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Mechanical behaviors of Fe_3Al with vanadium addition①

LOU Bai-yang(楼白杨)
(College of Mechanical Engineering,
Zhejiang University of Technology, Hangzhou 310014, P. R. China)

[Abstract] The effect of V on mechanical property of Fe_3Al-based ordered alloy was studied. The results show that V can refine grains which improves strength and plasticity of Fe_3Al. As contrasted with transgranular fracture of Fe_3Al at room temperature, the Fe_3Al containing V has intergranular and transgranular cleavage mixed fracture mode which is gradually changed into void fracture as tensile temperature increases. The DO_3-ordered Fe_3Al with V has maximum tensile strength at 700 ℃ which is much higher about 200 ℃ than that of DO_3-ordered Fe_3Al without V.

[Key words] DO_3-ordered Fe_3Al; vanadium; mechanical properties
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1 INTRODUCTION

The iron aluminide Fe_3Al occurs within the range of 24% ~ 32% (mole fraction) aluminum. It has three possible structures: BCC, which is stable at about 760 ℃, imperfect B_2-order structure at 540~760 ℃, and DO_3-order structure which is stable below the critical temperature of 540 ℃. DO_3-ordered Fe_3Al alloys have excellent oxidation resistance, good high temperature strength, relatively low density and cost. These advantages have led to consideration for structure applications at elevated temperatures[1]. However, the lack of ductility at room temperature and a sharp drop in strength above 600 ℃ have been major obstacles to their engineering applications. Recently many research reports showed that alloying elements can improve their mechanical properties. For example, addition of alloying elements such as Cr, Mn and Ce can improve their ductility at room temperature[2~7], and significant increase of yield strength of the alloys above 600 ℃ results from adding Cr, Mo, Ni or Si. The purpose of this paper is to report the effect of V on the mechanical properties of DO_3-ordered Fe_3Al at room and elevated temperatures.

2 EXPERIMENTAL

2.1 Materials and method

Two DO_3-ordered Fe_3Al alloys were studied. They were Fe-28% Al (mole fraction) and Fe-28% Al-1.5% V (mole fraction). The alloys were melted in a vacuum induction furnace and cast into moulds. After homogenized at 950 ℃ for 4 h, the alloys were hot-rolled at 950 ℃ and warm-rolled at 650 ℃ from 7 mm to 0.7 mm. The rolled sheets were cleaned in a solution of 95% H_2O and 5% hydrochloric acid to remove surface oxide layer. Tensile samples with a gauge section of 0.7 mm × 5 mm × 20 mm punched from the sheet and then heat treated for 1 h in air at 800 ℃ for recrystallization and at 450 ℃ for DO_3 ordering. The tensile samples were tested at 25 ~ 850 ℃ in air at a strain rate of $3.3\sim 5\times10^{-2}\ s^{-1}$ on an LX-250 kg tensile machine. The fracture surfaces were examined by DXS-X2 scanning electron microscope (SEM).

2.2 Mechanical properties

Tensile test results are shown in Fig. 1. It is known from Fig. 1 that both alloys have the characteristic of brittle material at room temperature, but Fe_3Al has lower strength than Fe_3Al with V. The DO_3-ordered Fe_3Al has the highest tensile strength at about 500 ℃. Its tensile strength increased with increasing temperature below 500 ℃ and decreased greatly with increasing temperature above 500 ℃. Necking occured in the Fe_3Al tensile samples at about 600 ℃. Addition of V could improve the strength of Fe_3Al at room temperature. The tensile samples of Fe_3Al with V showed that the tensile strength increases when the temperature is up to 700 ℃. Its ductility increased with temperature. The change of yield strength was more complicated for the alloys. The Fe_3Al containing V had change in yield strength similar to Fe_3Al, as shown in Fig. 1(b), but its yield-strength peak is about 200 ℃ higher than that of the alloy without V addition. This phenomenon was explained by order change in the alloys. Stoloff et al[8] reported that the unusual strength-temperature relation was connected with degree of ordering in DO_3 Fe_3Al. The increase of yield strength was related exactly to the change in degree of ordering from 0.8 to

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0 as the temperature increases from about 350 ℃ to 550 ℃. The increase of yield strength responds to super dislocations within the range of temperatures and ordinary unit dislocations above about 550 ℃. The yield strength peak was observed at the position of transition from unit dislocations to super dislocations. Mekhrabov et al's research result showed that V raised the temperature at which DO_3-ordered structure exists[9]. Because V raised DO_3-existing temperature, the increase of yield strength related to a mechanism of super dislocations could been retained at higher temperature, which made unusual strength-temperature relation of DO_3 Fe_3Al be at above 550 ℃. SEM observation in our experiment showed that V element distributed uniformly in the alloy and the gain sizes were smaller in the alloy with V than that in the alloy without V. It is suggested that V addition improves mechanical properties of DO_3-ordered Fe_3Al alloy.

