ALEMI workshop 2014

Numerical investigation of stress/strain localisation during diffusive phase transformation in steels

by

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- Phase transformation and elastic energy
- FFT numerical scheme for polycrystalline material
- Some calculation results of stress/strain localisation
- Pre-deformation effect on transformation dilatation
- Concluding remarks

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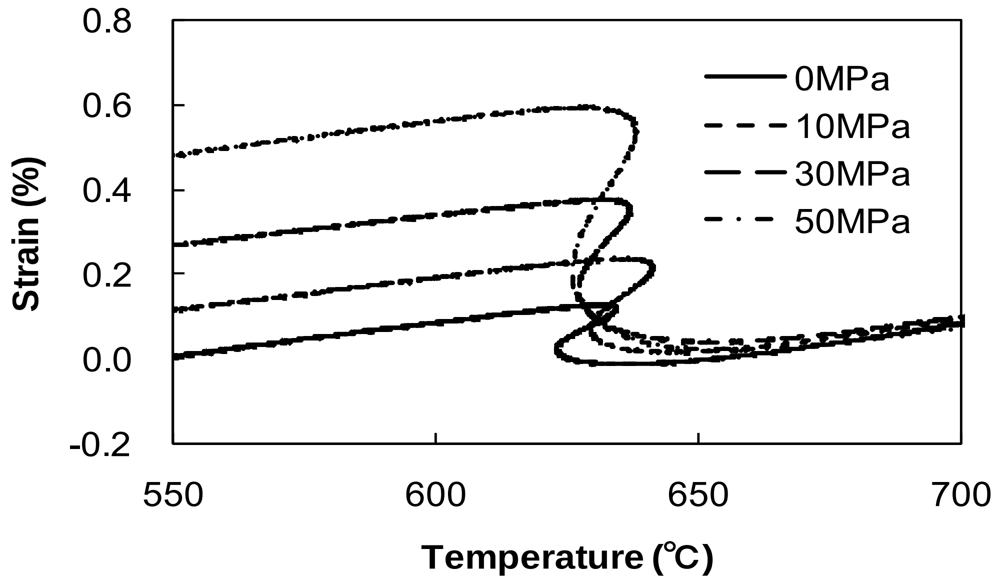
Transformation plasticity

◆ Microscopic stress/strain localisation

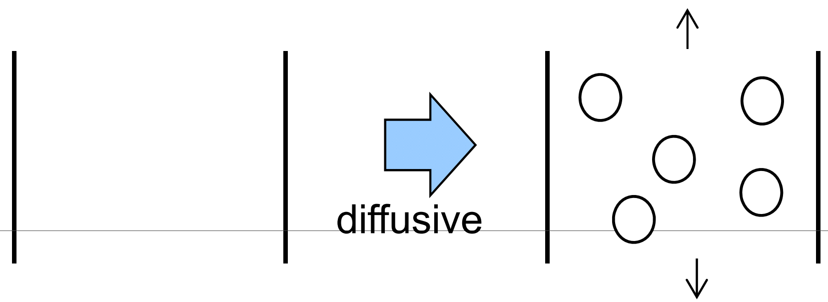


Plastic strain during phase transformation

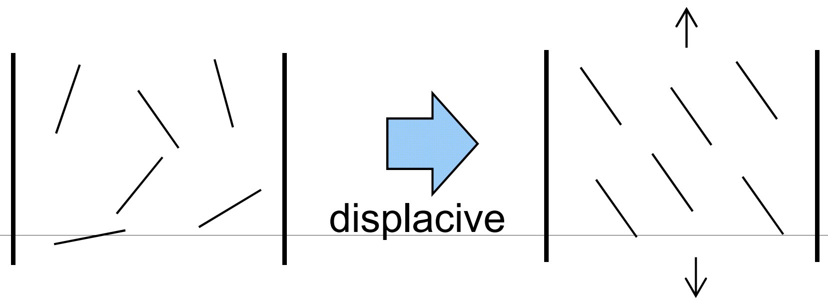
under small applied stress

◆ Mechanism

● Greenwood-Johnson effect



● Magee effect



➢ Plastic deformation during phase transformation

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Stress/strain calculation by FFT numerical scheme

