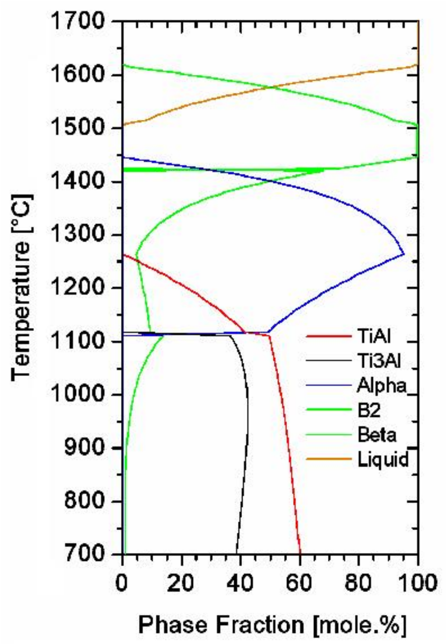
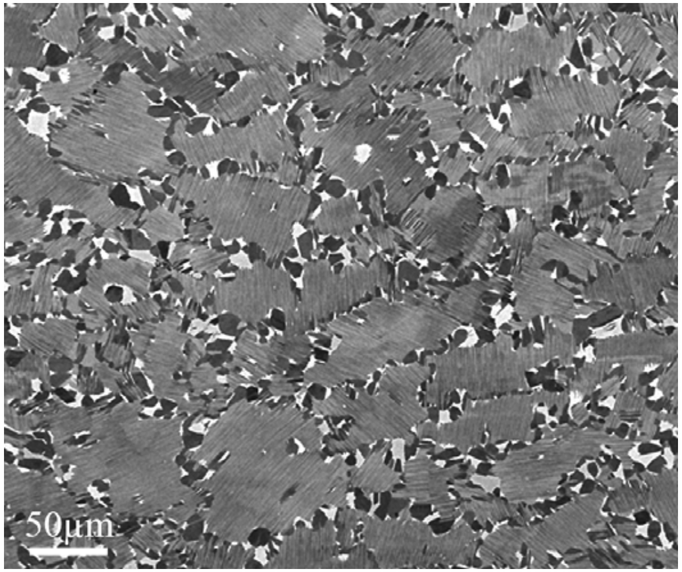
Advanced Intermetallic Titanium Aluminides - Development Status and Perspectives

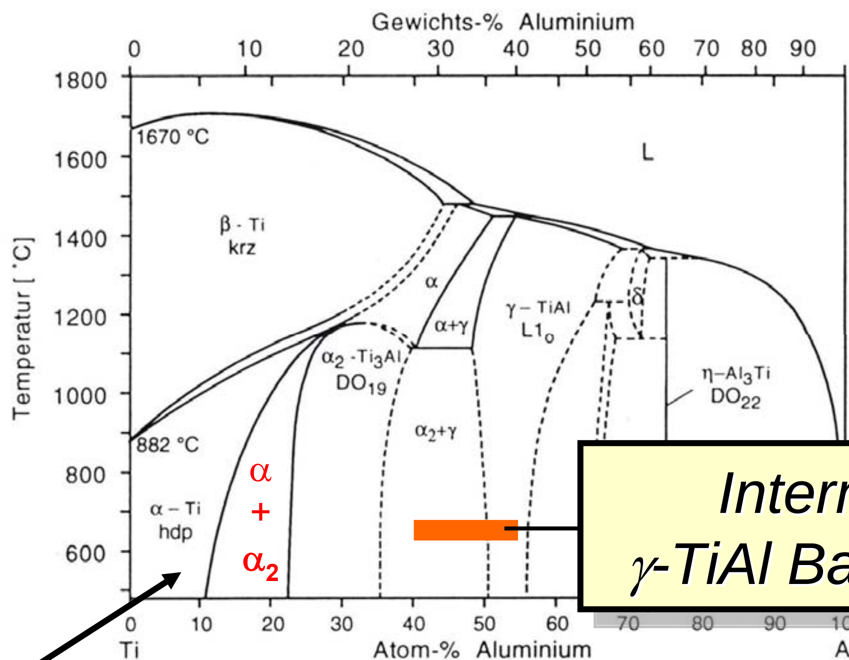
Helmut Clemens and Svea Mayer

Department of Physical Metallurgy and Materials Testing
Montanuniversität Leoben, Austria



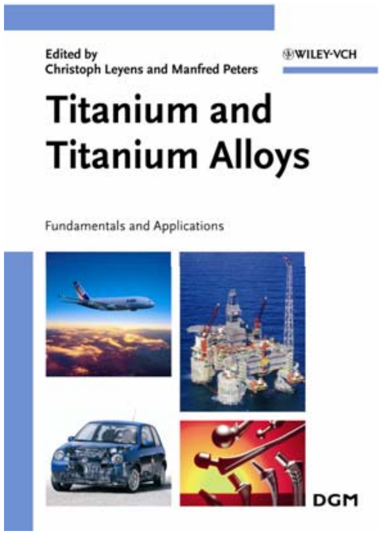


Characteristics of Intermetallic Materials & γ-Titanium Aluminides

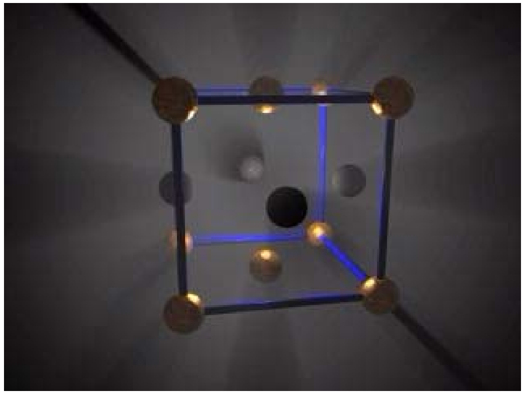


Intermetallic
γ-TiAl Based Alloys

$Al_{equiv.} = Al + 1/3 \cdot Sn + 1/6 \cdot Zr + 10 \cdot (O + C + 2N) < 9$ m-%



Characteristics of intermetallic materials



Ordered crystal structures due to strong bonding forces between the metal atoms

⇓

Unique mechanical properties

- high Young´s moduli, high-temperature strength retention, (low density → **TiAl**)

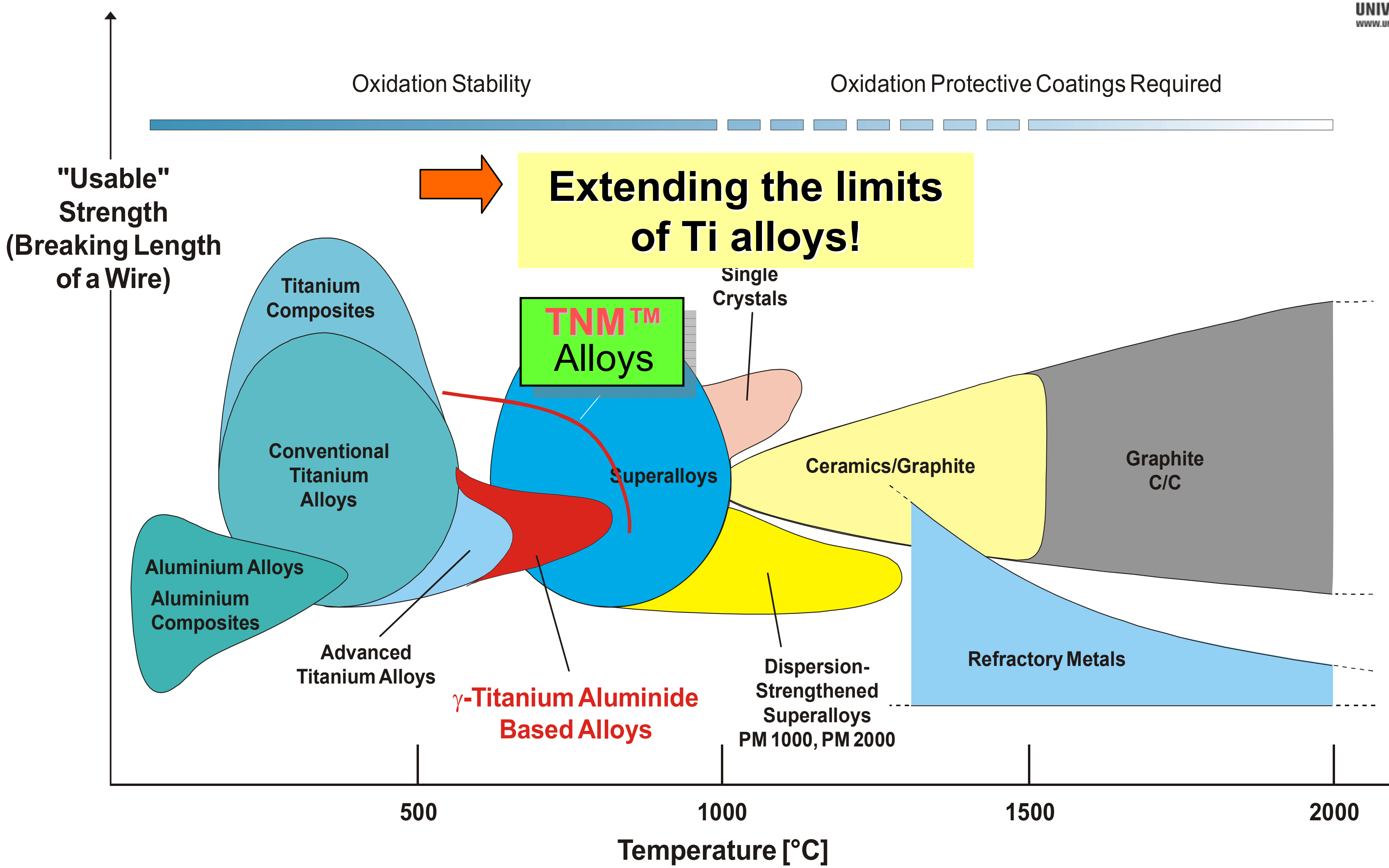
High thermal conductivities

- higher than engineering ceramics ⇨ higher cooling efficiency and lower thermal stresses

"**Ceramic**" behaviour at room temperature -
"**metallic**" behaviour at elevated temperature

- low (**TiAl**) or no (NiAl) ductility at room temperature
- some intermetallics (**TiAl**) can be processed using conventional metallurgical methods ⇨ economically competitive

The world of structural materials



→ **TNM™ alloys:** **T**i-(42-45)Al-(3-5)**N**b-(0.1-2)**M**o-(0.1-1)B

Intermetallic titanium aluminides

⇨ **Light weight structural materials:** ~ 4 g/cm^3
(50 % less dense than superalloys and steels)

⇨ …and several other attractive properties

- high specific modulus
- high specific strength
- good oxidation resistance
- resistance against “titanium fire”

