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Cooperative Grain Boundary Sliding at Room Temperature of a Zn-20.2%Al-1.8%Cu Superplastic Alloy

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Abstract.- By applying a new technique [1-2] which provides a mesoscopic coordinate system inscribed on the surface of a tensile specimen, with 371 μm gage length for a Zn-20.2%Al-1.8%Cu superplastic alloy deformed at room temperature it is possible to show that: Deformation of the sample it is homogeneous at macroscopic level, but inhomogeneous at mesoscopical level. The inhomogeneity is ascribed to the sliding of grain blocks. For 28.5% of deformation the distribution function for the block sizes is described by: $N(x) = 1.37\ x^3 \exp(-3x/12.2\ \mu m)$, where, $N(x)$ is the number of blocks of size x, inside an area of about $172 \times 244\ (\mu m)^2$.

1. Introduction

In 1971, Raj and Ashby [3] theoretically analyzed the possibility of shear of grain groups as an entity, and also this mechanism has been considered later by other authors [4,5]. However, the actual experimental accurrence of cooperative grain boundary sliding (CGBS), i.e, movement of grain groups as a unit, along with grain boundary sliding of individual grains during superplastic deformation, has been reported only recently [6-10].

Recently a technique has been presented [1-2] that allows to observe the superplastic deformation at three levels: macroscopical, mesoscopical and microscopical. Here, this technique has been used to determine the grain sizes, or of grain block sizes wich contibutes to the macroscopical deformation.

2. Experimental procedure

The material used for this investigation (Zn-20.2%Al-1.8%Cu) was extruded to obtain strips of 20 mm wide and 5 mm. The extruded plates of Zn-20.2%Al-1.8%Cu superplastic alloy were cold rolled into strips of 1 mm thickness. Tension test samples with gage length of 371 μm parallel to the rolling direction were prepared. The geometry and size of the specimen designed for tension test in SEM are shown in the microphotography given in Fig. 1(a), the grain size by using the mean linear intercept was 3.5 μm. The specimen was mechanically polished on successively finer grades of emery paper and diamond paste.

By using of a pyramidal-shaped micro vickers indenter three sets of diamond pyramidal figures were inscribed on the surface of the specimen along on a longitudinal straight line as follow one pyramidal-shaped figure was inscribed approximately at the center of the specimen and a regular trapezoid delimited by pyramidal indention figures in each corner of such figure was inscribed on the surface of the tension sample. Centered on each trapezoid another pyramidal indentation was inscribed see Fig. 1(b). The gage length size of the tension specimen is delimited by the two sets formed each by five pyramidal figures. This gage length has been used for the determination of the macroscopical deformation (371μm).

The experiments were performed at constant cross head velocity, v = 0.1 mm/min, giving a nominal macroscopic initial strain rate of 4.04 x $10^{-3}s^{-1}$.

3. Experimental results

Figure 2 illustrate the experimental data for the velocity of specific material objects as a function of distance along the tension axis, with origin fixed at the rest end of the specimen (left diamond pyramidal figure on the sample). The straight line is for homogeneous deformation. A good agreement it is found for x-values lowers than 500 μm. For distances larger than such distance the discrepancy between the condition for constant cross head velocity and the experimental data may be due to non-homogeneity of plastic deformation between the central region of the sample and the region near to the shoulders.

See also the Fig. 3 where the non homogeneous character of deformation it is shown by exhibiting a surface material sliding in parallel layers which descend toward to the center of the free surface sample; looking like what would happen with a set of playing cards which after be arranged one above other was subjected to the action of a shear stress that it was applied on the surface of the upper card.

On the other hand, between 5.4% and 28.5% of true deformation the sample surface display an extensive quantity of grain blocks sliding during deformation (see Fig. 4). The gliding zones between grain blocks appear like bright lines. In the Fig. 5, the histogram of the sizes of grains blocks as measured inside an area of 172 x 244 $(\mu m)^2$, it is shown. The area used for these measurements represents 11.4% of the total deformation area.

