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TECHNICAL NOTE

SINGLE-CRYSTALS AS AN INDICATOR OF FATIGUE DAMAGE

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Abstract—The possibility of using specially prepared single crystals as indicators of fatigue damage is outlined. Results are described of an analysis of deformation patterns developed in the single-crystal indicator surface, under fatigue and static loading. It is shown that the density and direction of deformation bands correlate with the number of loading cycles.

INTRODUCTION

The inspection and analysis of structural damage due to service spectrum loading is very important since existing calculation methods cannot provide the required level of accuracy. Two possibilities for the experimental evaluation of a structure's lifetime are:

(a) the inspection of the physico-chemical state of the material of the structural element; and
(b) the inspection of fatigue transducers of special sensitive elements that monitor the service spectrum of deformation that is applied to the element.

The second possibility has some advantages. It allows one to apply a large number of investigative methods to obtain immediate information about the possible lifetime of the structure. For this purpose a single-crystal can be used[1] and a quantitative assessment of fatigue damage can be performed by an analysis of PSBs (persistent slip bands), i.e. their number on some given base line.

The results from a single-crystal indicator related to the fatigue durability of an aircraft skin structural element are described below.

EXPERIMENTAL PROGRAMME AND RESULTS

The 30 mm long fatigue indicator was made of a single-crystal aluminium foil (99.99%wt Al). The indicator was stuck on a flat specimen 1.2 mm thick (Fig. 1). The maximum applied stress in fatigue was either 140 or 180 MPa. The frequency of loading was 9.8 cycles/s.

The indicator surface was periodically inspected by means of a microscope with a ×200 enlargement. Slip lines density was determined from the simple formula

$$K = M/L \qquad (1)$$

where M is the number of lines on a base of length L, which is perpendicular to the direction of the slip lines. In our case $L = 0.45$ mm and was parallel to the tensile axis.

Figure 2 shows the results of slip line density measurements after different cyclic loading levels. The same curve contains regression lines which are obtained by means of the least-square-root

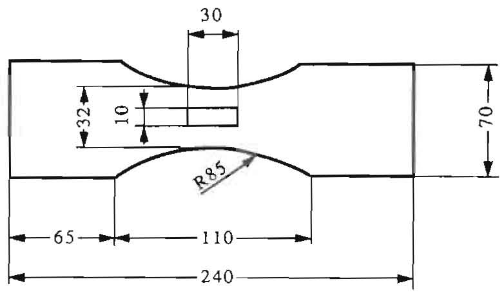

Fig. 1. Test specimen with the centrally located single-crystal indicator; all dimensions in mm.

method. It has been stated that the relation between slip line density and number of cycles can be described more precisely by a multiplication model [2]:

$$K = AN^{B}C. \tag{2}$$

The constants can be evaluated from Fig. 2. The correlation coefficient for both cases is greater than 0.9.

The single-crystal indicator can also be used for the evaluation of extreme values of singly-applied static loads. In order to check the results, special tests with indicators installed on some structural elements from aircraft skins have been performed. The loading was applied by a standard test machine. At a magnification of $\times 200$, primary slip lines were seen at a strain level of 1%. Their angle of inclination for a given orientation of the single-crystal was 82° relative to the tensile axis.

If the deformation was increased the density of the primary slip line became higher. When the strain was equal to 1.7%, secondary slip lines appeared on the surface. Their direction was 57° relative to the tensile axis. If the deformation increased to 4.3% the density for both types of slip lines became higher.

There exist definite relations between the density of primary and secondary slip lines and the applied strain (Fig. 3). The multiplicative model expressed by equation (2) appears adequate for the fatigue tests shown in Fig. 2. The coefficient of correlation was never lower than 0.9.

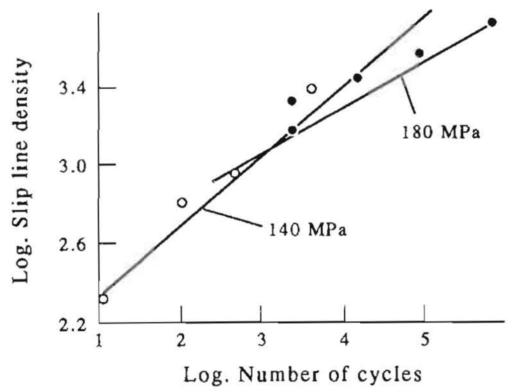

Fig. 2. Relationship between slip line density and number of applied cycles.

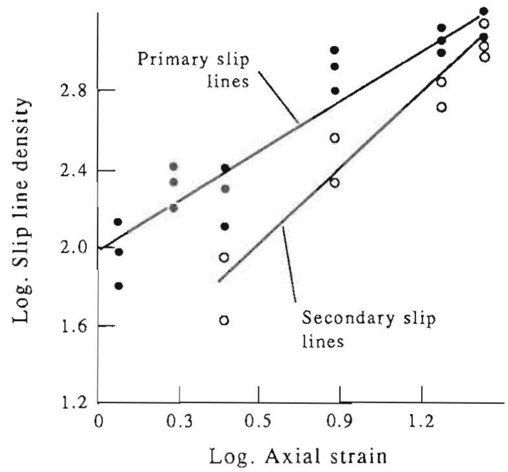

Fig. 3. Relationship between slip line density and applied axial strain.

It should be noted that it is not necessary for the operator to check the indicator nor disconnect the indicator during service. The indicator sensitivity, i.e. the rate of slip line density increase, under cyclic loading, can vary over a wide range by changing the crystallographic orientation of the indicator. In this way it is possible to select the optimal indicator position for a particular structure, bearing in mind the actual level of stresses and the predicted lifetime of the structure.

In order to increase the accuracy and to prolong the period of continuous inspection it is possible to stick several indicators of different sensitivities on the element under test. However, since many construction materials do not form stable PSBs under the action of cyclic deformation processes it is necessary to apply single-crystals of a given composition having good calibration characteristics.

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