Microstructural evolution in Fe-Al-Mn-C lightweight alloys

Ian ZUAZO
Yves BRECHET

Laboratory of Science and Engineering of Materials and Processes (SIMaP)
Grenoble Institute of Technology (INPG)

- Contents

1. Materials

Compositions

Fe-Al-Mn-C

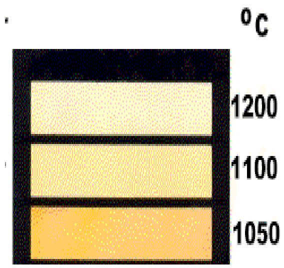
wt% (Fe balanced)

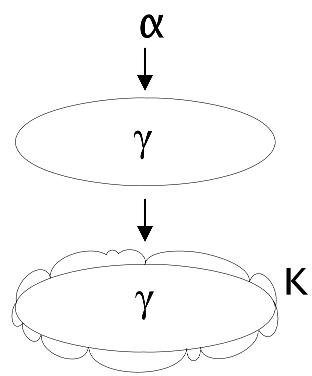
Alloy	C	Al	Mn
B (low-Mn) (1st cast)	**0.2**	**8.77**	**1.28**
B (low-Mn) (2nd cast)	**0.225**	**9.2**	**1.71**

- Contents

2. Transformations – low Mn alloy

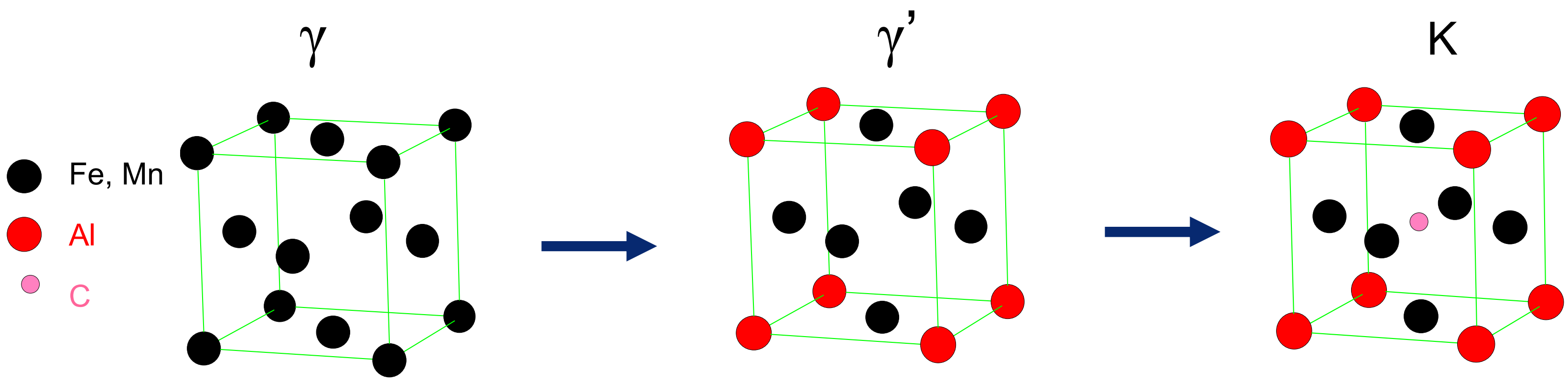
Phase transformations during cooling





Austenite nucleation and growth

Formation of K-phase
at the α/γ interphase boundary



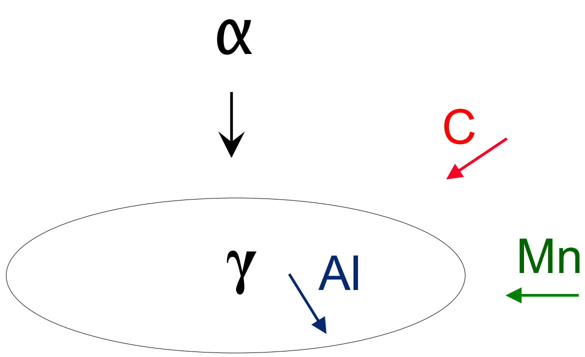
FCC disordered

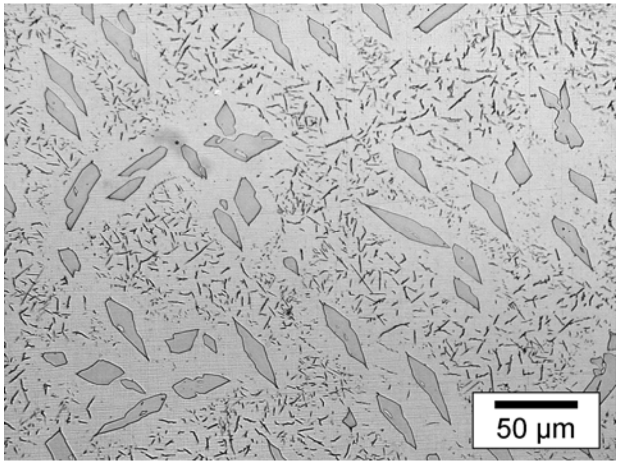
FCC ordered

K - phase (Fe,Mn)$_3$AlC

- Contents

