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ORDERING TRANSFORMATION OF γ TO γ_1 IN TiAl+Nb SYSTEM

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ABSTRACT A series of TiAl+Nb alloys with various Nb contents has been employed to explore phase relationship and the evolution of microstructure. A new ordered γ derivative (γ_1) has been observed in the alloy containing 20 at% Nb. The additional diffraction spots added to the diffraction pattern of $L1_0$ (TiAl) structure have been found in the alloy containing Nb up to 11 at% in terms of further ordering. The transformation from $L1_0$ (TiAl) structure to the further ordering phase, γ_1, is a continuous ordering process with the substitution of Nb atoms for Ti atoms in alloys with over-stoichiometric Al content of TiAl. The possible transformation characterzation has been discussed.

KEY WORDS intermetallics, Ti-Al-Nb system, superstructure, ordering transformation

THE Ti-Al-Nb system has stimulated considerable investigations because of the potential high temperature structural application. Detailed studies of this system conducted so far are mainly concerned with Ti_3Al alloys with Nb substitutions of up to 30 at% for Ti. The formation of various phases in these alloys, which include β (disordered bcc), B2 (ordered bcc), ω-like (ordered hcp), T (ordered teteagonal), O (ordered orthorhombic) and α_2 (ordered hcp) phases, depends primarily upon the composition of alloys and the history of heat treatment [1]. However, no detailed reports about TiAl+Nb system have been published so far. With a view to possible development of advanced intermetallic alloys to be worked at above 1 050 ℃, a systematic work has been performed in our research group on the phase diagram, crystallographic structures, oxidation and mechanical behavior of Ti-Al-Nb ternary system [2]. The present paper is primarily concerned with the continuous ordering process of γ (TiAl, $L1_0$) → γ_1 transformation.

1 EXPERIMENTAL

All alloys used in this study were made in ~ 50 g buttons from high purity Ti(99.99%), Nb (99.99%) by arc-melting in a purified argon atmosphere. The buttons were remelted

several times to ensure complete mixing of the constituents. The compositions of the alloys are listed in table 1. The buttons were then encapsulated in evacuated and Ar−backfilled quartz tubes and heat treated at 1 250 ℃ for 7 d followed by furnace cooling. All specimens were examined at SEM and TEM with energy−dispersive x−ray spectroscopy (EDS). Some specimens were also examined at 200 kV in a JEOL 2000EX II high resolution electron microscope (HREM) for lattice images.

Table 1 Chemical compositions of alloys

Alloy	Compositions /at%		
	Nb	Ti	Al
E1	–	50.00	50.00
E4	11.17	33.24	55.59
E6	20.00	20.00	60.00

2 RESULTS

2.1 MICROSTRUCTURE AND CRYSTALLOGRAPHY OF γ_1 PHASE

The microstructure of alloy E6 consists of the matrix and the needle−like precipitates. The needle−like precipitates contain two different microstructural scales−one on the order of 10 to 10^{-1} μm observed by SEM as shown in Fig. 1, and another on the order of 10^{-2} μm or less observed by TEM as shown in Fig. 2 (a) and (d) which is the magnification of the part of Fig. 2(a). Between the finer precipitates there also lie many even finer needle−like precipitates in the matrix. The size of these even finer needles is about within the order of 10 nm. The SADP of the area containing the matrix and the two scales of needles is shown in Fig. 2(c), Fig. (b) which merely images the needle−like phase is the dark field (DF) image taking from the weak diffraction spot B as indicated in Fig. 2(c). The diffraction spot B in Fig. 2(c) is $1/2<201]_\gamma$. This type of diffraction is additional to the $L1_0$ structure, implying the formation of superstructure or supercell of phase. It can also be directly confirmed by high resolution electron microscopy (HREM) images as shown in Fig. 3, the γ_1 precipitate and the matrix are imaged simultaneously. It can be seen that even in one needle the matrix and the γ_1 phase are intersected, implying that the ordering transformation is at different stage even in one needle.

