DEFORMATION BEHAVIOR OF FeAl INTERMETALLIC ALLOY AT ELEVATED TEMPERATURES①

Li Dingqiang, Lin Dongliang and Liu Yi
Department of Materials Science, Open Laboratory of Education Ministry of China for High Temperature Materials and Tests, Shanghai Jiao Tong University, Shanghai 200030, P. R. China

ABSTRACT The mechanical properties of Fe-36.5% Al (mole fraction) intermetallic alloy at elevated temperatures were measured. The results indicate that the specific elongation of the alloy increases significantly with the temperature increasing from 600 ℃ to 1000 ℃ and the maximum of specific elongation is up to 115% when the alloy is deformed at 1000 ℃. The dislocation features in the alloy were also investigated by transmission electron microscopy (TEM). There exist not only a large number of gliding dislocation lines but also a number of helical dislocations in FeAl alloy after deformed at elevated temperatures. All of these dislocations have a Burgers vector of ⟨111⟩. The climb motion as well as the glide motion of dislocations with ⟨111⟩ Burgers vector is responsible for a good ductility of FeAl alloy deformed at elevated temperatures.

Key words FeAl intermetallic alloy mechanical property dislocation

1 INTRODUCTION

Although B_2 structural FeAl intermetallic alloy has an excellent high temperature oxidation resistance and relative good high temperature strength, there are rather few researches on high temperature mechanical properties due to its difficulty to fabrication. It was reported that the ductility of FeAl alloy decreases rapidly with temperature increasing when the temperature is above 600~700 ℃[1-4].

Research results showed that the ductility of FeAl alloy increases rapidly with temperature increasing during 600~1000 ℃. It is generally known that there is a slip system transitting from ⟨111⟩{110} to ⟨100⟩{110} with temperature increasing, and there is only ⟨100⟩{110} slip system existing in FeAl alloy when deformed at elevated temperatures, which are above the temperature of slip system transition[1, 2]. It was discovered that the dislocations with ⟨111⟩ Burgers vector still exist in FeAl alloy when deformed at 900 ℃.

2 EXPERIMENTAL

An alloy with composition of Fe-36.5% Al (mole fraction) was prepared by arc melting under argon using commercial pure iron (99%) and aluminum (99.99%). The alloy ingots were homogenized for 24 h at 1000 ℃, then hot rolled at 1050~950 ℃, with a total reduction of 50%~60%. Tensile specimens with a gauge section of 12.0 mm × 3.2 mm × 1.0 mm were cut from the ingots by spark-erosion machine. All specimens were heated at 820 ℃ for 1 h for recrystallization, and then held at 700 ℃ for 2 h for ordering. Tensile tests were carried out on a SHIMADZU AG-100 kNA testing machine with a furnace. All specimens were strained to fracture under tension at a constant cross-head speed of $10\ mm \cdot min^{-1}$ (initial strain rate is about $1.39 \times 10^{-2}\ s^{-1}$) in air at temperatures from room temperature to 1000 ℃. Testing temperatures were controlled using a thermocouple directly attached to the gauge section of specimen. Yield strength was determined using the 0.2% offset method

① Project 59331010 supported by the National Natural Science Foundation of China
Received Jun. 14, 1997; accepted Nov. 10, 1997

when yielding was continuous. Specific elongation was calculated from the load-time chart agreed closely with that determined by the measured change in the length of specimen. TEM foils were cut from the gauge section of a specimen of FeAl alloy which was additionally annealed at 1 000 ℃ for 24 h for full recrystallization, strained to 1% plastic deformation at 500 ℃ and 900 ℃ respectively, and then cooled quickly to maintain the dislocation configuration. The foils were ion-beam milled using a Gatan Model 600 with a gun voltage of 5 kV and a current of 1 mA. The dislocations were imaged using two-beam conditions in an H-800 electron microscope operated at 200 kV. Dislocation analyses were performed using the $\boldsymbol{g} \cdot \boldsymbol{b} = 0$ invisibility criterion.