Isothermal austenite growth in the low Mn alloy

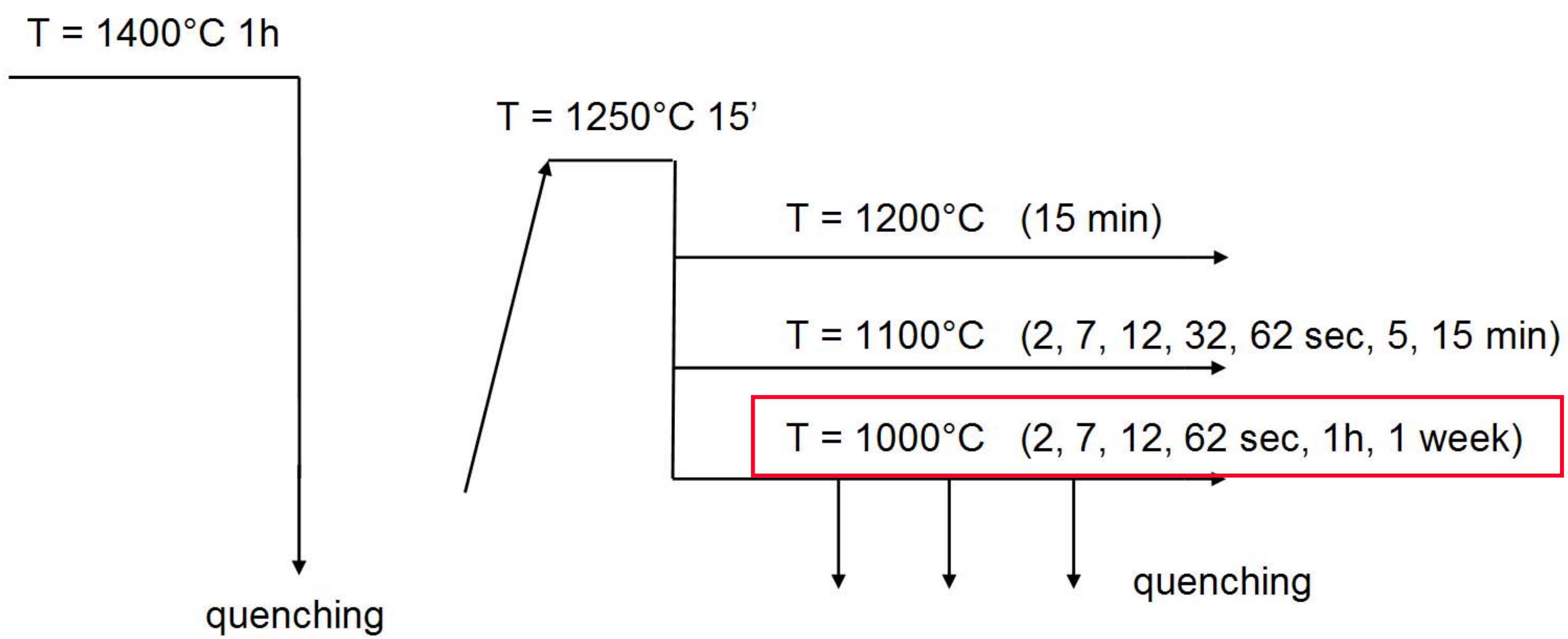




4. Austenite growth – 1000°C

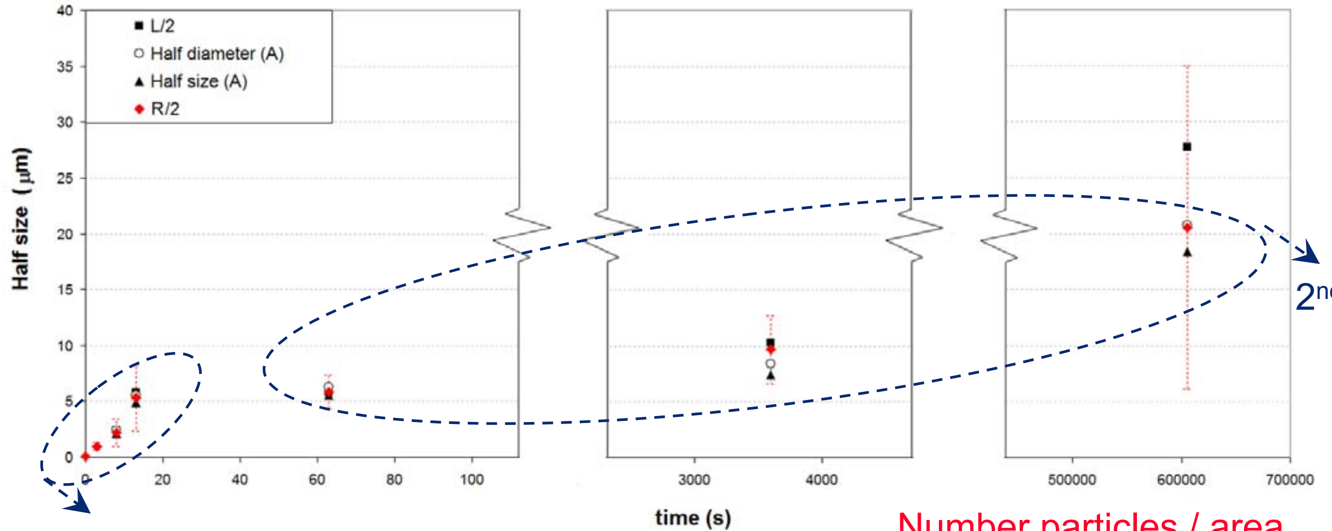
Composition and heat treatments

Alloy	C	Al	Mn
B (low-Mn) (2nd cast)	**0.225**	**9.2**	**1.71**



4. Austenite growth – 1000°C

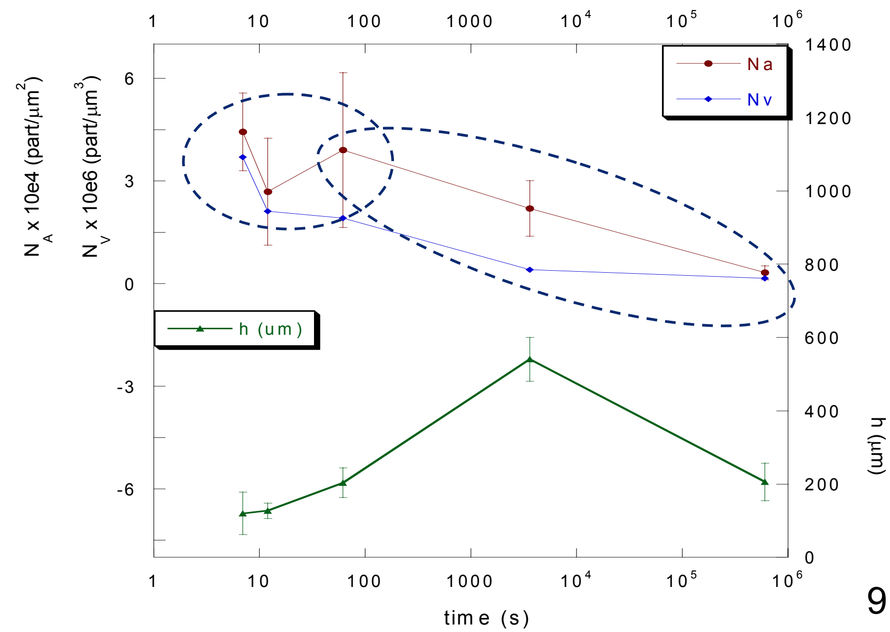
Growth kinetics



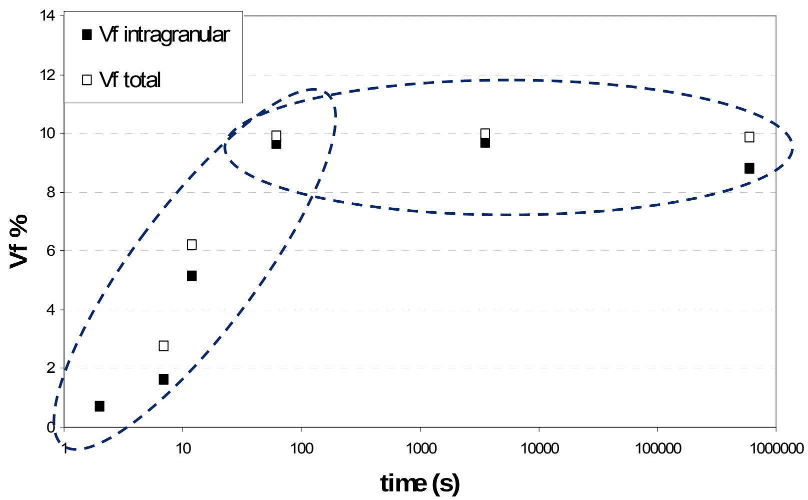
2^{nd} stage - Coarsening

1^{st} stage

Number particles / area
Number particles / volume

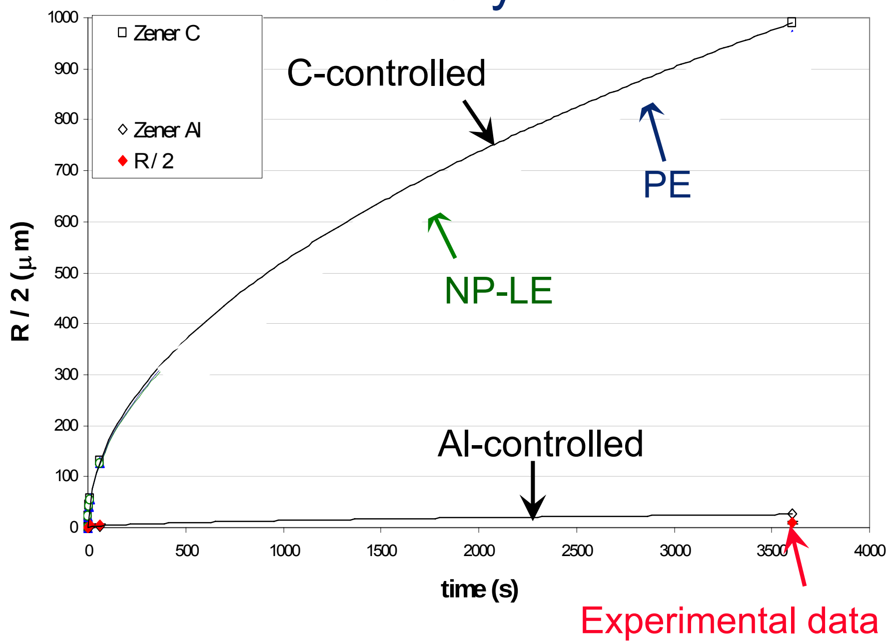


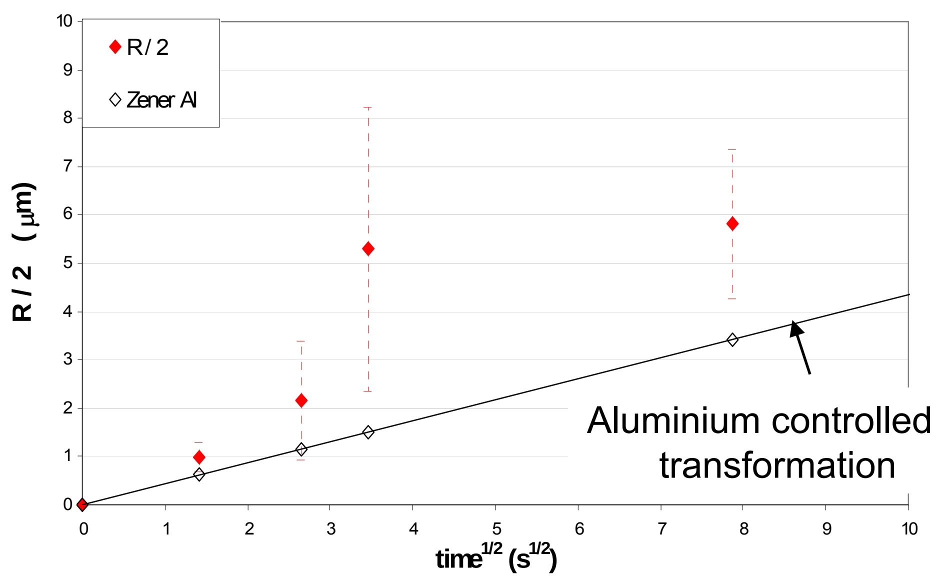
Volume fraction



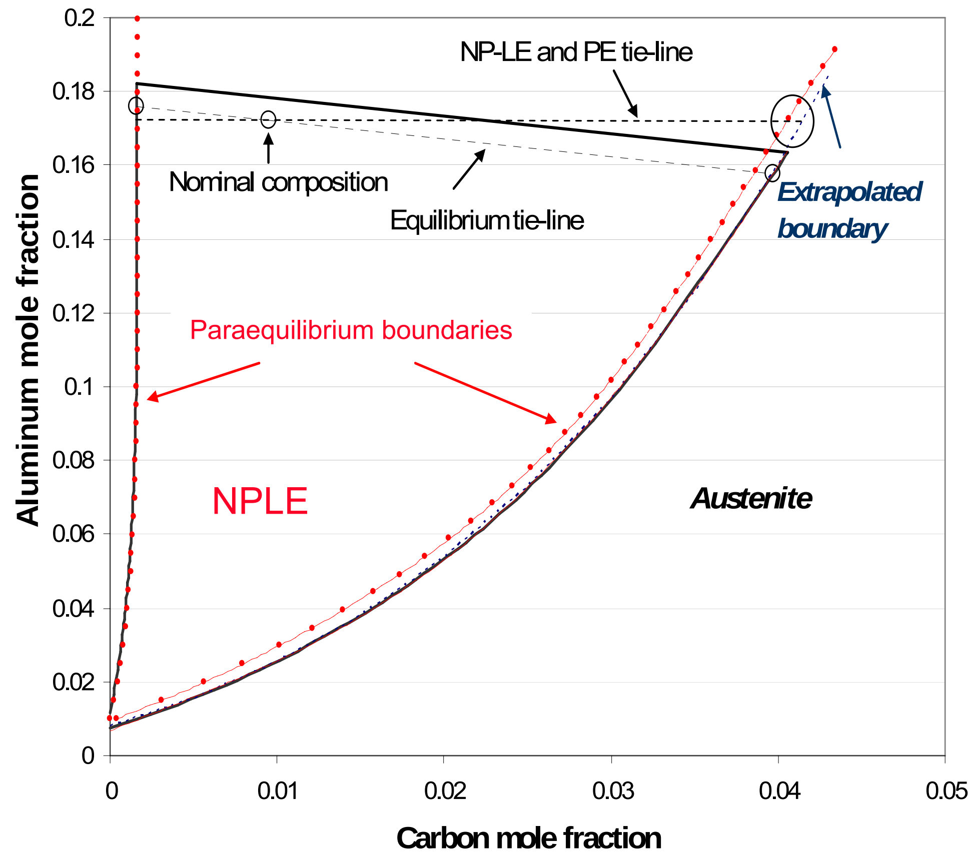
4. Austenite growth – 1000°C

Modeling binary





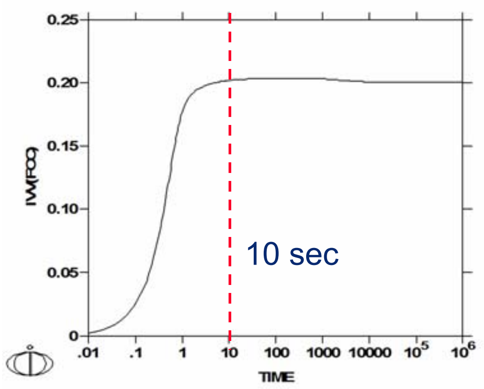
ternary



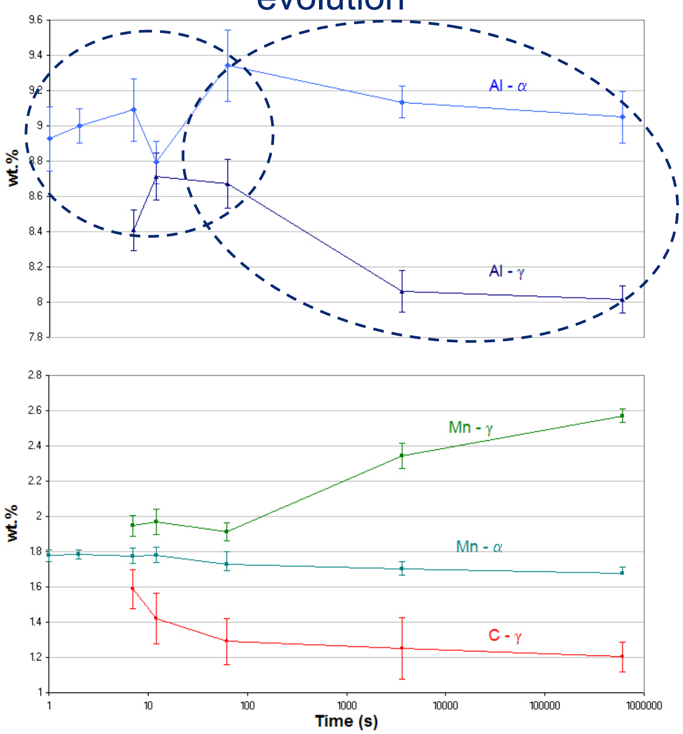
4. Austenite growth – 1000°C

DICTRA

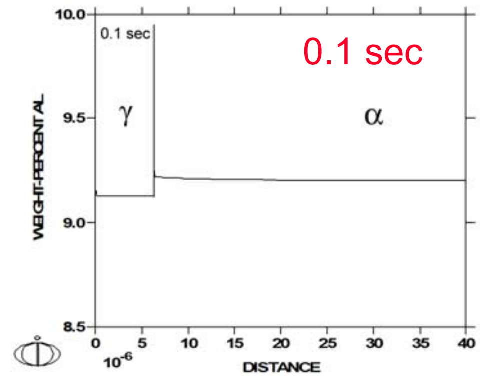
