LOW CYCLE FATIGUE OF BINARY Al-Li ALLOYS: III-COALESCENCE OF δ' PRECIPITATES IN FATIGUE: X-RAY LOW ANGLE SCATTERING INVESTIGATION

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ABSTRACT

Al 2.5 wt% Li binary alloys with small δ' precipitates ($R \sim 10$ Å) were cyclically deformed in torsion at constant applied strain amplitude $\Delta\varepsilon$, with the same strain rate $\dot{\varepsilon}$. The size of δ' precipitates was measured before and after fatigue by X ray low angle scattering. We have shown by this method that an enhanced coalescence takes place during fatigue.

It is concluded that the behaviour of δ' precipitates during fatigue is governed by two competing phenomena : the dissolution induced by shearing, and the coalescence induced by sursaturation of point defects produced by fatigue.

INTRODUCTION

The behaviour of δ' precipitation related to plastic localization has been studied in paper II. The purpose of this paper is now to investigate the average behaviour of this second phase in alloys submitted to torsion cyclic loading at room temperature (the macroscopic results of this mechanical testing are to be found in paper I).

Plastic straining is known to produce an excess in point defects (1) and therefore to enhance diffusion of solute atoms. The δ' coarsening is known to follow (2,3) very accurately a Lifschitz Slyosov Wagner kinetics (4) one expects plastic fatigue to increase the rate of precipitate coarsening (5,6).

MATERIALS and EXPERIMENTAL PROCEDURE

The experiments were carried out on the same alloys used for mechanical testing (paper I) before and after fatigue. The Al2.5% wt Li alloys were heat treated at 100°C during 1h (sample A) 1h30 (sample B) 2h00 (sample C) 8h00 (sample D). The fatigue tests were performed till rupture at applied strain amplitude in torsion of 0.3%, 0.5% and 0.8%. The strain rate was kept constant from an amplitude to another one, so that the period had to be changed. For each test the stress amplitude and the number of cycle to rupture (table 1) were measured.

The radii of δ' precipitates were too small to be accurately measured by T.E.M. but were investigated by small angle X Ray scattering.

In the small angle X Ray apparatus a copper source ($\lambda = 0.1542$nm) has been used, with a Ni filter to eliminate the K_β parasitic radiation. Our beam had a point focus geometry. Scattering intensity was collected on a position sensitive detector in the $q (= 4\pi \sin\theta / \lambda)$ range from 0.15 to 6nm^{-1} spectra were recorded and treated by a Solar minicomputer. Calibration of the experiment has been done by careful measurements of the beam intensity with Ni filters. Corrections were applied for background, brehmstrahlung, sample absorbtion and geometrical effects.

RESULTS

The average radius was estimated from the maxima of the curves $q^2 I(q)$ and of $q^4 I(q)$. The fatigue tests were performed at a strain rate $\dot{\varepsilon} = 10^{-3}\ s^{-1}$. The mean amplitude in stress was taken to be equal to the arithmetic mean between maximum stress amplitude and stress to failure (cf paper I) (to take into account the light softening).

TABLE 1 gives the average radius before and after fatigue for each sample

heat treatment	strain amplitude $\Delta\varepsilon/2$	mean stress amplitude $\Delta\sigma/2$	Number of cycles to failure	Lasting of the test	average radius of δ 'precipitates (A)
A	before fatigue				R_o = 8.5
A	0.3 %	94.5 MPa	1430	17160 s	R = 13.5
A	0.5 %	105.5 MPa	400	10000 s	R = 11
B	before fatigue				R_o = 8
B	0.3 %	89.5 MPa	4050	48600 s	R = 15
B	0.5 %	109 MPa	510	10200 s	R = 13
C	before fatigue				R_o = 7
C	0.3 %	90.5 MPa	3180	38160 s	R = 16
D	before fatigue				R_o = 10
	0.3 %	93.5 MPa	3590	43080 s	R = 17
	0.5 %	116 MPa	290	5800 s	R = 13.5
	0.8 %	138 MPa	90	2880 s	R = 10.5

DISCUSSION

One can first notice that the relevant parameter to characterize the coalescence under fatigue is the lasting of the test more than the amplitude of straining. The coalescence observed is realy a plastic deformation effect : whith an estimation of the diffusion coefficient at room temperature of $D \simeq 5.10^{-27}$ $m^2 s^{-1}$ (1), the maximum coalescence which would have been expected during a time t = 50000 s (the most lasting fatigue test) would have been of (3) 1.7 10^{-11} m, which is far under the observed coalescence during fatigue. One can have an order of magnitude of the enhanced coalescence by plotting $R^3 - R_o^3$ versus t (which would be a straight line in a LSW kinetics) (figure 1).

