INFLUENCE OF DELTA FERRITE ON THE FLOW STRESS GRAIN SIZE RELATIONSHIP OF AN AUSTENITIC STAINLESS STEEL

by

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Abstract
The effect of delta ferrite on the flow stress-grain size relation is investigated. Delta ferrite is found to lead to deviation from linear proportionality between flow stress and grain size in austenitic steels. This influence vanishes with increase in strain.

Introduction

Strengthening of metals and alloys by grain refinement is a well established mechanism. This strengthening is explicitly expressed in the Hall-Perch equation [1,2]. The equation has been extended to include tile flow stress [3] or:

$$\sigma_f = \sigma_o + k_f d^{0.5} \quad (1)$$

where σ_f is the flow stress, d - the average grain diameter, and σ_o and K_f are constants for a given strain. A comprehensive review of models explaining the flow stress grain size relationship has been presented by Li & Chou [4]. Deviations from linear proportionality between the flow stress and the inverse of the square root of the average grain diameter have been observed [5,6]. In an attempt to explain some of these deviations, new models have been proposed [4, 7, 8]. An adaptation of the Ashby model [9] which takes into account the surface to volume ratio S, of internal boundaries has recently been put forward. Thus, the flow stress - grain size relationship becomes:

$$\sigma_f = \sigma_o + k_f S_{vm} \quad (2)$$

where m is a constant.

The Hall - Petch relation has been shown to be satisfied for dual phase ustenitic steel [10], pearlitic structures [11] as well as for dispersed phases [12].

Delta ferrite contributes to the flow stress as well as t9 the tensile strength of austenitic steels [13,14] However, for Cr-Ni-Mn steels, there is little information available especially, as regards the role of delta ferrite on the flow stress - grain size dependence.

Experiment 1

The experimental material was received in the form of a bar of rectangular cross section. Its chemical composition is as follows: 0.02 wt% C, 17 wt% Cr, 8.5 wt% Ni, 9.1 wt% Mn and balance Fe. The as-received material was initially solution treated at 1373k for 3 hours and quenched in water. Further, the solution - treated material was given 40% deformation by cold rolling and annealed at different temperatures between 1173K and 1473K or two hours followed by quenching in water. The procedure was necessary in order to btain grains of different sizes or surface to volume ratios (see figure 1 for typical microstructures). Measurement of the surface to volume ratio was by the linear intercept method.

From the deformed stock, cylindrical specimens of 4mm diameter were repared for tensile tests. The tensile tests were carried out at room temperature with the help of an INSTRON machine, at a constant strain rate.

Results and Discussions

The annealing treatment resulted in fully recrystallized austenite grains and delta ferrite. The delta ferrite is arranged in the form of beads and/or stringers. This made it impossible to estimate the volume percentage of the delta ferrite [15]. Figure 2 shows a plot of the flow stress against the total surface to volume ratio S_V of internal boundaries. It is evident that below 0.077 true strain, the flow stress – S_V dependence is not linear. It should be noted that the correlation coefficient above 0.077 strain at 0.05 level of confidence is significant. Above this strain, a linear proportionality is observed. An attempt will be made to explain the deviation from a straight line.

The experimental material is a Cr-Ni-Mn steel. Cr is a ferrite former and Mn is not a strong autenite stabilize at high temperatures (16, 17]. With increasing temperature of annealing, the amount of

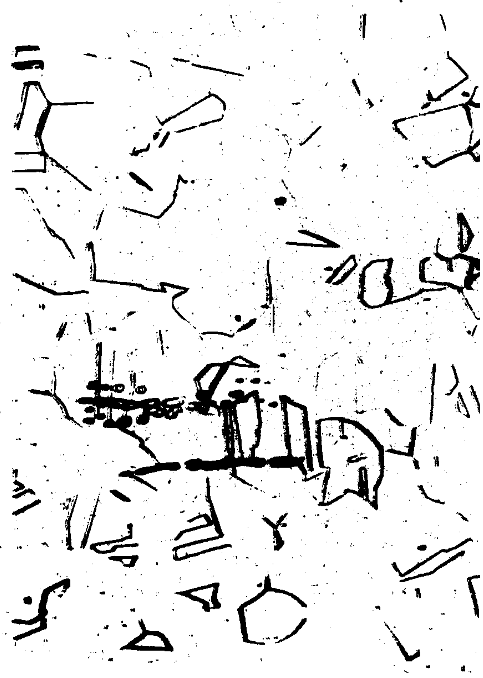

Figure 1a: Microstructure of austenitic steel (alloy Fe-
cold rolling, and subsequent annealing at 90