◆ **Iterative solution of Lippmann Schwinger equation**

◆ Application of Fourier transform for the solution of complex microstructure

H. Moulinec and P. Suquet (1998)

◆ Application of Fourier transform for polycrystal plasticity

R. A. Lebensohn (2001)

Local constitutive equation

equilibrium condition

$$\dot{\boldsymbol{\sigma}}(x) = \mathbf{C}(x) : \left(\dot{\boldsymbol{\varepsilon}} - \dot{\boldsymbol{\varepsilon}}^{p} - \dot{\boldsymbol{\varepsilon}}^{th}\right) = \mathbf{C}^{0} : \dot{\boldsymbol{\varepsilon}} + \dot{\boldsymbol{\tau}}(x)$$

$$\operatorname{div} \dot{\boldsymbol{\sigma}} = 0$$

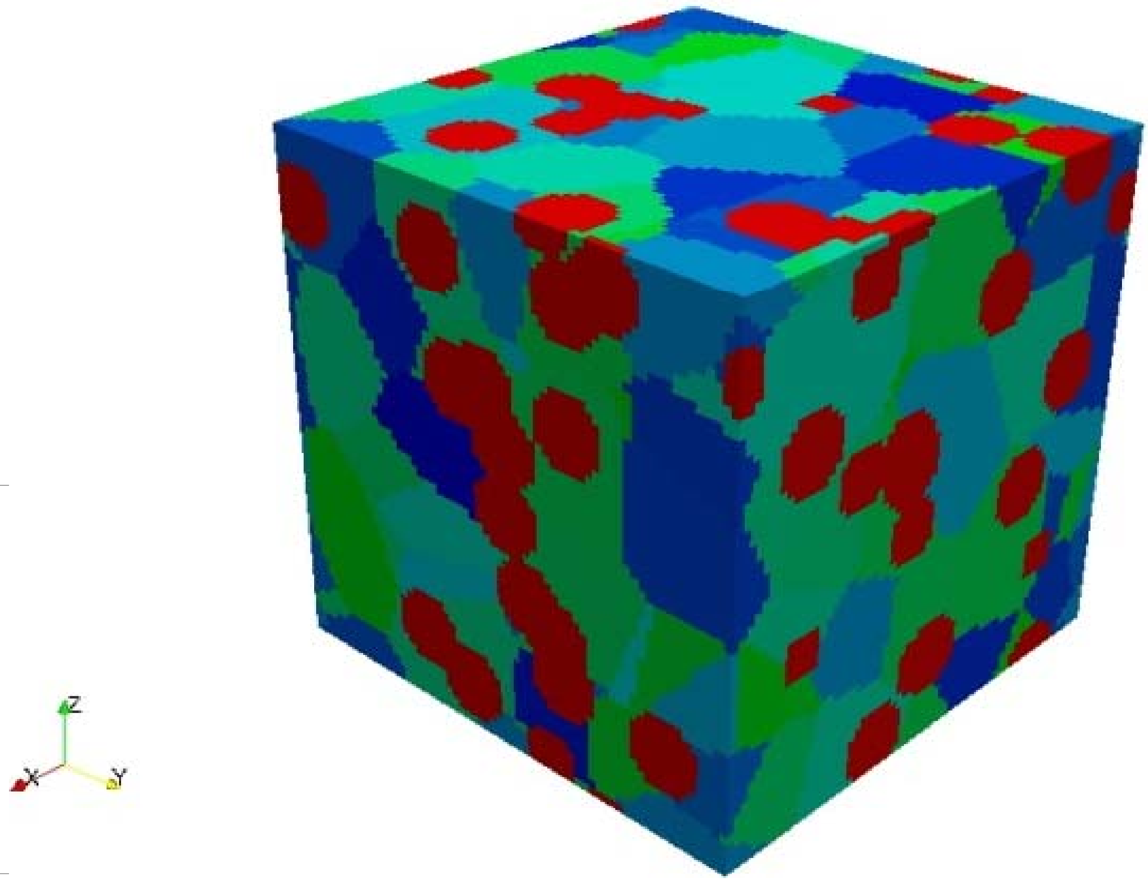
$\mathbf{C}^{0}$: Elastic modulus of reference media

