Archives of Materials Science and Engineering

Volume 30
Issue 1
March 2008
Pages 5-8

International Scientific Journal
published monthly by the
World Academy of Materials
and Manufacturing Engineering

The structure of FeAl and Fe_3Al-5%Cr intermetallic phase - based alloys after hot deformation processes

I. Bednarczyk*, D. Kuc, G. Niewielski
Faculty of Materials Science and Metallurgy, Silesian University of Technology,
ul. Krasińskiego 8, 40-019 Katowice, Poland
* Corresponding author: E-mail address: iwona.bednarczyk@polsl.pl

Received 20.01.2008; published in revised form 01.03.2008

ABSTRACT

Purpose: The major problem restricting universal employment of intermetallic phase base alloy is their low plasticity which leads to hampering their development as construction materials. The following work concentrates on the analysis of microstructure and plasticity of ordered Fe_3Al ($D0_3$) and FeAl (B2) during hot plastic deformation process.

Design/methodology/approach: After casting and annealing, alloy specimens were subjected to axial-symmetric compression in the Gleeble 3800 simulator at temperatures ranging from 800, 900 and 1000°C at $0.1 s^{-1}$ strain rate. In order to analyse the processes which take place during deformation, the specimens after deformation were intensely cooled with water. Structural examination was carried out using light microscopy. The examination of the substructure was carried out by transmission electron microscopy (TEM).

Findings: The microstructure analyses applying optic and electron microscopy have revealed the structure reconstruction processes occurring in Fe_3Al and FeAl alloys. It has been shown that different mechanisms of the structural changes ensue from the thermal plastic strain in the investigated alloys, which influences their technological plasticity.

Practical implications: The research carried out enabled the understanding of the phenomena taking place during deformation and annealing of the investigated alloy. The results will constitute the basis for modelling the structural changes.

Originality/value: The results obtained are vital for designing an effective thermo - mechanical processing technology for the investigated Fe_3Al and FeAl alloy.

Keywords: Metallic alloys; Flow curve; Substructure; Recrystallization

MATERIALS

1. Introduction

Intermetallic compounds particularly aluminides, are emerging as materiale for high temperature structural applications. They promise to bridge the gap between the operating temperature range of structural ceramics and nickel-based superalloys. [1-4] The position of alloys representing the Fe-Al system against other constructional materials is increasingly better as the research on the capacities for their fabrication and application advances. [5-7]

The iron aluminides Fe_3Al and FeAl have been among the most widely studied intermetallics because of their low cost, low density, good wear resistance, ease of fabrication and resistance to oxidation and corrosion create wide prospects for their industrial applications, for components of machines working at a high temperature and corrosive environment [8-10].

The major problem restricting their universal employment is their low plasticity and their brittle cracking susceptibility, which leads to hampering their development as construction materials. Consequently, the research of intermetallic-phase-based alloys focuses on their plasticising. [11-15]

The purpose of this work is to analyse the changes in the microstructure of the ordered alloys in Fe-Al system, based on Fe$_3$Al and FeAl intermetallic phases, following the high-temperature plastic strain ranging from 800 to 1000°C. The microstructure analyses applying optic and electron microscopy have revealed the structure reconstruction processes occurring in Fe$_3$Al i FeAl alloys. It has been shown that different mechanisms of the structural changes ensue from the thermal plastic strain in the investigated alloys, which influences their technological plasticity. The obtained results will be employed to develop the technology of shaping the structure of this group of materials by means of hot plastic working.

2. Material and methodology

Material for the research consisted of bars cast from an alloys based on an FeAl intermetallic phase of a chemical composition shown in Tabel 1 The alloys was prepared by casting into grafite moduls. The following contents were used for smelting: ARMCO iron, aluminium 99,98% wt. minimum, amorphous boron and technically pure molybdenum powder compact. Ingots were obtained in the form of cylinders of dimensions: ø 14mm and 120 mm in length.

