Analyses of faceted fracture surfaces of fatigue-tested type 304 stainless steel by means of selected area channelling patterns*

The crystallographic orientations of facets, observed on the fracture surfaces of fatigue tested specimens, have been analysed earlier by means of etch pit techniques and X-ray diffraction. The first technique has the disadvantage of being indirect and time-consuming considering suitable etching methods. X-ray diffraction, although having a direct relation with orientation, has a limited resolution. Only coarse facets, (smallest dimension about 0.5 mm) can be analysed. Determination of the orientation of facets by means of selected area channelling patterns (SACPs) has the advantage of giving direct crystallographic information from rather small areas (the limiting dimensions are of the order of 1 μm).

Highly reflective facets on the fracture surfaces of fatigue tested type 304, being an indication of separation along crystallographic planes, have been analysed by means of SACPs. Fatigue tests were performed at room temperature in air [1]. Facet dimensions varied between 30 and 300 μm. The crystallographic orientation has been determined with an accuracy of about 5° using stereographic pairs of micrographs and SACPs, obtained with a Philips EM 301 equiped with goniometer stage and scanning attachment.

It is well known that surface roughness and lattice disturbance by internal strain are limiting conditions to get SACPs. Fig. 1 shows on samples from the gauge length of strained tensile specimens how the channelling patterns disappear with increasing deformation due to increasing dislocation density. The limit for resolution appears to be 30% strain or a dislocation density of the order of magnitude of about 10^{11} cm^{-2}. Fig. 2 shows the benefit of reducing surface roughness by electrolytic polishing. Facet roughness, however, is considered to be a less stringent limitation because very small areas of the facet surfaces can be analysed.

No channelling patterns could be obtained of the facets directly after fatigue testing. Electro-

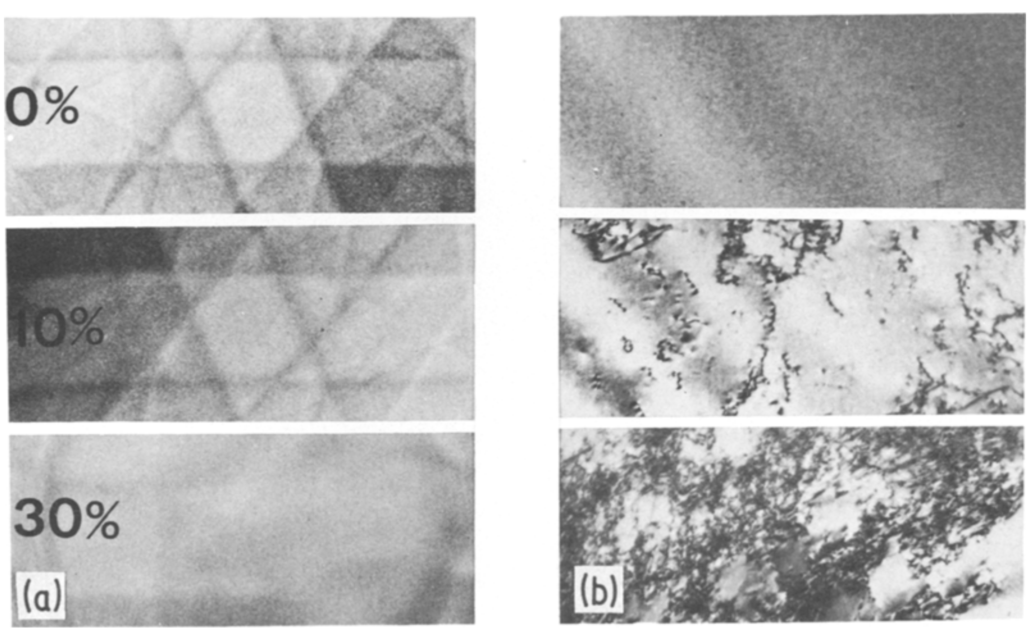

Figure 1 SACPs (a) from gauge length of tensile strained specimens of stainless steel type 304 and corresponding dislocation substructures, (b) × 40 000. (Tensile strain 0% *Hv* = 120; 10% *Hv* = 180; 30% *Hv* = 250).

