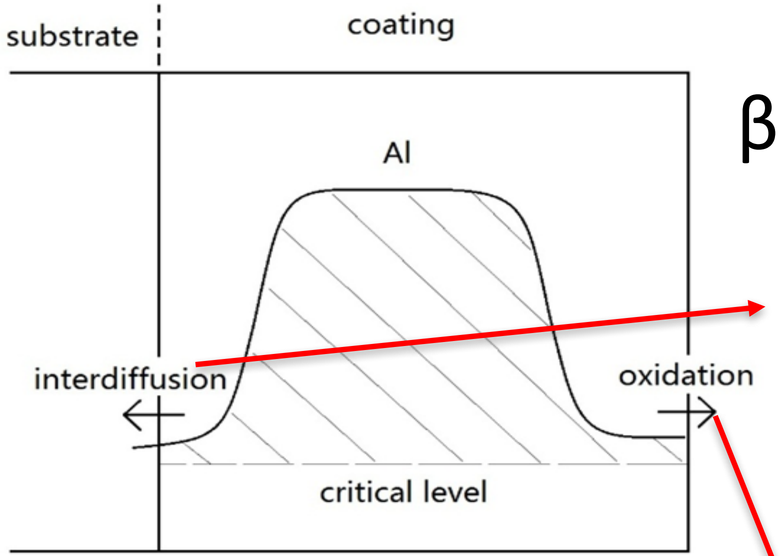
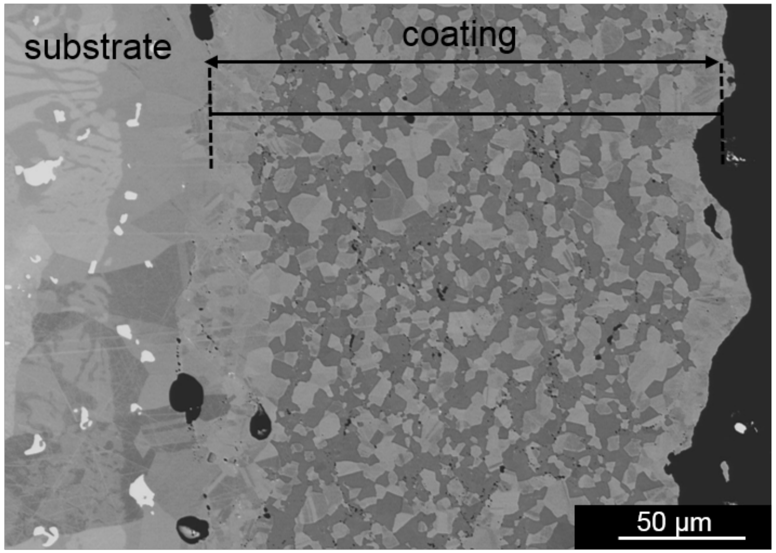
Oxidation-diffusion model