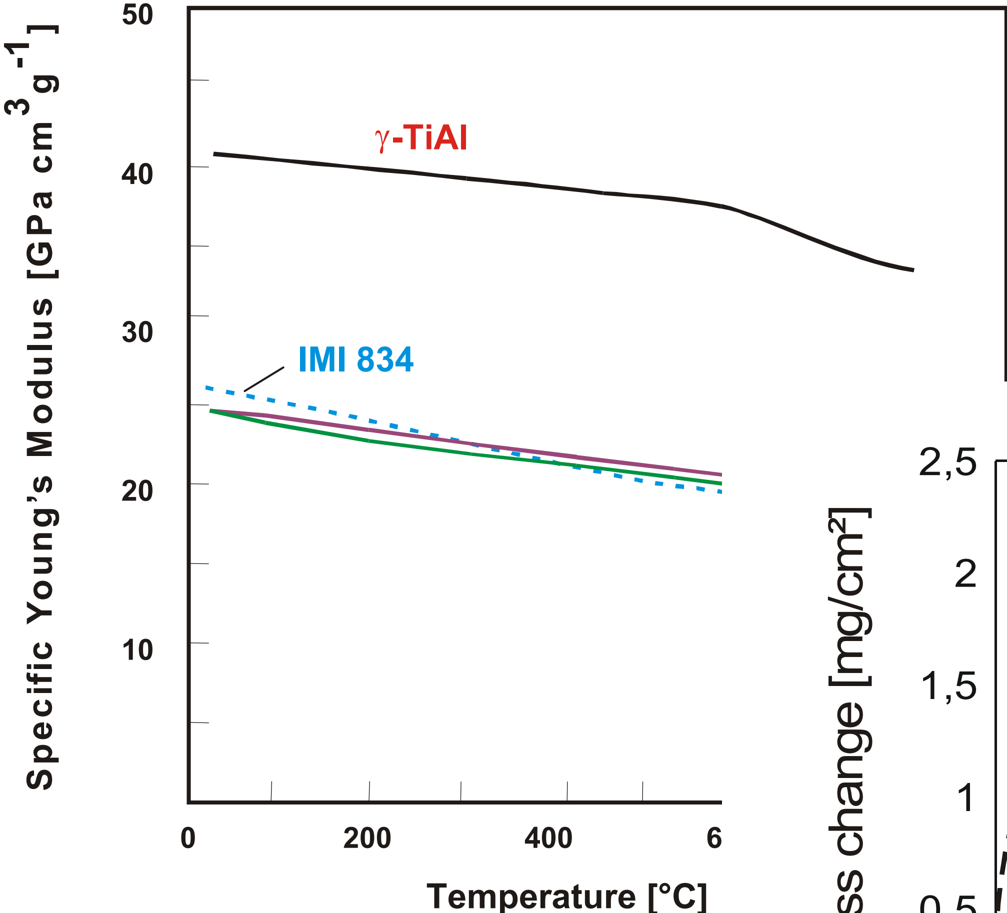
To be used in high-temperature technologies

➡ **Aircraft engines, automotive engines**

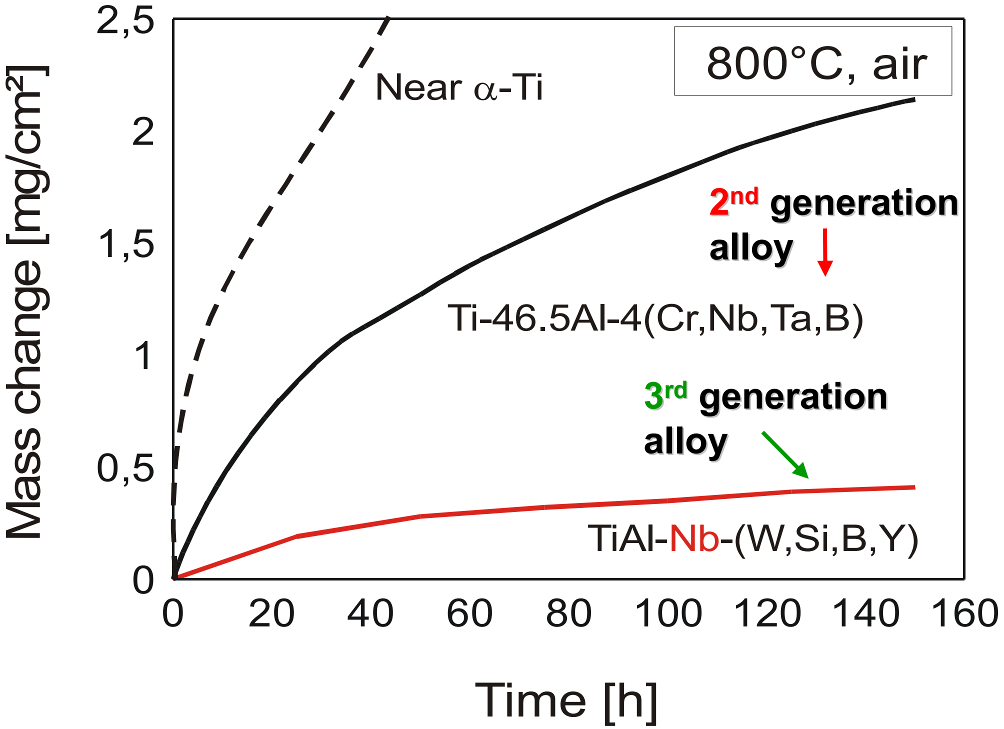
➡ **Application benefit:** higher efficiency, lower fuel consumption and reduced emissions

Basic properties

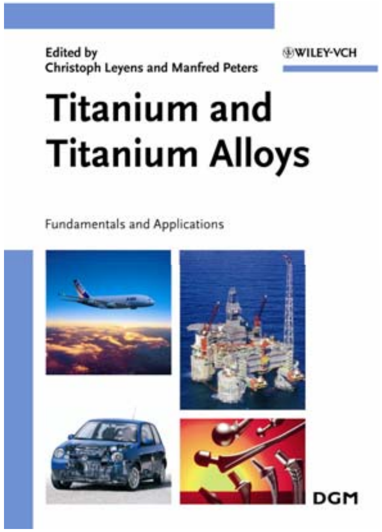
Elastic modulus



Oxidation behavior



Physical Metallurgy



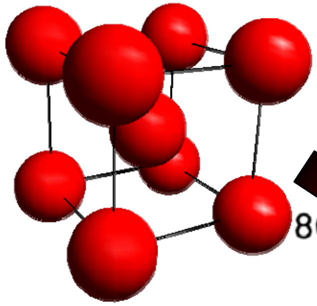
Phases present in TiAl alloys

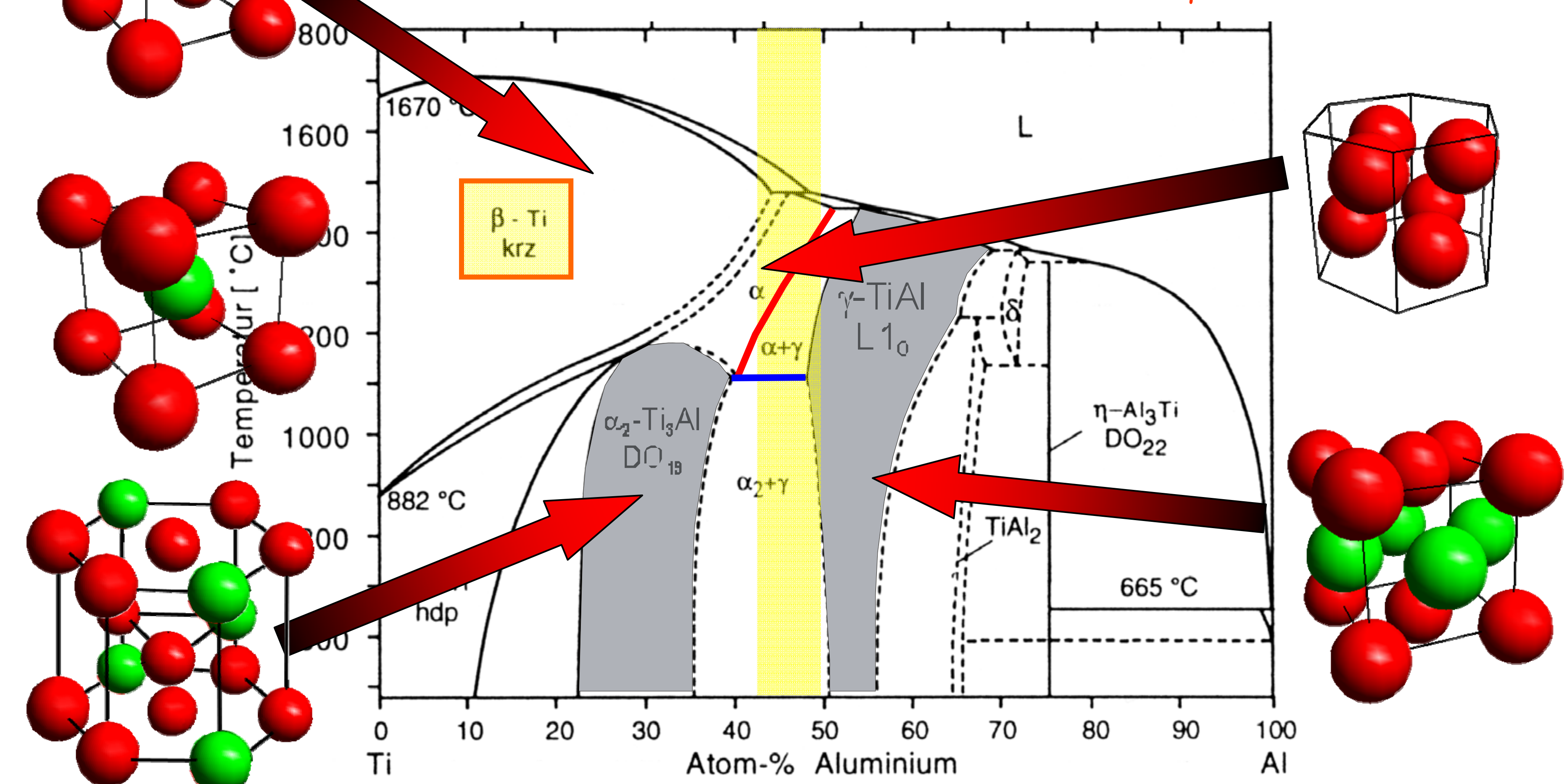
Alloy range: ~ 42 - 49 at% Al

Important temperatures:

eutectoid: $\alpha \rightarrow \alpha_2 (+\gamma)$

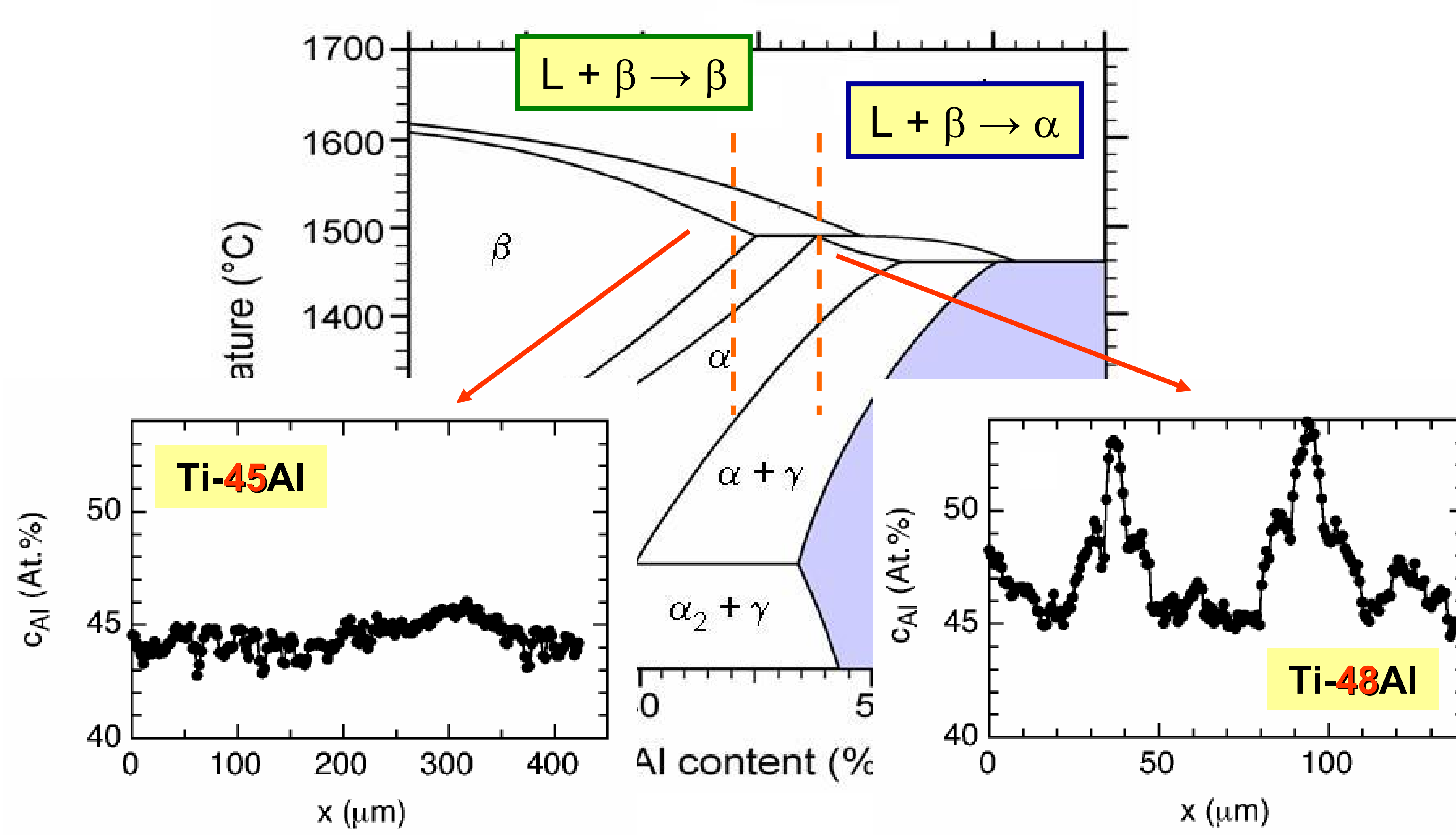
α-transus: $\alpha \rightarrow \gamma$





Further phases: borides, silicides, perovskites, Laves-phases, ω-phases, ...

Solidification of TiAl alloys: effect on segregation



M. Oehring, **V. Küstner**, A. Chatterjee, V. Güther, H. Clemens, and F. Appel, Proceedings "Gamma Titanium Aluminides 2003", pp. 89-96.

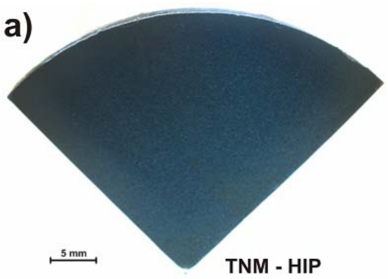
Solidification texture of a TNM^{TM} alloy

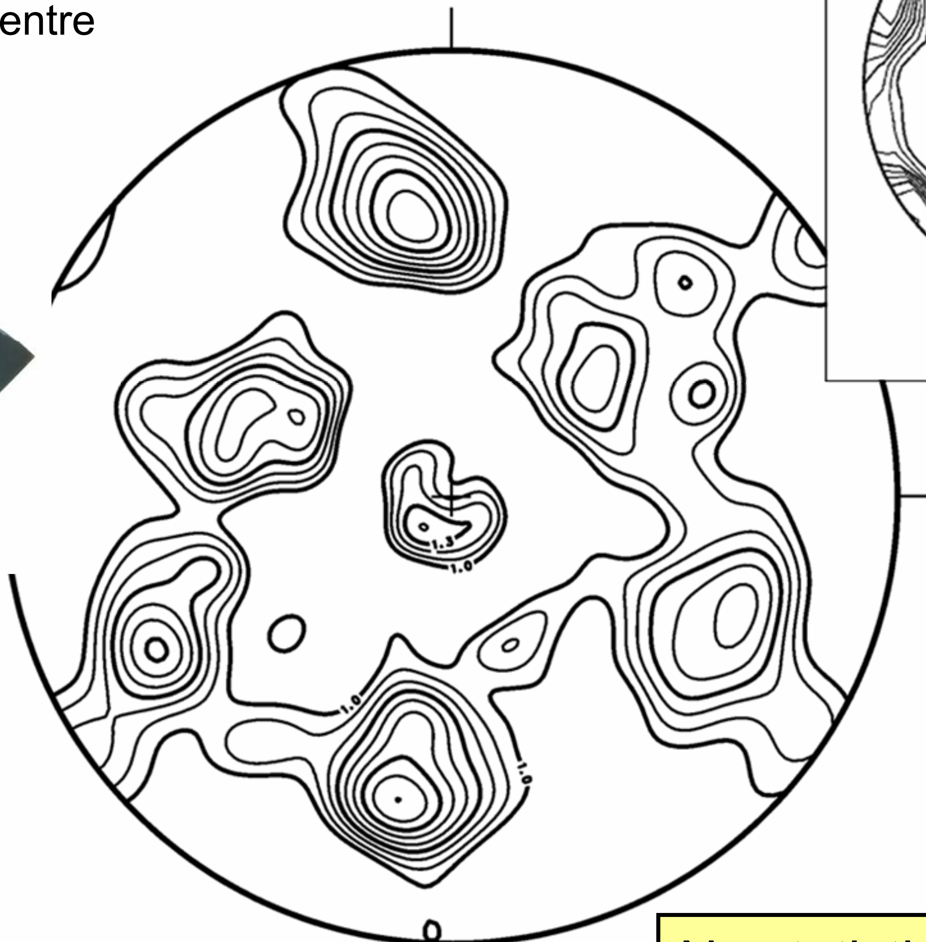
Neutron diffraction

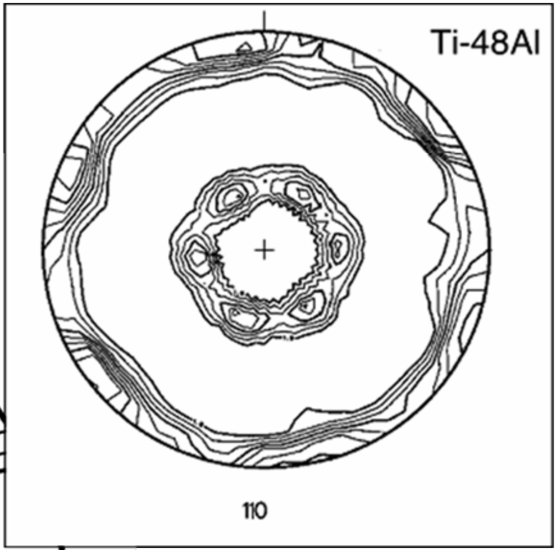
TEX-2 diffractometer,
HZG Research Centre

L + β → β

a)

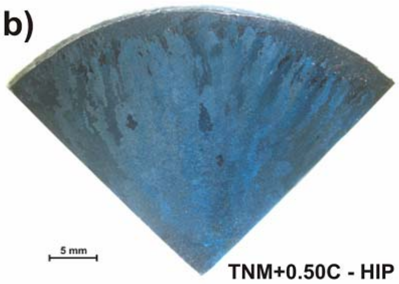






L + β → α

b)



No statistically significant texture is present after solidification

Impact of alloying elements

Ti - (42-48)Al

α_2 - Ti_3Al phase

- α_2 volume fraction ↑
- strength ↑
- RT ductility ↓
- oxidation resistance ↓

β/β_0 phase

- refinement of microstructure ↑
- hot-workability ↑
- oxidation resistance ↑
- creep strength ↑

silicides

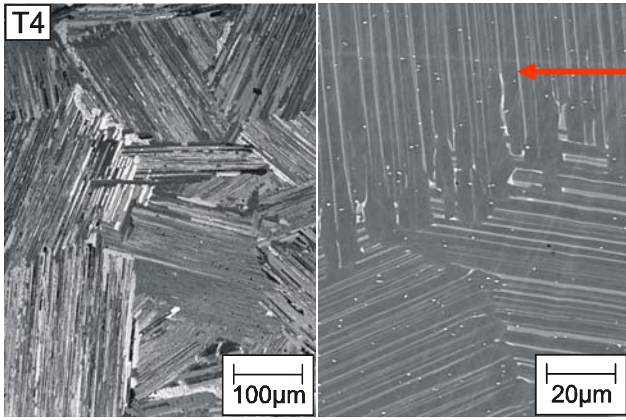
carbides

- refinement of microstructure ↑
- creep strength ↑

- RT ductility ↑
- superplasticity ↑

Heat treatments, microstructures and properties

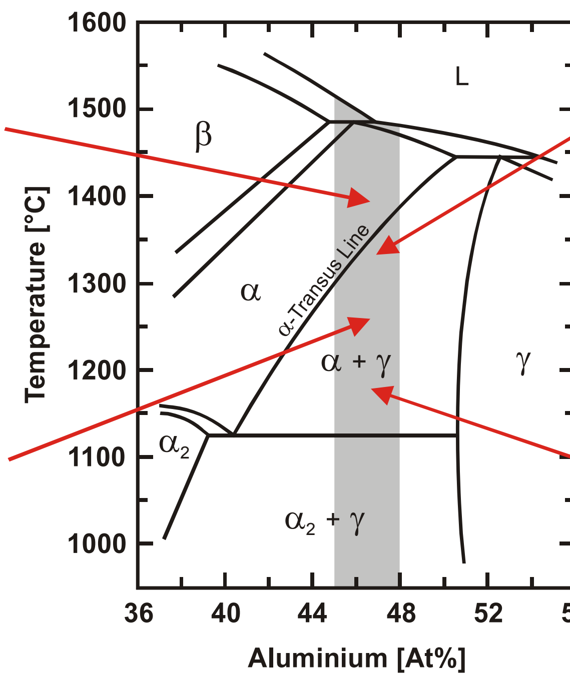
Creep↑, RT- ductility ↓



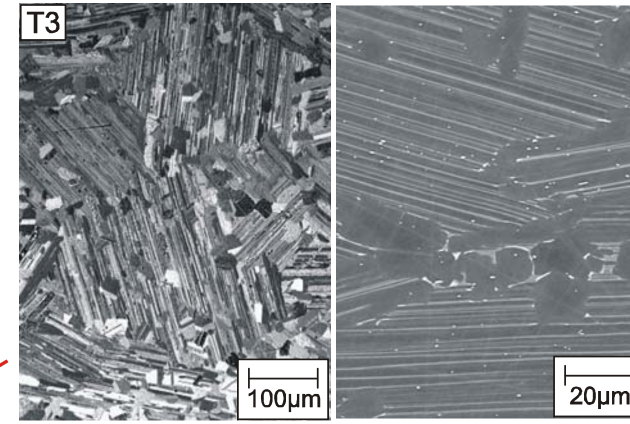
Fully Lamellar (FL)

