A STUDY OF THE T_1' PHASE IN THE Al-2. 6Li-1. 3Cu ALLOY[①]

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ABSTRACT

T_1' phase in Al-2. 6Li-1. 3Cu alloy was studied systematically by selected area electron diffraction, serial rotation and matrix analysis of electron diffraction pattern. The results show that the crystalline structure of T_1' phase is orthohombic. The lattice parameters are $a = 0.2876$ nm, $b = 0.86$ nm, $c = 0.406$ nm, and orientation relationship with the matrix is $(010)_{T_1'} // (110)_\alpha$, $[001]_{T_1'} // [100]_\alpha$.

Key words: Al-Li alloy T_1' phase orientation relationship crystalline structure

1 INTRODUCTION

Does T_1' phase exit in the Al-Li alloy, and if it does, what kind of crystalline structure does it have? This is a disputative problem in recent years. In this paper, T_1' phase was studied systematically by selected area electron diffraction, serial rotation and the method of matrix analysis of electron patterns. The results were tested by the program for calculating overlap electron diffraction patterns of double phases.

2 EXPERIMENTAL

Intermediate alloys of 99. 99% Al, Al-9%Li and Al- 40% Cu were melted in graphite crucible which was placed in a vacuum inductin furnace, and then was poured into an iron mold. All processing were conducted under argon. The ingot with dimension of 35 mm × 15 mm × 200 mm was homogenized at 510 ℃ for 24 h, then stripped before hot rolled at 450 ℃, and finally the sheet of 2 mm in thickness was obtained. The composition (wt. -%) of the alloy is 2. 55Li, 1. 29Cu, 0. 033Fe, 0. 019Si, and balance Al. The specimens were solution treated at 530 ℃ in KNO_3 salt bath for 30 min, quenched in water. Then after cold rolling with 10% reduction in thickess at room temperature, the alloy was aged at 190 ℃ for 0 ~ 8000 minutes. Microstructures and diffraction patterns were observed in a CM12/STEM transmission electron microscope (TEM). The transformation matrix of the orientation relationship between precipitates and alloy matrix, and index of the parallel crystalline planes and directions of double phases were computed by computer.

3 RESULTS AND DISCUSSION

3. 1 *Determination of T_1' Phase in* Al-2. 6Li-1. 3Cu *Alloy by Diffraction Patterns*

When aged at 190 ℃, a kind of thin

① Manuscript received May 10, 1993

plate-like phase was formed, Fig. 1. Fig. 2 is a serial diffraction patterns of the phase. The morphology and habit plane of the phase are the same as that of T_1' phase, but the [211]$_\alpha$ zone diffraction patterns of the two phases are different, indicating that the

Fig. 1 Bright field images of T_1' phase in the Al-2. 6Li-1. 3Cu alloy
(a)—190 ℃, 1 000 min; (b)—190 ℃, 8 000 min

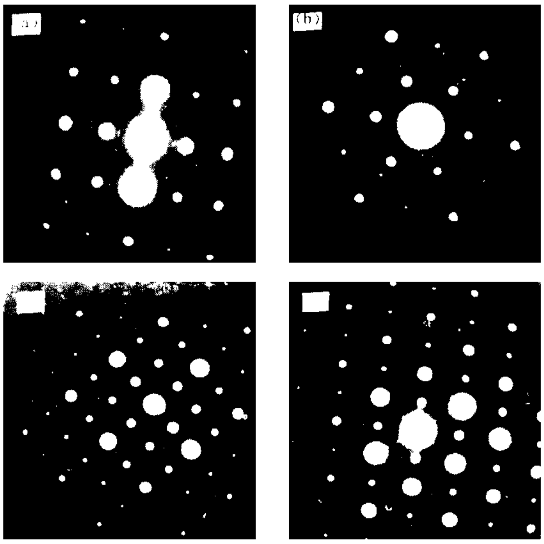


Fig. 2 A series of electron diffraction patterns of T_1' phase in the Al-2. 6Li-1. 3Cu alloy
(a)—[211]$_\alpha$; (b)—[111]$_\alpha$; (c)—[100]$_\alpha$; (d)—[110]$_\alpha$

crystalline structure of the thin plate- like phase is different from that of the T_1' phase, Fig. 3 RioJa *et al* [1] named the new phase as T_1'.

