DEFORMATION INHOMOGENEITY IN A SINGLE CRYSTAL NICKEL-BASE SUPERALLOY

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Abstract

The plastic inhomogeneity has been investigated in DD8 single crystal nickel-base superalloy. It has been found that this phenomenon occurs just after the alloy is yielded on the stress-strain curve during extension and compression at a certain strain-rate under the certain temperature ranges. When the plastic inhomogeneity (serration) on the stress-strain curve occurs, it can burst on a sound with " Ping-Pang ", and accompanies a catastrophic drop in yield strength of the alloy. This kind of plastic inhomogeneity in the alloy can be removed by a new heat treatment.

Introduction

Deformation inhomogeneity in metals and alloys has been the theoretical and experimental project during past few years since it may lead to the deterioration of materials in mechanical properties. Zhang et al (1) have found that the corrugation in Al-Cu-Mg alloy stemmed from PLC effect in working process may be eliminated by raising the activation energy of vacancy diffusion through quenching and short-term aging(1). Kubin et al (2) have studied the condition and mechanism of the deformation inhomogeneity in Nickel base single crystal superalloy CMSX-2 and AM-3.This kind of phenomenon has also been found in DD8 single crystal nickel-base superalloy under the combination of certain temperature and strain-rate(3).

The purpose of this research is explore the conditions under which the deformation inhomogeneity occurs in the alloy, and examine the effect of phenomenon on the mechanical properties and finally, to find a way to remove the deformation inhomogeneity in the alloy.

Material and Procedure

The alloy used in this study is made by selection method. The chemical composition (wt.%) of the alloy is 15.61%Cr, 8.45%Co, 5.74%W, 3.80%Al, 3.82%Ti, 1.16%Ta and Ni bal. The alloy was subjected to the following heat treatment:

$$1100^{o}C/8h.A.C + 1240^{o}C/4hA.C$$

$$+1090^{o}C/2hA.C + 850^{o}C/24hA.C$$

The tensile and compression tests at different temperatures under various strain-rates were performed on the alloy. The microstructure of the specimens tested was characterized by SEM and TEM, and the possibility for elimination of the deformation inhomogeneity by the selected heat treatment process was discussed.

Results and Discussion

The experimental results show that the deformation inhomogeneity (serrated) occurs at the temperature range of 300 to 700^{o}C at the strain-rate of $2x10^{-2}$/min, and also in the strain range of $8x10^{-3}$ to $4x10^{-2}$/min at 700^{o}C for the [001] oriented single crystal nickel-base superalloy during monotonic extension. Figure 1 is the stress-strain curves at different temperatures under a strain-rate of $2x10^{-2}$/min.

The dependence of the plastic inhomogeneity on the orientation of [001],[110] and [111] is observed during compression. The results show that all three kind of orientated alloys take place the deformation inhomogeneity in the temperature range of 550^{o}C to 850^{o}C, and the strain range of $6x10^{-4}$ to $6x10^{-2}$/min, but the difference among these three oriented crystals is that the tendency for occurrence of the deformation inhomogeneity is in the order of [110], [001] and [111]. This can be seen clearly from Figure 2, showing stress-strain curves of [001], [110] and [111] oriented crystals obtained during compression at 550^{o}C under strain-rate of 6x10^{-3}/min respectively.

Because the turbine blades are subjected to the centrifugal stress, and the stress axis is generally paralell to the [001] direction, therefore, the extension tests were performed on the specimen with [001] crystal direction. The results show that the deformation inhomogeneity can lead to a decrease in yield strength of the alloy as shown in Figure3.

Observations by SEM and TEM reveal that the deformation on surface of the specimen subjected to the plastic inhomogeneity displays an inhomogeneous slip trace (Fig.4a). Dislocations are concentrated highly in the slip bands, and the slip deformation shows a defined crystallographic orientation as shown in Figure 5(a) and (b). However, those which are not subjected to the plastic inhomogeneity, the dirstribution of slip trace on the specimen surface appears to be homogeneous (Fig.4b), the distribution of dislocations tends to be homogeneous as shown in Figure 5(c) and (d)

It is concluded that the occurrence of the plastic inhomogeneity of the alloy is a consequence of change of the deformation mechanism, and it depends on the relative crystal orientation of the alloy to the applied stress, microstructure, tested temperature and strain-rate and so on. But the microstructure among these factors is proposed to play a key role in occurrence of the phenomenon during deformation.

