HIGH-TEMPERATURE MECHANICAL BEHAVIOURS OF IRON ALUMINIDES WITH YTTRIUM ADDITION

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Abstract

Intermetallic compounds have many desirable properties as matrix-compatible 2-phase structural materials with good mechanical properties, and low diffusion rates due to their ordered structure. However, these materials show low strength at high temperatures and low ductility due to hydrogen embrittlement at room temperature. High-temperature strength and creep resistance of Fe3Al alloys are tried to be improved by alloying processes. In the present study, the effect of Tungsten addition on room temperature and high-temperature strength properties was investigated by applying a compression test at room temperature and 600 °C to Fe-28Al and Fe-28Al-0.1Y alloys. With the increase in tungsten content, an increase in strength was achieved.

Keywords: *intermetallics, iron aluminides, high temperature, yttrium*

1. INTRODUCTION

Intermetallic compounds have a combination of physical and mechanical properties such as high strength, high melting point, low density, good oxidation and creep resistance. However, the brittleness of intermetallics at room temperature has limited their structural use. Since the 1980s, significant progress has been made in improving the ductility of various intermetallic compounds such as Ni_3Al, TiAl, Fe_3Al, FeAl and Fe–Co–V alloys through alloying, machining, and microstructure control. Meanwhile, many other compounds have been found to have unique physical properties such as superconductivity, hydrogen storage capacity, high saturation, magnetization, etc. In Fe_3Al alloys, room-temperature ductility and high-temperature strength can be improved by controlling the composition and microstructure[1,2].

The crystal structure of Fe_3Al regular intermetallic compounds is DO3, and they have attracted considerable attention in recent years due to their high potential. The fact that Fe_3Al alloys have high oxidation, corrosion resistance, relatively low cost and low density compared to other alloys has further increased the interest in these alloys. The most important factors that make it difficult for Fe_3Al alloys to be applicable building materials are room temperature ductility (<5%, but >20% above 200°C and high-temperature strength)[3,4]. The presence of the third element such as Cr, Mo, Zr, Nb, C and B in the structure can suppress the phase transformation to the (DO3) structure.

According to the phase diagram of the binary Fe-Al system, there are four solid phases in the composition range from 0 to at.54% Al. Two regular compounds are formed in the range of at. 0–54% Al composition. Fe_3Al with DO3 order is in equilibrium at about at.27% Al content below 552ºC. FeAl with B2 order is formed in the range of at.23-54%Al depending on the temperature (between 552-800ºC). (Fig. 2). α + DO3 biphasic structure can be obtained in suitable aluminum amounts (figure 1) [5].

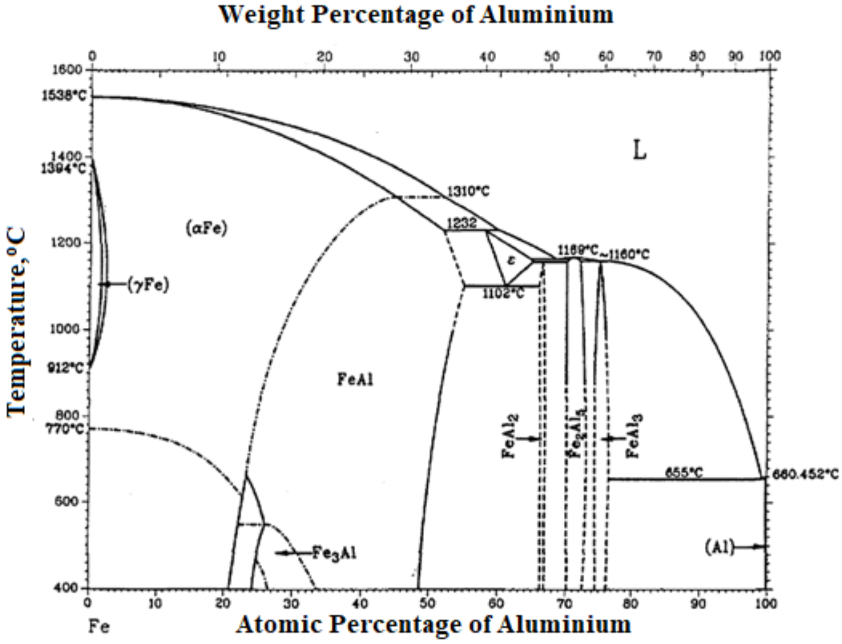

Figure 1. Fe-Al phase diagram[5].