3. 2 *Crystalline Structure of* T_1' *Phase*

Eikam *et al*[2] suggested that T_1' phase has the hexagonal structure, with lattice parameters of $a = 0.495$ nm, $c = 0.701$ nm, and its orientation relationship with the matrix is as follows:

$$(0001)_{T_1'} \,//\, (111)_\alpha$$
$$(10\bar{1}0)_{T_1'} \,//\, (1\bar{1}0)_\alpha$$

However, Rioja thought that T_1' phase has orthorhombic lattice (Pt_2Mo structure), with the parameters of $a = 0.2876$ nm, $b = 0.86$ nm, $c = 0.406$ nm, and the orientation relationship of T_1' with the matrix is:

$$(010)_{T_1'} \,//\, (110)_\alpha$$
$$[001]_{T_1'} \,//\, [100]_\alpha$$

If T_1' phase has the hexagonal lattice, then the orientation relationship of T_1' with the matrix can be obtatined from Fig. 2 (b):

$$(0001)_{T_1'} \,//\, (111)_\alpha$$
$$[10\bar{1}0)_{T_1'} \,//\, (1\bar{1}0)_\alpha$$

Then the three parts of parallel planes of T_1' with the matrix is found:

$$(00.1)_{T_1'} \,//\, (111)_\alpha$$
$$(10.0)_{T_1'} \,//\, (1\bar{1}0)_\alpha$$
$$(\bar{1}2.0)_{T_1'} \,//\, (11\bar{2})_\alpha$$

The transformation matrix of the parallel orientation indexes of the two phases got by matrix transformation method is shown

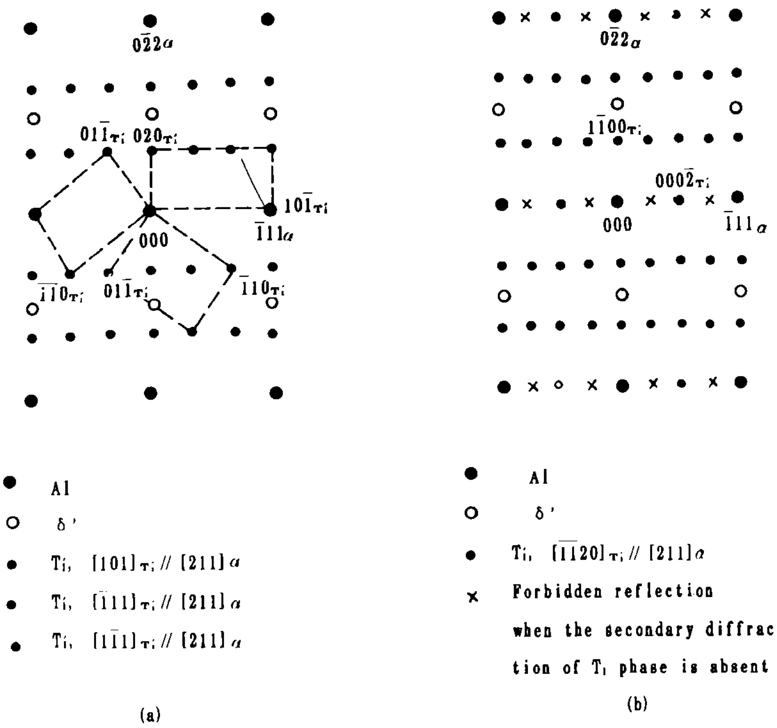


Fig. 3 Comparision of diffraction patterns between (a) T_1' and (b) Ti phase in the $[211]_\alpha$ direction

as follows:

$$B_{111}=\begin{vmatrix}001 & -1 \\ 100 & \\ \bar{1}20 & T_1'\end{vmatrix}\begin{vmatrix}\frac{d_{111}}{d_{00.1}} & 0 & 0 \\ 0 & \frac{d_{1\bar{1}0}}{d_{10.0}} & 0 \\ 0 & 0 & \frac{d_{11\bar{2}}}{d_{\bar{1}2.0}}\end{vmatrix}\begin{vmatrix}111 \\ 1\bar{1}0 \\ 11\bar{2}\end{vmatrix}$$

$$=\begin{vmatrix}0.668 & -0.668 & 0 \\ 0.668 & 0 & -0.668 \\ 0.332 & 0.332 & 0.332\end{vmatrix}$$