FFT method is based on permutation of heterogeneous plasticity problem

With homogeneous one by using polarisation field

Stress/strain calculation by FFT numerical scheme

◆ 3 dimensional calculations are performed



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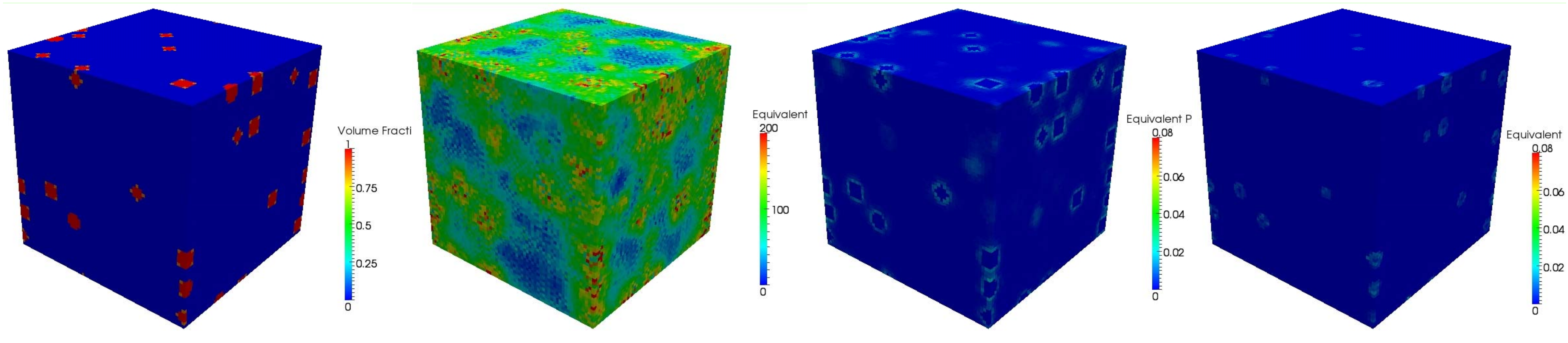
Results and discussions

◆ when 3% transformed

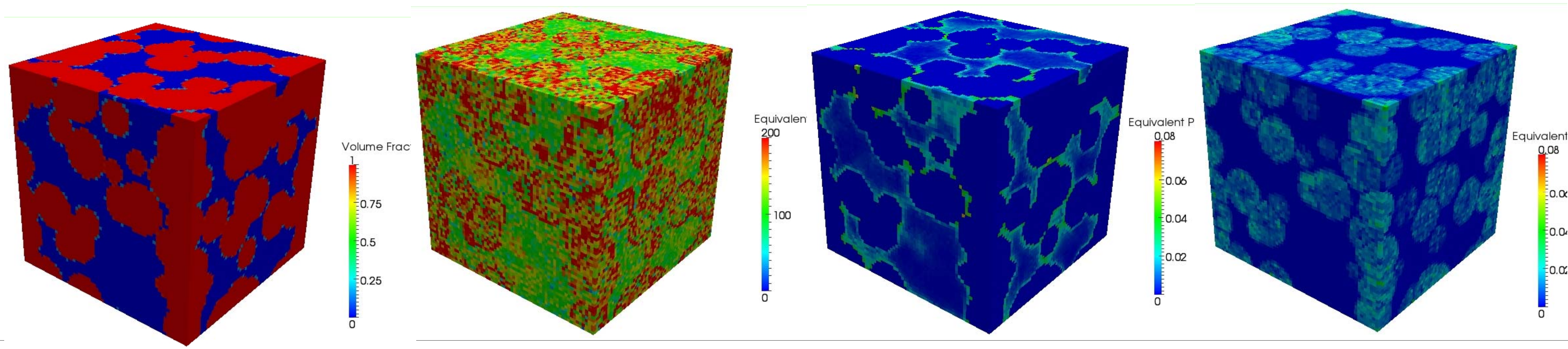


(a) Z (b) $\overline{\sigma}$ (c) $\overline{\varepsilon}_1^{eq}$ (d) $\overline{\varepsilon}_2^{eq}$