The results of the compositions of the coarser needles determined by SEM/EDS and TEM/EDS results show that the composition range of γ_1 phase are 20at% ~ 23at% Nb, 17at% ~ 19at%Ti, and 59at% ~ 60at% Al.

According to the method of construction of reciprocal planes proposed by Gard [3], The reciprocal lattices projected on to $(h00)^*$ and $(00l)^*$ were constructed, the possible structure parameters of γ_1 phase, i. e., $a=b=0.558$ ~ 0.584 nm, $c=0.815$ ~ 0.845 nm, and $\alpha=\beta=\gamma=90°$ were determined.

2.2 THE TRANSFORMATION PROCESS OF γ−TiAl TO γ_1 PHASE

The experimental results from TEM observations indicated that alloy E4 composed of only a single phase as shown in Fig. 4(a). Fig. 4(b) is the selected area electron diffraction pattern (SADP) and 4(c) is SADP of γ phase in alloy E1 with the same beam direction of

Fig. 1 Microstructure of E6 (Ti－20Nb－60Al) alloy by SEM

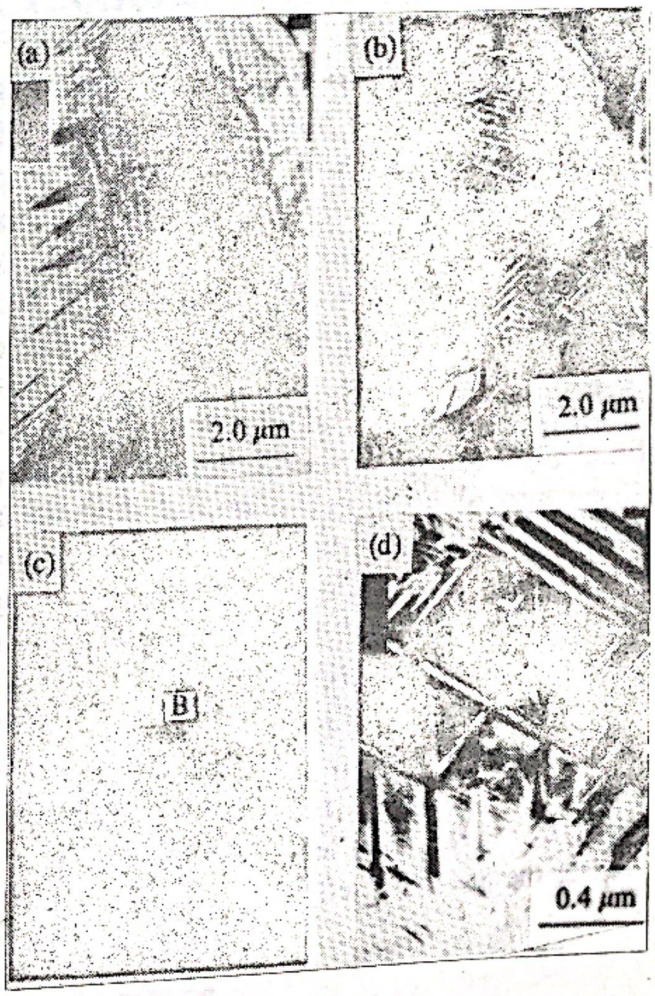

Fig. 2 Microstructures of E6 (Ti－20Nb－60Al) alloy by TEM
(a) BF (bright－field) image;
(b) DF (dark－field) image using B spot indicated in (c)
(c) SADP corresponding to (b)
(d) partly magnified image of (a)

