

Fatigue lifetime calculations using scaled normal stresses

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ECS Simulation Conference 2023

May 9th - 12th 2023, Linz, Austria

Agenda

- Introduction
- Scaled normal stress approach
- Generalization
- Example application and comparison with FEMFAT
- Conclusions

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Introduction

- In analytical strength assessments complex stress states need to be taken into account
 - The assessment for those complex stress states can be based on multiple different approaches
 - FEMFAT uses so called scaled normal stresses to account for these complex stress states (proportional and also non-proportional)
- In the following these scaled normal stresses will be investigated and generalized and a proposal for integration into the FKM Guideline will be presented

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Scaled Normal stress approach – as used in FEMFAT

$$\sigma_{eq,i}(t) = \left[1 + \left(1 - \frac{1}{f_{\tau,\sigma}} \right) \cdot V(t) \right] \cdot \sigma_n(t)$$

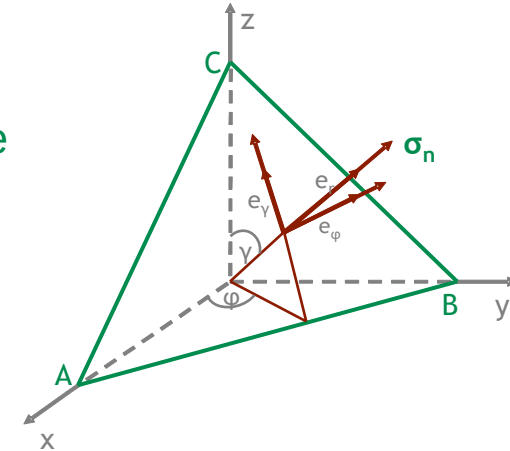
Material factor $f_{\tau,\sigma}$ depends on stress state $V(t)$ Normal stress in section plane $\sigma_n(t)$

$$f_{\tau,\sigma} = \frac{\tau_f}{\sigma_f}$$

τ_f = fatigue limit for shear stress
 σ_f = fatigue limit for normal stress

$$V(t) = \begin{cases} \frac{\sigma_3(t)}{\sigma_1(t)} & \text{if } |\sigma_1(t)| \geq |\sigma_3(t)| \\ \frac{\sigma_1(t)}{\sigma_3(t)} & \text{if } |\sigma_1(t)| < |\sigma_3(t)| \end{cases}$$

assuming $(\sigma_1(t) > \sigma_2(t) > \sigma_3(t))$



→ Scaled normal stress approach is used as default in FEMFAT

Gaier, C.; Dannbauer, H. A multiaxial fatigue analysis method for ductile, semi-ductile and brittle materials. Arabian Journal for Science and Engineering. 2008, 33, 223-235.

Scaled Normal stress approach

- Rearranging (more details in [1])

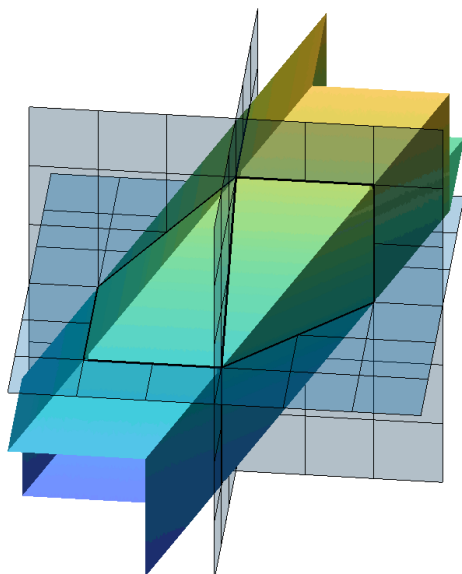
$$\sigma_{eq,n}(t) = \left[\frac{q \cdot \sigma_{eq,R}(t) + (1-q) \cdot \sigma_{eq,T}(t)}{\sigma_{eq,R}(t)} \right] \cdot \sigma_n(t)$$