➢ Plastic strain is accumulated in the parent phase

Results and discussions

◆ when 50% transformed

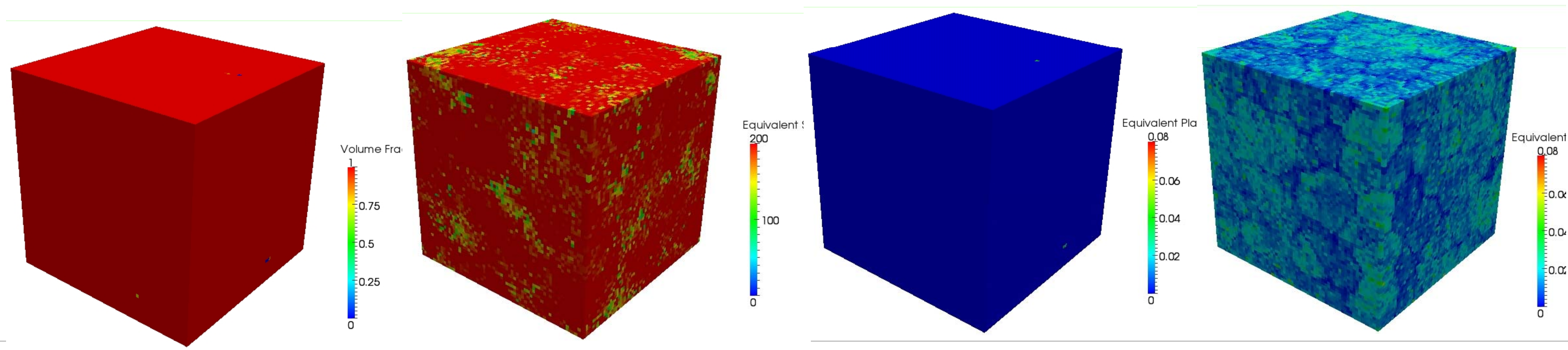


(a) Z (b) $\overline{\sigma}$ (c) $\overline{\varepsilon}_1^{eq}$ (d) $\overline{\varepsilon}_2^{eq}$

