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PLASTICITY OF LOW ALUMINUM ALLOYS FROM Fe-Al SYSTEM

PLASTYCZNOŚĆ NISKOALUMINIOWYCH STOPÓW Z UKŁADU Fe-Al

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. 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.

The aim of this work is study about the analysis of the influence of hot deformation parameters like a temperature and strain rate on the plasticity and structure changes in alloys on the base Fe-Al system. These alloys are competitive for their cost and properties in comparison with stainless and acid resistance steels. Were analyzed the properties determined in hot compression test of cast alloys Fe-28Al, Fe-28Al-5Cr, contain microelements Mo, Zr, C, B. The tests were carried out on the range of temperature 700°C÷1100°C with strain rate 0,1 s^{-1}. The results indicated that the Cr addition had an positively effect on the plasticity properties. Moreover exhibited that the Cr addition had an influence on the mechanism of the rebuilding the structure changes.

Keywords: Fe-Al alloys, hot compression test, microstructure, substructure

Stopy na osnowie faz międzymetalicznych z układu Fe-Al, zaliczane są do grupy tworzyw żarowytrzymałych, posiadających korzystne właściwości fizykochemiczne i mechaniczne. Zasadniczym problemem ograniczającym ich powszechne stosowanie jest niska plastyczność i skłonność do kruchego pękania co powoduje zahamowanie w dalszym rozwoju jako materiałów konstrukcyjnych.

Celem tej pracy jest ocean wpływu parametrów takich jak temperatura, prędkość odkształcenia na plastyczność i zmiany struktury stopów z układu Fe-Al. Ze względu na niski koszt oraz właściwości są konkurencyjne w porównaniu do stali nierdzewnych i kwasoodpornych. Analizowano właściwości w próbie ściskania na gorąco dla odlewniczych stopów Fe-28Al, Fe-28Al-5Cr, zawierających mikrododatki Mo, Zr, C, B. Próby były prowadzone w zakresie temperatury 700÷1100°C z prędkością odkształcenia 0,1 s^{-1}. Wyniki wskazują, że mikrododatek Cr ma zdecydowany wpływ na właściwości plastyczne. Dodatkowo mikrododatek Cr ma wpływ na zmianę mechanizmu odbudowy struktury.

1. Introduction

Alloys based on intermetallic phases from the Fe-Al system belong to a group of high-temperature creep resisting materials of advantageous physicochemical and mechanical properties at elevated and high temperatures [1÷5]. 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.

Properties Fe-Al alloys, 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 as structural parts working at high temperatures and corrosive environment [6÷7].

In general, limitation on the capacity for a broad application of Fe - Al intermetallics system, e.g. as an alternative to expensive alloy steels of specific properties, is their insufficient ductility, which is a factor inhibiting their further development as structural materials [7].

The purpose of this work is to analyze the stress-strain curves of Fe-Al alloys subjected to deformation in the temperature range of 700°C to 1100°C and changes in the microstructure of these materials. The microstructure analyses applying LM and TEM technique revealed the structure reconstruction processes occurring

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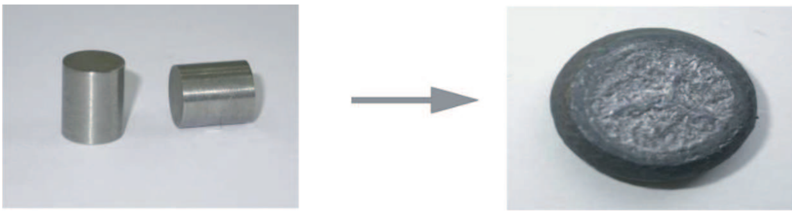


Fig. 1. Samples used for hot compression tests

in the investigated alloys. It was shown, that high temperature deformation in the investigated alloys causes different mechanisms of the microstructural changes, influencing their plasticity. The obtained results will be employed to develop the technology of shaping the microstructure of this group of materials by means of hot working.

2. Experimental procedure

Materials for the investigations constituted multicomponent alloys from Fe - Al system, the composition of which is presented in Table 1. 5 at.% of Cr was introduced into these alloys to enhance their ductility. The microadditions: Mo, Zr, C, B were used for modification of crystallization process. The alloys were produced by vacuum induction melting. The obtained heat was melted twice and drop cast into graphitoidal moulds to obtain rods of 12 mm diameter and 120 mm in length. Obtained material was subjected to homogenizing annealing at the temperature of 1000°C for 48 h and then to furnace cooling.

