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Review Article

Effects of Composition Nb on Structure & Mechanical Property of Ti_3Al

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Abstract

The Nb was the most effective alloy elements of Ti_3Al alloy on RT plasticity in the late 1970's. The effects of Nb content in as cast α_2 based Ti-25at.%Al-(11-16)at.%Nb alloys made by plasma arc melting on structures and mechanical properties were studied in this paper. The Prior β/α_2 grain boundaries were found to increase both ductility and strength. The size of α_2 plates resulted in finer α_2 cleavage facet which would be fine when Nb content was increased. They would cause high fracture strain and strength in high Nb content alloys. The lattice ratio of α_2 phase will be decreased when the Nb was increased. It was supposed that the Nb could substitute for the Ti so that the distance of a axis between atoms would be increased. According to Hall-Petch formula with $\sigma=\sigma_0+kD^{-1/}$ the grain boundary int these three alloys was calculated and knew that σ_0 is 168MPa, K is 10.8MPam$^{-1/2}$. The effective turn of four respects is lattice constant c> c/a> V> lattice a in terms of variance method with the deviation in these three alloys that means that lattice c is the best one and then c/a& V and finally lattice a in terms of deviation.. It was found the calculated value c/a is 0.81 meantime volume of unit has been 0.42nm^3 and their standard deviation is about 0.16% and 0.32% respectively. It expresses that the later volume is not preciser than the former c/a.

Keywords: Solidification, Composition, Structure, Mechanical property, Ti_3Al.

1. INTRODUCTION

The intermetallic compounds Ti_2Al-Nb would have the HCP α structure and occur heterogeneous change at 1180˚C. Those alloys were researched to develop and substitute the temperature zone on the basis of present quasi α Ti with 550~600˚C and Ni super alloys with 650~800˚C. However they would be low plasticity at room temperature to compare with other alloys [1]. Therefore the data base on it needs to be experimented to observe the properties in these temperature. As a turbine blade used in plane engine it has included dynamic properties whose one is an important factor.

The strength and elongation would be increased to add the stabilized element such as Nb more than 10at.% so that the β (B2) with b.c.c. phases were stabilized enough as for Ti_3Al [2]. The elongation at room temperature was good at Nb content more than Ti-25at.%Al-11at.%Nb [1, 2]. The effect to ductility was thought to take role in the grain size and local stress at grain boundaries [1]. The change with the addition Nb had been observed which affected the structure and properties in this study. Whether it fits to plane engine material the plastic properties are main purpose to be obtained so as to utilize from these ternary alloys. The more Nb will produce more elongation and stress according to references. Therein the maximum Nb can become an important factor to last elongation and stress in this alloys.

For the needs of higher temperature, light quality & speed, new advanced materials would be searched: 1) high melting point; 2) low density; 3) elastic modulus; 4) good structure stability & excellent oxidized resistance [3]. In the high temperature application, such as engines. Intermetallic Compounds of Ti_2AlNb could compete with late developed TiAl and all the HT titanium base alloys & nickel base materials [4-11]. From the view of stress in high temperature it is competitive production and from the view of its strain is one to be developed materials. It has high stress and a certain strain therein it is a promise material to be used as turbine blade in engine in future because it has 25% Al element to lighten the weight in plane and its elongation has several times than TiAl. So it is a significant promise in designing and making production as turbine blade.

2. EXPERIMENTAL METHOD

The binary and ternary alloys in Ti_3Al were produced to analyze. The 99.7wt.% sponge Ti, 99.9wt.% bulk Al and 99.9wt.%Nb were used to produce specimen. They were melted under 99.9% Ar gas in plasma arc furnace. For the homogeneous specimen they were melted more than 3 times. The compositions were investigated used EDS (energy dispersive X-ray spectroscopy). Macro- and micro structure were observed with OM (optical microscopy) and SEM (scanning electronic microscopy). The etching solution was 10mlHF+5mlHNO_3+ 35mlH_2O_2+ 100mlH_2O. The lattices constant were investigated on X-ray diffraction and lattice program. The micro structure was investigated with JEM-2010 TEM (transmission electron microscopy). The jet solution was 60%methanol+ 35% n-butanol+ 5% perchloric acid. The test was done at room temperature in order to search tensile curve. The strain rate was used to 1.25×10^{-4}/s. The specimens were extracted from the column rode casting shown as Fig 1. The specimens shown as Fig 2 were used to 8×3×1mm in gauge.