The transpositation inverse matrix of the above one is the transformation matrix of the index of parallel planes for double phases:

$$(B_{111}^{T})^{-1}=\begin{vmatrix}0.499 & -0.998 & 0.499 \\ 0.499 & 0.499 & -0.998 \\ 1.004 & 1.004 & 1.004\end{vmatrix}$$

The index of crystralline planes and directions of both phases and the matrix be determined from the following two equations:

$$\begin{vmatrix}u' \\ v' \\ w'\end{vmatrix} = B\begin{vmatrix}u \\ v \\ w\end{vmatrix} \quad (1)$$

$$\begin{vmatrix}h' \\ k' \\ l'\end{vmatrix} = (B^{T})^{-1}\begin{vmatrix}h \\ k \\ l\end{vmatrix} \quad (2)$$

There are four $(111)_\alpha$ planes in the *fcc* lattice, so there are four equivalent orientation relationships between the T_1' and the alloy matrix:

$(00.1)_{T_1'}//(111)_\alpha$ $(00.1)_{T_1'}//(1\bar{1}1)_\alpha$
$(10.0)_{T_1'}//(1\bar{1}0)_\alpha$ $(10.0)_{T_1'}//(110)_\alpha$
$(\bar{1}2.0)_{T_1'}//(11\bar{2})_\alpha$ $(\bar{1}2.0)_{T_1'}//(\bar{1}12)_\alpha$
$(00.1)_{T_1'}//(\bar{1}11)_\alpha$ $(00.1)_{T_1'}//(\bar{1}11)_\alpha$
$(10.0)_{T_1'}//(\bar{1}\bar{1}0)_\alpha$ $(10.0)_{T_1'}//(\bar{1}10)_\alpha$
$(\bar{1}2.0)_{T_1'}//(1\bar{1}2)_\alpha$ $(\bar{1}2.0)_{T_1'}//(\bar{1}\bar{1}2)_\alpha$

The T_1' phases on $(111)_\alpha$, $(1\bar{1}1)_\alpha$, $(\bar{1}11)_\alpha$ and $(\bar{1}11)_\alpha$ planes are referred to as variety 1, variety 2, variety 3 and variety 4 respectively in this paper.

The crystalline zone indexes of the diffraction patterns in Fig. 2 determimed by equations 1, 2 and the transformation matrix for the four varieties with the alloy matrix are shown in Fig. 4. A part of spots of the variety 3 do not appear in the $[\bar{2}110]_{T_1'}$ zone diffraction pattern, for example, the $(0002)_{T_1'}$ spot does not appear at 2/3 $(\bar{1}11)_\alpha$. Both the spots of varieties 2 and 3 in the diffraction patterns of $[10\bar{1}0]_{T_1'}$ and $[\bar{1}010]_{T_1'}$ zones which are parallel to $[110]_\alpha$ are also not observed. Therefore, the structure of T_1' phases is not hexagonal.

Rioja considered that the T_1' phase has orthorhombic lattice and Pt_2Mo structure, with the lattice paramters of $a=0.2876$ nm $b=0.86$ nm, $c=0.406$ nm. The lattice mode of the T_1' phase is shown in Fig. 5.