Based on the results in the present research, a new heat treatment process, which may eliminate the deformation ihmogeneity, and in turn increase the yield strength, was proposed.

Figure 6 shows the stress-strain curves obtained at 500^{o}C under the strain-rate of 2x10^{-2}/min.for the specimens subjected to an original(a), and a new(b) heat treatment processes. As compared with Fig.6(a), it can be found clearly that for the specimen subjected to this kind of heat treatment process, it does not displays the deformation inhomogeneity (serrated), and shows a high yield strength(Fig.6b).

Summaries

1. The occurrence of the plastic inhomogeneity in the alloy is a consequence of change in deformation mechanism, and it depends on the relative crystal orientation of the alloy to the applied stress, microstructure, tested temperature and strain-rate. But the microstructure is proposed to play the key role in occurrence of the plastic inhomogeneity during deformation.

2. Deformation inhomogeneity can deteriorate the yield strength of the alloy, but be improved, and even eliminated by an appropriate heat treatment process.

References

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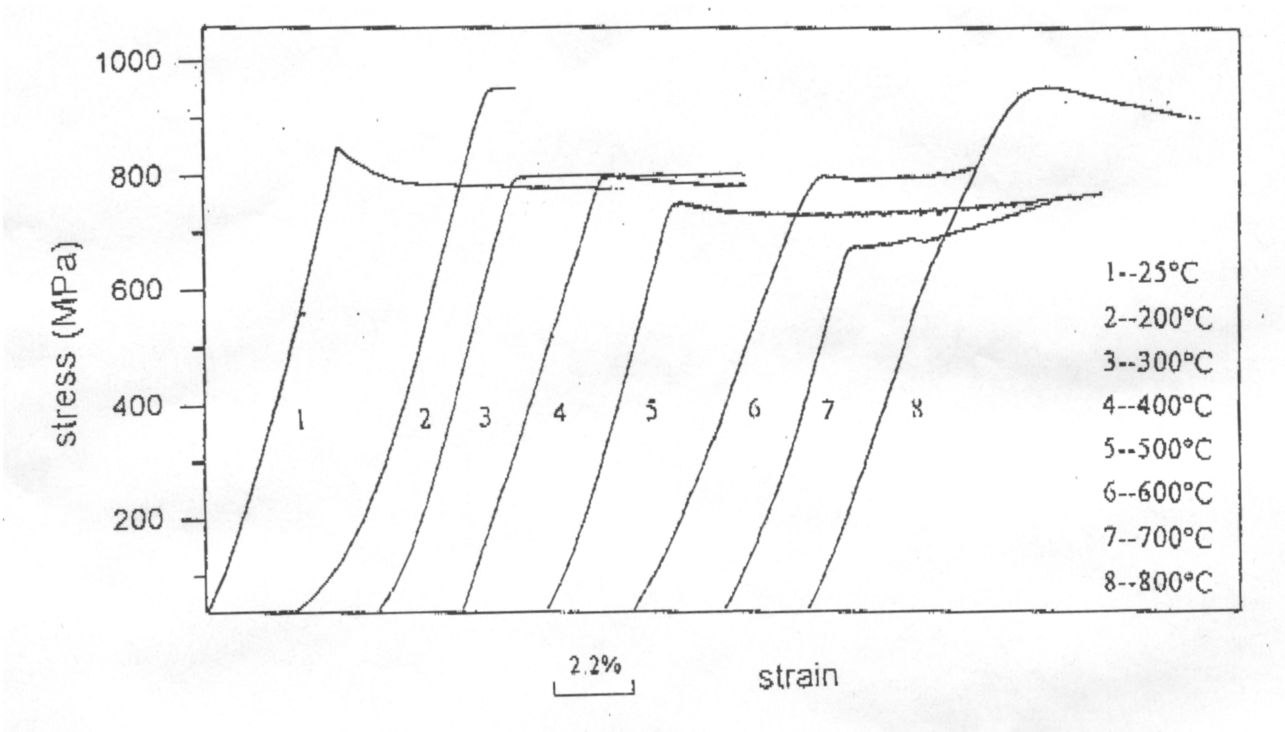

