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Deformability and recrystallisation of Fe-Al intermetallic phase - base alloy

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Materials

ABSTRACT

Purpose: Limitation on the capacity for a wide application of intermetallics from the Fe-Al system results from their insufficient plasticity. It is a factor which inhibits further development of intermetallics as constructional materials. Under this study, research has been conducted on the capacity for forming alloys based on intermetallic phases from the Fe-Al system, via thermo-mechanical processing.
Design/methodology/approach: After casting and annealing, alloy specimens were subjected to axial-symmetric compression in the Gleeble 3800 simulator in the range of 600÷1200°C . 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 and electron microscopy.
Findings: The capacity for alloys' hot deformation and limited plasticity of an alloy in ambient temperature have been shown. In addition, the processes of structural reconstruction, which take place during and after deformation, have been detected.
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 will be used to design the basis for a thermo-mechanical processing technology via rolling and inter-operational annealing of the investigated compound with an intermetallic Fe-Al phase matrix.
Keywords: Metallic alloys; Plastic forming; Microstructure; Compression test

1. Introduction

Alloys based on intermetallic phases from the Fe-Al system. They belong to a group of high-temperature creep resisting materials of advantageous physicochemical and mechanical properties at an elevated and high temperature [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.

Fe-Al alloys‘ properties, such as: low density, high melting temperature, high strength and good oxidizing resistance, coupled with good crack resistance, create wide prospects for their industrial applications, for components of machines working at a high temperature and corrosive environment [5-12].

In general, limitation on the capacity for a broad application of intermetals from the Fe-Al system, e.g. as an alternative to expensive alloy steels of specific properties, is their insufficient plasticity, which is a factor inhibiting further their development as constructional materials [13-15].

This paper analyses the changes in microstructure of an ordered FeAl alloy with 38 at.-% content of aluminium and structure B2 during high-temperature deformation in the range of temperatures from 600 to 1200°C. Moreover, research of an identifying nature was commenced for the purpose of evaluating the influence of cold plastic strain and recrystallization annealing on changes and the structure and microhardness of the Fe-38Al alloy. Also, the nature of fractures of samples deformed until failure was examined. This study constitutes the basis for the development of a basis of the technology of forming the structure and properties of Fe-Al intermetallics via thermo-mechanical processing.

2. Material and methodology

Material for the research consisted of bars cast from an alloy based on an feal intermetallic phase of a chemical composition shown in Table 1. The alloy was prepared by casting into graphite moulds. Ingots were obtained in the form of cylinders of dimensions: ø14mm and 120 mm in length.

Table 1.
Chemical composition of the Fe-38Al alloy (at.- %, % wt.)

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

After annealing, specimens were made from the material. Next, they were subjected to an axial-symmetric compression test in the Gleeble 3800 simulator with simultaneously freezing the structure after deformation by quick cooling with water. Compression tests were conducted in the range of temperatures from 600°C to1200°C at strain rate of $\dot{\varepsilon}$ =0,1s^{-1}. Compression was performed to the value of real strain amounting ε=0.9. After an axial-symmetric compression test, an analysis was made of the microstructure on a section parallel to the specimen's axis, with the use of light microscopy. The substructure was made by the thin foil method, using a transmission electron microscope (TEM), JEM 100B of Joel Company.

The cold compression tests was conducted in friction-free conditions, using teflon pads. Based on the tests made, the real rolling reduction ε_h and the mean unit pressure, p_{mean} [MPa] were determined. After compression until strain ε = 0.4, the specimens were subjected to recrystallization annealing at a temperature of 600, 700, 800 and 900°C, with 1-hour soaking time.

3. Results

The structure of the investigated alloy after casting and annealing is shown in Fig. 1. The tested Fe-38%Al alloy has a coarse-grain single-phase structure of a mean grain size amounting to 100µm.

The axi-symmetric hot compression tests made for Fe-38%Al alloys made it possible to determine the deformability characteristics in the form of flow curves in the stress-strain system (Fig. 2). The stress-strain curves represent a broad range of strain consolidation. The flow curves' courses differ, depending on the process temperature. In the temperature range from 1000°C to 1200°C, quick material consolidation is observed.

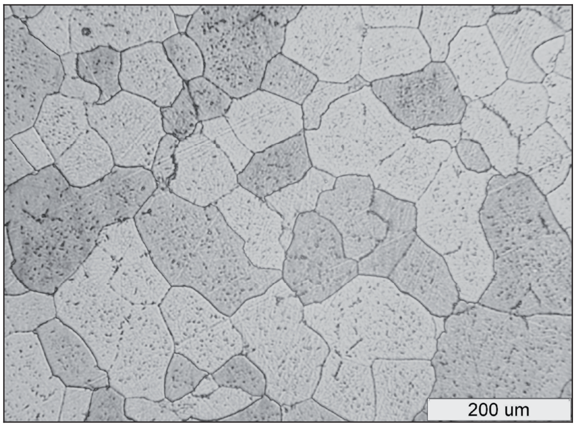

Fig. 1. Microstructure of the Fe-38%Al alloy after homogenization annealing at 1000°C for 48h, followed by cooling with furnace

The alloy reaches the maximum yield stress - σ_{pp} on the flow curve, with a low strain value - ε_p on the flow curve, after which the material consolidation and weakening processes counterbalance each other.