$(111)\gamma \parallel (0001)\alpha_2$

$[110]\gamma \parallel [11\bar{2}0]\alpha_2$

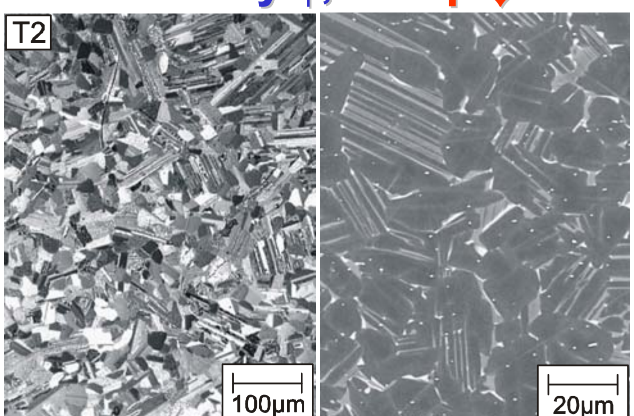


Balanced properties



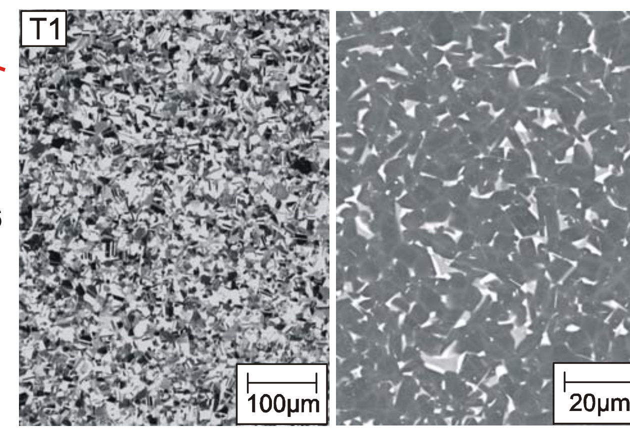
Nearly Lamellar γ (NLγ)

RT- ductility ↑, creep ↓



Duplex (D)

RT- ductility ↑, creep ↓

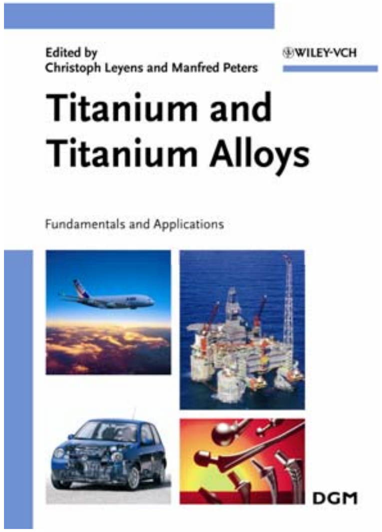


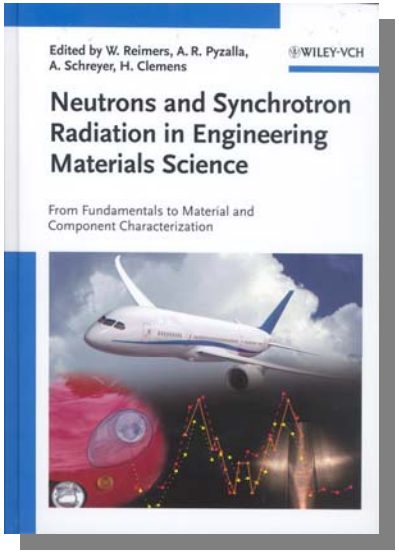
Near Gamma (NG)

Alloy Development

&

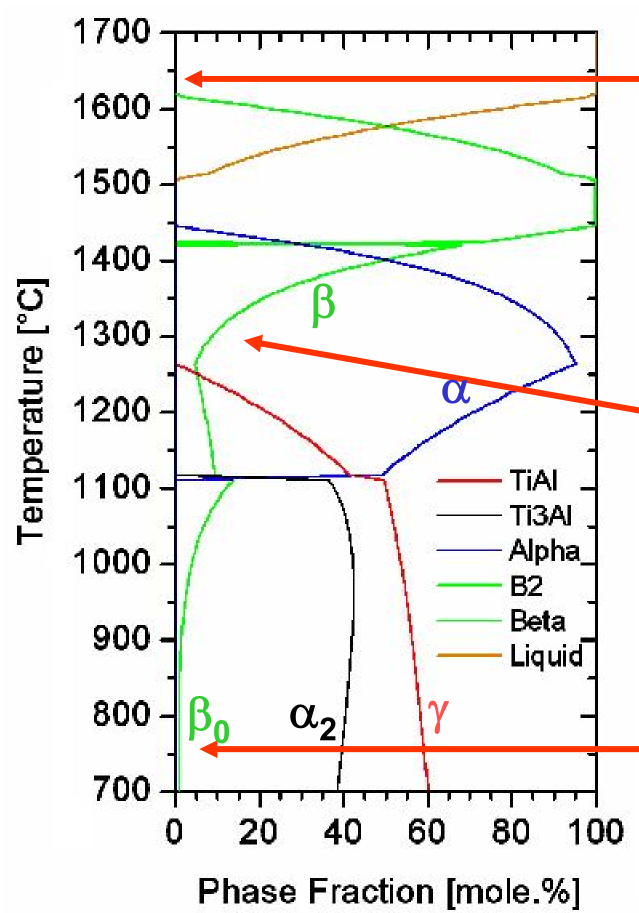
Alloy Characterization





Design strategy for TiAl alloys

…to aim at good hot-workability and balanced mechanical properties

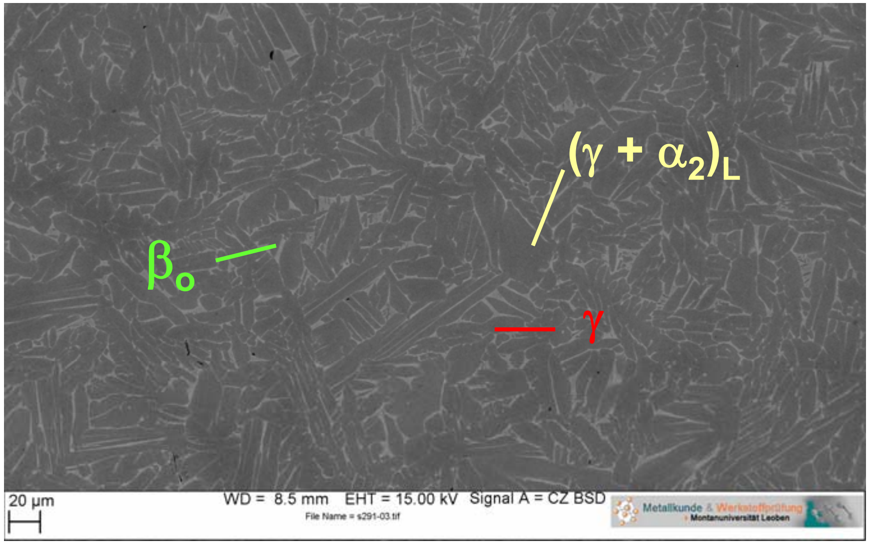


- **Solidification via the β-phase**
- **Minimized segregation and solidification texture**
- **Refined equiaxed microstructure**
  → utilization of borides
- **Presence of ductile bcc β-phase during hot-working**
- **No single α-phase field**
- **Small amount of ordered β_0-phase at service temperature**
- **Balanced mechanical properties due to optimized micro- and nanostructure**

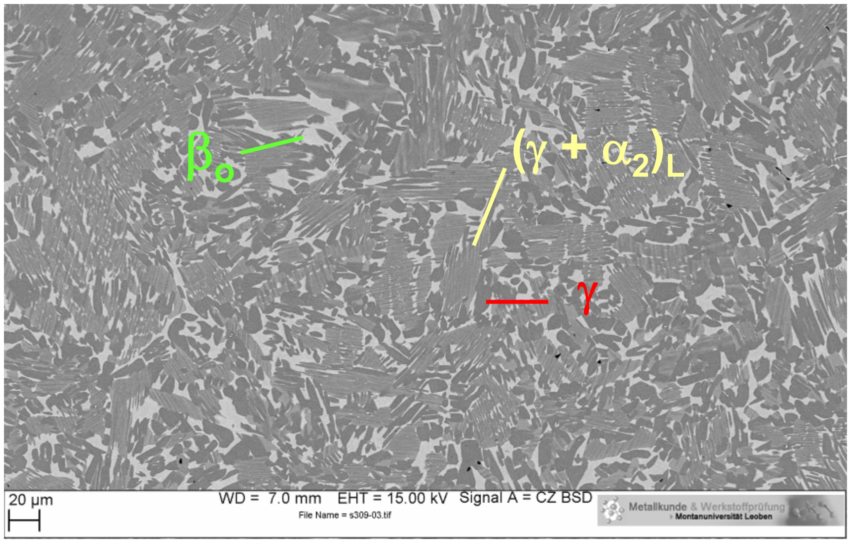
→ **TNM™ alloys:** **T**i-(42-45)Al-(3-5)**N**b-(0.1-2)**M**o-(0.1-1)B

