Influence of microstructural heterogeneity on the micro-meso deformation of a two-phase TiAl alloy investigated by nanoindentation and a numerical two scale model

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Outline

- Material and microstructure
- Investigation of material behavior
  - Nanoindentation testing
  - Influence of heterogeneity: scatter in Young's modulus
- Modeling approach
  - FE model
  - Model parameters
- Simulation of nanoindentation
  - Simulation results
- Summary and conclusion

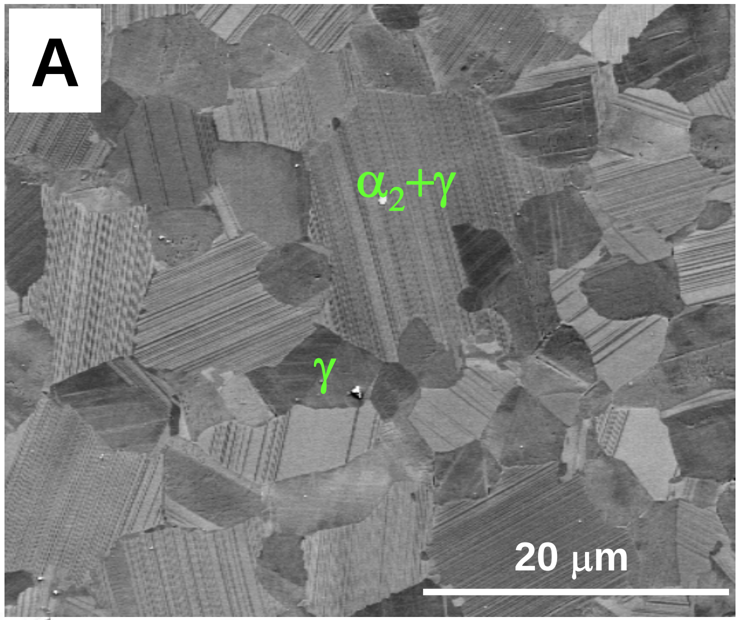
Material and microstructure

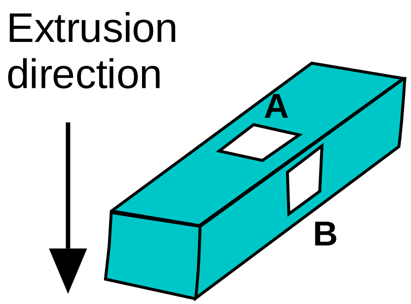
TNB alloy: Ti -45Al -5Nb-0.2B (at%)

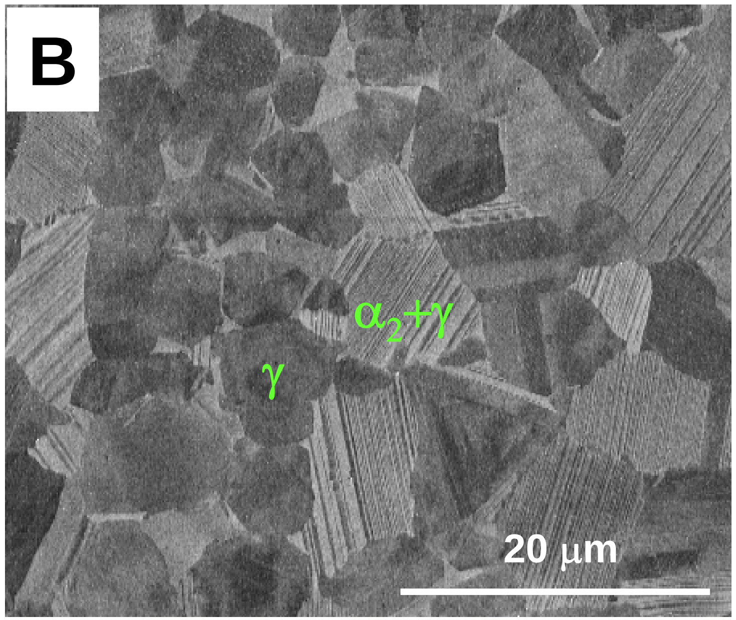
- Extruded and forged
- HT: 1260°C, 1h, AC + 850°C, 6h, FC in calm air
- Microstructure: Duplex type
- 20-30% vol. of globular grains

Microstructural heterogeneity

- Presence of different phases
- Distribution of grain/colony size and orientations
- Variable lamellae thickness
- Clusterization of grains/colonies

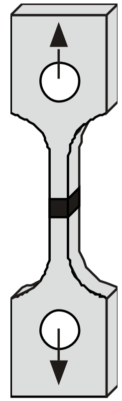






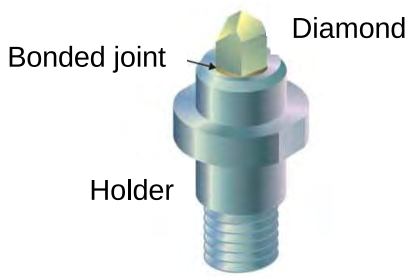
Influence of heterogeneity on material and structural behavior on different length scales

- **Macro scale (specimen, component)**
  - Scatter in E-modulus
  - Variable plastic strain limit
  - Scatter in fracture strength

