MECHANICAL BEHAVIOUR OF ALUMINIUM-LITHIUM SINGLE CRYSTALS AT 77 K

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Abstract

A series of tensile tests of binary aluminium-lithium single crystals with different heat treatments (underaged, peak-aged, overaged) were performed at 77 K and at room temperature. Load-displacement curves were recorded and analysed, critical resolved shear stress and strain hardening rates were calculated, microstructures were carefully observed with TEM. It was found that the critical resolved shear stresses at low temperature are different from that at room temperature and also different for the different temper. The strain hardening rates of the crystals at low temperature are higher than that at room temperature. Based on the experimental observations, explanation was proposed for rationalizing the results.

Introduction

Aluminium-Lithium alloys exhibit higher strength and better ductility at low temperature than that at room temperature. The reason for the improvement of mechanical properties of aluminium-lithium alloys at low temperature is still not well understood. Several mechanisms were proposed in the published literature. Miura et al attributed it to the $L1_2$ structure of precipitates (1-3). Webster emphasized the role of grain boundary impurities, especially Na and K(4). Glazer et al found the hardening rate of the materials at room temperature was lower than that at low temperature(5). In general, the matrix, the precipitates and the grain boundary all have influence on the phenomenon. In order to clarify the mechanism, aluminium-lithium binary single crystals were chosen in the present work to remove the influence of grain boundary.

Experimental Procedures

Single crystals were grown with a modified Bridgeman method, details of which were given in our previous paper(6). The dimensions of the specimen were 10 mm in gauge length, except No.13 and No.14 specimens with 13 mm gauge length,and 4 mm × 4 mm in cross section. All specimens were solid solution treated at 510 °C for 30 min, then quenched into ambient temperature water. Specimens were aged at 175 °C for 20 hrs as underaged ones (UA), for 48 hrs as peak-aged ones (PA), and aged at 200 °C for 120 hrs as overaged ones (OA).

The chemical composition, crystal orientation, temper and testing temperature of different crystals are listed in Table 1.

Table 1. Identification and conditions of the sppecimens

Specimen No.	Chemical Composition	Orientation	Temper	Testing Temperature
13	2.12%	[013]	UA	298K
14	2.12%	[013]	UA	77K
3	2.05%	[851]	PA	298K
4	2.05%	[851]	PA	77K
5	2.15%	[311]	OA	298K
6	2.15%	[311]	OA	77K
7	2.08%	[231]	UA	77K
8	2.08%	[231]	PA	77K
9	2.08%	[231]	OA	77K

Tensile tests were conducted with a 50KN MTS-880 machine by displacement control. The nominal strain rate was $\sim 2 \times 10^{-4}$ s^{-1}. Load-displacement curves were recorded. The microstructure of the specimens before and after the tests was observed with a Hitachi 800 transmission electron microscopy.

Results

Tensile properties of the specimens are listed in Table 2.

Table 2. Tensile properties of the crystals

Specimen No.	Yield Strength (MPa)	UTS (MPa)	Elongation (%)	Hardening Coeffient n
13	112	237	>79.2	0.33
14	124	330	>100	0.45
3	118	231	>59.6	0.24
4	134	306	>79.7	0.37
5	105	229	>28.8	0.39
6	83	346	>60.6	0.65
7	112	427	86.8	0.60
8	119	399	71.0	0.59
9	86	404	74.1	0.61

Load-displacement curves of the different heat-treated crystals at room temperature and 77 K were shown in Fig.1-3. Curves of hardening rate versus strain of the crystals at room temperature and 77K derived from the load-displacement curves are shown in Fig.4-6.