- $q = 2 - \frac{1}{f_{\tau,\sigma}}$

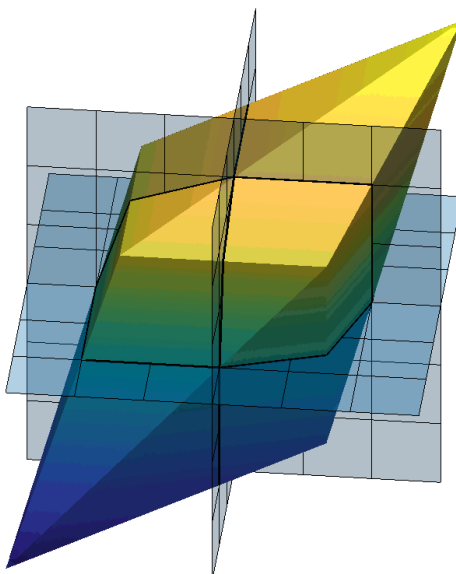
→ Depending on q the scaled normal stresses represent the Rankine- or Tresca-Hypothesis or a mixture of both

[1] - Wächter, M.; Linn, A.; Wuthenow, R.; Esderts, A.; Gaier, C.; Kraft, J.; Fällgren, C.; Vormwald, M. On Scaled Normal Stresses in Multiaxial Fatigue and Their Exemplary Application to Ductile Cast Iron. Appl. Mech. 2022, 3, 259-295. <https://doi.org/10.3390/applmech3010018>

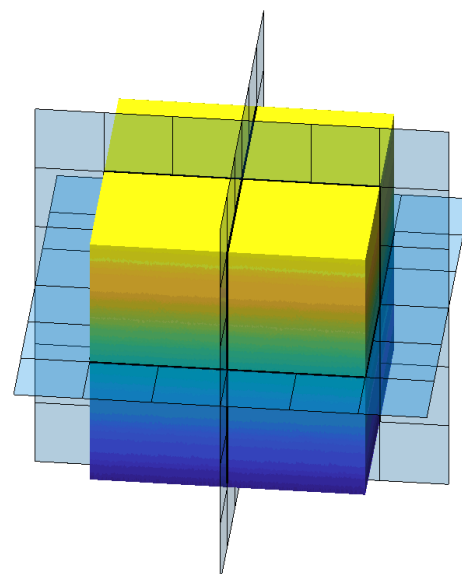
Principle stress diagrams depending on the material group



Steel, Wrought Aluminium:
 $q = 0$ (Tresca)
 $f_{\tau,\sigma} = 0.5$



GJM, Cast Aluminium:
 $q = 0.75$ (mixture)
 $f_{\tau,\sigma} = 0.75$



GJL:
 $q = 1$ (Rankine)
 $f_{\tau,\sigma} = 1.0$

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Generalization

- Further generalization

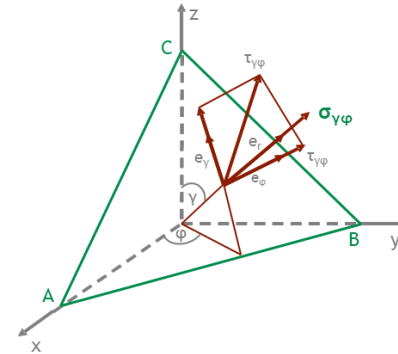
$$\sigma_{eq,n}(t) = \left[\frac{\sigma_{eq,X}(t)}{\sigma_{eq,R}(t)} \right] \cdot \sigma_n(t)$$

where $\sigma_{eq,X}(t)$ can be represented by any strength hypothesis

Generalization

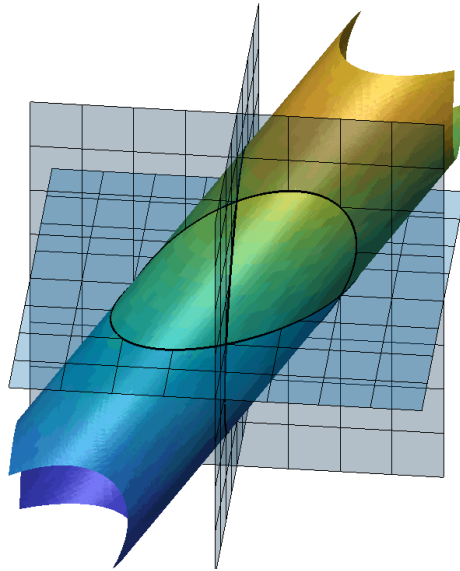
- In the following we will propose the generalized scaled normal stresses in the following formulation for use inside the FKM Guideline

$$\sigma_{eq,n}(t) = \left[\frac{q \cdot \sigma_{eq,R}(t) + (1-q) \cdot \sigma_{eq,Mises}(t)}{\sigma_{eq,R}(t)} \right] \cdot \sigma_n(t)$$