In this study, the effect of 0.5-1.0-1.5% tungsten addition on the room temperature and high-temperature compressive strength properties of Fe_3Al(Fe-at.%28Al and Fe-at.%28Al-at.%0.01Y) alloy was investigated.

2. MATERIALS AND METHODS

2.1. Materials

Elements of 99.97% purity Fe, 99.7% purity Al, 99.5% purity W, and 99.9% purity Y elements were used in the preparation of the alloys. The alloys whose compositions are given in Table 1 were cast in an arc furnace under argon gas in a water-cooled copper mold. A homogeneous distribution was achieved by melting three times and then casting. Changes in the amount of weight after casting were controlled. The prepared alloys were homogenized for 17 hours at 1000ºC.

Table 1. Chemical compositions (at.%) of the alloys

Alloy	Al	Cr	W	Y	Fe
Fe-28Al	28	-	-	-	Balance
Fe-28Al-0.5W	28	-	0.5	-	Balance
Fe-28Al-1W	28	-	1	-	Balance
Fe-28Al-1.5W	28	-	1.5	-	Balance
Fe-28Al-0.5W-0.1Y	28	-	0.5	0.1	Balance
Fe-28Al-1W-0.1Y	28	-	1	0.1	Balance
Fe-28Al-1.5W-0.1Y	28	-	1.5	0.1	Balance

2.2. Methods

The parts cut from the obtained alloys were grounded with SiC abrasives and polished using 3 and 1 µm diamond pastes. In the etching process of the samples, 5% Nital and Keller etchings were used. Optical microstructure images were obtained using Olympic GX 51 image analyzer and grain sizes were measured.

High-temperature compression tests were applied to the rectangular cross-section specimens prepared in the dimensions of approximately 4 x 2 x 2 mm, using Shimadzu AG-IS device at a strain rate of 0.5 mm/min at 600°C. In the same device, the compression test was applied to the circular cross-section samples of approximately 7 mm in diameter and 12 mm in length at room temperature at a speed of 2 mm/min.

In a study investigating the effect of adding tungsten to Fe-28Al (at.%) alloys, the alloys were first kept at 1000ºC for 15 hours for homogenization, and then kept at 850ºC for 1 hour for recrystallization, and then subjected to oil quenching. Tensile properties and grain sizes of these alloys are given in Table 2. With the addition of tungsten, the strength of the alloys has been increased and the grain size has been reduced [6].

Table 2. Tensile test data and grain sizes of Fe-28Al and W addition alloys[6].

Alloy	**Room temperature tensile properties** σ_{yield} **(MPa)**	**600 ºC Tensile properties** σ_{yield} **(MPa)**	**Grain Size (µm)**
Fe-28Al	360	267	90
Fe-28Al-0.W	467	338	80
Fe-28Al-1.0W	499	366	60
Fe-28Al-1.2W	510	381	40
Fe-28Al-1.5W	526	403	30

3. RESULTS

According to the microstructure images, the effect of W addition on grain size was the formation of equiaxed grains for 0.5 and 1 W (Figure 2). According to the table, the grain size decreased with the addition of W, but an increase in grain size was observed only with the addition of 1.5W. With the addition of Y, the grain sizes were considerably reduced and the grain shapes changed (Table 3). It is thought that the columnar structure originates from the casting conditions.

Alloy	**Grain Size (µM)**	**Grain Shape**
Fe-28Al	650	columnar
Fe-28Al-0.5W	341.27	equiaxed
Fe-28Al-1.0W	195.67	equiaxed
Fe-28Al-1,5W	832.6x206.4	columnar
Fe-28Al-0.5W-0.1Y	164.48	equiaxed
Fe-28Al-1.0W-0.1Y	187.2	equiaxed
Fe-28Al-1.5W-0.1Y	374.1x277.13	columnar

Table 3. Grain shapes and sizes as a result of compression test of alloys.

