Workshop „Material“

FEMFAT User Meeting 2021
Klaus Hofwimmer/ECS

June 21

Content

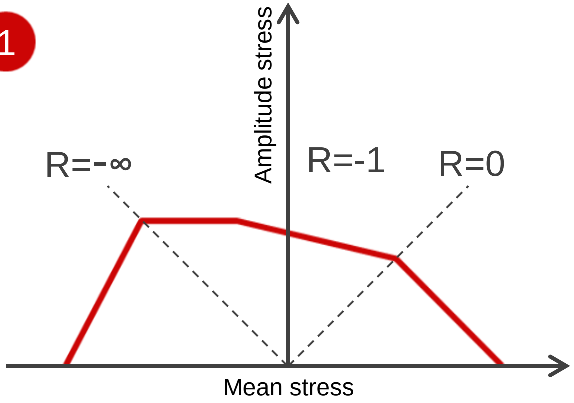
- Required Material Data
- Generation of Material Data
- Calibration of Material Data from Tests
- Plastic Material Data Generation
- Material Data for Elastomers

Required Material Data

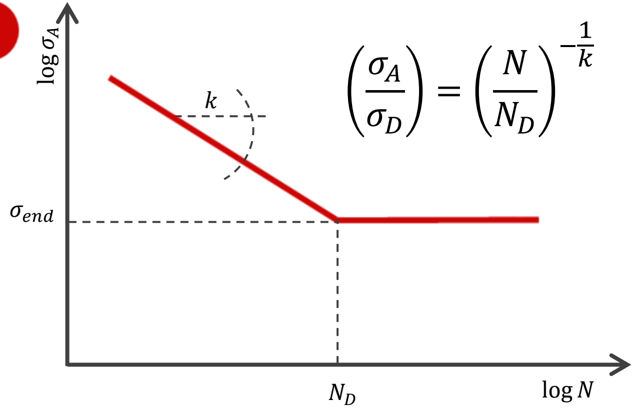
…for fatigue/safety factor analysis with FEMFAT

Measuring what matters

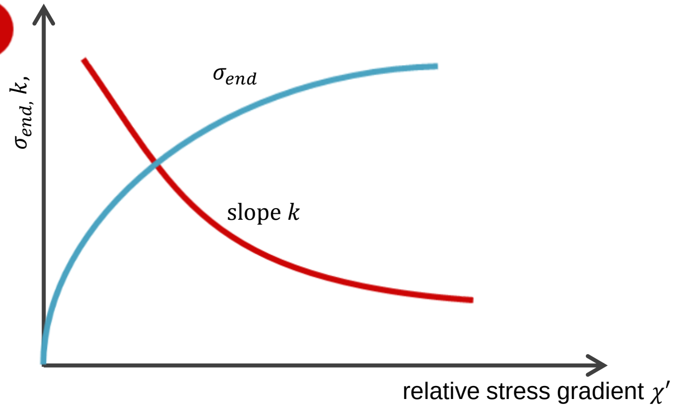
1



2



3



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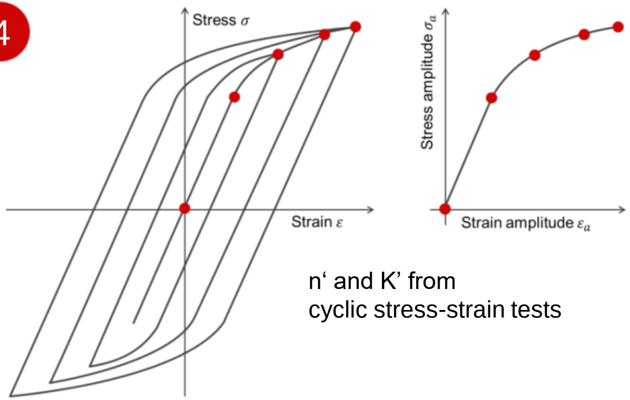
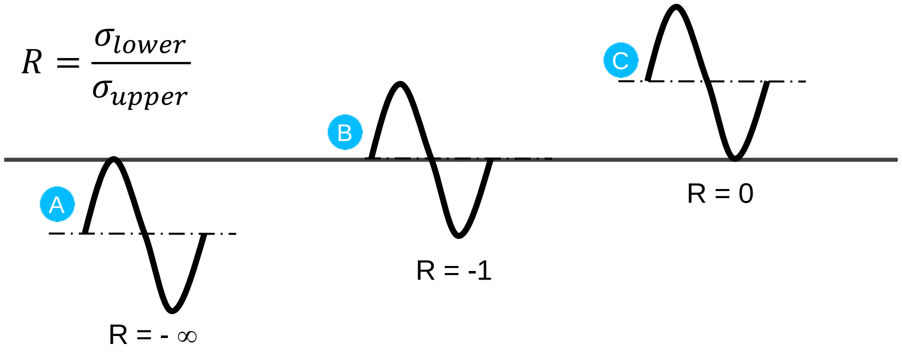
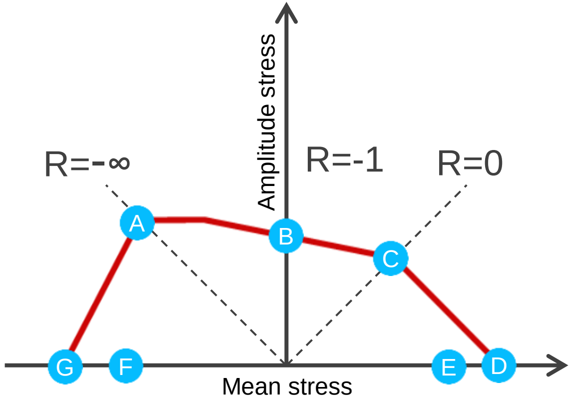


n‘ and K’ from
cyclic stress-strain tests

Parameters for Haigh-Diagram

$$R = \frac{\sigma_{lower}}{\sigma_{upper}}$$





1

A B C … derived from dynamic tests

D E F G … derived from static tests

Define Material Parameters

Select Material Class:

General Structural Carbon Steels

Material Parameters

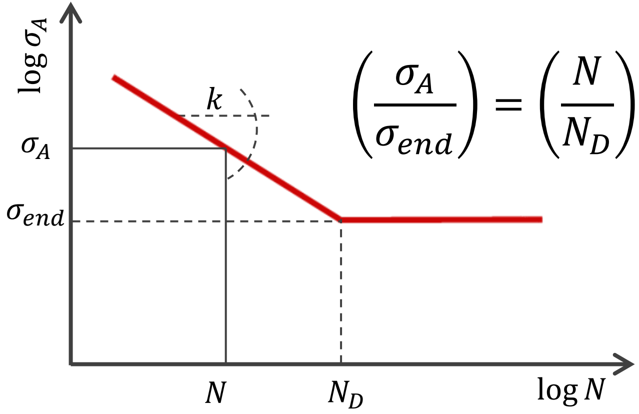
	Tension	Pressure	Bending	Shear
Ultimate Strength	400.0	400.0	478.8	230.9
Yield Strength	239.6	239.6	303.1	138.3
Pulsating Strength	346.2	0.0	423.1	221.5
Alternating Strength	180.0	180.0	200.9	103.9

- Parameters are determined for unnotched specimen in tension and compression, bending and shear from static and dynamic tests.

S/N curves

2

Tension/compression test rig with heat chamber

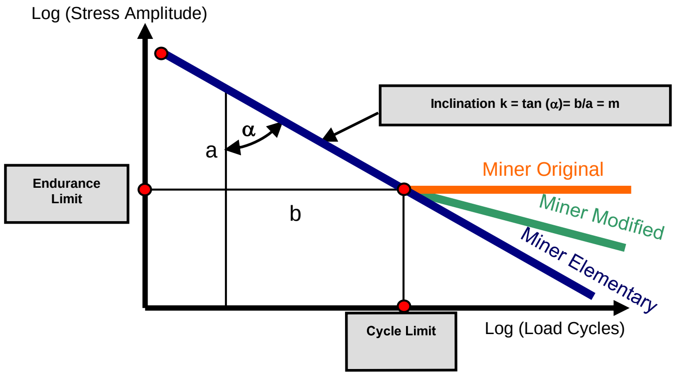


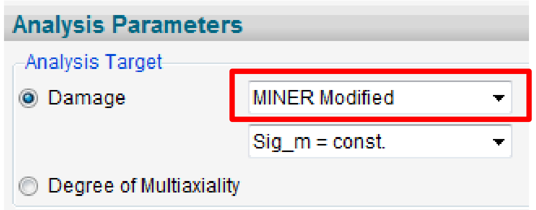
$$\left(\frac{\sigma_A}{\sigma_{end}}\right) = \left(\frac{N}{N_D}\right)^{-\frac{1}{k}}$$

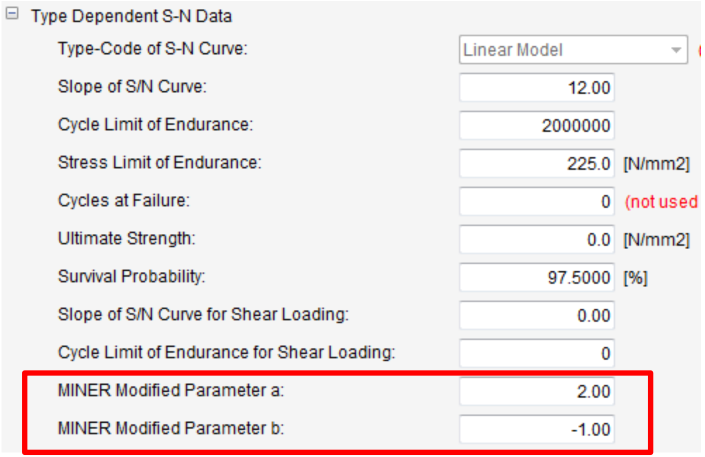
- The inclination k of S/N curve, endurance limit σ_{end} and cycle limit N_D are determined from tests at R=-1 for unnotched specimen.

Flexible Definition of Slope for the Infinite Life Domain

2







- For „MINER Modified“ the slope for the infinite life domain can be flexible defined with parameters a and b:

$$k_2 = a*k_1 + b$$

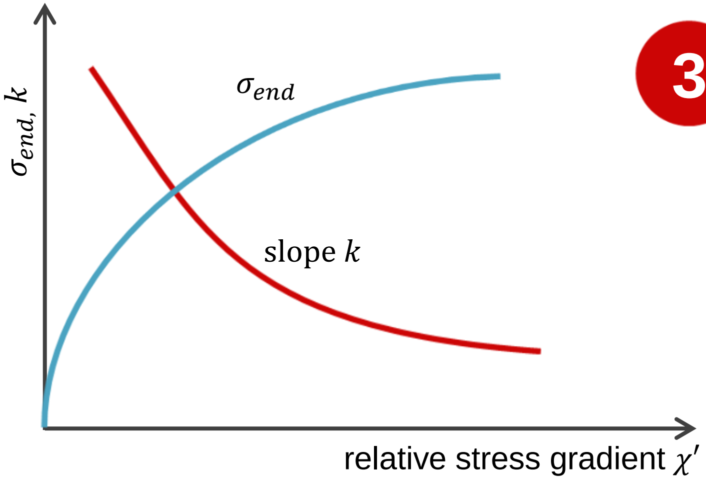
- Default settings according original Miner modified:

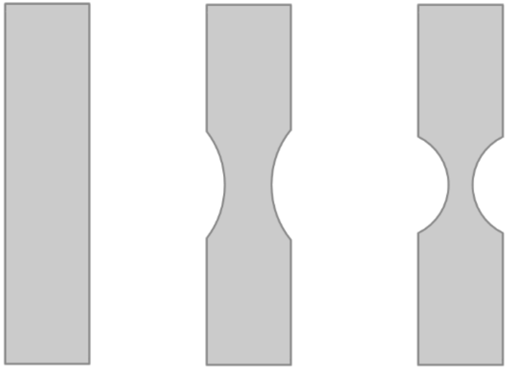
$a = 2$
$b = -1$

Notch influence – Stress gradient

- For taking the effect of stress gradient into account notched specimen are used at R=-1.
- The influence of relative stress gradient χ' is taken into consideration for endurance limit σ_{end} and the slope k of S/N curve.

3





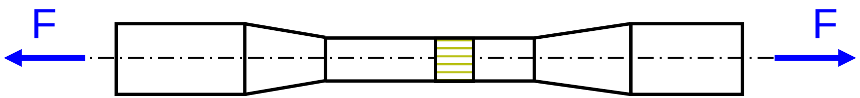
- The relative stress gradient is generated by using different notched geometries for the test specimens as well as alternating tensile and bending strength.