Gravity and centrifugal (spin) casting

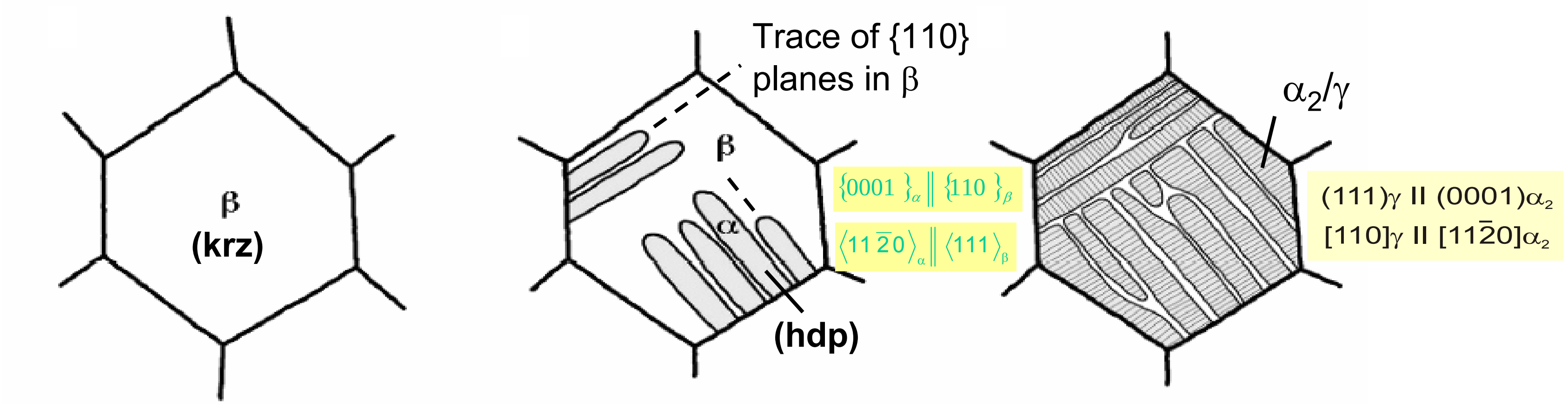
TNM alloy: as-cast microstructure



after HIPing

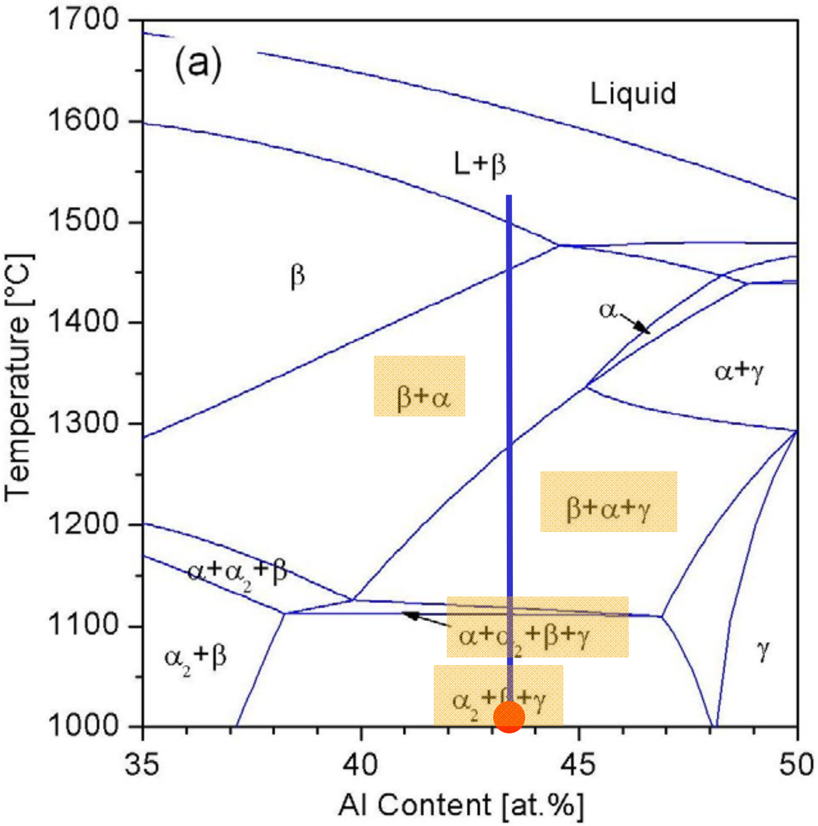


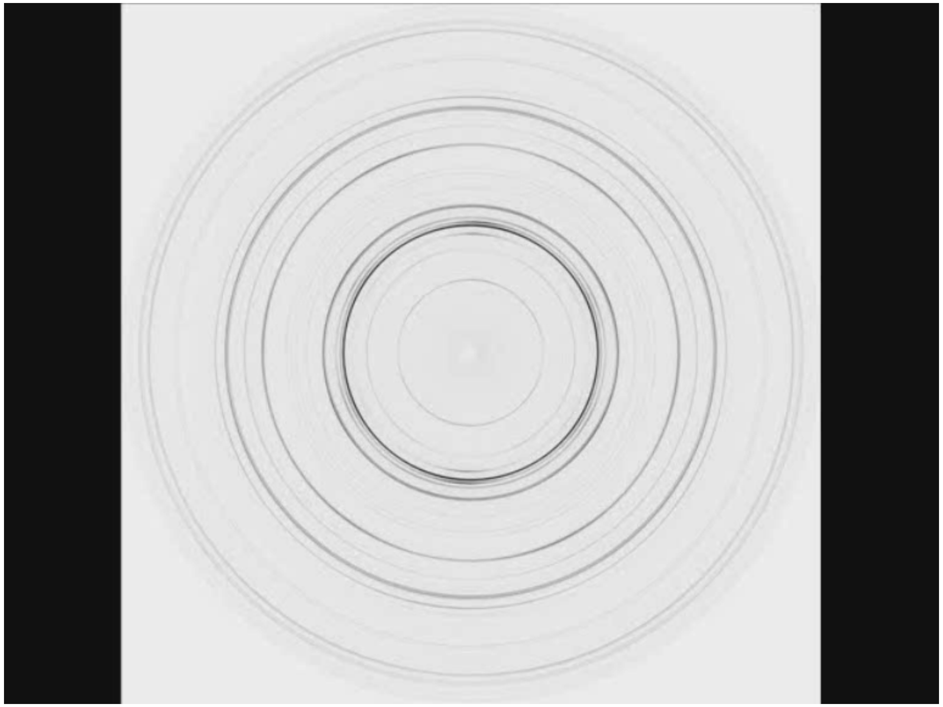
Solidification and transformation model:



$L \rightarrow L + \beta + \text{borides} \rightarrow \beta \quad \rightarrow \quad \beta \rightarrow \beta + \alpha \quad \rightarrow \quad \beta + \alpha \rightarrow \beta + \alpha + \gamma \rightarrow \beta_o + \alpha_2 + \gamma$

Calculated phase diagram





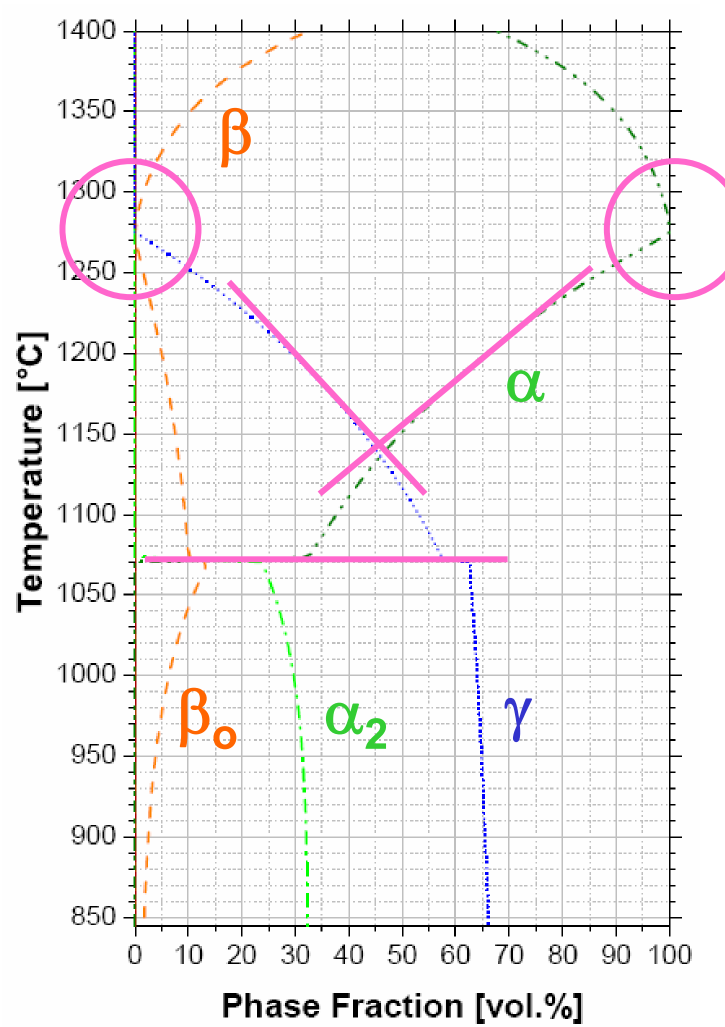
The corresponding diffraction pattern are analyzed by Rietveld method

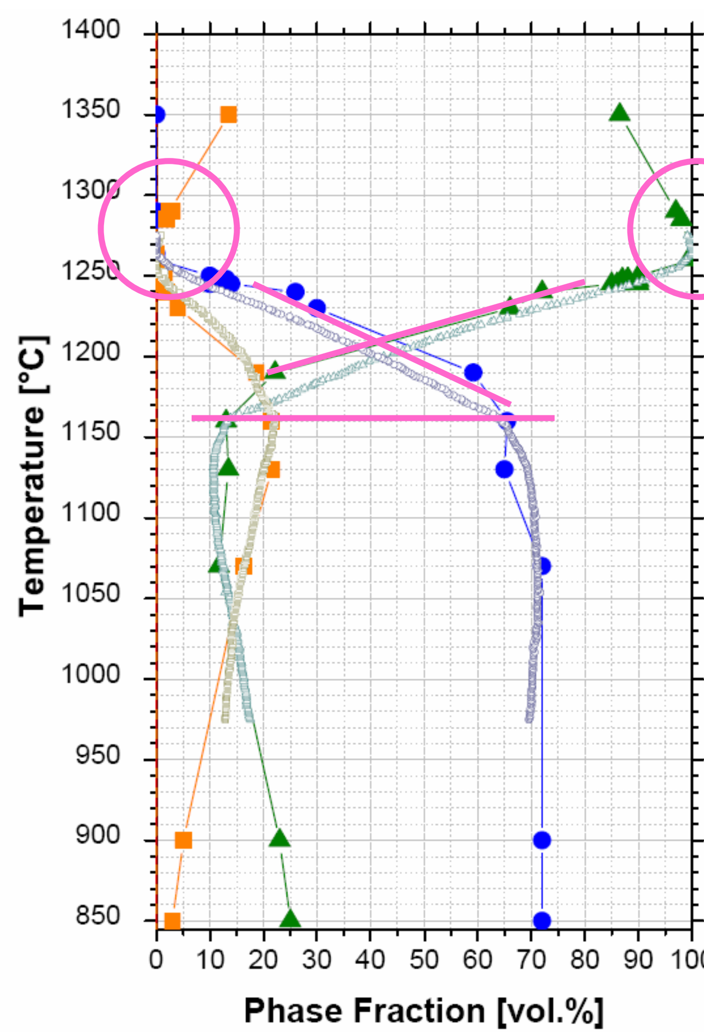
Comparison phase fraction diagram – Calculated and experimental