On the frequency distribution which appears in Fig. 5 the following aspects can be observed the distribution have a maximum in frequency at a size block of 12.2 μm. The blocks have discrete sizes: one, two... up to seven grain sizes length as calculated by using standard procedures [11, 12], 1.74 times the mean linear intercept, $L = 3.5$ μm. We make note that a natural grouping of block sizes around some values was observed on the raw data before Fig. 5 was build up.

To describe the experimental data on Fig. 5 it is required a distribution function which satisfies the condition that very small and very large blocks are rare. For blocks of sliding grains we have no experimental [6-10] or theoretical evidence [13] of any possible distribution that it corresponds closely with the actual distribution of blocks grain sizes in a Zn-20.2%Al-1.8%Cu superplastic alloy at room temperature deformed.

However, in other areas of plastic deformation of solids certain type of mathematical functions with similar features that here required has been used successfully, and some of these expression [14-17] appear to be the general kind of physical sensible function as needed for our case. Based on such previous work, here we propouse a modified algebraic expression as the following,

$$N(x) = Ax^{n}\exp(-nx/x_{m}) \qquad (1)$$

Like the more convenient to describe the experimental data on Fig. 5. A, n, and x_m are constant to be determined. To describe Fig. 5 a value $n = 3$ was chosen. The maximum on the experimental data occurs for a size $x = 12.2$ μm, and according to Eq. (1), N(x) has a maximum value of 124 blocks for $x = x_m = 12.2$ μm. So that $A = 1.37$ and N(x) appear like,

$$N(x) = 1.37x^{3}\exp(-3x/12.2\ \mu\text{m}) \qquad (2)$$

In Fig. 5 a drawing of the numerical calculations obtained with this expression it is shown as a continuous curve. The black points on the curve are to denote the calculated value at which an experimental measurement has been reported. The total number of blocks as calculated with Eq. (2) at the experimental blocks sizes is 383 which is very close to the experimental number of blocks of 374. From the close agreement between experimental data and the choosed curve we can arrive to the conclusion that Eq. (2) gives a good description to the experimental block size distribution.

4. Discussion

Experiments reported here showed and homogeneous deformation on the macroscopic level. A partially non-homogeneous deformation at mesoscopically scale can be observed. There is a strong experimental evidence that this inhomogeneity in deformation at mesoscopic level is due to blocks of grain sliding as an entity. Apparently one important reason for the occurrence of deformation in such a non-homogeneous manner can be attributed to the fact that the material here deformed, has been tested under stress and temperature conditions where a behavior of grain boundary sliding between individual grains it is not expected.

In our case (Zn-20.2%Al-1.8%Cu) to real strain rate of 1.6 x 10^{-3} s^{-1} and T = 300K, in a material with a grain size of 6.1 μm; the number of grains in each block has values between 1 to 7 grains. This data means a smaller number of grains for block that those observed for Zn-22%Al to strain rate 10^{-3} s^{-1} and T = 523 K with size of grain of 1.1μm (15 to 30 grains) [8]. In the case of Zn-22%Al a grain boundaring sliding, grain to grain would be expected, however it is not observed at least initially during deformation. This situation has explained by the authors of these report [8], with an analogy which relates the grain boundary sliding processes with the occurring processes during monocristals deformation. According to this analogy the gliding grain blocks could be forming arrangements at mesoscopical level with the grains occupying the place of atoms and forming in this way the pseudo particles called cellular dislocations (according to the Zeling and Mukherjee model) [13, 19]. This last possibility requires more experimental work in order to be supported or rejected.

5. Conclusions

1) Plastic deformation of the specimen it is homogeneous at macroscopic level, but partially inhomogeneous at mesoscopic level. This inhomogeneity is ascribed at the gliding of grain blocks which behaves as entities.