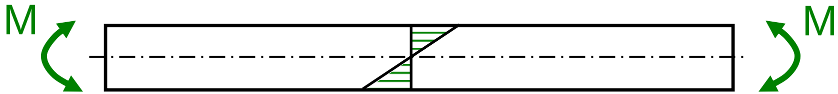
Notch influence – Stress gradient

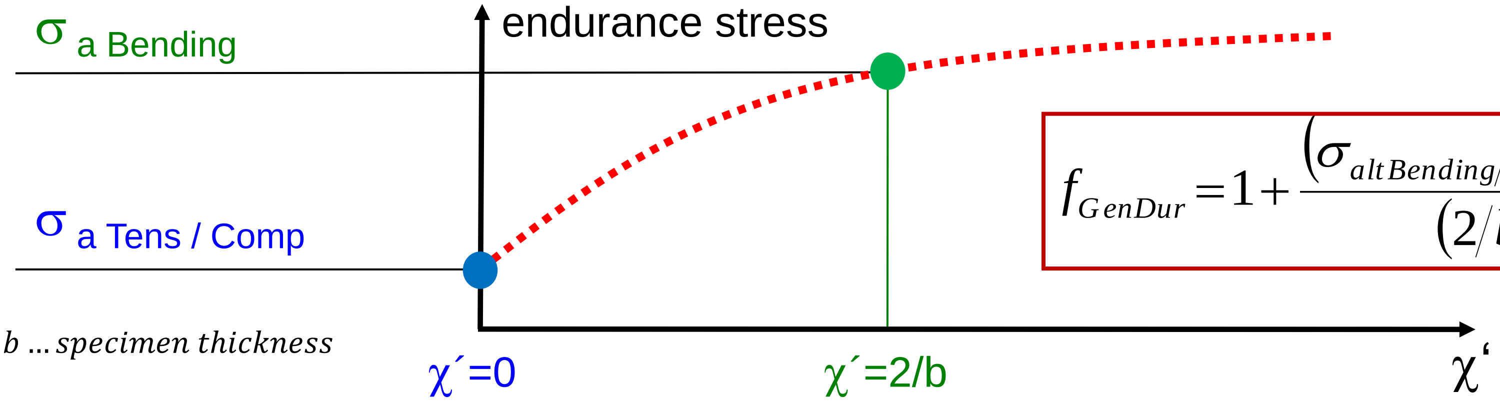
3

Relative Stress Gradient
Tension / Compression $\chi'_{alt\,TC} = 0$

Relative Stress Gradient
Bending $\chi' = 2/b$







$$f_{GenDur} = 1 + \frac{\left(\sigma_{alt\,Bending} / \sigma_{alt\,TC} - 1\right)}{\left(2/b\right)^{v}} \chi'^{v}$$

b ... specimen thickness

Notch influence – Stress gradient

- Material data can be used to adjust the gradient influence

$$f_{GenDur} = 1 + \frac{\left(\sigma_{altBending} / \sigma_{altTC} - 1\right)}{\left(2/b\right)^{\nu}} \chi'^{\nu}$$

userdefparam.dbs

3

```
$ M A T E R I A L - C L A S S - D E P E N D E N T   P A R A M E T E R
$ ==================================================================
$
```

Material Class	Exponent for Gradient - Influence	Slope Limit AK2	Exponent AK3	Diameter deff,N,m in mm	Diameter deff,N,p in mm	Constant ad,m for Kd,m	Constant ad,p for Kd,p
1	0.30	3.0	2.0	40.0	40.0	0.15	0.30
3	0.30	3.0	2.0	16.0	16.0	0.30	0.40
6	0.30	3.0	2.0	40.0	40.0	0.15	0.30
11	0.30	3.0	2.0	70.0	40.0	0.20	0.30
16	[illegible]	3.0	2.0	16.0	16.0	0.30	0.40

Parameters for Stress Gradient Influence (optional)

Data Source:	Test
Exponent nue:	0.30
Slope limit IFK2:	3.0
Slope exponent IFK3:	2.0

Define Material Parameters

Select Material Class:

General Structural Carbon Steels

Material Parameters

	Tension	Pressure	Bending	Shear
Ultimate Strength	690.0	690.0	826.0	398.0
Yield Strength	360.0	360.0	455.0	208.0
Pulsating Strength	540.0	0.0	660.0	331.5
Alternating Strength	310.0	310.0	340.0	180.0

Info

General S/N-Data

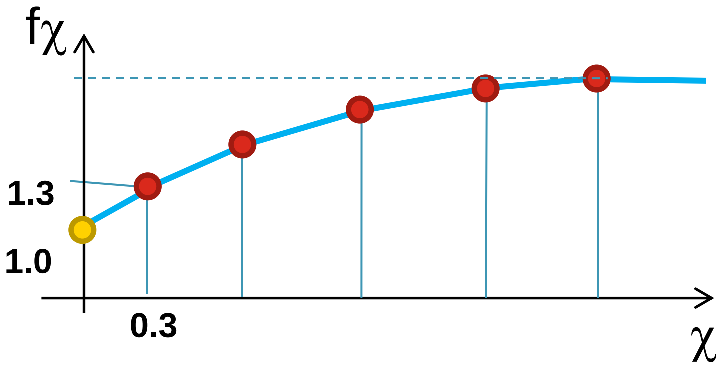
Stress Condition Code:	Tension/Compression		(not used for analysis)
Stress Ratio:	-1.000		(not used for analysis)
Notch Factor:	0.00		(not used for analysis)
Relative Stress Gradient:	0.00	[1/mm]	(not used for analysis)
Thickness of Specimen:	7.5	[mm]	
Roughness of Specimen:	1.0	[µm]	

Notch influence – Support number as polygonal line

3

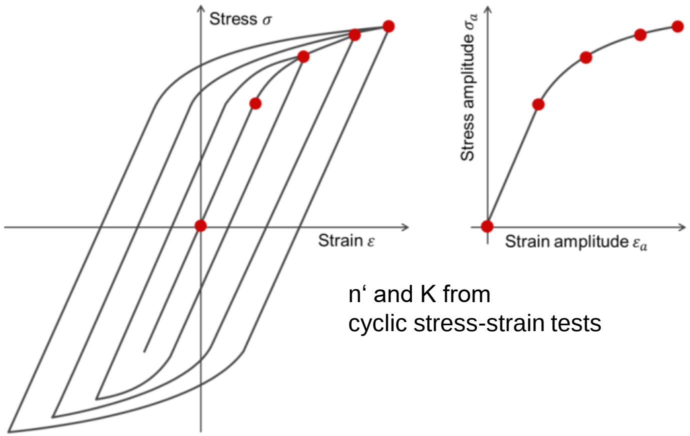
- Notch support number f_χ = Influence factor on endurance strength.
- Notch support number table for FEMFAT analysis: New dataset **237** in **ffd-file**.
  - No GUI representation of the dataset.
  - If dataset exists, analysis will be performed using this dataset.
  - If dataset does not exist, selected FEMFAT method will be used.
  - When gradient larger than last point, then support number of last point will be used.

```
  -1
 237
Support Number dependent on
relative stress gradient
Source:
     6
     0.00       1.00
     0.30       1.30
     1.00       1.50
     2.00       2.00
     3.00       2.50
     5.00       3.00
  -1
```



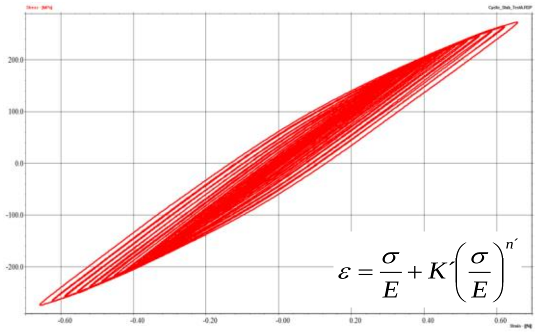
Cyclic stress strain curve

- The cyclic coefficient of hardening K´ and the cyclic exponent of hardening n´ are utilized in the FEMFAT plast module for consideration of mean stress redistributions by local plastification.
- K´ and/or n´ have not been defined, they will be automatically generated by FEMFAT based on the Uniform Material Law, as a function of the material group and the ultimate tensile strength Rm.



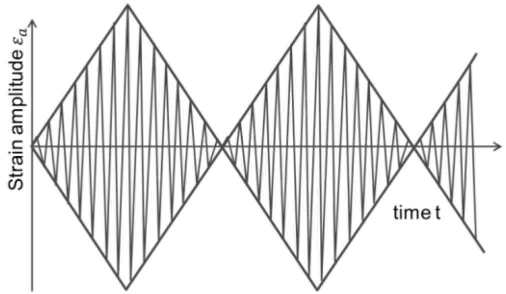
n‘ and K from
cyclic stress-strain tests

4



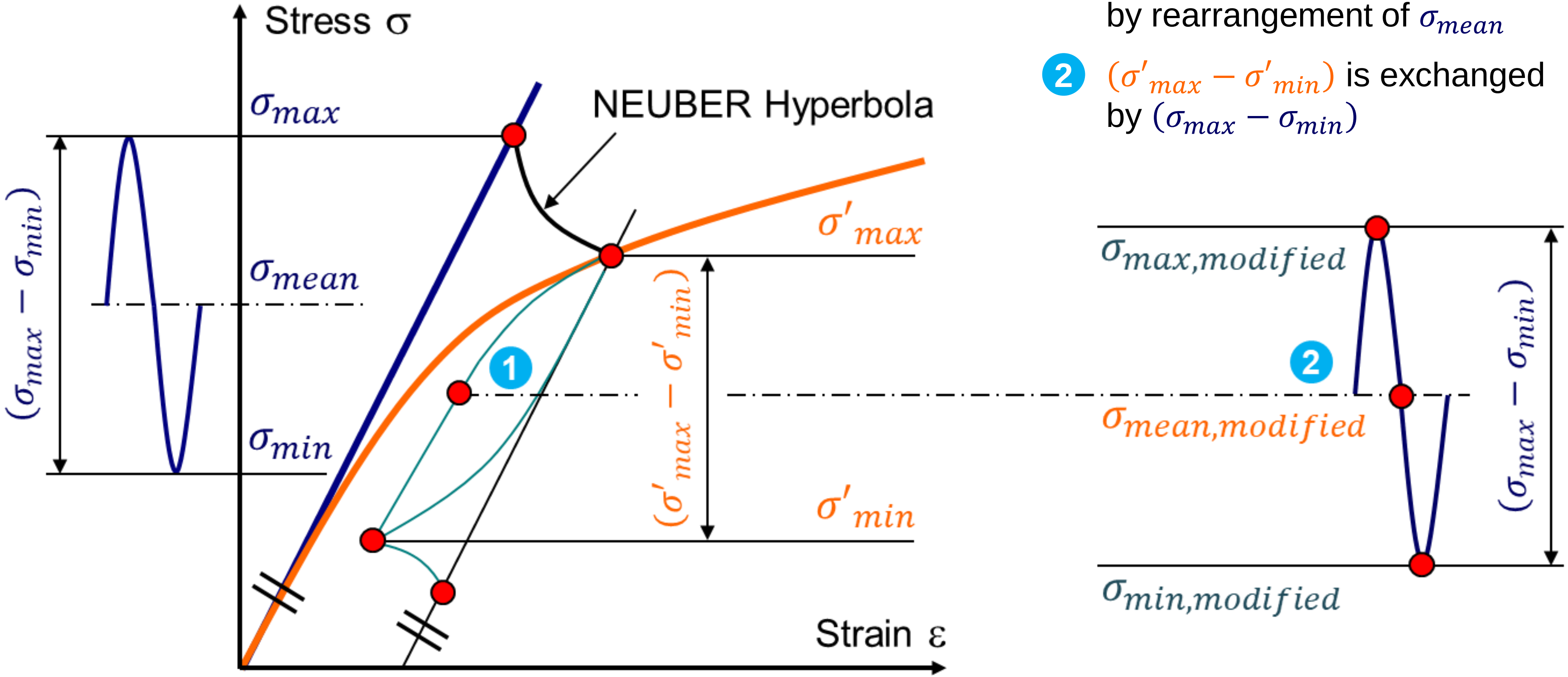
$$\varepsilon = \frac{\sigma}{E} + K´\left(\frac{\sigma}{E}\right)^{n´}$$

Incremental
step test



Neuber correction of mean and amplitude stress

FEMFAT plast:



4

1. $\sigma_{mean,modified}$ is determined by rearrangement of σ_{mean}
2. $(\sigma'_{max} - \sigma'_{min})$ is exchanged by $(\sigma_{max} - \sigma_{min})$

Scaled normal stress in critical plane

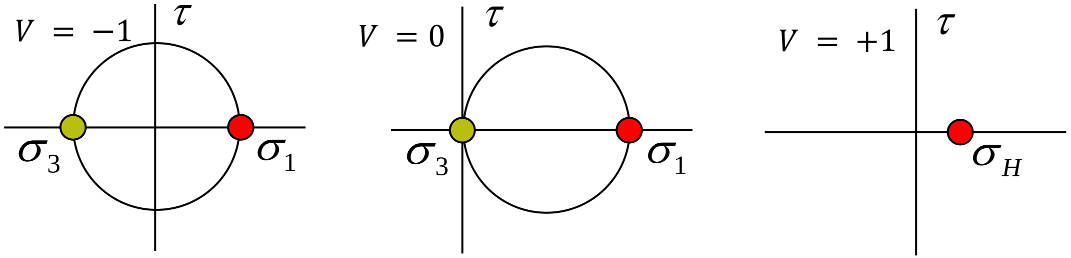
- Alternating shear stress is used for equivalent stress calculation:

1. Calculation of principal stresses $\sigma_1 > \sigma_2 > \sigma_3$

2. Calculation of the ratio of minimum/maximum principal normal stress at all times.

$$V = \frac{\sigma_3}{\sigma_1} \text{ for } |\sigma_1| > |\sigma_3|$$

$$V = \frac{\sigma_1}{\sigma_3} \text{ for } |\sigma_3| > |\sigma_1|$$



3. The stress tensor at all times is now scaled as a function of V.

$$f = 1 + (1-k)V \qquad k = \frac{\sigma_A}{\tau_A}$$

4. The critical plane procedure is performed with normal stress component.

$$\sigma_{eq} = f \cdot \sigma_n = (1 + (1-k)V) \cdot \sigma_n, \qquad \sigma_n = \sigma_{ij} n_j n_i$$

Material Parameters

	Tension	Pressure	Bending	Shear
Ultimate Strength	690.0	690.0	826.0	398.0
Yield Strength	360.0	360.0	455.0	208.0
Pulsating Strength	540.0	0.0	660.0	331.5
Alternating Strength	310.0	310.0	340.0	180.0

Necessary Material Properties for FEMFAT

- Depending on the requested calculation output, specific material parameters need to be defined or measured:

Necessary Material Parameters		Requested Calculation Output: Damage	Requested Calculation Output: Endurance Safety Factor	Requested Calculation Output: Static Safety Factor
UTS	Tension	[yellow]	[yellow]	[red]
UTS	Compression	[green]	[green]	
UTS	Bending			[red]
Yield	Tension	[yellow]	[yellow]	[blue]
Yield	Shear	[green] *	[green] *	
Tension/Compression S/N Curve	Endurance Limit	[red]	[red]	
	Inclination	[red]	[blue]	
	Cycle Limit	[red]	[blue]	
Endurance Limit Pulsating	Tension	[yellow]	[yellow]	
Endurance Limit Alternating	Bending	[red]	[red]	
Endurance Limit Alternating	Shear	[red]	[red]	
n‘ and K‘		[green]	[green]	
Quasistatic Stress-Strain Curve				[red]

*… Not defined for Grey Cast Iron

- [red] Absolutely needed
- [yellow] Absolutely needed if Mean stress is On
- [green] Value is generated by FEMFAT if not defined by User
- [blue] Based on analysis target option (Static Safety Factor Yield or Safety factor User defined Cycles)

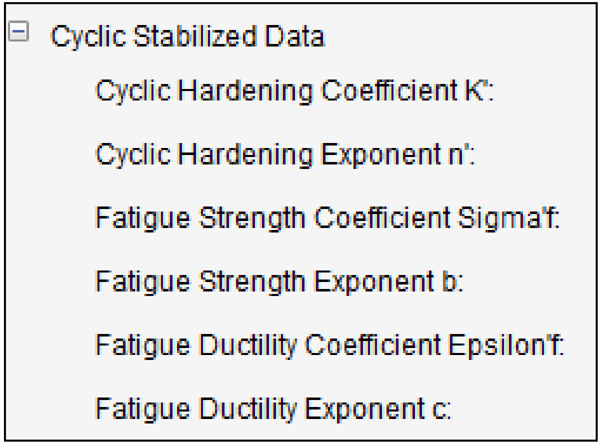
Generation of Material Data

…based on known values

I: Uniform Material Law and FKM Guideline

Uniform Material Law (UML)

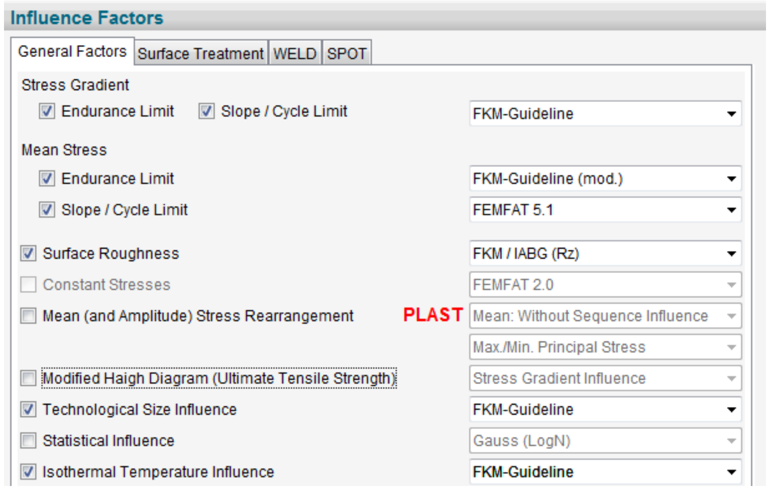
- The Uniform Material Law was developed on the basis of specimen tests for specific material classes to generate a correlation based on the material class and the UTS of the material.
- The UML can be used to produce values for creating a material file for FEMFAT (*.ffd).
- For unalloyed or low–alloyed steels, aluminium and titanium the cyclic stabilized data can be calculated.
  - All these values can be calculated by the help of UTS and the young's modulus.
  - Further cyclic strength data (endurance limit,…) are calculated based on FKM Guideline.



