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Relating the mechanical properties of a pseudo-binary a $L1_2$ alloy to the deformation induced microstructure

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Abstract

Compressive tests at a constant strain rate conducted on a pseudo-binary $L1_2$ $Ni_{55}Fe_{20}Ge_{25}$ intermetallic in a wide range of temperatures (from room temperature to 823 K) show the occurrence of a positive flow stress anomaly behaviour with a peak of flow stress occurring around 600 K. The induced dislocation substructures (morphology and core) were investigated by means of transmission electron microscopy (TEM) in weak beam conditions. In the domain of the increase of the flow stress, the dislocation substructure consists of screw dislocations locked in a Kear-Wilsdorf (KW) configurations as commonly observed in $L1_2$ alloys. With increasing temperature, gliding superdislocations are found to interact strongly with dislocations, in complete KW configurations. This interaction leads to a non-negligible quantity of dislocation dipoles. In the domain of the decrease of the flow stress, the most striking feature was the presence of a relatively high density of superlattice stacking faults. A close observation shows that the faulted defects exhibit in fact two linked faulted ribbons of unequal widths bounded by three superpartials having the same $1/3\langle 112\rangle$ Burgers vector and lying in the same plane. The observed mechanical behaviour is discussed in relation with the TEM investigations.

Keywords: Intermetallic; Superdislocation; Anomalous behaviour; Stacking fault

1. Introduction

The mechanical behaviour of a number of $L1_2$ compounds has been widely studied and classified into two types of compounds: (a) those exhibiting the so-called anomalous behaviour; and (b) those exhibiting a 'normal' behaviour. For example Ni_3Ge [1,2] belongs to the first kind of compound while Fe_3Ge [3] belongs to the second one. The work by Suzuki et al. [4] shows that the progressive substitution of Ni atoms by Fe atoms in the Ni_3Ge system leads to a variety of intermetallic alloys of $(Ni_XFe_{1-X})_3Ge$ types all having a $L1_2$ structure. The effect of this substitution on the mechanical behaviour has been also studied. It was shown that up to a concentration of about 27.5 at.% of Fe the pseudo binary compound exhibits the positive temperature dependence of the flow stress. Above, the alloy exhibits the behaviour similar to that of the Fe_3Ge that is a negative temperature dependence of the flow stress. It is well known that the observed mechanical behaviour has to do with the dislocation microstructure and the dissociation mode because it may impose the dislocation to glide in specific planes, affecting cross slip as well. Although TEM studies of dislocations core structure are widely documented in the literature as far as Ni_3Ge and Fe_3Ge compound are concerned [3,5], investigations concerning $(Ni_XFe_{1-X})_3Ge$ compounds are scarce [6]. It is the aim of the present study to correlate the dislocation core substructure investigation by TEM with the observed macroscopic behaviour of one alloy in the $(Ni_XFe_{1-X})_3Ge$ system.

2. Experimental procedures

The studied alloy is polycrystalline $Ni_{55}Fe_{20}Ge_{25}$ prepared on the basis of the procedure given by Ref. [4]. It was strained at room temperature, 473, 623 and 823 K (thus below and above the peak stress anomaly temper-

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Table 1
KW configurations (complete or incomplete) were intensively observed in the deformation induced microstructure

Temperature (K)	RT	623[a]	823
$\sigma_{0.2}$ (MPa)	700	800	560
$\sigma_{0.2}$ (MPa) by Ref. [4]	700	900	800
$\sigma_{0.2}$ (MPa) by Ref. [7]	700	780	500

[a] Dependence of the flow stress at 0.2% offset with temperature.

ature) under uniaxial compression for about 2% of permanent strain and at a nominal strain rate of 2×10^{-4} s^{-1}. Specimens for TEM investigations were prepared as in Ref. [6] and examined in a JEOL 200 CX electron microscope operating at 200 kV under weak beam conditions.

3. Results and discussion

3.1. Macroscopic behaviour

The results of the compressive tests together with results by Refs [4,7] for comparison are shown in Table 1. It confirms the existence of a positive temperature dependence of the flow stress which reaches a peak value of 800 MPa at a temperature around 600 K. These values are slightly in contrast from those by Ref. [4] (720 K for the peak temperature and 950 MPa for the flow stress for this alloy composition), but are in good agreement with those by Ref. [7]. Moreover, the flow stress value at room temperature (RT) is found to be greater for $Ni_{55}Fe_{20}Ge_{25}$ than for the iron-free Ni_3Ge compound (500 MPa at RT, not shown here). It shows that at low temperature replacing Ni by Fe increases the flow stress level. This effect is actually due to Fe promoting cross slip in the cubic plane. As shown by Balk [7], the complex stacking fault energy between the Shockley partials (due to the dissociation of the a/2$\langle 110\rangle$ superpartials) increases when Ni is replaced by Fe. It allows the leading superpartial to constrict more easily and so to cross slip in the cubic plane and form KW configurations.

3.2. Microstructural evolution

Fig. 1a shows the deformation-induced dislocation structures at RT. It consists mostly of screw dislocations with $[0\bar{1}1]$ Burgers vector dissociated in the (100) plane. Thus they are locked in KW configurations as commonly observed in $L1_2$ alloys in this temperature regime. Curved segments that ensure the overall mobility link some of the locked screw components (incomplete KW configurations).