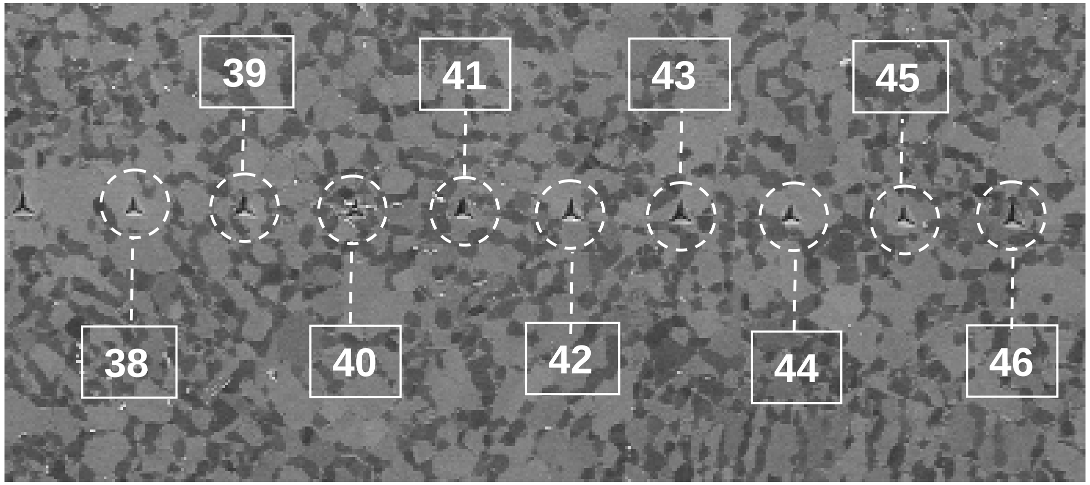


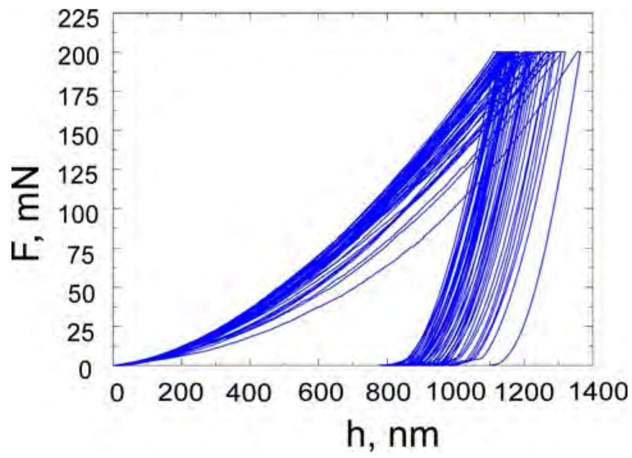
- **Meso-micro scale (on microstructure level)**
  - Scatter in E-modulus
  - Inhomogeneous local stresses and strains
  - Heterogeneous microcracking

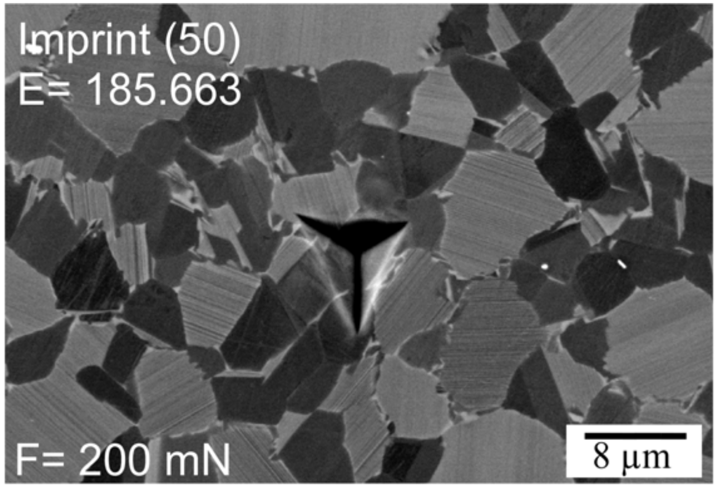
Material behavior on meso level: Nanoindentation