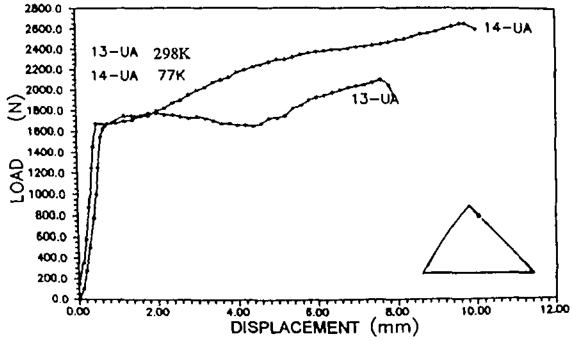

Fig.1. Load-displacement curves of UA samples at 298K and 77K

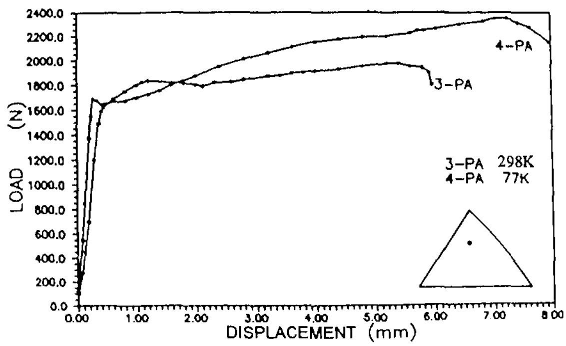

Fig.2. Load-displacement curves of PA samples at 298K and 77K

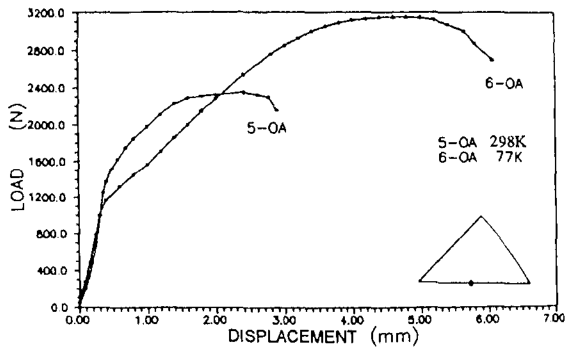

Fig.3. Load-displacement curves of OA samples at 298K and 77K

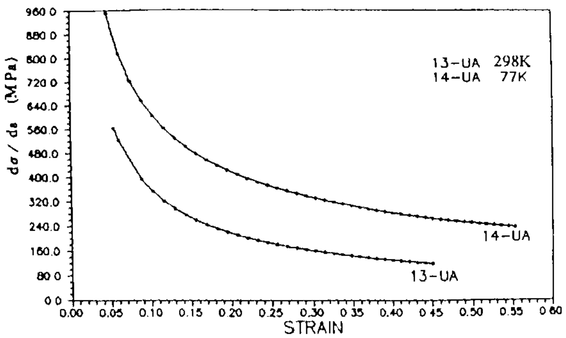

Fig.4. Hardening rate curves of UA samples at 298K and 77K

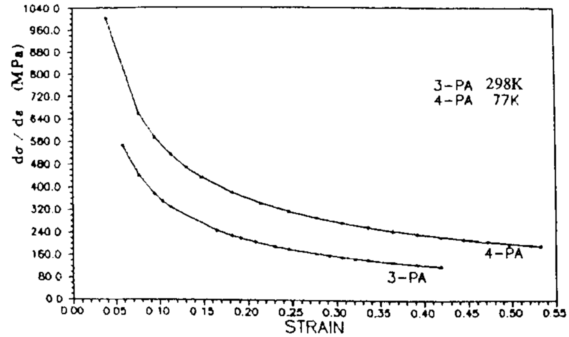

Fig.5. Hardening rate curves of PA samples at 298K and 77K

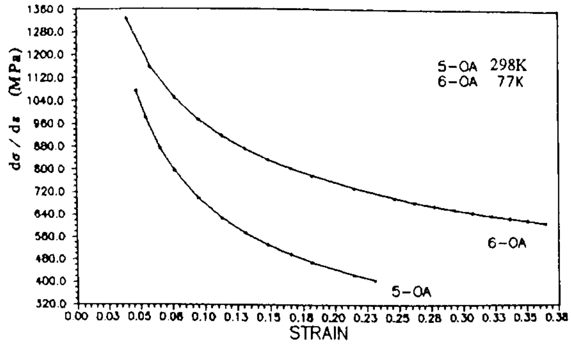

Fig.6. Hardening rate curves of OA samples at 298K and 77K

The typical dislocation configuration and precipitates are shown in Fig.7 and 8.

