

FATIGUE FAILURE MECHANISMS AND FATIGUE TESTING

Thomas Hansson
Volvo Aero Corporation, Sweden

1. Introduction

Most failures of engineering components is the result of damage accumulation during cyclic loading at loads well below the ultimate tensile strength of the material used for the component. For these types of failures the term fatigue is used. Fatigue was originally used to describe that the material became tired during applied cyclic loading and lost parts of its virgin strength. Through the use of experimental work, careful microscopy and mathematical modelling work we have increased the understanding of the fatigue phenomena since metal fatigue was first described for steel wires in 1838 [1]. However, surprisingly many issues are not clearly understood and the life predictions of moderately complex components are usually not better than within a factor 2, very often much worse. This implies that further work is necessary to avoid costly failures and unwanted conservatism when designing components subjected to cyclic loading.

2. Fatigue mechanisms

Fatigue failure is caused by cyclic loading at loads well below the ultimate tensile strength of materials. In order to cause fatigue damage the material must undergo a permanent change due to the applied cyclic loading. If the applied load is higher than the measured global elastic regime it is easy to observe that the properties of the material have changed. A permanent deformation can be measured and stress and strain can never reach zero at the same time again. This type of fatigue is termed Low Cycle Fatigue or LCF. In most metallic materials the LCF regime in life ranges from a few cycles and up to 10^4 - 10^5 cycles.

If the applied load amplitudes are in the elastic regime it is very difficult to observe any changes in the material on a global level and there is no change in the stress-strain behaviour. However, on a local level small volumes have been subjected to loads exceeding the elastic regime which have caused permanent local damage to the material. This type of fatigue is termed High Cycle Fatigue or HCF. In most metallic materials the HCF regime in life ranges from 10^5 and higher.

For both LCF and HCF type of loading the fatigue process can be divided in crack initiation and crack propagation. The amount of crack initiation is dependent on the definition of a crack and also if the material is defect free or contain large imperfections.

2.1 Crack initiation

A perfect material does not contain any imperfections such as porosities, inclusions or other defects. However, even a perfect material has a microstructure with characteristic dimensions that in practice will act as imperfections. Of course, no material is perfect but the characteristic dimensions in the microstructure are in many cases a weaker link than the inherent imperfections in the material. In such case the crack initiation can start in a grain with unfavourable direction with respect to the load direction. Each grain is a single crystal which may have very different properties in different directions. In order to initiate a crack,

plasticity is needed (even if only locally) and this is, in grain dominated crack initiation, caused by dislocation movement on the slip systems where the required shear stress is at minimum. Plastic deformation by shear is easier at a free surface than in the middle of the material due to constraints from surrounding grains. Consequently crack initiation is nearly always initiated at one of the larger grains at the surface having its favoured slip system in the same direction as the maximum shear direction of the fatigue load, i.e. 45° inclination to the load direction. The reason why crack initiation predominantly occurs in large grains is that the distance for slip is limited to the size of the grain in the slip direction. Slip in a grain on one slip system will ultimately cause a number of persistent slip bands (see Figures 1 and 2). This persistent slip bands will move back and forth and finally initiate a crack. The persistent slip bands are difficult to observe except on single crystals where they are allowed to move over very large distances (see Figure 2).

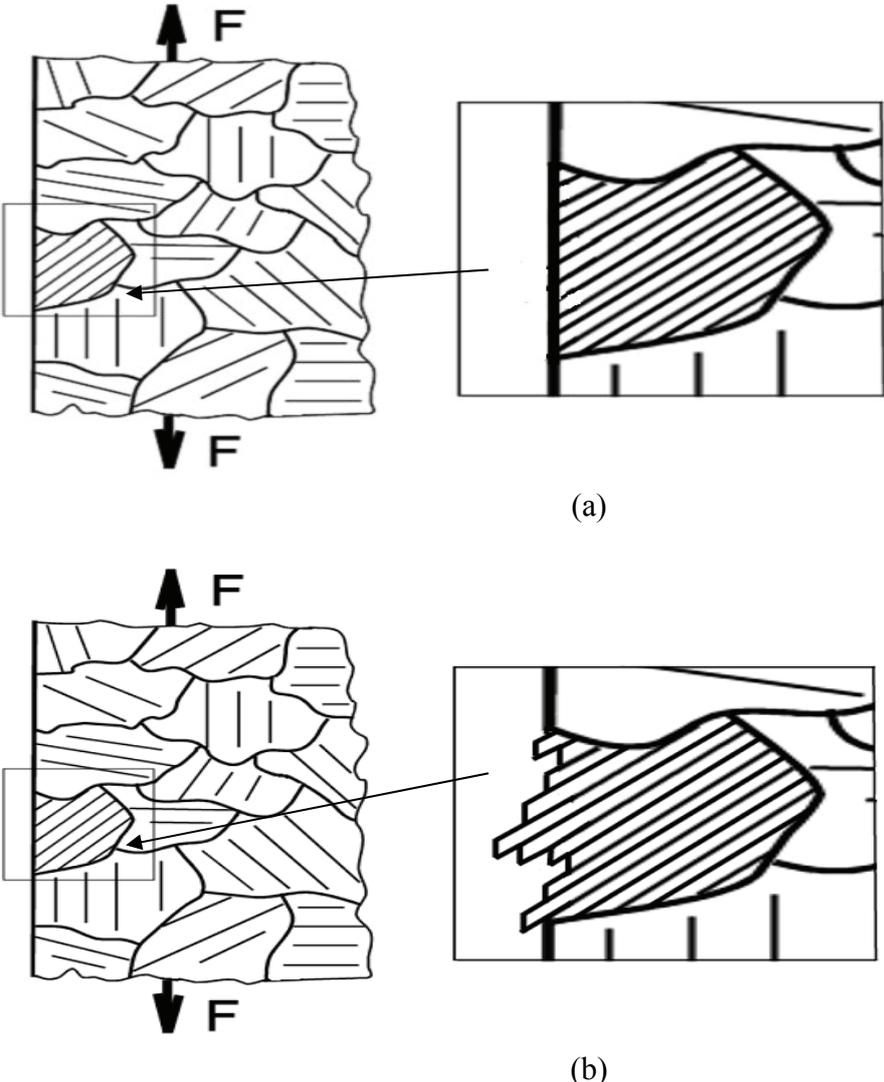


Figure 1. Schematic showing creation of persistent slip-bands during fatigue loading (a) first cycles and (b) close to crack nucleation

Some researchers claim that there is no such thing as crack initiation [2]. However, the existence of crack initiation is mainly a question of the definition of a crack. If the minimum