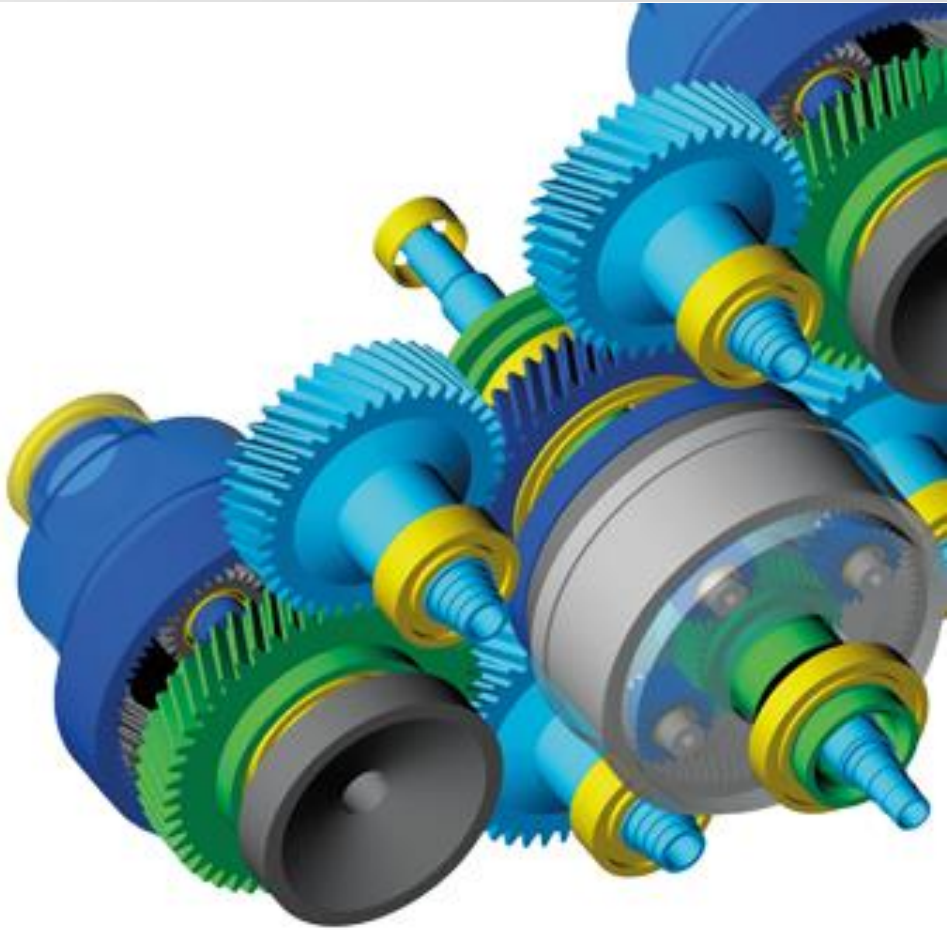
Plastics Manager



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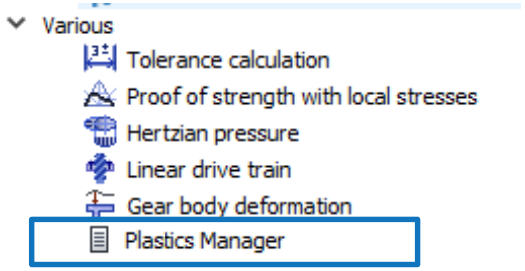
General

Located under various



Functionality

- Adding new plastic materials to the KS database
- Automatic generation of the corresponding DAT files

If fatigue data from gear testing is available

- Calculation of permissible tooth root/flank stresses for different lubrication regimes
- Statistical evaluation of cycles to failure

2 calculation cases possible

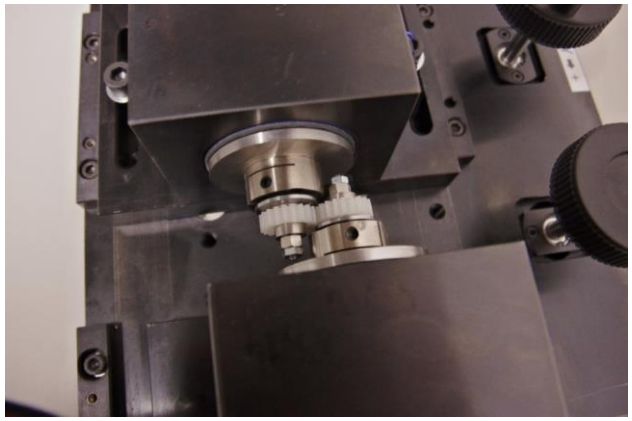
- Identical test gears for all tests (testing on the test bench)
- Different test gears used (Z12, Z14, Z15, Z16) – mainly testing in actual applications

