APPROXIMATE METHODS FOR CALCULATING NOTCH TIP STRAINS AND STRESSES UNDER MULTIAXIAL CYCLIC LOADING

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Study Field: Mechanics of Rigid and Deformable Bodies and Environment
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Motivation

Most initially isotropic engineering materials exhibit elastic-plastic behavior. To evaluate the damage imposed on components made from such materials, one has to obtain strains and stresses of the components in question. In order to speed up the process of calculating stresses and strains, an approximate calculation might be carried out.

The approximate methods transform the initial solution of a problem, obtained from a calculation with ideally elastic material behavior, into elastic-plastic estimates using basic material data. The transformation might be achieved by different approaches. The first one is by creation of a pseudo material, which relate theoretical purely elastic material and real elastic-plastic equivalent. The second approach relies on the connection between linear-elastic and elastic-plastic strain energies.

Aims

The main drawbacks of the current state of development of the approximate methods are the lack of detailed descriptions of how the plasticity part and the notch correction part are combined, and the lack of notch strain experimental responses on different than steel material. The following aims for the thesis are set:

1. Develop a methodology on how to combine a notch correction and a plasticity model and provide a detailed description and an implementation code;
2. Obtain new and original experimental data on the notch tip strains to validate the method predictions on specimens manufactured from a different than steel material.
3. **Propose a new and original approximate method for calculating elastic-plastic stresses and strains at the notch tip under multiaxial cyclic loading that provides results of better or of similar precision compared to the other existing methods**.

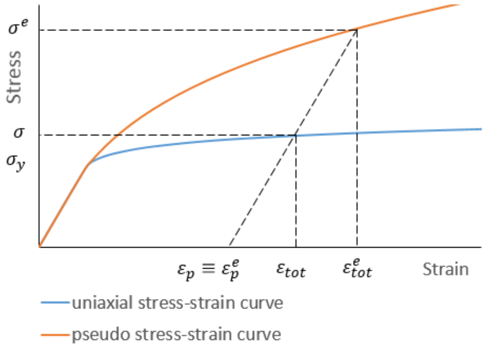
Used tools and proposed method

For the notch correction part, the pseudo stress-real plastic strain approach was chosen. The pseudo curve was established by combining elastic stress with plastic strain. The pseudo plastic strain values were the same as the plastic strain values of the real cyclic stress–strain (CSS) curve. The key part in calculating the real response from the pseudo variables was the equivalence of the plastic strain tensor of the pseudo curve and of the real stress–strain curve.

For the plasticity part of the proposed method, the Abdel-Karim-Ohno (AKO) plasticity model was chosen. In addition to requiring only a few material parameters, the model, depending on its settings, represents other plasticity models as its special cases.

A substitution algorithm by Kobayashi and Ohno was implemented to solve the nonlinear scalar equation for accumulated plastic strain.

The digital image correlation method was used to measure the notch tip axial and shear strains. Seven loading paths for two nominal stress ratios were applied to two types of notched specimens from the Al2124-T851 aluminum alloy. The strains were measured for the first 100 cycles.



Results

The estimates were evaluated using the relative error values of differences between estimated and measured strain ranges.

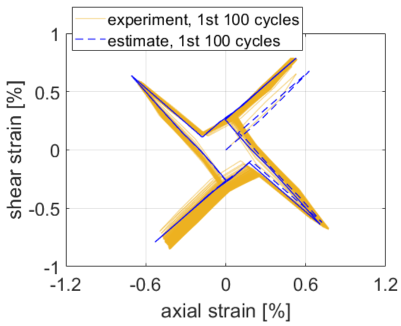
In the case of the axial component, 94% of the studied cases lie within 20% of the relative error in absolute values. The shear component for the same range shows a slightly lower value of 87.5%.

The estimates by the proposed method were also compared with estimates of other methods found in the literature. The comparison was made for 1070 steel, as it is the most frequently used material for the validations of the approximate methods. The proposed method provides the best predictions in 6 out of 13 cases.

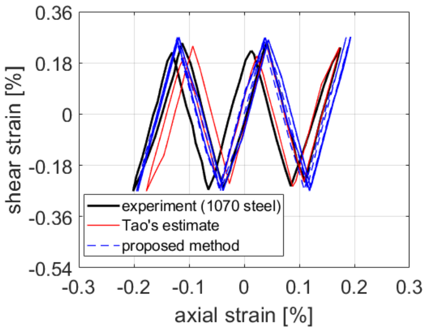
Conclusions

1. A methodology on how to combine a notch correction and a plasticity model was developed. The implementation code is available in Appendix C of the doctoral thesis.
2. New and original experimental data of notch tip strains were measured on aluminum 2124-T851 specimens for a variety of loading paths. A total number of 18 experimental loading cases is presented in this work.
3. A new and original approximate method for calculating the elastic-plastic stresses and strains at the notch tip under multiaxial cyclic loading was proposed. Its novelty lies in the ability to incorporate three plasticity models, Abdel-Karim-Ohno, Ohno-Wang, and Chaboche's model, as its special cases. The approximate method provides results of competitive precision to other existing methods and allows fast estimates of stress and strain responses on cyclic multiaxial loading.

Estimate for loading path X for Al2124-T851



Estimate for loading path NV



Relative errors for different loading paths between measured and calculated combined strain ranges for 1070 steel in percents

Path	σ_{nom}[MPa]/ τ_{nom} [MPa]	Li et al. [12]	Ince et al. [11]	Tao et al. [13]	proposed method
ksi	258/168	–	–	−1.45	−1.5
ksi	296/193	–	−4.5	–	−4.5
N	258/168	–	–	−4.62	1.1
N	296/193	6.5	−6.4	–	−4.8
NV	258/168	–	–	−5.29	3.3
NV	296/193	–	−4.2	–	−5
Proportional	296/193	–	–	−1.67	−8.8
Rotated V	296/193	4.9	–	–	−1.4
S	258/168	–	–	−1.87	−1.3
S	296/193	−0.7	−6.6	–	−8.3
Square	296/193	8.7	−4	−4.98	−8
Square (clockwise)	296/193	10.4	−4.1	–	−7.2
V	296/193	11.4	–	–	1.4

Future work

In order to improve the precision of the proposed method, a changeable value of the ratcheting parameter might be implemented. This would allow to match the measured material response for path with a mean stress more closely. Another way to increase the precision might be found by in-depth analyzes of differences between AKO and Jiang-Sehitoglu plasticity models, which showed itself as the most precise for the majority of its studied cases.

It should be possible to expand the method by including the Calloch-Marquis non-proportional parameter, which would allow a non-proportional hardening to be taken into account, appearing, for example, in the cases of stainless steels and coppers.

Finally, since thermo-mechanical loading is a common part of loading states and a need to calculate stresses and strains in such cases is as great as for mechanical loading under constant temperatures, the possibility to expand the method for thermo-mechanical loading might be investigated in the future.

Publications of the author related to the topic of the thesis

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A2. Papuga, J., Vízková, I., Lutovinov, M. & Nesládek, M. Mean stress effect in stress life fatigue prediction re-evaluated. English. *MATEC Web of Conferences* **165**, 8 pages. https://www.matec-conferences.org/articles/matecconf/pdf/2018/24/matecconf_fatigue2018_10018.pdf (May 2018).

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A5. Lutovinov M.; Papuga, J. *A Verification of Methods for Calculating Notch Tip Stresses and Strains in 19th Workshop of Applied Mechanics* (Czech Technical University in Prague, Faculty of Mechanical Engineering, 2015), 4 pages. ISBN: 978-80-01-05918-0.

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