Table 1.
The chemical composition of the investigated alloys (at %)

	Al	Cr	Zr	C	B	Fe
Fe$_3$Al	28.00	5.0	0.05	0.10	0.01	66.64
FeAl	38.00	-	0.05	0.10	0.01	61.64

After the casting, the samples were anealling at 1000°C for 48h with furnace cooling. Following the annealing, the material was used for the preparation of the samples for the compression test, which consisted of axisymmetrical strain on Gleeble 3800 simulator, with simultaneous structure-freeze by rapid quenching. The samples were cylindrical, measuring ϕ=10 mm and h=12mm. The compression samples were conducted at temperatures ranging from 800, 900 and 1000°C at a strain rate 0.1 s^{-1}, until the true strain values reached ε=1.0. The compression test results, such as the sample temperatures T [°C], stresses σ [MPa], forces [N] and strains ε, processed with the calculation sheet, provided the means for determining the flow curves in the stress σ - strain ε system. The metallographic investigation was performed on a light microscope in the range of magnifications 100-1000×.

The examination of the substructure was carried out by transmission electron microscopy (TEM) using a JEOL 100B transmission microscope operated at an accelerating voltage of 100 kV.

3. Results

The investigated alloys, based on Fe$_3$Al and FeAl intermetallic phases, having been cast (the diameter of the ingot: ϕ=12 mm, its height: 150 mm) and hot-worked, had coarse-grained one-phase structure, with diversified grain size. Within the grains, as well as on their borders, dispersive particles of carbides and borides have been observed. The Fe$_3$Al-5Cr alloy is characterised by the size of the grains, whose average surface of the plane section equals $\bar{A}$=22500µm^2 (d=150µm) and high homogeneity, described by the plane section variation index of the grain $\nu(\bar{A})$=256%. Smaller sizes of the grains have been obtained in B2-structure FeAl alloy, where the average surface of the plane section amounted to $\bar{A}$=12600µm^2 (d=115µm) for FeAl alloy, while the variation index equalled $\nu(\bar{A})$=152%. [2-3]

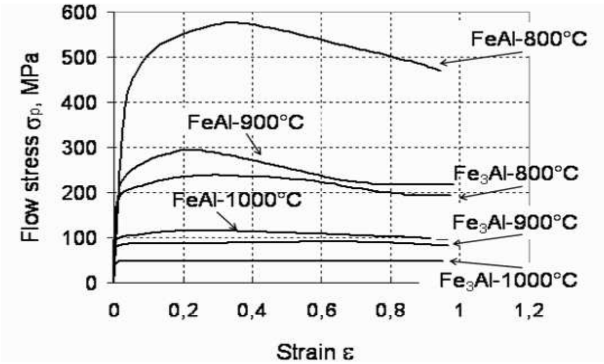

Fig. 1. The stress - strain flow curves of the FeAl and Fe$_3$Al alloy intermetallic phase-based alloys, following the strain at a rate of 0.1 s^{-1}

The performed axial-symmetrical compression trials of the investigated alloys have resulted in the determination of the flow curves of the stress-strain system, which have been presented in Figure 1. The obtained results clearly show that the increase in the strain temperature from 800 to 1000°C causes the intensive reduction in the maximum plasticising stress σ_p, as well as the decrease in the strain ε_p related to it, which leads to the rapid consolidation of the alloys. The samples of FeAl intermetallic-phase-based alloy exhibited threefold the value of the plasticising strain in comparison with Fe$_3$Al alloy for the same compression parameters (Fig. 2).