[more information about the UML in e.g. MATERIALS DATA FOR CYLCIC LOADING Supplement 1]

FKM Guideline

- The FKM is a standard which is very common in Europe and used by many European manufacturers.
- In general it can be seen as a conservative way of analysis.
- The material generator's formulae (FKM setting) calculates fatigue limits and cycle limit for a survival probability of 97.5%.
- Based on the FKM, several setting and influences can be used and activated in every analysis (stress gradient, mean stress, surface roughness,….).



[more information about the FKM can be found in FKM-Guideline-Analytical-Strength-Assessment-of-Components-in-Mechanical-Engineering-6th-Revised-Edition]

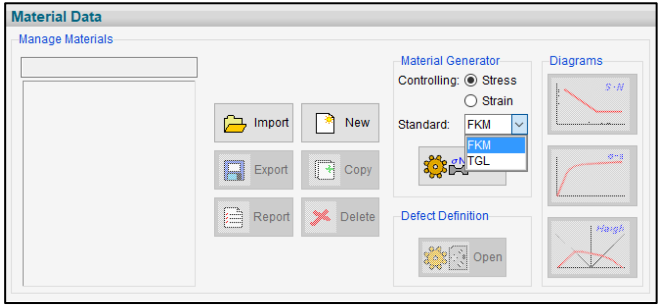
II: Material Generator

Material Generator

- A material data record is created for FEMFAT analysis based on the material class and several strength data and characteristics.

Standard	FKM (default)	TGL
Approach	stress-based	strain-based

FEMFAT entry screen

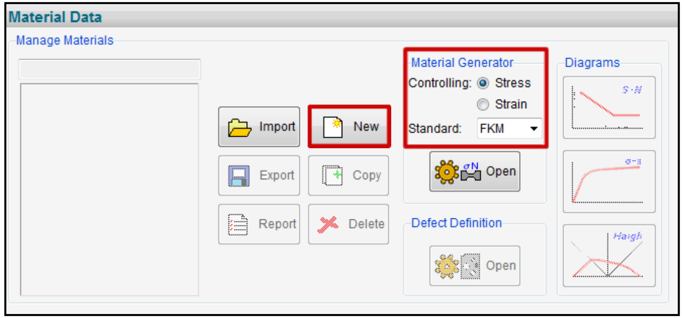


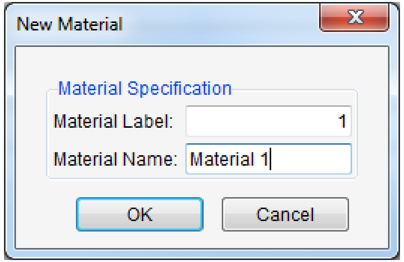
userdefparam_2021.dbs

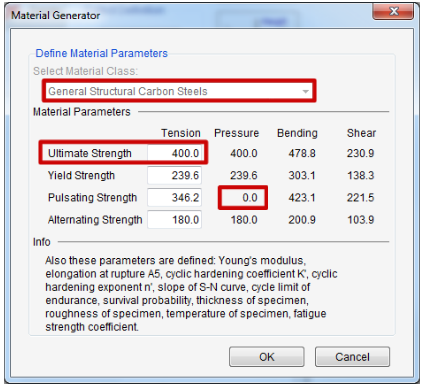
```
$
$                    ----------------------------------------
$                    | DATABASE FOR USER-DEFINED PARAMETERS |
$                    |      for Fatigue Solver   FEMFAT      |
$                    ----------------------------------------
$
$
$ FEMFAT-Version ...........: 2021, Sept. 2021
$ Filename .................: /material_database/userdefparam_2021.dbs
$
$
$ M A T E R I A L - C L A S S - D E P E N D E N T   P A R A M E T E R S
$ ======================================================================
$
$ Material | Exponent for | Slope   |Exponent|Diameter|Diameter|Constant|Constant| ... | ... | ... |
$  Class   |  Gradient -  | Limit   |        |deff,N,m|deff,N,p|  ad,m  |  ad,p  |     |     |     |
$          |  Influence   |  AK2    |   AK3  | in mm  | in mm  |for Kd,m|for Kd,p|     |     |     |
$ ---------|--------------|---------|--------|--------|--------|--------|--------|-----|-----|-----|
        1           0.30       3.0      2.0     40.0     40.0     0.15     0.30
        3           0.30       3.0      2.0     16.0     16.0     0.30     0.40
        6           0.30       3.0      2.0     40.0     40.0     0.15     0.30
       11           0.30       3.0      2.0     70.0     40.0     0.20     0.30
       16           0.30       3.0      2.0     16.0     16.0     0.30     0.40
       17           0.30       3.0      2.0     40.0     40.0     0.25     0.30
       20           0.30       3.0      2.0     16.0     16.0     0.50     0.50
       21           0.30       3.0      2.0     40.0     40.0     0.15     0.30
```

Stress based Material Generator

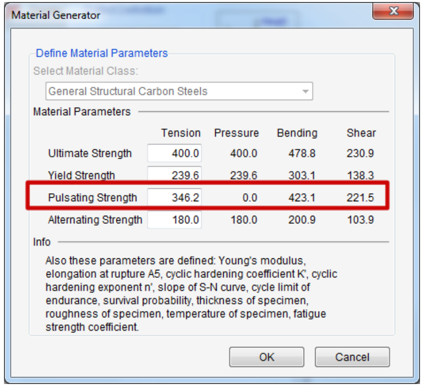
- After initial determination of the strength data, any changes can only be made on a „per line“ basis







Assign a material class and provide one single value for one single tensile strength value

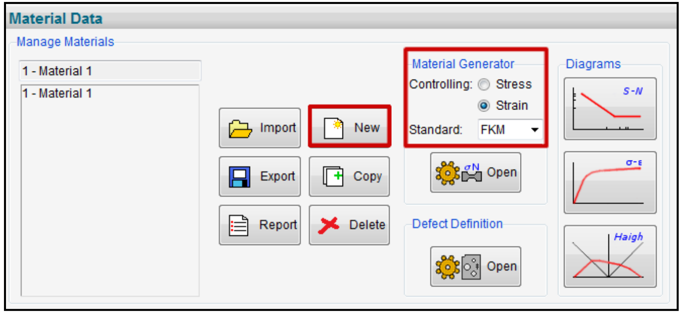


Parameters can only be changed on a line basis.
Note that pulsating strength for pressure is always set to zero for all material groups

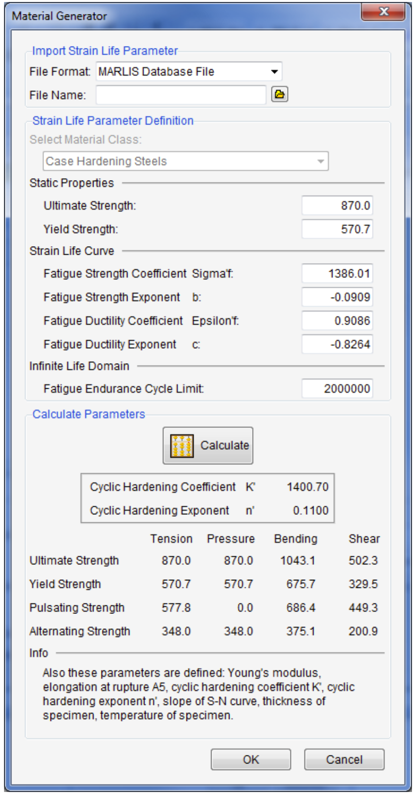
All strength values edited by the material generator must be confirmed by pressing <Enter>!

Strain based Material Generator

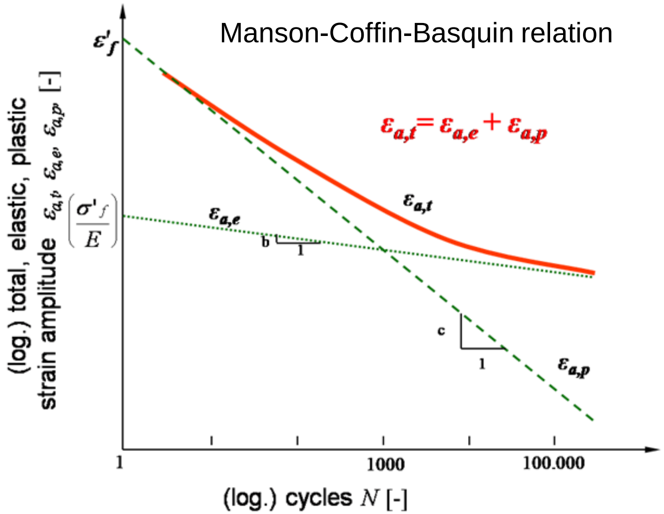
- Ultimate and/or yield stress as well as four strain S/N curve parameters need to be defined. Endurance cycle limit can be edited by the user.

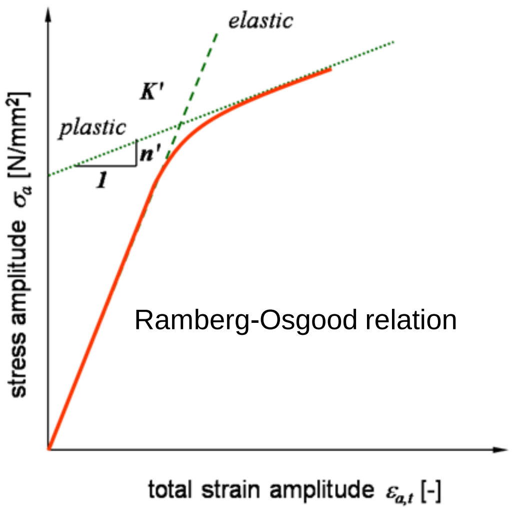


FEMFAT calculates stress based material parameters from strain life parameters.



Conversion of E/N-curves into S/N curves





$$\varepsilon_{a,e} = \frac{\sigma'_f}{E}(2N_f)^b$$

Basquin equation

$$\varepsilon_{a,p} = \varepsilon'_f(2N_f)^c$$

Manson-Coffin equation

strain equivalence condition

$$\varepsilon_{a,e} = \frac{\sigma_a}{E}$$

Hook's law

$$\varepsilon_{a,p} = \left(\frac{\sigma_a}{K'}\right)^{\frac{1}{n'}}$$

power law

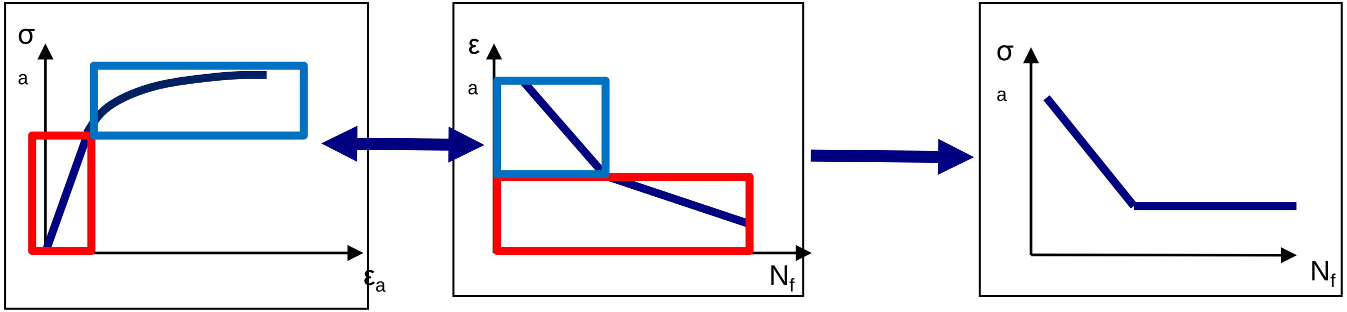
$$\varepsilon_{a,t} = \varepsilon_{a,e} + \varepsilon_{a,p} = \frac{\sigma'_f}{E}(2N_f)^b + \varepsilon'_f(2N_f)^c$$

$$\varepsilon_{a,t} = \varepsilon_{a,e} + \varepsilon_{a,p}$$

$$\varepsilon_{a,t} = \varepsilon_{a,e} + \varepsilon_{a,p} = \frac{\sigma_a}{E} + \left(\frac{\sigma_a}{K'}\right)^{\frac{1}{n'}}$$

Conversion of E/N-curves into S/N curves

- Strain equivalence is a necessary condition for comparison of coefficients to obtain the coefficients for description of S/N curve.