* Highly reflective, macroscopically flat, small local parts of the fracture surface.

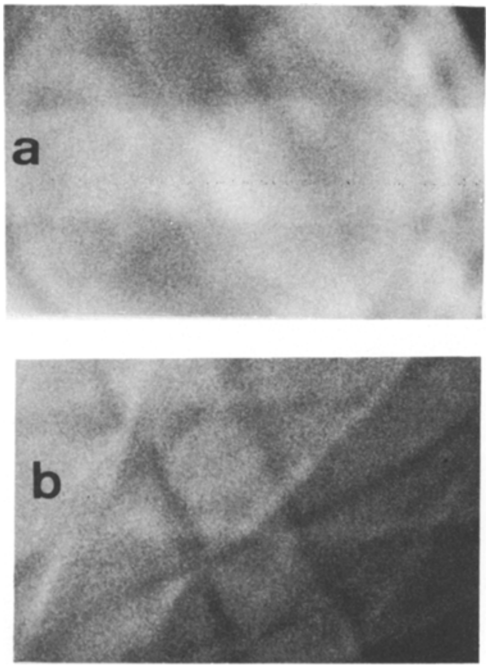

Figure 2 SACPs from gauge length of 20% tensile strained specimen showing the benefit of reducing surface roughness by electrolytic polishing. (a) ground, (b) polished.

polishing did not produce a positive result. However, SACPs were obtained after relief of internal strain by heat treatment during 10 min at 1000° C *in vacuo*. By means of an annealing series at temperatures between 700 and 1000° C during 10, 30 and 60 min, it was observed that SACPs started to develop after annealing at 900° C. Sharp SACPs were obtained after heat treatments at 1000° C. This combined evidence indicates that the subsurface material of the facets is heavily deformed and has a high dislocation density.

The facets analysed on fatigue samples tested at a stress ratio of $R = 0.05$ were not of a single orientation. Orientations near (1 1 0), (1 1 1), (1 1 2) and (1 1 4) were observed, with (1 1 4) being predominant. Sometimes SACPs were observed to change from one location to another on a flat facet as shown in Fig. 3. Here the orientation normal to the facet changes from ⟨1 1 0⟩ to ⟨1 1 4⟩. Apparently the facets did not always run through one grain, which was supported by the observation of grain boundaries on facets after electrolytic etching. Sometimes even microtwins were observed as shown in the micrographs of matching surfaces in Fig. 4. The channelling patterns indicate a change from (1 1 1) to (1 1 4) crystal orientation on that facet.

With respect to the frequently observed (1 1 4) orientation, it is considered that twinning in f c c lattices could change a ⟨1 1 1⟩ direction into a high-index direction which is 4° of from ⟨1 1 4⟩ and that a ⟨1 1 0⟩ direction could change exactly into a ⟨1 1 4⟩ direction by twinning. So the (1 1 4) orientation might be introduced by twinning. This could be a deformation twinning process at the front of a crack, progressing along low-index planes like (1 1 1) and (1 1 0) with respect to the original crystal orientation. Although it could also be twinning during the heat treatment required to obtain SACPs.