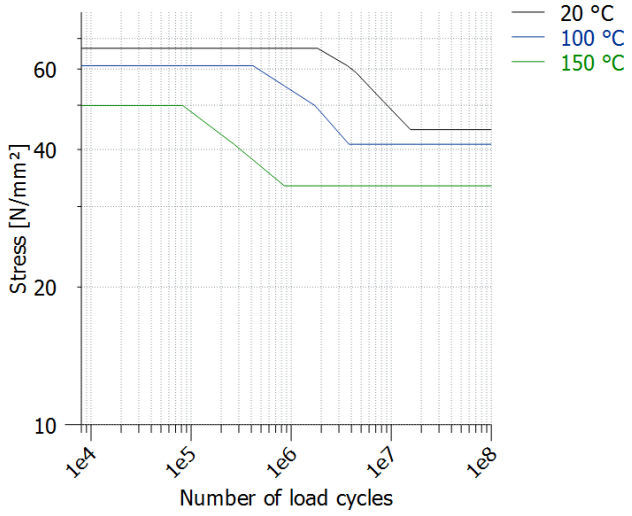
Possible to calculate wear factors and heat transfer coeffcients acc. to the VDI 2736

How to get permissible root/flank stresses from gear measurements?

	Torque, Nm	Speed, rpm	Cycles, 10^6	Room T, °C	Root T, °C (failed gear)	Flank T, °C (failed gear)	Flank T, °C (counter gear)	Failure
1	4.50	500	15.345	20	20	20	20	root
2	4.50	500	15.821	20	20	20	20	root
3	3.39	500	0.874	150	150	150	150	root
4	3.39	500	0.834	150	150	150	150	root
5	5.20	500	8.347	20	20	20	20	root
6	5.20	500	8.167	20	20	20	20	root
7	4.18	500	3.849	100	100	100	100	root
8	4.18	500	3.725	100	100	100	100	root
9	4.18	500	0.254	150	150	150	150	root
10	4.18	500	0.284	150	150	150	150	root
11	5.08						0	root
12	5.08						0	root
13	5.08						0	root
14	5.08	500	1.922	100	100	100	100	root
15	5.08	500	0.092	150	150	150	150	root
16	5.08	500	0.074	150	150	150	150	root
17	6.21	500	3.806	20	20	20	20	root
18	6.21	500	3.486	20	20	20	20	root
19	6.21	500	0.405	100	100	100	100	root
20	6.21	500	0.425	100	100	100	100	root
21	6.78	500	1.722	20	20	20	20	root
22	6.78	500	1.951	20	20	20	20	root