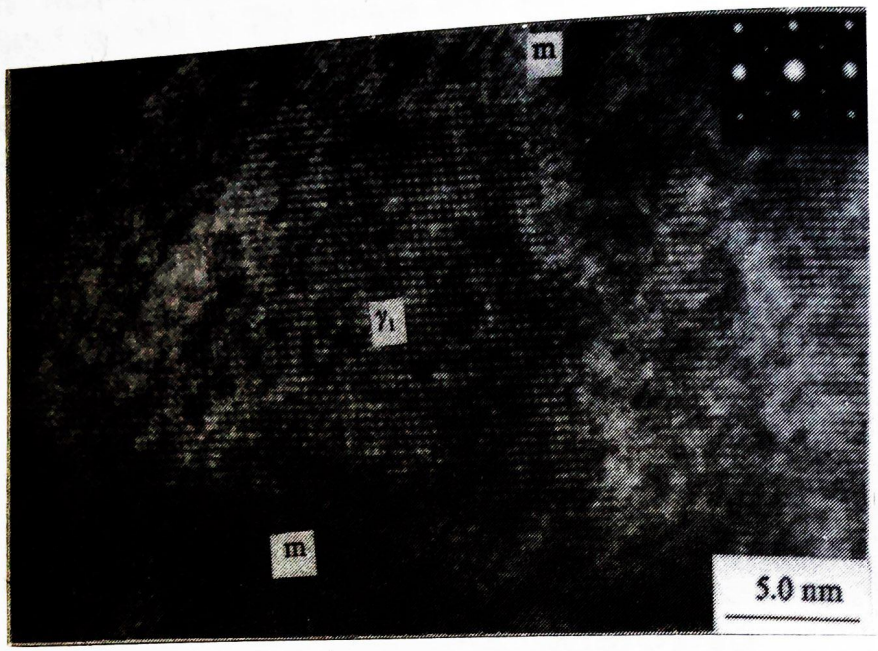

Fig. 3 HREM image of the needle-like ordered phase (γ_1) and the matrix (m)

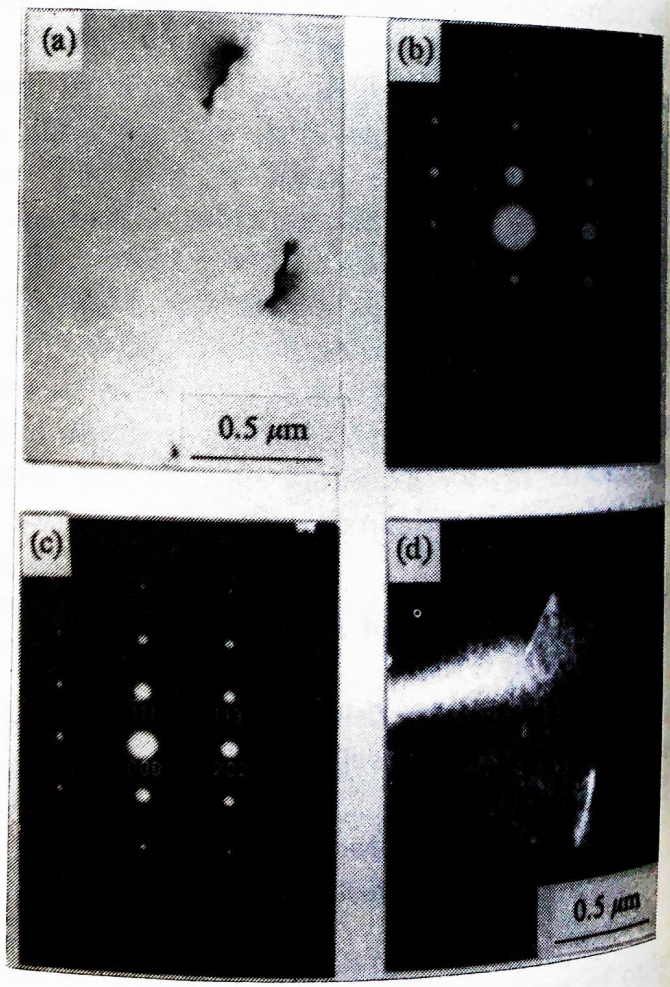

Fig. 4 Microstructure and diffraction patterns for alloy E4 (Ti−11.17Nb−55.59Al) alloy
(a) BF (fright−field) image
(b) SADP for alloy E4
(c) SADP for γ (TiAl) phase in alloy E1, the beam direction is $[121]_\gamma$
(d) DF (dark−field) image of alloy E4 using the additional reflection