3 RESULTS

Graph of specific elongation and yield stress as a function of temperature are shown in Fig. 1. In general, the ductility of FeAl alloy increases slightly from room temperature to 600 ℃, however, it increases significantly when deformation temperature is above 600 ℃. When deformation temperature is 1 000 ℃, the specific elongation is up to 115%. The yield stress decrease slightly from room temperature to 500 ℃. There is an abnormal yield effect in the temperature range of 500~ 700 ℃, above 700 ℃ the yield stress decreases drastically.

The dislocation features around direction [112] of Fe-36.5Al (mole fraction, %) alloy deformed at temperature of 500 ℃ examined by TEM is shown in Fig. 2. The results show that the defects are mainly dislocation lines as well as a few of dislocation dipoles (see the arrows). The dislocation labeled "1" is in contrast for $\boldsymbol{g} = \bar{1}\bar{1}0$ (Fig. 2(a)), but is out of contrast for $\boldsymbol{g} = \bar{1}10$ (Fig. 2(b)) and $\boldsymbol{g} = 011$ (Fig. 2(d)). According to the $\boldsymbol{g} \cdot \boldsymbol{b} = 0$ invisibility criterion and common knowledge of usually dislocations of ⟨111⟩ and/or ⟨100⟩ Burgers vectors existing in FeAl alloys, the Burgers vector of the dislocation labeled "1" is $[11\bar{1}]$. On the analyses above, the dislocation labeled "2" is in contrast for $\boldsymbol{g} = \bar{1}01$ (Fig. 2(c)) and $\boldsymbol{g} = 011$ (Fig. 2(d)), but is out of contrast for $\boldsymbol{g} = \bar{1}\bar{1}0$ (Fig. 2(a)) and $\boldsymbol{g} = \bar{1}10$ (Fig. 2 (b)), thus the Burgers vector of the dislocation labeled "2" is [001]. The analyses of some dislocations are listed in Table 1. From the results it was found that the dislocations with a ⟨111⟩ Burgers vector and with a ⟨100⟩ Burgers vector are all glissile.

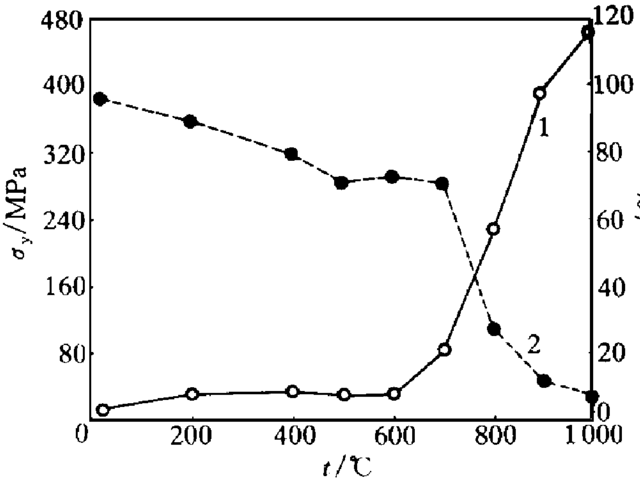

Fig. 1　Graphs of specific elongation (ε) and yield stress (σ_y) as a function of temperature for FeAl alloy

1—ε; 2—σ_y

Table 1　Values of $\boldsymbol{g} \cdot \boldsymbol{b}$ under different two-beam conditions

Fig. No.	$\boldsymbol{g}$	Burgers vector $\boldsymbol{b}$ and dislocation No.			
		±[111] –	$\pm[11\bar{1}]$ 1, 4	$[1\bar{1}1]$ –	±[001] 2, 3
2(a)	$\bar{1}\bar{1}0$	±1	±1	0	0
2(b)	$\bar{1}10$	0	0	±1	0
2(c)	$\bar{1}01$	0	±1	0	±1
2(d)	011	±1	0	0	±1

Fig. 3 shows the helical dislocations (see the areas labeled "*A*") and dislocation loops (see the areas labeled "*B*") in the FeAl alloy deformed at 900 ℃. There is a large number of point defects in the Fe-36.5Al (mole fraction, %) alloy due to its composition deviated from stoichiometry heavily and many Al sites being empty[5]. These point defects aggregate and then form the square dislocation loops with a ⟨100⟩ Burgers vector. The concentration and activity of point defects