Model



Exp



β phase depletion in coating

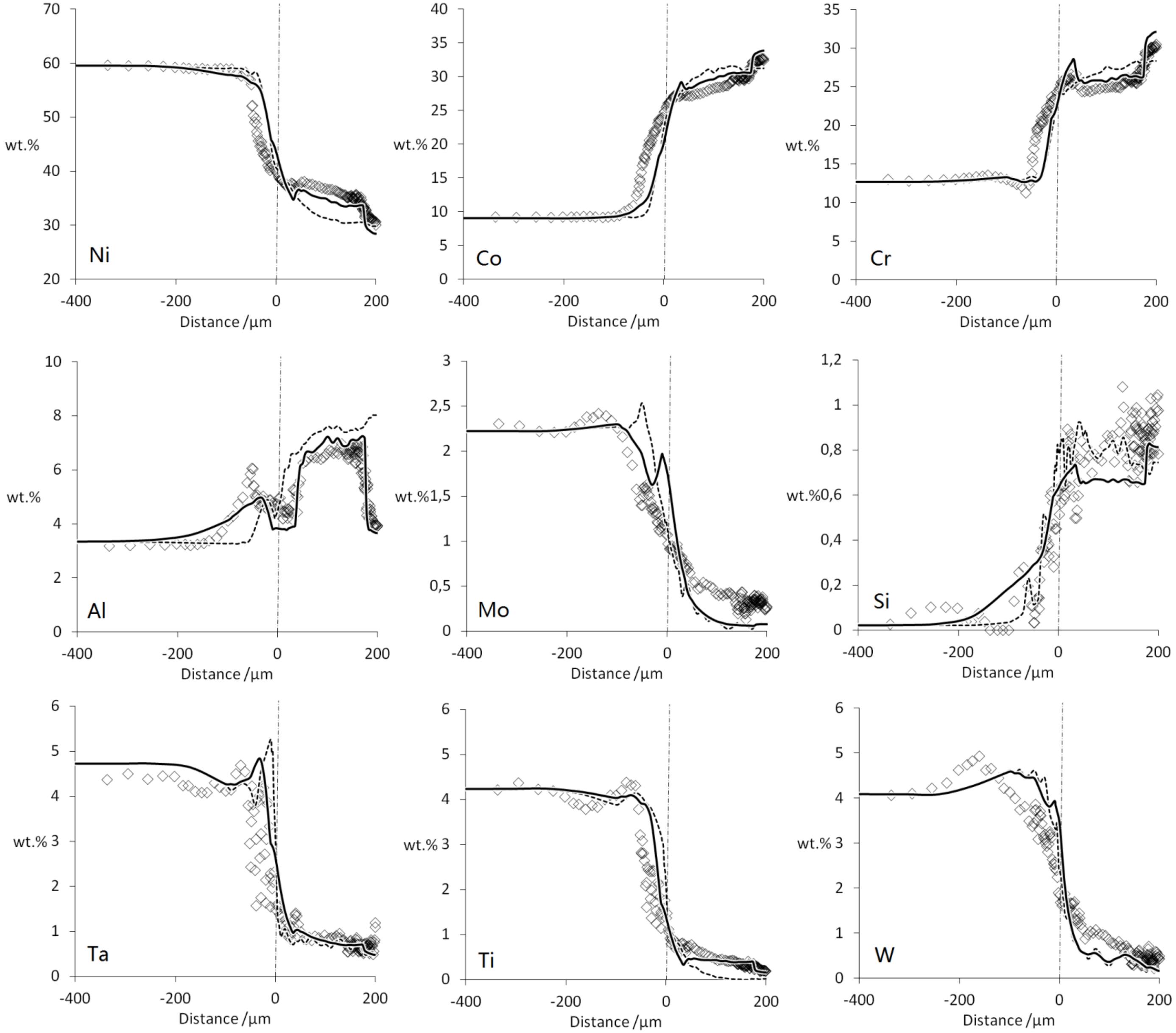
- Interdiffusion:

Thermodynamics and kinetics (diffusion, microstructures)
– DICTRA

- Oxidation:

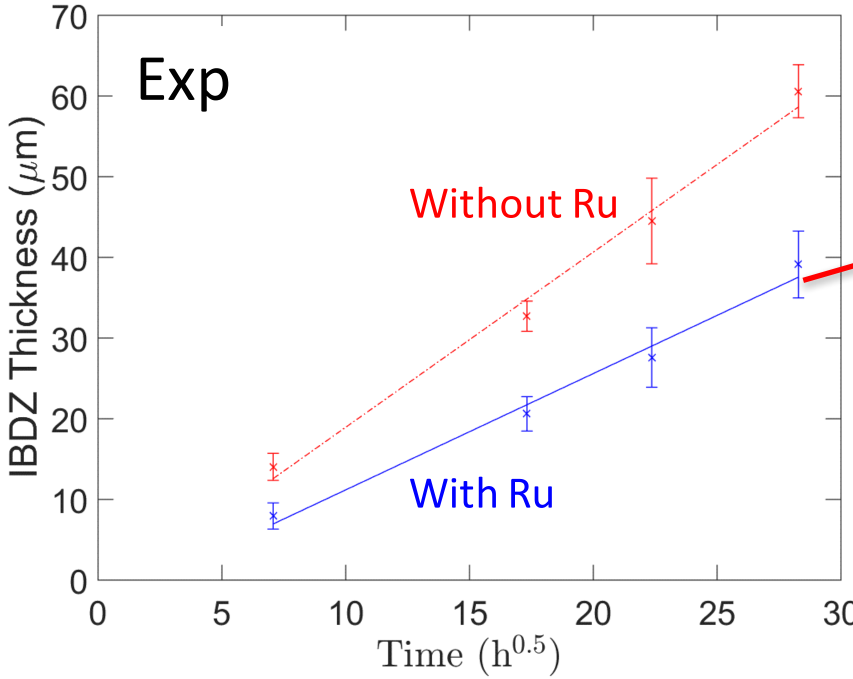
Oxidation law ($h = h_0 + (kt)^{1/n}$, $e.g.\ h = (kt)^{1/2}$)
– experimental fitting, Matlab