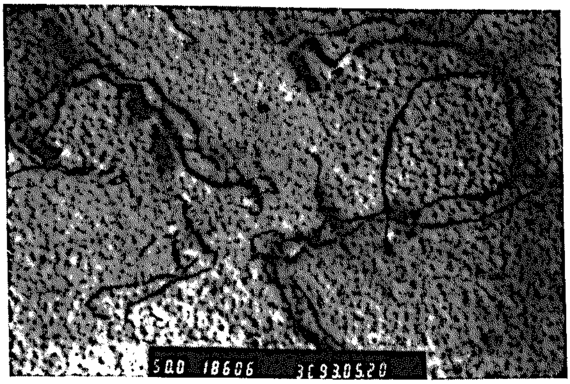

Fig.7. Dislocation strucure of UA sample at 298K

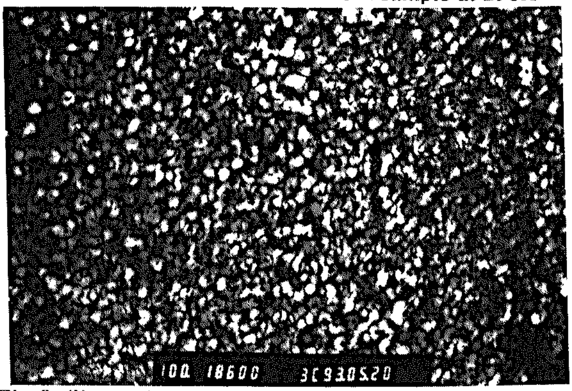

Fig.8. δ' precipitates of UA sample deformed at 77K

Discussion

Higher Strength and Better Ductility at Low Temperature

It is very clear from Fig.1-3 that the mechanical properties of aluminium-lithium single crystal at low temperature are improved, i.e. its strength is higher and its ductility is better at 77 K than that at room temperature. But, the critical resolved shear stress of the aluminium-lithium single crystal at 77 K was not alway higher than that at room temperature, Table 3. The reason is not clear.

Higher Hardening Rate at Low Temperature

The most impressive phenomenon of the results is that the strain hardening exponent of the crystal at 77 K is much higher than that at room temperature, Table 2, as well as the strain hardening rate, Fig.4-6. This should be the reason for the better ductility and high strength in turn.