V_f

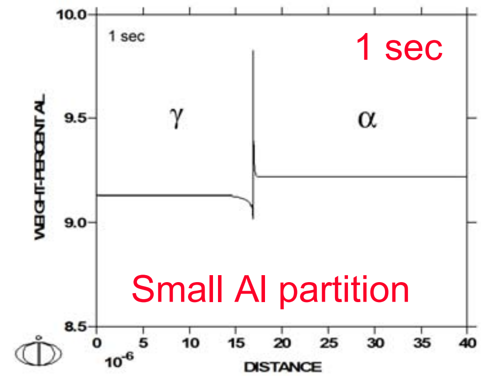


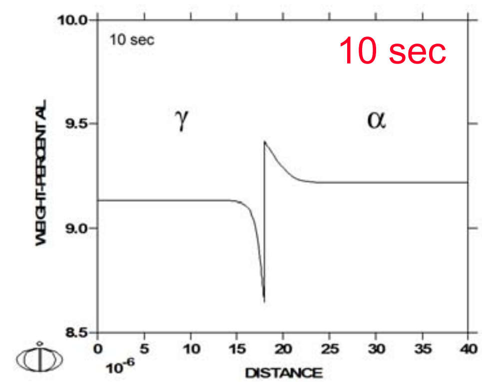
Experimental compositional evolution

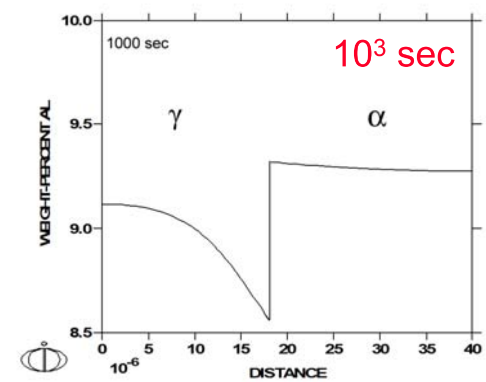


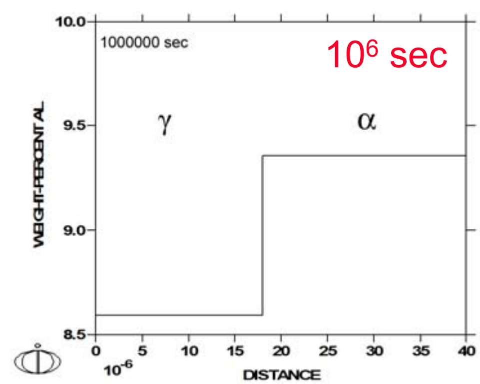
Al compositional profiles











Al partition towards equilibrium

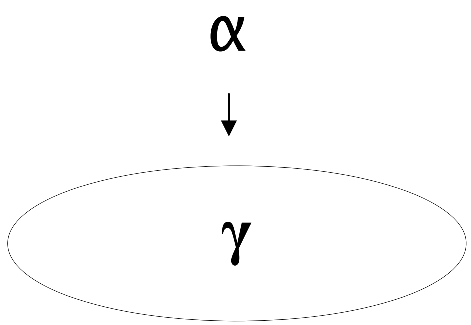
No growth

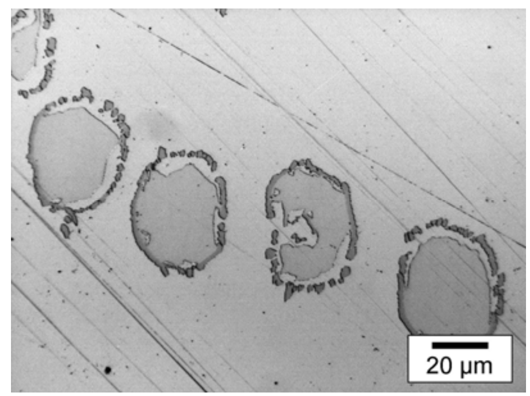
Summary

- 1000°C very short incubation time
- Two stages are observed, the first one relatively rapid with carbon partition and small partition of alloying elements, the second one marked by coarsening
- Thermodynamic database is not accurate enough for this composition
- Binary diffusion model show that Al might be the rate controlling element, ternary model shows too fast rates, DICTRA shows a rapid first stage and no growth at a second stage

