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Deformation and Dislocation Structure in $L1_2$ Titanium Trialuminide Alloys

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The deformation behaviour and the nature of dislocations of the Al_3Ti–base $L1_2$ alloys modified with Fe and Mn *etc.* were investigated. The results show that the deformation and fracture characteristics are closely related to the alloy compositions. The effect of hot–working process on the room temperature ductility is remarkable, not only resulting in an appreciable improvement of compressive properties but also showing a 0.28% plastic strain in tensile test. The SISF dissociation of $a<110>$ dislocations on {111} planes was found at room temperature. The determined dissociation scheme is consistent with the mechanical behaviour of these alloys in the lower temperature region.

1. Introduction

Because of the extremely brittle behaviour of the Al_3Ti intermetallic compound, many studies have been conducted in recent years to transform the tetragonal DO_{22} structure of Al_3Ti into the high–symmetrical cubic $L1_2$ structure so as to provide sufficient slip systems for homogeneous deformation. It has been found that by replacing a certain amount of Al in Al_3Ti with Fe, Mn, Cr and Ni *etc.*, one can lead to the $L1_2$ transformation [1—4]. The $L1_2$ ternary Al_3Ti alloys have attractive properties such as low density, relatively good strength at ambient and elevated temperatures [5], and excellent high temperature oxidation resistance [6]. There is improvement in compressive ductility at ambient temperatures, but remaining brittle in tension. So the research effort is still concentrated on ductilizing the $L1_2$ alloys. In this respect, besides exploring further the alloying effect and the fabrication process, it is necessary to examine the deformation characteristics and the nature of dislocations of these alloys for the sake of understanding the intrinsic aspects relating to their brittle behaviour. Research works on the $L1_2$ Al_3Ti alloys have been conducted at Shanghai Jiao Tong University since the late eighties and promising progress has been made in the Fe– and Mn–modified Al_3Ti–base alloys. In this paper, we will report our results on the deformation behaviour and dislocation structures of these alloys.

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2. Plastic Deformation of $L1_2$ Al_3Ti Alloys

2.1 Compressive plasticity of cast alloy

Unlike the DO_{22} Al_3Ti compound which is brittle in compression tests below 870 K [7], the $L1_2$ Al_3Ti–base alloys have shown apparent compressive ductility at ambient temperatures in the cast and homogenized state. Our results give that the ductility of the Ni–modified $Al_{67}Ni_8Ti_{25}$ alloy is lower than that of the Fe–modified $Al_{66}Fe_9Ti_{25}$ alloy, while the $Al_{67}Mn_8Ti_{25}$ has the highest ductility among them. The results also show that the deformation behaviour are closely related to the alloy compositions. For example, $Al_{66}Fe_9Ti$ exhibited about 11% plastic strain, there were flow markings in relief on the specimen surfaces during compression testing and the specimens finally fractured diagonally into two parts [8]. While $Al_{66}Fe_7Ti_{26}$ and $Al_{66}Fe_{11}Ti_{22}$ are quite brittle with only about 5% plastic strain, and the specimens were shuttered into many pieces on failure [9]. The effect of Ni+Mn additions on the compressive properties is shown in Fig.1. The ductility increases with increasing amount of Mn substituted for Ni in the alloys, but the yield strength changes inversely in the range of total (Ni+Mn) content of 8 at.–%.

Fractographic analyses showed that the fracture in $L1_2$ Al_3Ti alloys is transcrystalline and the fracture mode is cleavage in nature, but the fractograph of the alloys with better compressive ductility such as $Al_{66}Fe_9Ti_{24}$ and $Al_{67}Mn_8Ti_{25}$ exhibits the features of quasicleavage and tearing, as shown in Fig.2(a), where the microscopic irregularities of quasicleavage surface and the linking tear ridges are apparent. Curved subsurfaces with dense steps of slip bands can be observed under higher magnification [Fig.2(b)], illustrating that there was evident deformation occurred before fracture.