Fig.1. Stress-strain curves of the [001] oriented crystal during extension at strain rate of 2×10^{-2}/min under different temperatures

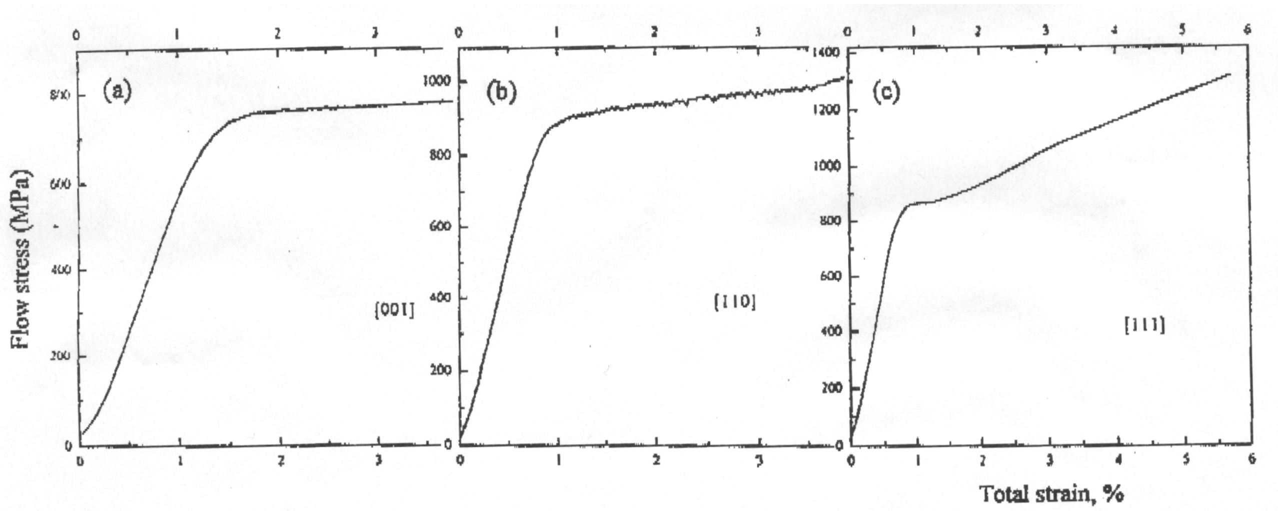

Fig.2. Stress-strain curves of the [001](a), [110](b) and [111](c) crystals during compression under strain rate of 6×10^{-3}/min at 550 °C