$$\varepsilon_a = \frac{\sigma_a}{E} + \left(\frac{\sigma_a}{K'}\right)^{\frac{1}{n'}}$$

$$\varepsilon_a = \frac{\sigma'_f}{E}\cdot(2N)^b + \varepsilon'_f\cdot(2N)^c$$

$$\varepsilon_{a,e} = \varepsilon_{a,e}$$

$$\varepsilon_{a,pl} = \varepsilon_{a,pl}$$

$$\sigma_a = K'\cdot(\varepsilon'_f)^{n'}\cdot(2N)^{n'c}$$

$$\sigma_a = \sigma'_f\cdot(2N)^b$$

$$K' = \frac{\sigma'_f}{(\varepsilon'_f)^{n'}}$$

Compatibility Conditions

$$n' = \frac{b}{c}$$

I. $\frac{\sigma_a}{\sigma_D} = \left(\frac{N}{N_D}\right)^{-\frac{1}{k}}$

II. $\sigma_a = \sigma'_f(2N)^b$

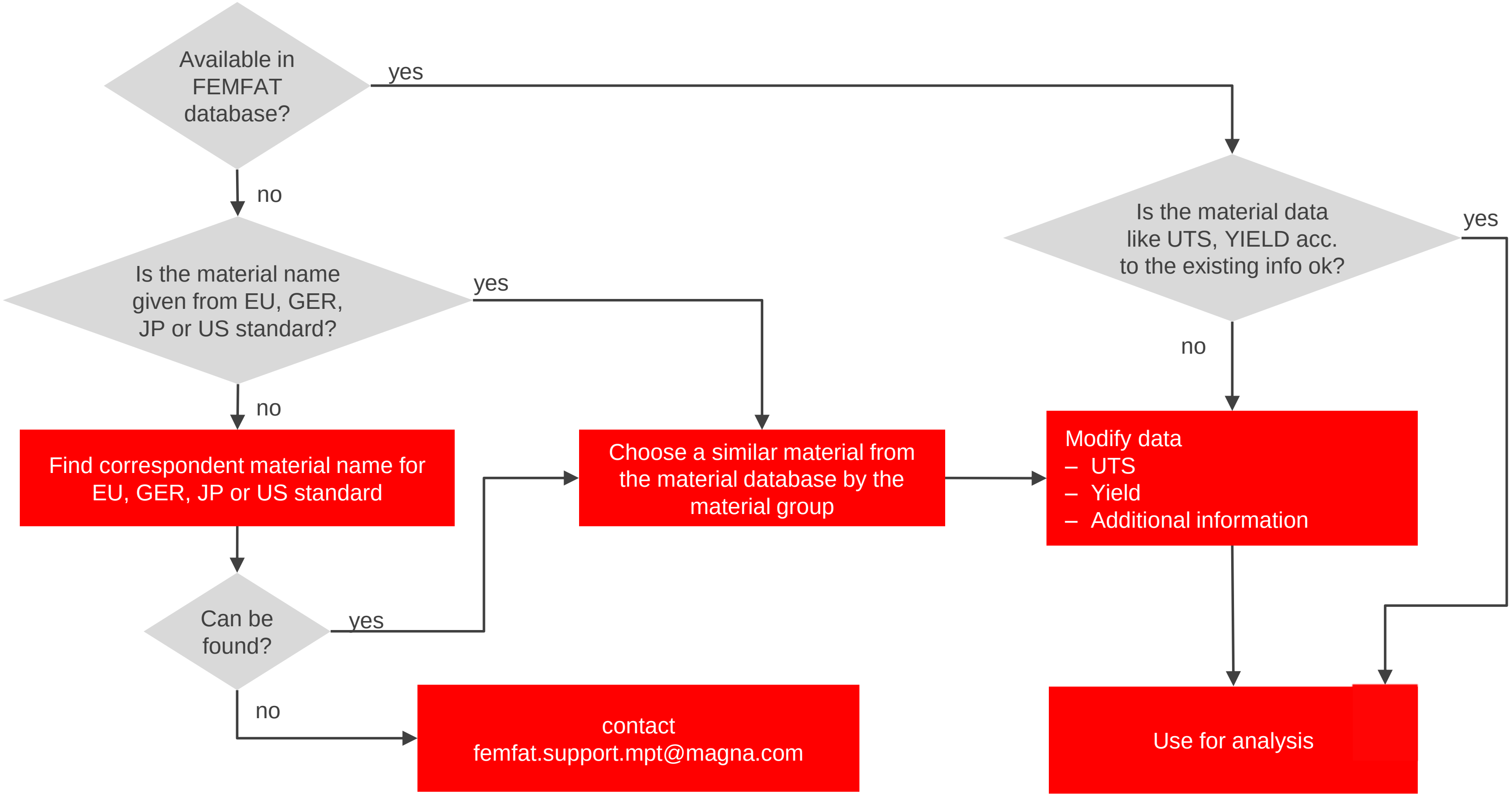
$\sigma_D = \sigma'_f(2N_D)^b$

II in I. $\frac{\sigma'_f(2N)^b}{\sigma'_f(2N_D)^b} = \left(\frac{N}{N_D}\right)^b = \left(\frac{N}{N_D}\right)^{-\frac{1}{k}}$

$$\Rightarrow\quad k = -\frac{1}{b}$$

III: How to generate a material in FEMFAT

General workflow



FAQ’s

- What is the minimum requirement to generate a material in FEMFAT?
  – The material class and UTS is needed to generate a complete material card.

- What if I do not know the material class?
  – The material class is defined in the standards. Therefore, it is recommended to search for the standard where the material is defined. Another possibility is to search the datasheet from a supplier. The datasheet includes also the information of the material class.

1.0038 (DIN EN 10025-2 : 2005-04)
S235JR
Structural steels (EN)

Material description

Material Number:	1.0038 (DIN EN 10025-2 : 2005-04)
Standard:	DIN EN 10025-2 : 2005-04
Replacement:	Supersedes DIN EN 10025 : 1994-03
Standard State:	valid
Origin:	Deutschland
Remark:	The hot rolled, unalloyed quality steel S235JR is applicated for welding constructions up to temperatures of -20°C subject to the load. The steel is not intended for heat treatment. Stress relieving annealing is allowed. Products in the delivery condition +N may be hot formed and/or normalized after delivery. For long products and continuous rolled flats the delivery condition is up to the producer +AR, +N or +M. The delivery condition of four-high rolled sheet is also up to the producer and may be +AR or +N. Both conditions can be ordered. For this steel are available (mat. no 1.0122, S235JRC) grades for folding, roll forming to shape and cold drawing.
Application temperature:	≤ 300.0

Source: WIAM material database IMA Dresden

FAQ's

- What if I do not know any strength data from my material?
  - This also can be found in the standards. Another possibility is a search in the internet at supplier homepages or material handbooks.

1.0038 (DIN EN 10025-2 : 2005-04)
S235JR
Structural steels (EN)

Mechanical Properties

Semi-finished Product: strip, sheet, wide flat, section, rod, wire rod
Condition: normalised or normalising rolled
Specimen Direction: longitudinal

Nominal Size [mm]	Temperature [°C]	Tensile Strength [N/mm²]	Yield Strength [N/mm²]
≤ 1.000	20	360.0 - 510.0	≥ 235.00
1.000 - 1.500	20	360.0 - 510.0	≥ 235.00
1.500 - 2.000	20	360.0 - 510.0	≥ 235.00
2.000 - 2.500	20	360.0 - 510.0	≥ 235.00
2.500 - 3.000	20	360.0 - 510.0	≥ 235.00
3.000 - 16.000	20	360.0 - 510.0	≥ 235.00
16.000 - 40.000	20	360.0 - 510.0	≥ 225.00
40.000 - 63.000	20	360.0 - 510.0	≥ 215.00
63.000 - 80.000	20	360.0 - 510.0	≥ 215.00
80.000 - 100.000	20	360.0 - 510.0	≥ 215.00
100.000 - 150.000	20	350.0 - 500.0	≥ 195.00

Source: WIAM material database IMA Dresden

SALZGITTER FLACHSTAHL
Ein Unternehmen der Salzgitter Gruppe

Mechanische Eigenschaften [1)]

Werkstoffnummer	1.0038
gemäß	DIN EN 10025-2
Festigkeitsklasse	A

S235JR

Unlegierte Baustähle

Nenndicke e	Streckgrenze R_{eH}
≤16 mm	≥ 235 MPa
>16 mm	≥ 225 MPa

Nenndicke e	Zugfestigkeit R_m
<3 mm	360 – 510 MPa
≥3 mm	360 – 510 MPa

Nenndicke e	Bruchdehnung A [2)] (längs/quer)
<3 mm	≥ 21/19 %
3≤e≤25 mm	≥ 26/24 %

Source: Internet Salzgitter Flachstahl datasheet from supplier

FAQ’s

- What if the strength data is given by a range?
  - To be on the safe side use the minimum values to generate the material in FEMFAT.
  - Also possible is to generate 3 materials, a worst case, a best case and a material with the mean values. Using the 3 different materials in a FEMFAT analysis will lead to 3 different results.

    Following conclusions can be derived:

    1) Sensitivity of the part due to material deviation

    2) Minimum requirement of the static material properties

- What if I just have the Yield strength?
  - Therefore, the material generation is done by directly input the Yield strength. If the material card is new either the UTS or the Yield strength can be used to generate a fully defined material card.

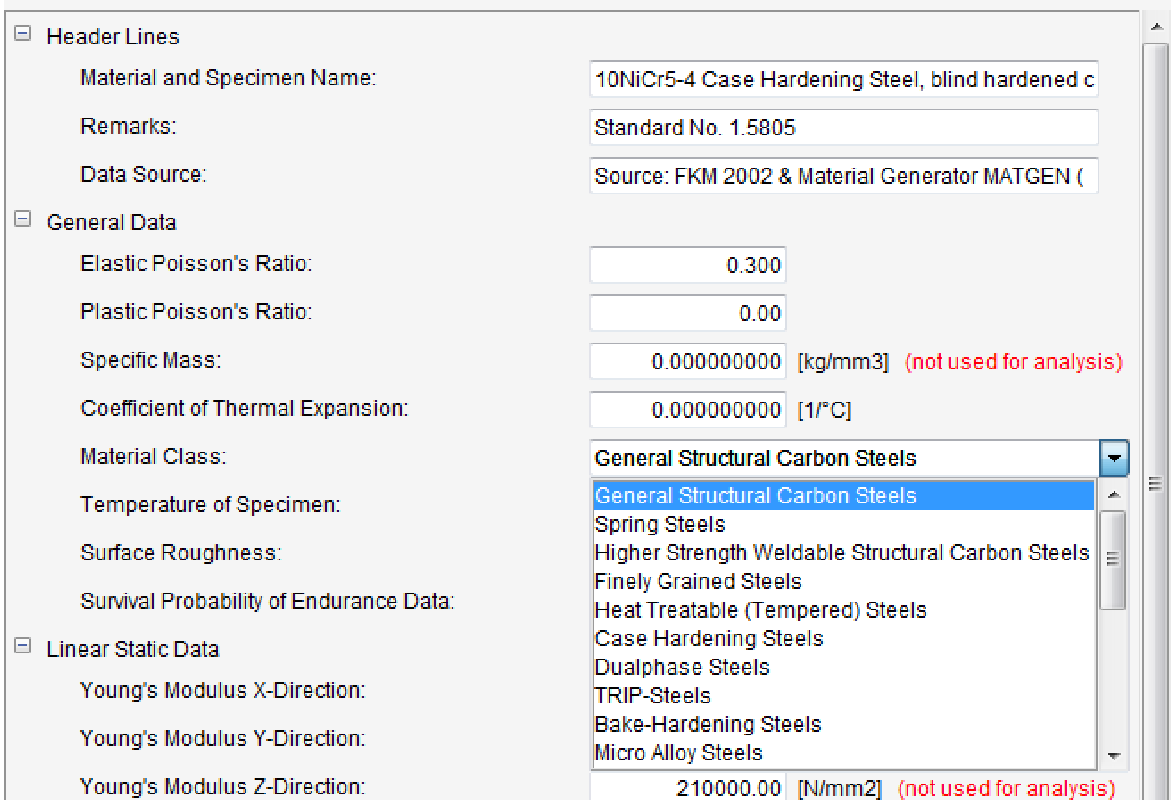
- What if the material class of my material is not available in the material database?
  - If the material class is not available in the FEMFAT material generator a comparable group has to be chosen. The next page shows a conversion table for the most common materials which are not listed in the material generator.

Material Classes for Generation of Missing Data

Material	Class for Material Generator	Remark
Stainless steel	Case hardening steel	
Plastic (not reinforced)	Alu wrought alloy	Switch material class to plastic
Plastic (fibre reinforced)	Alu cast alloy	Switch material class to plastic
Sinter metal	Nodular cast iron	Switch material class to sinter
Magnesium cast	Alu cast alloy	Switch material class to magnesium cast
Titan alloy	Case hardening steel	
Nickel base alloy	Heat treatable steel	Switch material class nickel base alloy
Copper alloy	Alu wrought alloy	
Spring steel	Heat treatable steel	Switch material class spring steel
Tool steel	Case hardening steel	Switch material class tool steel
Deep drawing steels	General structural steel	Switch material class deep drawing steel

- Please switch the material class manually to the corresponding material class if available. As the stress gradient influences and the influence on the inclination of the SN-curve can be different!