After deformation at a temperature of 800°C, a dynamic recrystallization process is observed. Initial stages of dynamic recrystallization are visible in the microstructure, which is shown by the formation of fine grain chains on primary grain boundaries and on slip bands.

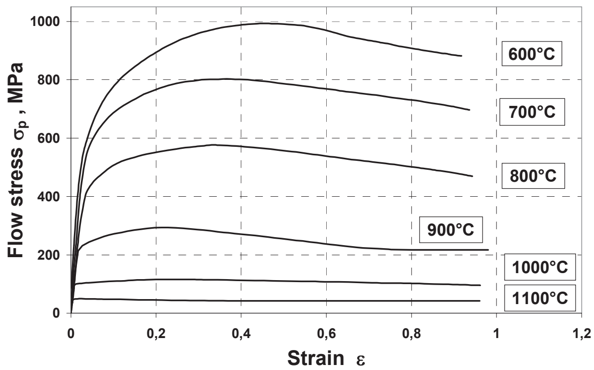

Fig. 2. Stress strain curves for Fe-38%Al alloy deformed at temperature 600 - 1100°C with a rate 0.1s^{-1}

Dislocation rearrangement takes place in the substructure and cellular dislocation systems are formed. At 900°C, a more advanced dynamic recrystallization process is observed, which is reflected by almost complete recrystallization of the structure (Fig. 3). The grain is of a small size, with the deformed primary structure grain still visible. Perfectly formed subgrain can be detected in the substructure (Fig. 4). After deformation at a temperature of 1000°C, further advance in the dynamic recrystallization is observed in the Fe-38%Al alloy (Fig. 5). Primary boundaries gradually disappear and the recrystallized grain grows. At deformation temperatures of 1100°C and 1200°C, a completely recrystallized structure and the new grain growth become visible.

During the cold deformation tested alloy is characterized by intensive consolidation during the test, to ca. 1800MPa at real draft of 0.4.

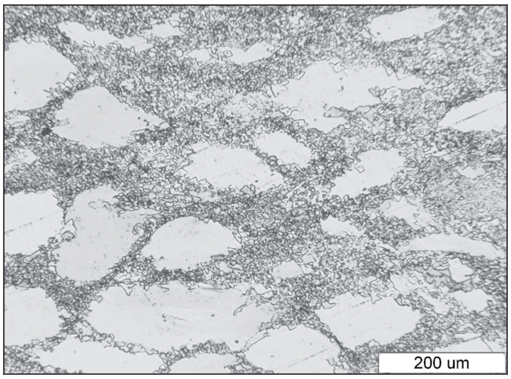

Fig. 3. Structure of the alloy after compression at 900°C

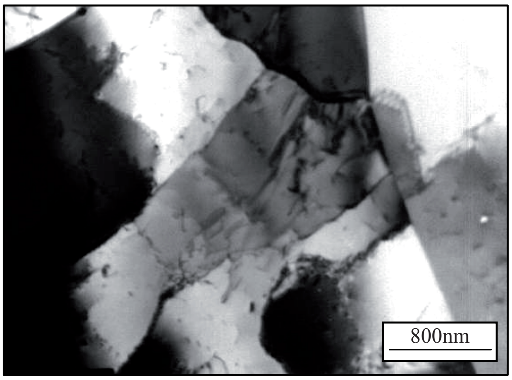

Fig. 4. Substructure of the alloy after compression at 900°C

Further deformation results in a loss of material cohesion - initially, in the external zone of the barrel and then, towards the internal zone.

Intensiveness of the recrystallization process depends on the annealing temperature applied. After annealing at 600°C, no new recrystallized grain is observed in the microstructure. Nuclei of recrystallized grain are observed in the substructure

Some fine, recrystallized grain, near primary grain boundaries, are detectable after annealing at a temperature of 700°C (Fig. 6). Increaing the annealing temperature to 800°C intensifies recrystallization (Fig. 7). The structure consists of fine recrystallized grain with a diamater of d=20µm (mean equivalent diameter of the grain plane section). A further increase of the annealing temperature leads to a gradual grian growth after recrystallization, up to a mean size of 80µm.

Results of microhardness measurement in the initial state after cold deformation and after recrystallization annealing are shown in Table 2. After cold compression, a significant increase of microhardness, by 240µHV, took place, compared to the alloy after homogenization annealing at 1000°C with soaking time of 24h, which testifies to considerable consolidation of the material.