2) After a real deformation of 5.4%, all the sample surface is covered by gliding grain blocks. This blocks have different sizes and their distribution function it is obtained after a true deformation of 28.5%.

3) The technique here used opens the possibility of further studies about some non-homogeneous aspects of superplastic deformation at mesoscopical level. As for instance, the kinetical role of the gliding of grain block during deformation.

Figure captions

Fig. 1(a) Tension test specimen for SEM after 5.4% of true deformation.

Fig. 1(b) Mesoscopical aspect of microestructure on the tension specimen after a true deformation of 5.4%.

Fig. 2 Linear relationship between velocity of material points at the surface of the sample and distance along tension axis as measured from the rest side of the sample. After a true deformation of 47%.

Fig. 3 SEM microphotography at mesoscopical level on the tension specimen after a true deformation of 47%.

Fig. 4 Grain blocks sliding during deformation. The gliding zones between grain blocks appear like bright zones where oxide films are absent. After a true deformation of 28.5%.

Fig. 5 The distribution function of sliding blocks as a function of the block sizes. After a true deformation of 28.5%.

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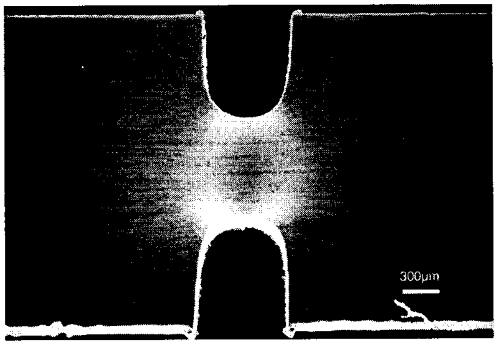

Fig. 1a

Fig.1b

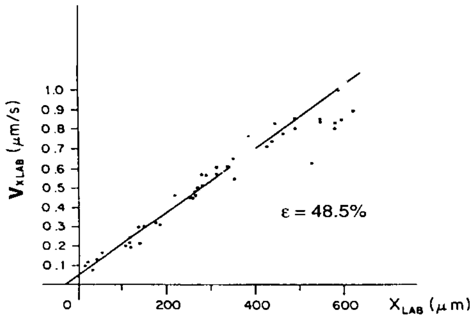

Fig.2

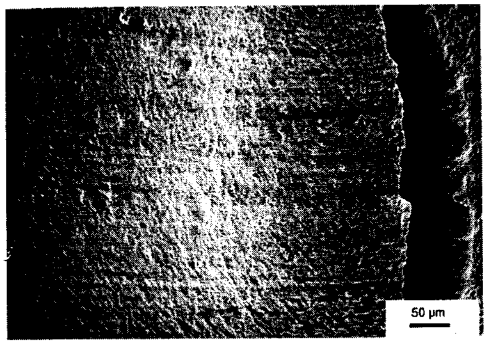

Fig.3

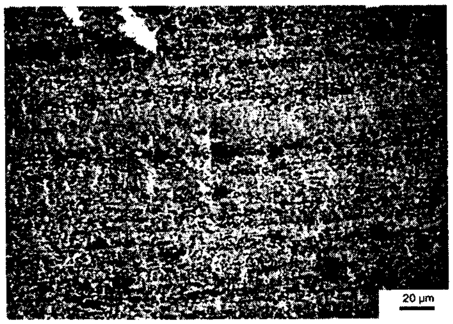

Fig.4

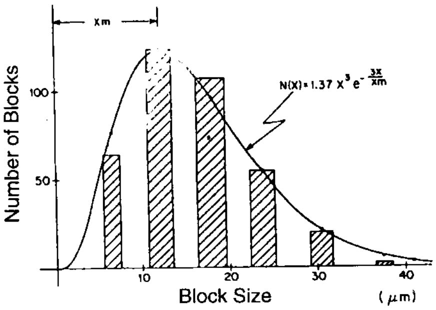

Fig.5