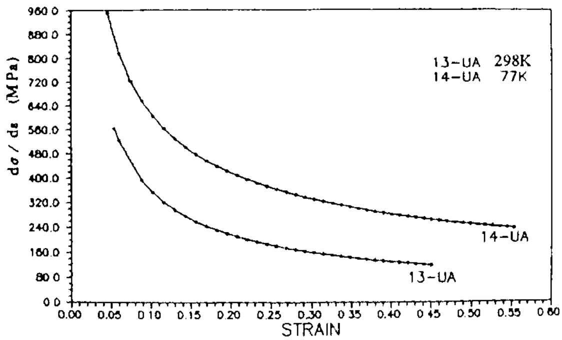

Fig.4. Hardening rate curves of UA samples at 298K and 77K

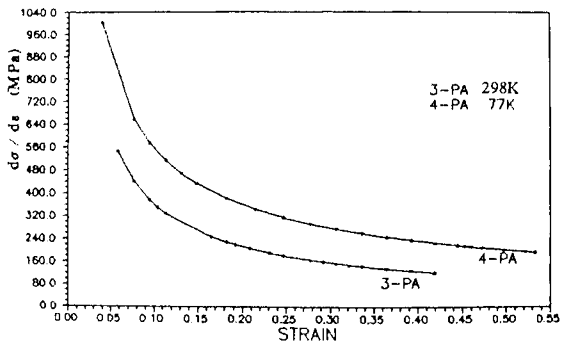

Fig.5. Hardening rate curves of PA samples at 298K and 77K

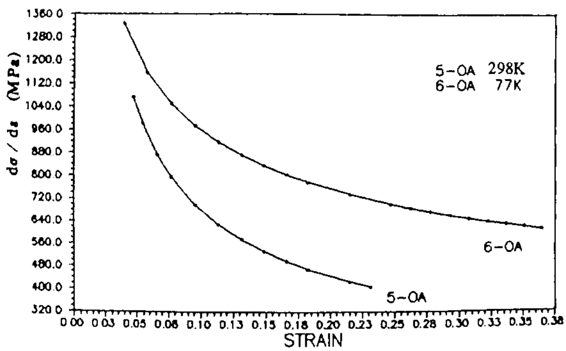

Fig.6. Hardening rate curves of OA samples at 298K and 77K

The typical dislocation configuration and precipitates are shown in Fig.7 and 8.

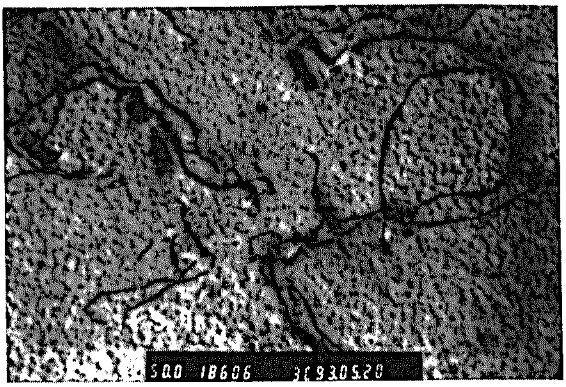

Fig.7. Dislocation strucure of UA sample at 298K

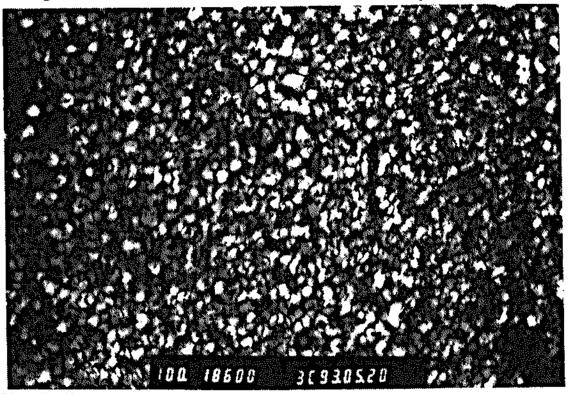

Fig.8. δ' precipitates of UA sample deformed at 77K

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Table 3. Critical resolved shear stress of Al-Li single crystals

Test Temperature	UA	PA	OA
298K	54.77MPa	19.38MPa	23.18MPa
77K	60.79MPa	21.92MPa	18.17MPa

Less dependent on temper at low temperature

Another impressive phenomenon of the results is shown in Fig.9. At low temperature the load-displacement curves of different heat-treated single crystals were less dependent on temper.

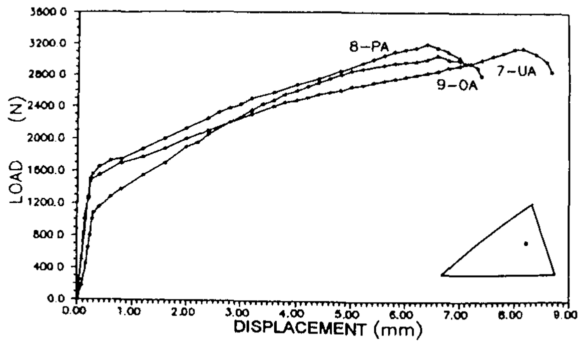

Fig.9. Load-displacement curves of the different heat-treated single crystals at 77K

Conclusions

The strain hardening exponent and the strain hardening rate of Al-Li single crystals at 77K are much higher than those at 298K. As a result, Al-Li single crystals exhibited better ductility and high strengh at 77K.

Acknowledgment

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References

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