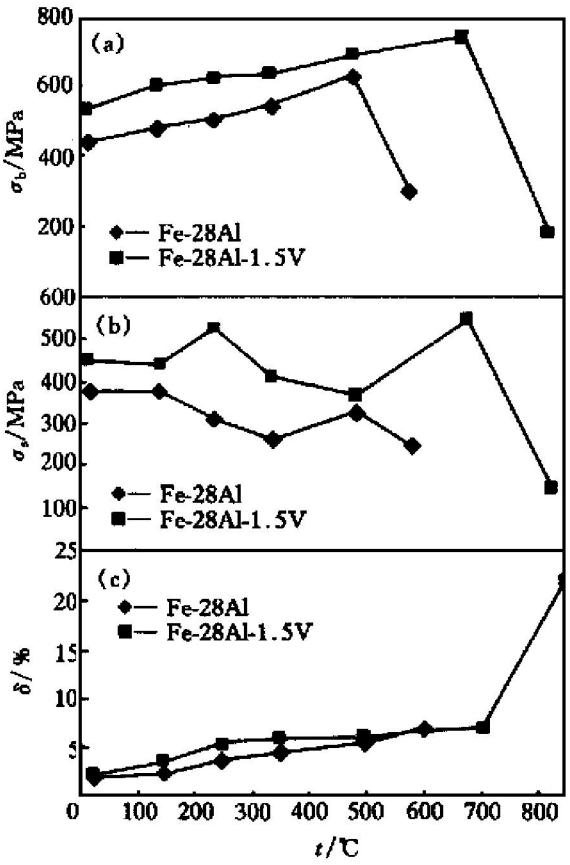

Fig. 1 Mechanical property —temperature curves of alloys

2.3 Fracture mode

The tensile fracture modes of alloys were observed by SEM. The results showed the differences in fractures, crack shapes, and distribution in the alloy with and without V, as shown in Fig. 2. DO_3-ordered Fe_3Al without V has transgranular cleavage fracture mode at room temperature. It can be seen from Fig. 2(a) that cleavage planes are large and there are many parallel secondary transgranular cracks from gain boundaries to inside grains, indicating easy crack propagation during the fracture of Fe-28Al alloy. As temperature increased to 350 ℃, the fine nests occured near grain boundaries. The fracture mode transformed from transgranular cleavage to void at 500 ℃, as shown in Fig. 2(b). On the other hand, the DO_3-ordered alloy with V had transgranular cleavage-intergranular fracture mode at room temperature, as shown in Fig. 2(c). Its cleavage planes are small and consisted of small cleavage steps and ripple ridges, which suggests higher cleavage strength in the alloy with V, compared with the alloy without V. The proportion of intergranular fracture increased with temperature in the alloy with V. The fine voids occurred at grain boundaries as temperature increased to 500 ℃, as shown in Fig. 2(d) and complete void fracture took place at 700 ℃. The optical observation of crack propagation was also done under tension. The cracks in the alloy with V additive appeared zigzag and there are a lot of slender slip lines around the tip of crack while the crack looked rather straight and no obvious trace of plastic deformation at crack tip was found in the alloy without V. It is indicated that the addition of V can refine grain and then improve the mechanical property of the alloy and is suggested that crack propagation is somehow retarded due to plastic deformation arising from the emission of dislocations at crack tip if Fe_3Al alloy contains V additive.

In general, there are two types of fracture in alloys: brittleness and plasticity. The brittle fracture can be transgranular or intergranular according to related value of cleavage strength to boundary strength. If cleavage strength is lower than grain boundary strength, the cleavage fracture occured, and vice versa. The trend of intergranular fracture is intensified with temperature. During tension, dislocations gather and merge to form voids in grain boundaries in alloy. The voids grow and join, resulting in intergranular fracture. If voids occur at higher temperature, they could exist in grain boundaries and grain inside, which tend to occur void fracture. Because DO_3-ordered Fe_3Al without V has low cleavage strength and its super dislocations cross slip very difficult, the generation and growth of void could be retarded or limited during tension[10]. As degree of ordering in DO_3 Fe_3Al without V decreases reduced rapidly above 350 ℃, the deformation was controlled by the mechanism which changed gradually from super dislocations to ordinary unit dislocations. It led to increase in cross slip of dislocations and then generation and growth of voids. The fracture mode becomes void type in that condition. Addition of V increased the fracture strength of Fe_3Al and produced some intergranular fracture, which suggested that V increased cleavage strength of Fe_3Al, resulting in larger plastic deformation before fracture, so Fe_3Al containing V