- Contents

K-phase growth at ferrite/austenite interface in the low Mn alloy

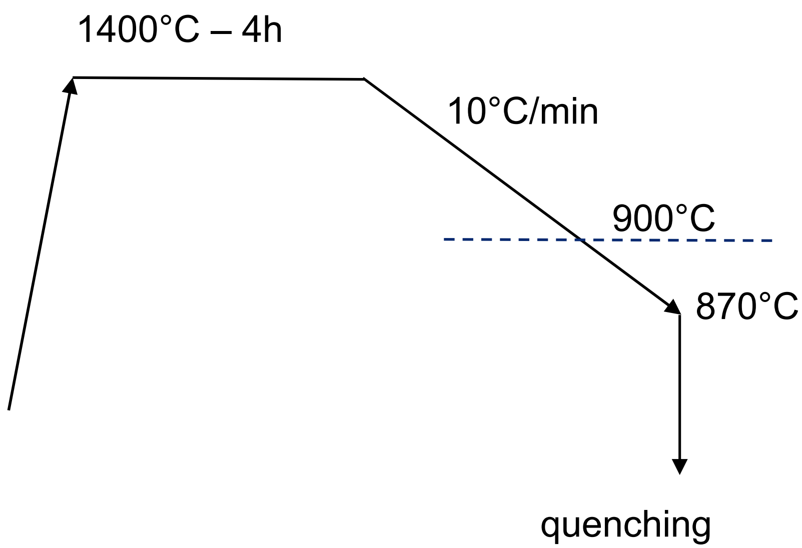




5. K-phase growth

Morphologies
Orientation relationships

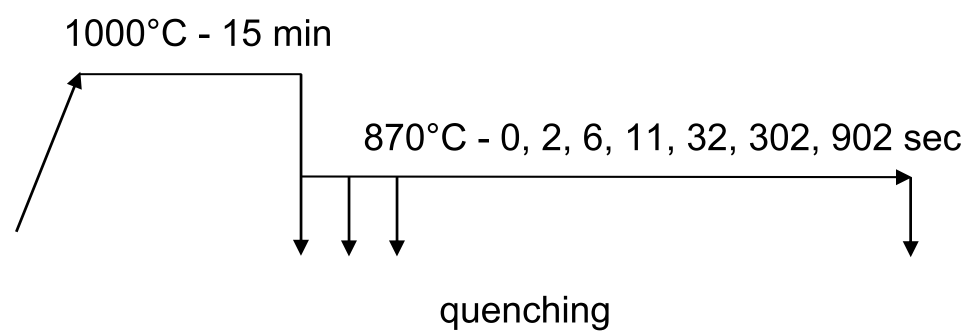
Non-isothermal



Alloy	C	Al	Mn
B (low-Mn) (1st cast)	**0.2**	**8.77**	**1.28**

Growth kinetics

Isothermal

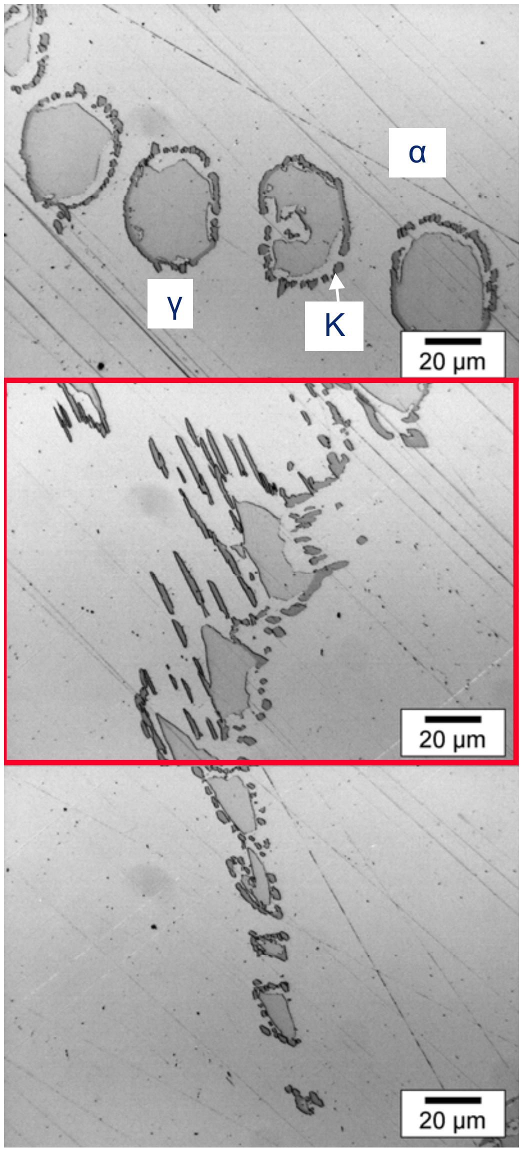


Alloy	C	Al	Mn
B (low-Mn) (2nd cast)	**0.225**	**9.2**	**1.71**

5. K-phase growth

2D microstructural observations

Large grains > 500 μm



- *Nucleation*

  mainly at α / γ boundaries, also intragranular and ocasionally α/α grain boundaries

- *Morphology*

  Allotriomorphs (continuous and broken)

  Needles (at GB and ends of rod-like austenite)

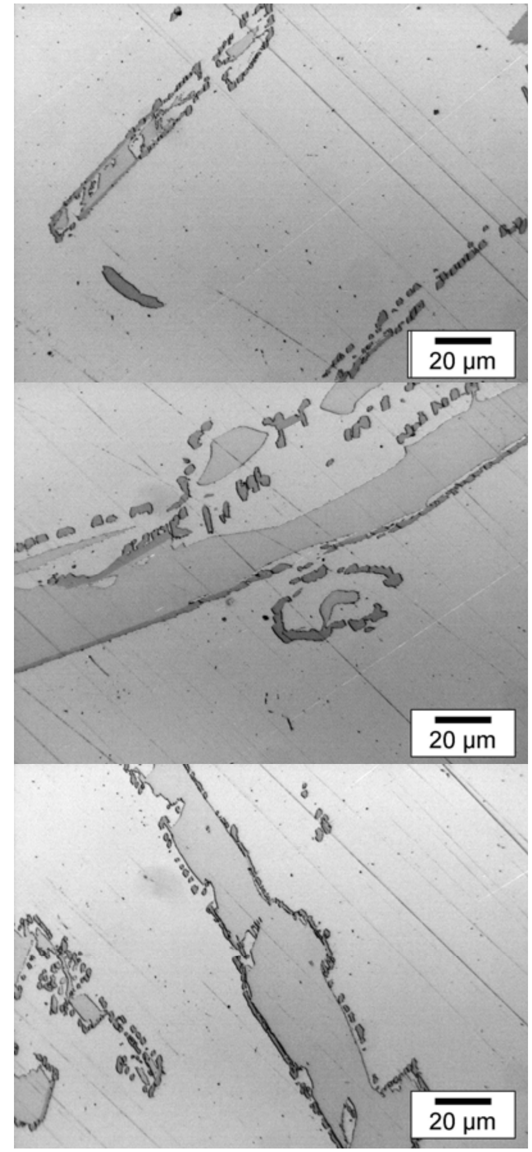
  Thickness less than 2 μm

- *Mechanism*

  Growth into ferrite but growth into austenite not evident

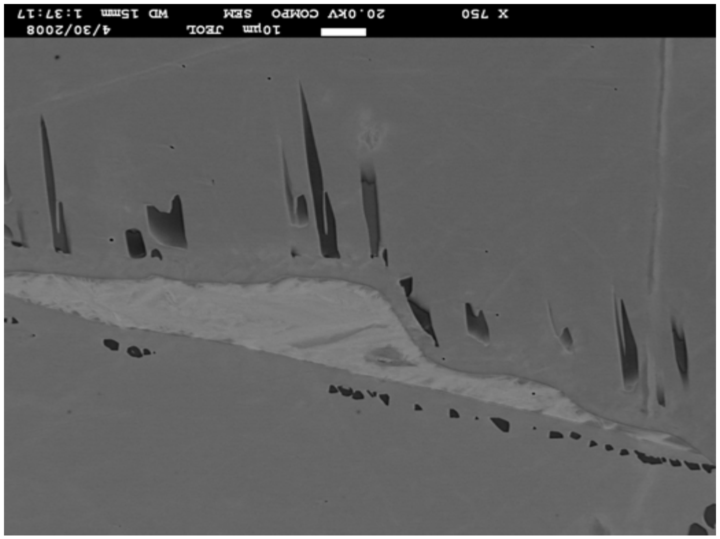
  Austenite instable due to carbon lost turn into ferrite

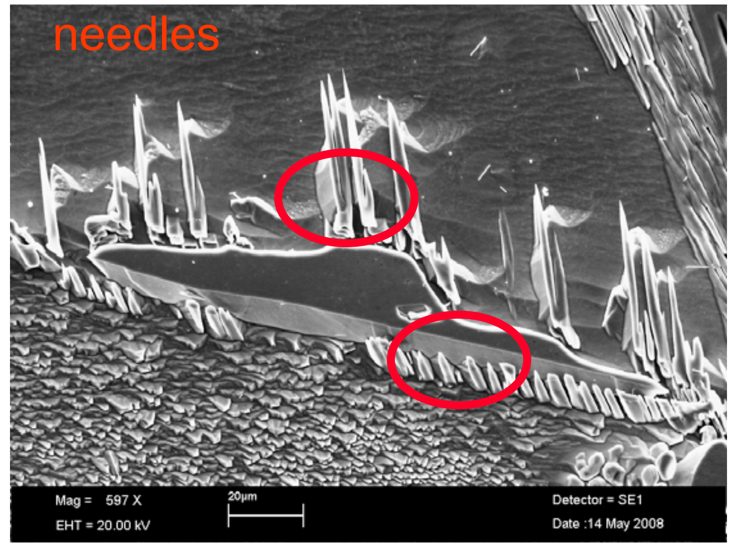
  Aluminium provided by ferrite and carbon by austenite



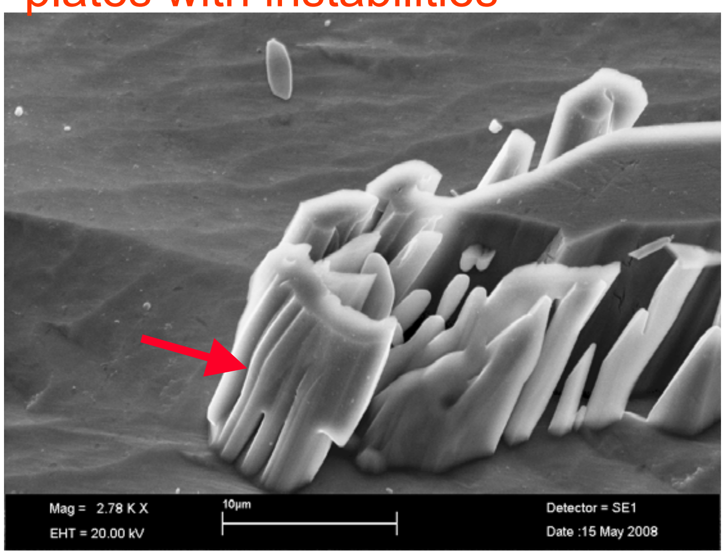
5. K-phase growth

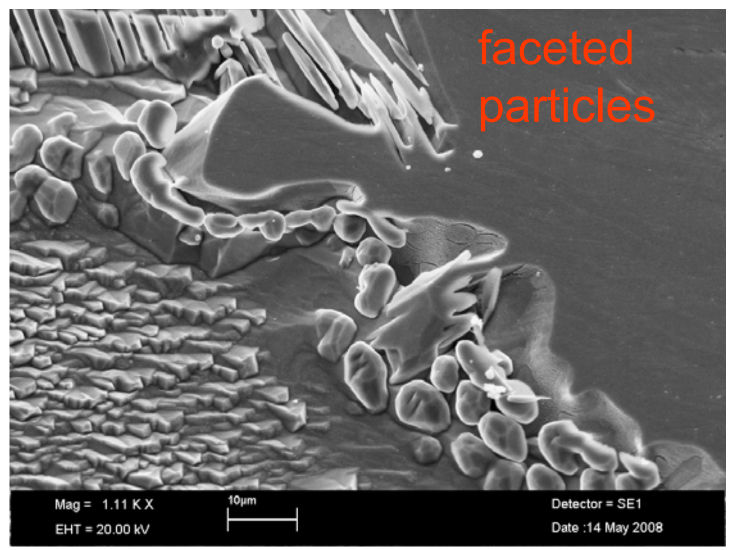
3D Morphologies





plates with instabilities





5. K-phase growth

2D	3D
Morphology	*Morphology*

2D

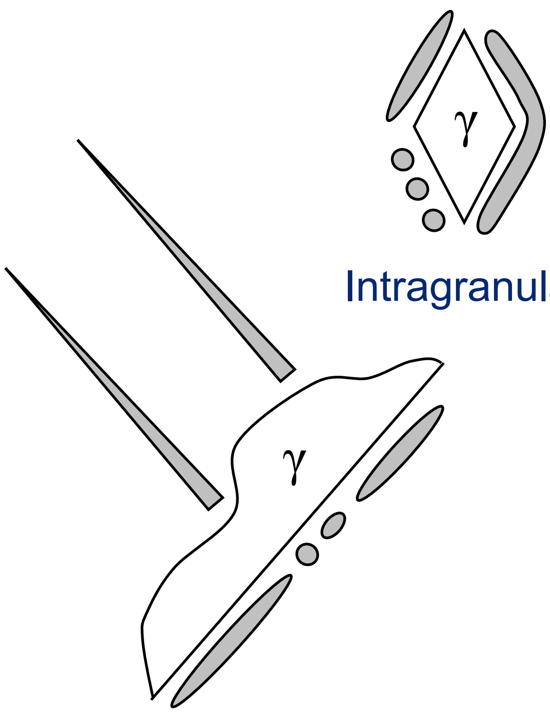
Morphology

- Allotriomorphs (continuous and broken)
- Needles (at GB or ends of rod-like austenite)