4(b) (the beam direction is $[121]_\gamma$ of γ phase). It is well known that the γ phase has $L1_0$ structure with $a=0.398$ nm and $c=0.405$ nm. Its diffraction condition is $h+k=2n$. It can be clearly seen that there exist additional diffraction spots in the SADP of alloy E4 compared with that of γ phase in alloy E1. Obviously, these additional diffraction spots result from the ordering of Nb atoms in the lattice of γ phase, which lead to the formation of the superstructure or the supercell of γ phase (named γ_1). So we can extent the sense of the superlattice or superstructure or supercell spots to these additional diffraction spots in terms of further ordering. These spots are so weak that one must be very careful to obtain. Fig. 4(d) is the dark field image using the additional diffraction spot, also it can be seen that there are no precipitates in the matrix.

From above work, the phase transformation of $\gamma-TiAl \rightarrow \gamma_1' \rightarrow \gamma_1$ is a continuous ordering process with the variation of the composition. As for the $\gamma-TiAl$ to γ_1' process it may be a second order phase transformation process, while for γ_1' to γ_1 process it may be the first order phase transformation process, since γ_1 phase has precipitated form the matrix.

3 DISCUSSION

According to our results of determination of the lattice site occupation of Nb in the TiAl($L1_0$) using the planar channelling ALCHEMI technique [4], when Nb atoms were added to TiAl as substitutional atoms, they situated preferentially on the Ti sublattice. When the content of Nb atoms added to TiAl was low the subsititution of Ti by Nb atoms may be randomly, i. e. the Nb and Ti atoms randomly occupied the same sublattice. However , with increasing the contents of Nb atoms added to TiAl to substitute Ti atoms, the ordering of Nb atoms may occur. For instance, when the Nb content is up to 11.17at% (E4 alloy), the supercell spots added to the diffraction pattern of the $L1_0$ structure occurs (see Fig. 4(b)). When the Nb content is up to $\sim$ 18at% , such as in E6 alloy, the ordering of Nb atoms in the lattice causes the Nb atoms to occupy completely a specific sublattice and the new ordered phase γ_1 is formed. The ordering digree varies even in one needle (see Fig. 3). The transformation of γ($L1_0$ structure) $\rightarrow$ γ_1(a new ternary compound) seems to be a continuous ordering process with increasing the Nb content in TiAl ($L1_0$) phase. This ordering phenomena has also been observed in super α_2 alloy [1], when the Nb content was higher than 5 at% , the transformation of B2$\rightarrow$ $B8_2$ occurs. In Banerjee's work, the ternary compound O phase appears at Nb levels exceeding 12 at %. Continuous ordering has also already been demonstrated in binary ordering systems, such as Fe$-$Al, Ni$-$Mo and $\beta-$brass [5]. The detailed structure analyses such as space group and the site occupation of atoms are in progress.

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TiAl+Nb 系中 γ 到 γ_1 相的有序化转变 *

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摘要 利用一系列不同 Nb 含量的 TiAl 合金研究了该体系的相关系及组织特征．在含有 20at%Nb 的合金中发现 1 个新的 γ_1 相．在含有 11at%Nb 的 TiAl 合金中，由于 Nb 原子的进一步有序化，在衍射图上出现 $L1_0$ 结构的超斑点．在具有过化学计量比 Al 含量的 TiAl 合金中，随着合金中 Nb 含量增加，Nb 不断地取代 Ti，合金由 $L1_0$ 结构转变为进一步有序化的 γ_1 相，是一个连续有序化过程．并讨论了可能的转变特征．

关键词 金属间化合物，Ti-Al-Nb 系，超结构，有序化转变
中图分类号 TG449.4
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