Calculated

Experimental

Ti-43.9Al-4Nb-0.95Mo-0.1B

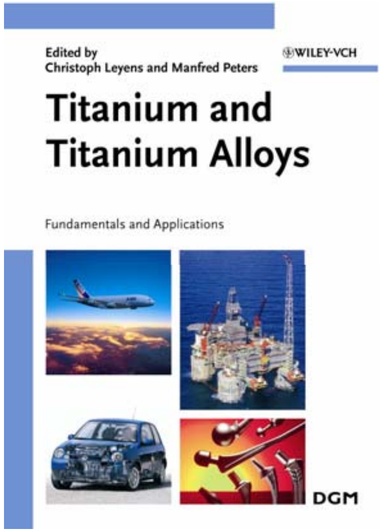




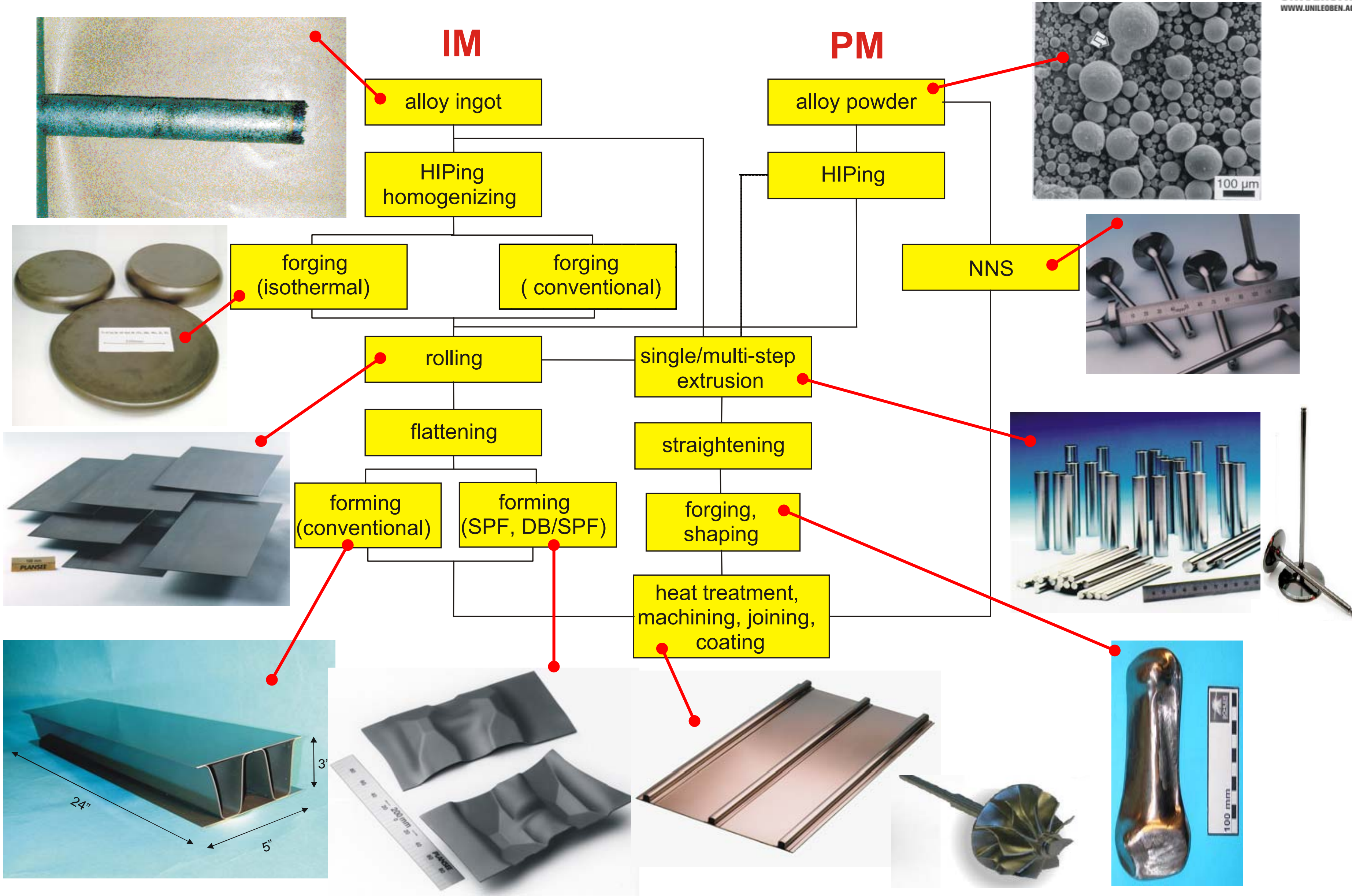
- ☞ Heat treat-ments and quantitative metallography
- ☞ in-situ synchrotron measurements

Processing


WV 16121 / 4
Ti48Al2Cr
Chg: R82847
16.12.1991


Edited by
Christoph Leyens and Manfred Peters
WILEY-VCH
Titanium and
Titanium Alloys
Fundamentals and Applications
DGM

Processing of titanium aluminides



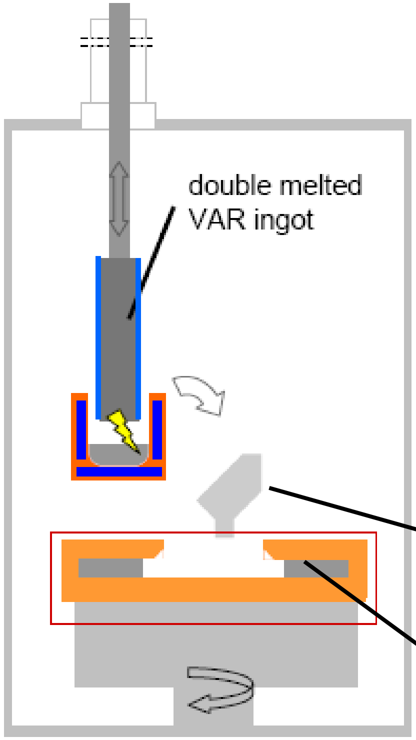
Primary material: production routes

Vacuum Arc Remelting (VAR)

Plasma Arc Melting (PAM)