Where to switch the material class



Material generation based on the UTS

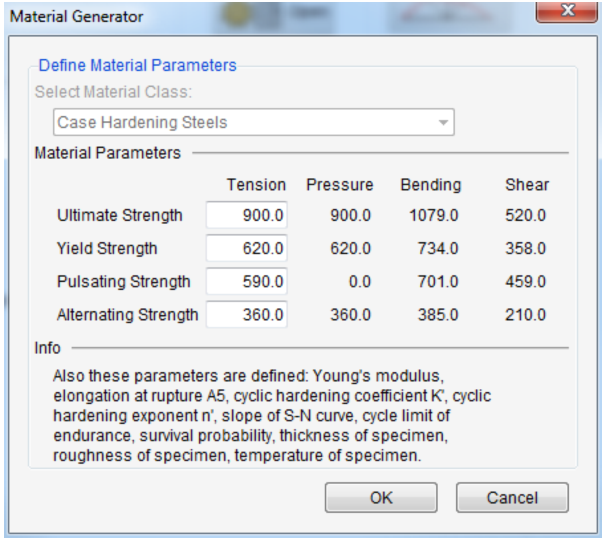
- **<u>A) Material card based on UTS</u>**

Example

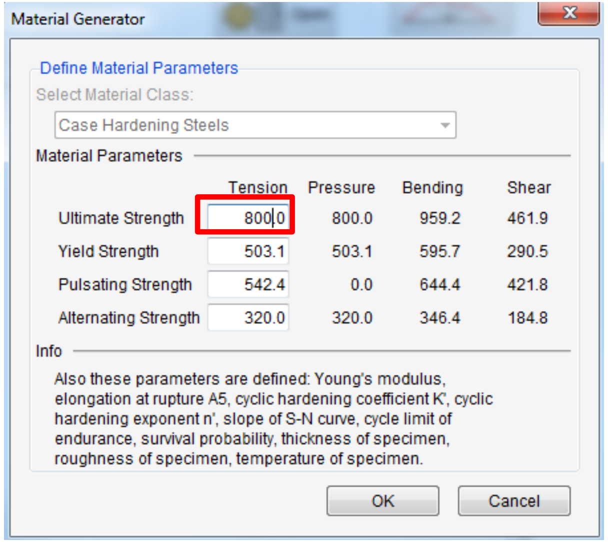
<u>Material name: 10NiCr5</u>
UTS= 800N/mm²

Steps for this example:

1. Available material from database: 10NiCr5-4_FKM2002.ffd
2. Type in the UTS



Imported standard material from FEMFAT database

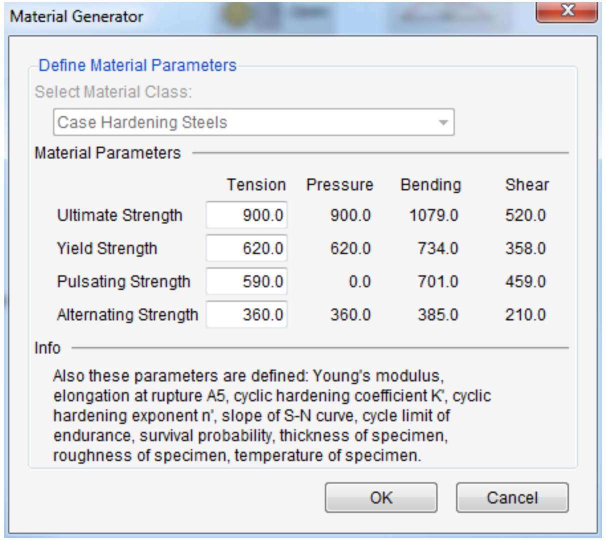


- Modify the UTS to 800 N/mm²
- Save the new material card

Material generation based on the Yield strength

- **B) Material card based on YIELD**

Material name: 10NiCr5
YIELD= 400N/mm²

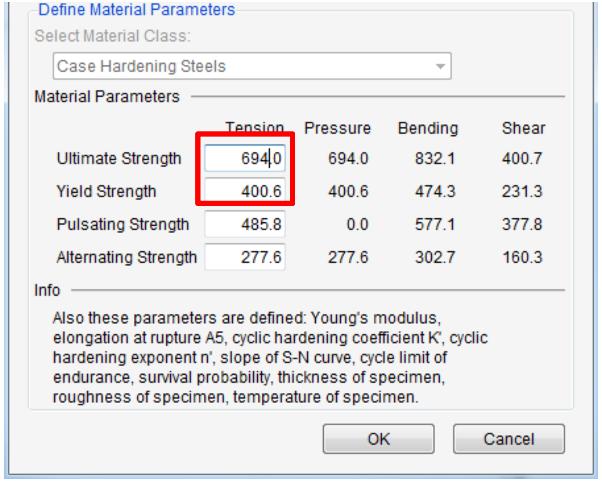


Imported standard material from FEMFAT database

Example

Steps for this example:

1. Available material from database: 10NiCr5-4_FKM2002.ffd
2. Type in the UTS such that the YIELD is matching. Also possible is to generate a new material card using the same material class and type in the YIELD directly



- Modify the UTS to 694 N/mm²
- Save the new material card

Material generation based on UTS and Yield strength

MAGNA

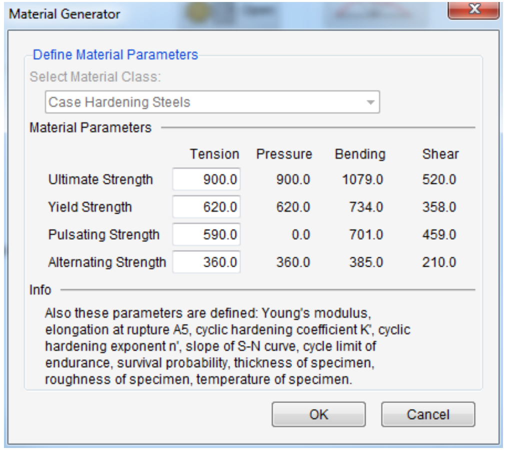
- **C) Material card based on UTS & YIELD**

Example

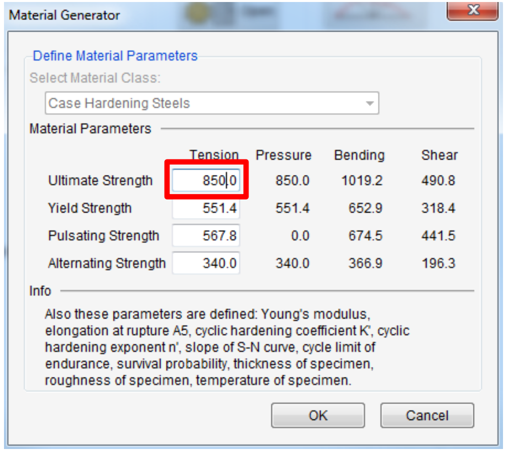
Material name: 10NiCr5
UTS= 850N/mm²
YIELD= 600N/mm²

Steps for this example:

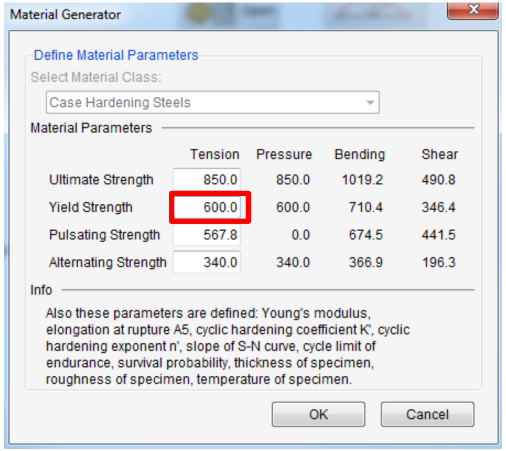
1. Available material from database: 10NiCr5-4_FKM2002.ffd
2. Type in the UTS
3. Modify the YIELD strength



Imported standard material from FEMFAT database



- Modify the UTS to 850 N/mm²



- Modify the YIELD to 600 N/mm²
- Save the new material card

Material generation based on the UTS, Yield and alternating tensile strength

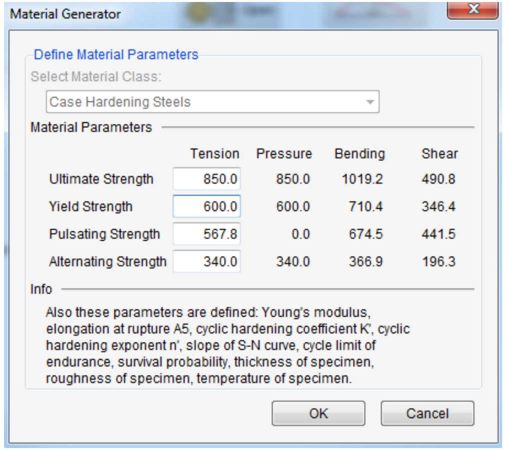
- **D) Material card based on UTS & YIELD & ATS (1/2)**

Example

Material name: 10NiCr5
UTS= 850Nmm²
YIELD= 600N/mm²
Alt. tensile str. = 400 N/mm²

Steps for this example:

1. Calculate the mean stress sensitivity
2. Type in the ATS
3. Modify the pulsating strength with the calculated mean stress sensitivity


Material Generator

Define Material Parameters

Select Material Class:

Case Hardening Steels

Material Parameters

	Tension	Pressure	Bending	Shear
Ultimate Strength	850.0	850.0	1019.2	490.8
Yield Strength	600.0	600.0	710.4	346.4
Pulsating Strength	567.8	0.0	674.5	441.5
Alternating Strength	340.0	340.0	366.9	196.3

Info

Also these parameters are defined: Young's modulus, elongation at rupture A5, cyclic hardening coefficient K', cyclic hardening exponent n', slope of S-N curve, cycle limit of endurance, survival probability, thickness of specimen, roughness of specimen, temperature of specimen.

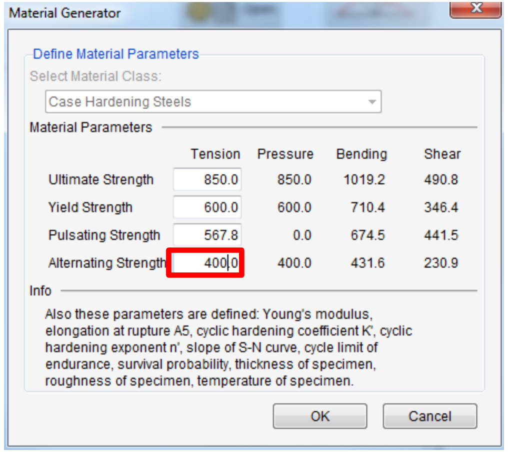
OK Cancel

Material modified due to UTS and YIELD

$$M = 2\frac{\sigma_{alt}}{\sigma_{puls}} - 1 \Rightarrow \sigma_{puls} = 2\frac{\sigma_{alt}}{M+1}$$

$$M = 2\frac{340}{567.8} - 1 = 0.1976$$

- Calculate the mean stress sensitivity


Material Generator

Define Material Parameters

Select Material Class:

Case Hardening Steels

Material Parameters

	Tension	Pressure	Bending	Shear
Ultimate Strength	850.0	850.0	1019.2	490.8
Yield Strength	600.0	600.0	710.4	346.4
Pulsating Strength	567.8	0.0	674.5	441.5
Alternating Strength	400.0	400.0	431.6	230.9

Info

Also these parameters are defined: Young's modulus, elongation at rupture A5, cyclic hardening coefficient K', cyclic hardening exponent n', slope of S-N curve, cycle limit of endurance, survival probability, thickness of specimen, roughness of specimen, temperature of specimen.

OK Cancel

- Modify the ATS to 400 N/mm²

Material generation based on the UTS, Yield and alternating tensile strength

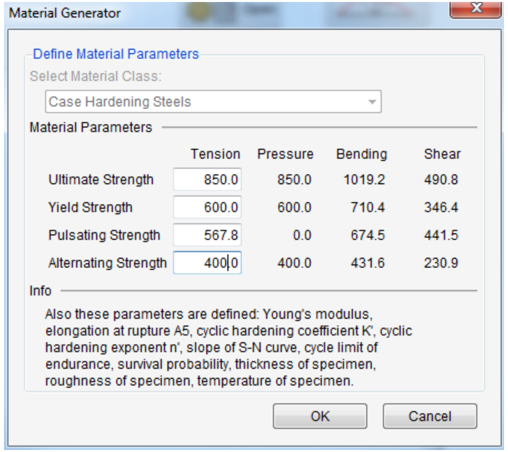
- **D) Material card based on UTS & YIELD & ATS (2/2)**

Example

Material name: 10NiCr5
UTS= 850N/mm²
YIELD= 600N/mm²
Alt. tensile str. = 400 N/mm²

Steps for this example:

1. Calculate the mean stress sensitivity
2. Type in the ATS
3. Modify the pulsating strength with the calculated mean stress sensitivity



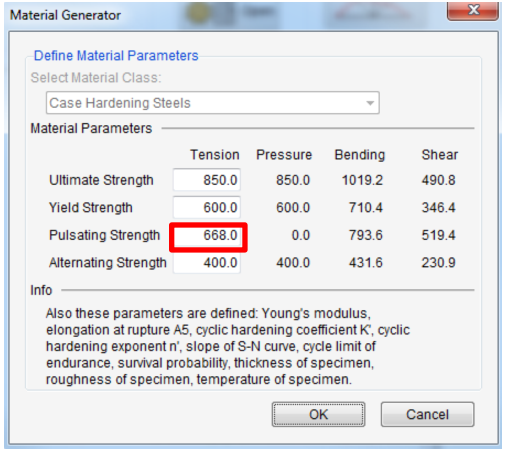
	Tension	Pressure	Bending	Shear
Ultimate Strength	850.0	850.0	1019.2	490.8
Yield Strength	600.0	600.0	710.4	346.4
Pulsating Strength	567.8	0.0	674.5	441.5
Alternating Strength	400.0	400.0	431.6	230.9

Material modified due to UTS and YIELD and ATS

$$M = 2\frac{\sigma_{alt}}{\sigma_{puls}} - 1 \Rightarrow \sigma_{puls} = 2\frac{\sigma_{alt}}{M+1}$$

$$\sigma_{puls} = 2\frac{400}{0.1976+1} = 668\frac{N}{mm^2}$$

- Calculate the new pulsating strength with the mean stress sensitivity 0.1976

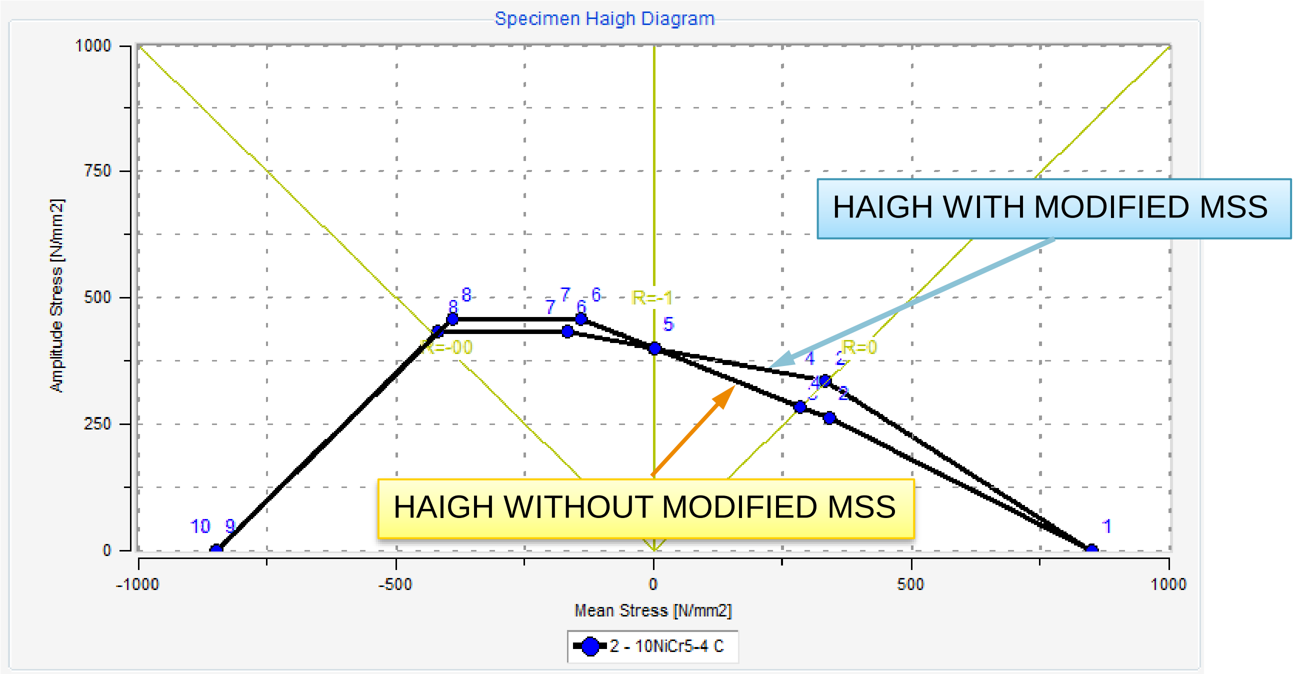


	Tension	Pressure	Bending	Shear
Ultimate Strength	850.0	850.0	1019.2	490.8
Yield Strength	600.0	600.0	710.4	346.4
Pulsating Strength	668.0	0.0	793.6	519.4
Alternating Strength	400.0	400.0	431.6	230.9

- Modify the PST to 668 N/mm²
- Save the new material card

FAQ

- Why is it necessary to modify the pulsating strength according the mean stress sensitivity?
  - For each material class a different value of the mean stress sensitivity (MSS) is calculated.
  - If the MSS is not known, it is better to use the standard values from the material generator.