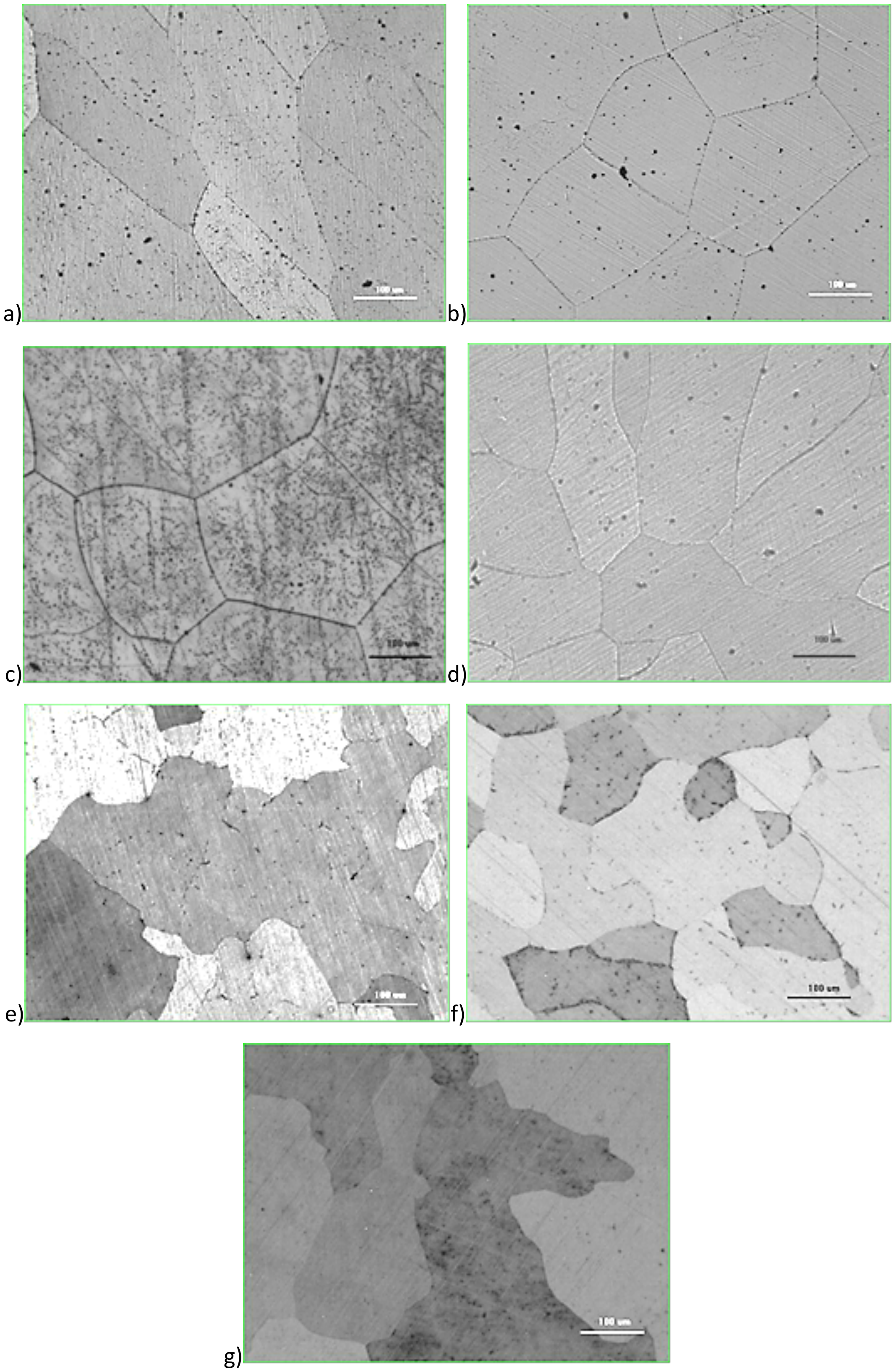

Figure 2. Optical microstructures of the samples, 100X a) Fe-28Al b) Fe-28Al-0.5W c) Fe-28Al-1W d) Fe-28Al-1.5W e) Fe-28Al-0.5W-0.1Y f) Fe-28Al- 1W-0.1Y g) Fe-28Al-1.5W-0.1Y

The results of the compression test applied to the alloys at room temperature at a deformation rate of 2 mm/minute are given in Table 4.

Two samples were tested for each alloy and average values were taken. In Figure 4, examples of some alloys are shown in the calculated compressive yield strength and % elongation diagrams.

Table 4. Compression test results applied at different strain rates

Alloy	**Room temperature Compression**	
	$e_{yield(0.2)}$ (%)	**$\sigma_{yield(0.2)}$ (MPa)**
Fe28Al	1.87	579
Fe28Al0.5W	1.8	553
Fe28Al1W	1.97	562
Fe28Al1.5W	2.06	591
Fe28Al0.5W0.1Y	1.94	604
Fe28Al1W0.1Y	2.11	617
Fe28Al1.5W0.1Y	2.23	628

The strength of the Fe-28Al alloy decreased with the addition of 0.5 and 1 tungsten, but with the addition of 1.5W, the strength increased slightly (Table 3). Addition of Y, the grain size and strength both decreased and the grain shape changed.