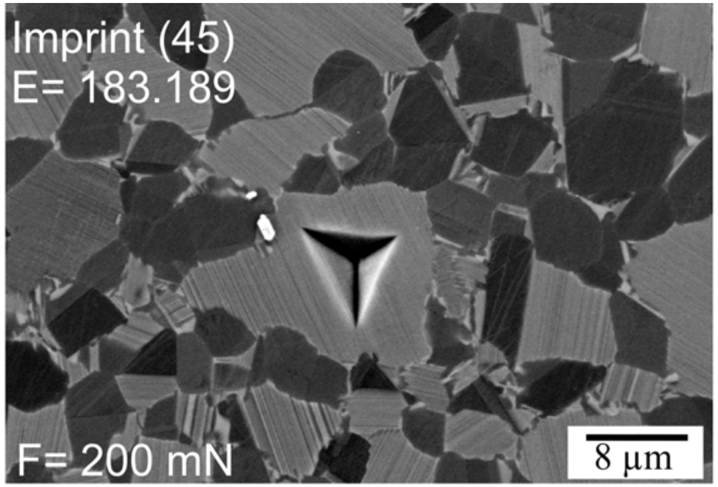
Berkovich tip



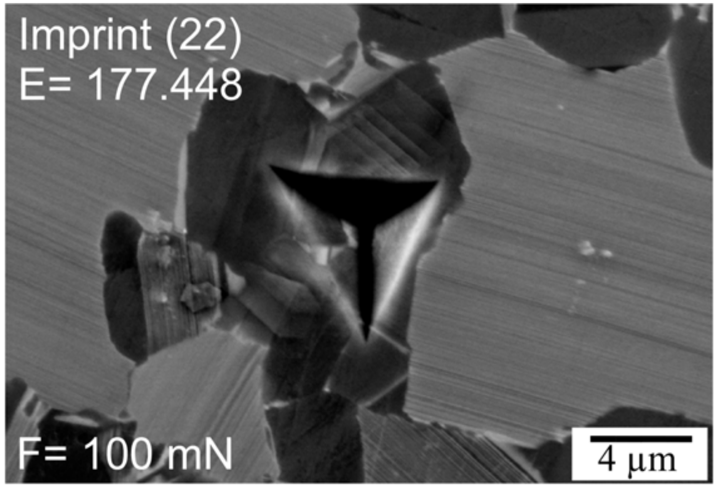




Poly grains



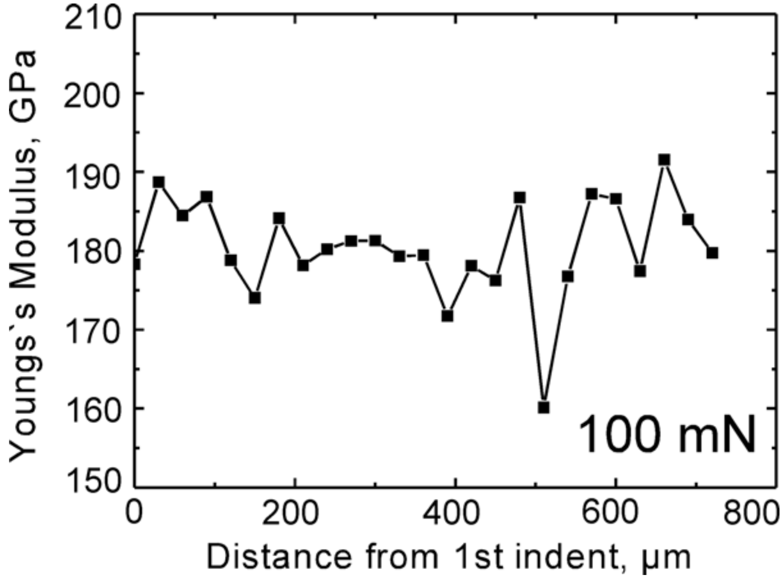
Lamellar colony

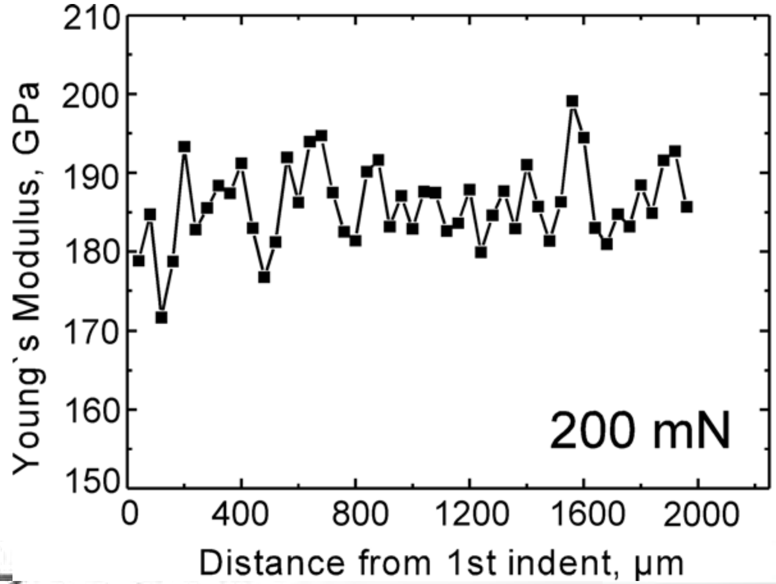


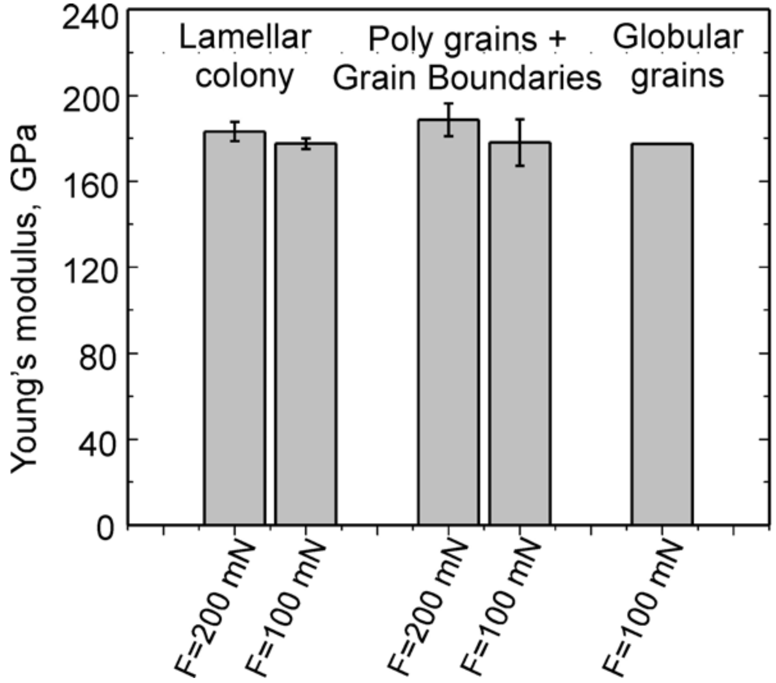
Globular grain

Experimental results: Nanoindentation

E-mod of grains and colonies (Max load: 100 & 200mN)