Material generation based based on the UTS, Yield and alternating bending strength

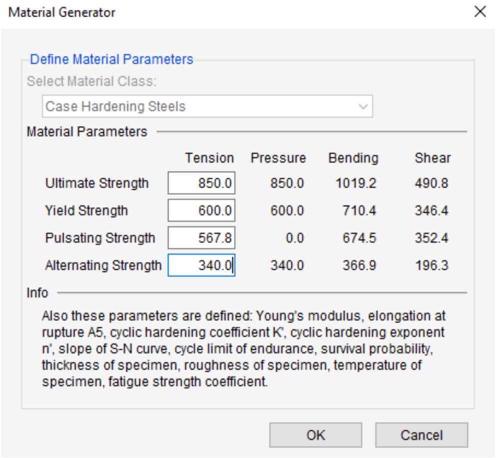
E) Material card based on UTS & YIELD & ABS (1/2)

Example

Material name: 10NiCr5
UTS= 850N/mm²
YIELD= 600N/mm²
Alt. bending str. = 480 N/mm²

Steps for this example:

1. Calculate the mean stress sensitivity
2. Type in the ATS so that the ABS is matching
3. Modify the pulsating strength with the calculated mean stress sensitivity

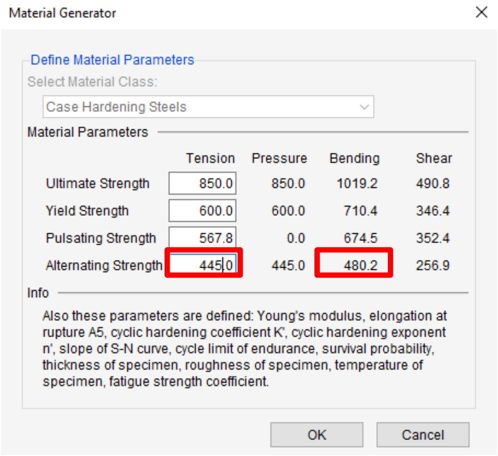


Material modified due to UTS and YIELD

$$M = 2\frac{\sigma_{alt}}{\sigma_{puls}} - 1 \Rightarrow \sigma_{puls} = 2\frac{\sigma_{alt}}{M+1}$$

$$M = 2\frac{340}{567.8} - 1 = 0.1976$$

Calculate the mean stress sensitivity



Modify the ATS to 445 N/mm² so that the ABS is matching 480 N/mm²

Material generation based on the UTS, Yield and alternating bending strength

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• E) Material card based on UTS & YIELD & ABS (2/2)

Example

Material name: 10NiCr5
UTS= 850N/mm²
YIELD= 600N/mm²
Alt. bending str. = 480 N/mm²

Steps for this example:

1. Calculate the mean stress sensitivity
2. Type in the ATS so that the ABS is matching
3. Modify the pulsating strength with the calculated mean stress sensitivity

Material Generator

Define Material Parameters

Select Material Class:

Case Hardening Steels

Material Parameters

	Tension	Pressure	Bending	Shear
Ultimate Strength	850.0	850.0	1019.2	490.8
Yield Strength	600.0	600.0	710.4	346.4
Pulsating Strength	567.8	0.0	674.5	352.4
Alternating Strength	445.0	445.0	480.2	256.9

Info

Also these parameters are defined: Young's modulus, elongation at rupture A5, cyclic hardening coefficient K', cyclic hardening exponent n', slope of S-N curve, cycle limit of endurance, survival probability, thickness of specimen, roughness of specimen, temperature of specimen, fatigue strength coefficient.

OK Cancel

Material modified due to UTS and YIELD and ATS

$$M = 2\frac{\sigma_{alt}}{\sigma_{puls}} - 1 \Rightarrow \sigma_{puls} = 2\frac{\sigma_{alt}}{M+1}$$

$$\sigma_{puls} = 2\frac{445}{0.1976+1} = 743\frac{N}{mm^2}$$

- Calculate the new pulsating strength with the mean stress sensitivity 0.1976

Material Generator

Define Material Parameters

Select Material Class:

Case Hardening Steels

Material Parameters

	Tension	Pressure	Bending	Shear
Ultimate Strength	850.0	850.0	1019.2	490.8
Yield Strength	600.0	600.0	710.4	346.4
Pulsating Strength	743.0	0.0	882.7	461.1
Alternating Strength	445.0	445.0	480.2	256.9

Info

Also these parameters are defined: Young's modulus, elongation at rupture A5, cyclic hardening coefficient K', cyclic hardening exponent n', slope of S-N curve, cycle limit of endurance, survival probability, thickness of specimen, roughness of specimen, temperature of specimen, fatigue strength coefficient.

OK Cancel

- Modify the PS to 743 N/mm²
- Save the new material card

Calibration of Material Data

… Based on Test Results

Date: December 2020

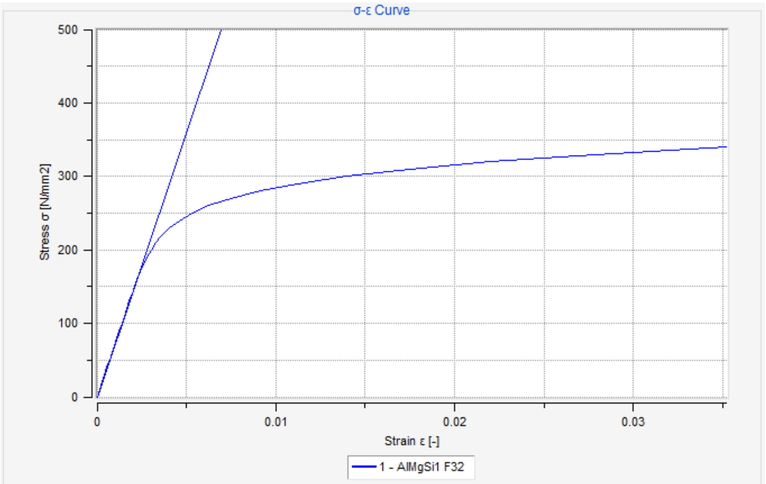
Author: FEMFAT SUPPORT

Overview

- Specimen tests of one material for:
  - Static tensile test or cyclic stabilized tensile test
  - SN curves for different tensile load condition (R=-1, R=0, R=0.5, ….)
  - SN curves for different notched specimens
  - SN curves for different load types (tension, bending, torsion/shear)

BASIS: Tensile Test for Unnotched Specimen

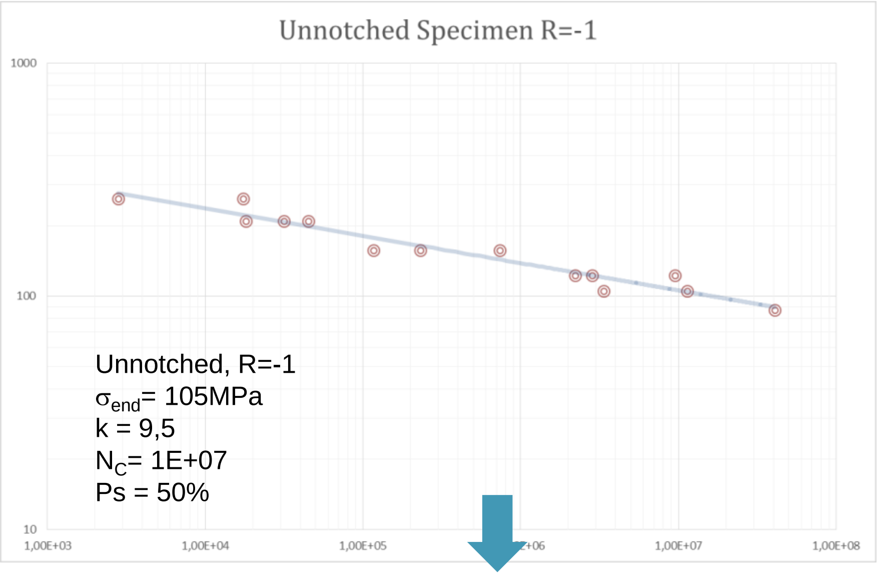
Static test



Ultimate Strength:	310.0	[N/mm2]	Yield Strength:	260.0	[N/mm2]
Young's Modulus:	72000.0	[N/mm2]	Elongation at Rupture A5:	10.0	[%]

Ultimate Tensile Strength (UTS)
Yield Strength

SN curve for R=-1

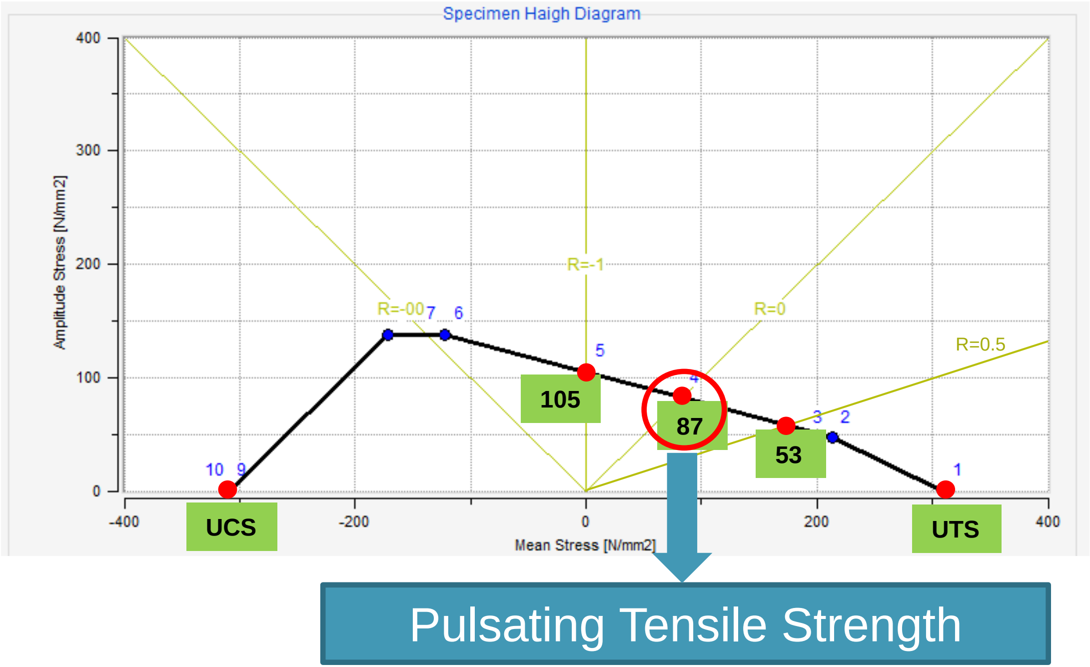


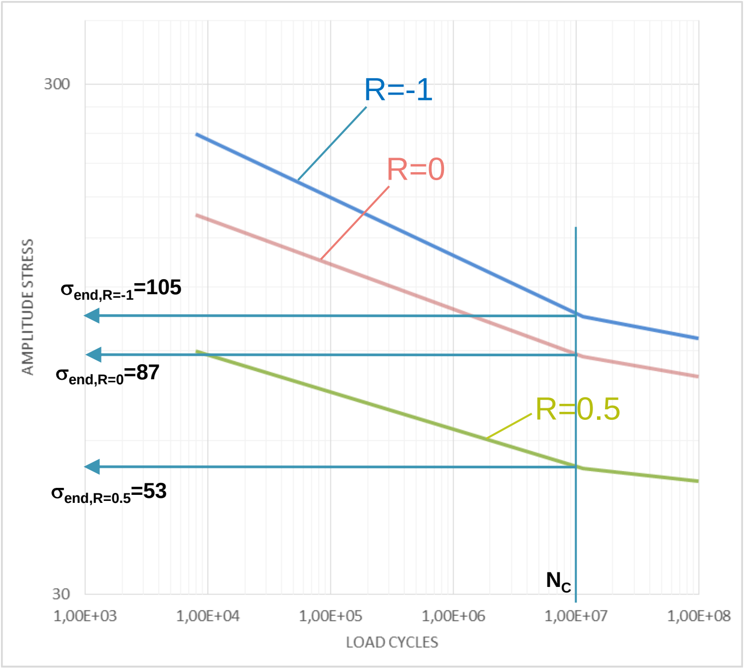
Parameter of SN Curve

- Endurance Limit σ_{end}
- Slope k
- Cycle Limit N_C

SN Curve Tests for different Stress Ratios R

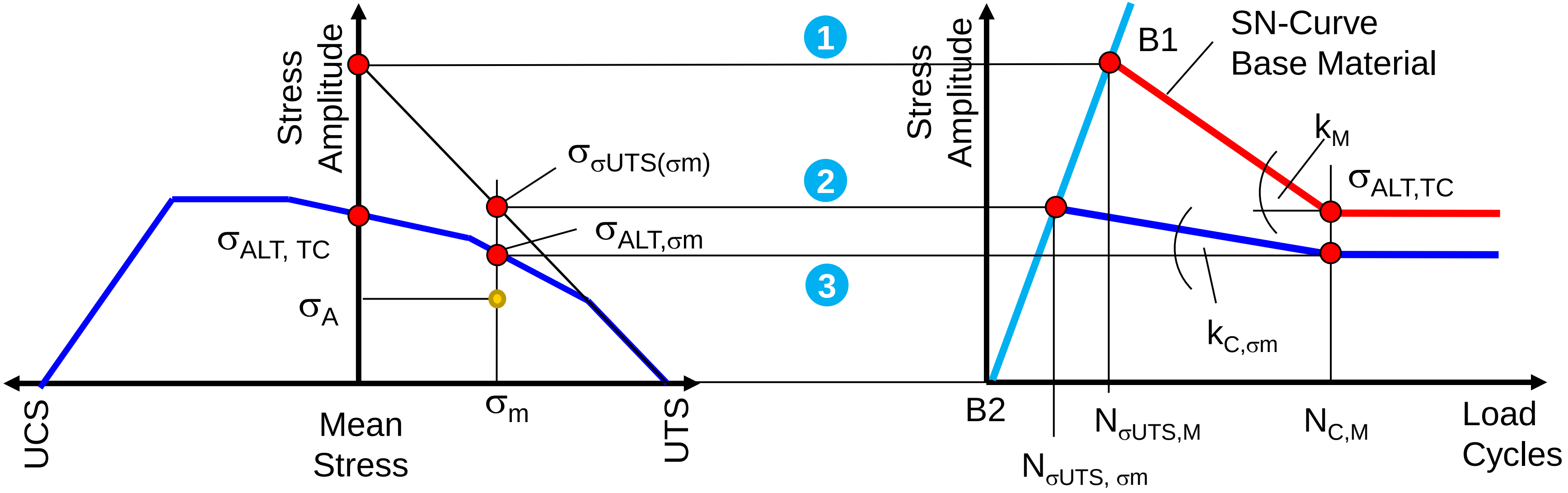
- Calibration for R=0, R=0.5…. => Haigh Diagram





