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Effects of Inclusions on the Very High Cycle Fatigue Properties of a High Strength Martensitic Steel within the Transition Area

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Abstract

In this paper fatigue tests of a high strength steel are presented. Focus was put on the transition area (TA) from 10^5 to 2×10^7 cycles. A change of crack initiation mechanism could be observed. Different specimen sizes D_4=4 mm, $D_{7.5}$=7.5 mm were tested at a stress ratio of R = -1 and $T = 20°C$. $D_{7.5}$ were additionally tested at $T = 350°C$. D_4 results showed a pronounced TA with defects mainly consisting of non-metallic inclusions (Al_2O_3, MgO and CaO). The average defect size ($\sqrt{area}$, D_4) was measured to be 28.98 μm. $D_{7.5}$ specimens indicated a less pronounced gap between surface and subsurface crack origins. Same type of non-metallic inclusions could be found by SEM analyses. The average defect size ($\sqrt{area}$, $D_{7.5}$) was measured to be 10.98 μm. Murakami's $\sqrt{area}$ approach showed a negligible dependance of the fatigue strength according to the different defect sizes combined with a large scatter.

Keywords: VHCF testing; Defect mechanisms; Non-metallic inclusions; Lifetime approaches;

1. Introduction

The traditional definition of the fatigue limit and, as a consequence, an infinite life of periodic loaded components like springs and shafts has been proved wrong several times on different metal materials by Mughrabi et al. (1983), Miller and O'donnell (1999) Bathias et al. (2001) and Marines (2003) amongst others.

Several todays applications like train axels and turbine blades are forced to whitstand a high number of cycles due to the high operating speeds and long lifecycles. Especially high rotating speeds sometimes lead to severe impacts like broken train wheels (ICE, Eschede). After a distance of $1.8x10^6$ km was covered the wheel broke as a result of $6.2x10^8$ loading cycles. This still might be within the transition area (TA) whereas the wheel was designed to have a

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constant amplitude limit (infinite life), which was discussed by Radaj and Vormwald (2007). An infinite life approach was defined after investigations were carried out by Wöhler (1866) in the 19th century.

Focus was put on the defect mechanisms within the TA from 10^5 to 2×10^7 cycles. Actual evaluation criteria implemented in simulation tools (fe-safe, etc.) do not pay attention to defect based approaches, which are important concerning the material's fatigue properties. Defects were analysed and the results were presented involving Murakami's defect based $\sqrt{area}$ (Murakami (2002)) approach. HCF tests and defect chracteristics were discussed in the first part. Further the effect of different specimen sizes and temperatures was examined. A conclusion was given about a present TA and finite life based design.

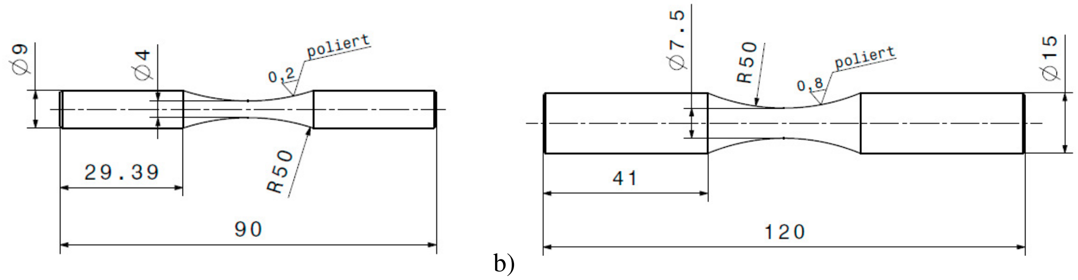
Nomenclature

TA	Transition area
EDS	Energy Dispersive X-Ray Spectroscopy
ECD	Equivalent circular diameter
UTS	Ultimate tensile strength
$^{\circ}C$	Degree celcius
R	Stress ratio
HCF	Hich cycle fatigue
VHCF	Very high cycle fatigue
k	Slope of the S / N curve
S_{aD}	Constant amplitude fatigue limit
$S_{a,norm}$	Normalised fatigue limit
σ_{norm}	Normalised stress
N_D	Cycles to the turn-off or inflexion point

2. Experimental procedure

Specimen and material

A martensitic steel was used after a heat treatment (precipitation hardening) established the final testing condition. The heat treatment depends on the field of use and therefore different material properties (up to UTS = 1400 MPa) are reachable. The chemical composition of most relevant alloying elements is (max. weight-%): 0.07 % C ,17.0 % Cr, 5.0 % Cu and 5.0 % Ni. Hourglass shaped specimen geometries were used with diameters of D = 4.0 mm (D_4) and D = 7.5 mm ($D_{7.5}$), which were outlined in Figure 1a),b).



a) b)

Fig. 1. Shape of tested specimens: a) D_4=4 mm; b) $D_{7.5}$=7.5 mm; The tested cross section was polished to its final condition.