3D

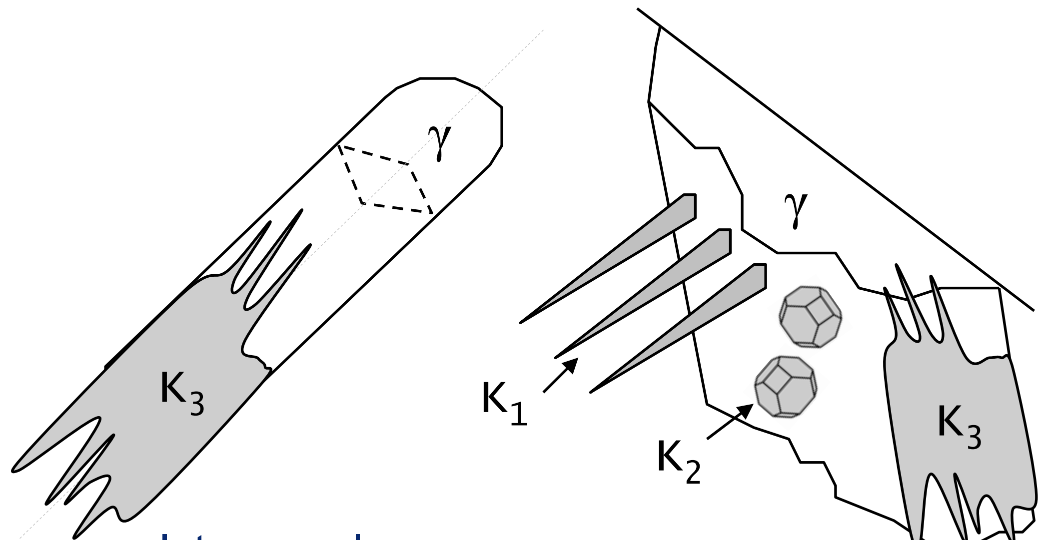
Morphology

- Plates (parallel to rod-like austenite develop instabilities, growth direction in intragranular particles follows long axis)
- Needles (at large angles at GB or // to rod-like intragranular austenite long axis)
- Faceted particles (at GB)