➢ Plastic strain is accumulated in the parent phase

Results and discussions

◆ when 99% transformed

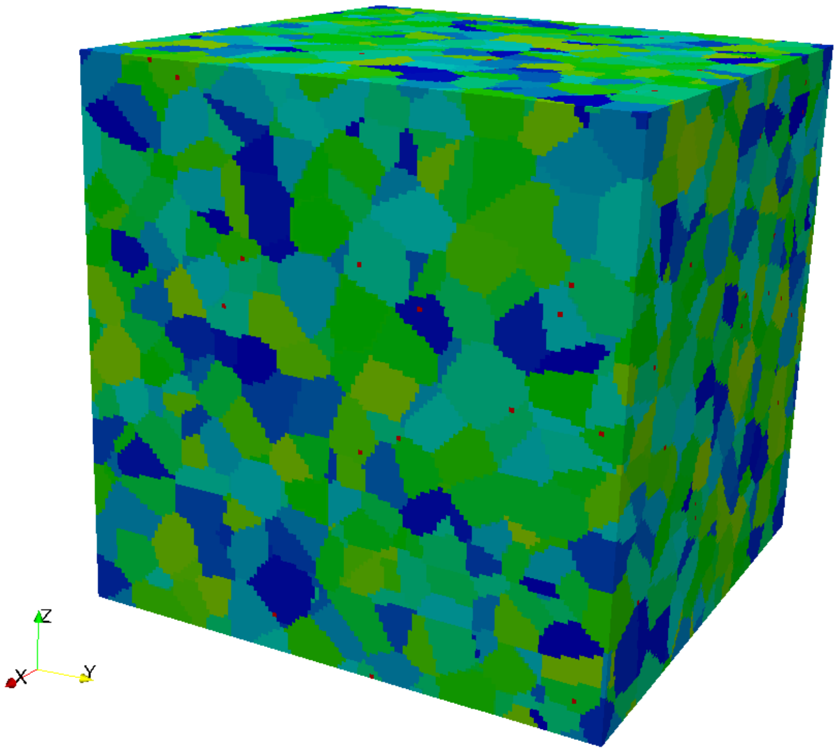


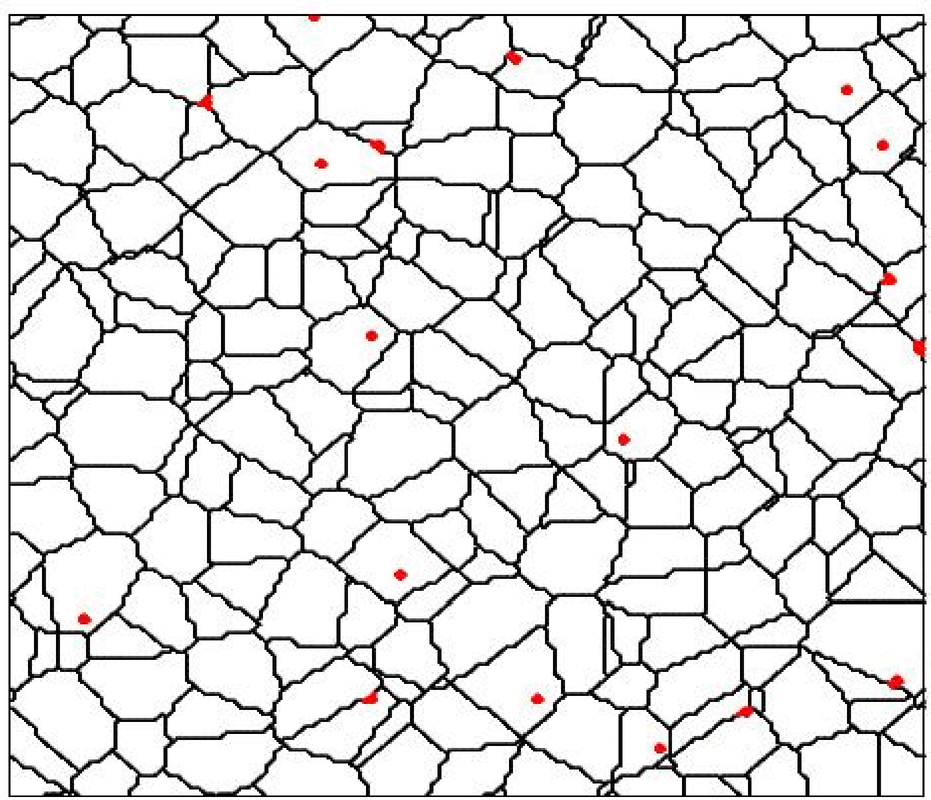
(a) Z (b) $\overline{\sigma}$ (c) $\overline{\varepsilon}_1^{eq}$ (d) $\overline{\varepsilon}_2^{eq}$

➢ Plastic strain in the daughter phase is not negligible

Dislocation density evolution during transformation

Comparison of total dislocation density (considering GND)





D=10μm

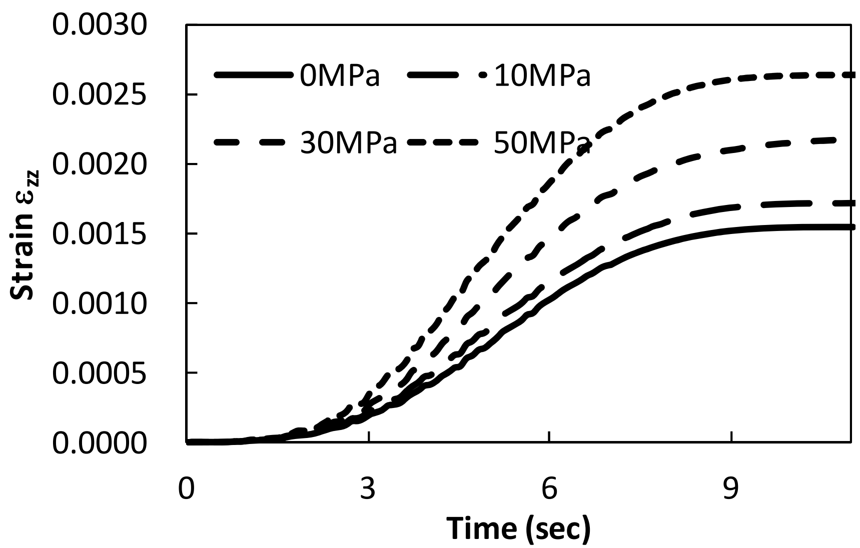
$\perp$: $\rho > 2 \times 10^{11}$ (m^{-2})

$\perp$: $\rho > 2 \times 10^{12}$ (m^{-2})