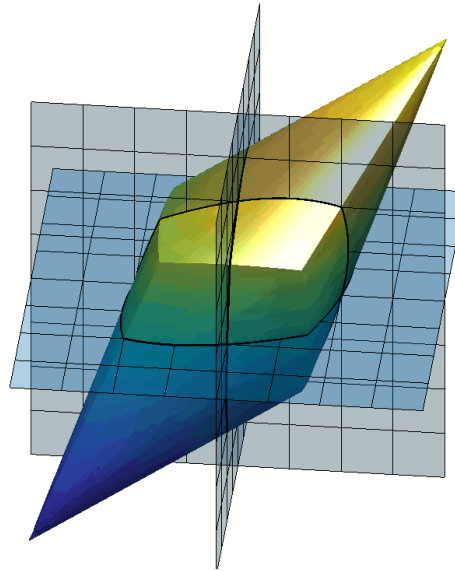


- q depends on the ductility of the material

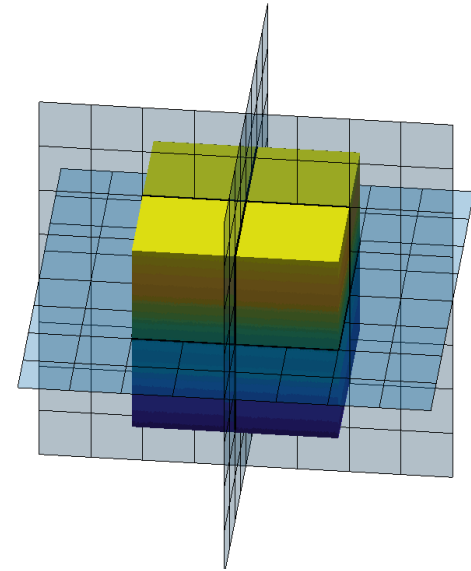
Principle stress diagrams depending on the material group



Steel, Wrought Aluminium:
 $q = 0$ (von-Mises)
 $f_{t,\sigma} = 0.577$



GJM, Cast Aluminium:
 $q = 0,75$ (mixture)
 $f_{t,\sigma} = 0.75$



GJL:
 $q = 1$ (Rankine)
 $f_{t,\sigma} = 1.0$

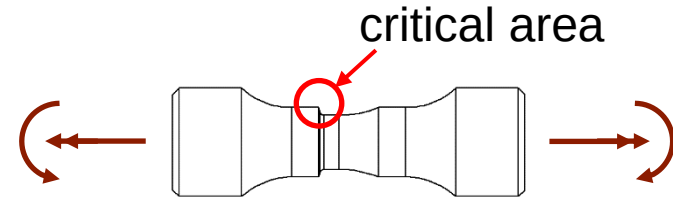
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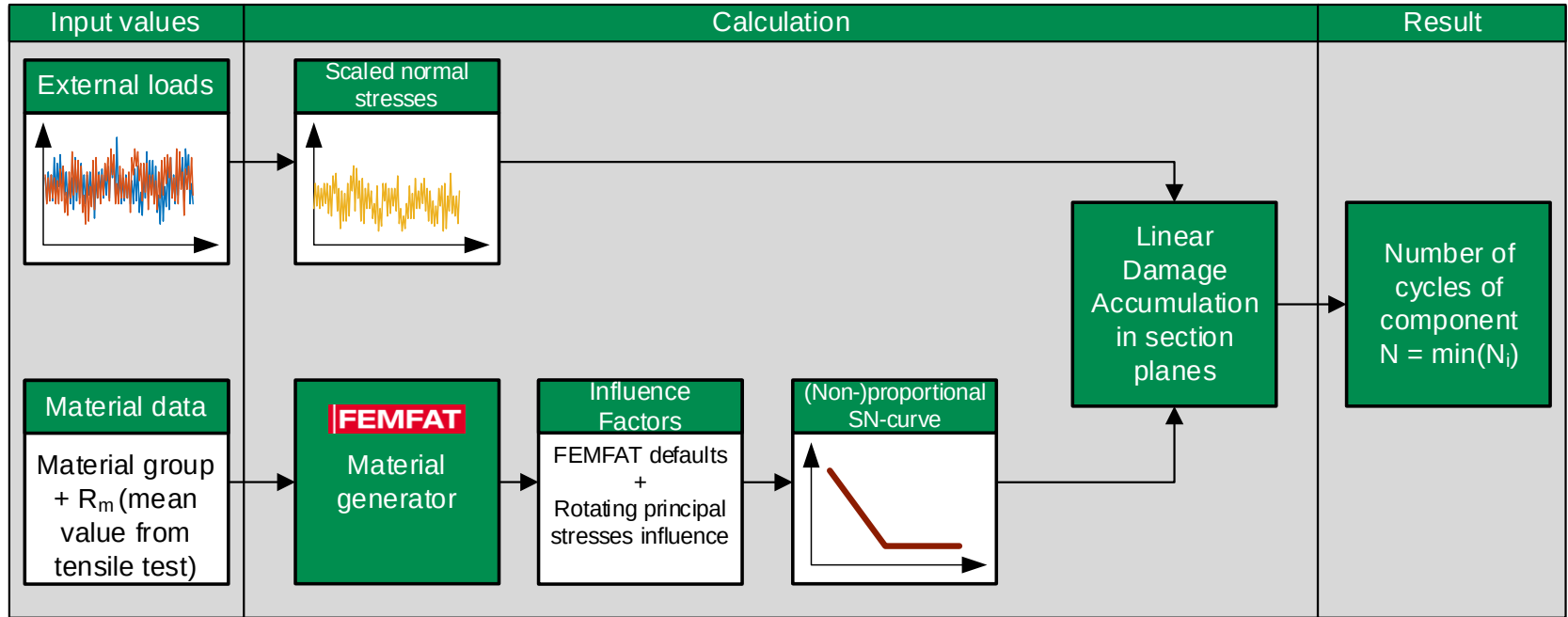
Example application and comparison with FEMFAT – Experimental data