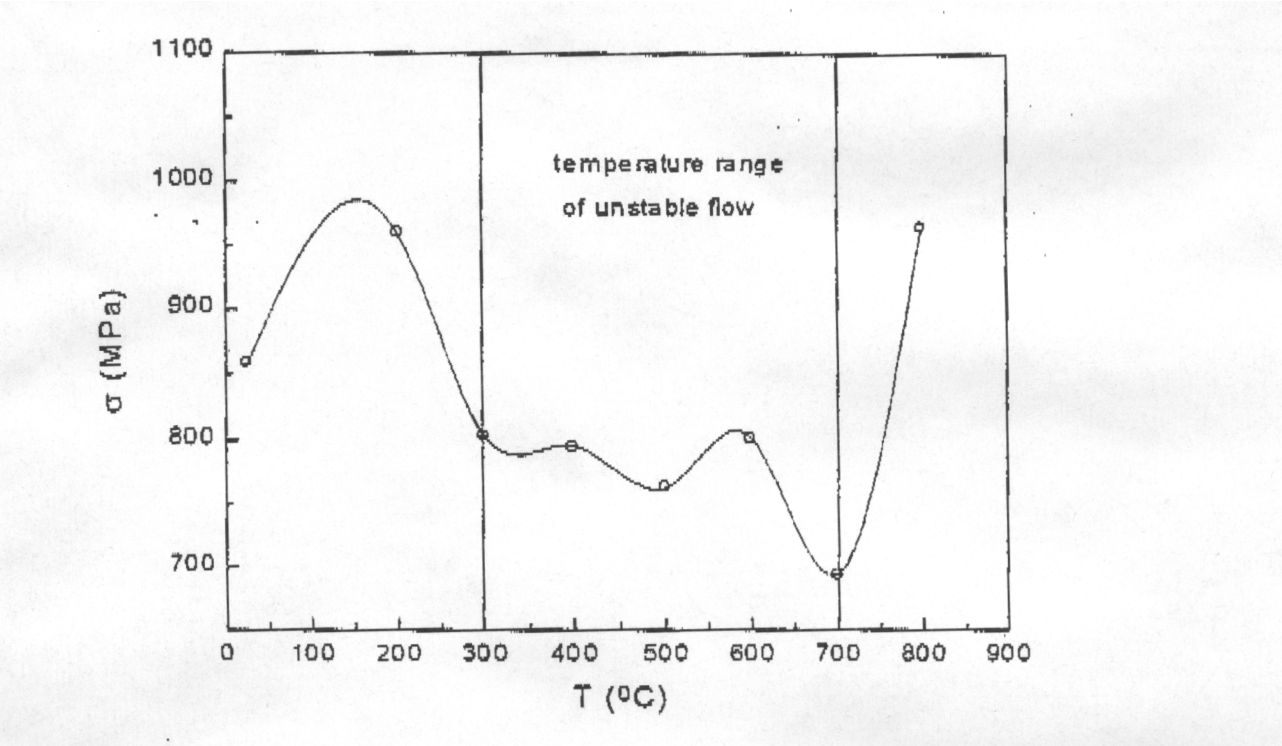

Fig.3. Variation of the yield strength with temperature at strain rate of 2×10^{-2}/min

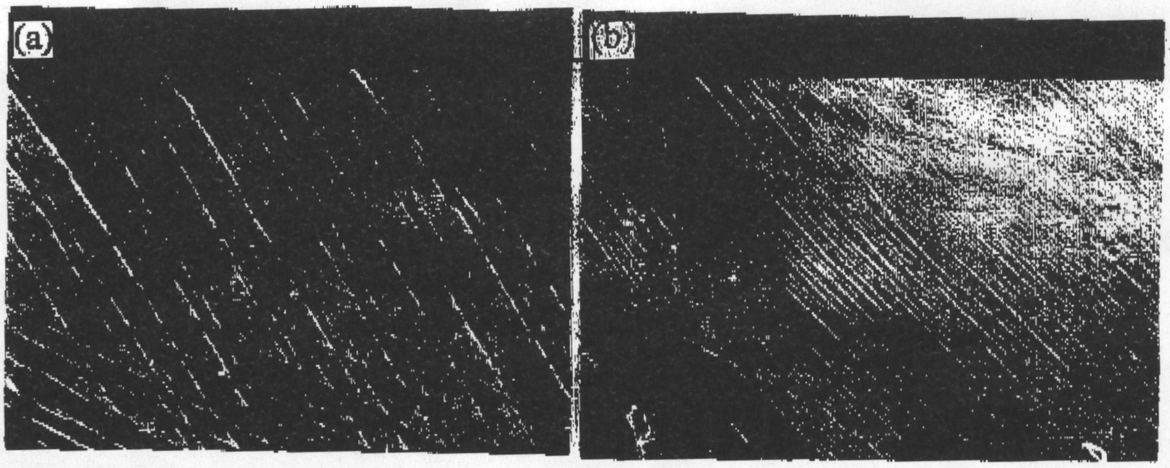

Fig.4. SEM morphology of slip trace on the surface of the specimen during extension under strain rate of 8×10^{-3}/min at 700 °C (a), and room temperature (b)