- Dislocation density is higher when grain size is small

Results and discussions

◆ **Modelling of transformation plasticity in polycrystalline materials**

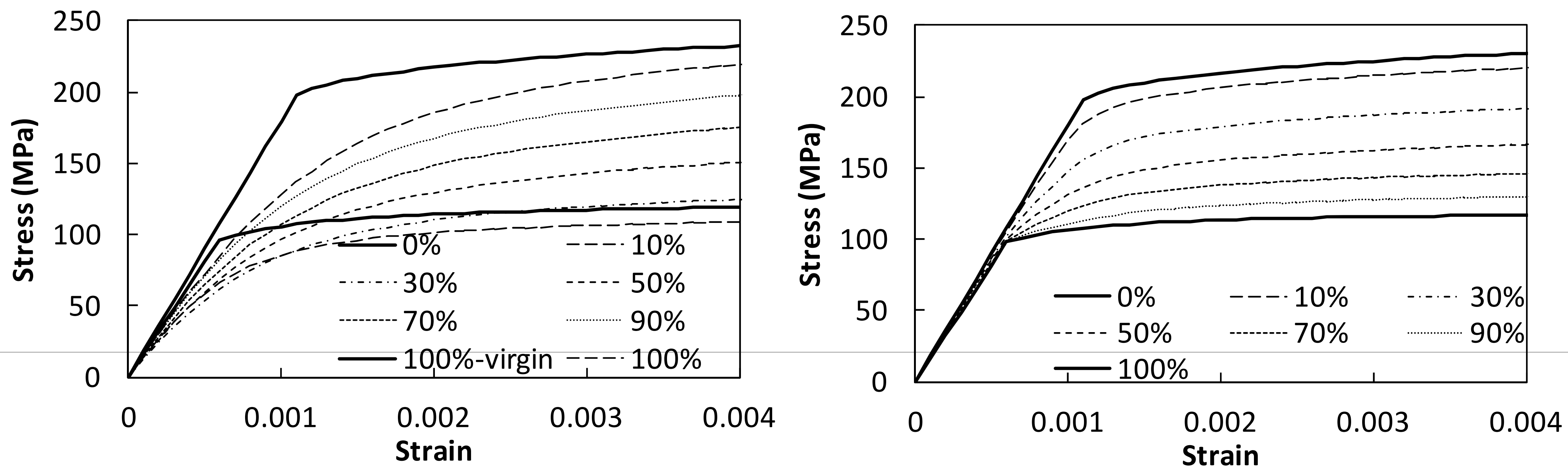


Time-Strain

Fig. Strain evolution during phase transformation under several applied stress.

➢ TP is obtained without 'artifcial' term ε^{tp}

Residual stress effect on macroscopic response



(a) With residual stress

(b) Without residual stress

- ➢ residual stress by phase transformation → macroscopic response

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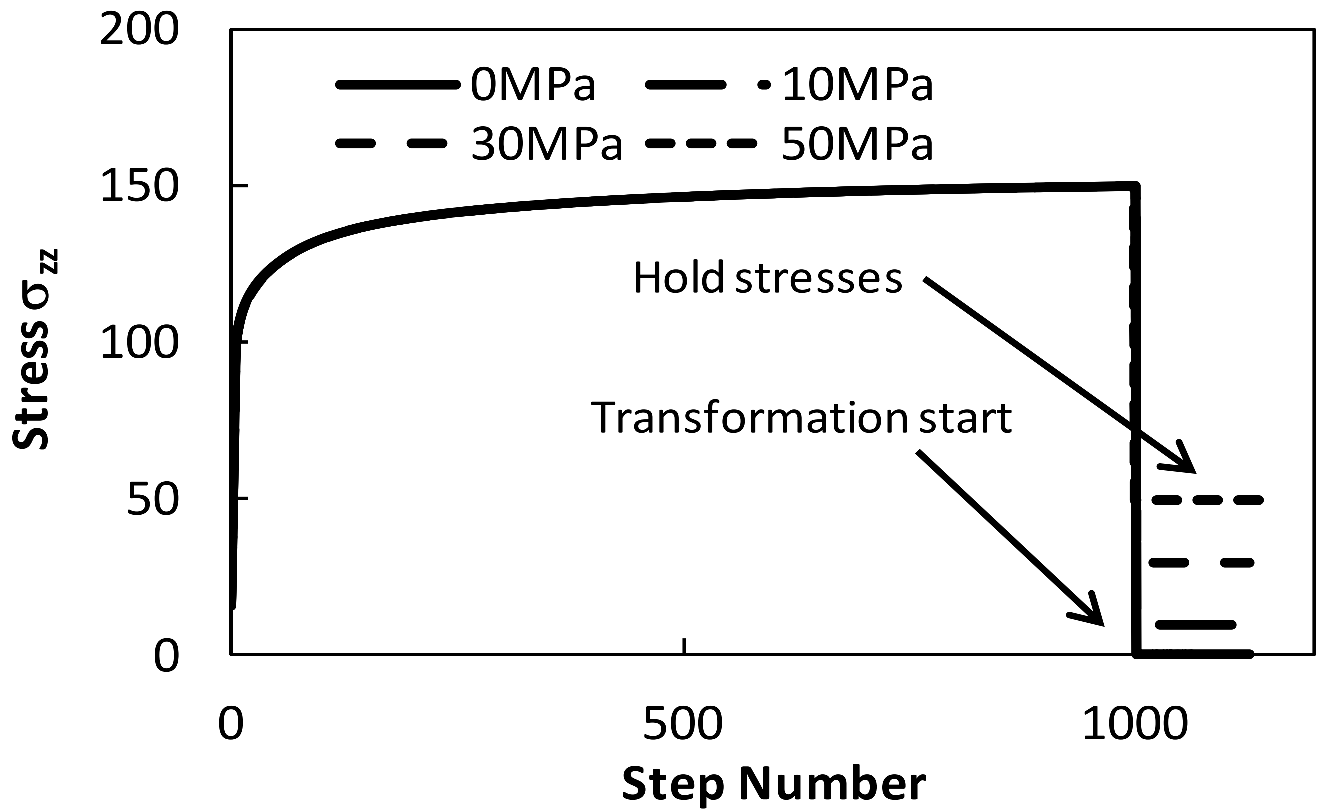
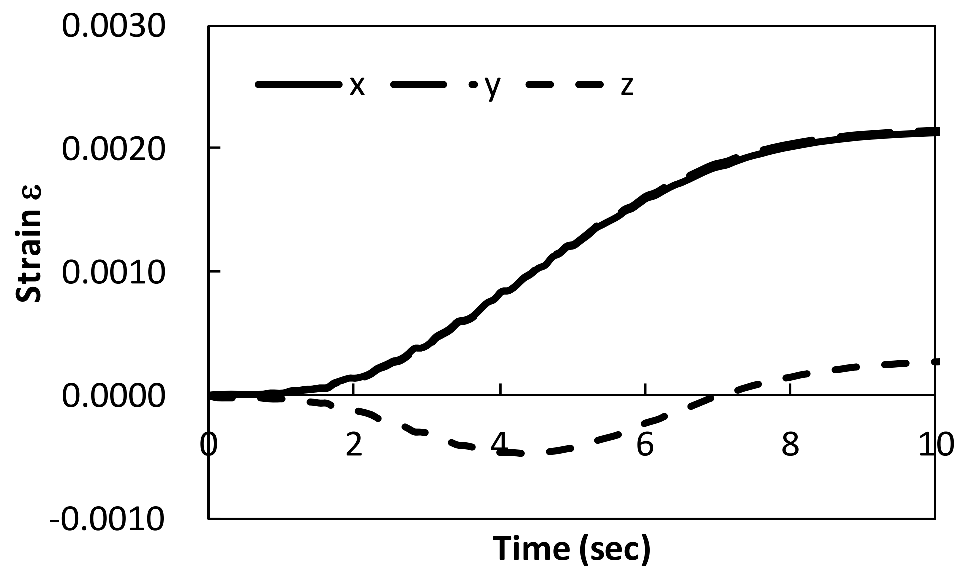
Schematic of calculation sequence

