博士論文（要約）

Quantification of Flow Stress and Microstructure Change for Duplex Stainless Steel

（二相ステンレス鋼の流動応力および内部組織変化の定量化）

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A Thesis Summary for the Degree of Doctor of Philosophy

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The main aim of this dissertation was to obtain a new material genome with the focus on the duplex stainless steel, in order to explore how the flow stress can be determined for two-phase alloys such as duplex stainless steel, and how the microstructure of those steels evolves during the hot deformation.

Material information, experimental facilities, and research objectives were presented in Chapter 1. In Chapter 2, basic theories for this research were reviewed with previous publications, which were related to plastic theory, microstructural evolutions (WH, DRX, and DRV), and constitutive descriptions to describe the flow stress for the metals and metal alloys. New methodologies to obtain flow stress for a two phase-alloy such as duplex stainless steel was proposed in Chapter 3. This methodology was applied to obtain the flow stresses of duplex stainless steel (SUS329J4) with temperatures of 1050, 1150, and 1250 ℃ and strain rates of 0.1, 1, and 10 s^{-1}. Dynamic kinetics and dynamic material genome of the alloy was calculated. To obtain the activation of the alloy, activation energy obtained with the new method was compared to the result by the method of previous work in Yanagimoto laboratory. These new results had the novel features of acquisitions of each activation energy of two constituents by the proposed method in Chapter 3 and Chapter4. In Chapter 5, the static kinetics were investigated, which were focused on the time effects between 1^{st} compression and 2^{nd} compression of double compression tests at temperatures of 1050, 1150, and 1250 ℃ and strain rates of 0.1 and 1 s^{-1}. Finally, future works and the significance of the research and industrial area were presented.

Thus, the features of this dissertation are summarized as follows.

(1) The proposed duplex flow model, which is a function of an equal strain ($\bar{\varepsilon}$) as a parameter, could express the different softening mechanisms in duplex stainless steel, with mainly DRX in austenite and DRV in ferrite.

(2) The ratio of saturated stress partitioning (λ) between $\overline{\sigma}_{\gamma,\mathrm{sat}}$ and $\overline{\sigma}_{\delta,\mathrm{sat}}$ was defined in the equilibrium state, which was calculated from the simulated relative stresses obtained while changing the volume fraction of each phase.

(3) Inverse analysis coupled with CAE in duplex stainless steel (SUS329J4L) was performed with five independent parameters, F_1, n, ε_c, F_3, and $\mathrm{b}^{\mathbf{D}}$, and provided a description of the heterogeneous flow stresses of austenite and ferrite.

(4) EBSD analysis showed the heterogeneity of the microstructural evolution (DRV and DRX), which confirmed that different softening mechanisms occurred in the γ and δ phases.

(5) The calculation methodology for flow stress with constituent flow stresses of austenite and ferrite was proposed. The flow stresses of duplex stainless steel (SUS329J4) were obtained by performing inverse analysis to compensate for experimental uncontrollable effects.

(6) The dynamic part of material genome for 24.79Cr-6.84Ni-2.83Mo-0.69Mn-0.5Si-0.16Co-0.015C-0.14N-0.024P-(Bal.)Fe was investigated with the obtained flow stresses by inverse analysis and regression methods at temperatures of 1050, 1150, and 1250 °C and strain rates of 0.1, 1, and 10 s^{-1}.

(7) By observing microstructures by EBSD, it could be found that the microstructural evolutions occurred heterogeneously in austenite and ferrite of duplex stainless steel. It can be confirmed that the flow stresses by combination with different equations of two phases were reasonable.

(8) The static part of the material genome for SUS329J4L duplex stainless steel was investigated with the experimental results at temperatures of 1050, 1150, and 1250 ℃ and strain rates of 0.1 and 1 s-1, and different inter-pass times of 1, 10, 100, 200 seconds.

(9) The quantification of essential parameters for the static kinetics was calculated by regression methods, such as softening fraction, the activation energy for static recrystallization, $t_{0.5}$, and average grain sizes of austenite and ferrite at the expected strain rates and temperatures.

(10) EBSD analysis showed the heterogeneity of the microstructural evolutions, which was caused by different SFE of austenite and ferrite. This difference most noticeably affects the change in grain size and recrystallization behavior.