



Deformation and microstructure-independent Cottrell–Stokes ratio in commercial Al alloys

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ARTICLE INFO

Article history:

Received 22 June 2010

Received in final revised form 5 November 2010

Available online 19 November 2010

Keywords:

Aluminum alloys

Thermally activated processes

ABSTRACT

Cottrell–Stokes-type experiments are performed with AA6022, a heat treatable commercial Al alloy, at different stages of precipitation. It is shown that the ratio of the flow stress at given temperature and that extrapolated to 0 K, measured at given material state, is independent of the strain and of the precipitation state. The ratio depends only on temperature and strain rate. However, when probed using strain rate jump experiments, the Cottrell–Stokes law appears not to be fulfilled in any of these materials, and the strain rate sensitivity parameter depends on the precipitation state. A model based on the interaction of dislocations with populations of obstacles of various types is used to provide an interpretation of the Cottrell–Stokes law. The model indicates that as the dislocation velocity increases, the effective Cottrell–Stokes ratio in systems with various obstacle compositions takes values in a narrow range close to the critical value of 1 (i.e. “microstructure” insensitivity). Conversely, the model suggests that the Cottrell–Stokes ratio should become more sensitive to the microstructure under creep conditions.

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1. Introduction

Thermal activation related to metal plasticity was studied extensively. One of the classic works in this area is due to Cottrell and Stokes and dates from 1955 (Cottrell and Stokes, 1955). Working with Al single crystals, they discovered that the ratio of the flow stress at two temperatures and same “material structure” is only a function of the two temperatures at which the test is performed and is independent of strain. This ratio is known as the Cottrell–Stokes (CS) ratio, $\sigma(T)/\sigma(T_0)$, and the strain independence is known as the CS law.

An intense activity aimed at elucidating the process of thermal activation of plastic flow followed (Basinski, 1959, 1974; Basinski et al., 1972; Bochniak, 1993; Ezz et al., 1995; Hollang et al., 2006; Kruml et al., 2004; Mecking and Lucke, 1967; Mecking and Kocks, 1981; Saimoto and Sang, 1983; Wielke et al., 1977; Zeyfang et al., 1974). With the conjecture that the CS law is valid for any two temperatures T and T_0 (provided these are low enough) and the CS ratio is a function of the difference between them, $\sigma(T)/\sigma(T_0) = f(T - T_0)$, it was proposed that testing the validity of the CS law amounts to demonstrating that $(\sigma(T_0) - \sigma(T))/\sigma(T_0)$ is independent of strain or, taking the limit to infinitesimal changes of temperature, that $\frac{1}{\sigma} \frac{\partial \sigma}{\partial T}$ is strain independent (Basinski, 1959).

Testing these ideas requires performing experiments in which the temperature is changed rapidly at given strain. Typically, the sample is partially unloaded to avoid significant structural evolution by creep, and the temperature is modified (decreased), upon which the test continues. The temperature has to be changed fast and unloading should be kept to a minimum. Reloading leads to a yield point which is larger when the unloading is more pronounced.

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