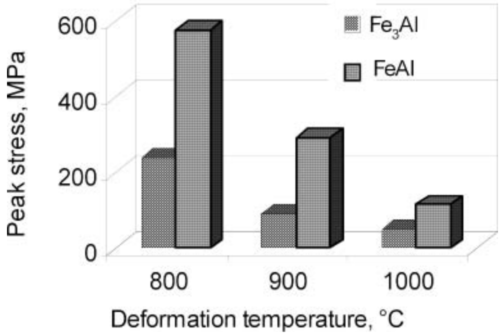

Fig. 2. The influence of the strain temperature on the peak flow stress of the investigated alloys

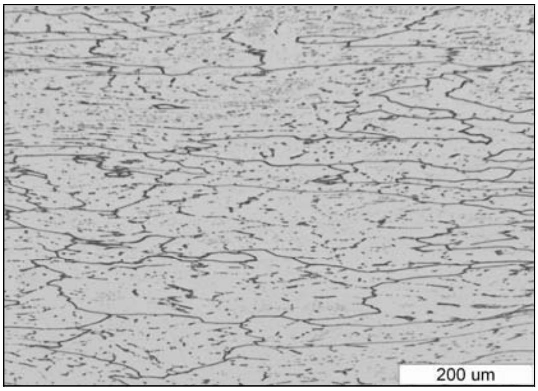

Fig. 3. The microstructure of the Fe_3Al-5Cr alloy following the thermal plastic strain at 800 °C at the rate of 0.1 s^{-1}

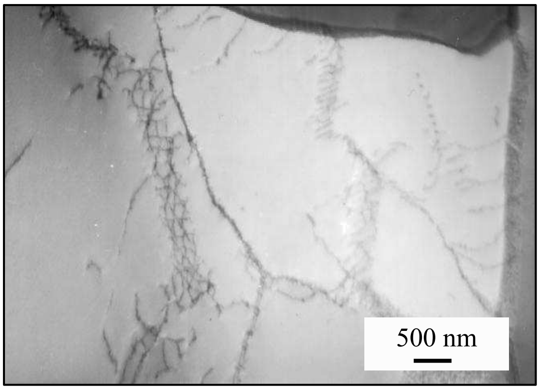

Fig. 4. The substructure of the Fe_3Al-5Cr alloy following the thermal plastic strain at 900 °C at the rate of 0.1 s^{-1}

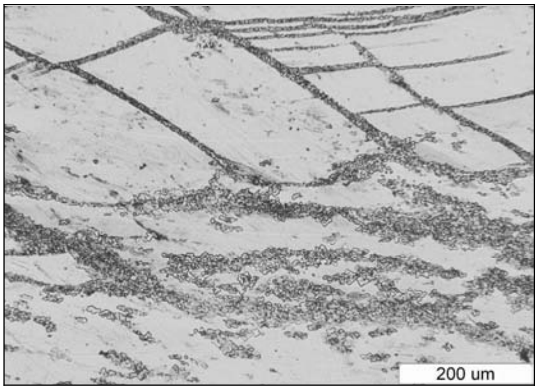

Fig. 5. The microstructure of the FeAl alloy following the thermal plastic strain at 800 °C at the rate of 0.1 s^{-1}

The observed microstructures of the investigated Fe_3Al-5Cr and FeAl alloys following the thermal plastic strain have been shown in Figures 3-8. The microstructure of Fe_3Al-5Cr alloy following the straining at 800°C and 900°C displays elongated primary grains with clear boundary migration (Fig. 3). The creation of sub-grains with single dislocations and the effects of poligonization are apparent in the substructure (Fig. 4).

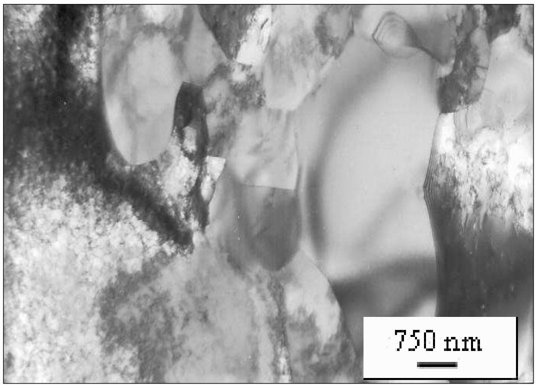

Fig. 6. The substructure of the FeAl alloy following the thermal plastic strain at 900 °C at the rate of 0.1 s^{-1}