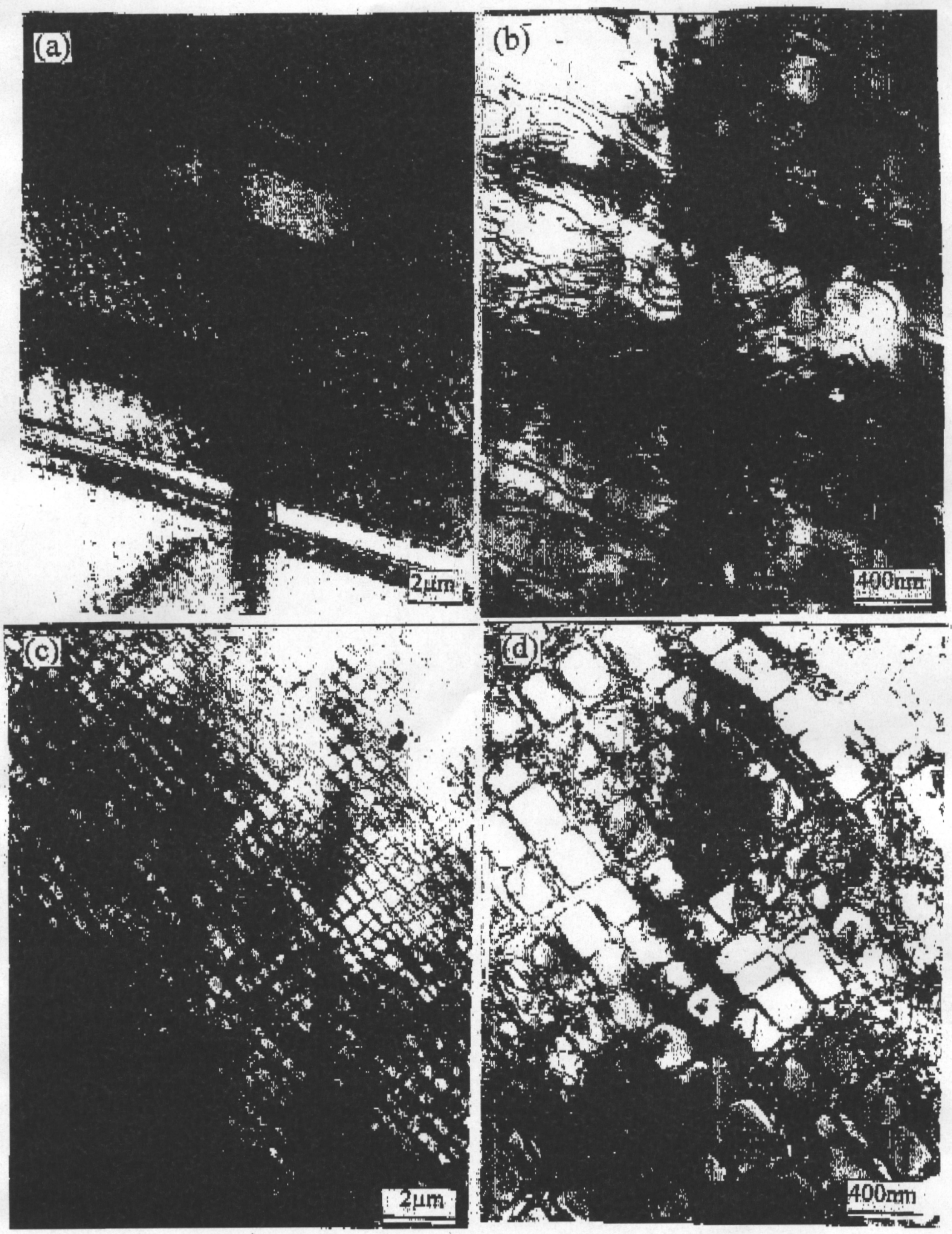

Fig.5. Slip bands (a) and dislocation structure (b) in inhomogeneous flow produced during extension under strain rate of 8×10^{-3}/min at 700 °C . Slip bands(c) and dislocation structure (d) in inhomogeneous flow produced during extension under strain rate of 4×10^{-3}/min at 700 °C