The orientation relationships between the T_1' phase and the alloy matrix got from Fig. 5 are shown as follows:

$(010)_{T_1'}//(110)_\alpha$, $[001]_{T_1'}//[100]_\alpha$

There are six $\{110\}_\alpha$ planes in *fcc* lattice. It is inferred that there are six kinds of orientation relationships between the T_1' phase and the matix:

$(010)_{T_1'}//(110)_\alpha$ $[001]_{T_1'}//[001]_\alpha$
$(010)_{T_1'}//(\bar{1}10)_\alpha$ $[001]_{T_1'}//[001]_\alpha$
$(010)_{T_1'}//(101)_\alpha$ $[001]_{T_1'}//[010]_\alpha$
$(010)_{T_1'}//(10\bar{1})_\alpha$ $[001]_{T_1'}//[010]_\alpha$
$(010)_{T_1'}//(01\bar{1})_\alpha$ $[001]_{T_1'}//[100]_\alpha$
$(010)_{T_1'}//(\bar{0}11)_\alpha$ $[001]_{T_1'}//[100]_\alpha$

The six groups of parallel crystalline planes and directions can be transformed into three parts of crystalline planes, and the T_1' phases from the six orientations are named variety 1, variety 2, variety 3, variety 4, variety 5 and variety 6 respectively. After determining the transformation matix for the orientation relationships of T_1' phase with the matrix from the above six relationsips,

