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Evaluation of fatigue damage in steel structural components
by magnetoelastic Barkhausen signal analysis

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This paper is concerned with using a magnetic technique for the evaluation of fatigue damage in steel structural components. It is shown that Barkhausen effect measurements can be used to indicate impending failure due to fatigue under certain conditions. The Barkhausen signal amplitude is known to be highly sensitive to changes in density and distribution of dislocations in materials. The sensitivity of Barkhausen signal amplitude to fatigue damage has been studied in the low-cycle fatigue regime using smooth tensile specimens of a medium strength steel. The Barkhausen measurements were taken at depths of penetration of 0.02, 0.07, and 0.2 mm. It was found that changes in magnetic properties are sensitive to microstructural changes taking place at the surface of the material throughout the fatigue life. The changes in the Barkhausen signals have been attributed to distribution of dislocations in stage I and stage II of fatigue life and the formation of a macrocrack in the final stage of fatigue.

I. INTRODUCTION

This paper reports on recent investigations to evaluate fatigue damage in steels using a Barkhausen effect measurement technique. When a ferromagnetic material is magnetized the resulting hysteresis plot appears smooth, but close inspection reveals that the magnetization changes occur in a discontinuous, steplike manner called the Barkhausen effect.\(^1\) The micromagnetic Barkhausen effect is attributed to irreversible Bloch wall motion. As do-

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of fatigue life is due to fatigue softening. This causes an increase in the mean distance between dislocations which act as domain wall pinning sites. Softening is evident from a decrease in load necessary to reach 0.3% strain, as shown in Fig. 2 and is called the Bauschinger effect. The Bauschinger effect is characterized by a decrease in flow stress of a material in compression, when it was initially stressed beyond the elastic limit in tension. If the material is then stressed again in tension, the flow stress will be even lower. This softening process continues in the initial stages of fatigue, until an equilibrium state is achieved, at which point the flow stress does not change between subsequent cycles.

Orowan explained the Bauschinger effect by examining the motion of dislocations. During the plastic portion of deformation dislocations move causing slip until they pile up at grain boundaries or precipitates, forming dislocation tangles. With reversed loading, the dislocations at the trailing edges of the tangles move away from the grain boundaries and precipitates more easily causing an apparent softening.

The Barkhausen measurement technique indirectly measures this phenomenon of dislocation movement. As dislocation tangles are broken up, the dislocations are dispersed more evenly throughout a material, thus their mean separation distance will increase. A larger separation distance between pinning sites gives rise to a larger discontinuous change in magnetization when a domain wall breaks away from a dislocation. Therefore the Barkhausen signal amplitude increases in stage I.

Stage II: Fatigue in stage II, is marked by the appearance of slip lines that often occur on free surfaces due to fatigue. As loads necessary to reach 0.3% strain stabilize, existing dislocations move and generally accumulate at the surface, eventually causing slip lines. As this happens, mean separation distance between dislocations decreases, causing a decrease in Barkhausen signal amplitude from the surface seen in stage II.

Stage III: The Barkhausen signal is observed to increase rapidly in stage III of fatigue deformation (Fig. 1) which corresponds to macrocrack propagation stage. When a macrocrack is produced, closure domains are created at the surface of the crack leading to a higher domain density, higher domain wall density and consequently a higher Barkhausen signal. As the crack grows, the numbers of these domains grow and the Barkhausen signal amplitude increases as seen in Fig. 1.

IV. CONCLUSIONS

The Barkhausen measurement technique appears to be a viable method for detecting the fatigue damage in steel structural components. Significant changes were observed in the Barkhausen signal amplitude in the first 30% and the last 20% of fatigue life. These changes are associated with the nature of domain wall–dislocation interactions. The changes in the surface sensitive Barkhausen signals during fatigue have been described by a three stage sequence. In stage I, the increase in Barkhausen signal amplitude has been attributed to the fatigue softening which causes a break-up of dislocation bundles and a resulting increase in the mean separation distance between dislocations acting as domain wall pinning sites. The decrease in Barkhausen signal in stage II is caused by the migration of dislocations towards the surface leading to a smaller mean distance between dislocations. In stage III, the creation of closure domains at the surface of a macrocrack results in a higher domain density and hence an increase in Barkhausen activity.

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