X-RAY FRACTOGRAPHY STUDY ON A CYCLIC HARDENING ALUMINIUM ALLOY

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X-ray fractography was applied to the fatigue fracture surfaces of a cyclic hardening Al-alloy specimens. The shape of the diffraction peak breadth in-depth distribution lead to the estimation of the monotonic plastic zone size.

Moreover, a relationship between B(°) and the stress level reached during tensile or low cyclic fatigue tests suggests that stress essentially depends on material substructure.

INTRODUCTION

X-ray fractography is now considered a methodology leading to crack tip monotonic and cyclic plastic zone sizes and then to the load controlling the fatigue crack growth process. The plastic zone sizes of the fatigue cracks are estimated from in-depth distribution of residual stresses and X-ray diffraction peak broadening (Bignonnet et al (1,2). In the present work this technique is used to study fatigue fracture surfaces in the case of 5083 Al-alloy, tested at different positive load ratio, in a laboratory environment. These results obtained with a cyclic hardening alloy, complement previous works (1,2) carried out on steels showing mostly a cyclic softening of the material at the crack tip. Only one work (Jaensson (3) is known about X-ray fractography applied to the fatigue fracture surface of an aluminium alloy.

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MATERIAL AND EXPERIMENTAL PROCEDURE

Material

The present investigation has been carried out on an 5083 Al-alloy. The chemical composition of the material is given in table 1. Specimens were machined from cast and rolled plates, with 12mm thickness. Grain size was 20µm.

TABLE 1 - Chemical composition of 5083 Al-alloy (wt. percent)

Mg	Mn	Fe	V	Cu	Zn	Si	Sn	Pb	Ti	Al
4.5	0.55	0.37	< 0.5	0.12	0.10	< 0.10	< 0.05	< 0.05	< 0.05	balance

Mechanical tests

Interrupted tensile tests were carried out for samples deformed at different plastic strain levels. Low cycle fatigue tests have been performed under constant amplitude strain control. Traction and fatigue specimens were machined from plates to have both longitudinal and transversal orientations.

CT specimens have been used for crack propagation tests, under constant amplitude load control and room environment. Two R load ratio ($R = P_{min} / P_{max}$), R=0.05 and R=0.5, have been chosen for the experiments. Samples were machined from plates in a way that allows for longitudinal loading.

X-ray fractography

Residual stresses and diffraction peak broadening distributions near the fatigue fracture surface of CT specimens were estimated with the x-ray diffraction method. Measurements were made at several ΔK levels (different crack lengths) on fracture surface and at various depths below the surface, after the surface layer step-wise electrochemical polishing. X-ray diffraction experimental parameters were chosen after the determination of the crystallographic texture of the material. The details of the stress measurement procedure are given in table2. The work hardening of the material was controlled through the half value breadth of the {222} diffraction peak.

TABLE 2 - Data for X-ray Stress Measurement

Radiation and diffraction plan	K_α Cr , {222}
Irradiated surface	1mm width rectangle
Number of Ψ angles	15 by Φ direction
Detection	Position Sensitive Detector
Acquisition time by Ψ angle	100 seconds

RESULTS AND DISCUSSION

Relationship Between Plastic Strain and X-ray Diffraction Peak Broadening

Monotonic and cyclic mechanical properties of the material are shown in table 3, for longitudinal and transversal specimens. It points out the cyclic hardening of this alloy and the influence of specimens orientation concerning rolling direction. The relationship between the diffraction peak broadening, B, and the plastic strain, ε_p, is presented in figure 1, for monotonic tensile and low cycle fatigue tests of samples. It can be observed that the work hardening introduced by the plastic strain is influenced by the deformation mode. Nevertheless, figure 2 shows relationship between the diffraction peak broadening and the stress level reached during tensile or low cycle fatigue tests independent from the solicitation mode. It suggests that stress essentially depends on the substructure of the material. These results are in good agreement with previous studies carried out on a chromium alloyed steel (1,2).

