Effects of Strain Rate on Tensile Properties of Cr Doped Gamma TiAl

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Cr doped titanium aluminides (TiAl) have relatively good tensile ductility (more than 3%) at room temperature to 500°C, and good high temperature deformability above 600°C. Effects of strain rate on tensile properties of Cr doped TiAl have been investigated at various strain rates and test temperatures. Deformation behavior of Cr doped TiAl obeys classical metal deformation at elevated temperatures, that is $\dot{\varepsilon} = B\sigma^n$. Imaging Plate X-ray Diffraction (IPXRD) observations indicated texture development of α_2/γ lamellar structures. TEM observation revealed that both ordinary dislocations having 2/a<110> type and super dislocations whose Burgus vector was twice larger than ordinary dislocations were activated and interacted each other to make sessile dislocation locks. These dislocation interactions create inverse temperature relationship of flow stresses in TiAl up to 600°C. At higher temperature, both ordinary and super dislocations moved more freely, and dynamic recrystalization occurred. At 800°C dislocation polygonizations were frequently observed and seems to be the most stable configuration. Strain rate sensitivity value *n* of Cr doped TiAl exceeded more than 0.3 above 1050°C, that indicates super-plastic deformation capability at the elevated temperatures.

Keywords: *gamma TiAl, high temperature deformation, strain rate sensitivity factor, texture, dislocation structure*

1. Introduction

Past twenty five years, extensive investigations have been conducted to develop gamma titanium aluminides (γ-TiAl) base intermetallic compounds for the high temperature structural applications, because of their high specific strength at the elevated temperatures[1,2]. Cast γ-TiAl was applied on the turbocharger rotator of the automobile in 2001[3]. However, wrought γ-TiAl has not been commercialized yet. The difficulty in the γ-TiAl practical use originates in lack at both ductility at room temperature and deformability at high temperatures. It was found that microstructure controlled γ-TiAl whose chemical composition was Ti-(46-48)at.%Al-(3-5)at.%Cr improved the room temperature ductility and demonstrated the capability of the super-plastic deformation at high temperatures[4,5].

Although the effects of microstructures on the mechanical properties of γ-TiAl have been studied extensively, the mechanical property data of γ-TiAl such as basic tensile properties, creep and fatigue tests have not been accumulated to satisfactory level yet. In this paper, the mechanical properties of the microstructure controlled Cr doped γ-TiAl have been investigated. The effects of strain rate on the tensile stresses at the elevated temperatures have been focused.

2. Experimental Procedure

2.1 Specimen Preparation

Melting and ingot processing is the most appropriate method to manufacture γ-TiAl with the high purity and reliable chemical composition. It was reported that low oxygen level of γ-TiAl improved the ductility at room temperature. Plasma arc melting (PAM) process was chosen in this study, since it was possible to produce a low oxygen (400wtppm) of γ-TiAl ingot. The alloys were twice melted in the water cooled copper hearth, and solidified. The ingots were homogenized at 1050°C for 96hours in a vacuum atmosphere. Table 1 lists the chemical compositions and impurity levels of current material.

Table 1. Composition of Cr doped TiAl

Alloy elements,at%			Impurity elements,wt%		
Ti	Al	Cr	O	H	Cl
51.3	46.0	2.7	0.04	0.005	0.005

To control the microstructure, isothermal forging (ITF) was carried out at 1200°C with an initial strain rate of $1x10^{-4}$ s^{-1}. The cylindrical specimens were deformed up to 70% in a single step. Forged specimens (150mm diameter, 15mm thickness) were designated as microstructure controlled specimen(MC). In order to obtain full lamellar microstructure, specimen heated up to 1350°C with heating rate 20 °C /min, subsequently cooled different cooling speeds. Ar gas cooled specimen is designated AC, and water quench specimen is designated WQ, respectively.

2.2 Tensile Tests

The mechanical properties of the microstructure controlled γ-TiAl, MC, AC and WQ were examined by tensile tests at temperature range from room temperature to 1200°C. The tensile specimens whose gauge section was 16x2x2mm^3 were cut by the electric discharge machine and polished all the surfaces by emery papers. The tensile tests were carried out on the Instron type machine with various strain rates in a vacuum atmosphere. In order to clarify the effects of the strain rate, two types of tensile tests were conducted. One was individual specimen deformed at different strain rate at the constant temperature until fracture. The other was a specimen deformed to 0.1 strain, then abruptly changed strain rate 10 times or 1/10 during tensile test at constant temperature.

