DETERMINATION OF SOME PARAMETERS OF
THE THERMALLY ACTIVATED PLASTIC
DEFORMATION OF IRON

A. Ya. Krasovskii and V. A. Stepanenko

At moderate and low temperatures the physical mechanism of plastic deformation of crystals is the conservative movement of dislocations in the natural field of the crystal lattice, which is distorted by all kinds of defects. There is a sufficiently large body of experimental evidence that this movement as a function of temperature to some extent is activated by thermal fluctuations which, together with the applied stress, throw the individual sections of dislocations over the obstacles. The parameters characterizing the elementary process of overcoming the obstacles are the activation energy of plastic flow, the activation volume, and the frequency factor (the so-called pre-exponential factor). The determination of these parameters in the process of relatively simple mechanical tests makes it possible to predict the temperature and rate dependence of the characteristics of plastic flow of the material under more complicated conditions.

In order to determine the thermal activation characteristics of the plastic deformation of iron (C = 0.05%), we made a series of tensile tests on cylindrical samples. From the stress–strain curves we determined, by methods to be described below, the "friction" stress of the crystal lattice, from the temperature and rate dependence of which we found the parameters of the kinetic equation of plastic deformation.

Fig. 1. Temperature dependence of the lower (\(\sigma_l\), dashed curves) and upper (\(\sigma_u\), dash-dotted curves) yield points and of the flow stress (solid curves) corresponding to 3% residual strain for polycrystalline iron for various grain sizes and two strain rates.
that is, the pre-exponential factor \( y_0 \), the activation energy \( \Delta H \), and the activation volume \( V^* \).

The investigations were done on bulk cylindrical samples, 4 mm in diameter, and with a gauge length of 20 mm. To obtain the grain sizes 0.03, 0.06, and 1.00 mm the finished samples were annealed at 450°C for one hour, at 1000°C for two hours, and at 1280°C for four hours, respectively.

The experiments were done at two velocities of the moving clamp of the testing machine: 3 and 0.006 mm/min, which, for the chosen sample geometry correspond to average deformation rates of \( 1.75 \cdot 10^{-3} \) and \( 3.5 \cdot 10^{-4} \) sec\(^{-1}\). The testing was done in the 78-873°C temperature range, at low temperatures in nitrogen vapor and at high temperatures in vacuo (10\(^{-5}\) mm Hg). The details of the experimental method and some results are given in [1, 2].

In our analysis we use the lower yield point in the cases where it is clearly distinguishable, and the flow stress corresponding to 0.2% residual strain otherwise.

The friction stress was determined by the following methods:

1. By constructing the stress-strain curve in a \( \log \sigma vs \log \varepsilon \) plot and extrapolating to its intersection with the elastic part [3-5]. We carried out another version of this method as well, constructing the curve in a \( \sigma vs \varepsilon^{1/2} \) plot and proceeding with a similar extrapolation according to the equation

\[
\sigma_\delta = a \varepsilon^{1/2}.
\]

Both versions of this method lead to a clear dependence of the friction stress on the grain size, which shows their incorrectness. Therefore, we abstained from presenting data obtained by such extrapolation [3].

2. By extrapolating the \( \sigma_\delta vs \delta^{-1/2} \) diagrams to \( \delta^{-1/2} = 0 \) (\( \sigma_\delta \) is the lower yield point and \( \delta \) the mean grain size). The temperature dependence of the friction stress obtained by this method is compared below with the dependences constructed by methods 1. Since this method is well known and described in numerous works, we will limit ourselves to the basic results of the procedure.

As is seen in Fig. 1, the curves are not monotonic in the whole temperature range. In particular, in the region of blue brittleness we observe a characteristic discontinuous deformation, increasing strength, and decreasing plasticity.

These effects, explained at present in terms of the interaction between dislocations and interstitial impurities (for iron primarily C and N) prevail close to the temperature range which is important for the thermoactivation analysis, where practically all short range obstacles are overcome due to thermal fluctuations. Therefore, an underestimation of this circumstance may lead to errors in the determination of the athermal component of the friction stress.

The correctness of the thermoactivation analysis of plastic deformation processes depends to a great extent on the accuracy of the yield point determination in two important ranges of its temperature dependence: close to the absolute zero and in the range around \( T_C \), the lowest temperature at which all short-range obstacles are overcome due to thermal fluctuations.

However, several circumstances make the yield point determination in these ranges difficult. The most important ones are: brittle fracture at low temperatures, which leads to premature fracture in tensile tests, the presence of the blue brittleness range, and twinning. In our experiments brittle fracture took place only in samples with 1 mm grain size (at 78°C).

For the construction of the \( \sigma_\delta vs \delta^{-1/2} \) diagram the mean grain size was metallographically determined for each sample.