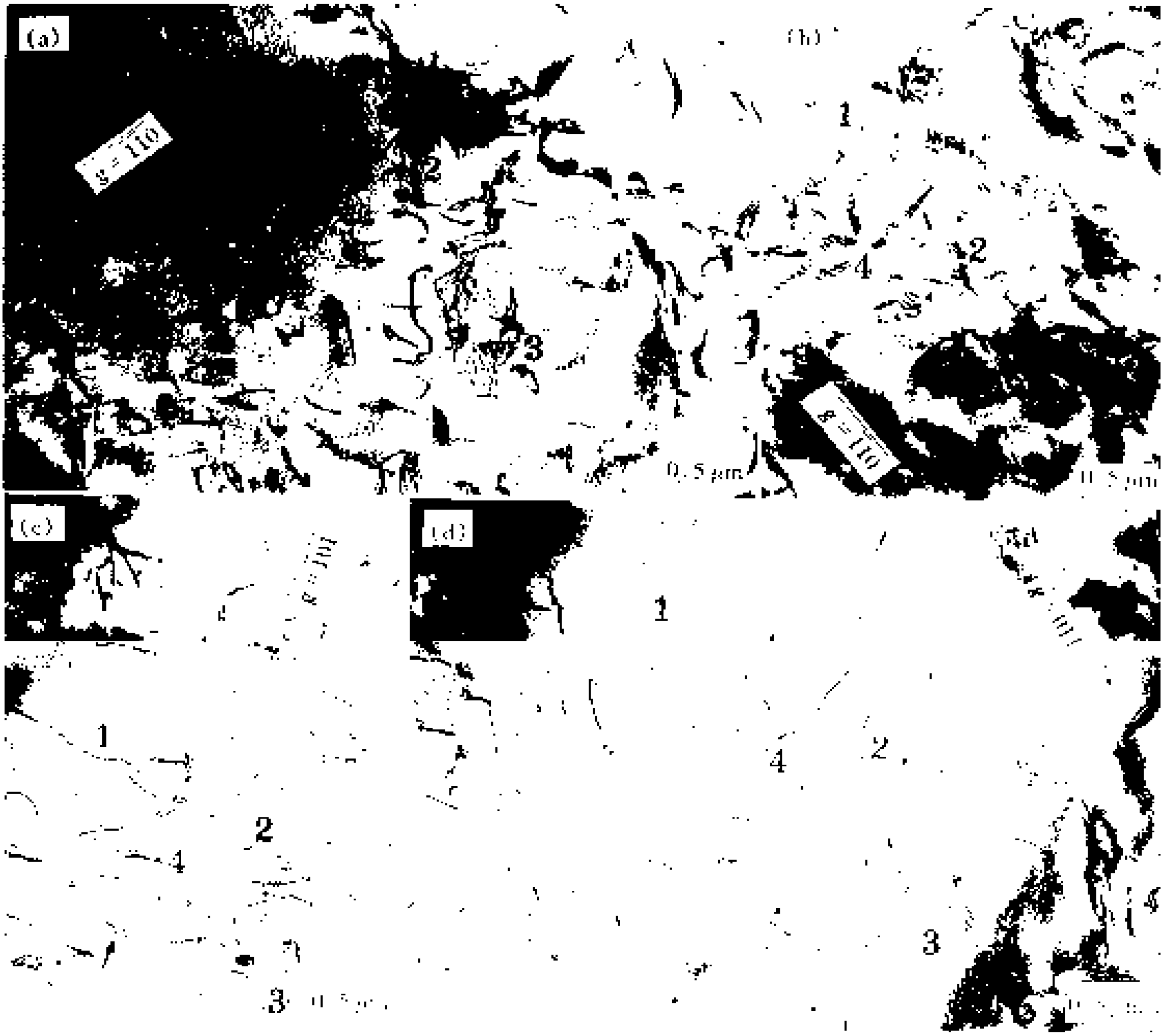

Fig. 2 TEM micrographs showing dislocation configurations in FeAl alloy deformed at 500 ℃
(Taken under different two-beam conditions)