With replicas of fracture surfaces, fine details of the facets could be observed. Facet appearance varied from flat and smooth surfaces to rather rough with variations in microscopic height. Facets with (1 1 1) and (1 1 4) orientations were relatively smooth. On those facets, sets of intersecting parallel slip line markings could be observed, as

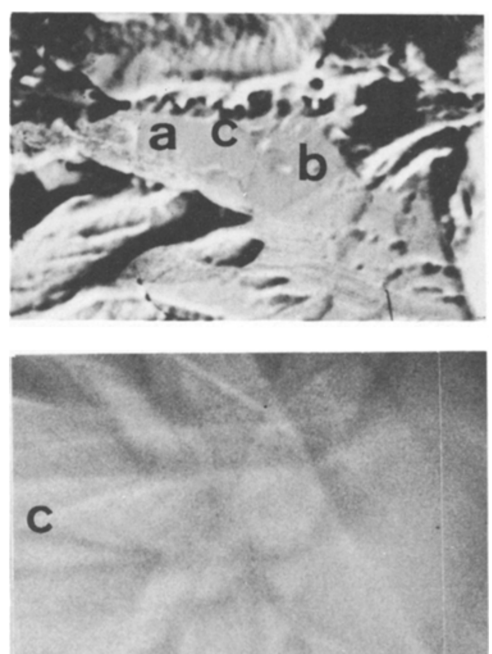

Figure 3 Flat surface (× 640) with different crystallographic orientations at a (1 1 0), b (1 1 4), and c change from (1 1 0) to (1 1 4) as shown by the SACP.

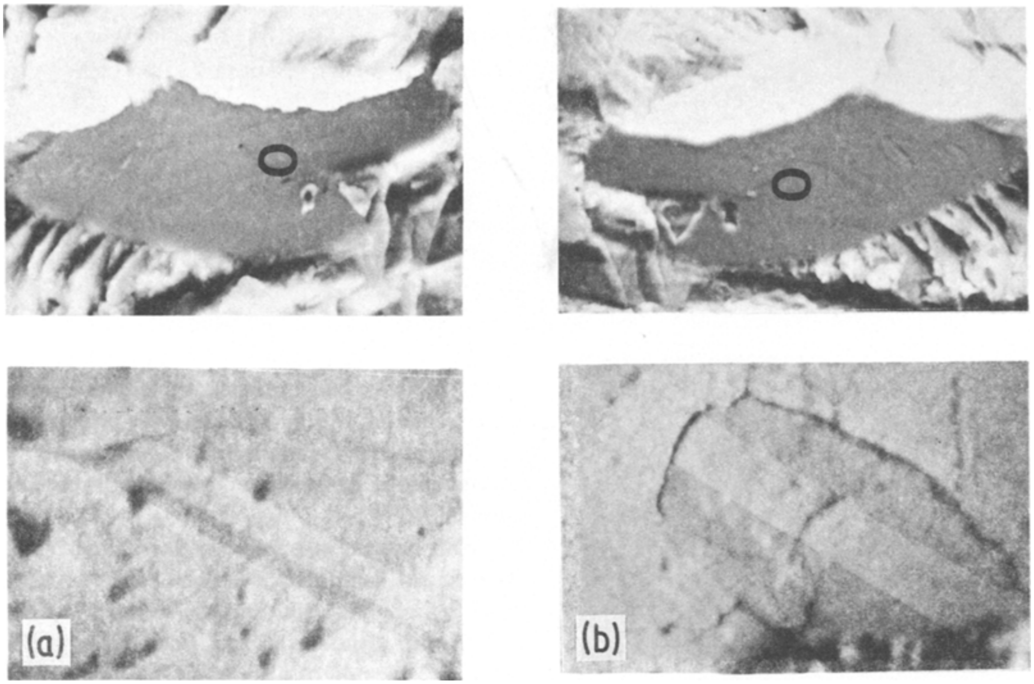

Figure 4 (a) and (b) Matching surfaces of facet (× 320) and details (× 2500) showing microtwins. Both locations showed (1 1 1) and (1 1 4) orientations.

Figure 5 Replica of facet surface showing intersecting sets of parallel slipline markings (× 11 000).

shown in Fig. 5. This also indicates a substantial amount of plastic deformation. After testing at higher stress ratios of $R = 0.3$ and 0.5, a larger fraction of (1 1 1) facets was observed.

