Abstract

This thesis presents the results of investigations on the thermal activation strain rate analysis (TASRA) in Zr, Ti, and Zr-1.6 Cu alloy, the work-hardening characteristics in Zr and Ti, and the grain-size effects in Zr. The usual tensile tests were employed, along with strain rate change tests, stress relaxation or temperature cycling or their combination, and transmission electron microscopy (TEM) of the deformed specimens.

TASRA was carried out on the basis of the strain rate equation $\dot{\gamma} = \dot{\gamma}_0 \exp\left(\frac{\Delta S}{k}\right) \exp\left(-\frac{\Delta H}{kT}\right)$. The apparent activation enthalpy $\Delta H^*$ given by $-kT^2 \left(\frac{\delta \ln \dot{\gamma}}{\delta T}\right)_T \left(\frac{\delta \dot{\gamma}}{\delta T}\right)_T$ is found to show a hump and/or abnormal rise with temperature in the region 300°-400°K. The activation free energy values evaluated for the two cases where the obstacles are considered either 'inelastic' or 'linear elastic' also show non-linear variation with temperature in the same region. The effective stress $\sigma^*(SR)$ evaluated from stress relaxation shows a minimum in Ti and a plateau in Zr in the same region. Further, the values of $\dot{\gamma}_0$ estimated from $\Delta G$ do not show a systematic variation with stress or temperature. These anomalies are explained as due to the occurrence of dynamic strain ageing.

The Crussard-Jaoul analysis shows 'multiple stage' work hardening in Zr and Ti. The greater ease of cross slip at higher temperatures, and the consequent differences in the density and arrangement of dislocations with temperature results in a decrease in work hardening with temperature. Flow stress varies with dislocation density (obtained from TEM studies) as per the relation $\sigma = \sigma_0 + \beta \mu M b \bar{\rho}$; $\beta$ was found to decrease with temperature; the strengthening is, therefore, not entirely dependent on dislocation density, but also on their distribution and arrangement; this is in agreement with the increased tendency for cell formation observed at higher temperatures.
Grain size effects in Zr were studied. The Hall-Petch intercept $\sigma^0$ was found to increase with strain and decrease with temperature. From temperature cycling experiments, it is concluded that the whole of the thermal component of flow stress is in $\sigma^0$. The Hall-Petch slope $K$ also decreases with temperature and generally increases with strain, except at and above 483 K where $K$ decreases with strain at higher strains, possibly due to dynamic recovery. At low strains, the variation of $K$ with temperature is proportional to the shear modulus, while at higher strains, it is more than that predicted by the shear modulus variation, possibly due to the higher work hardening at lower temperatures coupled with the dynamic strain ageing at intermediate temperatures. Anomalous humps are found in both $\sigma^0$ Vs. T and $K$ Vs. T plots. TASRA using $\sigma^0 = \sigma^K$ also shows the anomalies due to strain ageing.

In chapter I, the concepts of thermally activated deformation together with a brief review of work hardening and grain size effects in polycrystals are presented. The experimental details are given in chapter II. The results and discussion are presented in chapter III and the final chapter summarises the major findings and conclusions.