PLASTIC DEFORMATION AND THE EFFECTS OF DYNAMIC RECRYSTALLIZATION IN AN ALLOY IN THE MATRIX OF ORDERED SOLID SOLUTION

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PLASTICKÁ DEFORMÁCIA A VPLYVY DYNAMICKEJ REKRYŠTALIZÁCIE V ZLIATINE S MATRICOU USPORIADANÉHO TUHÉHO ROZTOKU

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Abstrakt

Cieľom tejto práce je štúdium možností plastickej deformácie za tepla intermetalickej zliatiny FeAl. Aluminidy železa, ako je známe, sa vyznačujú nízkou ťažnosťou pri teplote okolia. Jedným zo spôsobov ich tvárnenia je deformácia pri stredných a vysokých teplotách pri špeciálnych podmienkach procesu. Skúmaná bola zliatina Fe-Al s 38 at. % Al so štruktúrou usporiadaného B2 typu. Deformácia v podmienkach tlaku prebiehala v rozsahu teplôt od 800 do 1250 °C so 100°C krokom. Skúška tlakom bola uskutočnená na simulátore Gleeble 3800 až do predpokladanej hodnoty deformácie = 1,2. Analyzovaný bol vplyv parametrov procesu deformácie za tepla (teplota a rýchlosť deformácie) na mechanické vlastnosti v priebehu skúšky tlakom. Určený bol vzťah medzi parametrami deformačného procesu (Zener-Holomonov parameter) a mechanickými vlastnosťami počas skúšky tlakom. Analýza štruktúry pred a po procese deformácie bola uskutočnená využitím svetelnej mikroskopie. Zmeny v štruktúre zliatiny, ktoré sú typické pre proces uzdravenia a dynamickej rekryštalizácie, poukázali na široký rozsah možností plastického tvárnenia. Bolo potvrdené, že optimálne parametre procesu deformácie za tepla ovplyvňujú proces dynamickej prestavby štruktúry, ktorá zodpovedá za dobrú plasticitu.

Abstract

The aim of this work is to study the possibilities of hot plastic deformation of the FeAl intermetallic alloys. Iron aluminides, as we now, has poor ductility at room temperatures. One way of their forming is at medium and at high temperature plastic deformation with specially process conditions. We investigated the Fe-Al alloy of 38%at. Al with a structure of ordered B2 type. It was deformed at the range of temperatures of 800º C to 1250 Cº with a step on 100°C, by means of compression. Compression tests was performed on Gleeble 3800 simulator up to the assumed value of the deformation □=1,2. Influence of the parameters of the hot deformation process (temperature and strain rate) on the mechanical properties during the compression have been analyzed. The relations between the parameters of the deformation process (Zener-Holomon's parameter) and the mechanical properties during the compression test was determined. The analysis of the structure before and after the deformation process was performed with the use of LM technique. Changes in the structure of the alloy, which are typical of the recovery process and dynamic recrystallization, indicating a wide range of possibilities of plastic forming have been revealed. We confirm that the optimally parameters of the hot deformation process influenced on the process of the dynamic rebuilding of the structure which is responsible of the good plasticity.

Keywords: intermetallic alloys, dynamic recrystalization, hot compression tests

1. Introduction

During the last few years the growth in interest in the subject of development of materials engineering in a range of searching for new materials and their alloys has been observed, what mainly aims at reaching a progress in many industrial branches. It is made conditional on the possibilities of producing modern materials which are supposed to meet very high requirements, such as: high mechanical strength, low real density, resistance to high temperature and corrosion.

One of groups of such materials are alloys based on ordered intermetallic phases, from the Fe-Al systems which are the alloys with a good oxidation resistance at a higher temperature, good abrasion resistance , relatively low density, and moreover, at a good value for money, e.g. in comparison with high-alloy steel. [1÷4]. However, those properties determine the potential of developing the Fe-Al alloys, producing them is still a problem, as well as processing them for industrial usage. It arises due to the fact that those materials possess limited possibilities of conventional deformation by means of plastic processing, and at a room temperature they demonstrate the effect of embrittlement [2,3,5]. It determines the potential of improving the methods which aim at eliminating causes of their embrittlement, and at the same time the possibility of effective plastic processing of the Fe-Al alloys, The research that are currently carried out have been the bases to stating that despite all the difficulties, those materials can be processed during hot plastic deformation and, at the same time, all the assumed values of the deformation will be obtained [6,7]. Since during the deformation dynamic processes of regeneration take place, that gives structural bases for the analysis of the possibilities of controlling hot plastic deformation processes. [5÷7].

In that study the subject of the analysis of the initial structure and the alloy plasticity of the alloy in matrix of the intermetallic FeAl phase at high and very high temperatures was taken up.