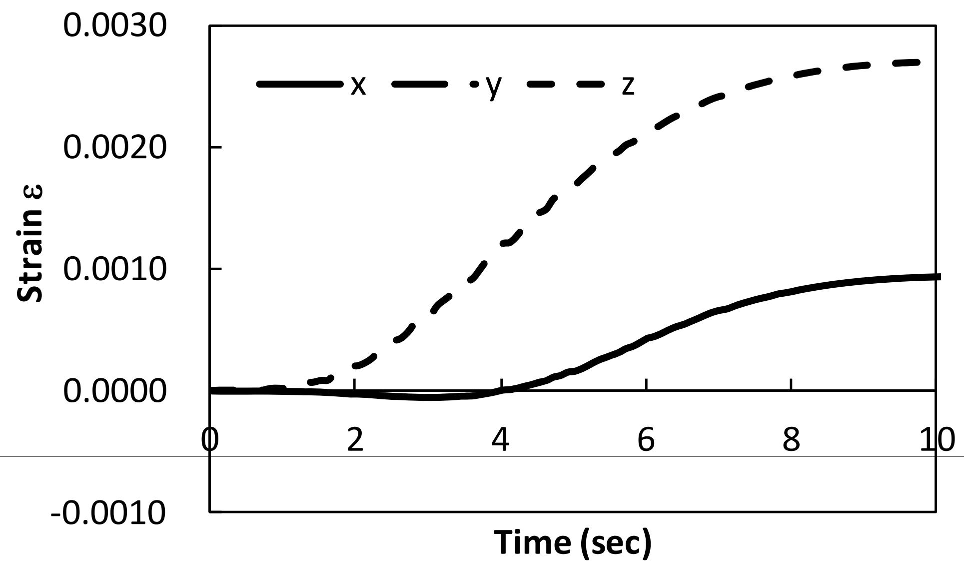


- Transformation plasticity after pre-tension(compression)