and vacancies are beneficial to the climb of dislocation during deformation at elevated temperatures because concentration and activity of point defects and vacancies increase with the temperature increasing. When deforming at elevated temperatures, a thermal fluctuation or internal stress can cause a small deviating from screw orientation which develops edge components, at last these edge components can initiate helix formation[6]. The motion of jogs of screw dislocations with 〈111〉 Burgers vector produces the zigzag configuration, where all segments have developed some edge component. The signs of the edge components differ, so that they move in different directions as they climb by vacancy absorption. In our study, the discovery of a large number of helical dislocations existing in FeAl alloy indicates that the climb is the main motion way of the dislocations when FeAl alloy deformed at elevated temperature.

There are not only helical dislocations and dislocation loops but also a large number of gliding dislocations in FeAl alloy when deformed at 900 ℃, as shown in Fig. 4. The Burgers vector

Fig. 3　TEM micrograph showing helical dislocations and dislocation loops in FeAl alloy deformed at 900 ℃

of these gliding dislocations is 〈111〉 using $\boldsymbol{g} \cdot \boldsymbol{b} = 0$ invisibility criterion. The result shows that the glide of the dislocations with 〈111〉 Burgers vector also exists in FeAl alloy besides the glide of the dislocations with 〈100〉 Burgers vector, even the deformation temperature is as high as 900 ℃.

4　ANALYSES AND DISCUSSION

The deformation behavior of FeAl in a range from room temperature to 700 ℃ is similar to that reported by Baker and Gaydosh, *et al*[3, 4]. However, there are different results between ours and theirs when FeAl alloy' s deformation temperature is above 600 ℃. With the temperature increasing, the specific elongation increases in our study but it decreased drastically in their studies. It was thought that cavitation took place during deforming at elevated temperatures, thus resulted in the alloys′ fracturing and failing. It was observed that a great amount of cavities appeared in the surface of the deformed alloys. However, in our study it wasn' t found any significant cavity in the surface of the deformed alloy, It is thought that the following two aspects lead to the difference:

(1) The amount of cavities in the alloy, which was investigated in our study and prepared by hot-rolling, is much less than that in the alloy prepared by powder metallurgy;

(2) The grain size of about 400 μm in the investigated alloy of our study is much larger than that of ≤20 μm in their studies. The results reported by Sainfort *et al*[7] showed that large grain could constrain the cavitating during high temperature deformation. In the published paper[8] the formation mechanism of helical dislocations and dislocation loops was discussed. It was thought that the helical dislocations with 〈111〉 Burgers vector were formed from the climb of the dislocation with 〈111〉 Burgers vector and the climb was the main motion way of the dislocations of the alloy when deformed at elevated temperatures.

There are not only the helical dislocations with 〈111〉 Burgers vector but also dislocation lines with 〈111〉 Burgers vector in the microstructure of FeAl alloy deformed at 900 ℃. It indicates that even in the temperature as high as 900 ℃ there still exists glide of the dislocation with 〈111〉 Burgers vector besides dislocations with ⟨100⟩ Burgers vector in Fe-36.5Al (mole fraction, %) alloy. This discovery can explain why FeAl alloy obtains a good ductility when it deformed at elevated temperatures. The activation of ⟨111⟩{110} slip system can provide five independent slip systems, which are sufficient for uniform plastic flow in a polycrystalline alloy and result in a good ductility for FeAl alloys when deformed at elevated temperatures. ⟨100⟩{110} slip system is insufficient for uniform plastic flow in a polycrystalline FeAl alloy, so a larger specific elongation occurred in our investigation could not be explained only by the glide of dislocation with ⟨100⟩ Burger vector existing in the alloys.