2.2 Ductility of hot–worked alloy

Samples for the hot–workability upsetting tests were cut from the induction melted $Al_{67}Mn_8Ti_{25}$ ingot which had been homogenized at 1373 K for 50 h. The results are shown in Fig.3. The deformation at 1173 K was limited to about 20% reduction, micro–cracks were found in the 34% reduced samples. At 1273 K, the alloy shows good hot–workability, reduction up to 59% can be made by a single stroke without surface– or micro–cracking. Since the metallurgical quality of the induction melted ingot is not so good as the arc–melted button ingots, the compressive ductility of the cast and homogenized $Al_{67}Mn_8Ti_{25}$ specimens is about 12% which is much lower than the 17% of the arc–melted specimens. But the ductility is markedly improved by hot–working. Typical load–deformation curves are shown in Fig.4, and the effect of hot deformation on the compressive ductility can be seen in Fig.5. It is found that the ductility is not improved until the reduction increased to 34%, and remarkable improvement is obtained when the reduction is over 50%. The compressive plastic strain increases from 12% in the cast state to 19% of the hot–worked specimens.

It is interesting to find that the hot–worked alloy has shown plastic strain under tension even though it is very small. Figure 6 is a typical stress–strain curve recorded from the output of resistance strain gage during tensile testing, which revealed an elastic deformation region followed by the smooth parabolic portion of plastic strain. The measured plastic strain is 0.28%, this is the uniform plastic strain of the tensile specimen since the fracture occurred outside the strain gage measuring portion. Neither fibrous zone nor shear lip could be found on the fracture surface, indicating the brittle

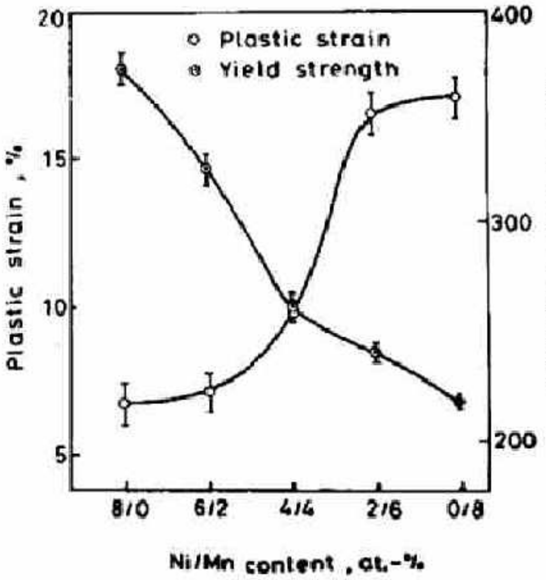

Fig.1 Compressive ductility and yield stress of Al_3Ti–base alloys with various Ni / Mn contents (at.–%), tested at room temperature