Results from gear tests





Simple solution:
Use Plastics Manager

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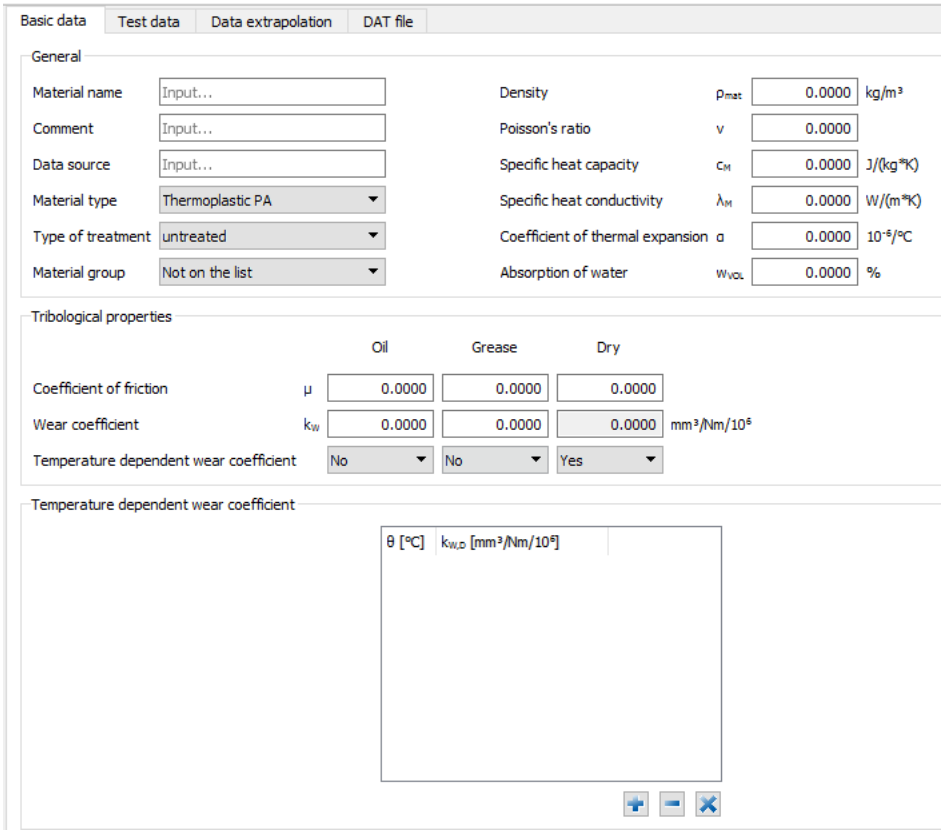
General – Tab basic data



General material properties

Tribological properties

Temperature dependent wear coefficients

General – Tab Test data and extrapolation

Basic data | Test data | Data extrapolation | DAT file

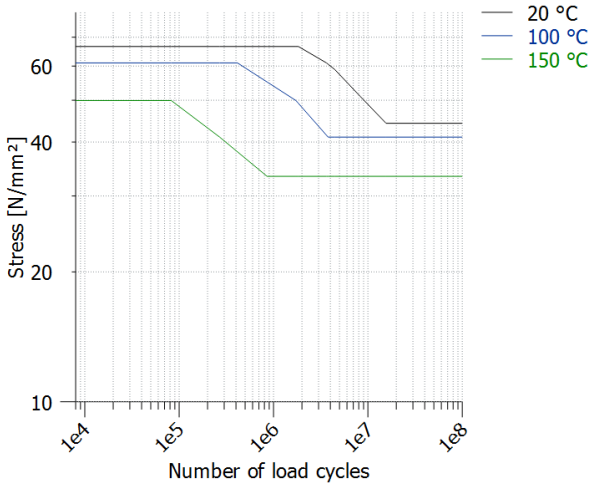
Calculation

Damage probability		50.0000	%	Statistical method: Acc. to VDI 2736-4
Merge temperature deviation	$\Delta\theta_{merge}$	1.0000	°C	Test gear file: SABIC_standard_geometry.Z12
Torque merge deviation	$\Delta T/T$	1.0000	%	Failed gear: 2
Group temperature deviation	$\Delta\theta_{group}$	1.0000	°C	

Test gear measurements

	Status	T [Nm]	n [1/min]	N_L [10^6]	θ_U [°C]	θ_GUT_{root} [°C]	θ_GUT_{flank} [°C]	Failure mode	$\theta\_counter_{flank}$ [°C]
7	active	4.1800	500.0000	3.8490	100.0000	100.0000	100.0000	Root	100.0000
8	active	4.1800	500.0000	3.7250	100.0000	100.0000	100.0000	Root	100.0000
9	active	4.1800	500.0000	0.2540	150.0000	150.0000	150.0000	Root	150.0000
10	active	4.1800	500.0000	0.2840	150.0000	150.0000	150.0000	Root	150.0000
11	active	6.0000	500.0000	4.5440	20.0000	20.0000	20.0000	Root	20.0000
12	active	6.0000	500.0000	4.3440	20.0000	20.0000	20.0000	Root	20.0000