2.3 Characterization of Deformed Specimen

Microstructures of deformed γ-TiAl, were studied by means of the imaging plate X ray diffraction (IPXRD) and the transmission electron microscope (TEM). IPXRD provided the two dimensional crystallographic information from the surface. After tensile test, deformed gauge section was cut perpendicular to the tensile axis and polished the surface. Using 0.8mm diameter Cu Kα X-ray beam, diffraction image was taken on the imaging plate. Incident X-ray beam angle to specimen surface normal direction was 20 degrees.

TEM observations were carried out using thin foil specimens which were prepared from the deformed gauge section by a conventional electro-polishing technique and the focused ion beam(FIB) technique.

3. Results and Discussion

3.1 Tensile Properties of Cr Doped TiAl

Cr doped γ-TiAl is the most ductile composition among developed γ-TiAl base intermetallics. If the room temperature ductility and the high temperature deformability are the limiting factors for their commercial applications, Cr doped γ-TiAl would be the most suitable alloy composition among γ-TiAl based alloys . Phase stability and microstructure evolution of Cr doped TiAl have been studied extensively. Based on the experimental results, a calculated Ti-Al-Cr ternary phase diagram has been proposed[6]. Utilizing the Ti-Al-Cr ternary phase diagram, transformation temperature of α phase to α+γ phases is 1330°C in the case of 46at%Al-2.7at%Cr. Specimen quenched from the α phase region, shows full lamellar microstructure. Lamellar spacing between γ and α_2 depends on the cooling rate. Therefore WQ specimen shows the finest lamellar spacing among the three types of specimens. Table 2 lists the lamellar colony size and lamellar spacing of Cr doped TiAl with different heat treatments.

Figure 1 shows the temperature dependence on the tensile strength of Ti-46at%Al-2.7at%Cr wrought specimen at strain rate 5×10^{-4} s^{-1}. From room temperature to 600°C, MC specimens showed higher tensile strength than AC and WQ specimens. From 700 to 1100°C, AC and WQ specimens showed higher tensile stress than MC specimens. These results suggest that specimen consist of finer lamellar colony size and finer lamellar spacing have higher strength at temperature range 700-1100°C. The most preferable microstructure is a stratified microstructure with a more fine lamellar spacing, and a stratified lamellar colony size is as small as possible.

Table 2. Microstructure of Cr doped TiAl

Heat treatment	Colony size/μm	Lamellar spacing/nm
As forged	240	250
1350 °C 1h Argon gas cooling	180	200
1350°C1h water quench	160	190

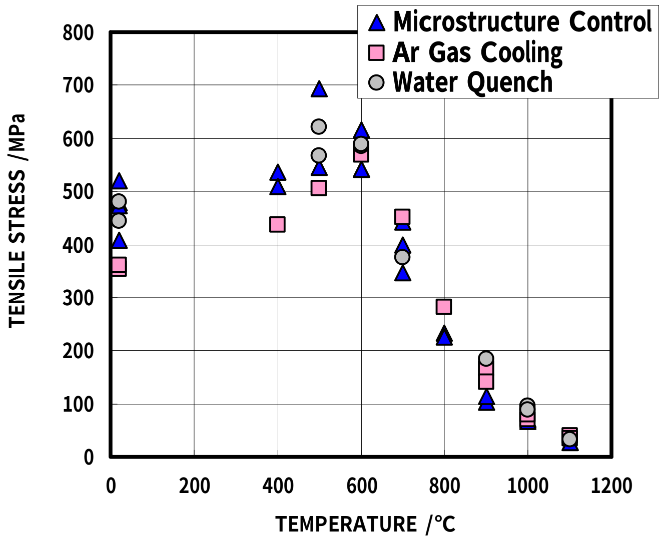

Figure 1. Temperature dependence on tensile strength of Cr doped TiAl

Tensile elongation of these three types of specimen showed slightly different behaviors. At room temperature, MC specimen showed 3.0% plastic strain, however AC and WQ specimens did not show any detectable plastic strains. Above 500°C, all the specimens showed more than 10% plastic strains. Fracture toughness value of Cr doped TiAl showed 30 $MPam^{1/2}$ at room temperature. At elevated temperature, enough plastic elongations were obtained.

