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# SHORT CRACK GROWTH BEHAVIOR OF IN718 UNDER HIGH TEMPERATURE CONDITIONS IN CONSIDERATION OF PLASTICITY INDUCED CRACK CLOSURE

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**Abstract**
The behavior of short fatigue cracks under high temperature conditions is of significant importance for lifetime predictions and defect assessment of components in aircraft and gas turbine applications. The cyclic R(esistance) curve provides a possibility to describe phenomenologically the crack growth behavior below the long crack threshold. Within this paper experimentally determined cyclic R-curves of the nickel based alloy IN718 for varying load ratios ($R_\sigma$ = -1, 0 and 0.5) at 650 °C are compared to each other. Furthermore, an approach supporting a mechanism-based understanding of the cyclic R-curves, taking plasticity induced crack closure (PICC) into account, is developed. Finite element analysis is used to estimate the amount of PICC in the short crack regime. For a systematic investigation of the impact of different ductility properties on short crack behavior, results from an additively and two conventionally (cast and wrought) manufactured material variants of IN718 are part of the investigations.

## 1. Introduction

Rotating turbomachinery components are subjected to vibrations with very high frequencies. Due to this high cycle fatigue (HCF) loading, it is imperative to assure that no growable fatigue cracks are initiated at internal material defects like pores or carbide nests or manufacturing imperfections such as grooves or notches. In order to design these components with a safe life approach at a given defect size, a fundamental understanding of the fatigue crack growth (FCG) behavior is of crucial importance. The long crack behavior of IN718, the material examined in this study, is well known and part of many publications. However, there is a lack of studies on the short fatigue crack growth behavior (SFCG) below the long crack threshold ($\Delta K_{th,lc}$) which is of great importance, as it is known that it determines a significant amount of the fatigue life. The crack growth behavior between the material specific intrinsic threshold ($\Delta K_{th,int}$) and $\Delta K_{th,lc}$ is described by cyclic R-curves. The SFCG behavior of cracks is highly impacted by evolving crack closure mechanisms such as plasticity induced crack closure (PICC), roughness induced crack closure (RICC) and oxide induced crack closure (OICC).

In this paper cyclic R-curves for one additively ($IN718_{LPBF}$) and two conventionally ($IN718_{cast}$ and $IN718_{wrought}$) manufactured material states of IN718 at 650 °C are experimentally determined. Investigations with three different load ratios ($R_\sigma$ = -1, 0 and 0.5) are used to examine the effect of loading conditions on the short crack behavior. With the help of finite element (FE) analysis the amount of PICC to the cyclic R-curves, of different material states and loading conditions, is estimated. The results are compared to results from the Newman approach, which is widely used for the consideration of PICC in FCG. The impact of RICC and OICC are discussed based on microstructural and fractographical investigations.

## 2. Experimental and simulation procedure

The experimental threshold procedure, applied in this study, is developed by Tabernig et al. for room temperature applications and was adapted to high temperature conditions in this study. In a compression precracking stage a sharp crack in front of a crack starter notch with a stress-free crack tip has been procuced on a Single Edge Notched (SEN) specimen. This stage was conducted at room temperature, with a load ratio of 100. In a load increasing procedure with a constant load ratio $R_\sigma$ at 650 °C, starting with loads below $\Delta K_{th,int}$, the SFCG beahvior is determined. Thus, cyclic R-curves for three different material states under three different load ratios at 650 °C can be presented in this paper.

To recalculate the amount of PICC to the cyclic R-curves, cyclic elastic-plastic finite element (FE) simulations were used. A 2D - FE model of a SEN specimen was used to simulate crack growth in the short crack regime. By releasing boundary conditions of nodes on a predefined crack path after cyclic loading the crack growth is simulated. A linear kinematic hardening material model based on results from tensile tests at room temperature and 650 °C has been used. Calculated field quantities are used to determine the effective crack tip loading, the effective cyclic J-integral, under consideration of PICC. These results are compared to results from the Newman approach.