- Test specimen is a EN-GJS-500-14
 - $R_m = 532 \text{ MPa}$, $R_p = 420 \text{ MPa}$
- Test configuration:
 - bending and torsion
 - proportional and non proportional loading
 - constant amplitude and variable amplitude

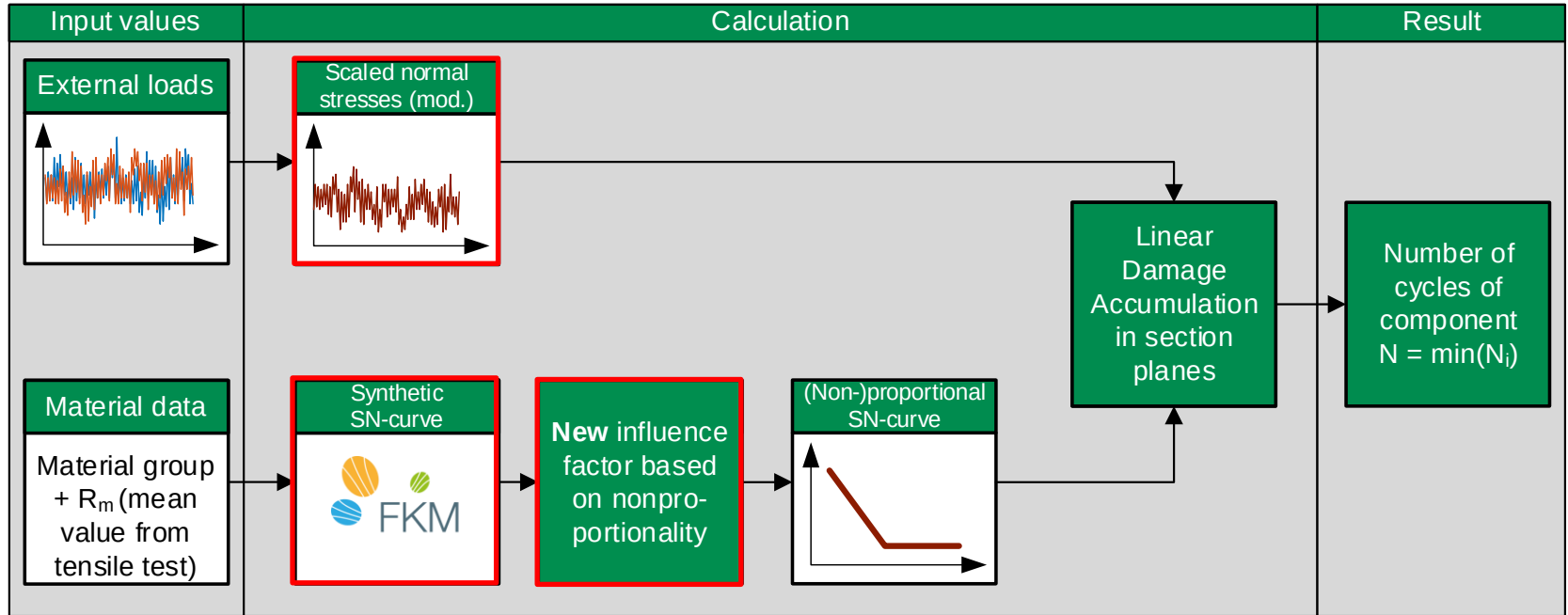


→ 82 data points for comparison purpose

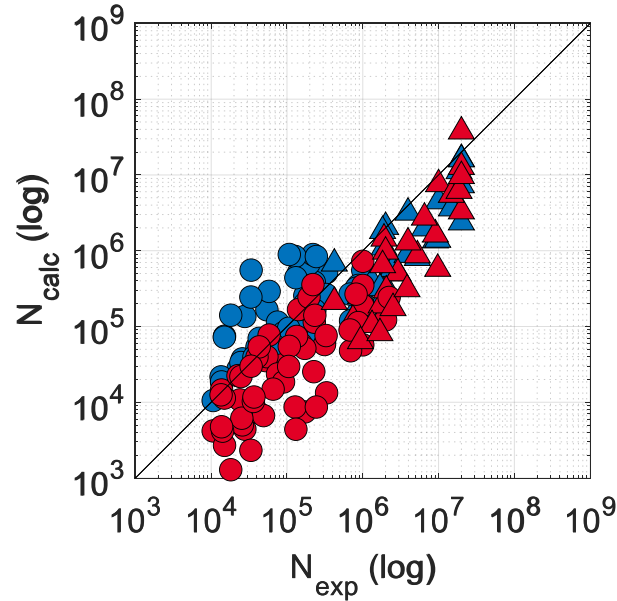
Example application – Calculation approach – FEMFAT