TABLE 1

Chemical composition of the investigated alloys

Mark of the alloy	Chemical elements contents [at.%]						
	Al	Mo	Cr	Zr	C	B	Fe
"1"	28.0	0.20	-	0.05	0.1	0.01	71.64
"2"	28.0	0.20	5.0	0.05	0.1	0.01	66.64

After 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 (Fig. 1).

The compression samples were deformed at the temperatures range of 700÷1000°C at the strain rate of 0.1 s^{-1}, until the true strain values reached ε =1.0. The temperature of the samples T [°C], stresses σ [MPa], deformation forces [N] and strains ε were recorded during the tests. Recorded data anabled obtaining stress σ – strain ε curves. Metallographic investigations were carried out using light microscopy and scanning electron microscopy. The microanalysis of the chemical composition was carried out using HITACHI S-3400N scanning microscope with EDS spectrometer.

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

3. Result of the research

The microstructure of the investigated alloys after heat treatment is presented on figures 2÷5. Both tested alloys exhibited primary dendrite structure with phases and precipitates. Phases enriched with Al and Fe (Fig. 4 – A) and numerous precipitates containing Zr (Fig. 4. – B) were observed in Fe-28Al ("1") alloy. The microstructure of Fe-28Al-5Cr ("2") alloy contained mainly Cr and Zr precipitates (Fig. 5. – A, B, C).

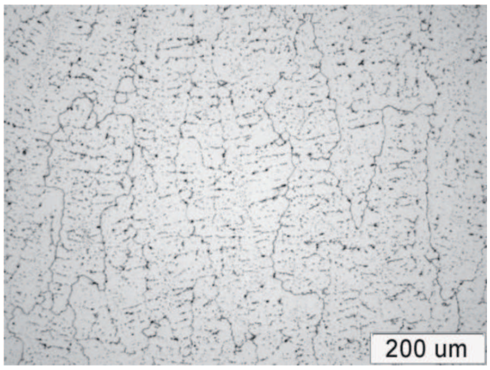


Fig. 2. Microstructure of alloy **"1"** after heat treatment

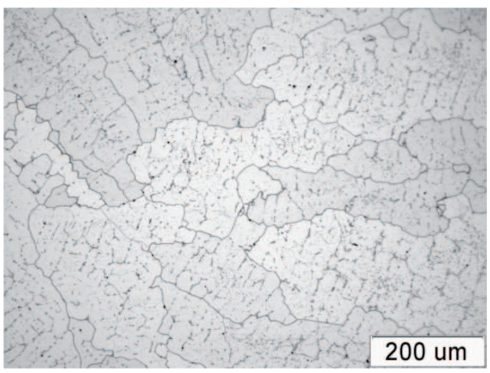
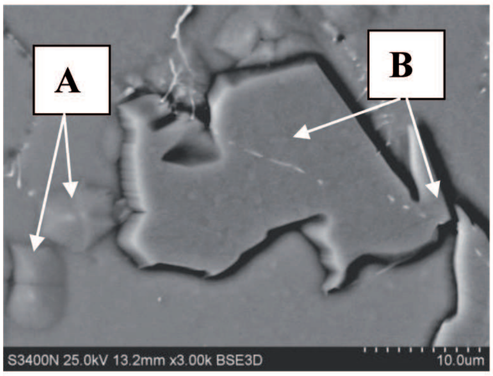
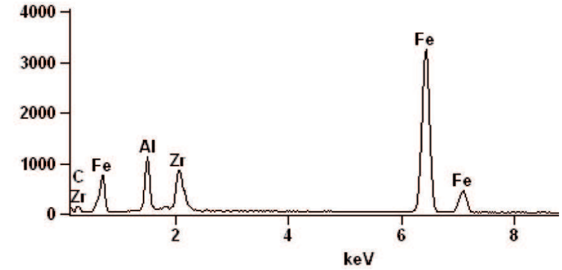


Fig. 3. Microstructure of alloy **"2"** after heat treatment

a)



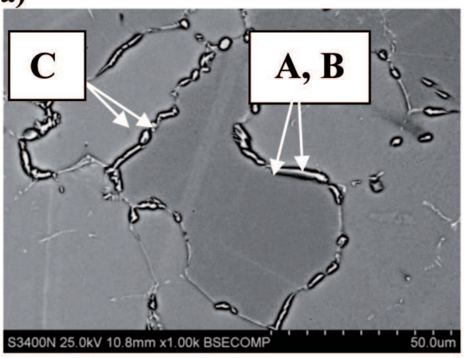
b)