Read data from file: C:/Users/apogacnik/Desktop/tests.DAT



Extrapolation options

Basic data | Test data | Data extrapolation | DAT file

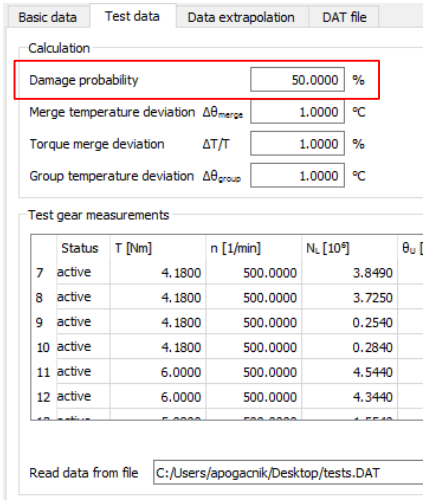
Permissible tooth root stress

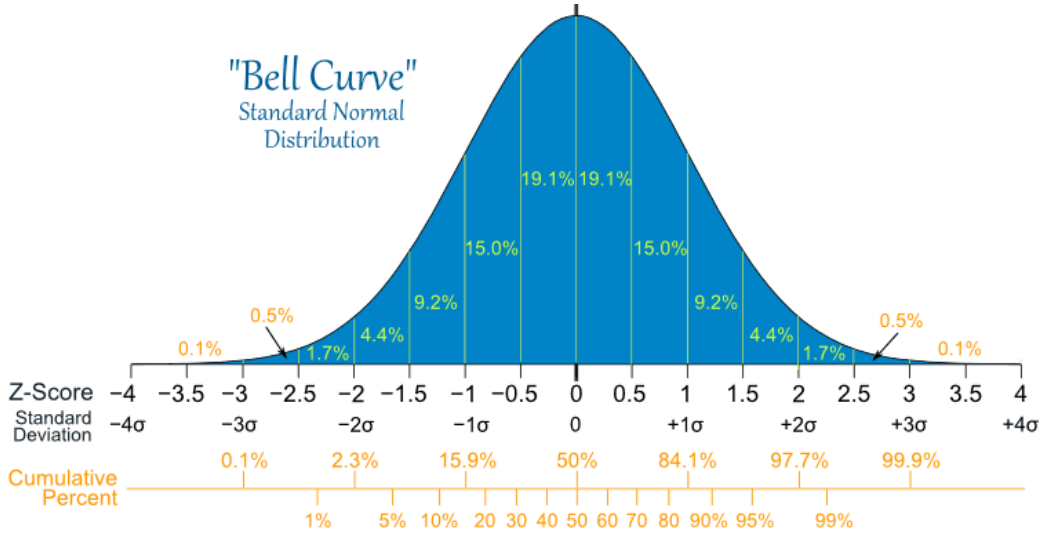
Method 1	Extrapolate with average slope	☑ Extend temperature range	
Extrapolate to cycles	10000.0000 10^6	Extend to temperature θ_F	0.0000 °C
Method 2	Set cycles to infinity	Increase permissible stress by factor	1.0000

To calculate safety factors with load spectrum in KISSsoft, S-N curves should be defined until 10^{30} cycles. It is not possible to measure that long, so instead, extrapolation is used.

```
-- Permissible tooth root stress sigFlim [N/mm2], all lubrication regimes
-- Calculated with 10% damage probability
-- Calculated with root safety factor SF=1
-- Values with * measured, other interpolated/extrapolated
:TABLE FUNCTION FootSigFlim
    INPUT X ZahnTempFuss TREAT LINEAR
    INPUT Y Lastwechsel TREAT LOG
DATA
                20      100     150
0.000e+000     33.3     30.5    25.0
7.709e+004     33.3     30.5    25.0*
2.492e+005     33.3     30.5    20.5*
3.839e+005     33.3     30.5*   19.0
7.865e+005     33.3     27.6    16.7
1.585e+006     33.3     25.0*   16.7
1.681e+006     33.3*    24.6    16.7
3.327e+006     30.5*    20.7    16.7
3.457e+006     30.3     20.5    16.7
4.053e+006     29.5*    20.5    16.7
7.503e+006     25.5*    20.5    16.7
1.411e+007     22.1     20.5    16.7
1.000e+099     22.1     20.5    16.7
END
```

Damage probability





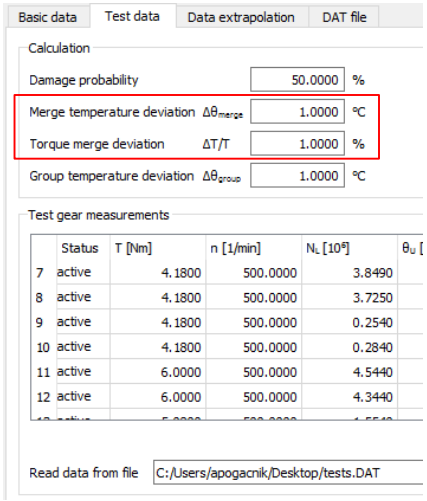
According to the VDI 2736-4, each test condition (torque, temperature) should be measured at least 3 times. The calculated average cycles to failure represent 50% damage probability.