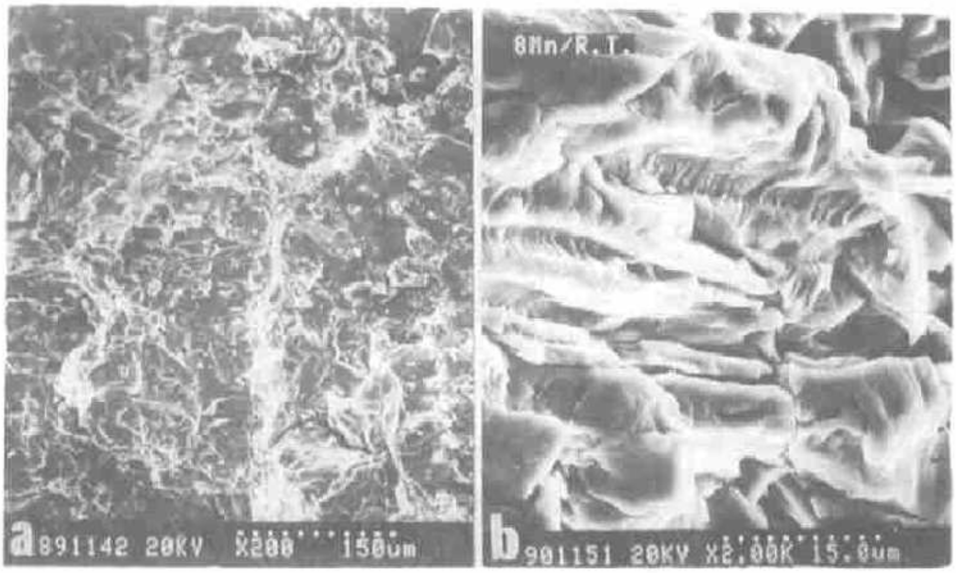

Fig.2 SEM fractographs of the compression tested specimens
(a) $Al_{66}Fe_9Ti_{24}$, (b) $Al_{67}Mn_8Ti_{25}$

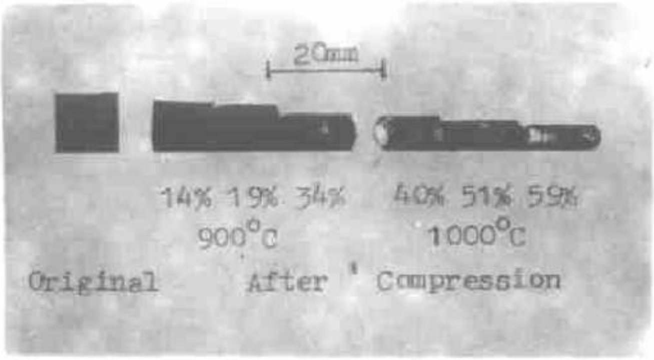

Fig.3 Hot-workability of $Al_{67}Mn_8Ti_{25}$ by upsetting tests

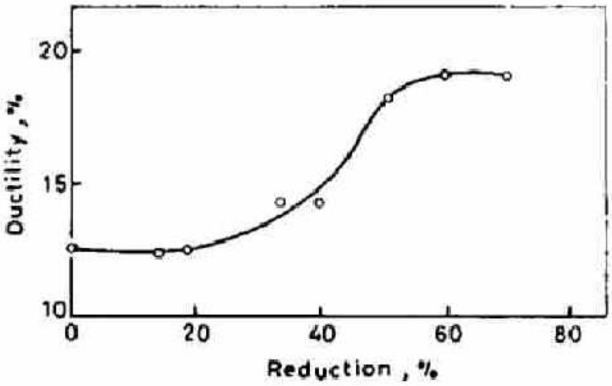

Fig.5 Relation between room temperature compressive ductility and hot-work reduction of $Al_{67}Mn_xTi_{25}$ alloy after annealing at 1273 K / 2 h

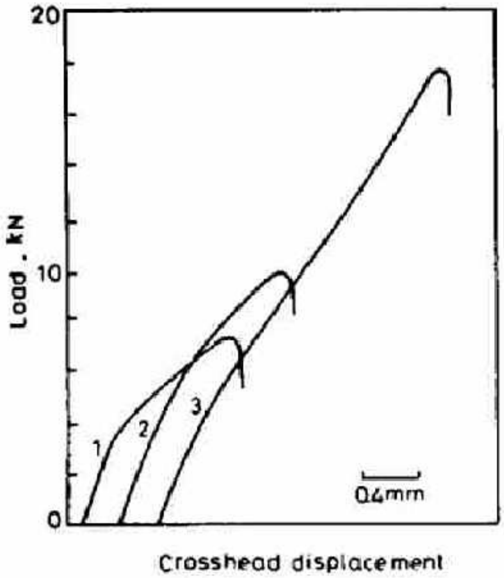

Fig.4 Typical load-deformation curves of $Al_{67}Mn_8Ti_{25}$ compression tested at room temperature.
1—cast and homogenized. 2—19% hot-pressed and 1273 K / 2 h annealed. 3—60% hot-pressed and 1273 K / 2 h annealed