2. Purpose, range and methodology of the research

The purpose of this research was to determine the structure and the properties as well as possibilities of hot plastic deformation of an alloy in the matrix of FeAl- ordered solid solution . The research was carried out on the Fe38Al alloy with the chemical composition as presented in the Table 1.

Table 1 Chemical composition of Fe38Al alloy

The content of elements [% at.]					
Al	Mo	Zr	C	B	Fe
40	0,2	0,05	0,1	0,01	59,64

The alloy in the form of bars with the diameter of d = 14mm and the length of l = 120mm, was subjected to homogenizing annealing at the temperature of 1000°C with the time of holding 48h. The measurements of hardness and compression tests at the temperature of

700°C – 1200°C , at two speeds of deformation $\dot{\varepsilon}$ =0,01s^{-1} and $\dot{\varepsilon}$ =1s^{-1} were carried out on the obtained material. he research of the plasticity of the Fe38Al alloy with means of the hot compression method was carried out in a deformation simulator, Gleeble 3800. The samples were in the shape of cylinder with the diameter of d=10 mm and the height of h=12mm. After the deformation, the samples were cooled with water with the aim of the structure freeze. The analysis of the properties of the tested alloy and the analysis of its structure during hot deformation were carried out.

3. Results of the researches

The characteristic of the alloy after annealing was heterogeneous one-phase structure with a varied size of the grain. Not only were there big grains present, but also some single small grains. (Fig.1a and b). The hardness of the alloy after annealing amounted to 286HV$_{0,2}$.

a) b)

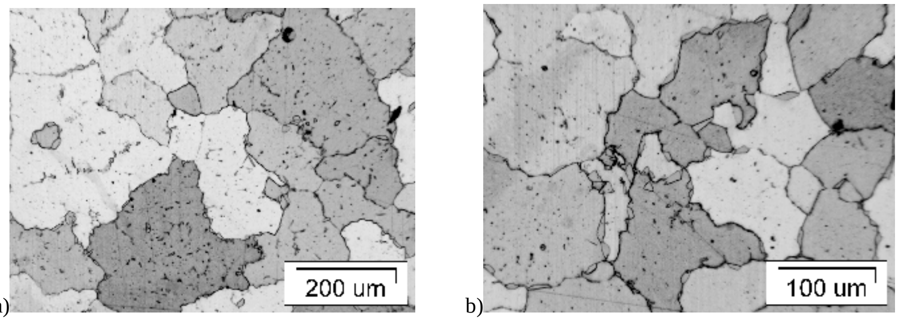

Fig.1 The initial structure of the Fe38Al-alloy after annealing at 1000°C during 48h

Compression tests allowed us to determine the characteristics of deformability in a form of curves in the plastic stresses - deformation system (Fig.2 and 3). The highest values of the maximum plastic stresses σ_{pmax}=498 MPa and σ_{pmax}=690 MPa were obtained for the deformation at the temperature of T=700°C and at the deformation speed of $\dot{\varepsilon}$ =0,01s^{-1} and $\dot{\varepsilon}$ =1s^{-1}, relatively. The lowest values of plastic stresses σ_{pmax}=7,5 MPa and σ_{pmax}=18 MPa were obtained for the deformation at the temperature of T=1250°C at the deformation speed of $\dot{\varepsilon}$ =0,01 s^{-1} and $\dot{\varepsilon}$ =1s^{-1}, relatively. The maximum values of the stresses and deformations, as well as the value of the threshold deformations determined during hot torsion test are presented below, in the figure 2.

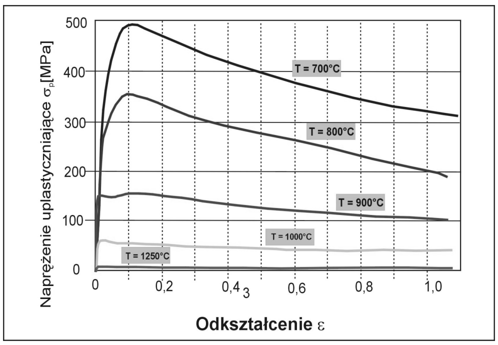

Fig.2 The strain-stress curves for the alloy deformed at the speed of $\dot{\varepsilon}$ =0,01 s^{-1}

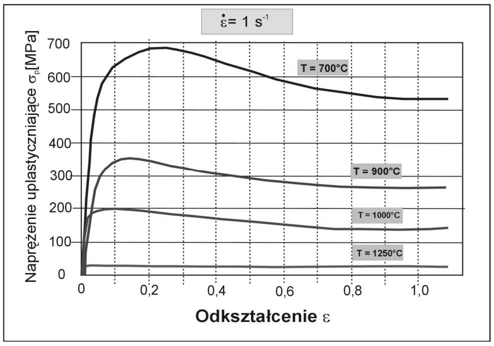

Fig.3 The strain-stress curves for the alloy deformed at the speed of $\dot{\varepsilon}$ =1 s^{-1}

