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Review

A critical review of experimental results and constitutive descriptions for metals and alloys in hot working

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A R T I C L E I N F O

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A B S T R A C T

In industrial forming processes, the metals and alloys are subject to complex strain, strain-rate, and temperature histories. Understanding the flow behaviors of metals and alloys in hot working has a great importance for designers of metal forming processes. In order to study the workability and establish the optimum hot formation processing parameters for some metals and alloys, a number of research groups have made efforts to carry out the thermo-mechanical experiments (compressive, tensile and torsion tests) over wide forming temperatures and strain-rates, and some constitutive equations were developed to describe the hot deformation behaviors. This paper presents a critical review on some experimental results and constitutive descriptions for metals and alloys in hot working, which were reported in international publications in recent years. In this review paper, the constitutive models are divided into three categories, including the phenomenological, physical-based and artificial neural network models, to introduce their developments, prediction capabilities, and application scopes, respectively. Additionally, some limitations and objective suggestions for the further development of constitutive descriptions for metals and alloys in hot working are proposed.

1. Introduction

Material flow behavior during hot forming process is often complex. The hardening and softening mechanisms are both significantly influenced by many factors such as strain, strain-rate, and forming temperature. On the one hand, a given combination of thermo-mechanical parameters yields a particular metallurgical phenomenon (microstructure evolution); on the other hand, microstructure changes of the metal during the hot forming process in turn affect the mechanical characteristics of the metal such as the flow stress, and hence influence the forming processes. Understanding the flow behaviors of metals and alloys at hot deformation condition has a great importance for designers of metal forming processes (hot rolling, forging and extrusion) because of its effective role on metal flow pattern as well as the kinetics of metallurgical transformation (for example, static, dynamic, and metadynamic recrystallization behaviors) [1–5]. The constitutive relations are often used to describe the plastic flow properties of the metals and alloys in a form that can be used in computer code to model the forging response of mechanical part members under the prevailing loading conditions. Meanwhile, numerical simulations can be truly reliable only when a proper constitutive model is built. Therefore, based on the experimentally measured data, a number of research groups have made efforts to develop constitutive equations to describe the hot deformation behaviors of metals and alloys.

Some thermo-mechanical experiments over wide forming temperature and strain-rate indicate that: (1) In the initial stage of the forming process, the stress abruptly increases to a peak due to the dominance of work hardening; (2) When the strain-rate increases while the temperature is fixed, or the temperature decreases while the strain-rate is kept constant, the overall level of the flow curve enhances correspondingly due to the growing work hardening; (3) The flow stress shows steady-state region due to the equilibrium of work softening and work hardening. Fig. 1a shows the typical true stress–strain curves obtained from the hot compression of 42CrMo steel [6]. It is obvious that the effects of the temperature and strain-rate on the flow stress are significant for all the tested conditions. The true stress–true strain curves exhibit a peak stress at a small strain, after which the flow stresses decrease monotonically until high strains, showing a dynamic flow softening. The stress level decreases with increasing deformation temperature and decreasing strain-rate. This is because lower strain-rates and higher temperatures provide longer time for energy accumulation and higher mobilities at boundaries for the nucleation and growth of dynamically recrystallized grains and dislocation annihilation and thus reduce the flow stress level. Meanwhile, due to the combined effect of work hardening and thermally activated softening mechanisms, the flow stress obtained from experiments consist of four different stage, i.e.,

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