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ACCELERATED FATIGUE TESTING TO EVALUATE THE FATIGUE LIFE CURVE

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ABSTRACT

A main target of fatigue research is the development of accelerated fatigue testing methods in order to provide fatigue properties for the design process of cyclic loaded components and safety relevant parts.

The scope of load controlled fatigue tests is the characterisation of the influence of mean stresses and notches on the fatigue strength as well as the determination of the influence of material selection and joining technologies on the fatigue life of components. The usage of high test frequencies is possible, if an influence of the test frequency on fatigue life can be neglected. If it is not possible to quantify the influence of the load frequency on the fatigue life, service load relevant test frequencies should be used to perform fatigue test in order to evaluate reliable fatigue properties for the numerical fatigue approach.

A Fatigue Life Curve is introduced, which allows a description of fatigue life from the Low Cycle Fatigue (LCF) regime across the High Cycle Fatigue (HCF) up to the Very High Cycle Fatigue (VHCF) regime. It comprises a combination of strain and load controlled fatigue testing in order to derive the parameters for the description of the fatigue-life relation This continuous fatigue life curve for aluminium wrought alloys, which is based on the evolution of the elastic-plastic material behaviour as well as on the results of high frequency testing up to the VHCF regime, will be discussed.

Keywords: fatigue, continuous fatigue life curve, LCF, HCF, VHCF.

INTRODUCTION

In order to consider the cyclic material behaviour during the design process of cyclically loaded components and safety relevant parts the importance of local strain based fatigue design approaches is growing continuously. For the damage impact of load-time histories on components like chassis parts, standard service loads with amplitudes settled in the HCF and VHCF regime as well as overloads and misuse with load amplitudes from the LCF regime have to be considered in order to perform a reliable fatigue life estimation. Therefore a continuous fatigue life curve from the LCF up to the VHCF regime, which covers all relevant damage mechanisms, is required.

In order to evaluate the cyclic material behaviour up to $1{\cdot}10^6$ or maybe $1{\cdot}10^7$ cycles to failure, strain controlled fatigue tests are the appropriate choice. In case of aluminium wrought alloys the tri-linear strain life curve, which has been developed and validated during previous research, enhances the accuracy of the mathematical approximation of the test results.

Regarding the time consumption and overall expenses, the experimental evaluation of the properties to describe the third regime is a challenging task. As a result of the load magnitude within this fatigue regime, the stress-strain behaviour is macroscopic elastic. In this case, no differences between load or strain controlled fatigue tests should be noticeable. A fatigue test result transfer from the stress-life to the strain-life system may then be realized by dividing the amplitude by the Young's modulus, as long as the fatigue strength is not influenced by the test frequency.

RESULTS AND CONCLUSIONS

The results of fatigue testing have shown, that the influence of test frequency on fatigue life of aluminum wrought alloys significantly depends on the heat treatment. This means that fatigue strength of a chemically identical material can be subjected to an influence of the test frequency or not. In case of a noticeable influence of the test frequency on the fatigue strength, the endurable load amplitude will increase or decrease for a given number of cycles. As long as a reliable method to consider the frequency influence on the fatigue strength is not available, an acceleration of fatigue testing by increasing test frequency is not appropriate. Possible methods for an assessment of the frequency influence have to consider the observation, that the slopes of the Wöhler curve are not affected by the test frequency, while the fatigue strength depends on the test frequency.

In order to describe a continuous fatigue life curve from the LCF up to the VHCF a combination of strain and load controlled fatigue testing enables a time and cost reduction. In order to assign damage relevant material models, the course of the fatigue life relation is divided into three parts with a linear approximation for the elastic and plastic strain part in order to describe the fatigue life relation in each part. The first part contains predominantly loads belonging to the Low Cycle Fatigue regime, which cause macroscopically observable yielding. In the second part of the fatigue-life relation, the medium fatigue regime, the initial loading cycles cause an elasto-plastic stress strain state, which, as a result of the cyclic hardening, converts to a macroscopically elastic stress-strain state after a certain number of cycles. Due to the elasto-plastic nature of the stress-strain, strain-controlled fatigue testing have to be used to determine the fatigue-life relation for the first and the second part. In the third part, the high cycle and very high cycle fatigue regime, only elastic loads are present. The slope from the high frequency load controlled fatigue tests is therefore determined by stress controlled testing with high frequencies. Accordingly, the concave knee point between the second and the third part of the fatigue life relation, which refers to the transition from macroscopic elastic to elastic-plastic stress-strain behavior during the initial loading, will be derived by the evaluation of stress-strain behavior. The slope and the knee point allow the description of the third part of the fatigue life relation, which covers the Very High Cycle Fatigue regime. Furthermore, analyzing the initial stress-strain curves of all strain controlled fatigue tests allows the derivation of a scatter band for the third regime.

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