A growth in plastic stresses up to its maximum value occurs during the compression of the tested alloy at the speed of $\dot{\varepsilon}$=0,01s^{-1} at the temperature of 700°C; 800°C, 900°C and 1000°C and at the speed of $\dot{\varepsilon}$=1s^{-1} and the temperature of 700°C , 900°C and 1000°C. After that a gradual decrease in the value of the plastic stresses occurs until it reaches the deformation of ε=1,2 (the compression process was carried out up to this value). It proves that at that level of deformation the process of dynamic recrystallization (DR) dominates in the material. During the deformation of the tested alloy at the speed of $\dot{\varepsilon}$=0,01s^{-1} and $\dot{\varepsilon}$=1s^{-1} at the temperature of 1250°C having exceeding the deformation ε_{max} corresponding to maximum plastic stresses σ_{pmax} , the stresses is on a fairly constant level and the alloy reaches the state of the fixed plastic flow (ε_{ss}). The shape of the curves $\sigma - \varepsilon$ indicates that the process of dynamic recrystallization is dominant as a main mechanism of rebuilding the structure during which occurs the balance between structure rebuilding processes and material strengthening processes.

The growth in the speed of the deformation of the samples causes an increase in the value of the maximum stresses σ_{pmax} for all ranges of the considered temperatures. For the tested alloy, increasing the temperature of the compression in the whole range of the temperature of deformation causes a decrease in the value of the deformation that is corresponding to the maximum stresses ε_{max} .

The relations between the parameters of the deformation process (Zener-Holomon's parameter) and the mechanical properties determined during the compression test were shown in Fig. 4. and 5. The influence of the Zener-Holomon's parameter on the maximum plastic stresses σ_{pmax} in the logarithmic system, as well as on the maximum deformation ε_{max} in the semi-logarithmic system can be presented in a form a linear function.

Table 2 The characteristics of the plasticity of the Fe-38Al alloy determined during a torsion test, depending on the temperature and the deformation speed

Deformation temperature T [°C]	Deformation speed $\dot{\varepsilon}$ [s^{-1}]	Maximum plastic stresses σ_{pmax} [MPa]	Deformation ε_{max}
700	0,01	498	0,11
900		137	0,10
1000		59	0,04
1250		7,5	0,02
700	1	690	0,25
900		359	0,13
1000		199	0,09
1250		18	0,03

The values of the maximum plastic stresses σ_{pmax} , as well as of the deformation ε_{max} depend on Zener-Holomon's parameter, what is proved by the correlation coefficient R^2 = 0,871 and R^2 =0,792.

After hot compression tests an estimation of the alloy microstructure was made, what was supposed to reveal the course of the dynamic processes of rebuilding the defective structure. Some chosen examples of the alloy microstructure after the hot compression tests are shown in Fig. 6, 7 and 8. It can be seen that the compression at the speed $\dot{\varepsilon}$ =1s^{-1} at the temperature of 700°C (Fig. 6.) causes changes in the microstructure in forms of strongly elongated grains; however, no effects connected with the recrystallisation processes are observed. At the temperature of 800°C first effects of the dynamic rebuilding of the structure occur. Elongated recrystallised original grains are visible (Fig. 7). Similar results in the structured are caused by the deformation at the temperature of 900°C.

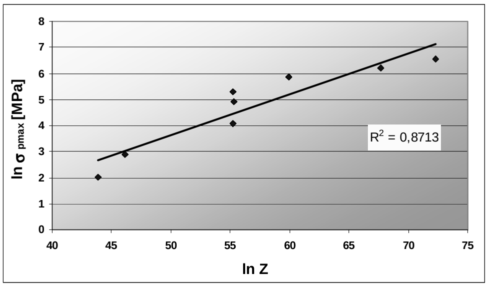

Fig.4 The dependence of the maximum plastic stresses σ_{pmax} on the Zener- Hollomon's parameter

