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Characterization of the structure of FeAl alloy after hot deformation

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Materials

ABSTRACT

Purpose: Purpose of this paper was the study of the microstructure of Fe-38Al alloy after hot deformation with the dislocation structure description.
Design/methodology/approach: Methodology of the microstructures research included LM (light microscopy) and TEM (transmission electron microscopy) techniques which has characterized the dislocation structure in these materials. The Fe-38Al alloy has been deformed by torsion plastometer within the range of temperatures from 850°C to 1250°C. All samples has been deformed to rupture.
Findings: The findings of this study is that the deformation in this alloy is controlled by dislocation motion. The observed dislocations are predominantly of <100> and <111>. At a deformation temperature of 1100°C TEM observations have shown dislocation loops and helices. In this alloy was observed dynamic recrystalization process during the hot deformation.
Practical implications: Practical implications of this research is that this alloy may by deformed in long range of strain in temperatures at 800°C to 1000°C Occure 1100°C the plasticity is limited by order - disorder transformation. This transformation could be responsible for dislocations structure behavior what was found.
Originality/value: Value of this paper was important in providing a better understanding of technological plasticity of FeAl alloys. The dislocation and reactions between the defects of the structure play a dominant role and are responsible for the variation of technological plasticity.
Keywords: Metallic alloys; Transmission electron microscopy; Substructure; Dislocations; Order-disorder transition

1. Introduction

In alloys on the base of ordered solid solution of the Fe-Al system, during hot plastic deformation processes of dynamic structure reconstruction have been observed, such as dynamic recovery and recrystallization. Dislocation and reactions between the defects of the structure play a dominant role. Deformation is controlled by dislocation motion [1,2,3]. At the temperature of 700°C deformation of FeAl alloys is limited because the movement of <110>, ½<111>, <100> dislocations is blocked. Dislocation is characteristic mainly of <111> superdislocations whose climbing ability is limited because of an antiphase boundary [1]. At higher temperatures, dynamic recrystallization process develops as a result of a decrease in dislocation energy while ½ <111> dislocation splitting into two mobile <100> or <110> dislocation pairs, and thus plasticity of the alloy increases [4,5,6]. However, plasticity of the ordered solid solutions of the Fe-Al system is determined by conversions from order to disorder which occur there [7,8,9]. These conversions change plasticity characteristics, and this fact may be caused by mutual reactions between dislocation systems during the conversion [8]. The coexistence of two structural states, ordered and disordered ones, may contribute to prevent the dislocation motion responsible for the localization of a rupture [8]. The present study is aimed at a descriptions of order – disorder transformation on the dislocations structure and a technological plasticity.

2. Experimental details

The investigations have been carried out on the alloy of FeAl of the chemical composition given in table1.

Table 1.
Chemical composition of the Fe-38Al alloy

Composition	Al	Mo	Zr	C	B	Fe
% - at.	38,00	0,20	0,05	0,10	0,01	61,64

The Mo addition has been used for the purpose of improving high temperature resistance. In order to decrease grain sizes after the crystallization process, a modifier in the form of zirconium has been used, in the amount of 0,05%-at. The Zr addition has been used for the purpose of improving resistance resulting from the creation of strengthening particles. The carbon addition has been used in order to increase resistance, and boron has been used in order to increase the resistance of grain boundaries [4].
For cast performed in the VS G-02 Balzers Co. vacuum induction furnace, with a working chamber operating at a pressure of ca. 1,0 Pa, the following materials have been applied: ARMCO iron, minimum 99,98%-wt. aluminium, amorphous boron, molybdenum, carbon in the form of anthracite. After casting, bars have been subjected to homogenizing annealing in the CARBOLITE vacuum furnace. Annealing has been carried out in the vacuum of 10^{-2} Pa with soaking at the temperature of 1000°C for 24 hours and furnace cooling for 24 hours [8]. A monophase alloy structure has been obtained. After the homogenizing process, the material has been subjected to plastometric tests at the temperatures of 850°C ÷ 1250°C with concurrent structure freezing after deformation. The investigations have been carried out by means of a torsion plastometer, using three deformation speeds: 0,1 s^{-1}, 1 s^{-1} and 10 s^{-1}. The investigations of sample substructures after hot deformation have been carried out on the Jeol JEM-100B transmission electron microscope by means of a thin foil technique. The occurrence of superdislocations for chosen structural images has been proved on the basis of fulfilling the visibility criterion for dislocations:

$$|g \times b| = 2,$$

where:
g – diffraction vector; b - Burger's vector of dislocation, under the conditions of a weak beam. Burger's vector of dislocation has been determined on the basis of the invisibility criterion: $|g \times b| = 0$, under the conditions of double-beam diffraction in the bright field of view [10,11]. In determining Burger's vector of dislocation it is crucial to obtain such diffraction conditions, under which dislocation image is visible for three different g_{hkl} vectors, and at least one of them belongs to a different zone axis. Dislocation thicknesses have been measured using the method of random secants [11]. Total length of secants has amounted to 1500 mm. Dislocation thickness has been calculated by means of the following relation (1.1):

$$\rho = \frac{2N_L}{t} \quad (1)$$

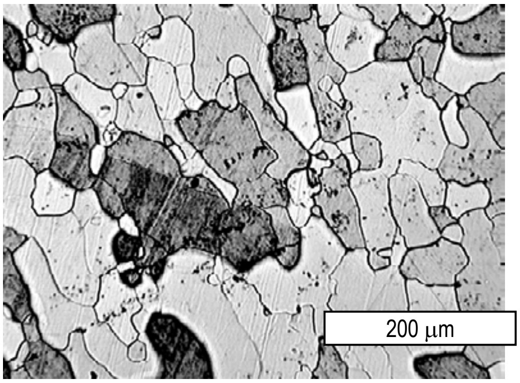
where: N_L – average number of dislocations per 1 mm of secant length; t – foil thickness,

The analysis of structure ordering has been carried out by means of the Jeol JEM 3010 microscope of an accelerating voltage of 300 kV using a high resolution technique.

3. Results of researches

In the Fe-38Al alloy investigated after deformation at a speed $0{,}1s^{-1}$ at a temperature of 850°C, shown in Figure 1a, reveals microstructure made of singular recrystallized grains on the background of prolonged original grains [12]. We observed cellular dislocation systems as in Figure 1b. After deformation at a temperature of 1000°C at a speed 0,1 s^{-1} the presence of dislocations of different Burger's vectors as in Figure 2 and in Table 2, has been discovered. In the substructure of the alloy deformed at a temperature of 1100°C dislocation dipoles have been observed, inside which dislocation loops are being formed. Inside dislocation dipoles in Figure 3, dislocation loops are created, whose presence prevents the climbing processes.

a)



b)

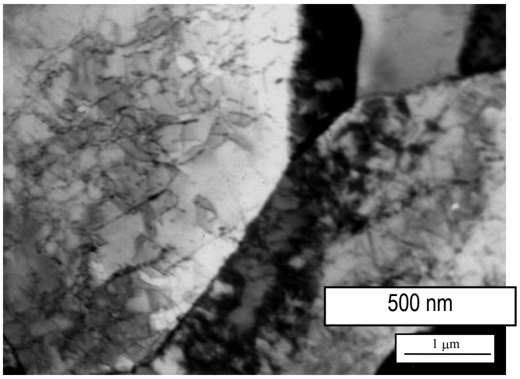


Fig. 1. Microstructure of the Fe-38Al alloy deformed at a temperature of 850°C at a speed 0,1 s^{-1} a) singular small grains recrystallized dynamically, b) cellular dislocation structure

After deformation at a temperature of 900°C shown in Figure 4 a dislocation structure has been discovered consisting of interlacing dislocations of different Burger's vectors: a[100], a[111] and a[011].