Intragranular

Intergranular

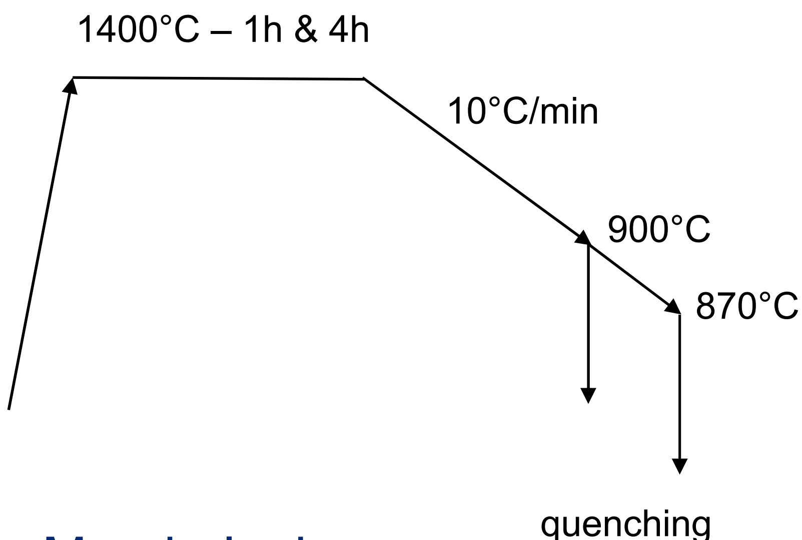


Intragranular

Intergranular

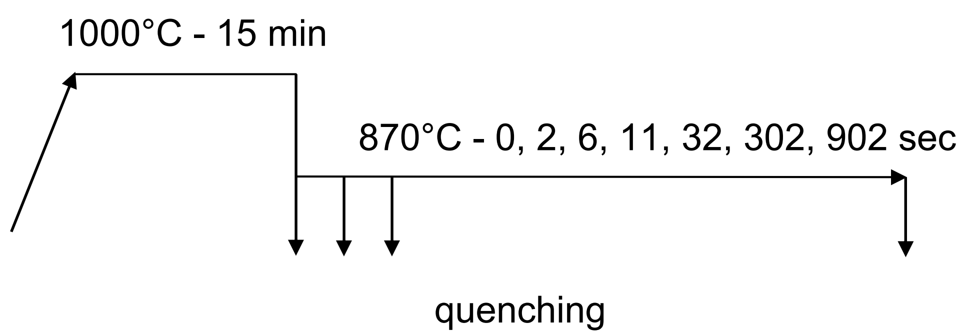
5. K-phase growth

Non-isothermal



Morphologies
Orientation relationships

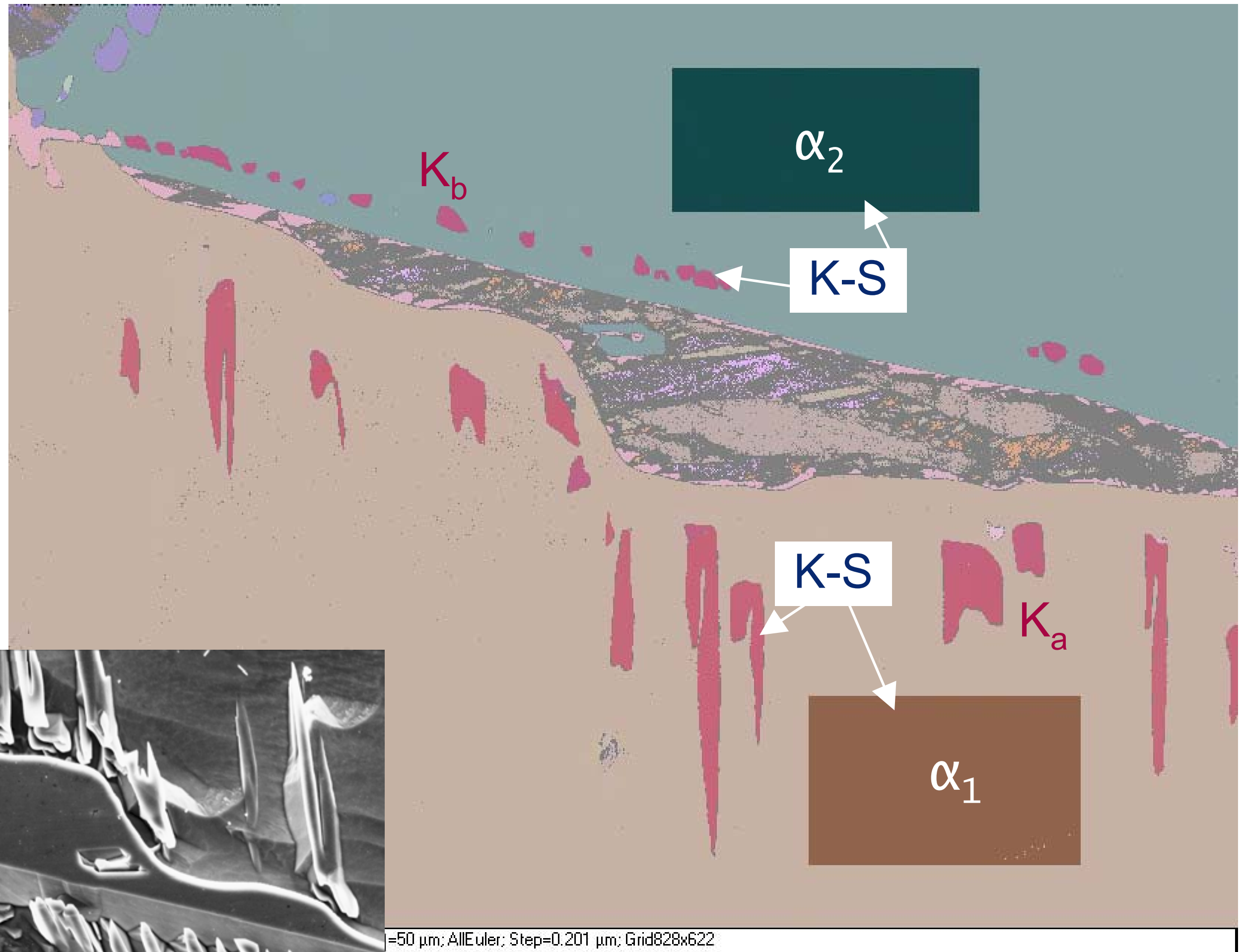
Isothermal

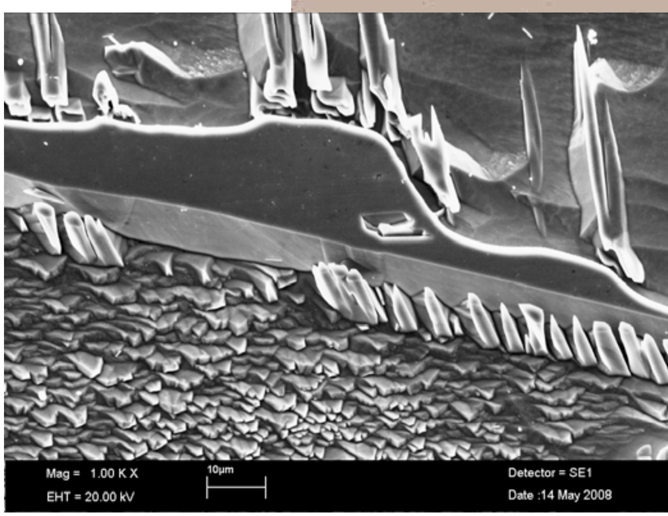


Growth kinetics

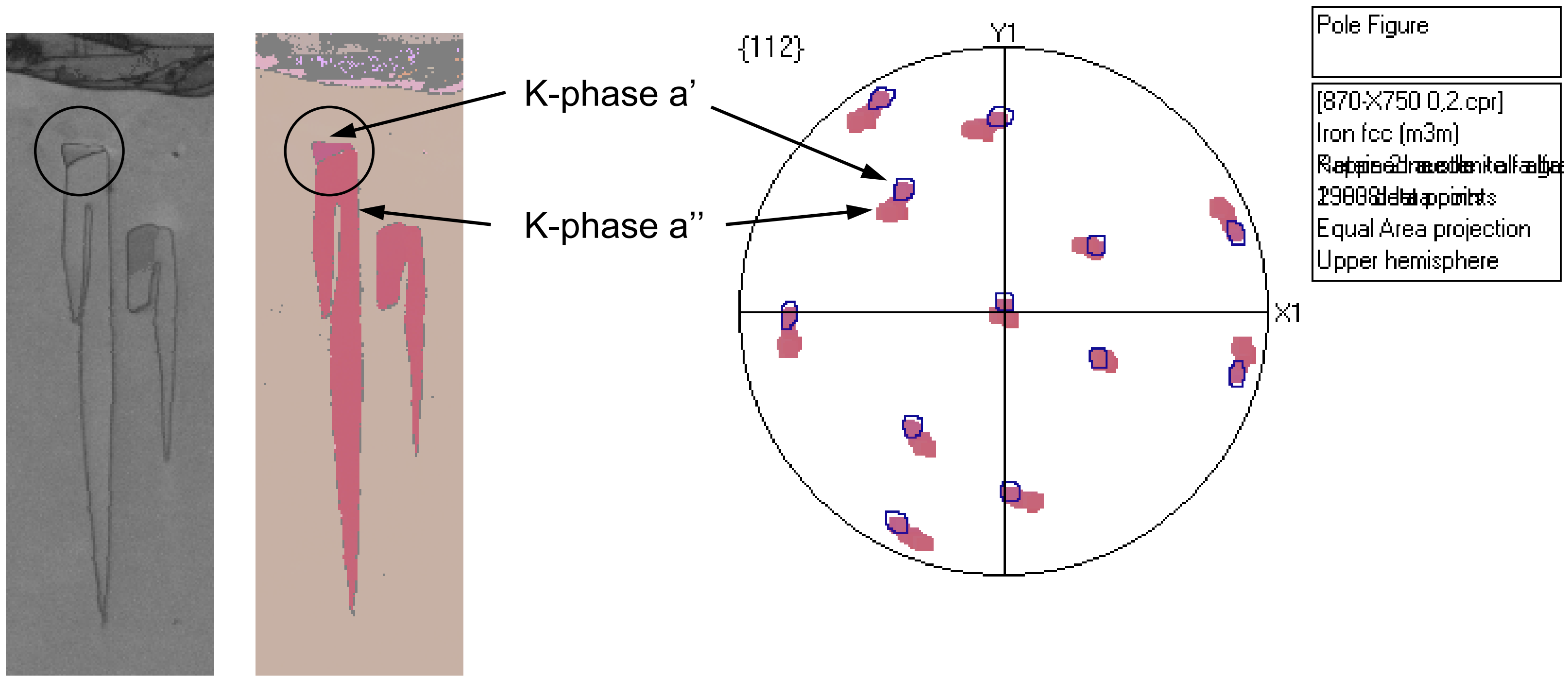
5. K-phase growth

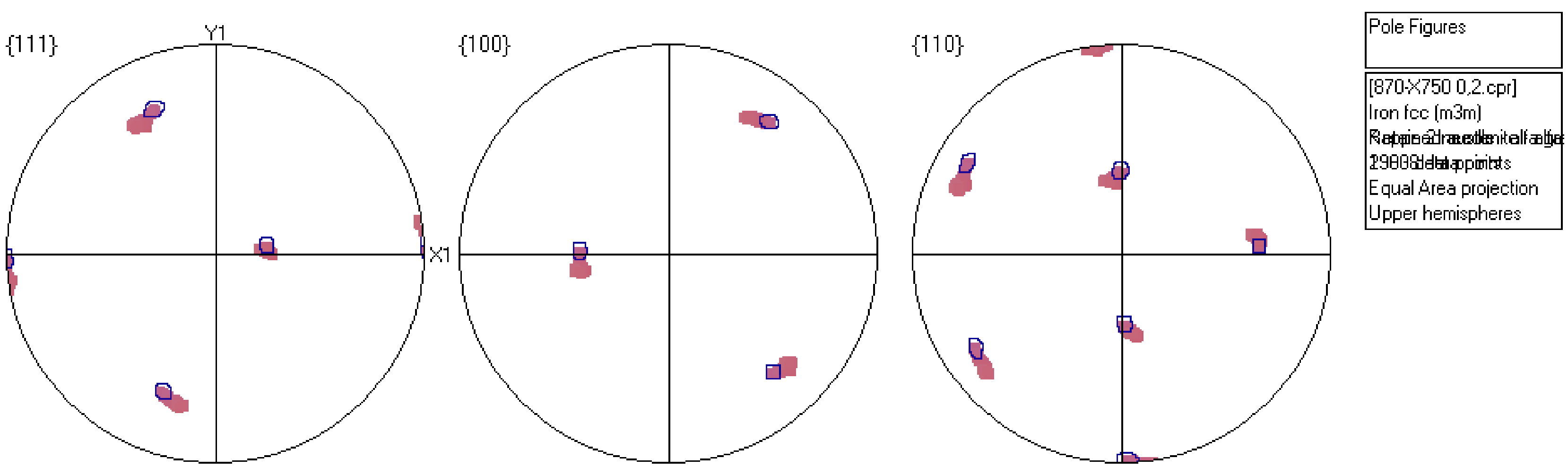
EBSD ORs



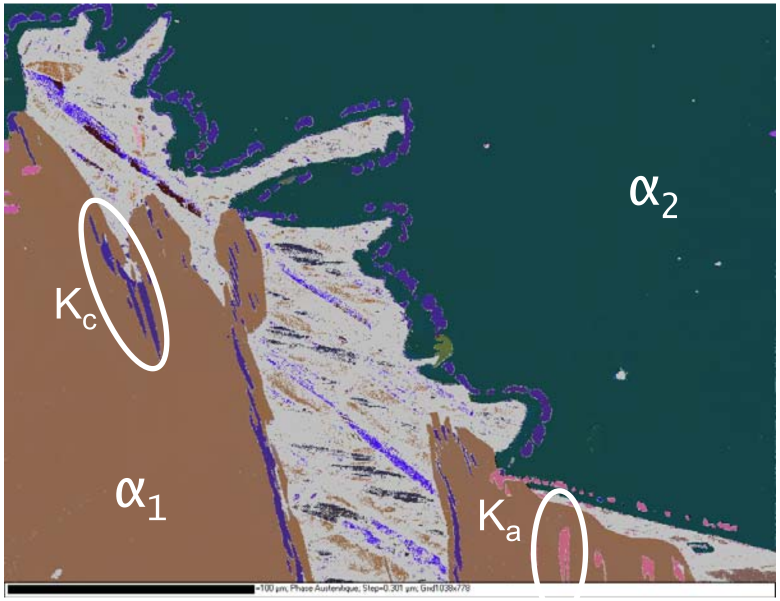


Formation / $K_{a''}$ on $K_{a'}$

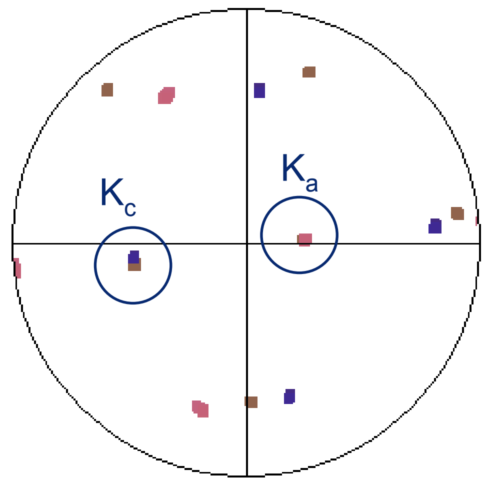


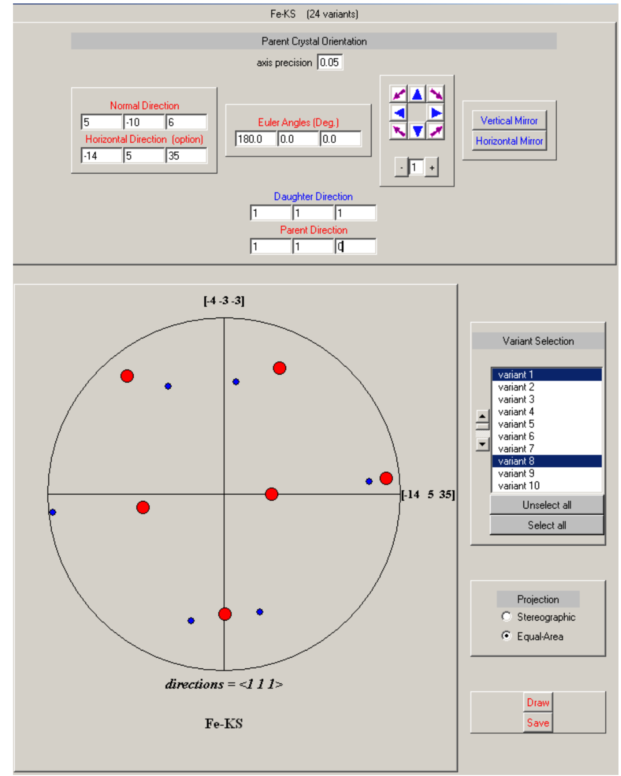