Facets on fracture surfaces of fatigue-tested type 316 stainless steel have been analysed by Priddle and Walker [2]. From X-ray diffraction on large facets, they concluded that the facets were (1 1 1) cleavage type fatigue fractures, associated with reduced plasticity. Their fatigue tests were performed at a stress ratio of $R = 0.3$.

It is well known that cleavage plays an important role in fatigue-fracture of b c c and h c p metals. Cleavage is not expected to occur in ductile f c c metals like austenitic stainless steels. Although our observations on 304 indicate a tendency to (1 1 1) orientations at higher stress ratios, we found that facets are not of a single type orientation and that the subsurface material is heavily deformed. Our observations are more in accordance with those of Weber and Hertzberg on large grain size 70 Cu–30 Zn brass, tested at a stress ratio of $R = 0.01$ [3]. By X-ray back-reflection they found a large variety of orientations. They also found that (1 1 1) facets were relatively flat and showed sets of parallel slip-line markings.

References

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Received 7 January
and accepted 18 February 1977

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A method for measuring cyclic microstrains in both tension and compression

Microstrain tests have been carried out on different materials during the last years mainly to check the validity of current theories of yielding and to have a better knowledge of the behaviour of dislocations moving at low stresses. A review of the possibilities and experimental methods of microstrain measurement has been published by Brown [1].

Most studies of micro-deformation have aimed at measuring the lattice friction stress and the anelastic limit of crystalline solids. However the possibility of comparing the results obtained from microstrain tests with those of internal friction measurements has also been discussed by several authors [2–4]. Some difficulty arises when comparing the results obtained with these two techniques. This is mainly due to the fact that microstrains are usually measured in either tension or compression only. The work of Lukas and Klesnil [5] is the only research known to us where measurements in both tension and compression have been reported.

There are many problems associated with microstrain experiments in single crystals. They have already been discussed in some detail by Cowling and Bacon [6] who proposed at the same time a method to overcome them. Their method, useful for tests in compression only, is based on the introduction of a very high stiffness in parallel with the sample under test which reduces the instabilities usually associated with small loads. A method, useful for tests in both tension and compression, and which is based on an opposite principle is presented in this note.

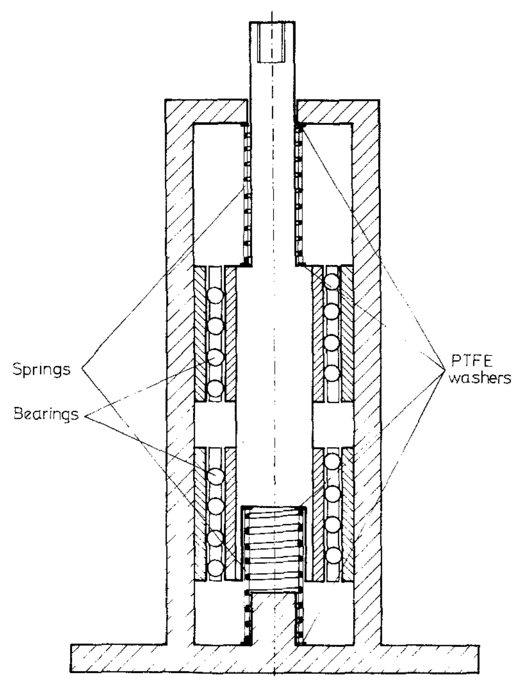

Figure 1 Drawing of the dash-pot arrangement.

A very low stiffness dash-pot is placed in series with the specimen, so that a very large displacement of the loading ram is transformed into a very small load on the sample under test. This technique has been used in conjunction with a servo-hydraulic testing machine which has the advantage over the screw-driven machines of better axial loading and unloading.

Fig. 1 is a drawing of the dash-pot arrangement. A central shaft moves along the line defined by two coaxial low friction cylindrical linear bearings deforming two helical springs, one at each end,