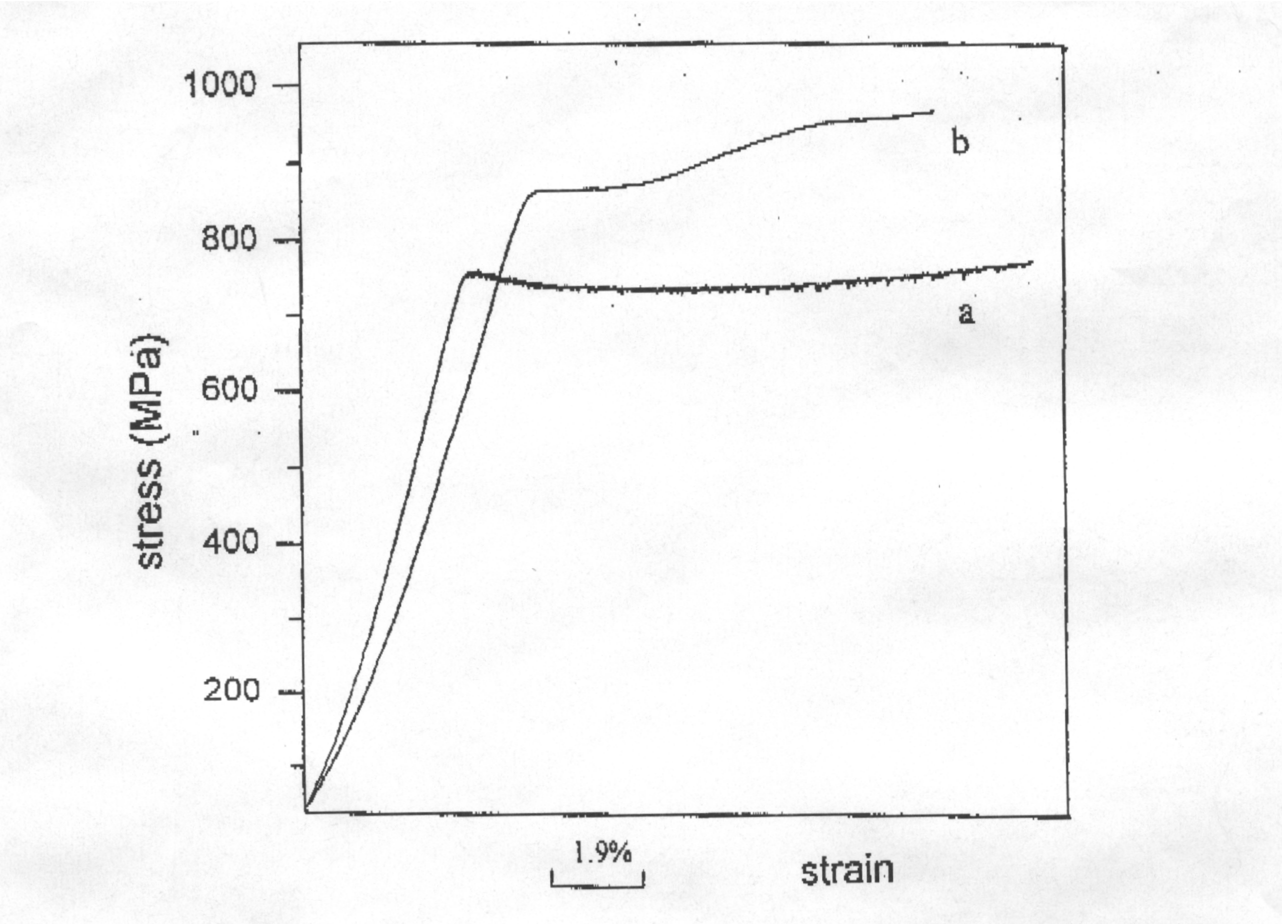

Fig.6. Stress-strain curves for original (a) and new (b) heat treatment process under strain rate of 2×10^{-2}/min at 500 °C