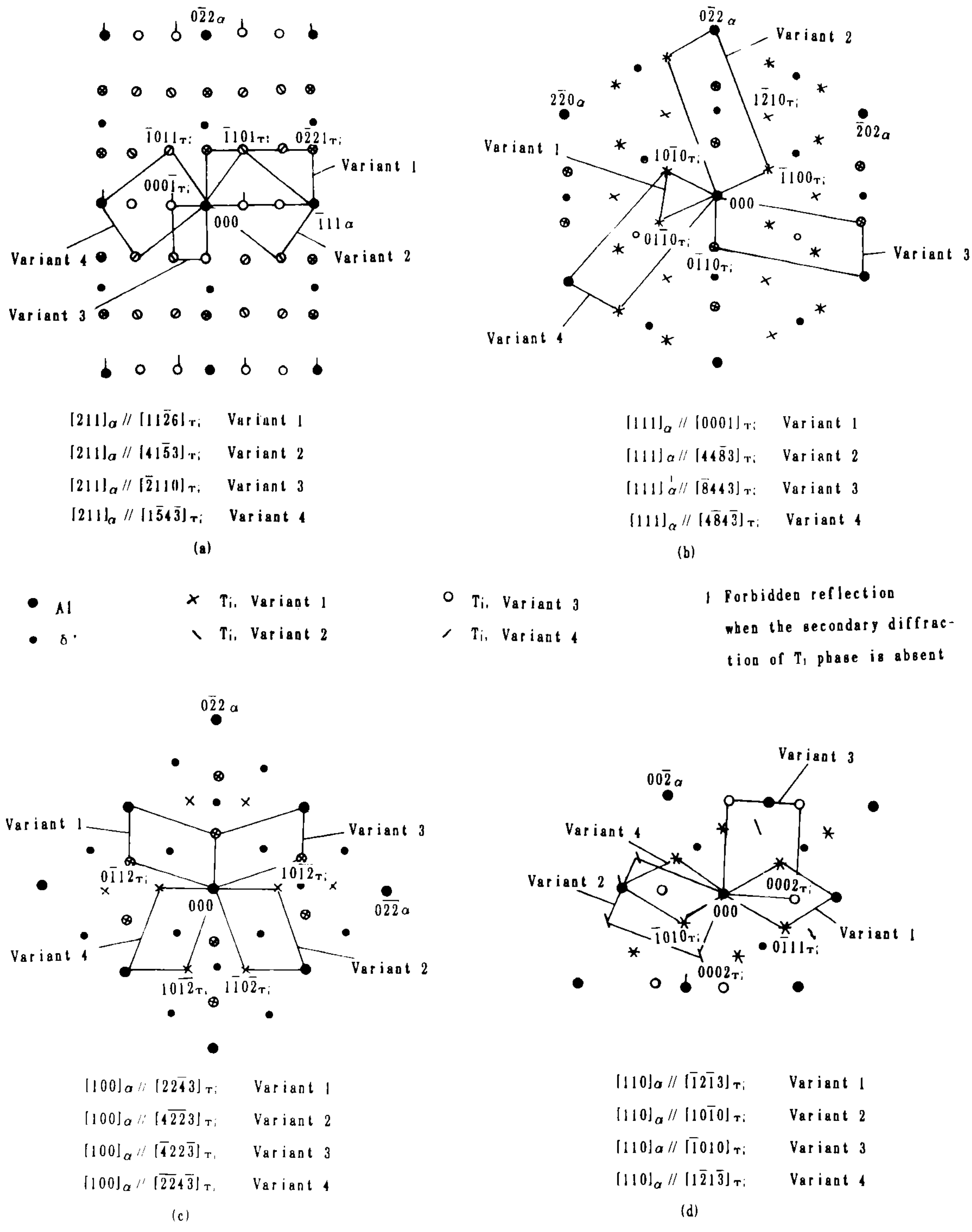


Fig. 4 Electron diffraction patterns of T_1' phase with hexagonal strueture
(a)—$[211]_\alpha$; (b)—$[111]_\alpha$; (c)—$[100]_\alpha$; (d)—$[110]_\alpha$

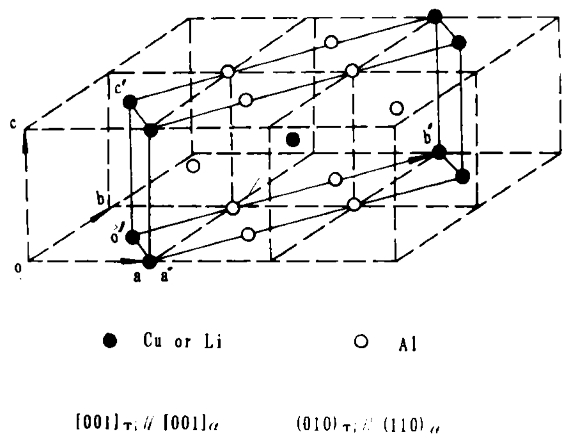


Fig. 5 Lattice model of T_1' phase with orthorhombic atructure

the series of electron diffraction pattern in Fig. 2 are indexed, as shown in Fig. 6.

Expect for the spots indexed according to the alloy matrix, T_1' and δ' phases, the remained weak spots are considered to be the results of secondary diffraction produced by δ' phases, and thus, all the indexings are well explained.

The results of this study show that the T_1' phases has orthorhombic lattice, and habit planes of $\{111\}_\alpha$, which is verified to be right by program of double phases to overlap electron diffraction patterns.