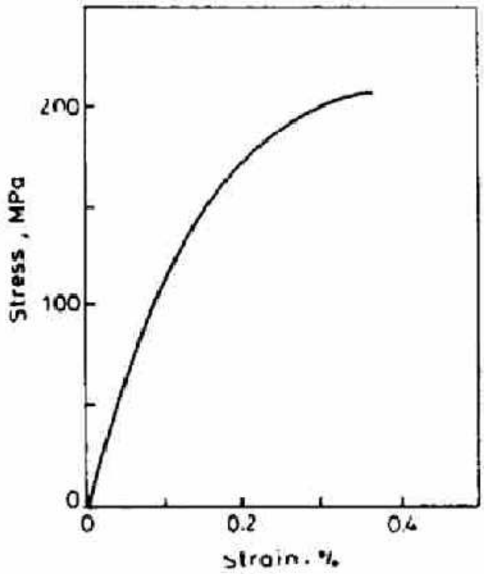

Fig.6 Tensile stress-strain curve of $Al_{67}Mn_8Ti_{25}$ alloy, 70% hot-pressed and 1273 K / 2 h annealed

response of the material. High magnified SEM observations revealed that the fracture mode is predominantly cleavage, but some traces of plastic deformation could be found in the cleavage ledges as shown in Fig.7. This feature, associated with the small but definite plastic strain in the tensile tests, provided evidence that the hot-worked Al_3Ti-base alloy may have potential tensile ductility.

3. Dislocation Structures

To elucidate the deformation mechanism of the $L1_2$ Al_3Ti-base alloys, dislocation structure should be studied. However, only limited TEM investigations on these alloys have been reported,

Fig.7 SEM fractograph of tensile tested $Al_{67}Mn_8Ti_{25}$ specimen

and the results so far are controversial. Earlier observations on room temperature deformed $Al_{67}Ni_8Ti_{25}$ [2,10] or Al_5Ti_2Fe [11] samples concluded that the $a<110>$ superdislocations on {111} slip planes are undissociated. Further works on the $Al_{66}Fe_6V_5Ti_{23}$ [12], $Al_{67.5}Ti_{25}Fe_{7.5}$ [13], or Al_5Ti_2Fe [14,15] alloys have shown that at room temperature the $a<110>$ dislocations tend to dissociate into $a/2<110>$ partials on {111} planes separated by antiphase boundary (APB). While our analyses on the $Al_{66}Fe_9Ti_{24}$ alloy found out that the dissociation is of the $a/3<112>$-type with superlattice intrinsic stacking fault (SISF) between the dissociated partials on {111} planes [8,16], the same result has been reported by Inui *et al.* for the $Al_{67}Fe_8Ti_{25}$ alloy [17]. Therefore, it is necessary to conduct more TEM study to determine the dissociation scheme of the superdislocations in $L1_2$ Al_3Ti alloys. On this account, we have performed further TEM works on the room

