ABSTRACT It is well understood that the fatigue limit behavior of a metal is a function of defect size within the Linear Elastic Fracture Mechanics (LEFM) regime. Conversely, it is not well understood how microstructural defects affect the fatigue limits of heterogeneous materials of apparently smooth specimens and engineering components. Consequently in the latter case investigations have concentrated on the cyclic stress-strain, or deformation, approach to fatigue fracture e.g. the Basquin and Coffin-Manson type studies.

By introducing micro-structural fracture mechanics and elastic-plastic fracture mechanics it is possible to link the deformation and the fracture approaches to metal fatigue investigations. This chapter considers these developments and their implications.

9.1 Introduction

The divide between death and everlasting life is the subject of this chapter. Under what conditions will a metal, component or structure survive indefinitely when subjected to cyclic forces, and what changes occur that introduce the possibility of failure?

Many trails have been followed to find answers to these questions. For example historically (perhaps based on the resemblance of fatigue fracture surfaces to brittle cleavage fracture in steel) it was incorrectly supposed that a material changed its structure due to the application of cyclic forces and became crystalline and brittle. In more recent times, studies of dislocations and the diffusion of small atoms through body-centered cubic structures led to theories and experiments to support ideas of dynamic strain ageing in ferrous materials.

At the present time investigations based on classical fatigue-endurance \( S-N \) curves are still hotly pursued in endeavors to find links between deformation behavior and fatigue failure. Sometimes the stress and strain range approaches have been combined to derive energy-based theories of fatigue, probably with the hope that below the fatigue limit a critical but as yet undefined state is attained in which all the available energy goes up
FIGURE 9.1. An initial shear (Stage I) crack developing into a tensile (Stage II) crack in a polycrystalline metal subjected to cyclic tensile stresses.

in smoke (heat) and none is available for the processes of fatigue.

Into this fiery arena came Frank McClintock (1956). In that 1956 conference in London at which world-wide experts met to discuss reasons for metal fatigue, only his paper out of a total 80 was related to the conditions required for the development and extension of a shear crack in a metal; an understanding of the Stage I crack had begun. Some five years later, Peter Forsyth (1961) presented his paper on Stage I and Stage II crack growth, see Fig. 9.1.

Since metal fatigue failure under a cyclic tensile stress, $\Delta \sigma$, is caused by the growth of Stage I followed by Stage II cracking, both of the above quoted papers are central to this representation which concentrates on the behavior of cracks; first in relation to the orientation of cracks with respect to the applied stress or strain field, and second to the effect of crack size.

9.2 Orientation of Cracks

Figure 9.2 shows two identical stress or strain states. In particular Fig. 9.2(a) represents the critical zone of a component or structure while Fig. 9.2(b) is a laboratory simulation of that state. In both cases, the cyclic nature of the applied stresses is identical, as is the material, its processing route, the temperature, and the environment. Consequently the Tresca or