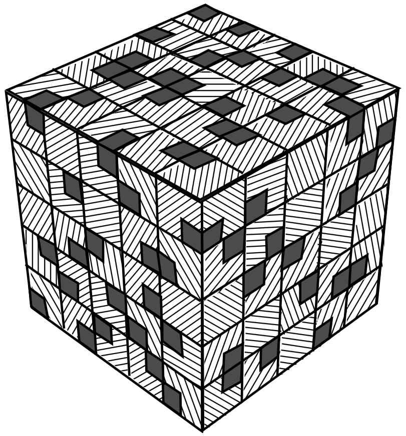




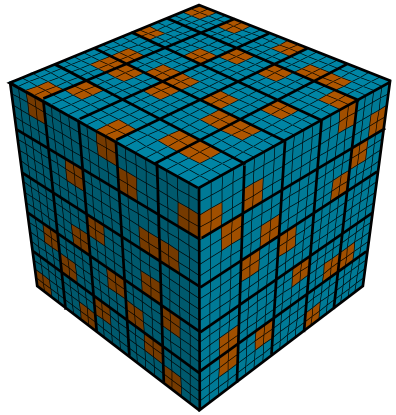
Indentation location	Elastic modulus [GPa] (average value)
Globular grains	169
Lamellar colonies	182
At interfaces between grains/colonies	192