Calibration of inclination of S/N curve for Mean Stress

Inclination of S/N curve for a given mean stress is calculated from Haigh Diagram

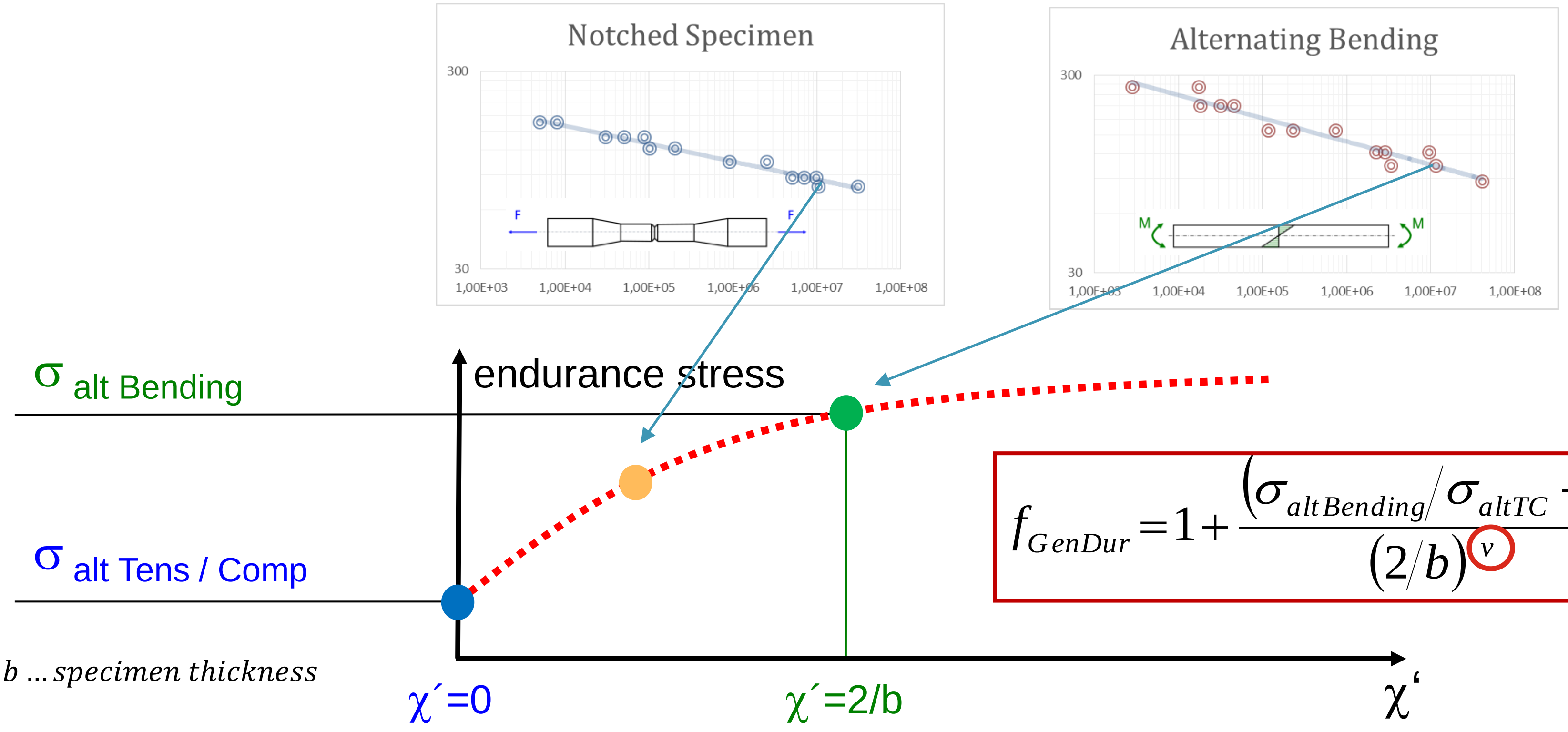


1. Determine the original S/N curve of the base material
2. Map the ultimate tensile stress on the line B1-B2
3. Determine the inclination of the modified S/N curve $k_{C,\sigma m}$

$$k_{C,\sigma m} = \frac{\log\left[\frac{N_{c,M}}{N_{\sigma UTS,\sigma_m)}}\right]}{\log\left[\frac{\sigma_{\sigma UTS}(\sigma_m)}{\sigma_{ALT,\sigma m}}\right]}$$

Bending Test and Notched Specimen Test

- Calibration of stress gradient influence:



$$f_{GenDur} = 1 + \frac{\left(\sigma_{altBending} / \sigma_{altTC} - 1\right)}{\left(2/b\right)^{\nu}} \chi'^{\nu}$$

Design of experiments for a standard steel

- Awareness of the influences that are taken into account by material properties helps designing test plans.

Material property	Following influences are concerned
Endurance stress limit tension/compression R=-1	Component S/N curve endurance limit Mean stress influence (Haigh-Diagram) Notch influence (stress gradient) Equivalent stress computation (cutting plane stress)
Endurance stress limit tension R=0 (pulsating)	Mean stress influence (Haigh-diagram)
Endurance stress limit bending R=-1	Notch influence (stress gradient)
Notch sensitivity exponent ν	Notch influence (stress gradient), derived from component S/N curve
Endurance stress limit shear R=-1	Equivalent cutting plane stress
Slope of S/N curve R=-1	Slope of component S/N curve
Yield stress in tension	Mean stress influence in Haigh-diagram
Cyclic stress-strain curve	Consideration of local plastification
Yield stress shear	Mean stress influence (mean stress)
Ultimate stress tension	Mean stress influence (Haigh-diagram)
Yield stress compression	Mean stress influence (Haigh-diagram)
Ultimate stress compression	Mean stress influence (Haigh-diagram)
Cycle limit of S/N curve R=-1	Cycle limit of component S/N curve
Modulus of elasticity E	Plasticity law (mean stress changes)
Elongation at rupture	Property ratio tension/shear (ductility)

Overview Material Database (FEMFAT 5.4, 2019)

MAGNA

Material Class	Number of Materials
Steel	157
Cast Iron	82
Aluminum Wrought Alloys	89
Aluminum Casting Alloys	208
Magnesium Casting Alloys	4
Copper and Nickel Base Alloys	4
Epoxy Adhesive	1
Plastics without Reinforcement	2
Plastics with Short Fibers	15
Plastics with Continuous Fibers	1

5 Natural Rubber Materials in FEMFAT 5.4.2

564 materials

Sources:
- 398 FKM-Guideline
- 17 WIAM-Database
- Other sources (datasheets, books, papers, google, etc.)

Plastic Materials

Material generation for non reinforced and short fiber reinforced plastic materials

FEMFAT material generation: Overview

Two possible ways:

- Usage of FEMFAT material generator

- Modification of an existing similar material (*.ffd file)

Plastic material generation: Material Generator

Non-reinforced Material

Define Material Parameters

Select Material Class:

Aluminium Wrought Alloys

Material Parameters

	Tension	Pressure	Bending	Shear
Ultimate Strength	100.0	100.0	119.3	57.7
Yield Strength	45.4	45.4	54.4	26.2
Pulsating Strength	56.6	0.0	60.0	33.4
Alternating Strength	30.0	30.0	40.5	17.3

Reinforced Material

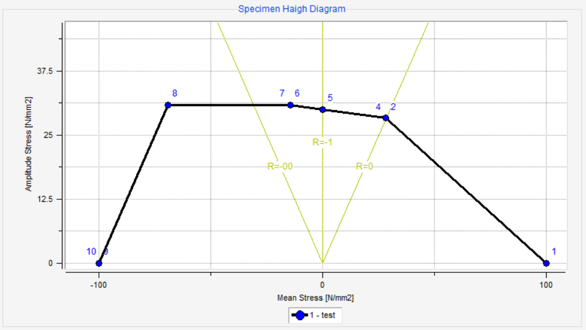
Define Material Parameters

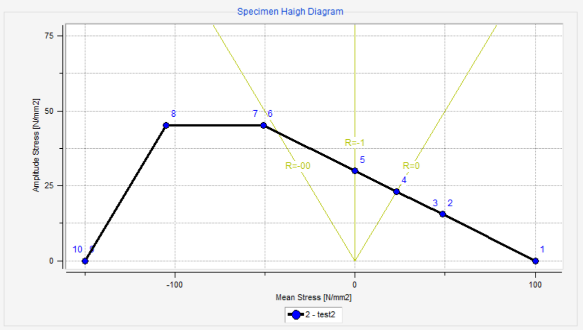
Select Material Class:

Aluminium Casting Alloys

Material Parameters

	Tension	Pressure	Bending	Shear
Ultimate Strength	100.0	150.0	120.0	75.0
Yield Strength	64.1	96.1	77.1	48.1
Pulsating Strength	46.2	0.0	61.0	36.8
Alternating Strength	30.0	30.0	46.2	22.5





__Non-reinforced plastic material__
Material class
Aluminum Wrought Alloy.

__Reinforced plastic material__
Material class
Aluminum Cast Alloy.

Change the material class to ‚Plastic‘ after generation

The aim of this procedure is to get a FEMFAT material that identifies highly stressed areas. The damage value itself is still to be evaluated by the engineer.

Plastic material generation: Material Generator

Reinforced Material

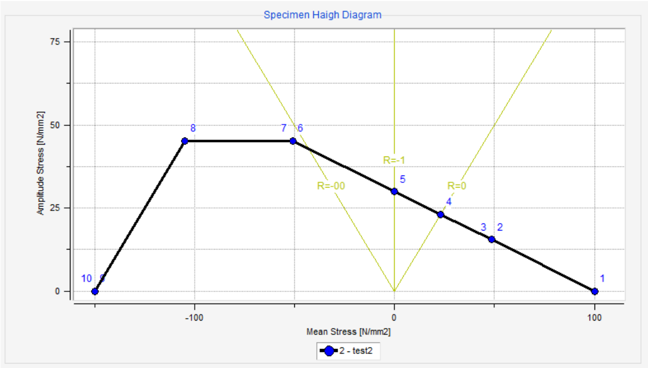
Define Material Parameters

Select Material Class:

Aluminium Casting Alloys

Material Parameters

	Tension	Pressure	Bending	Shear
Ultimate Strength	100.0	150.0	120.0	75.0
Yield Strength	64.1	96.1	77.1	48.1
Pulsating Strength	46.2	0.0	61.0	36.8
Alternating Strength	30.0	30.0	46.2	22.5



Relations:

$$f_{G\,enDur} = 1 + \frac{\left(\sigma_{alt\,Bending} / \sigma_{alt\,TC} - 1\right)}{(2/b)^{\nu}} \chi'^{\nu}$$

- Stress gradient: (Attention to the specimen thickness)
  $\sigma_{\text{alt Bending}} / \sigma_{\text{alt TC}} = 46.2 / 30.0 = 1.54$
- Mean stress influence:
  $(\sigma_{\text{alt TC}} * 2 / \sigma_{\text{pulsating TC}}) - 1 = (30.0*2/46.2)-1 = 0.30$
  Attention: In the case of the pulsating strength, the upper stress is entered in the table.
- For equivalent stress:
  $\sigma_{\text{Yield, shear}} / \sigma_{\text{Yield, T/C}} = 48.1 / 64.1 = 0.75$
  $$\sigma_E = \sqrt{\sigma_n^2 + k^2 \tau^2} \qquad k = \frac{\sigma_A}{\tau_A}$$
- Static relations:
  $\sigma_{\text{alt TC}} / \sigma_{\text{UTS T/C}} = 30 / 100 = 0.30$

Plastic material generation: Further Settings

What else must be done:

- Change material class from ‘aluminum wrought’ or ‘-cast’ to ‘plastic’.
- S/N Curve:
  - Change cycle Limit from 1.0E7 -> 1.0E6
  - Change slope from 11.0 -> 12.0
- Settings for Gradient influence:
  Exponent ν=0.6, AK2=5.0, AK3=0.55 (not necessary as of version 5.4.1, because of modified userdefparam.dbs)
- Check survival probability. If test data are used -> Ps=50%.
- Change specimen thickness from 7.5mm to 3.85mm :

Reference material for gradient influence:	1.80 for specimen thickness 2.0mm
Aluminum cast alloy gradient influence:	1.54 for specimen thickness 7.5mm (corresponds to 2.19 for thickness 2.0mm)
	1.54 for specimen thickness 3.85mm (corresponds to 1.80 for thickness 2.0mm)

- Miner Modified Parameter in material: A=1 B=0 (Miner Elementary is automatically calculated for this material even if the calculation parameter is set to Miner Modified. So one can treat steel and plastic part in one analysis.)

FEMFAT material generation: Modification of a existing similar material (*.ffd file)

- The entries in the FEMFAT *.ffd file are changed, e.g. starting from an already existing plastic material. The stress gradient, the mean stress sensitivity ... must be taken into account as described in the previous point.

