Flow stress by inverse analysis with dynamic recovery and recrystallization model of duplex stainless steel

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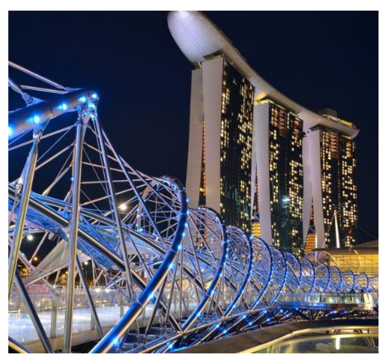
Introduction

Material flow stress is one of the most important parameters in hot working. The hot working behavior is constitutively modeled as a function of temperature, strain and strain rate. However, the determination of flow stress of the duplex stainless steel seems more complex because the two principal phases of the austenite and the ferrite, coexist and behave dissimilarly during the hot working by undergoing heterogeneous metallurgical and microstructural kinetics behaviors. The heterogeneity results in a complex determination of flow stresses from the work hardening rate with the softening interacted in each two-phase. With the aim of obtaining more accurate flow behavior of duplex stainless steel, the duplex flow model was proposed. The inverse analysis by the proposed duplex model was performed coupled with thermomechanical FEM, as the countermeasure of uncontrollable experimental influences by the internal-external heat transfer, the friction and the heat generation from the deformation of a specimen under hot working.