As a result of the high-temperature compression test applied to the alloys, when the 0.2 yield strengths are compared, it is seen that the strength values increase with the addition of tungsten element, while the increase in these strength values is higher with the addition of yttrium element. In the binary alloy containing W, a decrease in strength was observed, similar to the literature [7]. With the addition of element Y to these alloys, an improvement in strength was achieved, while a slight decrease was observed in strength with the increase of the amount of W element (Figure 3, Table 5).

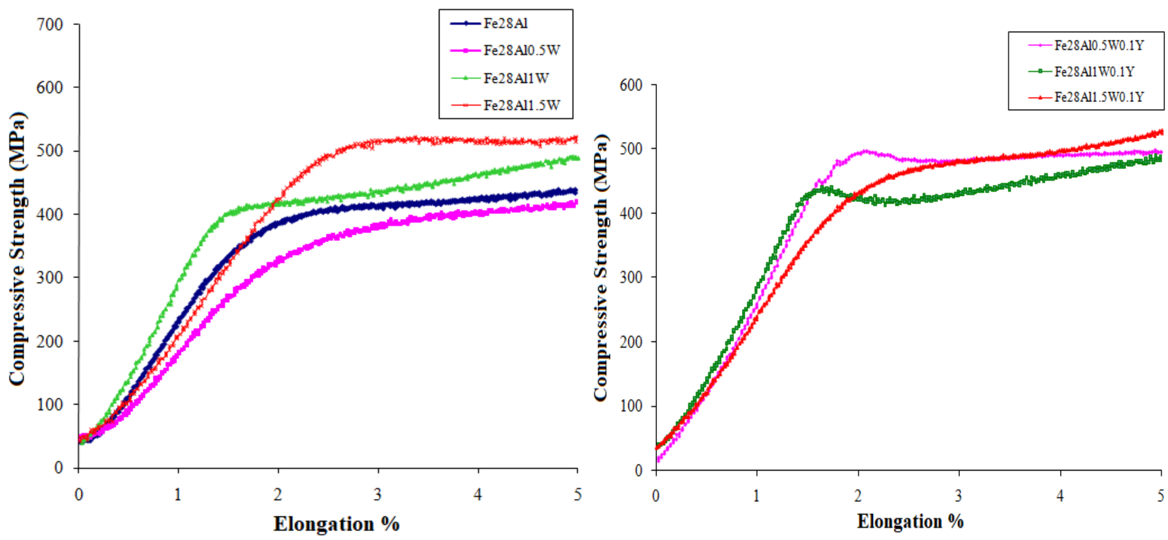

Figure 3. Yield strength-% elongation diagrams obtained as a result of the high-temperature compression test applied to the alloys at 600 ºC a)Fe-at.%28Al and Fe–at.%28Al-at.%(0.5-1.5)W b) Fe-at.%28Al-at.%(0.5-1.5) W–at.%0.1Y.

Table 5. 0.2 yield strengths as a result of the compression test applied at 600°C

Alloy	**σ yield (0.2) (MPa)**	**Alloy**	**σ yield (0.2) (MPa)**
Fe28Al	350	**Fe28Al0.5W0.1Y**	460
Fe28Al0.5W	332	**Fe28Al1.0W0.1Y**	440
Fe28Al1.0W	408	**Fe28Al1.5W0.1Y**	434
Fe28Al1.5W	467		

4. DISCUSSION

The W element seems to increase the high-temperature strength due to solid solution strength and increasing the residence time of the DO3 structure, which is known to be more durable. It has been said that hydrogen embrittlement of iron aluminides can be reduced with passivating elements such as Cr, Ni, Mo, W, V, Nb, Ta, Si, Ti, Zr, and Al [8]. Accordingly, it is thought that the positive effect of the addition of the W element on the ductility of the material at room temperature may be related to the fact that it is the element that provides passivity. Again, in the literature, it has been attributed to the fact that Mo, Nb, and Ti elements provide solid solution strengthening and increase room temperature ductility, as they are passivating elements [9]. W element is also thought to increase ductility along with solid solution strengthening.

CONCLUSIONS

In alloys containing W, the strength increased due to solid solution strengthening and reduction in grain size. The W element increases the high-temperature strength due to the solid solution strengthening and increasing the residence time of the DO3 structure, which is known to be more durable. The best strength values were obtained in W and Y added Fe-28Al alloy at room temperature and high temperature.

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