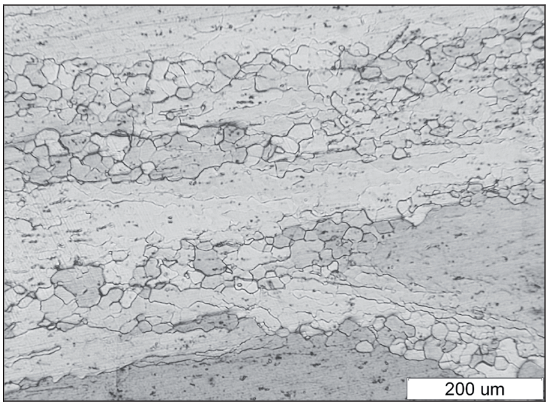

Fig. 5. Structure of the alloy after compression at 1000°C

After recrystallization annealing, a gradual decrease of microhardness is observed. Minimal microhardness is characteristic for specimens after annealing at a temperature of 800°C. A further increase of the annealing temperature results in an in significant increase of microhardness.

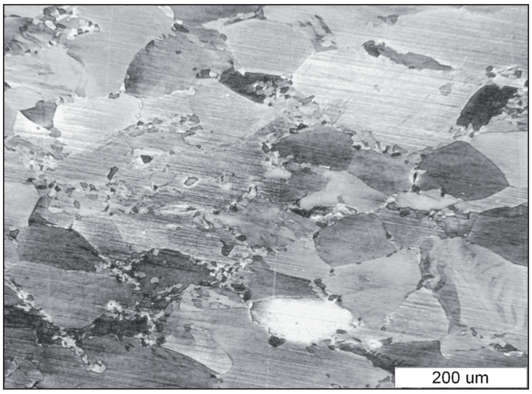

Fig. 6. Structure of the FeAl alloy after cold compression and annealing at 700°C

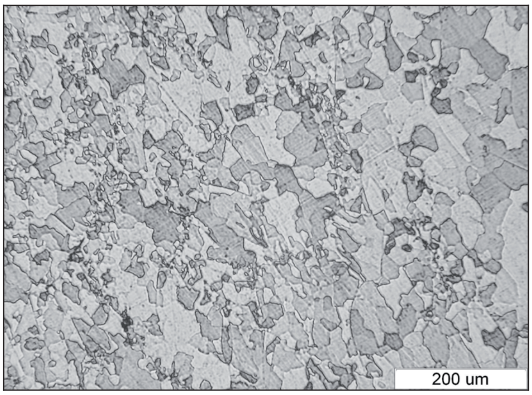

Fig. 7. Structure of the FeAl alloy after cold compression and annealing at 800°C

Table 2.
Results of microhardness measurement of the investigated alloy

	Microhardness, HV
after homogenization	300
cold compression	540
annealing 600°C	420
annealing 700°C	350
annealing 800°C	340
annealing 900°C	345

4. Conclusions

The investigated alloy, Fe-38Al, based on an ordered solid solution, after homogenization annealing has a coarse-grain single-phase structure. At deformation temperatures of 600 or 700°C, phenomena connected with recrystallization are not noted. This manifests itself with intensive consolidation of the intermetallic and achieving high yield stress values. A limited recrystallization process takes place at a temperature of 800°C. In alloy specimens strained at 900°C and higher temperatures, after exceeding strain ε_p, the stress becomes steady at σ_s. After deformation at 1100 and 1200°C, the structure is completely recrystallized and the phenomenon of new grain growth becomes visible.

In the case of a cold deformation process, the alloy intensively consolidetes to ca. 1800MPa at strain of ε=0.4. It is an almost twice higher value when compared to the austenitic Cr-Ni AISI304 grade steel.

The structure after cold deformation consists of deformed grain. High density of defects was detected in the substructure. After annealing of the cold deformed specimens, static recrystallization is observed. At temperatures of 600 and 700°C, recrystallization proceeds at low intensity. Fine recrystallized grain is observed at primary grain boundaries as well as recrystallized grain nuclei in the substructure. Optimal annealing conditions in the investigated range of parameters‘ variability, as regards the structure (grain size d=20μm and the lowest microhardness), are: temperature of 800°C and 1h soaking time. A further increase of the recrystallization temperature induces a growth of new grain. Further compression above ε=0.4 leads to crack initiation, at the beginning – from the specimen's lateral side.

As a result of the proceeding dynamic and static recrystallization, in the specimens of an intermetallic phase based alloy, considerable grain-size reduction is obtained, which in consequence, has an effect on mechanical properties of the material. Alloy Fe-38%Al is also characterized by limited plasticity at an ambient temperature.

It has been proved that the alloy tested can be formed via thermoplastic processing. The structure reconstruction processes, which take place during deformation, lead to a decrease in plastic flow resistance, in particular at temperatures above 1000°C. The static recrystallization process, detectable after cold deformation and annealing, intensively reduces consolidation of the tested alloy and leads to an intensive grain size reduction in the intermetallic phase. The results obtained will be used for designing the basis of the rolling technology for this group of materials.

Acknowledgements

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