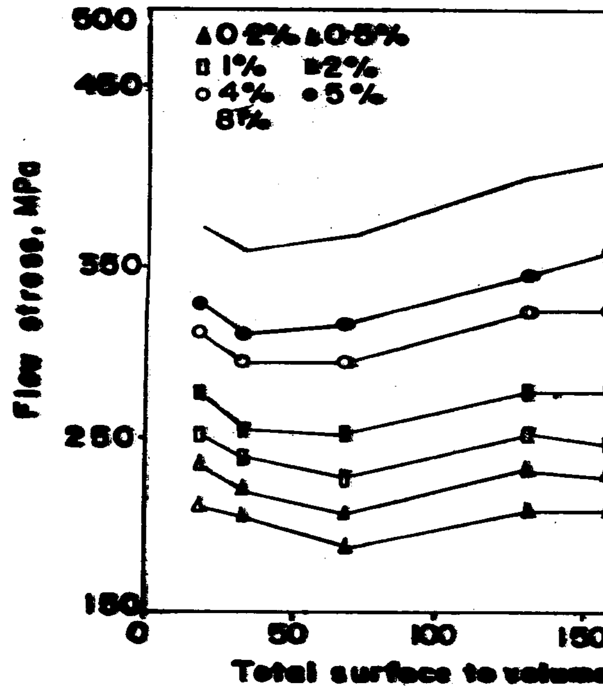

Figure 2a: Flow Stress versus Surface-to-volumn Ra

Figure 1b: Microstructure of austenitic steel (same as fi
subsequent annealing at 1200°C for 2 hours.

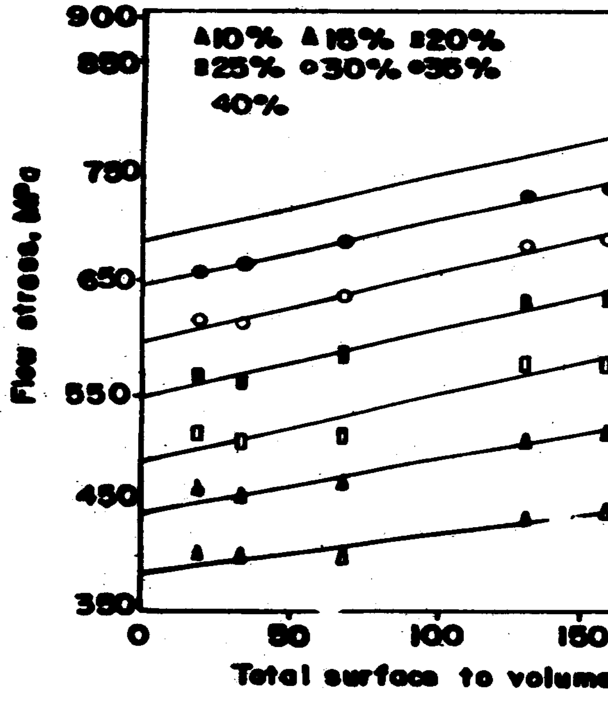

Figure 2b: Flow Stress versus Surface-to-volumn Rat
(for medium and higher strains, from 108

delta ferrite will increase [18]. One may therefore expect the specimen annealed at higher temperature to contain a higher volume % of delta ferrite. Under deformation, the contribution to de1ta ferrite to the flow stress may not be similar to that of the austenite grain boundaries. Delta ferrite introduces additional strengthening [13] by acting as a fibre strengthening agent. Also, partitioning of elements between the austenite and the delta ferrite could introduce extra solid solution hardening in either or both phases. Quenching from a high temperature may lead to a super saturation by carbon of the delta ferrite, thereby leading to extra hardening.

The contribution of the delta ferrite to the flow stress may also be rationalised in terms of Geometrically necessary dislocations (GNDs). At the early stage of deformation, the interfaces between the austenite and delta ferrite will act as sources of GND. For the specimens annealed at higher temperatures, a larger amount of delta ferrite will result in a higher density of sources for GNDs, A negative gradient of the flow stress - grain size relationship may therefore result due to the higher flow stress of the specimen annealed at higher temperatures.

An alternative to the above explanation may be to attribute the observationsto quench-induced ε -phase [19]. This alternative explanation may be difficult to accept since the volume percentage of this phase will increase with deformation (see paragraph below). A conclusive evidence may be obtained from an examination of the microstructure of' a quenched specimen with the help of the TEM, and subsequent measurement of the volume fraction of .the ε-phase. Both experiments are in progress.

The contribution of delta ferrite to the flow stress seems to diminish above 8% strain, probably due to greater contribution by other hardening mechanisms. In a material of similar composition [20], deformation-induced hexagonal phase was observed in most of the grains at about 8% deformation. It may be proposed that, with increasing deformation, the experimental material continuously behaves as a dual phase material. Therefore its characteristic behaviour will be due to the in homogenous distribution of plastic strain between the austenite .and the hexagonal phase.

Conclusions

(1) Delta ferrite in Cr-Ni-Mn steels leads to deviations from linear proportionality between now stress and S_V.
(2) These deviations tend to diminish with increasing strain.

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