	Al % at.	Fe % at.	Zr % at.
A	24,62	64,52	10,86
B	26,02	73,98	-

Fig. 4. Alloy *"1"* after homogenization: a) The SEM image of the precipitates A – a precipitate rich in Zr and B – an area slightly enriched with Fe; b) The energy spectrum for precipitate A and the chemical composition microanalysis of precipitates A and B

a)



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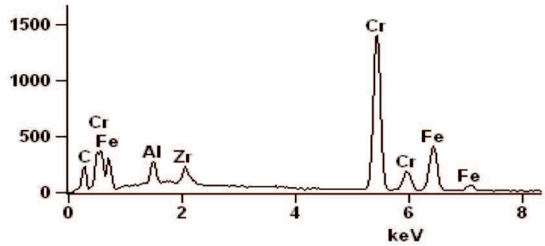

c)

	Al % at.	Fe % at.	Cr % at.	Zr % at.
A	24,62	64,52	10,86	-
B	26,02	73,98	-	-
C	4,93	63,42	29,24	2,41

Fig. 5. Alloy *"2"* after homogenization: a) The SEM image of the precipitates: A, B: the Cr-rich precipitates; C: the Cr-rich precipitates in which Zr was present; b) The results of the chemical composition microanalysis of precipitates A and B. The energy spectrum and the chemical composition microanalysis of precipitate C

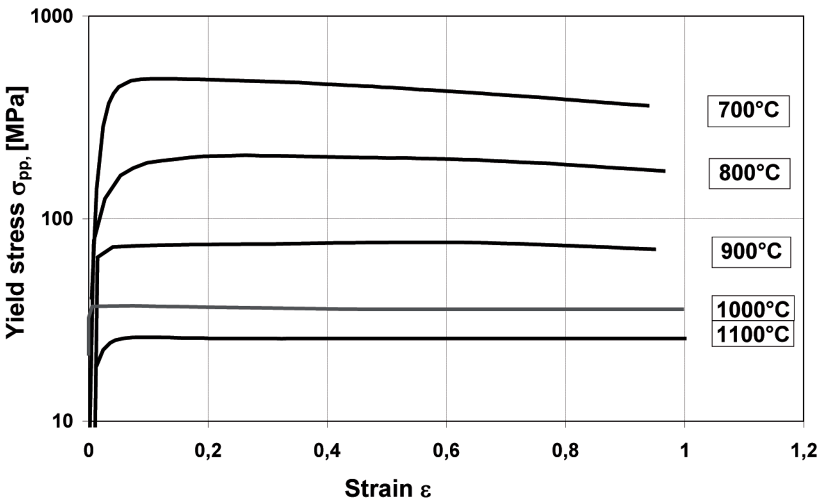

Fig. 6. The stress – strain flow curves for alloy *"1"*. Samples deformed at the strain rate of 0.1 s^{-1}

The performed axial-symmetrical compression tests resulted in the determination of the flow curves (Fig. 6, 7). Significant influence of deformation temperature on the flow stress level was observed. The shape of the flow curve indicates very wide range of the strain hardening.

For both alloys deformed at the temperature of 700°C the shape of the flow curves and the value of the σ_{pp} is different. For alloy "1" $\sigma_{pp=}$490 MPa, and for alloy "2" $\sigma_{pp=}$550 MPa. For higher temperatures values of the σ_{pp} are comparable.

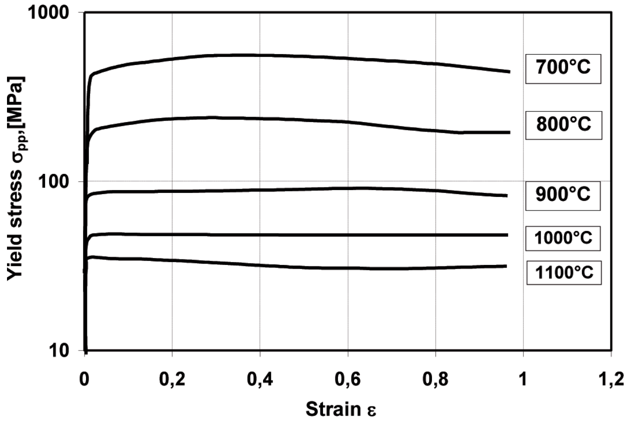

Fig. 7. The stress – strain flow curves for alloy ***"2"***. Samples deformed at the strain rate of 0.1 s^{-1}