- This is also the procedure for anisotropic plastic material.

```
    -1
   201
STEYR-FILE  2.0
EMS GRILON TSG 50/4, conditioned, 50% short glass fibers, PA66+6 semicrystalline
EMS GRILON TSG 50/4, conditioned
Confidental !!!
Last modification: 21.7.2015 by A. Mösenbacher
    -1
    -1
   218
EMS GRILON TSG 50/4, conditioned, 50% short glass fibers, PA66+6 semicrystalline
21.7.2015 by A. Mösenbacher, Lehrstuhl für Allgemeinen Maschinenbau, Montanuni
MUL AMB, EMS-Grivory
0.3300E+000.1550E-050.1500E-04         0        91     23.00      0.00 50.000000
0.1165E+050.0000E+000.0000E+000.2621E+030.2100E+000.0000E+000.3870E+010.0000E+00
0.0000E+000.0000E+000.0000E+00
0.0000E+000.0000E+000.0000E+000.0000E+000.0000E+000.0000E+00
  262.1200    0.2100    0.0000    0.0000    0.0000    0.0000    0.5000   0.00000
    0.0000    0.0000    0.0000

0.1551E+030.9990E+020.6450E+020.4610E+020.2000E+01
0.2125E+030.1369E+030.0000E+000.4610E+020.2000E+01
0.2543E+030.1638E+030.0000E+000.9060E+020.2000E+01
0.1097E+030.7070E+020.0000E+000.3260E+020.0000E+00



    -1
    -1
   223
Grilon TSG 50/4, conditioned, 50% short glass fibers, PA66+6 semicrystalline
konditionierte Biax und trockene Kurzprüfkörper aus Platte und UB-Versuche
EMS-Grivory und Lehrstuhl für Allgemeinen Maschinenbau der MUL
basierend auf Modelle für den trockenen Werkstoff mit TG-Verschiebung
         1         1     -1.00      1.00      0.00      2.00      0.00     23.00
     13.80   1000000     46.10         0      0.00      0.00      0.00 50.000000
      0.00         0
    -1
```

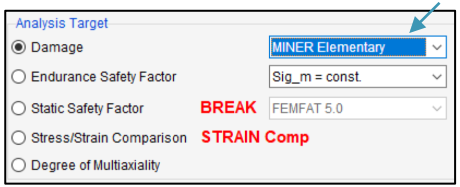
FEMFAT Modules for SFRP Assessment

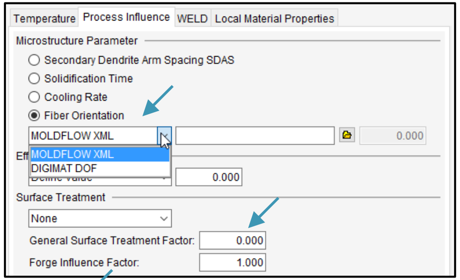
Anisotropic material (SFRP with fiber orientation) can be assessed with following **FEMFAT** modules:

	BASIC/BREAK	ChannelMAX	TransMAX	Spectral
FEMFAT 5.3a	no	yes	yes	no
FEMFAT 5.4a	no	yes	yes	no
FEMFAT 5.4.1	no	yes	yes	**yes**
FEMFAT 5.4.2	no	yes	yes	**yes**

FEMFAT Settings

- The analysis target should be set to MINER Elementary, because plastics have no fatigue strength (can also be set in *.ffd and then this material is calculated with Miner Elementary despite Miner Modified setting).
- For anisotropic material the fiber orientation has to be entered under *Node Characteristics*. Under *General Factors* the "Fiber Orientation" influence has to be checked.
- Easy consideration of the lower fatigue properties of weld lines:
  - Export weld lines from Moldex3D when mapping (node list).
  - Map with DIGIMAT -> nodes are mapped to elements. -> generate node list (ANSA)
  - Read weld line nodes into FEMFAT and reduce strength with a factor 0.5 using "General Surface Treatment Factor" under *Node Characteristics* (the factor 0.5 is not based on tests, just an idea!).





Material Data for Elastomers

….ffd-files for natural rubber for different Shore hardness

Fatigue assessment of Elastomers

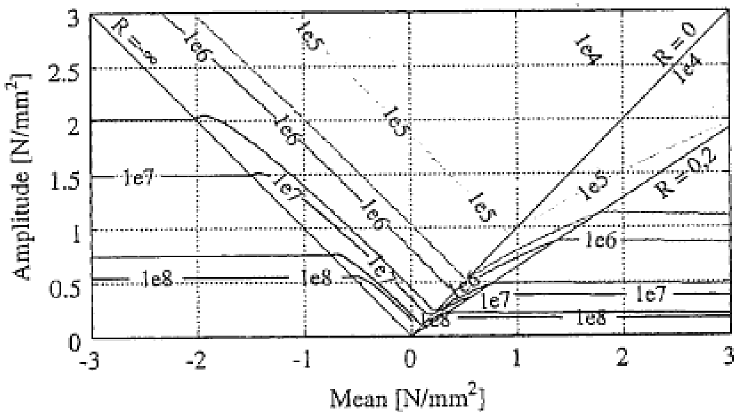
1) Different material behavior hyper elastic (Mullins effect).

2) Fatigue analysis can be done stress based.

3) Haigh diagrams can be used.

4) The maximum upper stress is responsible for the crack (between R=-∞ and R=0).

5) Influence of stress gradient is not known and assessed at the moment.



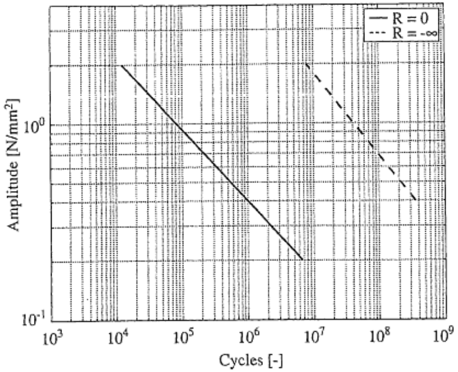
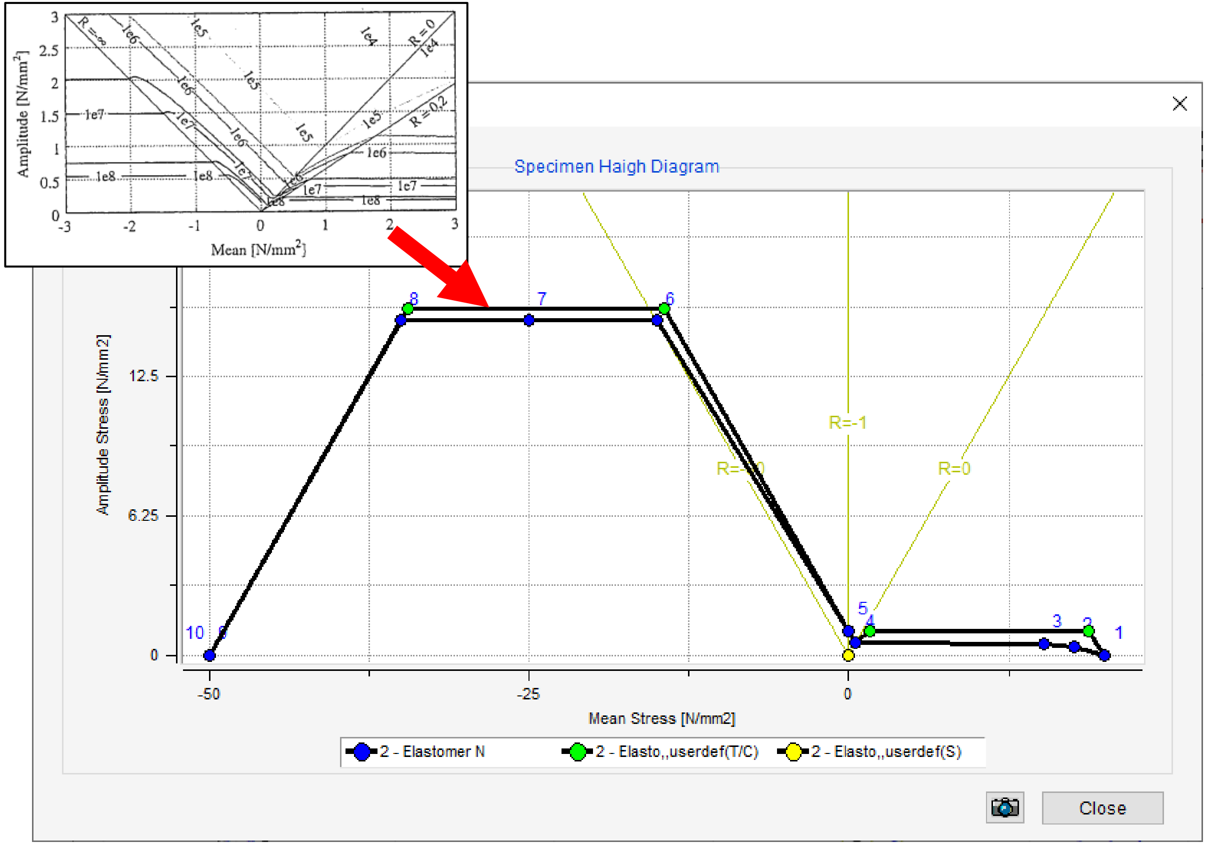


Figure 5. Estimated Woehler-curves for pulsating loads R = 0 and R = −∞.

<u>Source</u>: **M. Flamm: Ein Beitrag zur Betriebsfestigkeitsvorhersage mehraxial belasteter Elastomerbauteile. VDI Verlag, 2003**

Standard Haigh-Diagram for Elastomers



- Elastomers behaves like brittle material.
- Construction of Hiagh Diagram analogous to Gray Cast Iron.
- Mean stress sensitivity M ≥ 1 is possible.

New Material Datasets for Elastomers

- Released in **FEMFAT 5.4.2**
- New Material class „301 Elastomers (NR)"
- 5 new material datasets for natural rubber:
  - Elastomer_NR_40ShA_Sig1p1_ECS.ffd
  - Elastomer_NR_45ShA_Sig1p25_ECS.ffd
  - Elastomer_NR_50ShA_Sig1p4_ECS.ffd
  - Elastomer_NR_55ShA_Sig1p5_ECS.ffd
  - Elastomer_NR_60ShA_Sig1p7_ECS.ffd

Natural Rubber

Shore Hardness

Tension/Compression alternating strength

Gradient Influence and PLAST deactivated

MAGNA

- Material Files has been generated in way, that the gradient influence and PLAST was deactivated:

Gradient Influence on fatigue limit

$$f_{GenDur} = 1 + \frac{\left(\sigma_{altBending} / \sigma_{altTC} - 1\right)}{(2/b)^{\nu}} \chi'^{\nu}$$

→

$\sigma_{alt\ Bending} = \sigma_{altTC}$

$\nu = 0$

Gradient Influence on slope

$$k_C = \left[\frac{k_M - AK2}{\left(f_{GR,sf}\right)^{AK3} - 1 + \frac{1}{\left(f_{1,af}\right)^{AK3}}} + AK2 \right] \frac{1}{f_{m,sf}}$$

→

AK2 = 3.4

AK3 = 0

PLAST:

$$\varepsilon_a = \frac{\sigma_a}{E} + \left(\frac{\sigma_a}{K'}\right)^{\frac{1}{n'}}$$

→

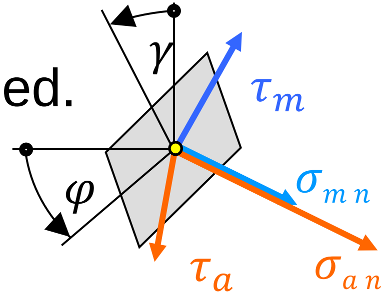
n‘ = 1.0

K‘ = 1000

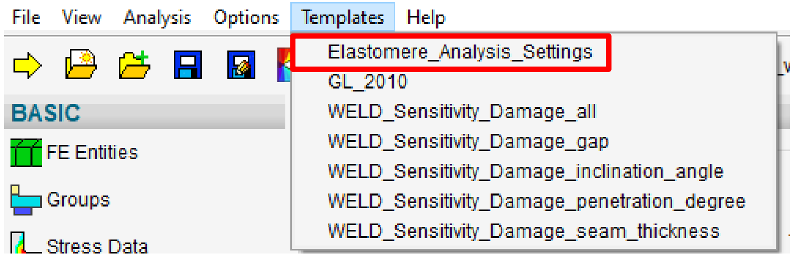
FEMFAT Analysis Settings

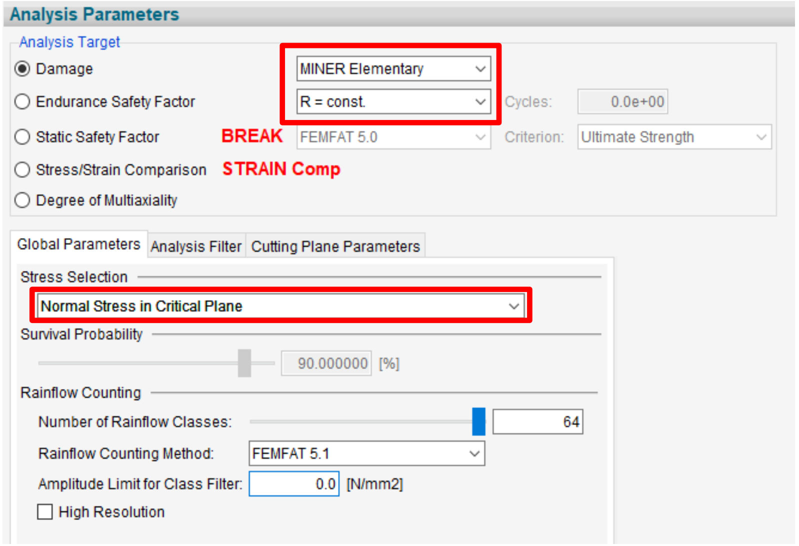
MAGNA

- Elastomers behaves like brittle material.
  => „Normal Stress in Critical Plane“ ($\sigma_{a\,n}$, $\sigma_{m\,n}$) shall be used.



- Miner elementary option
- R = const. Option
- Template for Elastomere analysis





Summary

- Extensive material database is provided with FEMFAT.
- Material generator for the most important material classes can be used to estimate the cyclic material data.
- User has many flexible options for incorporating test results into FEMFAT material data.
- Data for non-metallic materials can be generated.
- Future Development of Material Generators for:
  - Microalloyed steels
  - Stainless and forged steels
  - Elastomers
  - …

DRIVING **EXCELLENCE.**
INSPIRING **INNOVATION.**