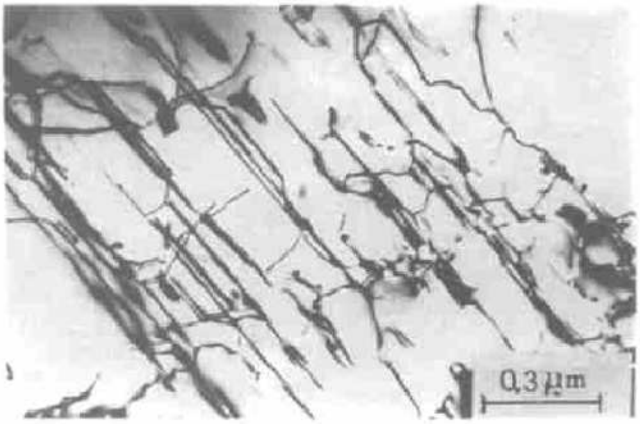

Fig.8 Dislocation structure in $Al_{67}Mn_8Ti_{25}$ deformed at room temperature

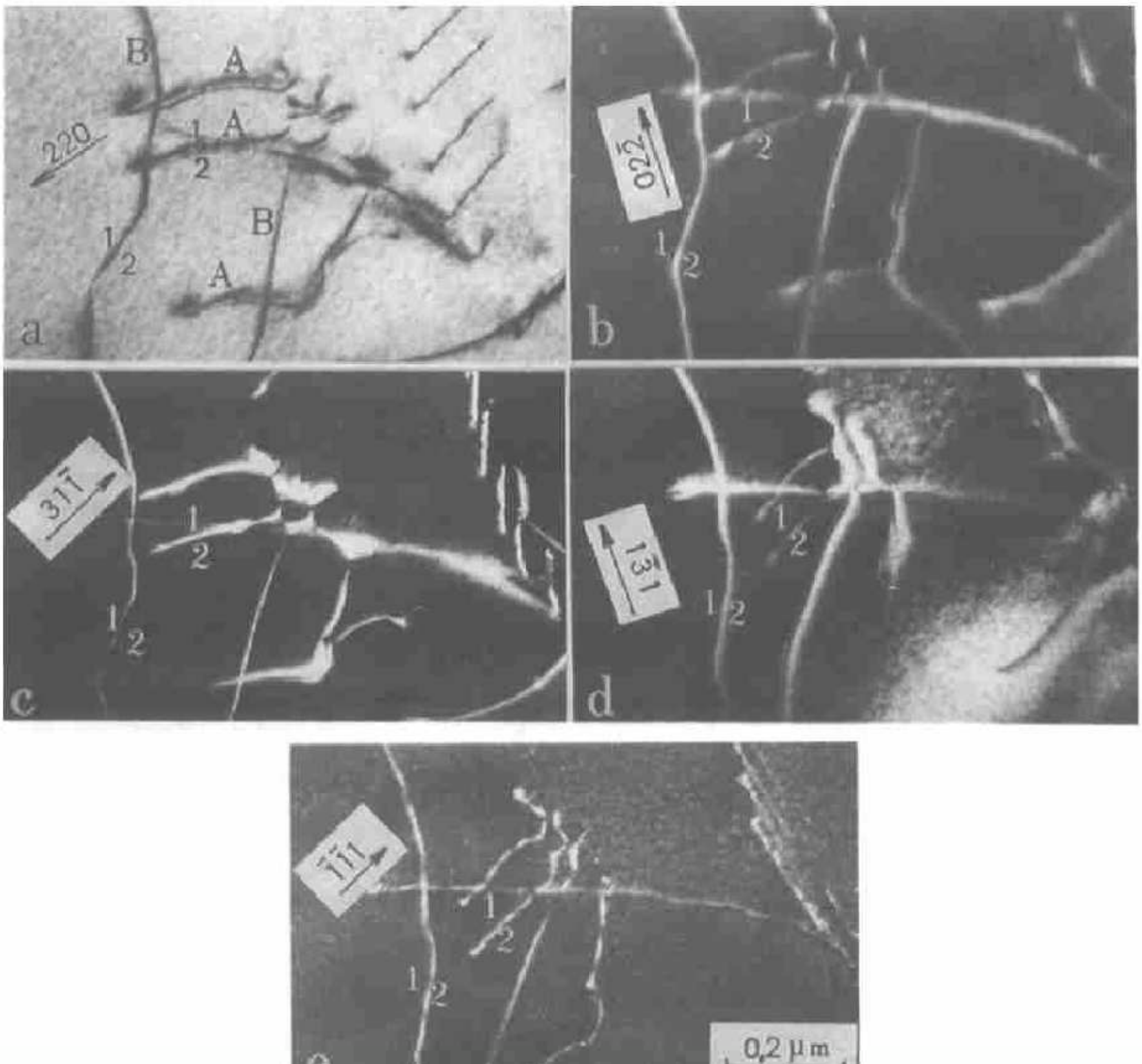

Fig.9 TEM micrographs for contrast analysis of the superdislocations in $Al_{67}Mn_8Ti_{25}$ after room temperature deformation