Pre-deformation effect on transformation dilatation



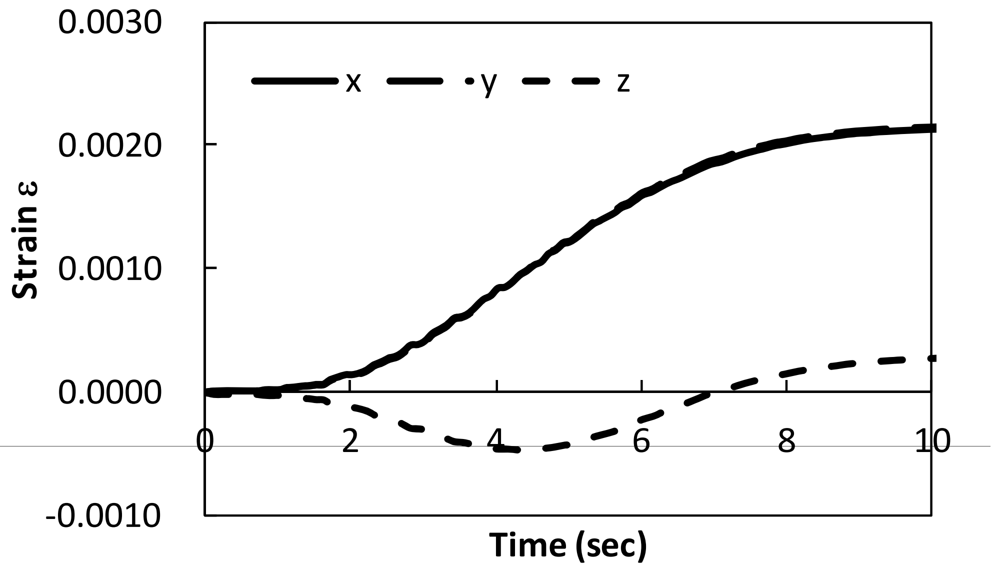
10% Pre-tension



10% Pre-compression

- Strong anisotropic behaviour of transformation expansion

Pre-deformation effect on transformation dilatation



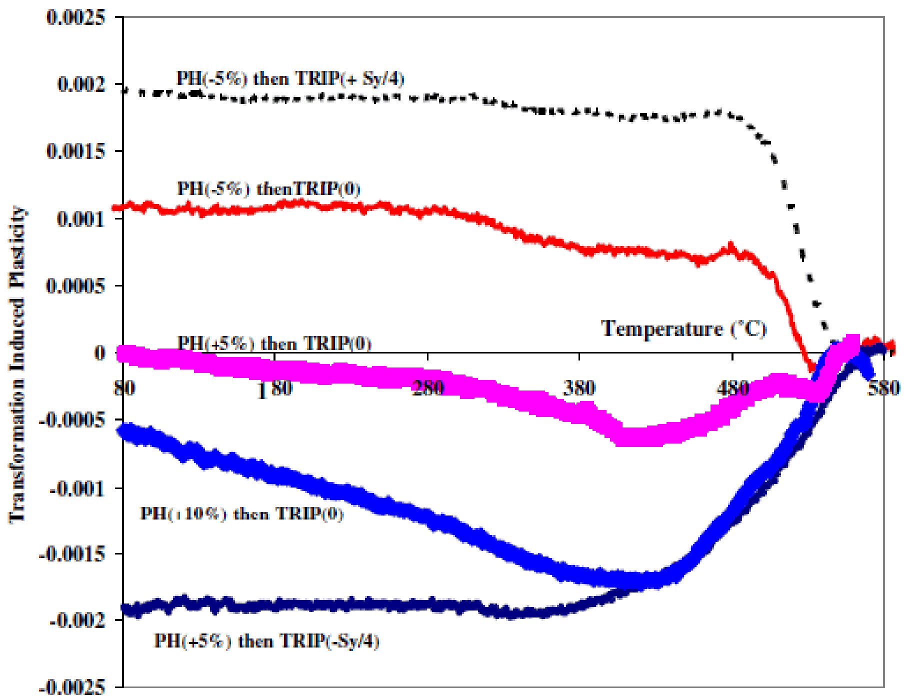


Fig. 7. Transformation induced plasticity $E^{tp}(T)$ in the pre-hardening tests.

Result by FFT

L. Taleb , S. Petit, 2006

➢ The calculated results can explain the mechanism

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Concluding Remarks

- Numerical modelling by using FFT has been developed in order to find stress/strain field during phase transformation
- The strain localisation has been found near the transformation front of austenite phase
- The irreversible strain in ferrite phase occurs after the second half of phase transformation
- Back stress causes significant anisotropic dilatation during phase transformation

for your attention