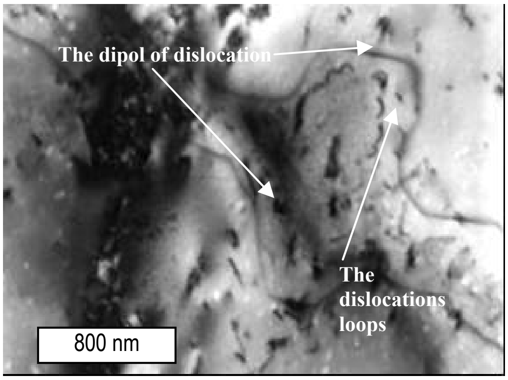


Fig. 2. Substructure of the Fe-38Al alloy deformed at a temperature of 1000°C at a speed 0,1 s^{-1}

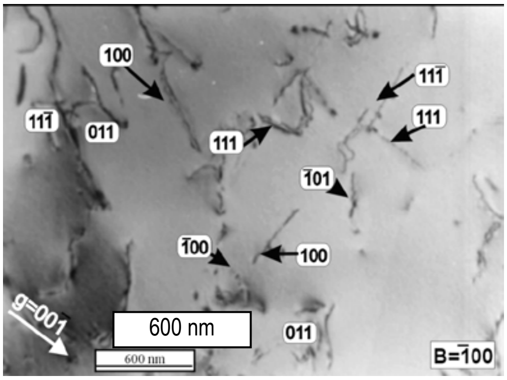


Fig. 3. Substructure of the Fe-38Al alloy deformed at a temperature of 1100°C at a speed 0,1 s^{-1}

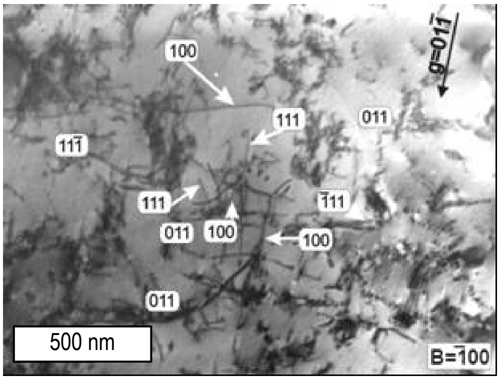


Fig.4. Microstructure of the Fe-38Al alloy deformed at a temperature of 900°C at a speed 1 s^{-1}

Reactions take place between dislocations in order to decrease in their energy. According to experimental measurements, average dislocation density has amounted $2{,}7{\cdot}10^{13}m^{-2}$.

Moreover, after deformation at a temperature 1100°C the following forms of dislocations have been observed: dislocation loops in Figure 5, dislocations barriers and prismatic dislocations loops in Figure 6. The Burger's vectors has shown the presence of a<111> and a<100> dislocation.

On the basis of dislocation distributions observed, the diagrams of possible dislocation configurations in the Fe-38Al alloy after deformation at a temperature of 1100 at a speed 1 s^{-1}. At a deformation temperature of 1250°C, at a speed 1 s^{-1} one may observe cross-cutting prolonged a[100] dislocation lines parallel to the direction of [101] and $[12\bar{1}]$. Average dislocation density has amounted to $1{,}4{\cdot}10^{-11}m^{-2}$.

