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Influence of size effect and stress gradient on the high-cycle fatigue strength of a 1.4542 steel

Igor Milošević[a*], Gerhard Winter[a], Florian Grün[a], Martin Kober[b]

[a]*Chair of Mechanical Engineering, Montanuniversität Leoben, Franz-Josef-Strasse 18, Leoben 8700, Austria*
[b]*LEC GmbH, Inffeldgasse 19/II, Graz 8010, Austria*

Abstract

Nowadays technical applications require very small components which leads to the question of how to handle fatigue strength data gained from tests carried out on specimen which are even larger than the component itself. Previous high-cycle-fatigue (HCF) tests have outlined the negative influence of increasing "risk volumes" due to enlargement of the specimen size. Additional to the effect of "risk volumes" the influence of stress gradient may not be neglected as the gradient changes as well due to the enlargement of the specimen size. Especially thin profiles could be affected by high stress gradients which results in high and low stress loaded profile areas. The fatigue strength of an hourglass shaped specimen with a standardized diameter of 7.5 mm tends to have higher fatigue strength than a specimen with a larger diameter. In this work rotating bending tests were carried out on specimens with a diameter of 4 and 7.5 mm. Lifetime simulations with different specimen diameters (D2.5, D4 and D7.5) were carried out by a common simulation tool FEMFAT and simultaneous testing of D4 and D7.5 specimens was performed to compare the results. An outlook is given on how such influences can be estimated and an appropriate method can be derived for damage calculations.

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Keywords: fatigue, size effect, stress gradient, lifetime simulation, 1.4542 steel

Nomenclature

FEA	Finite element analysis
LEPP	lifetime estimation postprocessing
ODB	FEA Output database

* Corresponding author. Tel.: +43 3842 402 1457; fax: +43 3842 402 1402
E-mail address: igor.milosevic@unileoben.ac.at

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E	Youngs modulus
K_t	Elastic stress concentration factor
K_f	Fatigue strength reduction factor
b	Thickness of a specimen
χ	Stress gradient
χ'	Relative stress gradient
σ_t	Tension/compression fatigue strength
σ_{rb}	Rotating bending fatigue strength
σ_f	Local fatigue strength
σ_N	Nominal stress
σ_{max}	Maximum notch stress
σ_v	von Mises stress or equivalent tensile stress
S_{22}	Stress in the axial direction of the specimen
N_D	Number of cycles at the fatigue limit
k	Slope of the S/N curve
D	Damage
UTS	Ultimate tensile strength
YS	Yield strength

1. Introduction

In times of developing lightweight structures including very complex shapes finite element analysis (FEA) is a common tool to calculate reasonable strains and stresses which have an effect on the considered structure. The process of fatigue life estimation starts with the evaluation of the prevailing loads on the component (strains, stresses, load spectra, etc.) and additional material data. Such data generally, but not only, described as S/N-curves and Haigh-diagrams leads to the derivation of several material parameters implemented into the lifetime estimation post processing (LEPP).

Material properties are determined by the application of material testing. Especially testing cyclic material properties (for example fatigue testing under completely reversed stresses) is influenced by testing conditions such as loads, temperatures, size effects, mean and residual stresses, manufacturing processes and the stress distribution itself. The tests have to be evaluated and certain values can be used in the LEPP to define material fatigue properties.

Within the FEA no difference is made between the assessment of stresses in the tension/compression or bending mode. All the load information is implemented into the LEPP through the import of the FEA output database (ODB) including especially node stresses of the meshed geometry. In the present work a focus was put on the application of the stress gradient approach on different specimen sizes. Therefore, it's necessary to take a look at the local stress distribution in comparison with the testing method of the unnotched or notched specimen. [1,2]

2. Stress distribution

The most common used approach of taking the stress distribution of notched components into account is described by the work of Neuber. As long as functional components are needed for a certain purpose engineers will be forced to find a way on how to apply effects of geometrical discontinuities in the LEPP.

The failure potential tends to be higher due to unfavorable impacts through notched areas. Especially crack initiation takes place at notched areas of stressed components in an early stage of fatigue life. These notches could be optimized in order to prevent reduction in fatigue life. [2]