Table 1: EDS analysis of α_2 base alloys. (at.%)

Nominal composition	Ti	Al	3rd element
Ti_3Al	76.56	23.44	-
Ti_2Al-11Nb	64.45	24.32	11.23
Ti_2Al-13.5Nb	60.18	25.90	13.92
Ti_2Al-16Nb	56.76	26.88	16.36

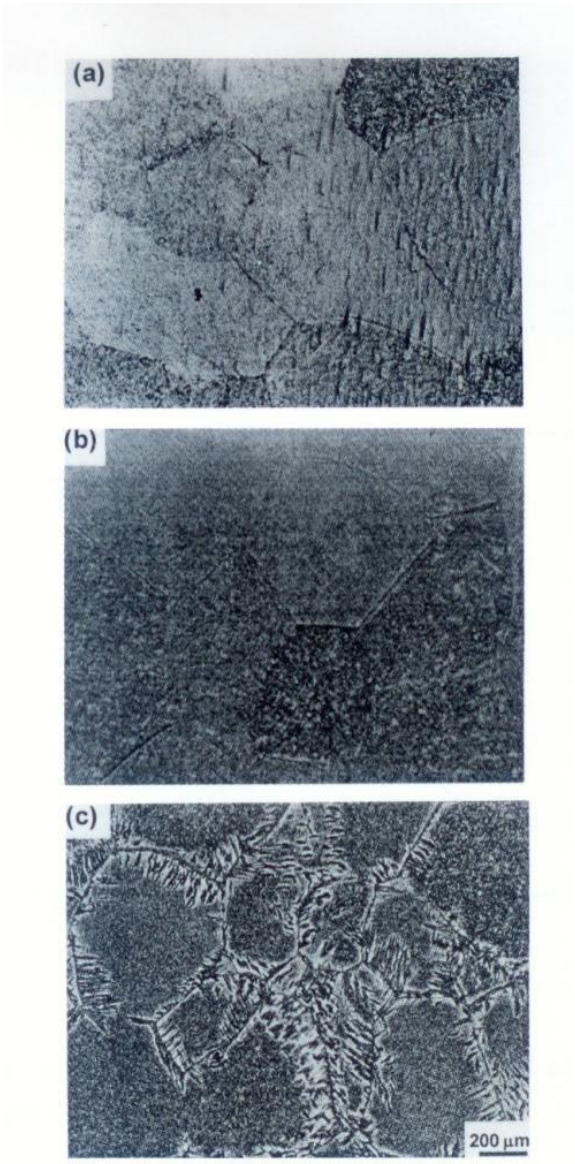

Fig 1: Optical micrographs of as cast α_2 base alloys: (a) Ti_3Al-11Nb, (b) Ti_3Al- 13.5Nb, (c) Ti_3Al-16Nb

3. RESULT AND DISCUSSIONS

3.1 Phase analysis and crystallography

The results with EDS were shown in Table 1. It was found that the composition distribution would be existent with theoretical value. The whole alloy had been equiaxed coarse grain boundaries shown in Fig 1. In the Ti-25at.%Al-(11~16) at.%Al they were aligned with basket-weave in prior β/B2. The secondary phase α_2 had grown from grain boundaries to center was observed.

To find the change of phase, when the content of Nb addition was increased the increasing in β/B2 and the broadening peak was observed as shown in Fig. 3. It was thought that the prior β/B2 grain boundary and plates would be fine. That will be existent with the measurement of the grain and α_2 plate size. They were from 670 to 500μm as shown in Fig 2. They would fit to the Hall-Petch formula appropriately i.e. $\sigma=\sigma_0+kD^{-1/2}$.

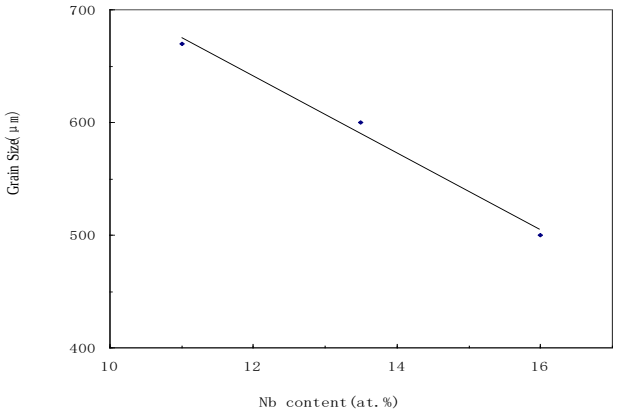

Fig 2: The effect of Nb content on grain size of α_2 alloys

Here, σ-yield strength, σ_0-single crystal yield strength, D-crystal diameter, K-constant. According to yield strength and diameters of specimens which were measured with a certain line intersecting the boundaries we can calculate the σ_0 and K. Here σ_0 is 168MPa, K is 10.8MPam$^{-1/2}$. it was found that the deviation was about 12.5% that's little higher than 10%. So the yield stress and diameters have a Hall-petch relations.