3.2 Strain Rate Dependence of Cr Doped TiAl

Effects of the strain rate on the flow stresses are analyzed by the strain rate change during tensile test. Plastic deformation of metallic material characterized by following equation.

$$\dot{\varepsilon} = B\sigma^n \qquad (1)$$

$\dot{\varepsilon}$:strain rate
B : stress independent constant
σ :stress
n : strain rate sensitivity factor

Specimens were tested at strain rate of $5x10^{-5}$ to $5x10^{-3}$ and temperatures from 500 to 1200 ℃. Effects of the strain rate on the flow stresses were examined by the strain rate change tests during deformation. Figure 2 shows the effects of the strain rate on the flow stresses at various test temperatures. The slopes of these data indicate the strain rate sensitivity factor *n*. Table 3 lists the strain rate sensitivity factor *n* at the various temperatures. *n* value exceed 0.3 which is criterion of super-plastic deformation at 1200℃. Clearly *n* value is a function of temperature. *n* value increases with increasing deformation temperature.

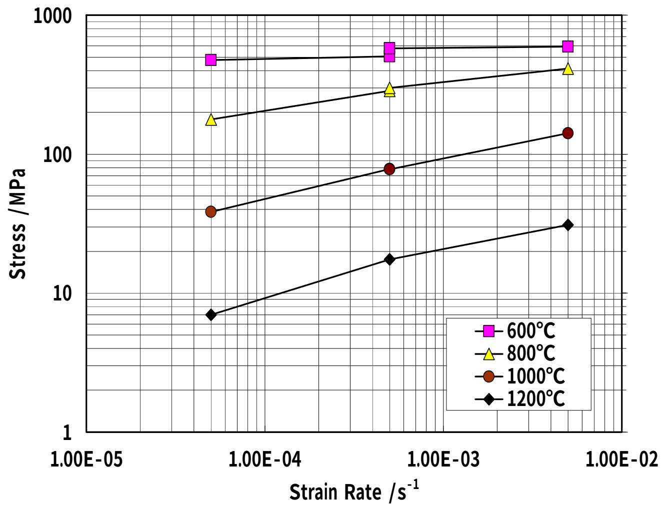

Figure 2. Effect of strain rate on flow stress at various temperatures

Table 3. Strain rate sensitivity of Cr doped TiAl

Temperature ℃	*n*	Strain
500	0.052	0.1
600	0.050	Rate change
700	0.15	0.1
800	0.18	Rate change
900	0.24	0.1
1000	0.28	Rate change
1200	0.47	0.1

3.3 Texture Development

Most of the metallic materials show texture after hot rolling or the high temperature deformation. In order to investigate texture development of Cr doped γ-TiAl, two dimensional XRD images from the deformed specimen were taken. X-ray beam direction is 20 degree from tensile axes. Figure 3 demonstrates that IP image of specimen deformed at 1200 ℃. Ring patterns indicate specimen contains a lots of randomly oriented grains. Because γ phase (111)plane and β phase (110)plane have the quite similar Bragg's angle 2θ value, appeared ring pattern can not be distinguishable each other. One more outer ring is diffraction from α_2 phase (210) planes. Intensity distribution of α_2 grains is not uniform and spot like, comparing with γ phase (111)plane and β phase (110)plane. This observation indicates that grains of α_2 phase have a texture.