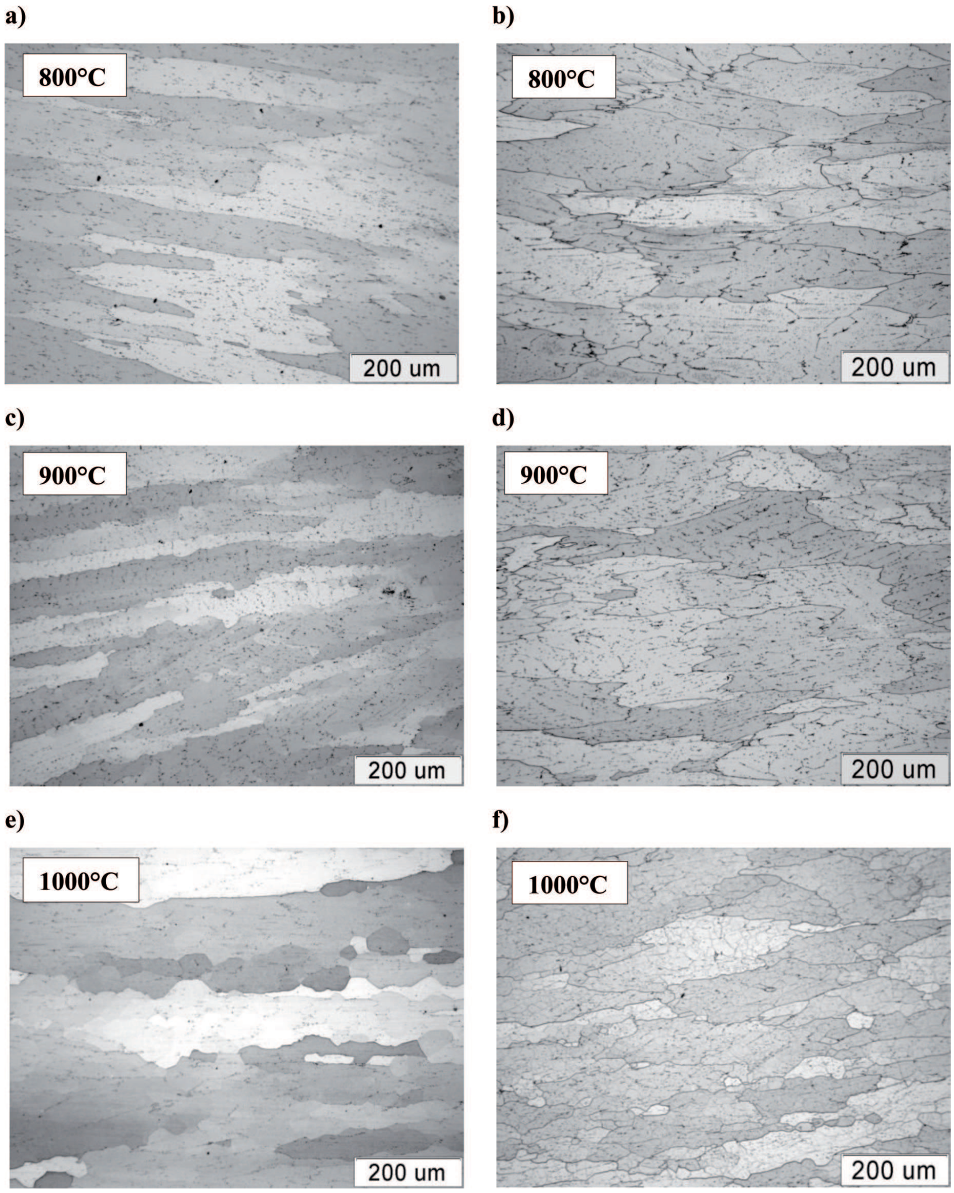

Fig. 8. Microstructures of the investigated alloys after hot deformation: a), c), e) alloy ***"1"***; b), d), f) alloy ***"2"***

The microstructures of the analyzed alloys after hot deformation are shown on Fig. 8. Compression in the temperature range of 700°C to 900°C leads to strong deformation of grains without rebuilding the microstructure in both alloys. An intensive recrystallization process initiated by creating new grains and their growth was observed in alloy ”1” deformed at 1000°C (Fig. 8e). Alloy “2” also recrystallized at 1000°C, but recrystallization was initiated by different mechanism. In this case subgrain coalescence was observed as the mechanism of the structure rebuilding.

The analysis of the substructure of the investigated alloys (Fig. 9,10) confirmed that the addition of Cr (5 at.%) has an influence on the change in the mechanism of rebuilding the structure. In alloy “1” the predominant mechanism is dynamic recrystallization with migration of grains (Fig. 10a), but in alloy “2” it is recovery process with coalescence of subgrains (Fig. 10b).

