論文の内容の要旨

Quantification of microstructure evolution under hot forming for the control of mechanical properties of tool steel

（工具鋼の材質制御のための熱間加工内部組織変化の定量化）

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Abstract:

Geometry and mechanical properties are the most important required parameters in formed products. Geometry optimization relates to the forming technology while the mechanical properties are governed by the microstructure. One of the most important topics in recent decades is the simultaneous generation of geometry and microstructures in industrial hot forming. The aim of the present thesis is to develop a procedure for quantification of microstructure evolution under hot forming of tool steels and acquisition of the microstructural evolution kinetics for two representative tool steel with higher applications. In the first chapter, tool steels, their classifications, and their manufacturing methods are briefly described. Then motivation of this study from industrial and scientific point of view is discussed.

In the second chapter the previous researches for analysis of microstructure evolution during hot forming and the method of implementation of the empirical equations for definition of microstructural changes in optimization of products are briefly reviewed. Most of the models for evaluation of the microstructural changes necessitate laborious experiments and analyses. Since performing such kind of procedures for different type of steels with various chemical compositions is almost impossible, during recent years many efforts have been done to reduce the number of necessary experiments for definition of microstructural evolution kinetics. But precise acquisition of the complete material genome still requires lots of experiments and analyses. In the field of tool steels, the quantity of the researches for definition of microstructural evolution in hot forming is truly low. The researches of this category are mainly focused on the evaluation of the resistance to hot deformation and even the microstructural changes are investigated from this point of view. In few researches, the microstructure optimization is also considered but the results are only applicable for a special case study and cannot be used as a general method.

A standard package for acquiring the material genome is presented in the third chapter. This package could be applicable to other types of steels to acquire the bases of microstructure optimization in hot forming products. In this package, the material genome for microstructural kinetics, except grain size evolution, could be acquired by analyzing the flow curves obtained by inverse analysis. Hence, it requires fewer metallographic tests. A new method for separation of effects of static recovery and static recrystallization is also presented while previous researches were not able to perform accurate estimation of these parameters without observation of frozen microstructure. Beside this, new approaches for estimation of grain size from partially recrystallized microstructure, revelation of PAGB in SKS31, global curve fitting for acquisition of work hardening coefficient are proposed.

Based on the newly developed method, the kinetics of microstructural evolution in the hot forming of SKD61 and SKS31 tool steels are investigated and presented in chapter 4 and 5, respectively. A series of single and double compression tests, inverse analysis to obtain flow curves, micrography of compressed specimens and the regression analysis of coefficients in material data are used to evaluate the material genome. Obtained equations are capable to reflect the transient changes in forming conditions, such as strain rate and temperature, and can be used in simulation and optimization of multi-pass hot forming processes. The validity of the method is checked by coupled finite element and microstructural simulation of plain strain compression test. The predicted microstructures agree with the micrographs obtained from a quenching experiment.

Finally, in the last chapter the effects of high alloy contents of tool steels in microstructure evolution during hot working is described and some key features of SKD61 and SKS31 tool steels are compared from this point of view. Industrial and scientific significance of this thesis is discussed and some offers for future works are presented.