Table 1 **g** · **b** values for the dislocations formed by room temperature deformation under different reflections

g	A 1 (b=1/3[211]) obser.	g·b	A 2 (b=1/3[12$\bar{1}$]) obser.	g·b	B 1 (b=1/3[$\bar{1}\bar{2}$1]) obser.	g·b	B 2 (b=1/3[1$\bar{1}$2]) obser.	g·b	Fig.
220	V.	2	V.	2	V.	−2	I.V.	0	9(a)
02$\bar{2}$	I.V.	0	V.	2	V.	−2	V.	−2	9(b)
31$\bar{1}$	V.	2	V.	2	V.	−2	I.V.	0	9(c)
3$\bar{1}$1	V.	2	I.V.	0	I.V.	0	V.	2	
1$\bar{3}$1	I.V.	0	V.	−2	V.	2	V.	2	9(d)
$\bar{1}\bar{1}$1	R.C.	−2/3	V.	−4/3	R.C.	4/3	V.	2/3	9(e)

Note: V.—visible, I.V.—invisible, R.C.—residual contrast

temperature deformed $Al_{66}Fe_9Ti_{24}$ alloy to check our previous results. It is confirmed that the $a<110>$ superdislocations dissociated into two $a/3<112>$ superpartials separated by SISF on the {111} planes [18]. Since the studies reported so far are mostly working on the Fe–modified Al_3Ti–base alloys, we have also examined the dislocations in a Mn–modified $Al_{67}Mn_8Ti_{25}$ alloy which has shown better ductility than the Fe–modified alloys.

The samples of room temperature deformed $Al_{67}Mn_8Ti_{25}$ were studied by TEM using conventional and weak beam techniques. The general feature of dislocation structure is shown in Fig.8, the dipoles (D) can be distinguished from the superdislocation pairs by operating with **g** and −**g**, or **s** and −**s**, respectively. Superdislocations A and B were chosen for analysis. Trace analysis through a series of dislocation images taken with different beam directions determined that both A and B are lying on ($\bar{1}$11) plane. The dislocation core structure was studied by the diffraction contrast analysis using various reflections. Typical TEM micrographs are shown in Fig.9 and **g** · **b** values for the superpartials are listed in Table 1. It is found that the superdislocations formed in $Al_{67}Mn_8Ti_{25}$ by deformation at room temperature are also dissociated into $a/3<112>$ superpartials on {111} planes with SISF between them. For the dislocation A: $a[110] \rightarrow a/3[211]$+SISF+$a/3[12\bar{1}]$, and for **B**: $a[011] \rightarrow a/3[\bar{1}\bar{2}1]$+SISF+$a/3[1\bar{1}2]$.

The dissociation scheme of the superdislocations has great influence on the deformation behaviour of $L1_2$ alloys. The $a<110>$ superdislocations in ductile Ni_3Al alloy split into two APB–coupled $a/2<110>$ superpartials. It has been shown by atomistic modeling [19] that when $a/2<110>$ superpartials with APB on {111} planes, one of the three core configurations of $a/2<110>$ is glissile with the core spreading on {111} planes. On the other hand, the atomistic modeling gives that the dislocation core structure of $a/3<112>$ superpartials is non–planar so the superdislocations are sessile and are moved by thermally activated process. The low ductility of $L1_2$ Al_3Ti–base alloys can be explained in terms of their SISF type dissociation. It has been reported that the $Al_{66}Fe_9Ti_{24}$ alloy shows rapid increase of flow stress with decreasing temperature in the low temperature region [20]. Such temperature dependence is also related to the SISF type dissociation [21]. The fact that a SISF dissociation is rather consistent with the mechanical behaviour of the Al_3Ti–base alloys further supports our TEM results.

4. Conclusions

(1) The ductility of $L1_2$ type Al_3Ti–base alloys is closely related to the alloy compositions. Hot–working improves the ductility appreciably, a small but definite plastic strain has been measured in the tensile test of the hot–worked $Al_{67}Mn_8Ti_{25}$ alloy.

(2) It is confirmed by further TEM studies that the $a<110>$ superdislocations in room temperature deformed Fe– and Mn–modified $L1_2$ Al_3Ti alloys dissociated into two $a/3<112>$ superpartials with SISF between them on {111} planes.

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