As the temperature of the test is raised there is a change in the dislocation pattern Fig. 1b is an example of the dislocation substructure at 623 K, which shows a superdislocation bowing out between 'forest' dislocations. The dislocation has a $[\bar{1}10]$ Burgers vector and is gliding on the $(\bar{1}\bar{1}1)$ plane. The movement of the gliding dislocation is impeded by numerous interactions along the dislocation line. Straight dislocations in the screw

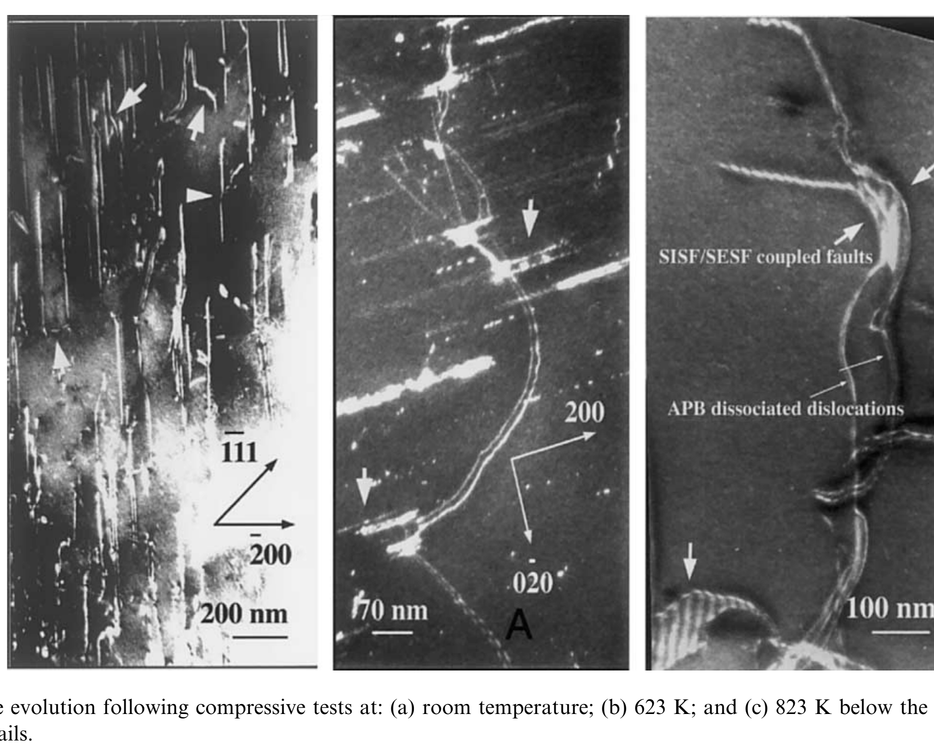

Fig. 1. Microstructure evolution following compressive tests at: (a) room temperature; (b) 623 K; and (c) 823 K below the peak temperature. See the text for more details.

orientation are seen exhibiting a single contrast. These are complete KW configurations dissociated in the (010) plane. The driving force for the dissociation in the cube plane is the reduction in the antiphase boundary (APB) energy γ^{APB} which is lower in {001} planes than in the octahedral {111} planes. Segment A, which is in a screw orientation, is dissociated in the (001) plane. The measured dissociation width of about 6 nm lead to estimated antiphase boundary energy (APB) on (001) of about 124 mJ mm^{-2} in agreement with Ref. [7]. The configurations at this temperature being almost always observed dissociated in {001} planes it was not possible to get a reproducible value of the dissociation width in the {111} planes, preventing us to calculate γ^{APB} on {111} planes.

Significant changes occur with a further increase of the temperature test. First it is found that most of the dislocations are dissociated and gliding in {100} planes. Secondly another kind of feature occurs: dislocations are dissociated onto three partials bordering a double ribbon of stacking fault of unequal width. These faults are in fact coupled intrinsic/extrinsic faults according to a two step mechanism [8]: (i) interaction of two APB dissociated $\langle 110\rangle$ superdislocations leading to a $\langle 112\rangle$ type-dislocation; and (ii) the dissociation of the $\langle 112\rangle$ product dislocation onto three identical Schokley partials in the same plane {111} according to:

$$\langle 112\rangle \rightarrow \tfrac{1}{3}\langle 112\rangle + \mathrm{SISF} + \tfrac{1}{3}\langle 112\rangle + \mathrm{SESF} + \tfrac{1}{3}\langle 112\rangle$$

This configuration should move easily to move under straining because the dislocations and the related faults are all located in the same octahedral plane.

4. Conclusions

Compressive tests conducted on a polycrystalline $Ni_{55}Fe_{20}Ge_{25}$ intermetallic compound confirmed the existence of an anomalous behaviour in the flow stress versus temperature diagram as reported elsewhere [4,6,7]. The flow stress peak temperature occurs at about 600 K in agreement with previous studies [6,7] but is 100 K below the value given by Ref. [4]. This may be due to the quality of the single crystals or the initial microstructure (grain size, grain morphology).

The present study shows that the observed macroscopic anomalous behavior of the $Ni_{55}Fe_{20}Ge_{25}$ alloy can be related to the induced deformation microstructure in the way of most $L1_2$ alloys, that is screw dislocation segments locked in KW configurations. Post-mortem TEM investigations pointed out dislocations locked in KW configurations (complete and incomplete) in the domain of the flow stress anomaly. Also, dislocation-dislocation interactions were found. In particular, dislocations gliding on the octahedral plane are found to interact with dislocations in KW configurations. Above the peak temperature features which consist of coupled SISF/SESF faults occur together with glide of dissociated superdislocations on {111} type plane as well as on {010}. This can be related to the decrease of the flow stress with increasing temperature.

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