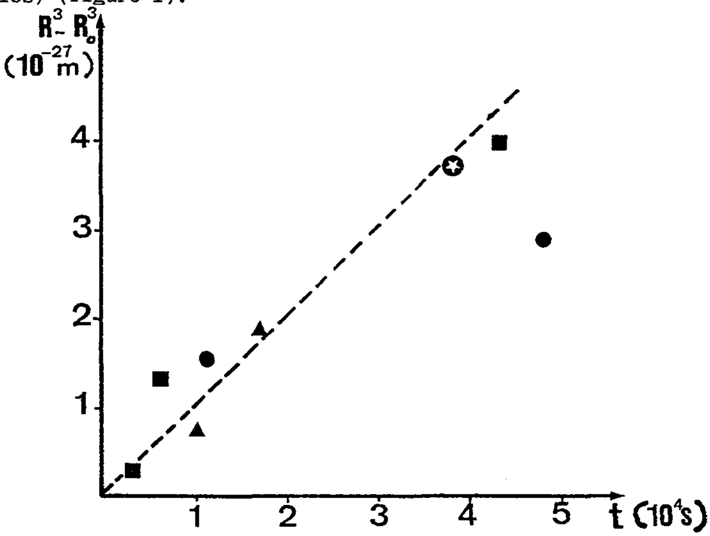

FIGURE 1

the estimation of the slope gives 10^{-31} $m^3 s^{-1}$: the coalescence which has taken place during fatigue is of the same order of magnitude of the one which would have taken place with a diffusion coefficient D^{fat} 6 orders of magnitude larger than the room temperature diffusion coefficient.

This order of magnitude of the ratio of fatigue created vacancy concentration $\langle C \rangle$ over thermal equilibrium concentration $\bar{C}$ can be estimated (6) from the Meckin

Estrin model of point defects production /1//, assuming that dominant sinks for vacancies are dislocations /7/8/ one gets

$$\langle C \rangle = \bar{C} + 0.1(\dot{\varepsilon}.\Lambda_o^{2}.\Delta\sigma)/(2D_o.\mu)$$

Λ_o^{-2} being the density of dislocations, μ the shear modulus, D_o the diffusion coefficient for vacancies at room temperature.

A numerical estimation leads to $\langle C \rangle D_o \lesssim 10^{-19}$ to 10^{-21}. At room temperature $\bar{C}D_o$ 10^{-27} therefore $\langle C \rangle/\bar{C} \sim 10^{+6}$ to 10^{+8}. The vacancies created by fatigue are far more numerous than the thermal ones.

The plot $R^3 - R_o^3$ as a function of t can give an idea of the order of magnitude of the fatigue induced coalescence at room temperature, but one cannot expect a true LSW kinetics because of the redisolution phenomenon studied in part II. The repeated shearing of precipitates by dislocations leads to a redissolution of precipitates in slip bands, and the smaller the precipitates are, the sooner they will be sheared enough to disappear (/7/). Therefore this mechanism adds a new driving force in the coalescence process which favours the large precipitates at the expense of the small ones : this driving force, different from the interfacial energy reduction which rules the LSW kinetics can be expected to change not only the speed of the coalescence process but also the power law itself.

CONCLUSION

The behaviour of δ' precipitates under fatigue appears to be controlled by two competitive phenomena : the repeated shearing which leads to a dissolution of precipitates (part II) and the fatigue induced coalescence which makes them grow. On the average the coalescence process is dominant as can be seen from X Ray diffraction experiments, but the localization of plastic deformation in intense slip bands creates regions of the material where the dissolution process is dominant. In these regions, vacancies created by fatigue enhance the diffusion of lithium, and prevent the reprecipitation in the bands.

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REFERENCES

/1/ MECKING H., ESTRIN Y. Scripta Met. 14, 815 (1980).
/2/ SAINFORT P. Thesis Grenoble University (1984).
/3/ LIVET F., BLOCH D., Scripta Met. 19, (1985).
/4/ LIFSCHITZ I., SLYOSOV V. J. Phys. CHem. Solids, 19, 35 (1961).
/5/ CALDERON H.A., WEERTMANN J.R., FINE M.E. Scripta Met. 18, 587 (1984).
/6/ SOUAMI N., FAGOT M., CHOMEL P., COTTU J.P., Scripta Met. 20, 1673 (1986).
/7/ BRECHET Y., LOUCHET F., MARCHIONNI C., VERGER-GAUGRY J.L., Phil. Mag. under press.
/8/ WINTEMBERGER M., Acta Met. 7, 549 (1959).