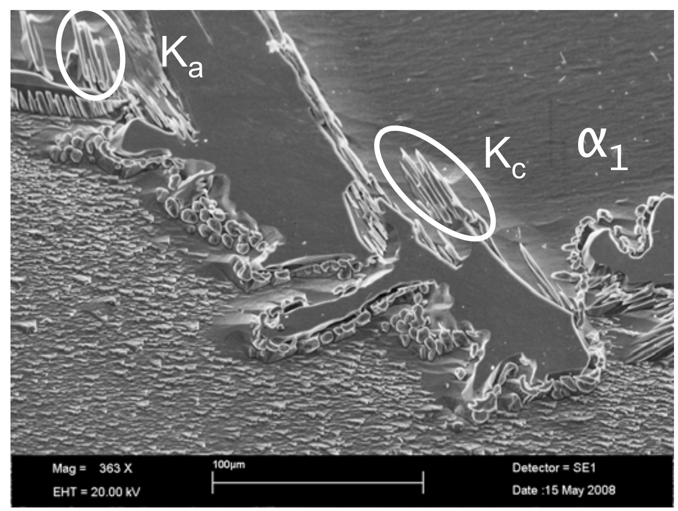
Variants needles / α1



111 γ / 110 α







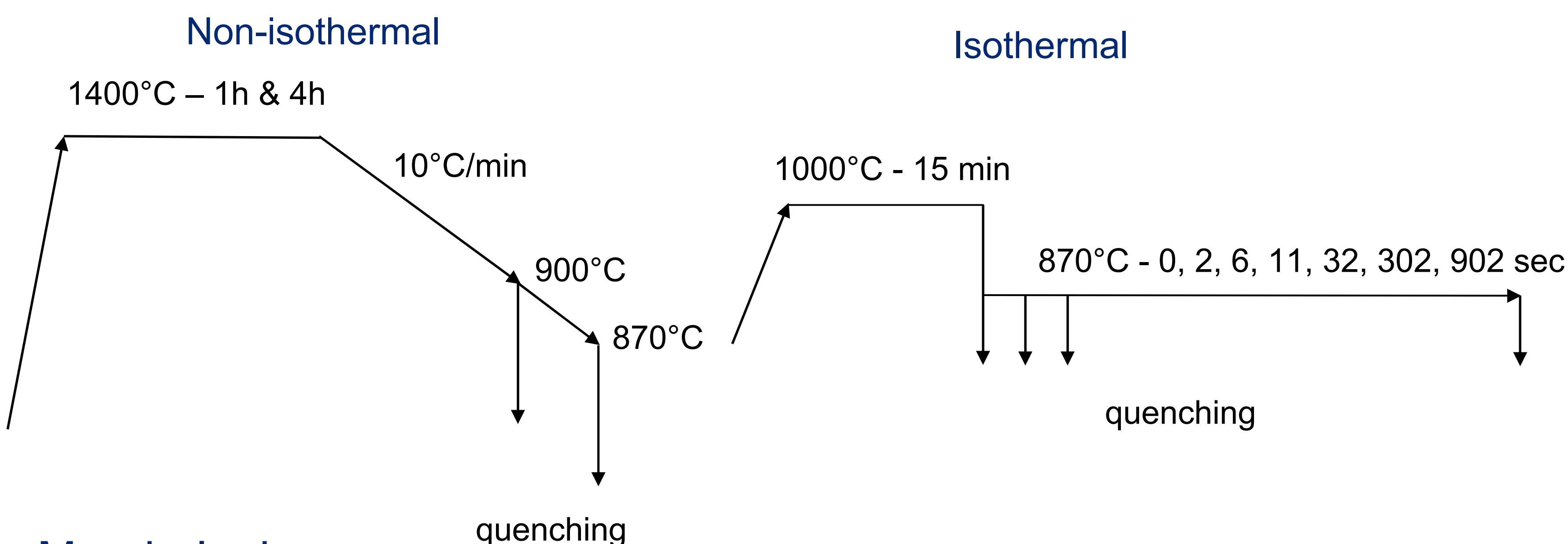
Ka and Kc variants of K-S OR

Cayron C., GenOVa: a computer program to generate orientational variants, J. Appl. Cryst., 2007

Summary

- 2D classification improved
- 3D analysis – Three precipitation morphologies
- K-phase needles prefer to grow with K-S

5. K-phase growth

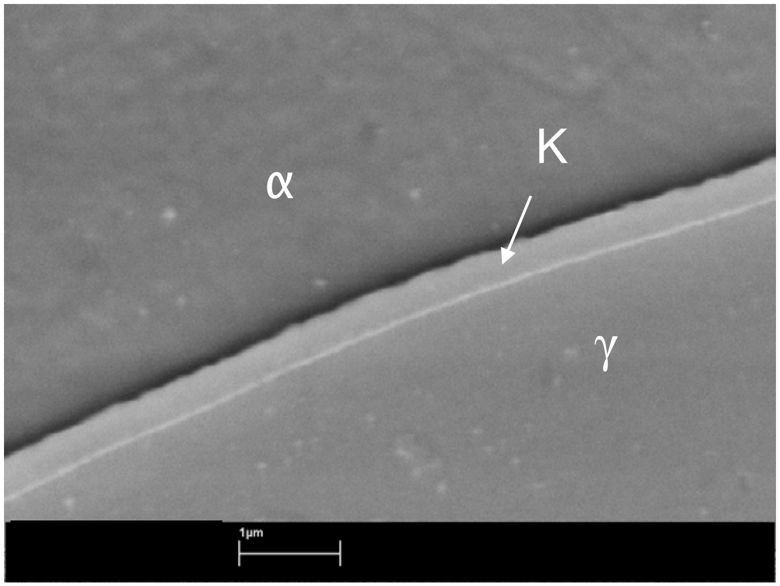


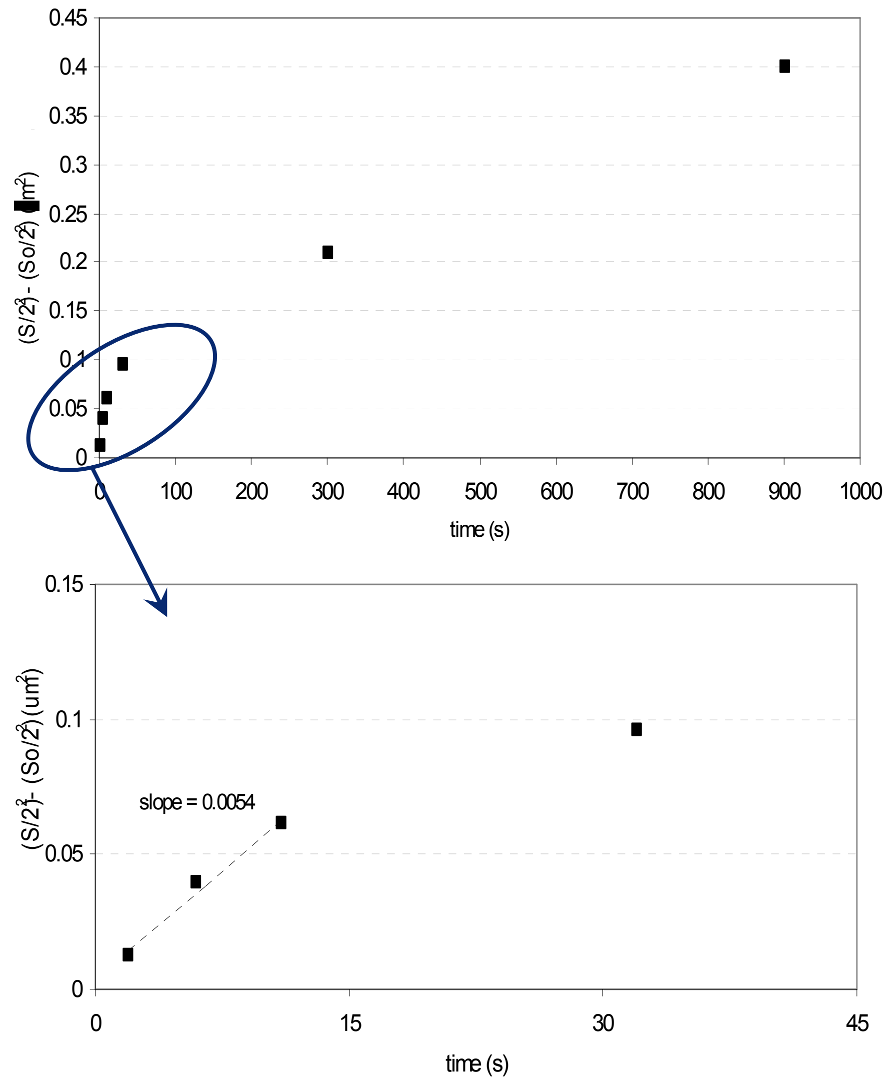
Morphologies
Orientation relationships

Growth kinetics

5. K-phase growth

Allotriomorphs (plates)