Representative microstructure for modeling

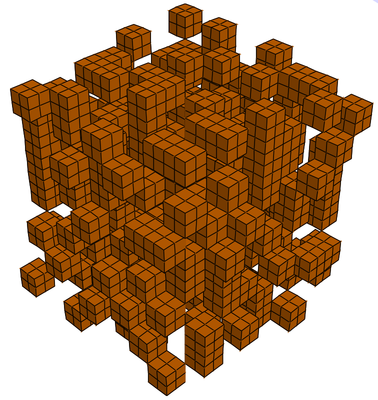
Meso scale description



Idealization of the microstructure

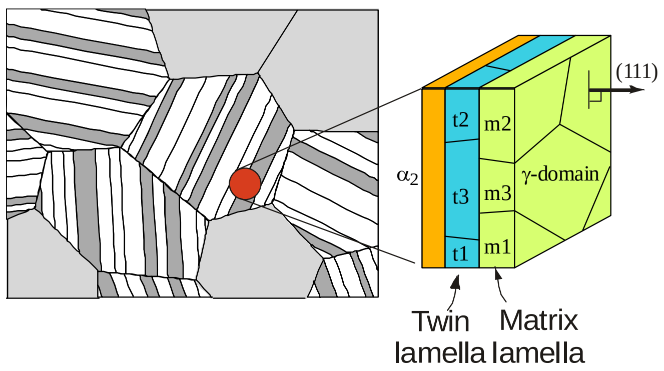


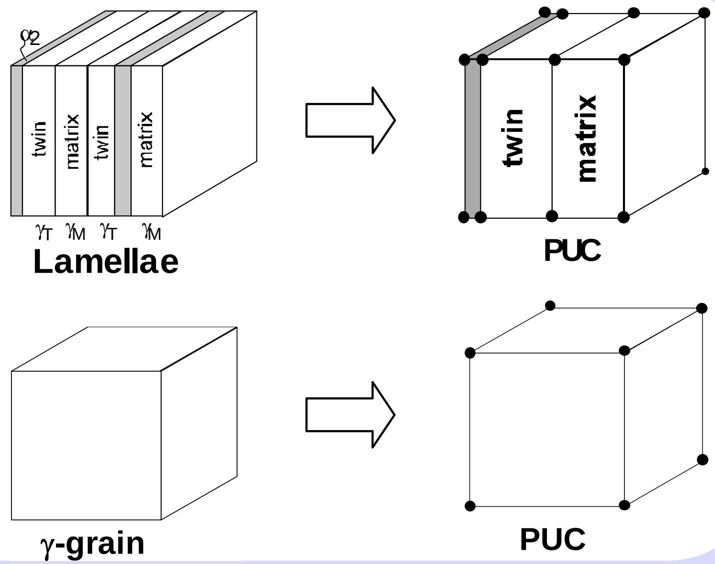
FE Model



Globular grains

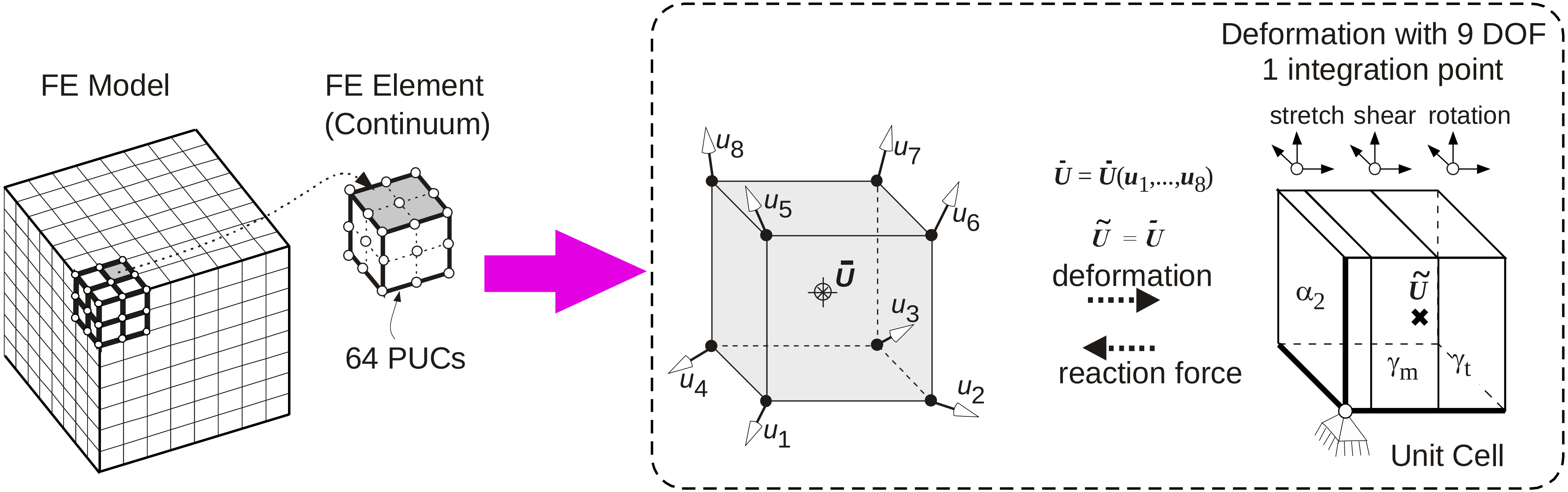
Micro scale description





Two scale linking – FE2-method

FE2 model



Periodic Unit Cell - PUC

Crystal plasticity

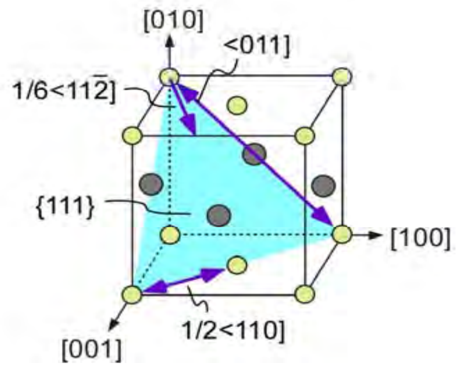
Crystalline slip is assumed to obey Schmid's law with resolved shear stress:

$$\tau = n^{*(\alpha)} \left(\rho_0/\rho\right) \sigma m^{*(\alpha)}$$

Viscoplastic power law