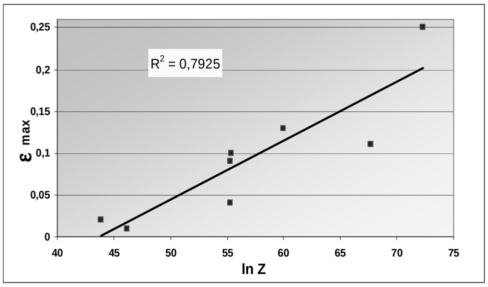

Fig.5 The dependence of the deformation ε_{max} on Zener- Hollomon's parameter

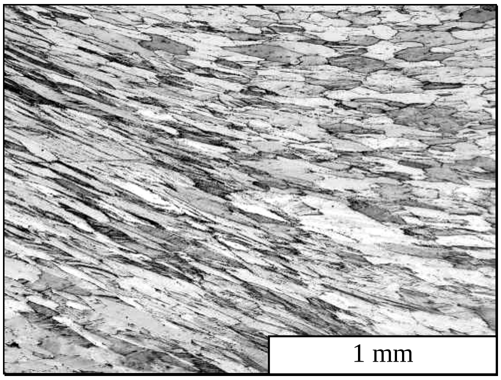

Fig.6 The microstructure of the Fe-38Al alloy deformed at the temperature of 700°C at the speed of $\dot{\varepsilon}$ =1 s^{-1}.

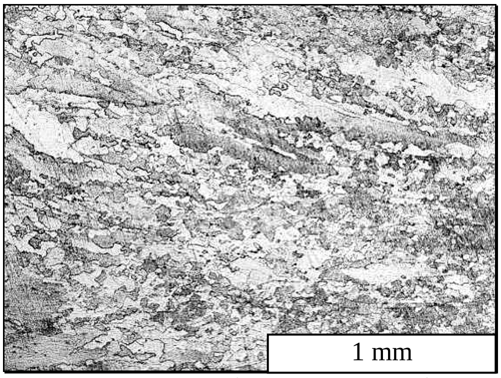

Fig.7 The microstructure of the Fe-38Al alloy deformed at the temperature of 800°C at the speed $\dot{\varepsilon}$ =0,01 s^{-1}

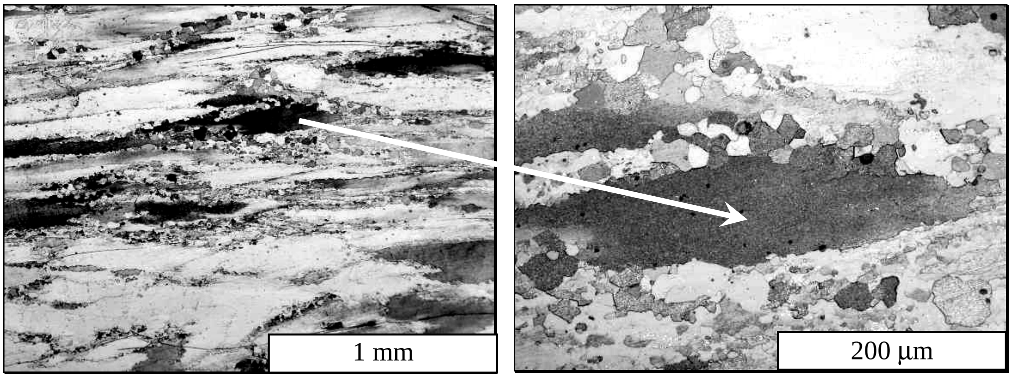

Fig.8 The microstructure of the Fe-38Al alloy deformed at the temperature of 1000°C At the speed $\dot{\varepsilon}$ =1 s^{-1}

The increase in the deformation temperature of the alloy causes effects of proliferation of the grains. Further analysis of the structure of the Fe38Al alloy revealed that nucleation and growth in fine equilateral grains occur mainly on the boundaries of the initial grains. A structure resembling "a necklace" is formed, where colonies of new fine grains are growing which have been recrystallized in a dynamic way round the initial boundaries of the grains (Fig. 8). With the growth in deformation, the colonies of fine grains gradually grow and the area that has been recrystallized in a dynamic way starts spreading to the grains initially deformed.

Such a process spreads gradually to all the deformed grains, and its finishing is connected with the moment of reaching the fixed state of plastic flow.

4. Conclusions

The characteristic of the tested alloy is an uneven initial structure after the homogenising annealing process. It seems legitimate to carry out the optimizing of the selection of the parameters of the initial thermal treatment.

Despite a high level of plastic stresses, the compression tests that have been carried out prove good deformability of the Fe38Al alloy, particularly at high temperatures in which the material reaches the state of fixed flow. It is satisfying that in all the assumed variants of temperature, the compression tests were carried out up to the assumed value of the deformation $\varepsilon=1,2$ without fractures.

In the tested alloy, the processes of dynamic rebuilding of the structure start intensively at the temperature of about 700°C.

It seems to be inevitable to continue the research in a range of the influence of the initial structure on the properties of the tested alloy, as well as a detailed analysis of the processes and changes taking place in the inner structure and influencing the technological characteristics of the alloy.

Acknowledgement

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