Oil Recovery Equipment @ Aquatech

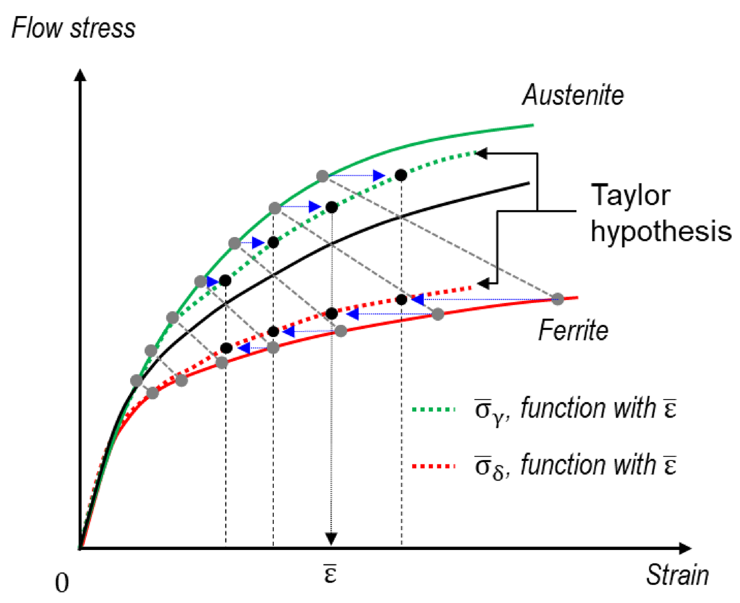


Helix bridge in Singapore, Duplex stainless

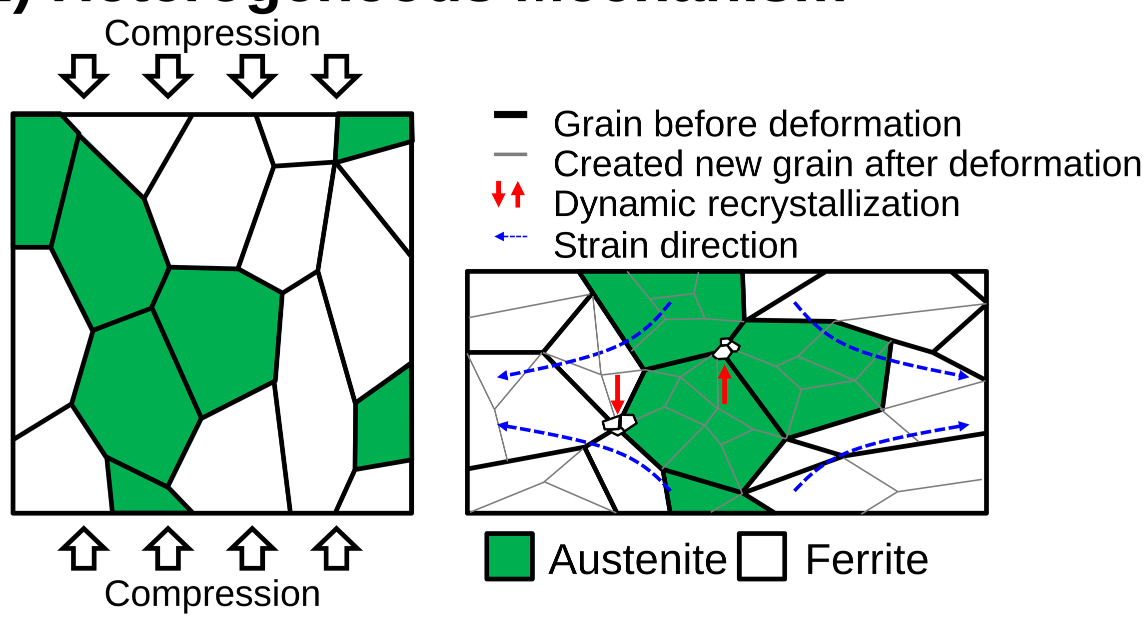
Marine Chemical tanker @ ArcelorMittal

Multi-Phases Model Development

1) Stress-Strain Partitioning



2) Heterogeneous Mechanism



3) Constitutive Duplex Model

$$\bar{\sigma} = a\sqrt{\rho} \quad (1)$$

$$\frac{\partial \rho}{\partial t} = -b^{D}\rho \quad (2)$$

$$d\rho = \frac{\partial \rho}{\partial \bar{\varepsilon}} d\bar{\varepsilon} + \frac{\partial \rho}{\partial t} dt \quad (3)$$

$$\bar{\sigma}^{*}_{\delta} = \bar{\sigma}_{\delta,sat}\left(1 - exp\left(-b^{D}\bar{\varepsilon}\right)\right)^{\frac{1}{2}} \quad (4)$$

$$\bar{\sigma}_{\delta,sat} = \left(c/b^{D} \times \dot{\bar{\varepsilon}}\right)^{\frac{1}{2}} \quad (5)$$

$$\bar{\sigma} = \bar{\sigma}^{*}_{\delta}(\bar{\varepsilon}) \times Vf_{\delta} + \bar{\sigma}^{*}_{\gamma}(\bar{\varepsilon}) \times Vf_{\gamma} \quad (6)$$

