



HAL
open science

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

Y. Brechet, F. Livet

► **To cite this version:**

Y. Brechet, F. Livet. LOW CYCLE FATIGUE OF BINARY Al-Li ALLOYS : III-COALESCENCE OF δ' PRECIPITATES IN FATIGUE : X-RAY LOW ANGLE SCATTERING INVESTIGATION. Journal de Physique Colloques, 1987, 48 (C3), pp.C3-717-C3-719. 10.1051/jphyscol:1987383 . jpa-00226614

HAL Id: jpa-00226614

<https://hal.science/jpa-00226614>

Submitted on 4 Feb 2008

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

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

Y. BRECHET and F. LIVET

*Laboratoire de Thermodynamique et Physico-Chimie
Métallurgiques, ENSEEG, Domaine Universitaire, B.P. 75,
F-38402 Saint-Martin-d'Hères Cedex, France*

ABSTRACT

Al 2.5 wt% Li binary alloys with small δ' precipitates ($R_p \approx 10 \text{ \AA}$) were cyclically deformed in torsion at constant applied strain amplitude $\Delta \epsilon$, with the same strain rate $\dot{\epsilon}$. 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 ($\lambda = 0.1542 \text{ nm}$) 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 6 nm^{-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 absorption and geometrical effects.

RESULTS

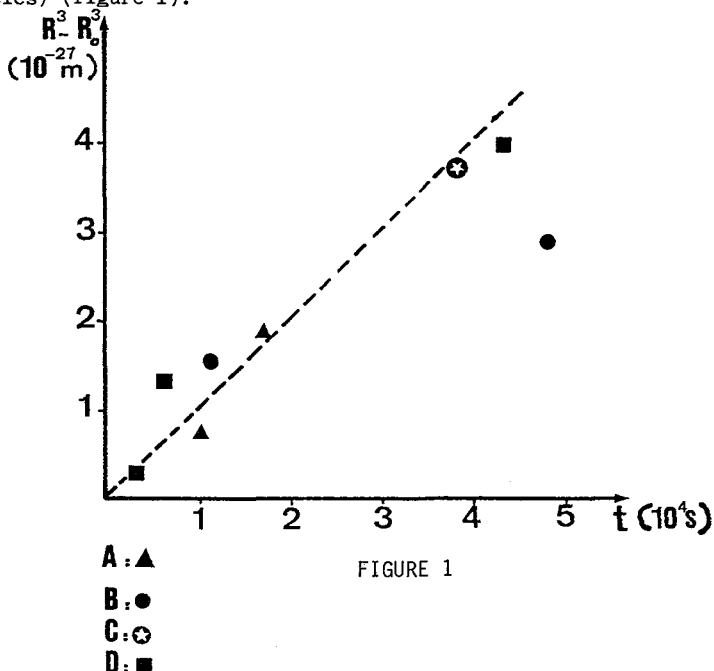
The average radius was estimated from the maxima of the curves $q^2 I(q)$ and of $q^4 I(q)$. The fatigue tests were performed at a strain rate $\dot{\epsilon} = 10^{-3} \text{ s}^{-1}$. The mean amplitude in stress was taken to be equal to the arithmetic mean between maximum stress amplitude and stress 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 $\Delta\epsilon / 2$ | mean stress amplitude $\Delta\sigma / 2$ | Number of cycles to failure | Lasting of the test | average radius of δ 'precipitates (A) |
|----------------|---------------------------------------|--|-----------------------------|---------------------|--|
| A | before fatigue | | | | $R = 8.5$ |
| A | 0.3 % | 94.5 MPa | 1430 | 17160 s | $R^0 = 13.5$ |
| A | 0.5 % | 105.5 MPa | 400 | 10000 s | $R = 11$ |
| B | before fatigue | | | | $R = 8$ |
| B | 0.3 % | 89.5 MPa | 4050 | 48600 s | $R^0 = 15$ |
| B | 0.5 % | 109 MPa | 510 | 10200 s | $R = 13$ |
| C | before fatigue | | | | $R = 7$ |
| C | 0.3 % | 90.5 MPa | 3180 | 38160 s | $R^0 = 16$ |
| D | before fatigue | | | | $R = 10$ |
| | 0.3 % | 93.5 MPa | 3590 | 43080 s | $R^0 = 17$ |
| | 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 really a plastic deformation effect, which an estimation of the diffusion coefficient at room temperature of $D = 5.10^{-27} \text{ m}^2 \text{ s}^{-1}$ (1), the maximum coalescence which would have been expected during a time $t = 50000 \text{ s}$ (the most lasting fatigue test) would have been of (3) $1.7 \cdot 10^{-11} \text{ m}$, which is far under the observed coalescence during fatigue. One can have an order of magnitude of the enhanced coalescence by plotting $R^3 - R_0^3$ versus t (which would be a straight line in a LSW kinetics) (figure 1).



the estimation of the slope gives $10^{-31} \text{ m}^3 \text{ s}^{-1}$: 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

$$\langle C \rangle = \bar{C} + 0.1(\dot{\epsilon} \cdot \Lambda_0^2 \cdot \Delta\sigma) / (2D_0 \cdot \mu)$$

Λ_0^{-2} being the density of dislocations, μ the shear modulus, D_0 the diffusion coefficient for vacancies at room temperature.

A numerical estimation leads to $\langle C \rangle D_0^{-19}$ to 10^{-21} . At room temperature $\bar{C} D_0^{-27}$ 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 $R_3 - R_0$ 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 redissolution 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.

ACKNOWLEDGMENTS

The authors thank Aluminium Pechiney company for having provided the material, and for financial support of one of them (Y.B.).

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).