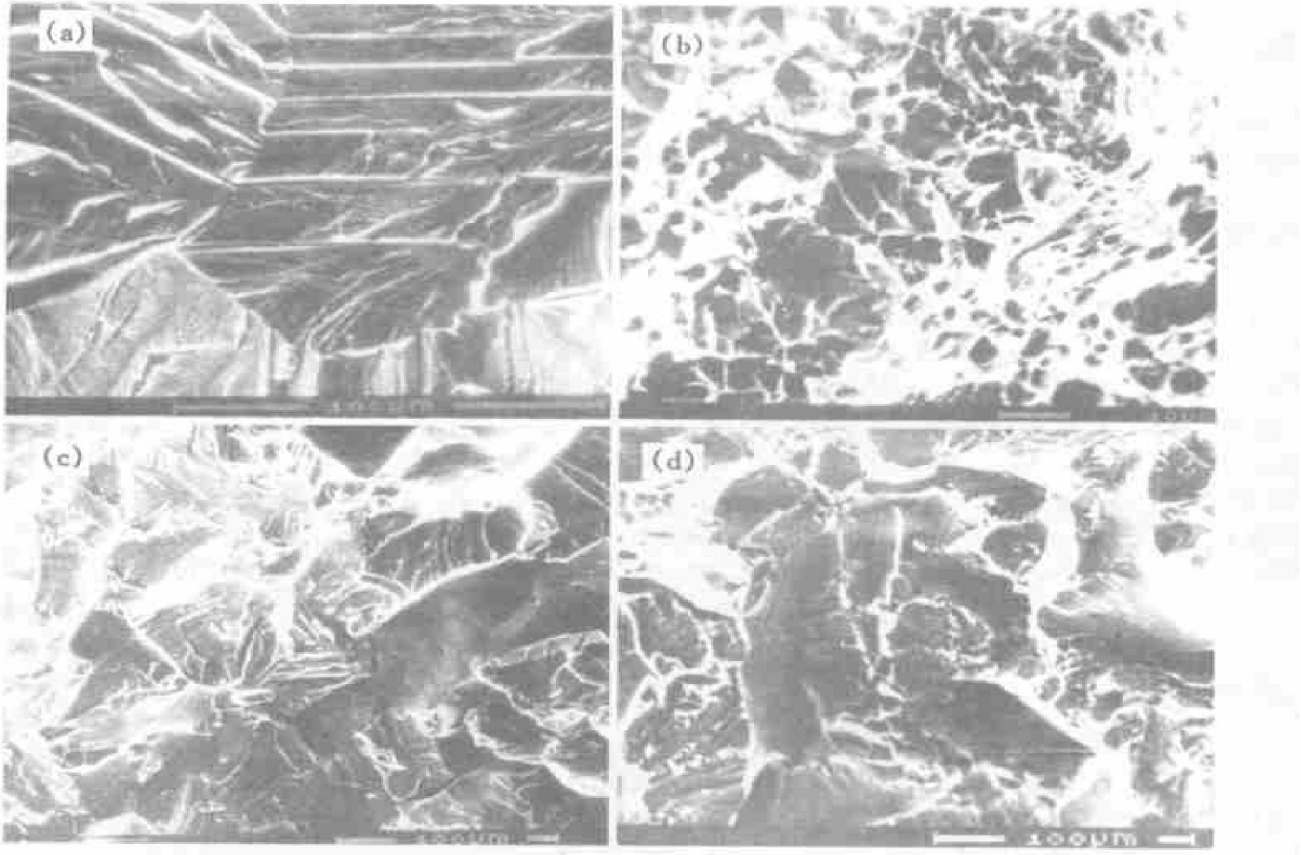

Fig. 2 Fracture surfaces of Fe-28Al alloy at 25 ℃ (a) and at 500 ℃ (b), Fe-28Al-1.5V alloy at 25 ℃ (c) and at 500 ℃ (d)

had better ductility at room temperature. Besides, V increases DO_3-existing temperature and retained DO_3-ordered structure at higher temperature may retard void fracture to take place at higher temperatures than Fe_3Al without V.

3 CONCLUSIONS

1) V refines grains and changes DO_3-ordered Fe_3Al fracture mode from transgranular cleavage to transgranular cleavage-intergranular mixed type.

2) V raises the temperature related to DO_3-ordered Fe_3Al strength peak about 200 ℃, which can make DO_3 Fe_3Al alloy to be applied above 600 ℃.

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