$$\frac{\dot{\gamma}^{(\alpha)}}{\dot{\gamma}_0} = \left|\frac{\tau^{(\alpha)}}{g^{(\alpha)}}\right|^{n-1} \operatorname{sign}\left(\frac{\tau^{(\alpha)}}{g^{(\alpha)}}\right)$$

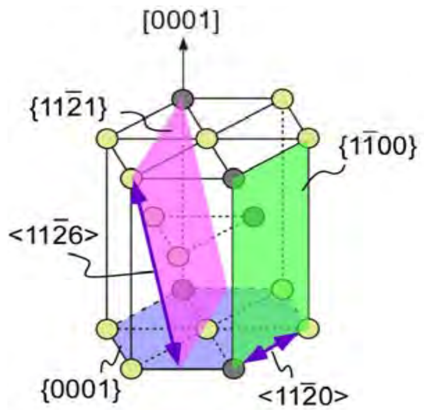
Applied values for elastic constants of single phases



γTiAl

Experimental values of the phases, after Yoo and Fu [*], determined for binary Ti-49Al alloy

	E_{1111}	E_{1122}	E_{2222}	E_{1133}	E_{3333}	E_{1212}	E_{1313}	E_{2323}
γ-TiAl	190	105	190	90	185	50	120	120
α_2-Ti_3Al	221	71	221	85	238	75	69	69



α_2 Ti_3Al

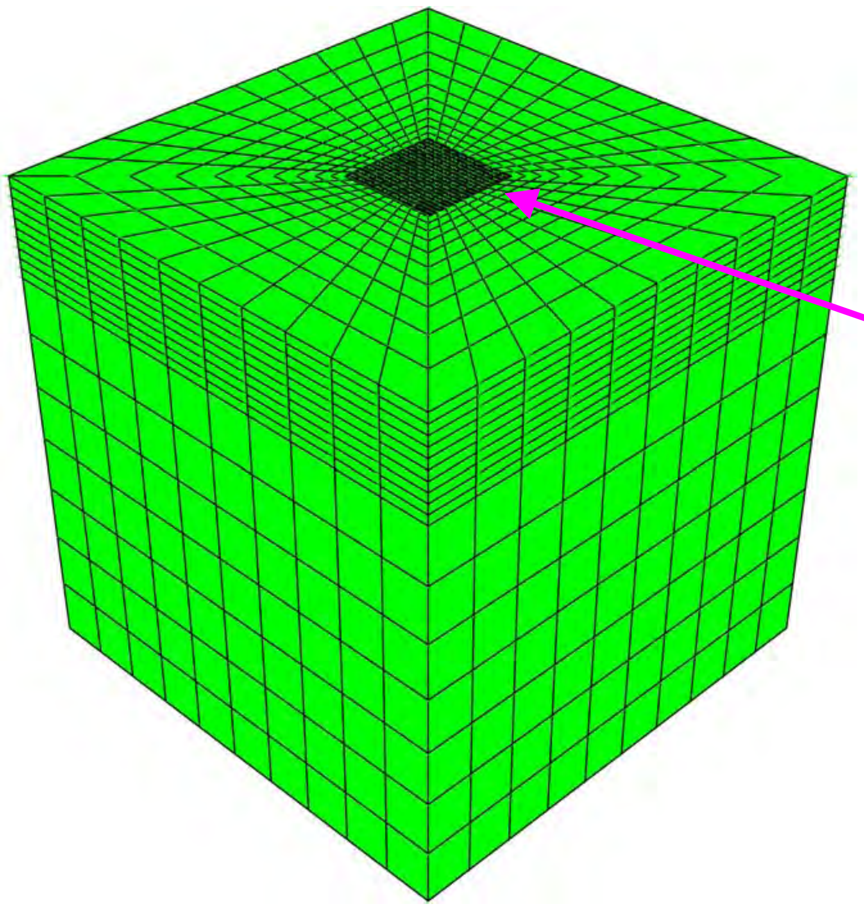
Obtained values for TNB (Ti-45Al-5Nb-0.2B) from Simulation

