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High-temperature mechanical properties of Zr alloyed Fe_3Al-type iron aluminide

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Abstract

High-temperature tensile and creep tests of a Fe_3Al-type iron aluminide with Zr addition were performed. Very pronounced influence of annealing at 1150 °C/2 h namely on creep properties (time to rupture − TTR, and minimum creep rate − MCR) was observed. The nature of dislocation obstacles was described using TEM. The behaviour of the material was explained by a combined effect of solid solution and precipitation hardening.

Keywords: A. Iron aluminides, based on Fe_3Al; B. Mechanical properties at high temperatures

1. Introduction

Ordered intermetallic alloys exhibit generally good high-temperature strength, low density, and environmental resistance. Especially, the chemical resistance at high temperatures is a great advantage of these materials (see e.g. Refs. [1,2]) and the interest in these materials is growing in the field of high-temperature applications. However, it is necessary to improve further their high-temperature tensile and creep strength. To follow this idea, the high-temperature properties of iron aluminides containing either TiB_2 or Ce were studied [3,4]. It was documented that both the creep and tensile strength at temperatures 600−800 °C can be substantially enhanced by annealing at 1150 °C. The precipitates formed during cooling from the annealing temperature 1150 °C and remaining stable at the testing temperatures 600−800 °C were suggested to be responsible for this strength increase. Very recently Morris et al. [5,6] summarized the results of numerous authors studying the high-temperature tensile and creep properties of iron aluminides. Main attention was paid to the influence of second phase particles formed in Fe_3Al-type iron aluminides alloyed with various additives. This summary documents clearly that the addition of Zr brings the best results. Zirconium was used by Alven and Stoloff [7,8] to modify disordered FAPY and iron aluminides FA129 (both developed by the Oak Ridge National Laboratory) and to improve their tensile and fatigue properties. Simultaneously, a beneficial effect of Zr (up to 1 at%) was observed on the ductility and on the fatigue crack growth behaviour. The positive effect of Zr can be explained by the improved grain boundary strength and by trapping of hydrogen by zirconium rich precipitates. The formation of Zr-rich particles depends strongly on the zirconium to carbon ratio. Similar results were also found by Prahl et al. [9]. Very recently two papers have appeared dealing with the structure and mechanical properties of the alloys within the Fe−Al−Zr ternary system [10,11]. Unfortunately, most of the information presented there is related to the compositions very different from that tested in this paper.

It is the purpose of this paper to present recent results with a Zr alloyed Fe_3Al-type iron aluminide alloy. Compared to

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previous results on the zirconium alloyed iron aluminides (room temperature properties of the disordered FAPY [7] and Zr alloyed FA129 [9], high-temperature creep properties of ferrite with 16 at% Al alloyed with Zr [12]), the present paper deals with the high-temperature tensile and creep properties of the Fe_3Al-type aluminide with zirconium addition.

2. Experimental

The composition of the alloy used for the experiment was as follows (at%):

Al	Cr	Zr	C	Fe
31.5	3.5	0.25	0.19	Balance

The alloy was prepared in the vacuum furnace and cast under argon in the Research Institute for Metals in Panenské Břežany, Czech Republic. The casting (dimensions $400 \times 120 \times 38$ mm) was hot rolled to the final thickness of 13 mm at 1200 °C in several steps with 20% reductions for each pass. The rolled piece was heated after each second pass and the temperature did not decrease under 1000 °C during the whole rolling period. After final pass, the slab was quenched from the temperature at least 1000 °C into oil. One set of samples was additionally annealed at 1150 °C/2 h after rolling and air cooled.

The samples for tensile and creep tests (the gauge length 25 mm, the sample diameter 5 mm) were prepared with the axis parallel to the rolling direction. The tensile tests were performed at temperatures 600 and 700 °C in air using the deformation machine INSTRON 1186. The initial strain rate was $1.5 \times 10^{-4}\ s^{-1}$. The creep experiments were carried out under constant load at temperatures between 600 and 800 °C. The temperature was kept with the accuracy of 3 °C during both tests.

The microstructure was studied using both the light optical (LOM) and transmission electron (TEM) microscopy. Nikon Epiphot 200 for LOM and JEOL 2000 FX equipped with AN10000 EDX analyser for TEM were used. The preparation of samples for LOM consisted of polishing using Struers OP–S solution and etching in the solution of 100 ml H_2O + 50 ml 38% HCl + 5 g Fe_3Cl. The samples for TEM were electrolytically twin-jet polished in 20% solution of HNO_3 in methanol at −30 °C.

3. Results

3.1. Initial microstructure

The initial grain structure both in the as-rolled and annealed state is shown in Fig. 1. It is obvious, that the recrystallization took place during annealing at 1150 °C/2 h. The elongated grains present in the as-rolled material are replaced by nearly equi-axed polygonal grains.

The detailed investigation of the microstructure of both types of samples was carried out by TEM. Extremely inhomogeneously distributed particles of two typical sizes were found in the as-rolled sample:

- middle size particles with typical dimensions of 100 nm (Fig. 2);
- very rare coarse particles with dimensions reaching 500 nm (see e.g. the microstructure after creep in Fig. 9).

Both types of these particles were identified by SAD as a cubic Zr–C phase. The WDX analysis carried out on coarse particles revealed Zr and C only. The middle size particles disappeared (dissolved) during annealing at 1150 °C/2 h, and only the coarse ones remained being still inhomogeneously distributed (for details see Ref. [13]).

3.2. Deformation experiments

The results of tensile tests performed at 600 and 700 °C with both as-rolled and annealed samples are given in Fig. 3. A pronounced increase of the yield stress and ultimate strength caused by annealing at 1150 °C/2 h was observed especially at 700 °C. This strength increase is accompanied by a remarkable decrease of ductility. Similar behaviour is typical also for the Fe_3Al-based alloy containing TiB_2 [3,4].

The minimum creep rate (MCR) of the as-rolled material measured at various temperatures is summarized in Fig. 4. MCR increases with increasing load at all temperatures

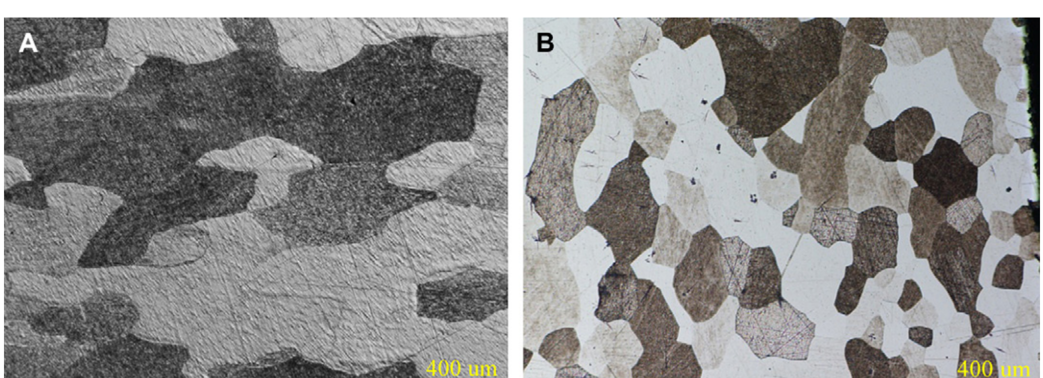

Fig. 1. (a) The structure of the material after rolling. (b) The structure of the material after rolling and annealing at 1150 °C/2 h.