Inclined defects and their effect on the fatigue limit and small crack growth

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Abstract. Small FIB (Focused Ion Beam) milled notches were introduced in quenched and tempered 34CrNiMo6 steel to monitor initiation and growth of cracks in situ. The effect of the defects on the fatigue limit is discussed in terms of the √area model. Notches with projected √area of 30 to 56 µm normal to the applied stress were inclined by 0, 45, and 60 degrees. The effect of size and inclination on the small crack growth as well as the fatigue limit is discussed.

1 Introduction

A common feature of high strength steels is the untimely fatigue failure from non-metallic inclusions or defects in the material. A fundamental approach for understanding and modeling effects of these defects is given in the book: *Metal Fatigue: Effects of Small Defects and Nonmetallic Inclusion*. [1] The largest inclusion in a volume is estimated using statistics of extreme values (SEV). The projected square root area of this inclusion is used together with the microhardness of the steel to predict the fatigue limit σ_w for the steel using equation:

$$\sigma_w = \frac{C \cdot (HV + 120)}{\left(\sqrt{area_{max}}\right)^{1/6}} \quad , \tag{1}$$

where C is a constant that depends on wether the inclusion is on the surface, touching the surface or below the surface. HV is the microhardness and the $\sqrt{area_{max}}$ is the largest predicted inclusion in the volume.

This paper focuses on the effect of defects that are not normal to the remote stress, but at an angle and therefore under mixed mode loading. This is the case in many applications experiencing combinations of different modes of loading and/or defect orientations. We examine this problem using experimental data and the $\sqrt{area}$ parameter.

2 Method and results

Wrought quench and tempered steel 34CrNiMo6 with a tensile strength of 1025 MPa with a micro-hardness of HV 373 is used. The fatigue limit of smooth test bars was estimated to be 475 MPa ± 11 MPa using the staircase method with a step of 20 MPa.

FIB has been successfully utilized in fatigue research. [2-6] For these tests we mill sharp notches in varied angles and sizes leading to identical projected square root areas as shown in Fig. 1.

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Notched specimens were fatigued for 10^7 cycles using tension compression (R=-1) loading below, at and just above the smooth specimen mean fatigue limit. Cracks were detected at both edges of all notches. They consistently initiated within 20 000 cycles, but surface cracks typically arrested before 300 000 cycles. Some continued growing, but since the test material contains also inclusions, in many cases the final fracture occurred at an inclusion.

The results can be summarized by noting that the angled notches were less detrimental than the perpendicular ones. An example of this can be seen in Fig. 1. Test bar 2 was remotely broken, while the crack in test bar 1 continued to grow until fracture at a smaller number of cycles.
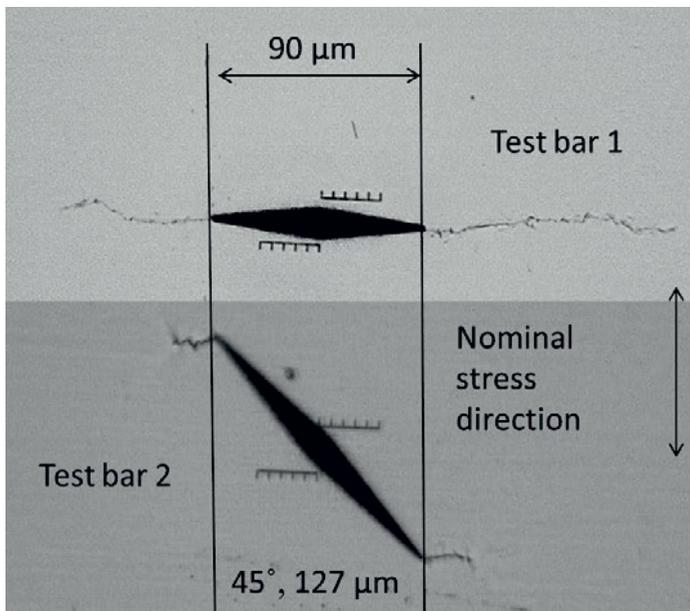

Figure 1. Two notches with the same projected square root area of 56 μm failed at 490 MPa. The test bar 1 failed from the notch, and test bar 2 failed from another location.

References

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