4 CONCLUSION

The T_1' phases are formed in the Al-2.6Li-1.3Cu alloy when aged at 190 ℃. It

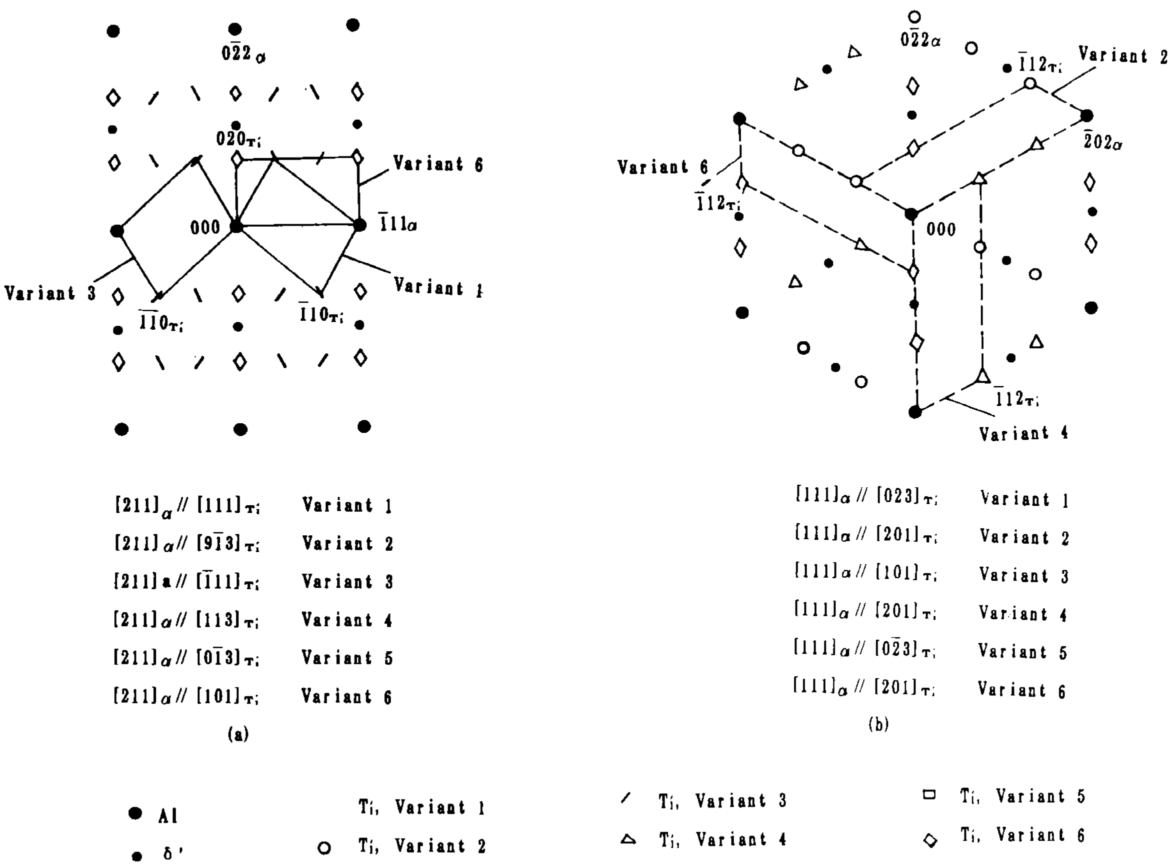
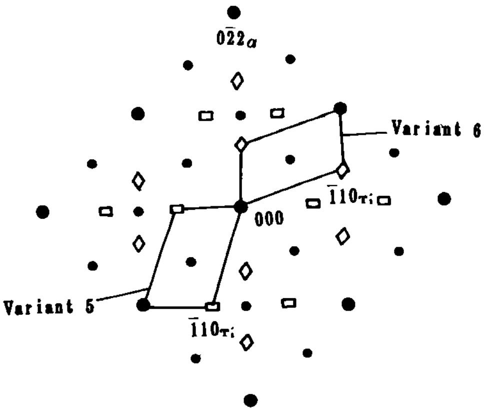
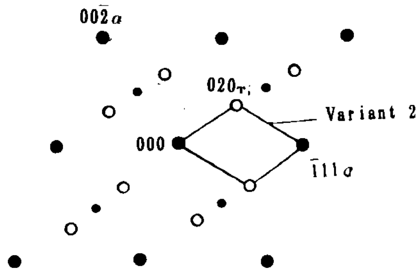


Fig. 6 Electron diffraction patterns of T_1' phase with orthorhombic structure
(a)—$[211]_\alpha$; (b)—$[111]_\alpha$



$[100]_\alpha // [310]_{T_i}$	Variant 1
$[100]_\alpha // [1\bar{3}0]_{T_i}$	Variant 2
$[100]_\alpha // [\bar{3}10]_{T_i}$	Variant 3
$[100]_\alpha // [310]_{T_i}$	Variant 4
$[100]_\alpha // [001]_{T_i}$	Variant 5
$[100]_\alpha // [001]_{T_i}$	Variant 6

(c)



$[110]_\alpha // [010]_{T_i}$	Variant 1
$[110]_\alpha // [100]_{T_i}$	Variant 2
$[110]_\alpha // [\bar{3}13]_{T_i}$	Variant 3
$[110]_\alpha // [313]_{T_i}$	Variant 4
$[110]_\alpha // [\bar{3}\bar{1}3]_{T_i}$	Variant 5
$[110]_\alpha // [3\bar{1}3]_{T_i}$	Variant 6

(d)

Fig. 6 Electron diffraction patlerns of T_1' phase with orthorhombic structure
(c)—$[100]_\alpha$; (d)—$[110]_\alpha$

is verified that this phase has orthorhombic lattice and habit planes of $\{111\}_\alpha$, and six possible orientation relationships with the alloy matrix.

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