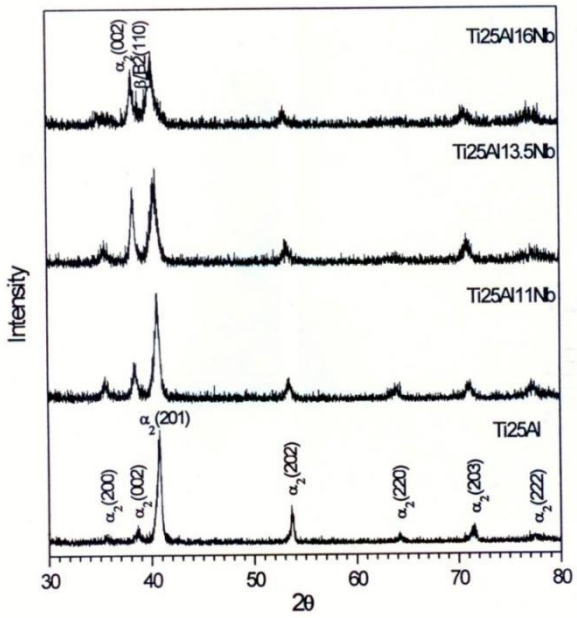

Fig 3: The variation of X-ray diffraction spectra in α_2 base alloys

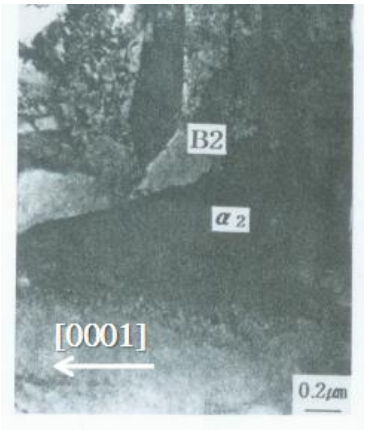

Fig 4: TEM micrographs of Ti_2Al-13.5 at.%Nb alloys

The B2 with the ordered b.c.c. at the zone axis $[\bar{1}12]$ and the α_2 phase at the zone axis $[2\bar{1}\bar{1}0]$ were observed by TEM. As shown in Fig. 4 the direction[0001] was indicated from right to left according to the plane(0001) and direction $[2\bar{1}\bar{1}0]$. The B2 matrix and precipitated α_2 plate were confirmed as shown in this image.

In the case of lattice constant it was found that c was nearly constant when the Nb was increased as shown in Fig. 5. On the contrary a axis was increased so that c/a would be decreased. The lattice volume of α_2 phase would be decreased when the Nb was increased. It was thought that the Nb can substitute for the Ti [1] so that the distance (specially a axis) between atoms would be increased. Here as to hexagonal there is $V = \frac{3}{2} * \sqrt{3}a^2c$ in Table 2. The high of standard deviation σ means the high of the deviation. By the analysis the value had good credit from the deviation. That means the constant had approached more to near 0.47nm and 0.583nm with c and a respectively as Table 2. It was included that measurement standard deviations was 0.057% and 0.19% in c and a lattice constant respectively as below with the range of scope were happened according to variance in TiAl alloys. The lattice c is preciser than a in terms of their deviation value, therein it is explained that the standard deviation is very small whose value is feasible to use in measuring lattice of TiAl specimen. In additional the c/a has been measured with variance. It is found that the calculated value c/a is 0.81 meantime volume of unit has been $0.42nm^3$ and their standard deviation is about 0.16% and 0.32% respectively. It expresses that the later volume is not preciser than the former c/a. The effective turn of these four respects is lattice c> c/a> V> lattice a. It means that lattice c is the best one and then c/a& V and finally lattice a in terms of deviation.