Example application – Calculation approach – FKM Guideline



Example application and comparison with FEMFAT

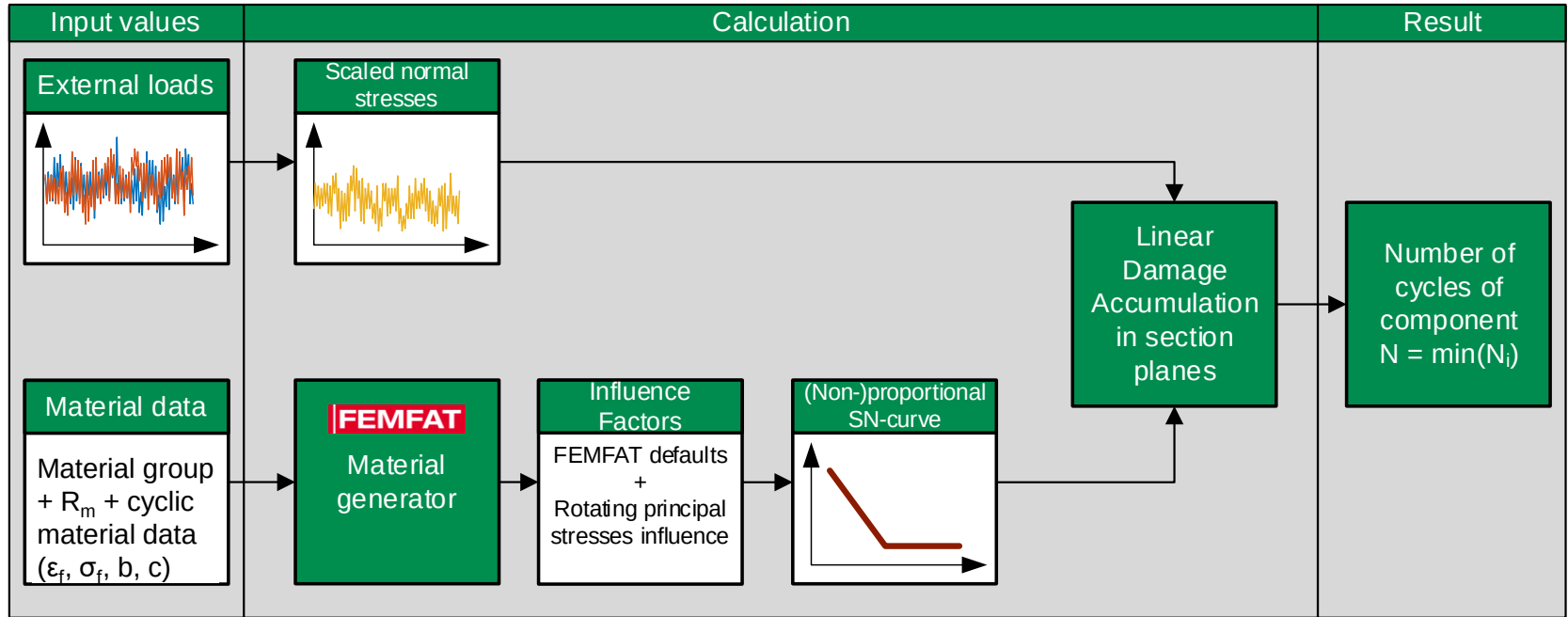


- FKM Guideline (constant amplitude)
(new approach using scaled normal stresses)
- ▲ FKM Guideline (variable amplitude)
(new approach using scaled normal stresses)
- FEMFAT (constant amplitude)
(Default Settings + influence rotating principle axis)
- ▲ FEMFAT (variable amplitude)
(Default Settings + influence rotating principle axis)

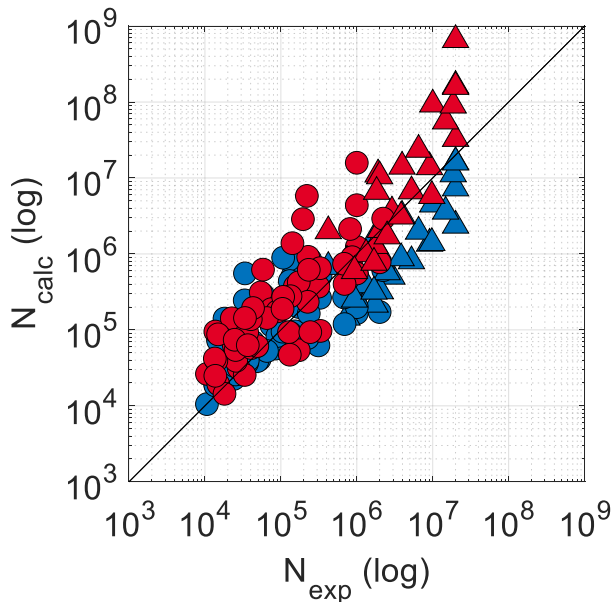
Note: In this calculations no safety factors are considered

FKM Guideline		FEMFAT	
M	T	m	T
1,24	28	3,37	15

Example application – Calculation approach – FEMFAT



Example application and comparison with FEMFAT – optimized material



- FKM Guideline (constant amplitude)
(new approach using scaled normal stresses)
- ▲ FKM Guideline (variable amplitude)
(new approach using scaled normal stresses)
- FEMFAT (constant amplitude)
(Default Settings + influence rotating principle axis)
- ▲ FEMFAT (variable amplitude)
(Default Settings + influence rotating principle axis)

Note: In this calculations no safety factors are considered

FKM Guideline		FEMFAT		FEMFAT (optim.)	
M	T	m	T	m	T
1,24	28	3,37	15	0,46	13

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Conclusions

- Scaled normal stresses can be used with every arbitrary strength hypothesis

$$\sigma_{eq,n}(t) = \left[\frac{\sigma_{eq,X}(t)}{\sigma_{eq,R}(t)} \right] \cdot \sigma_n(t)$$

- Scaled normal stresses are proposed as a new approach for use in the FKM Guideline
- Exemplary comparison of FEMFAT and a new approach for the FKM Guideline on a GJS 500-14 shows similar accuracy
- FEMFAT results can be further optimized using additional experimental data

Acknowledgements

This research was funded through a project by the German Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag. This project of Allianz Industrie Forschung (Aif), having IGF No. 20613, are professionally supervised by Forschungskuratorium Maschinenbau e.V. (FKM).

The authors would also like to thank the Engineering Center Steyr GmbH & Co KG for supporting the aforementioned project by providing Licenses for FEMFAT.



Supported by:



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**Thank you for
your kind
attention!**

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