- Simulation of tensile tests
- Adjust crystallographic parameters to satisfy the experimental response

	E_{1111}	E_{1122}	E_{2222}	E_{1133}	E_{3333}	E_{1212}	E_{1313}	E_{2323}
γ-TiAl	161,5	89,25	161,5	76,50	157,25	42,5	102	102
α_2-Ti_3Al	187.85	60.35	187.85	72,25	202.3	63,75	58,65	58,65

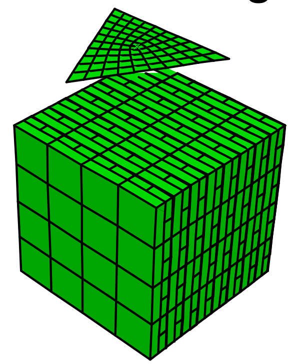
[*] ISIJ International, Vol. 31 (1991), No. 10, pp. 1049-1062

Model approximation for nanoindention simulation

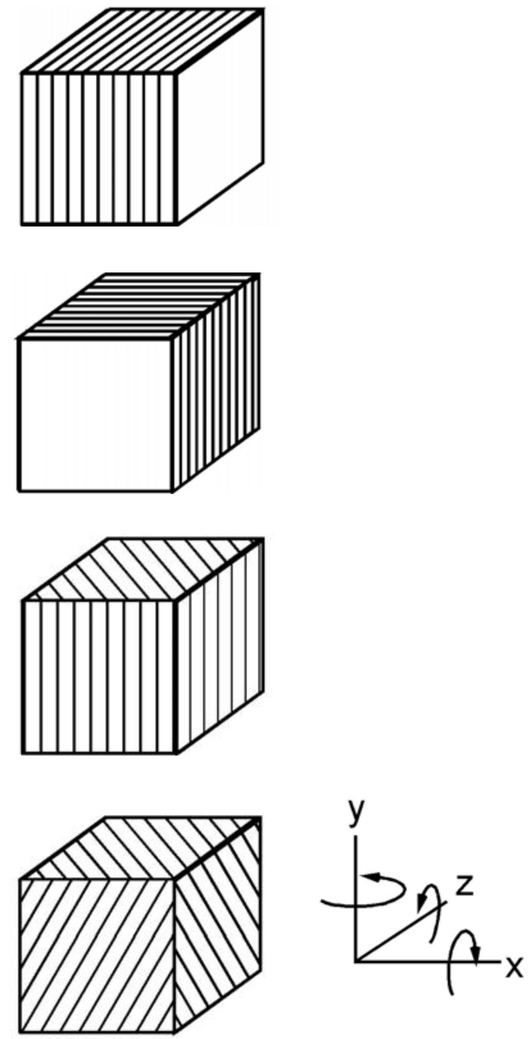


Different types of
embedded FE-Modells

Rigid indenter

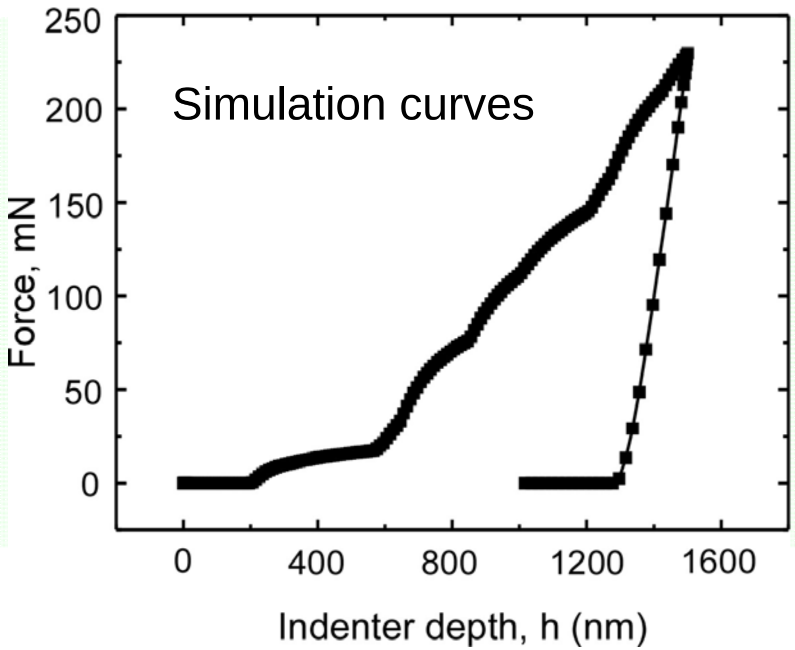


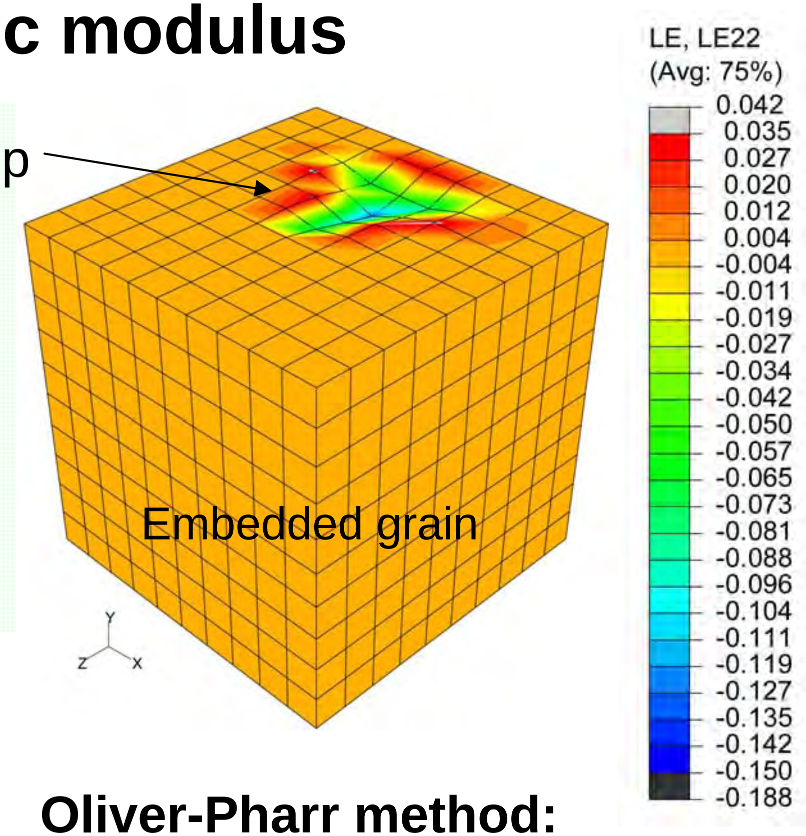
Embedded grain
or lamellar colony



Orientation of colonies
in the Embedded model

Calculation of elastic modulus





Calculation of E-mod:

$$E = (1 - \nu^2) / \left[1/E_r - (1 - \nu_d^2)/E_d \right]$$

E = Young's modulus

ν = poisson's ratio

for diamond:

$\nu_d = 0.07$, E_d = 1140 GPa

Oliver-Pharr method:

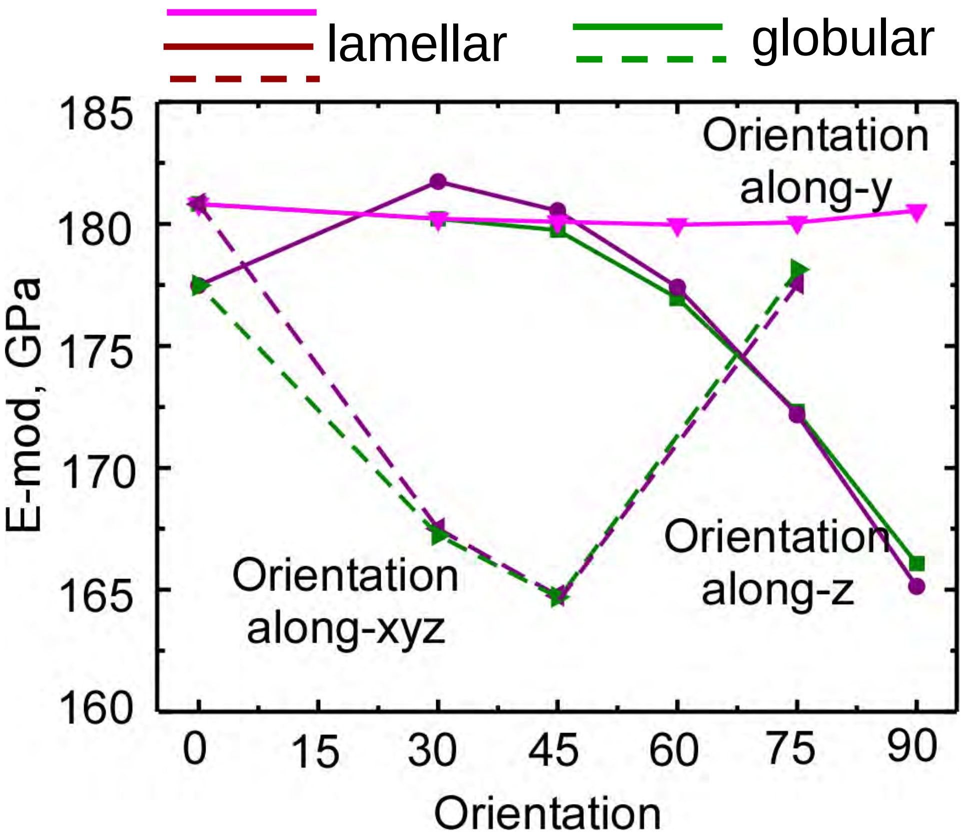
$$E_r = 1/2(\pi / A_c)^{1/2}(1/\beta)S_u$$