Table 2: Variance and standard deviation analysis results of α_2 base alloys

Item	Lattice c	Lattice a	c/a	V
Mean value	0.47nm	0.583nm	0.806	$0.415nm^3$
Deviation σ^2	3*E-6	3.6*E-6	2.8*E-6	1*E-5
Standard deviation σ, %	5.7*E-2	1.9*E-1	1.66*E-1	3.20E-1

3.2 Mechanical properties in α_2 specimens

The results in tensile test at room temperature were seen in Fig 6. The binary Ti2Al was manufactured two to make tensile tests. It was found that the tensile strength of them were both weak extremely like a loosen ones. But their hardness were normal. So we speculated the grains were cracked and form crack. maybe hydrated brittleness was the probable cause like states at the literature [5]. The addition Nb being the stabilization β/B2 was high so that strength and strain would be increased. The strength and strain could be raised highly to compare with binary system. That will be explained to stabilize β/B2 phase which was high temperature stabilized phase with b.c.c. structure to room temperature to form the α_2 +β/B2 which limited the crack to happen in α_2 and enhanced ductility. In addition, it was supposed that with the increasing Nb the unit cell would increase in terms of increasing a axis. The cell volume will be increased that means there are no relation between the unit cell and the stress. It was thought that they enhanced the ductility. Maybe they were in relation to increasing the cell volume somewhat which was referred to as above.

The fracture structures were shown in tensile test at room temperature in Fig 7. They would change with the composition of Al. It was observed that the transgranular fracture would be the general type. The large α_2-cleavage facet was observed in Ti-25at.%Al-11at.%Nb while the fine α_2-cleavage happened in Ti-25at.%Al- 16at.%Nb. So when Nb was increased the better room temperature properties would be shown due to finer α_2-cleavage.

The tensile fracture plane will show the forming that was transgranular generally in α_2. The B2 for better ductility increased the strain value at which the local critical stress happened to in α_2-cleavage. With the increasing Nb the α_2 plates was fine so that they could have good ductility at room temperature. The phase to enhance ductility would have relation to strain. The B2 will have dual roles [1] in ductility and strength because they had high yield strength. In addition, the

size of particle and α_2 phase will take the effect in ductility.

When Nb was added it caused the basal a slip. Upon a slip in prismatic plane it had been deformed firstly. As deformation twins with order structures were extracted from α Ti four independent slip systems had existed in Poly crystalline [4, 2]. With Nb addition the basal slip and homogeneous prismatic slips had been raised and c composition would not be promoted [1].

It is also important to analyze the types of dislocations and their transformations in the plastic zone of a growing crack and its mechanism. But only the mechanisms of crack nucleation and growth in a slip band in the basal plane have been analyzed in detail. Experimental studies have proved that basal slip results in shear-type crack. In some paper a theoretical analysis was proceeded to take into account the structure of the super dislocation in the basal. A model was proposed for crack formation during basal slip, which was found to agree with experimental results. As for other orientations of deformed single crystals, crack nucleation process and the developing of a plastic zone at the tip of a growing crack had not been studied. They would need to be investigated in the later study.

