X-RAY MEASUREMENTS OF LONG-RANGE STRAINS:
A BRIDGE BETWEEN MICROMECHANICS AND MACROMECHANICS

S. Weissmann, Z.H. Kalman, J. Chaudhuri, R. Yazici and W. Mayo
Department of Mechanics and Materials Science
Rutgers University, Piscataway, N.J. 08854

ABSTRACT

Long-range, elastic strains emanating from stress raisers, such as notches, holes and inclusions were investigated in bent silicon crystals which functioned as a model material. The strains and strain interactions were characterized by x-ray pendellösung fringe topography and were quantitatively evaluated by x-ray intensity measurements of traverse-oscillation topographs. The experimental results were compared to calculations based on continuum mechanics and satisfactory agreement was obtained. The x-ray analysis of long-range plastic strains and deformation gradients in technological polycrystalline materials by a computer-aided rocking curve analyzer (CARCA) was described. It was shown how CARCA can be used in alloys to obtain aggregate information of the defect structure of a large grain population and to isolate regions of intense deformation. Applications of the method were given to determine prefracture damage in fatigued and corrosion fatigued aluminum alloys and in stress corroded steel.

INTRODUCTION

There are several important, recurring problems in fracture mechanics dealing with the determination of the strain distribution caused by stress raisers and by their interactions. They have received extensive theoretical treatment (1,2,3) but have not been sufficiently correlated to experimental examination and verification by microfracture mechanics. Conversely, many local observations of lattice defects encountered in microfracture, particularly dislocation arrangements near stress raisers observed by transmission electron microscopy, do not lend themselves readily
to a systematic treatment of continuum mechanics. It is felt, therefore, that there exists a distinct gap between micro- and macromechanics and that a systematic attempt should be made to bridge this gap. Encouraged by the results of recent x-ray studies (4,5,6) the authors embarked on an extensive program of interdisciplinary correlation studies. The special x-ray method developed in the course of these studies and their applications will be described in this paper. The authors will deal first with the experimental characterization and quantitative determination of long-range, elastic strains in single crystals, induced by stress raisers such as cracks and inclusions, and with their interactions. The results will then be correlated to calculations based on continuum mechanics. Subsequently a computer aided x-ray method will be described by which long-range plastic strains and deformation gradients in alloys can be determined. It will be shown that application of this nondestructive method to fatigued and corrosion fatigued commercial aluminum alloys makes it possible to determine rapidly prefracture damage and to predict incipient catastrophic failure.

1. Determination of Elastic Strains

Usually when one thinks of x-ray measurements of elastic strains in a material one will immediately think of precision measurements of interatomic spacings. Measurements of this kind rest on the averaging of strains over relatively large volumes of the probed material. Consequently, for the correlation study which we plan to carry out and for which measurements of long-range strains from point to point are essential, precision measurements of interatomic spacings are not very helpful at all.

Our approach is entirely different and is based on the principle that local variations of elastic strains of a set of (hlk) planes are manifested by local variations of the diffracted intensity (4,5).

The method is much more sensitive than the conventional strain methods and is capable of determining quantitatively the local curvature in elastically bent crystals. Unlike the conventional x-ray methods, however, this method is restricted to perfect, dislocation-free crystals, as will be briefly shown with the aid of Fig. 1. In the undistorted, perfect crystal, disregarding absorption, the crystal will reflect throughout its entire thickness over a definite small angular range of a few seconds, \( \omega \), known as the halfwidth of the rocking curve of the crystal. In the curved crystal diffraction effects generally take place only in parts of the crystal, namely in those regions where the angles of incidence between primary beam and reflecting planes lie between \( \theta_B + \omega/2 \), and \( \theta_B - \omega/2 \).