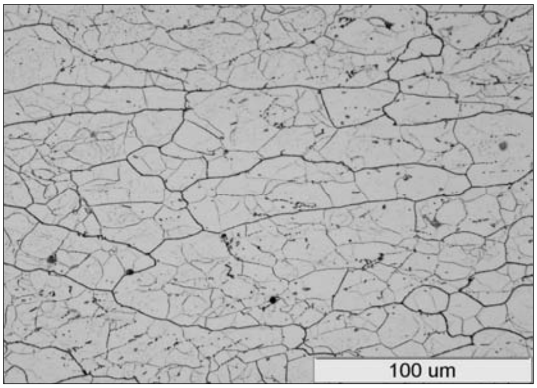

Fig. 7. The microstructure of the FeAl alloy following the thermal plastic strain at 1000 °C at the rate of 0.1 s^{-1}

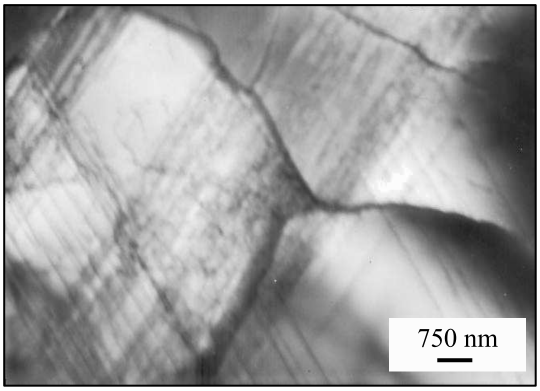

Fig. 8. The substructure of the Fe_3Al-5Cr alloy following the thermal plastic strain at 1000 °C at the rate of 0.1 s^{-1}

After the strain at 1000°C, the deformed primary grains become significant, within which the boundaries are visible: most likely subgrains of a large misorientation angle. In the substructure, within the finely shaped subgrains, the secondary effects of the strain are noticeable in the form of intersecting strain bands (Fig. 8).

The strain of FeAl alloy at the temperatures of 800°C and 900°C results in the initiation of the dynamic re-crystallisation process, which is confirmed by the appearance of the chains of fine grains on the boundaries of the primary grains and the slip bands (Fig. 5). The clear intensification effect of the re-crystallisation process has been observed at the temperature of 900°C, as indicated by the singinficant area taken by the re-crystallised grains on the boundaries of the primary grains as well as within these grains.

In the substructure, the nuclei of re-crystallisation are formed, which spread towards the areas with very high dislocation density (Fig. 6.). The upsetting of the strained alloy at 1000°C leads to the re-crystallisation of the structure, which is formed of finely shaped subgrains (Fig. 7.).

4. Conclusions

In their initial state (and following the introductory heat treatment), the Fe_3Al and FeAl intermetalic-phase-based alloys had coarse-grained single-phase structure with diversified grain size. A significant influence of the chemical content on the structure reconstruction processes occurring during thermal plastic strain in the investigated alloys in the Fe-Al system. The former determines the plasticising stress, a number of times higher for the FeAl alloy.

In the Fe_3Al-5Cr alloy with a DO_3 structure, the dynamic recovery dominates, as evidenced by the observed microstructures with deformed primary grains within which the boundaries of subgrains are visible. These are, most likely, the subgrains of a high misorientation angle, as may be confirmed by the planned EBSD analysis. Furthermore, no re-crystallisation nuclei are apparent in the substructure; only subgrains with single dislocation can be observed and the effects of poligonisation.