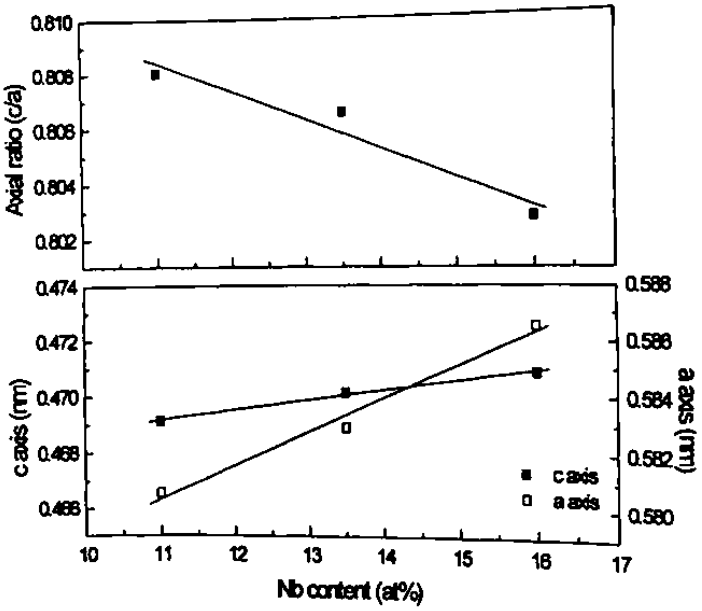

Fig 5: The variation of axial ratio of α_2 phase in α_2 base alloys

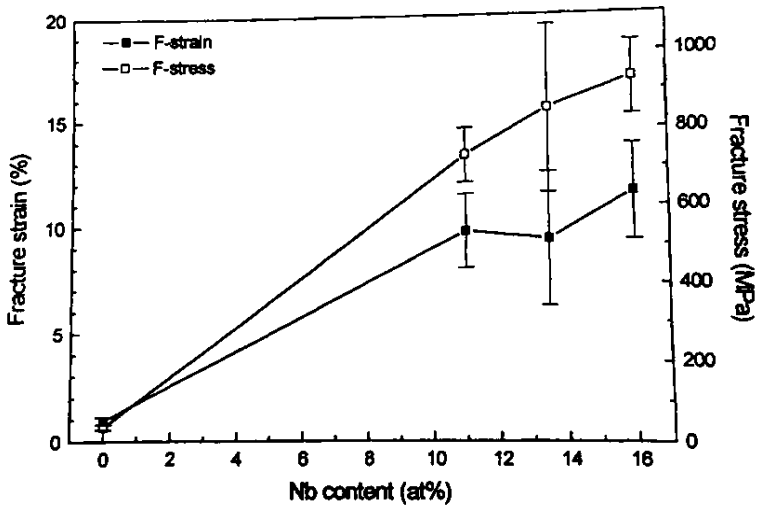

Fig 6: The variation of tensile properties for α_2 base alloys at room temperature in air. (Strain rate: 1.25×10^{-4}/s)

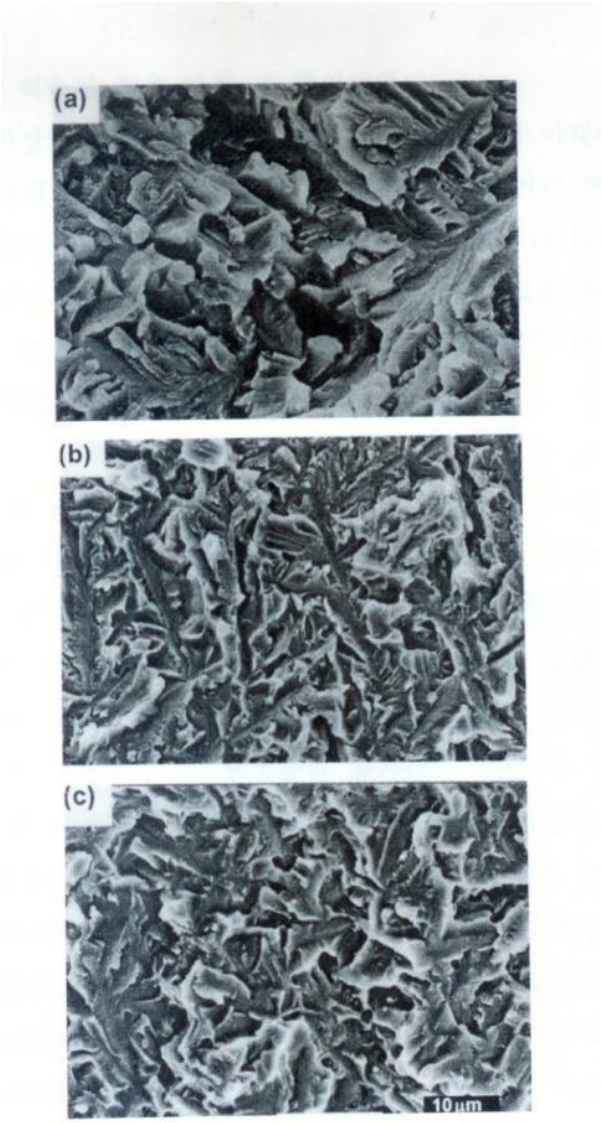

Fig 7: Top views of fracture surface for α_2 base alloys: (a) Ti_2Al-11at.%Nb, (b) Ti_2Al- 13.5at.%Nb, (c) Ti_2Al-16at.%Nb

CONCLUSION

1. In terms of Hall-Petch formula the constant of σ_0 is 168MPa, K is 10.8MPam$^{-1/2}$ in this paper on Ti_2AlNb. The deviation was little about 12.5%.
2. When the Nb was increased the prior B2 grain and α_2 plates was fine so that the fracture strength and strain would be enhanced.
3. The lattice volume will be decreased with increasing Nb. It was thought that the Nb could substitute for the Ti so that the atomic distance of a axis would be increased.
4. The mean elongation is 7.5% being little less than 10%. The addition Nb being the stabilization B2 was high so that the strength and strain would be increased.

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