Oxidation-diffusion model

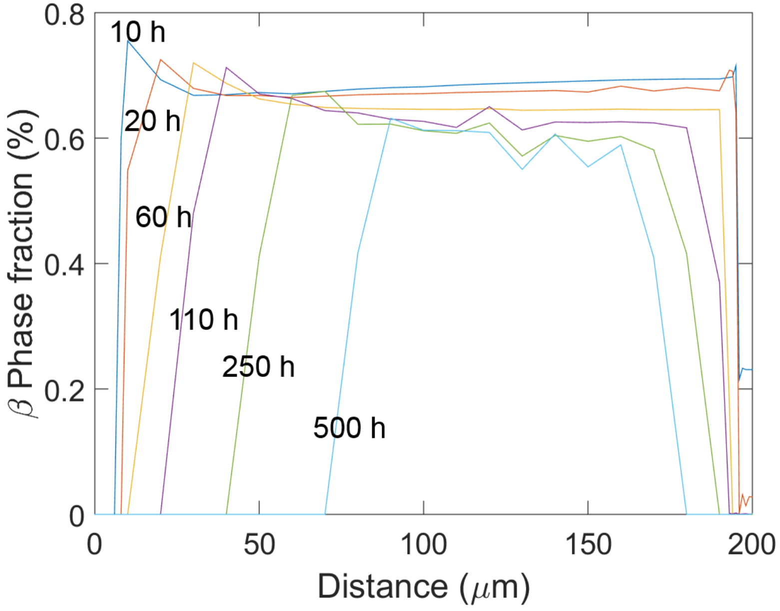


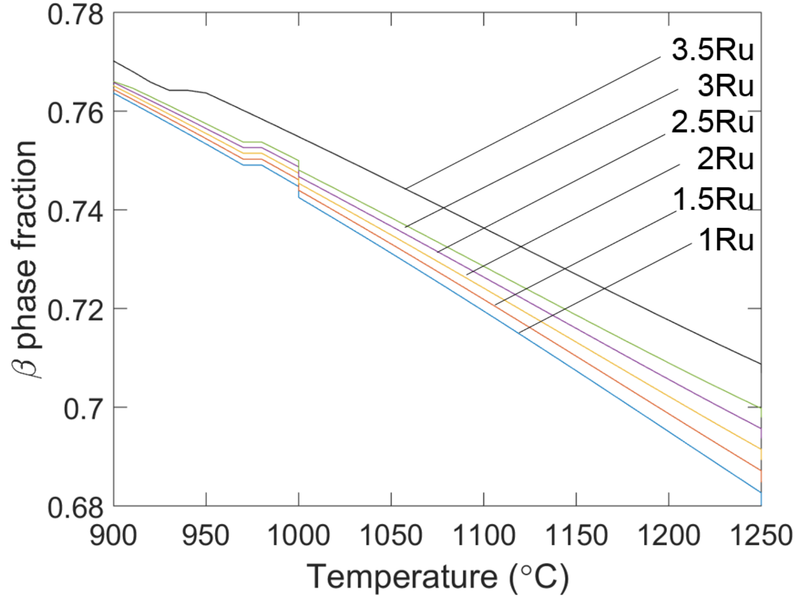
Simulation result: the Al composition profile in a sub-coat system after an oxidation at 1100 °C for 50 hours

Ru-effect



Simulation





Ru:

- β phase stabilizer
- Retard inward diffusion of Al

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Summary

- New MCrAlX coatings were tested.
- Reactive elements (e.g. Hf): significant influence on oxidation rate, temperature effects
- Ru retards interdiffusion between coating/substrate.
- Replacement of Y by Ce: more rapid β-depletion (cyclic oxidation test).
- D7#: good inner beta depletion resistance, big influence on substrate.
- D71 and D11: the best resistance against overall β-depletion.
- Good progress in the project as planned

Future work

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

Thank you for your attention!

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