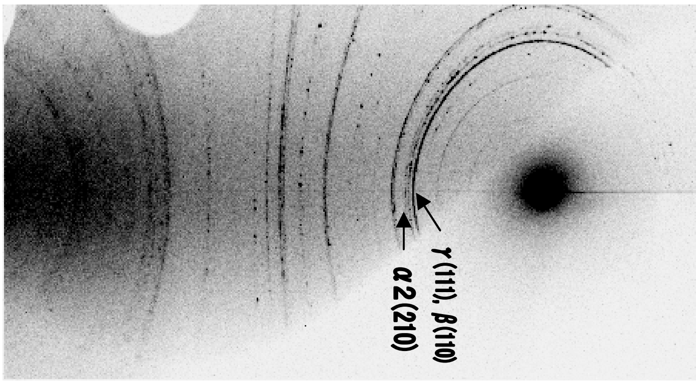

Figure 3. Two dimensional XRD image of specimen deformed at 1100C

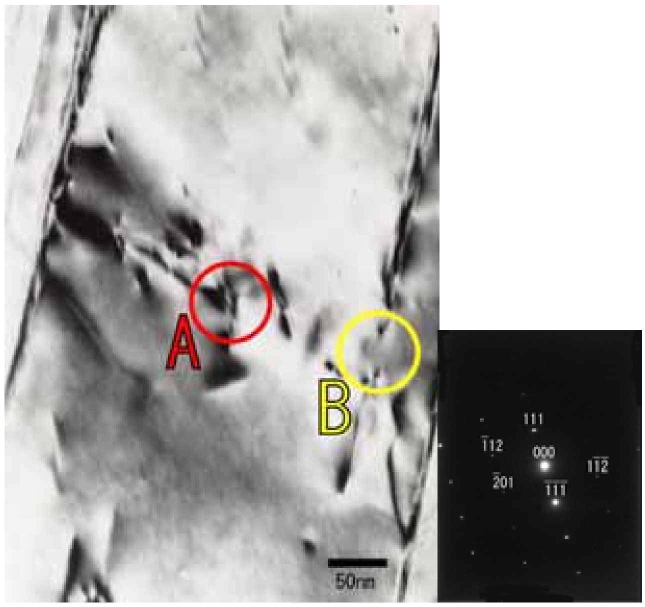

Figure 4. dislocation structure of specimen deformed 600℃. A is super dislocation and B is ordinary dislocation(invisible)

3.4 TEM Observation of Deformed Specimen

Figure 4 shows dislocation structures of the specimen deformed at 600℃. The same dislocation images were taken from the different two beam conditions of TEM. Burgus vector of dislocations were identified according to visible and invisible conditions of TEM images. Both ordinary dislocations having a/2<110> type (dislocation B) and super dislocations whose Burgus vector was twice as large as ordinary dislocations (dislocation A) were activated and interacted each other.

Figure 5 shows a array of dislocation from the specimen deformed at 800℃. Edge dislocations were arrayed to form polygonization. This observation suggests that dynamic recrystalization is playing an important role on the high temperature deformation. Both ordinary and super dislocations moved without any interactions, so that more stable dislocation configurations such as poligonization were developed.

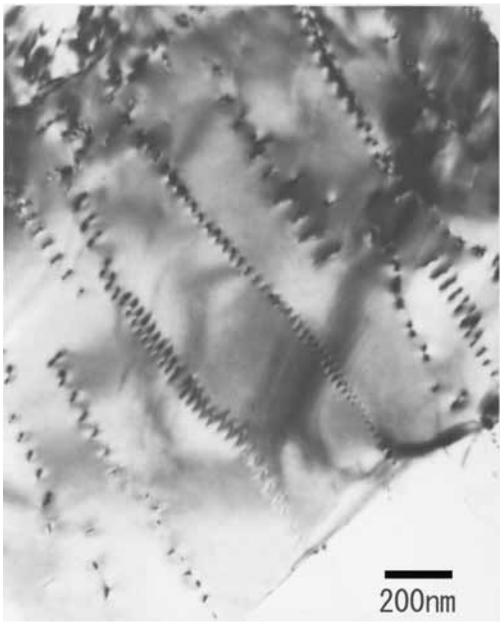

Figure 5. TEM observation of specimen deformed at 800C. Dislocation poligonizations were formed

4. Conclusions

1.Tensile strength of Cr doped γ -TiAl demonstrated the inverse temperature relationships, whose peak temperature was 600℃.
2.Full lamellar microstructures having different lamellar spacing show small differences of their tensile strength.
3.Strain rate sensitivity factor *n* is increase with increasing deformation temperatures. n value exceed 0.3 above 1050℃.
4.IPXRD study revealed that deformed region had a strong texture.
5.According to TEM observations, ordinary dislocations and super dislocations were activated at 600℃.
6.Dislocation polygonization was frequently observed in the specimen deformed at 800℃.

Acknowledgements

The authors would like to thank staff in Advanced Research Laboratory in Nippon Steel Corp. for providing the materials which examined in this study.

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