Table 2.
Examples of determining a[100], a[110], a/2[111] Burger's vectors in the Fe-38Al alloy after hot deformation

Deformation temperature T[°C]	Conditions for double-beam diffraction [B- crystal zone axis, g – reflection plane]					Burger's vector
900	$B=[\bar{1}00]$ $g=(00\bar{1})$	$B=[\bar{1}00]$ $g=(01\bar{1})$	$B=[\bar{1}00]$ $g=(110)$	$B=[111]$ $g=(110)$	$B=[\bar{1}11]$ $g=(1\bar{1}0)$	$[100],[001],[011],$ $[\bar{1}00],[\bar{1}01],[111],$ $[11\bar{1}],[\bar{1}10],[1\bar{1}0]$
1100	$B=[\bar{1}00]$ $g=(00\bar{1})$	$B=[\bar{1}00]$ $g=(110)$	$B=[\bar{1}00]$ $g=(110)$	$B=[111]$ $g=(01\bar{1})$	$B=[111]$ $g=(110)$	$[100],[001],$ $[011],[\bar{1}00],$ $[010],[11\bar{1}],$ $[\bar{1}11]$
	$B=[111]$ $g=(1\bar{1}2)$	$B=[\bar{1}12]$ $g=(110)$	$B=[\bar{1}11]$ $g=(01\bar{1})$	$B=[\bar{1}11]$ $g=(1\bar{1}2)$	$B=[\bar{1}13]$ $g=(110)$	
	$B=[023]$ $g=(\bar{3}12)$					
1250	$B=[111]$ $g=(12\bar{1})$	$B=[11\bar{1}]$ $g=(110)$	$B=[11\bar{1}]$ $g=(101)$	$B=[11\bar{1}]$ $g=(01\bar{1})$		$[100],[001],$ $[010]$

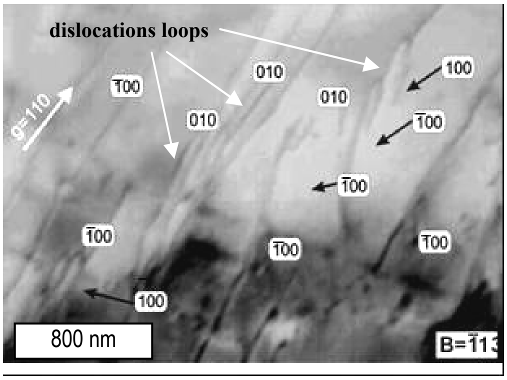


Fig. 5. Dislocation structure of the Fe-38Al alloy deformed at a temperature of 1100°C at a speed 1 s^{-1}

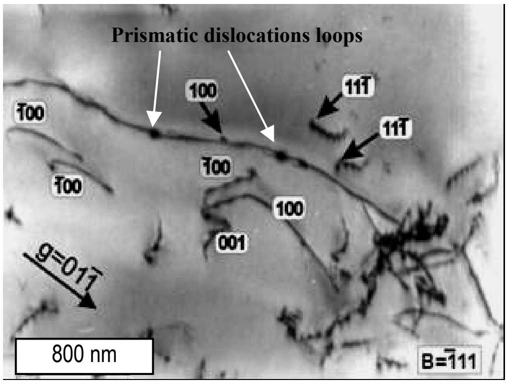


Fig. 6. Dislocation structure of the Fe-38Al alloy deformed at a temperature of 1100°C at a speed 1 s^{-1}

4. Conclusions

In the Fe-38 alloy substructure after deformation at a temperatures of 850°C÷1000°C the systems of linear dislocations of a/2[111], a[110], and a[110]. Burger's vectors have been observed. The creation of dislocation loops or other configurations of dislocations strengthening of the material has not been observed. At a temperature of 1100°C the following dislocation combinations have been observed: dislocation loops, dipoles, jogs and the so-called "dislocation teeth," Inside dislocation dipoles, dislocation loops are created, whose presence prevents climbing processes. The majority of dislocations revealed for a given temperature are dislocations of a[111] or a[100] Burger's vector. Such dislocation configurations constitute obstacles for the motion of other dislocations, which may result in considerable deformation limitation. Occurrence of the above-mentioned dislocation configurations may result from the occurrence of two types of structures at a temperature of 1100°C, i.e. ordered and disordered ones. Mobile dislocation segments in the form of a[100] "dislocation teeth," constitute dislocation jogs, dislocation loops, created as a result of climbing it constitutes another cause for a quick rupture localization.

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