論　文　の　要　旨

Abstract of Dissertation

題　目　Optimization Framework for Material Parameter Identification Applied to Hot Forging Process

（熱間鍛造プロセスに適用される材料パラメータ同定のための最適化フレームワーク）

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Material parameters are a central aspect for the proper modeling of physical phenomena in manufacturing, as in any other application. This study deals with the necessity of quickly and accurately identifying material parameters for complex applications, such as hot forming. There are many aspects that influence the material’s behavior at temperature, such as the processing variables (temperature, deformation, and velocity), as well as intrinsic aspects such as microstructure, chemical composition, and defects. These factors influence each other via complex mechanisms such as dynamic recovery (DRV) and dynamic recrystallization (DRX). Moreover, microstructural transformation takes place during the process, which allows us to obtain improved material properties under a proper process design. However, the process design currently relies on the simulation results. In this study, a phenomenological approach was considered to model the material behavior and parameters for two constitutive models are identified: the Hensel-Spittel (H-S) model and the Jonson-Cook (J-C) model.

The experimental data to be fitted by the above-mentioned model were obtained through a hot compression test using 38MnVS6 microalloyed steel (commonly used in hot forging applications). Temperatures from 900°C to 1200°C were used, with strain rates of up to 30 s^{-1}, and the strain achieved was up to 100% real strain. The specimens were cylinders 18 mm in height and 12 mm in diameter machined from an as-received billet. The experimental apparatus was placed in a vacuum chamber to avoid the formation of oxide scales when the specimen was heated. A thermocouple was welded at the center of the specimen using an inductor to control the temperature. The apparatus provides a variable velocity profile in order to ensure a constant strain rate during compression while the inductor maintains the temperature under control. The stroke and force were measured, and based on these measurements, we calculated the strain and stress, respectively.

Using optimization and reverse engineering, the difference between the experimental dataset and the output from each model (error) was minimized. To calculate this error, two objective functions (OF) were used: the first was the commonly used least squares method (OF1). The second is what is called the “true error function,” referred to here as OF2. This is based on the instruction of a logarithmic function in combination with a mathematical term. This function represents part of the novelty presented in this study. Several starting points were considered during the optimization process. A genetic algorithm (GA) was used to search over a wide region; afterwards, a gradient-based algorithm was used to fine-tune around the point given by the GA.

The parameters for two commonly used constitutive equations in industrial applications were identified: the above-mentioned H-S equation and J-C equation, using two objective functions OF1 and OF2. The J-C model has four parameters, and the H-S model has eight parameters to be identified. When comparing these two models, it was found that the H-S model does not have a unique set of parameters, because different sets give a similar error value, which means that the function has several local minima. On the other hand, for the J-C model, all starting points converged to the same final set of parameters, which allowed us to conclude that the model had a unique solution (absolute minimum). This is understandable because H-S model is much more complex mathematically, as long as it has twice the number of parameters than J-C model. When comparing two objective functions, it was concluded that the proposed OF2 could reduce the optimization

time by up to 30 % compared to OF1. In addition, a simplified identification procedure was proposed, which is scalable for industrial applications and any type of constitutive model.

In further steps, we may mention that it is necessary to determine a modification for the constitutive equation. The aim of this modification is to provide them with the ability to catch the softening produced by dynamic recrystallization (DRX). This ability is convenient for metal forming simulations. Additionally, it is necessary to conduct more experiments using the same material to assess the performance of the identified parameters for interpolations and extrapolations. In future work, we will conduct additional experiments to measure the capability of the models when interpolating and extrapolating process conditions. Moreover, the incorporation of machine-learning algorithms is an open field of opportunity.