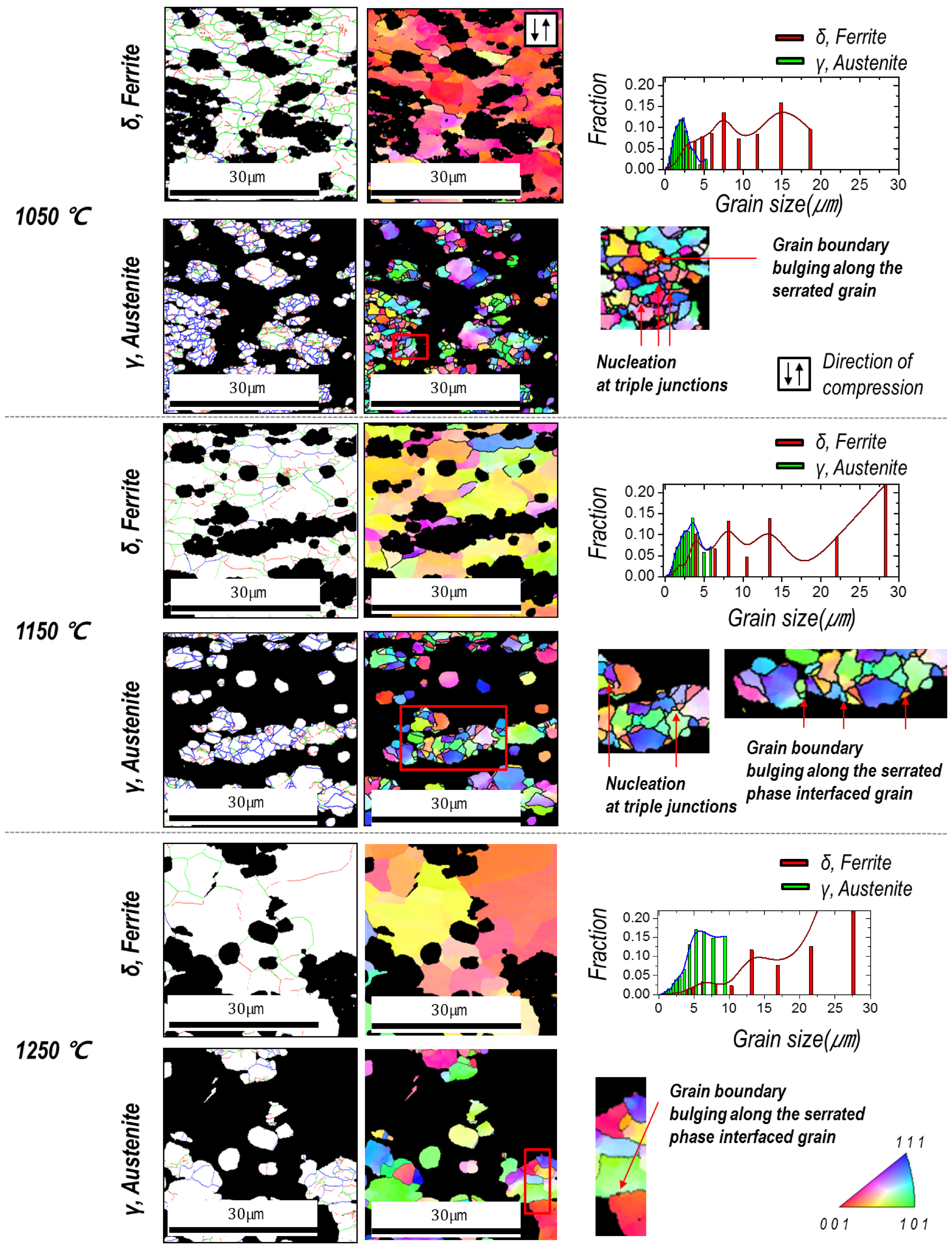
$$\bar{\sigma}_{\delta,sat} = \frac{\bar{\sigma}_{\gamma,sat}}{\lambda} \quad (7)$$

$\bar{\sigma}$ Flow stress $\bar{\sigma}^{*}_{\delta}(\bar{\varepsilon})$ Stress of δ
$\bar{\varepsilon}$ Strain $\bar{\sigma}^{*}_{\gamma}(\bar{\varepsilon})$ Stress of γ
$\dot{\bar{\varepsilon}}$ Strain rate
ρ Dislocation density
Vf_{δ} Volume fraction of δ
Vf_{γ} Volume fraction of γ
b^{D} DRV rate
a, c Material constant

λ Ratio of saturate stress of two-phase 「when the work hardening and the dynamic recovery are balanced」
$\bar{\sigma}_{\delta,sat}$ Saturate stress of δ
$\bar{\sigma}_{\gamma,sat}$ Saturate stress of γ

Microstructural Observation

The rate of work hardening with softening varies from the conditions during hot working. Moreover, the ratio of work hardening with softening is affected by chemical composition, and microstructures with different metallurgical phases of the austenite and ferrite. EBSD investigation was performed to explorer microstructure evolutions and softening mechanism using two specimens in terms of dynamic recovery and dynamic recrystallization.



Invers Analysis and Thermomechanical CAE

Inverse analysis coupled with thermomechanical CAE provides the isothermal and homogeneous flow descriptions.