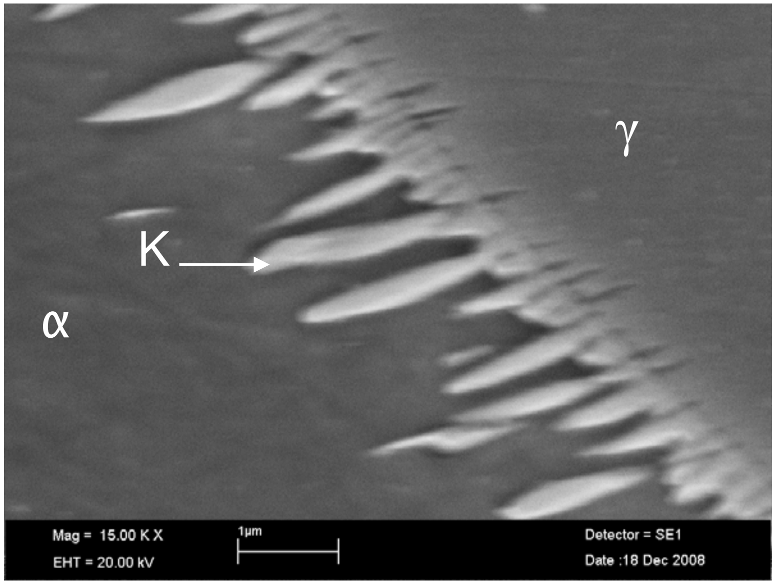


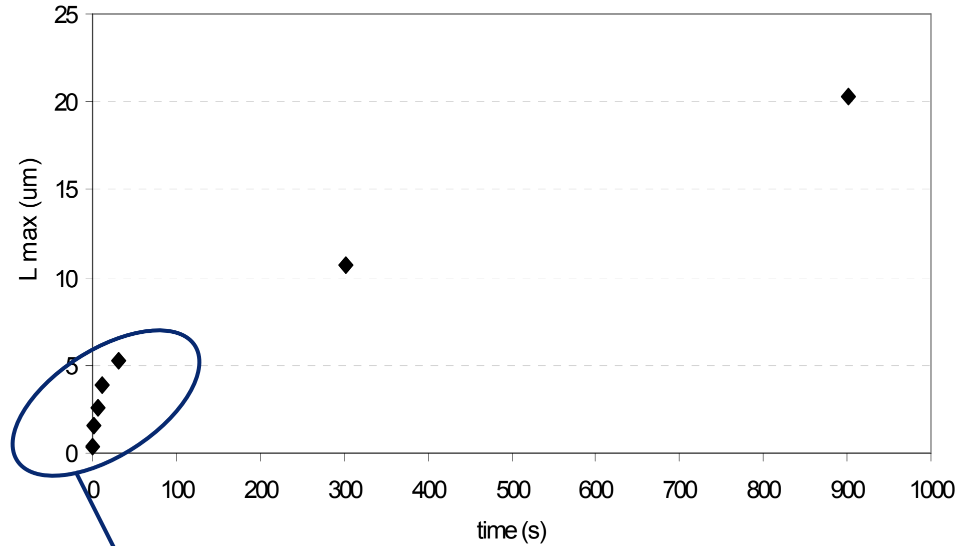


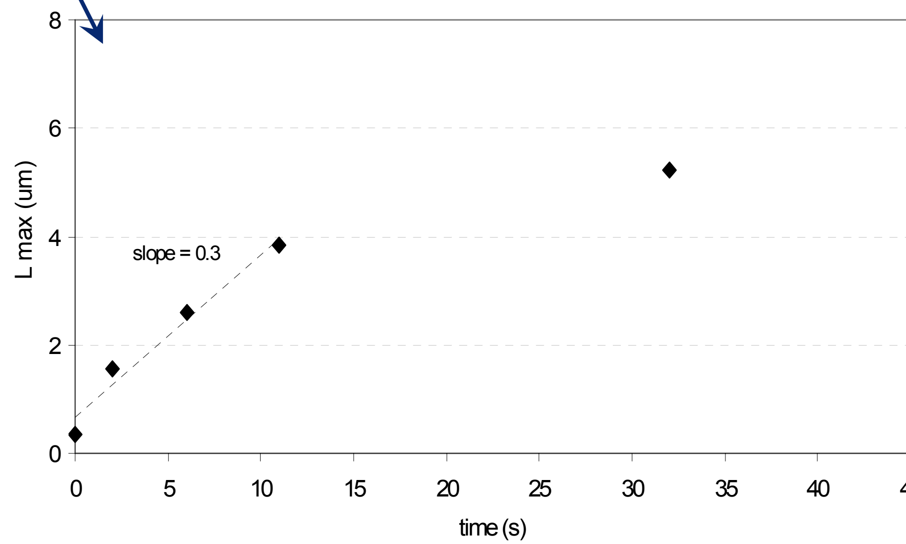
Parabolic growth

5. K-phase growth

Needles







Linear growth

Growth velocity = 0.3 μm/s

Modeling – needles

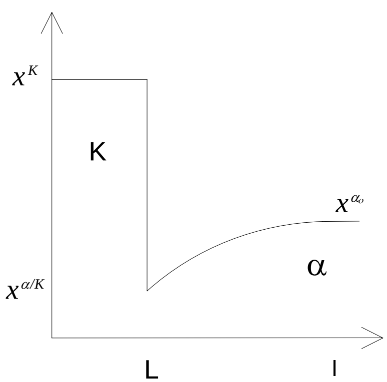
Zener - Hillert

$$\frac{v\rho}{D} = \frac{\Omega}{2\,(1-\Omega)}$$

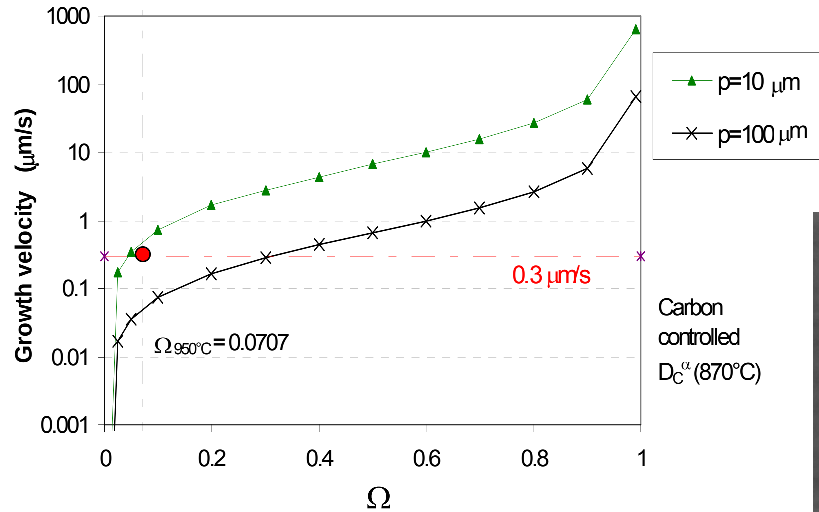
$v =$ *growth velocity*

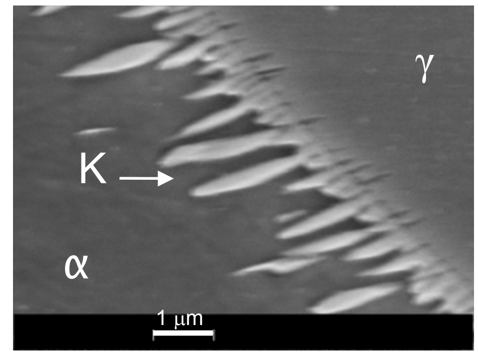
$\rho =$ *tip radius*

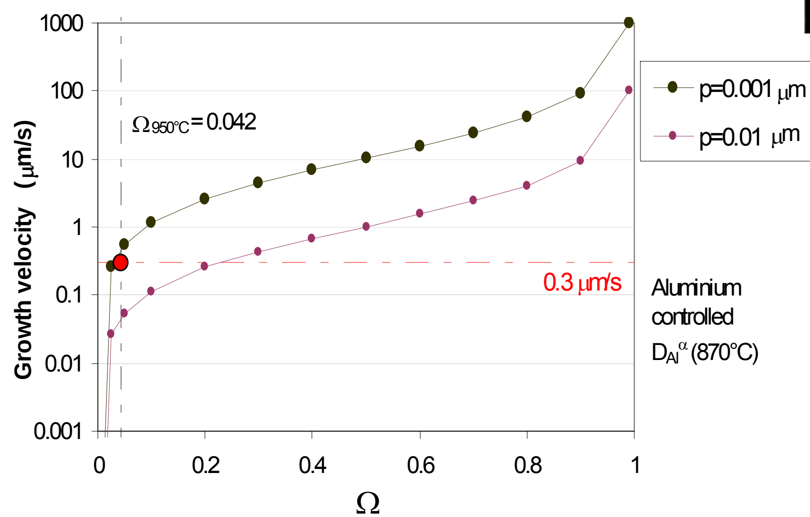
$$\Omega = \frac{x^{\alpha_o} - x^{\alpha/K}}{x^{K} - x^{\alpha/K}}$$



Carbon controlled







Aluminium controlled

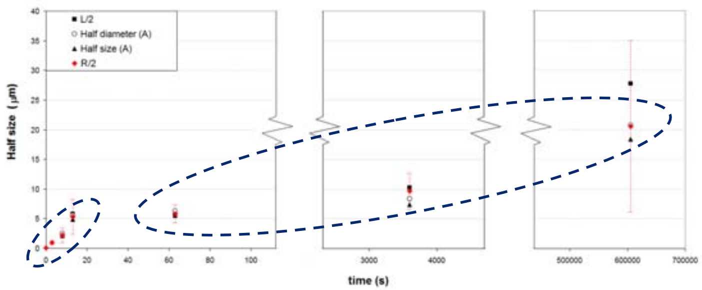
Summary

- Allotriomorphs (plate) thickening follows parabolic growth for early stages
- Needles lenghtening follows linear growth for early stages
- Thermodynamic database not suitable for this composition
- Z-H model gives a hint that an aluminium-controlled transformation is more realistic than a carbon-controlled

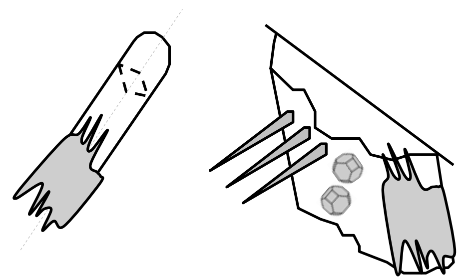
- Contents

6. Conclusions

Austenite kinetics described



K-phase growth morphologies, orientation relationships and kinetics described



Intragranular

Intergranular

END