VAR skull melter + centrifugal (spin) casting

Large dimensions

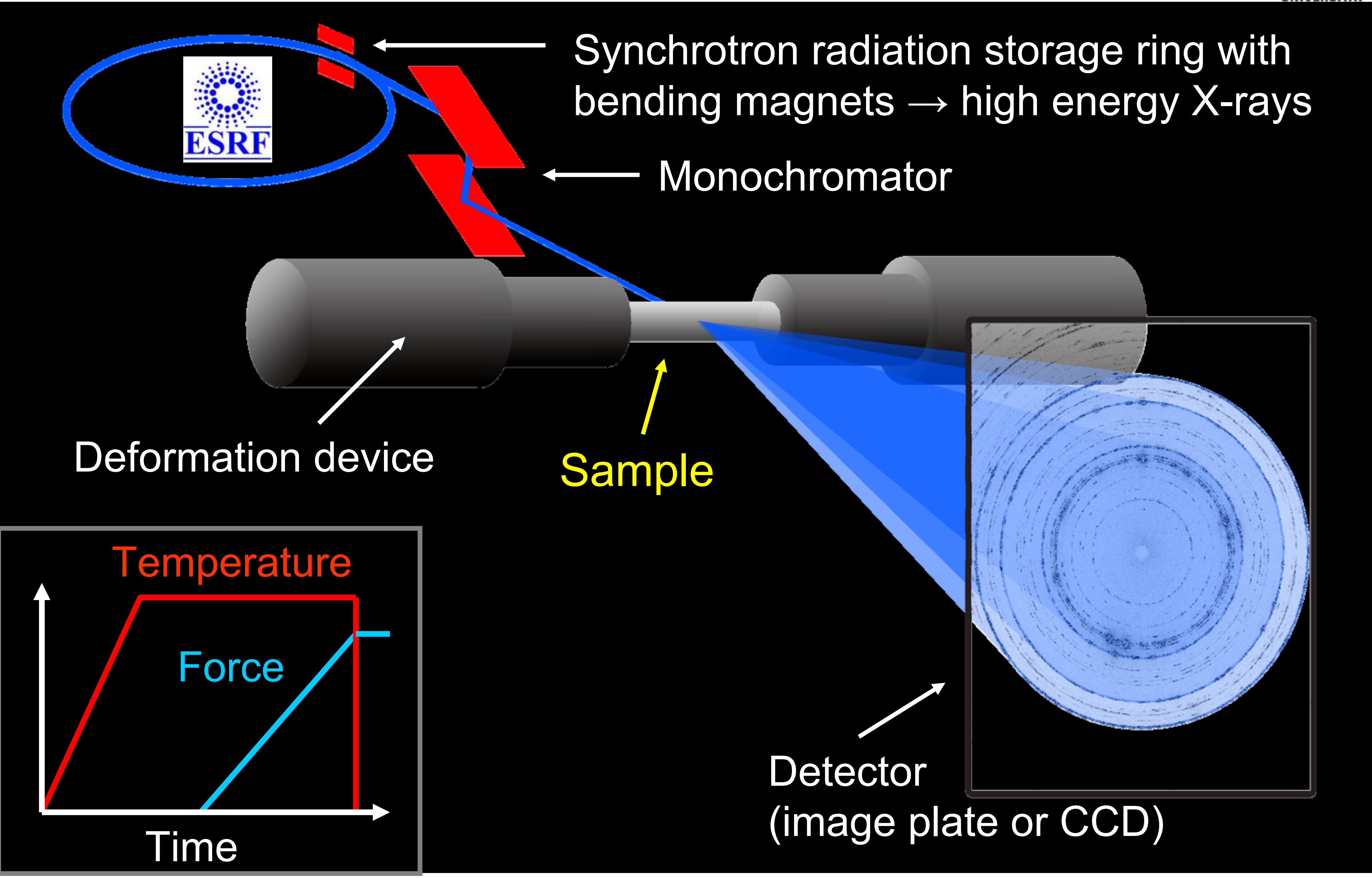


Pouring via **tundish** in rotating **permanent molds**

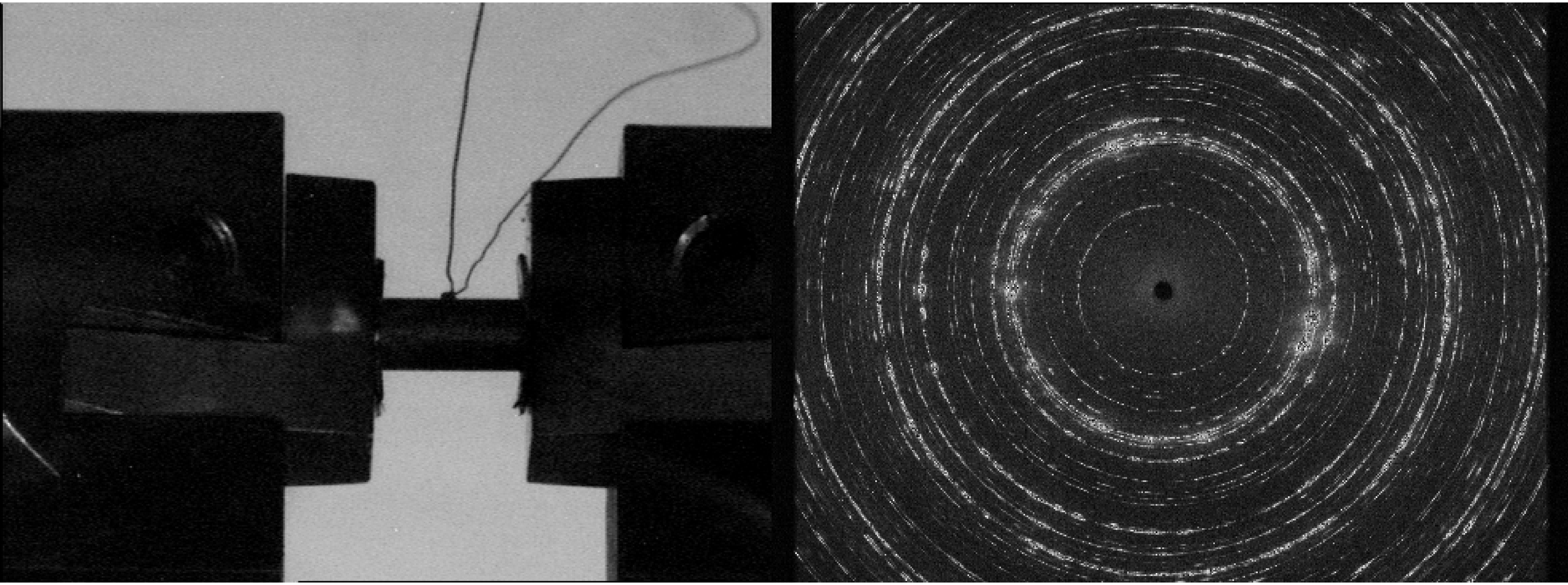
Böhler Schmiedetechnik, Kapfenberg, Austria

Conventional hot-die forging process

In-situ deformation experiment

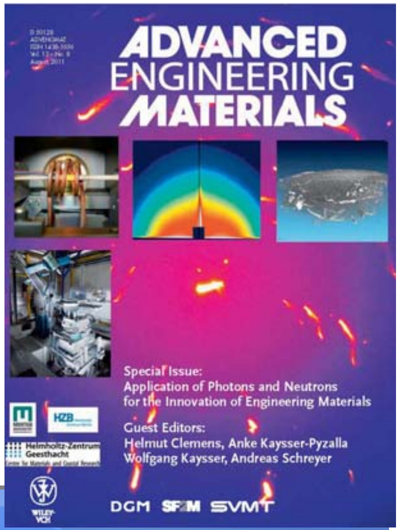


In-situ deformation experiment

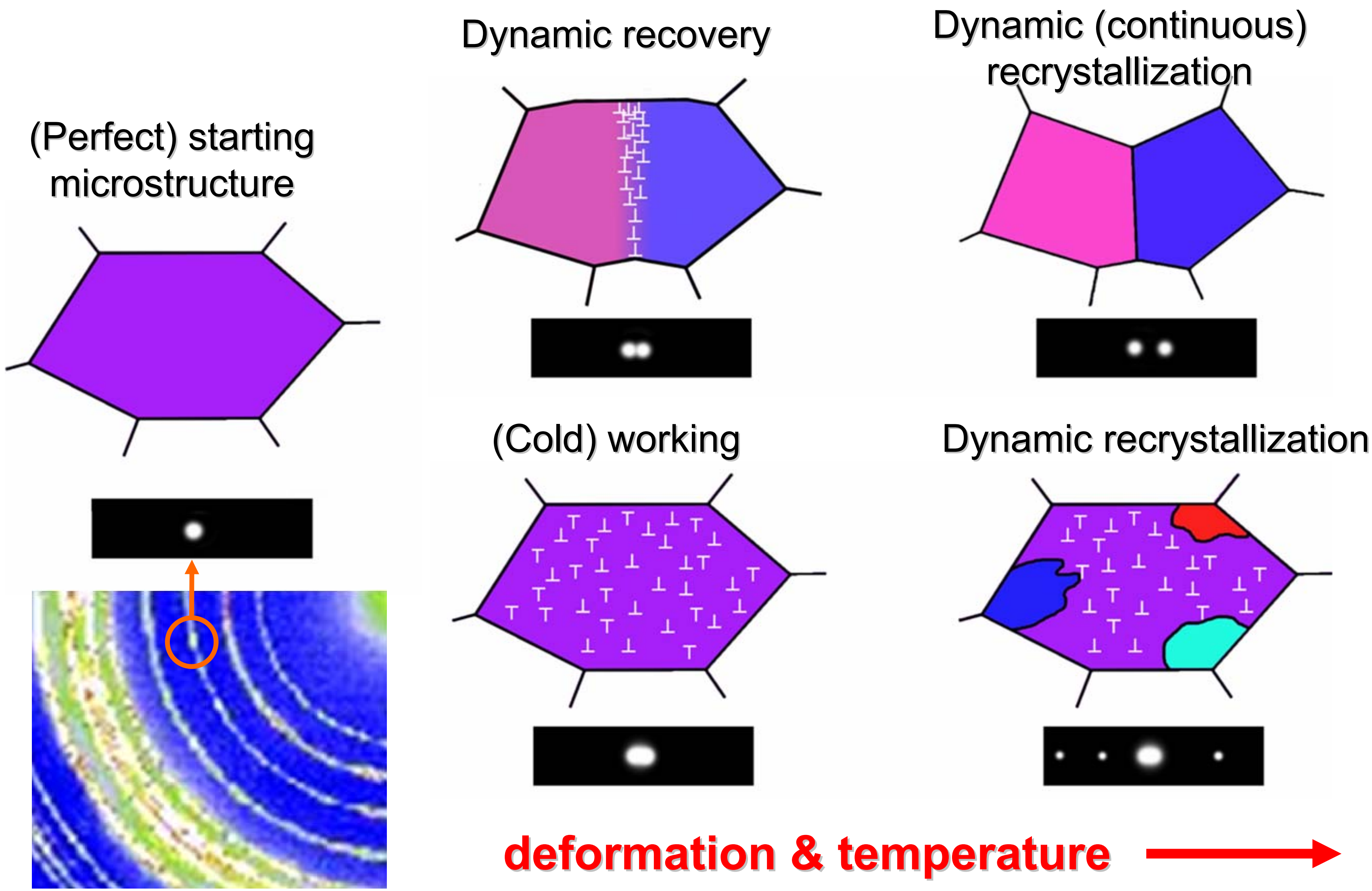


Information on:

- phases & phase fractions
- phase transition temperatures
- ordering behaviour
- recrystallization & grain growth behaviour
- texture



Response of patterns on hot-working, e.g. forging



Résumé of in- and ex-situ experiments

- Overall grain refinement occurs during deformation in the (α+β)-phase field region
- A high defect density is observed in the α-phase, a lower one in the β-phase

Proposed predominant processes occuring during hot-working in the (α + β)-phase field region :

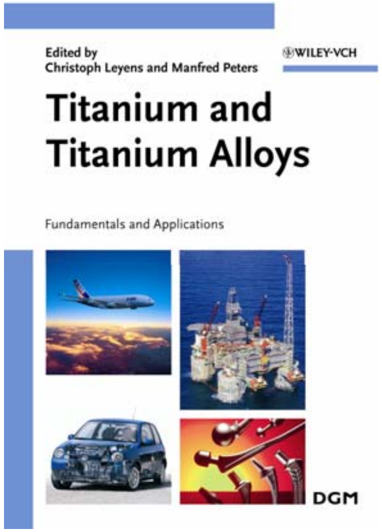
- Dislocation slip and slow recovery in α-phase (smaller SFE)
- Slip and very fast recovery in β-phase (higher SFE)
  → extended recovery (in-situ recrystallization)

SFE: stacking fault energy

Microstructure, Heat-Treatments

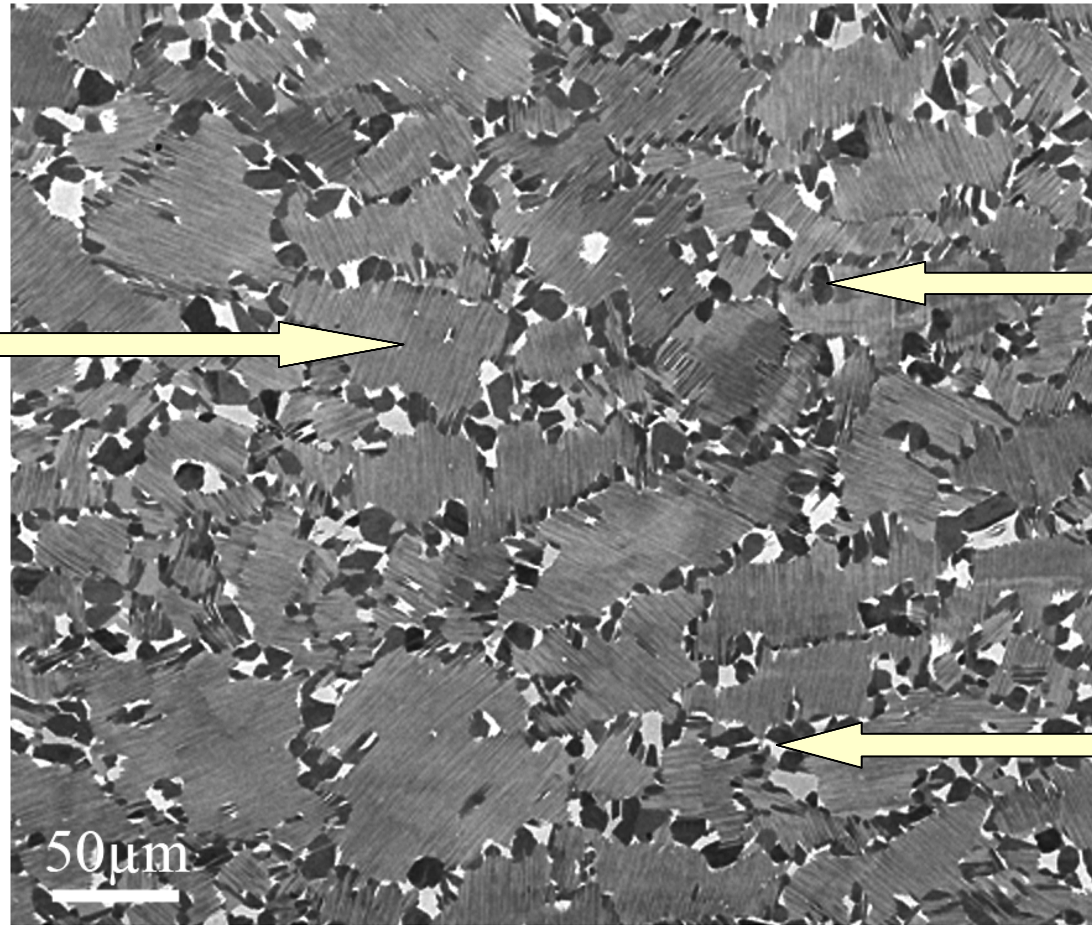
&

Mechanical Properties



Example of NLγ microstructure showing balanced mechanical properties

Lamellar γ /α_2-colonies



Globular γ-grains

Globular β_o- grains

Microstructural parameters:

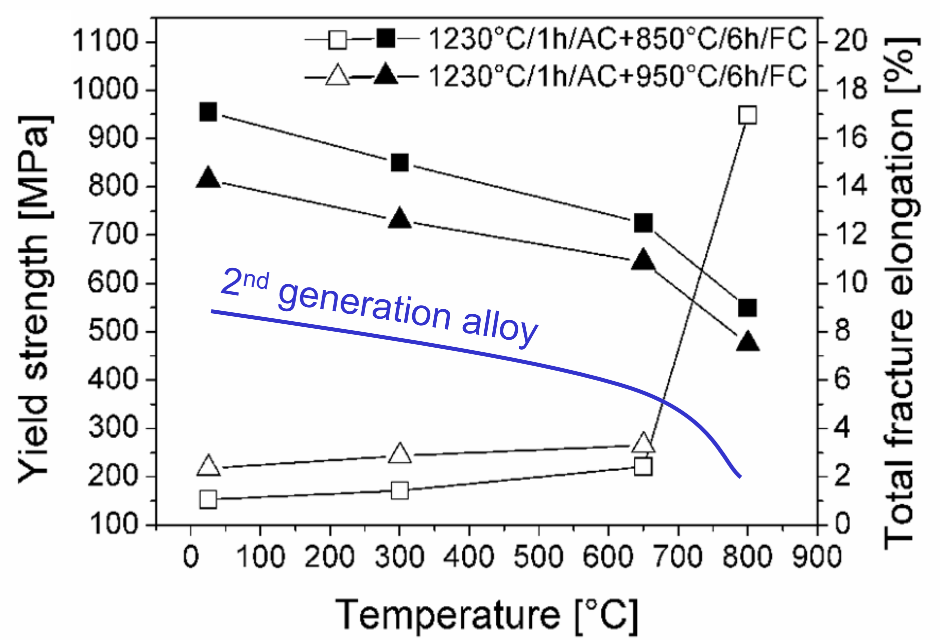
- lamellar colony size and lamellar spacing
- volume fraction and size of globular β_o and γ

Mechanical properties of TNM alloys

Tensile test

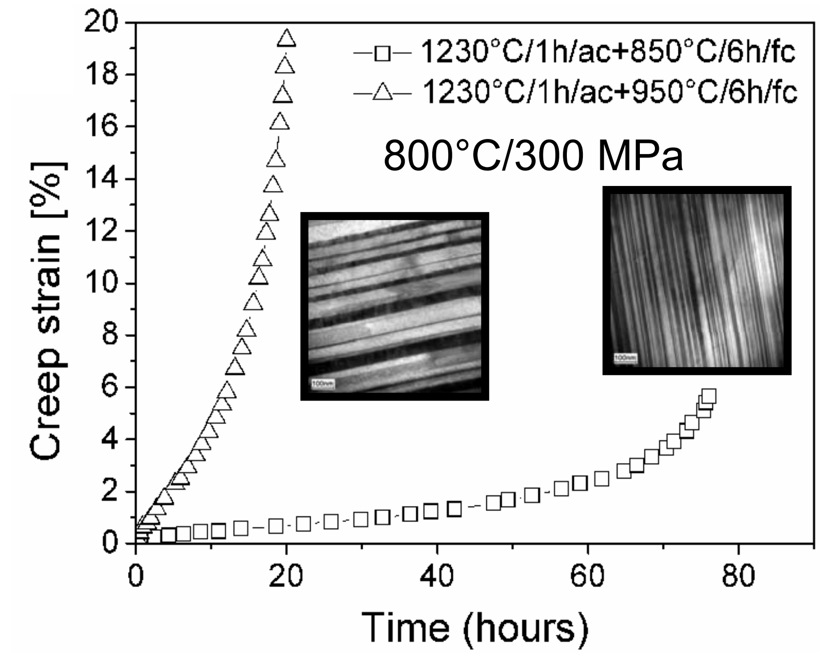
Ti-43at%Al-4at%Nb-1at%Mo-0.1B

Volume fraction of globular γ- and β_0-grains is constant!

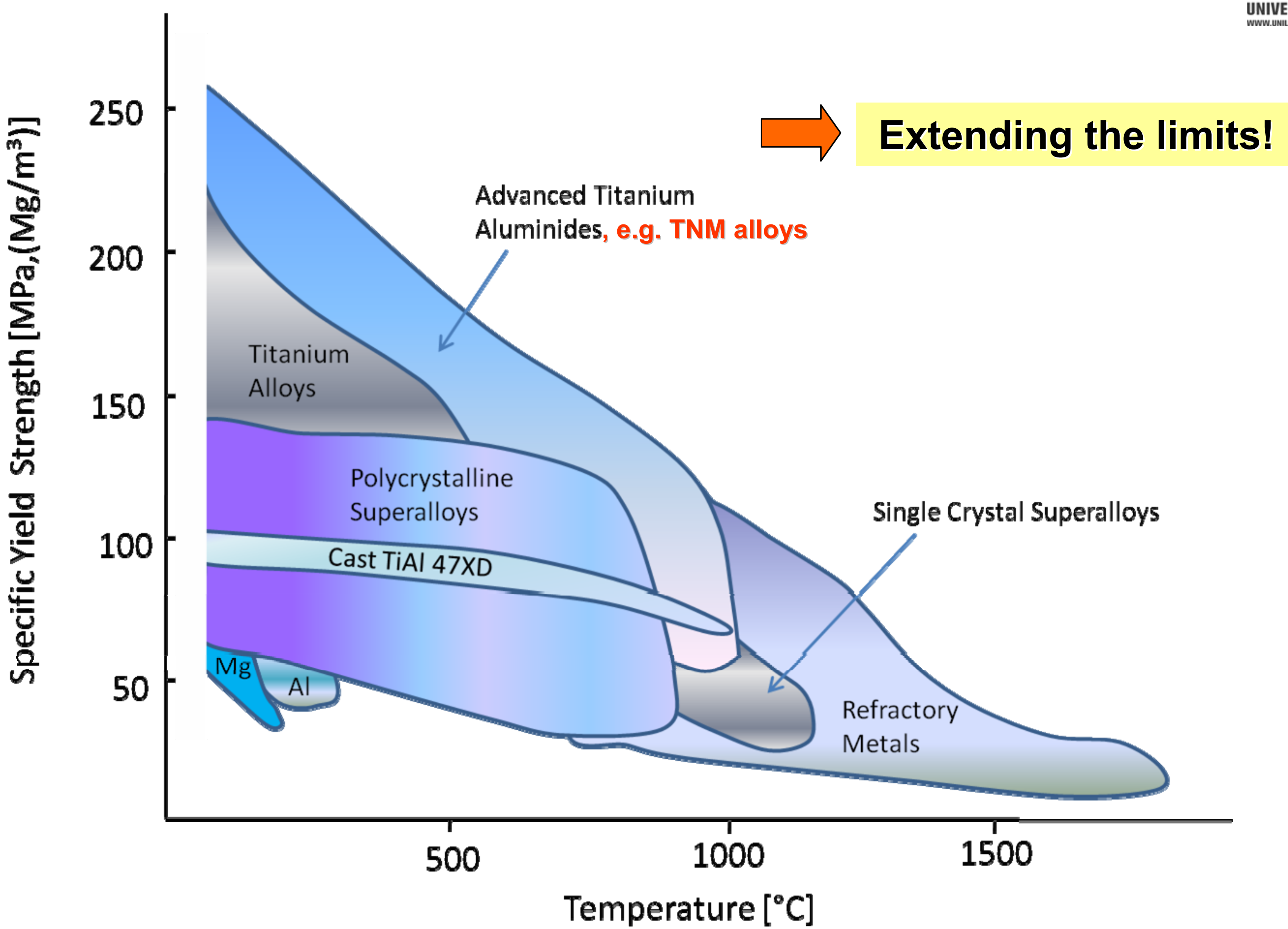


Tensile ductility is mainly determined by the fraction of globular γ-grains!

Creep test



TiAl alloys in comparison



Thanks go to …

Wilfried Smarsly, Ulrike Habel, Falko Heutling, Dietmar Helm, *MTU Aero Engines*

Volker Güther, Andreas Otto, Anita Chatterjee, *Matthias Achtermann, GfE*

Daniel Huber, Sascha Kremmer, Martin Stockinger, *Böhler Schmiedetechnik*

Gopal Das, *Pratt & Whitney*

Patrick Voigt, Robert Hempel, *Titanium Solutions*

Masao Takeyama, Hirotoyo Nakashima, *Tokyo Institute of Technology*

Peter Schretter, Heinrich Kestler, *Plansee*

Hartmut Baur, Rainer Joos, *Daimler AG*

Arno Bartels, Wolfram Schillinger, *TU Hamburg Harburg*

Peter Staron, Andreas Stark, Florian Pyczak, Fritz Appel, Michael Oehring, Rainer Gerling, H.-P. Schimansky, *Helmholtz Zentrum Geesthacht*

Klaus-Dieter Liss, Ian Watson, Saurabh Kabra, *ANSTO*

Reinhard Pippan, Otmar Kolednik, Gerhard Dehm, *Erich-Schmid-Institut, Leoben*

Harald Chladil, Dieter Fischer, Limei Cha, Paul Mayrhofer, Ronald Schnitzer, Wolfgang Klauber, Wilfried Wallgram, Barbara Böck, Laura Drössler, Thomas Schmölzer, Martin Schloffer, Emanuel Schwaighofer, Christian Sailer, Lukas Pritz, Eva Eidenberger, Andrea Gaitzenauer, Robert Werner, *Montanuniversität Leoben*

….. and many more …. !