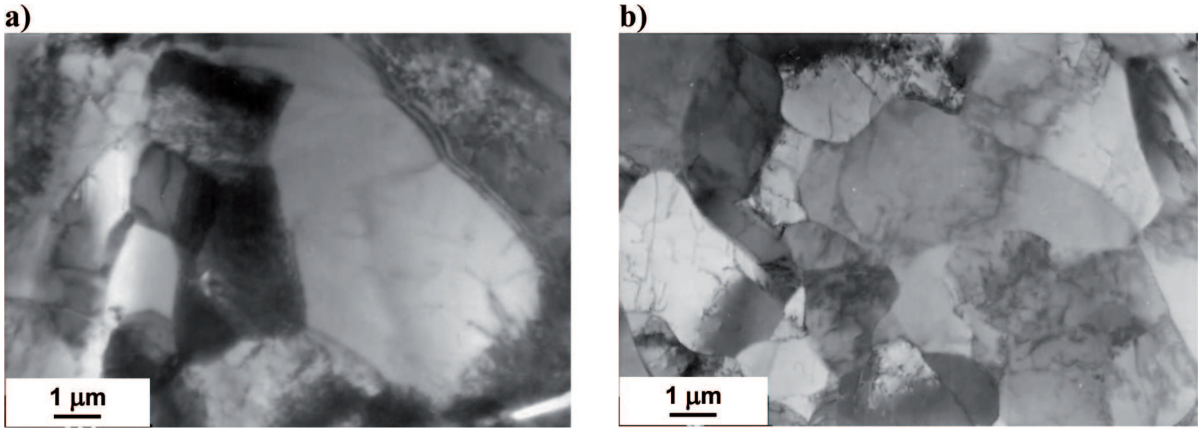

Fig. 9. Substructure of alloy: a) ***“1”***, b) ***“2”*** after deformation at the temperature of 700°C

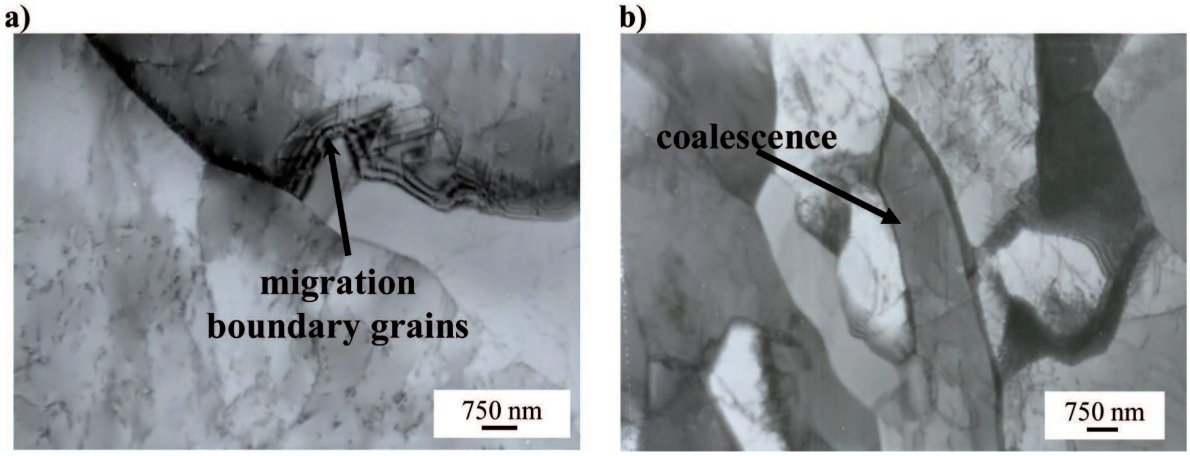

Fig. 10. Substructure of alloy: a) ***“1”***, b) ***“2”*** after deformation at the temperature of 900°C

4. Conclusions

This research confirmed the influence of Cr addition on the hot deformation of Fe-28 at.% Al alloy. Obtained flow stress values for alloy “2” (with Cr addition) compared with flow stress value in alloy “1” (without Cr) indicated, that Cr as a substitute element influences solution hardening. Moreover Cr addition causes changes in the mechanism of rebuilding the microstructure of the investigated materials. In alloy “1” the dominant mechanism of microstructural changes is dynamic recrystallization whereas in the case of alloy “2”, it is recovery process. For both alloys the process of rebuilding the microstructure is initiated at the temperatures higher than 900°C.

Acknowledgements

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