A_c = contact area, from ABAQUS

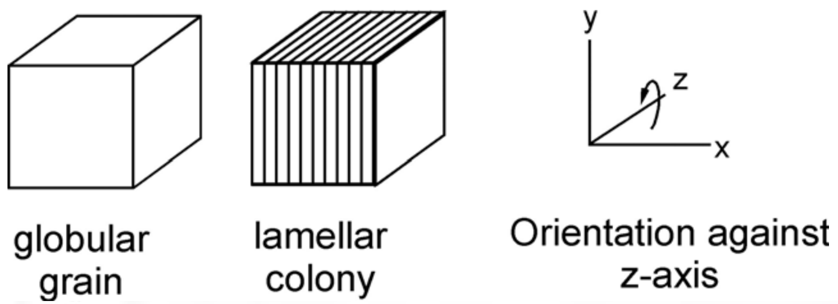
β = shape function Berkovich tip = 1.034

S_u = slope, from F-h plot

Simulation results: Influence of grain/colony orientation

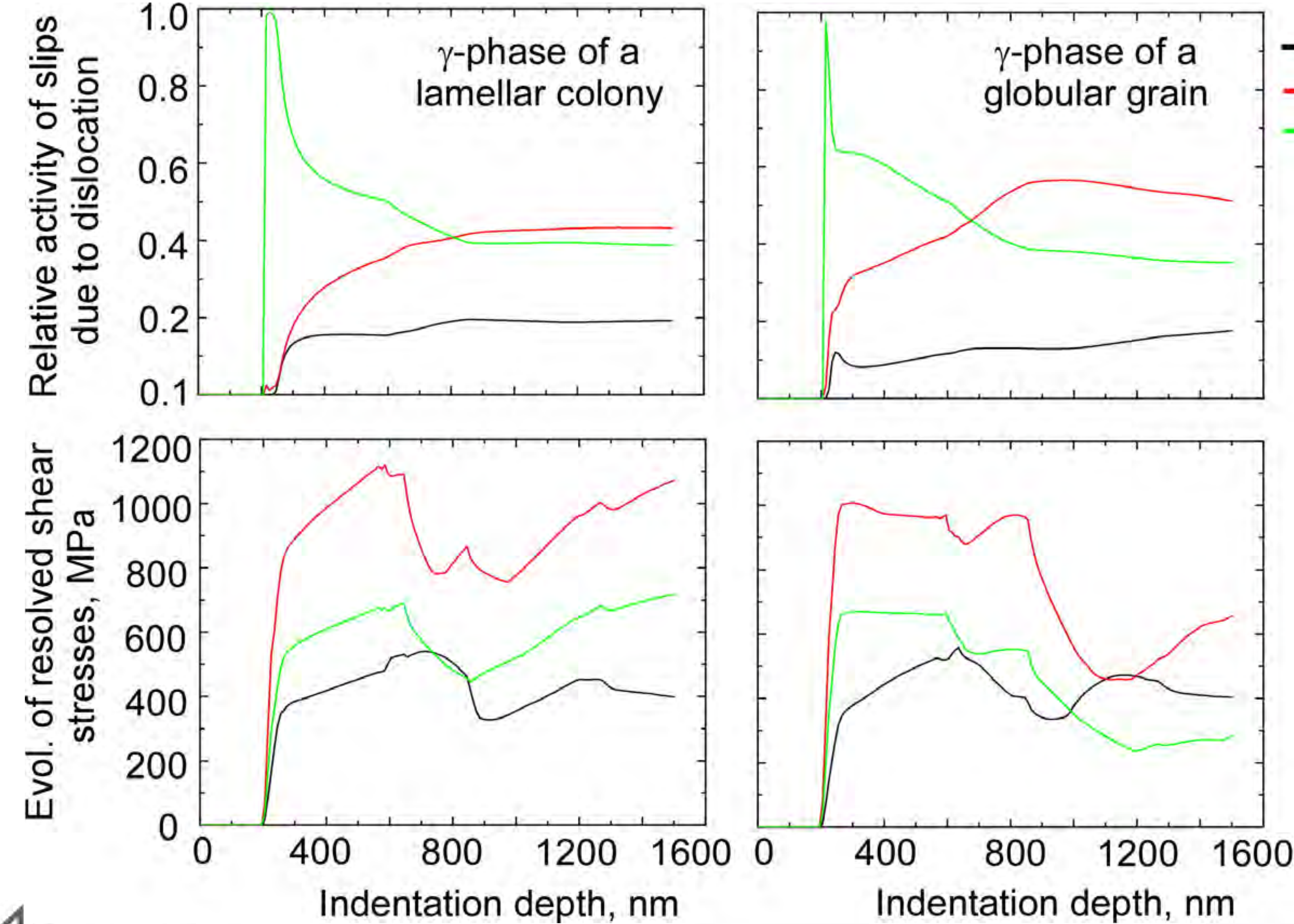


Average - Emod	Exp	Sim.
Macro (Tensile test)	146	142
Meso grain: Lamellar (nanoindentation)	182	177
Meso grain: Globular (nanoindentation)	169	175



Inconsistency:
Due to model simplicity
a) Thick lamellae
b) 4% α2-phases

Simulation results at indenter tip:
Slip system activation and shear stress evolution



Summary and Conclusion

- The nanoindentation experiments showed that the meso scale elastic modulus varies due to microstructural heterogeneity.

- Simulation of nanoindentation showed that
  - Elastic modulus of the colonies and grains vary due to grain orientation
  - The scatter band of elastic modulus due to the influence of colony/grain orientation is +- 25 GPa
  - Activation of slip systems and the evolution of shear stresses in the crystallographic plane are influenced by deformation constraint of the present phases

Thank you for your attention