TABLE 3 - Mechanical properties

Mechanical properties			L orientation	T orientation
Yield strength,	σ_{ys}	(MPa)	180	160
Tensile strength,	σ_{TS}	(MPa)	320	314
Elongation,	ε	(%)	18	24
Cyclic yield strength,	σ'_{ys}	(MPa)	310	310

Residual Stresses and Work Hardening Near the Fracture Surface

Experimental data of x-ray diffraction measurements close to fracture surface are given in figures 3 and 4. Standard deviation of the illustrated average values are about 30 MPa and 0.04°, for residual stresses and diffraction peak breadth respectively. Surface tensile residual stresses distributions, with values inversely proportional to the depth, are in agreement with the results of several studies (1,2,3), for crack growth under positive stress ratio.

Peak breadth distributions decrease also continuously in depth to the nominal value. In such a case, the increase in peak breadth toward the cracked surface can be interpreted through the different plastic strain level around the crack tip.

Similarly to the model introduced in a previous work (1,2). for a cyclic softening steel, two zones can be defined in the distribution of the peak breadth, as schematic represented in figure 5: region A, basically due to monotonic plastic strain; and region B, interpreted by a strong cyclic work hardening of the Al-alloy, as described above. However, a minimum number of data was not available to clearly define the region B, because whatever the studied ΔK value might be, cyclic plastic strain zone is too small in the wake of the crack.

Monotonic Plastic Zone Size

As it can be seen in figure 5, the limit of the monotonic plastic zone (r_{pm}) corresponds to the depth at which the in-depth distribution of peak breadth reaches the nominal value. As illustrated in figure 6 the relationship between the estimates of r_{pm} and the stress intensity can be expressed by the equation $r_{pm} = \alpha \cdot (K_{max}/\sigma_{ys})^2$, with $\alpha = 0.07 \pm 0.01$ for both R ratio. This α value is in good agreement with Jaensson data obtained on AA7010-T73651 aluminium alloy (3). However, according to Tresca and Von Mises plasticity criteria, α coefficient should be 0.159 and 0.129 respectively, for plane strain conditions.

CONCLUSIONS

X-ray fractography was applied to the fatigue fracture surfaces of a cyclic hardening 5083 Al-alloy. Fatigue crack growth tests were performed under two different stress ratio (0.05 and 0.5) and laboratory environment.

The shape of diffraction peak breadth distribution beneath the fracture surface was understood through the monotonic and cyclic work hardening of the material and lead to the estimation of the monotonic plastic zone size. This parameter was related to the stress intensity factor by the following fracture mechanics equation $r_{pm} = 0.07 \cdot (K_{max}/\sigma_{ys})^2$.

Moreover, a relationship, independent from the solicitation mode, between the diffraction peak broadening and the stress level reached during tensile or low cycle fatigue test was pointed out, thus suggesting that stress is essentially dependent on material substructure.

REFERENCES

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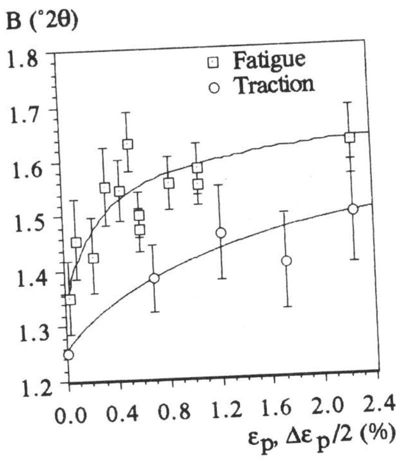