In the alloy with a higher aluminium content: 38% at Al, fine re-crystallised grains forming on the boundaries of the primary grains and slip bands are perceptible in the microstructure, and their number increases with the rise in the process temperature. A considerable increase in the defect density and the nuclei of new grains, growing towards the defected areas, have been noted to appear in the substructure. The high level of defectation led to the high plasticising strain level.

The observed different mechanisms of the structure reconstruction result from the chemical content variation, which influences the stacking fault energy (SFE) of the investigated alloys, which affects the plastic properties.

Acknowledgements

This work was supported by the Ministry of Education and Science of Poland under grant No. 3T08A 053 30.

References

[1] N.S. Stoloff, Iron aluminides: present status and future, Materials Science and Engineering A 258 (1998) 1-14.

[2] D. Kuc, G. Niewielski, M. Jabłońska, I. Bednarczyk, Deformability recrystallization of Fe-Al intermetallic phase – base alloy, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 143-146.

[3] D. Kuc, G. Niewieski I. Bednarczyk, The influence of deformation on the plasticity and structure of Fe_3Al-5Cr alloy, Journal of Achievements in Materials and Manufacturing Engineering 22/1 (2007) 27-30.

[4] B.S.J. Kang, R. Cisloiu, Evaluation of fracture behaviour of iron aluminides Theoretical and Applied Fracture, Mechanics 45 (2006) 25-40.

[5] J. Cebulski, S. Lalik, Changes in the structure of alloy on the matrix of FeAl intermetallic phase after primary crystallization and homogenizing treatment, Proceedings of the 13th Scientific International Conference „Achievements in Mechanical and Materials Engineering" AMME'2005, Gliwice–Wisła, 2005, 59-62.

[6] M. Jabłońska, K. Rodak, G. Niewielski, Characterization of the structure of FeAl alloy after hot deformation Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 107-110.

[7] P. Chakraborty, I.G. Sharma, A.K. Suri, D.K. Bose, Studies on preparation, characterisation and evaluation of properties of Fe_3Al-based intermetallic alloy of composition Fe–16Al–5.44Cr–1Nb–0.5C, Journal of Materials Processing Technology 115 (2001) 413-422.

[8] D.H. Sastry, Y.V.R.K. Prasad, S.C.Deevi, Influence of temperature and strain rate on the flow stress of an FeAl alloy, Materials Science and Engineering 5 (2001) 157-163.

[9] D. Huang, W. Y. Yang, Z. Q. Sun, L. Froyen, Preparation and mechanical properties of large-ingot Fe_3Al-based alloys, Journal of Materials Processing Technology 146 (2004) 175-180.

[10] D.G. Morris, M.A. Muñoz-Morris, J. Chao, Development of high strength, high ductility and high creep resistant ironaluminide, Intermetallics 12 (2004) 82-826.

[11] P.I. Ferreira, A.A. Couto, J.C.C. de Paola, The effects of chromium addition and heat treatment on the microstructure and tensile properties of Fe-24Al(at. %), Materials Science and Engineering A192/193 (1995) 165-169.

[12] Y.D. Huang, W.Y. Yang, Z.Q. Sun, Effect of the alloying element chromium on the room temperature ductility of Fe_3Al intermetallics , Intermetallics 9 (2001) 119-124.

[13] P. Chakraborty, I.G. Sharma, A.K. Suri, D.K. Bose, Studies on preparation, characterisation and evaluation of properties of Fe_3Al-based intermetallic alloy of composition Fe–16Al–5.44Cr–1Nb–0.5C Journal of Materials Processing Technology 115 (2001) 413-422.

[14] D.H. Sastry, Y.V.R.K. Prasad, S.C. Devi, Influence of temperature and strain rate on the flow stress of an FeAlalloy, Materials Science and Engineering A299 (2001) 157-163.

[15] M. Jabłońska, E. Bernstock, A Jasik, Microstructure and mechanical properties of intermetallics on the base of Fe-Al alloy obtained by casting, Archives of Materials Science and Engineering 28/10 (2007) 625-628.