## 3. Results

In Fig. 1a) experimentally determined cyclic R-curves for the additively manufactured material state of IN718 at 650 °C are presented. Starting from a $\Delta K_{th,int}$ value, calculated based on the materials young's modulus, the cyclic R-curves evolve up to $\Delta K_{th,lc}$ at crack increments of 0.04 mm. There is a strong dependency of the short crack behavior on the applied loading. With increasing load ratio the slopes of the cyclic R-curve and $\Delta K_{th,lc}$ are decreasing. This behavior has been expected due to the decreasing amount of crack closure at higher load ratios. Fig. *1*b) shows the data points for the effective cyclic R-curve (as dots, stars and triangles) gained from the application of the Newman approach. The experimentally determined cyclic R-curves are indicated by straight lines. The strong dependency on the applied load ratio in the cyclic R-curves is reduced by the Newman approach. There is no longer any significant difference between the effective cyclic R-curves for the load ratios -1 and 0 and only a small gap to the effective cyclic R-curve for $R_\sigma = 0.5$. Since the Newman approach is actually valid only for cracks with completely build up PICC and not for cracks in the short crack regime, the results are recalculated using FE based simulations on the evolution of PICC in the short crack regime. To assess the impact of RICC and OICC portions as the remaining crack closure portions microstructural and fractografical investigations were performed.

a) b)

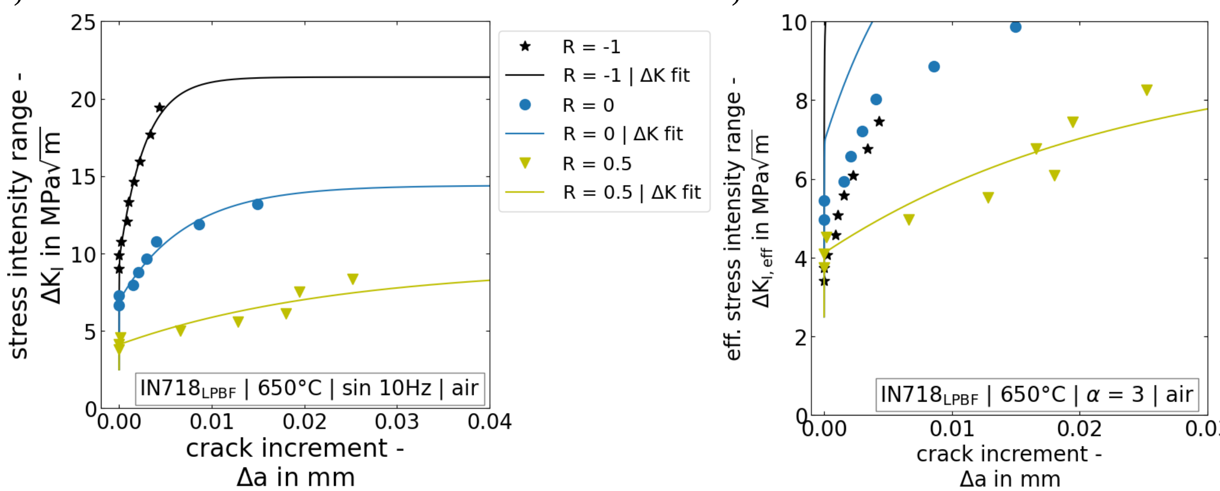


Fig. 1 – a) Experimentally determined cyclic R-curves of $IN718_{LPBF}$ at 650 °C for three load ratios. b) effective cyclic R-curves gained from the application of the Newman approach on data shown in a).

## 4. Conclusion

Within this study a procedure to quantify the amount of PICC, RICC and OICC on the SFCG behavior of nickel based alloys has been developed. Additionally to the experimental determination of the SFCG behavior at high temperatures, FE investigations are used to quantify the effect of PICC on the SFCG behavior. The effect of RICC and OICC on the SFCG behavior is discussed using microstructural and fractographical investigations.

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