Figure 1 Relationship between the peak breadth B and the plastic strain

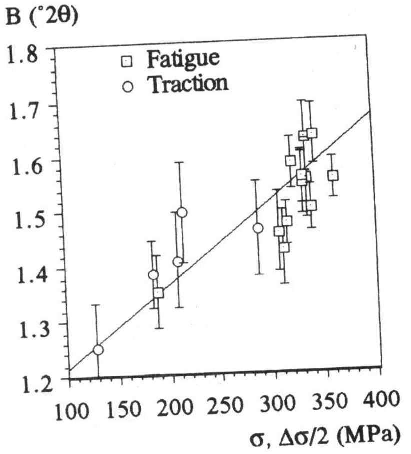

Figure 2 Relationship between the peak breadth B and the stress

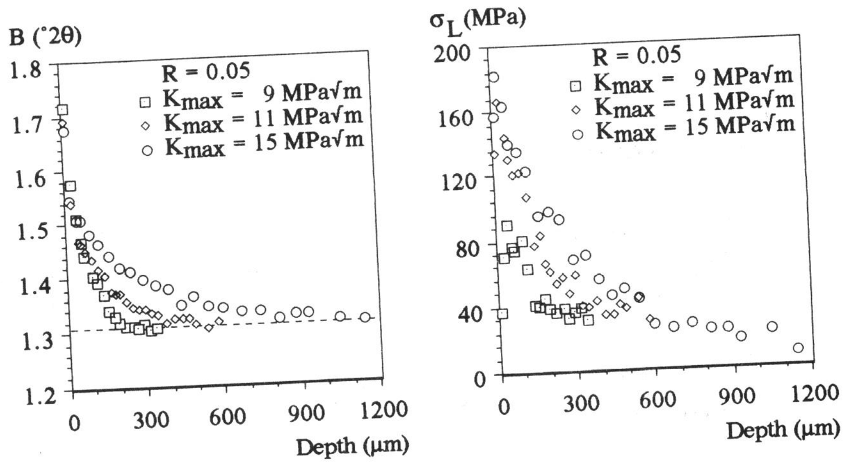

Figure 3 Distribution of the peak breadths and residual stresses below the fracture surface for test at R = 0.05

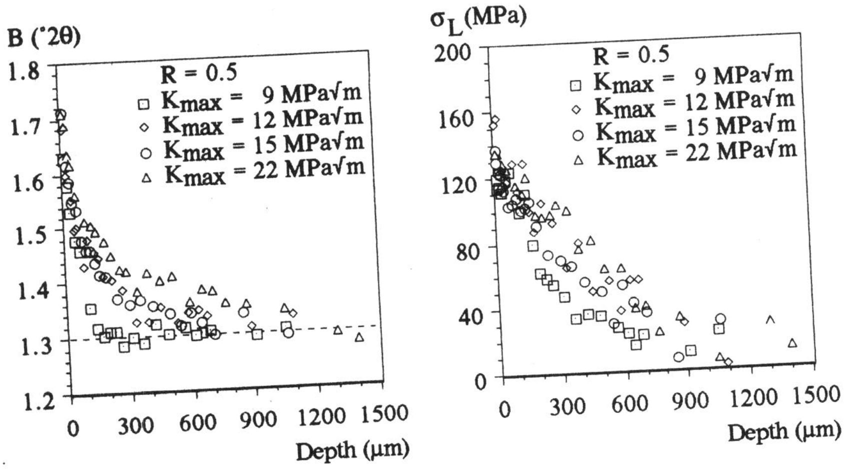

Figure 4 Distribution of the peak breadths and residual stresses below the fracture surface for test at $R = 0.5$

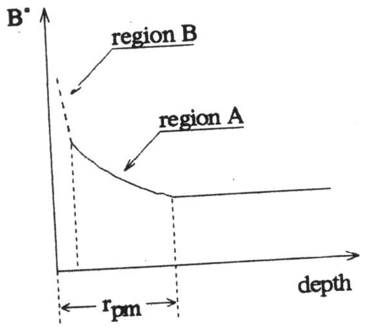

Figure 5 Schematic representation of peak breadth evolution

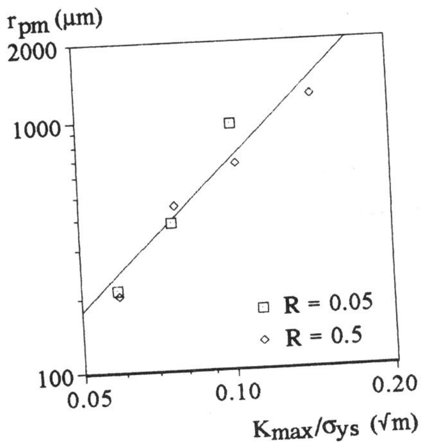

Figure 6 Relationship between the monotonic plastic zone size and K_{max}/σ_{ys}