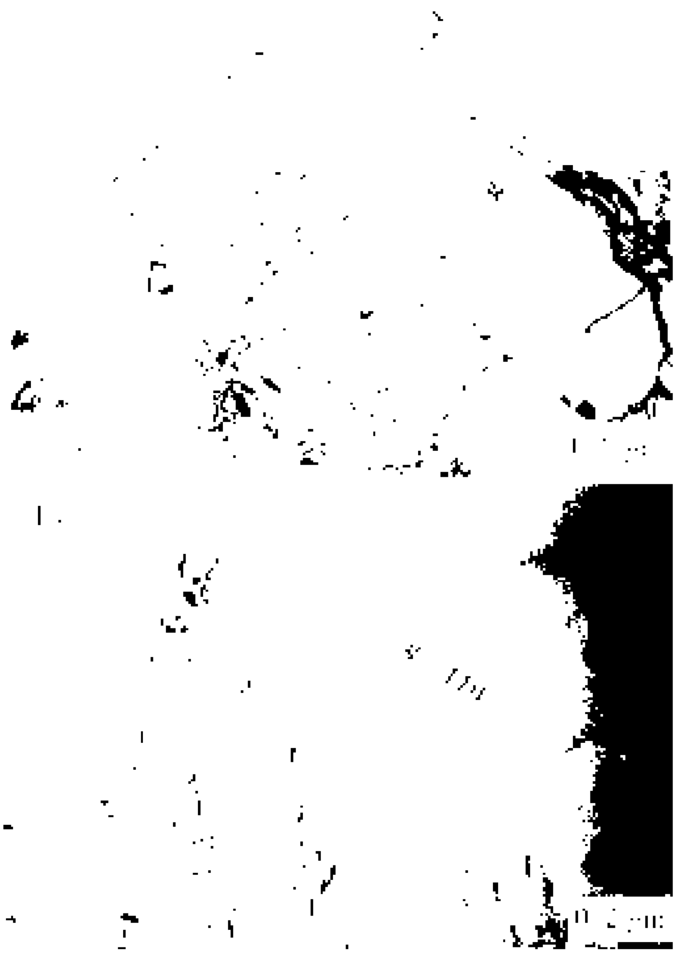

Fig. 4 TEM micrographs showing gliding dislocation lines in FeAl alloy when deformed at 900 ℃

(Taken under different two-beam conditions)

No dislocations with ⟨100⟩ Burgers vector in FeAl alloy were observed when it was deformed at 900 ℃ in present study. From this it can not be thought that there is no dislocation with ⟨100⟩ Burgers vector in the FeAl alloy when deformed at 900 ℃, but it can be thought that the glide motion of dislocations with ⟨111⟩ Burgers vector plays an important role in the ductility of the FeAl alloy when deformed at elevated temperatures.

5 CONCLUSIONS

(1) The specific elongation of the intermetallic Fe-36.5Al (mole fraction, %) alloy increases significantly with the temperature increasing when the alloy tensilely deformed at 25 ~ 1 000 ℃.

(2) The defects of the Fe-36.5Al (mole fraction, %) alloy deformed at 900 ℃ are mainly helical dislocations and straight dislocations, both with Burgers vector of ⟨111⟩. The helical dislocations formed from the climb of dislocations with ⟨111⟩ Burgers vector.

(3) The climb motion as well as the glide motion of dislocations with ⟨111⟩ Burgers vector are responsible for the high ductility of the Fe-36.5Al (mole fraction, %) alloy when deformed at elevated temperatures.

REFERENCES

1 Umakoshi Y and Yamaguchi M. Phil Mag, 1981, 44A: 711- 715.

2 Mendiratta M G, Ehlers S K, Chatterjee D K *et al*. In: Mehrabian R ed. Proc 3rd Int Conf on Rapid Solidification Processing: Materials and Technologies, Gaithersburg: MD, NBS, 1983: 240- 248.

3 Baker I and Gaydosh D J. Mater Sci Eng, 1987, 96: 147- 158.

4 Gaydosh D J, Draper S L and NathaI M V. Metal Trans, 1989, 20A: 1701- 1716.

5 Neumann J P, Chang Y A and Lee C M. Acta Metall Mater, 1976, 24: 593- 604.

6 Hirth J P and Lothe J. In: John Wiley and Sons eds. Theory of Dislocations, 2rd Edition, New York, 1982: 625- 626.

7 Sainfort G, Moururat P, Pepin P *et al*. Mém Sci Rev Metall, 1963, 60: 125- 134.

8 Liu Y, Li D Q, Lin D L *et al*. Acta Metallurgica Sinica, 1995, 31: A24- 28.

(Edited by Huang Jinsong)