Example: 143300, 100780 and 94020 cycles to failure (calculated standard deviation: 26715).

Damage probability	1%	5%	10%	20%	30%	40%	50%
Calculated cycles	50500 (-55%)	68700 (-40%)	78500 (-30%)	90250 (-20%)	98700 (-13%)	106000 (-6%)	112700

SOURCE: http://www.mathsisfun.com/definitions/standard-normal-distribution.html

Merge temperature and torque deviation



	Torque	Speed	Root θ	NL
1	1.00 Nm	750 rpm	100 °C	$1.01 \cdot 10^6$
2	1.05 Nm	750 rpm	120 °C	$1.13 \cdot 10^6$
3	1.00 Nm	750 rpm	105 °C	$0.82 \cdot 10^6$
4	1.00 Nm	750 rpm	98 °C	$1.05 \cdot 10^6$
5	0.98 Nm	750 rpm	102 °C	$0.88 \cdot 10^6$

According to the VDI 2736-4, each test condition (torque, temperature) should be measured at least 3 times.

$\Delta\theta_{merge} = 8°C$ and $^{\Delta T}/_{T} = 5\%$

Tests 1, 3, 4, 5 merged together

Torque: 0.98 Nm

Root temperature: 98 °C

NL: $0.80 \cdot 10^6$ (10% failure)

$\Delta\theta_{merge} = 3°C$ and $^{\Delta T}/_{T} = 2\%$

Tests 1, 4, 5 merged together

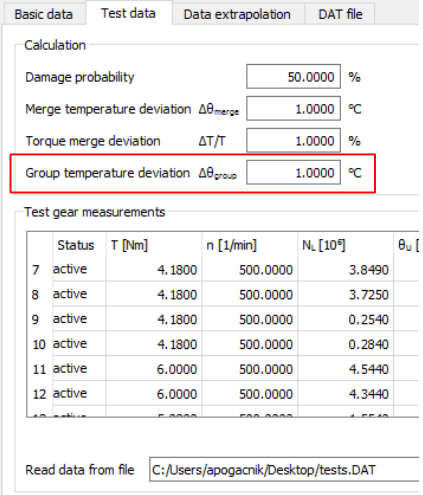
Torque: 0.98 Nm

Root temperature: 98 °C

NL: $0.87 \cdot 10^6$ (10% failure)

Points, that are merged together, form only 1 point on the S-N curve.

Group temperature deviation



	Root stress	Root T	NL
1	55 MPa	41 °C	$1.00 \cdot 10^6$
2	45 MPa	42 °C	$2.10 \cdot 10^6$
3	35 MPa	44 °C	$3.80 \cdot 10^6$
4	28 MPa	50 °C	$4.00 \cdot 10^6$
5	15 MPa	80 °C	$5.00 \cdot 10^6$

According to the VDI 2736-4, S-N curve at 1 temperature should be measured at 4 different loads (root stresses)

$\Delta\theta_{group} = 10°C$

Tests 1, 2, 3, 4 grouped together

root T = 41 °C

$\Delta\theta_{group} = 4°C$

Tests 1, 2, 3 grouped together

root T = 41 °C

```
-- Tooth root strength sigFlim [N/mm2] -
-- SigFlim values noted with * were measu
:TABLE FUNCTION FootSigFlim
      INPUT X ZahnTempFuss TREAT LINEAR
      INPUT Y Lastwechsel    TREAT LOG
DATA
              20     80
0.000E+00   41.5   27.7
1.000E+05   41.5*  27.7
3.400E+05   34.6*  27.7
3.600E+05   31.2*  27.7
4.700E+05   30.6   27.7*
6.000E+05   30.1   24.2*
8.200E+05   29.4   20.8*
1.770E+06   27.9   19.1*
2.000E+06   27.7*  17.3*
2.001E+06    0.0    0.0
1.000E+99    0.0    0.0
END
```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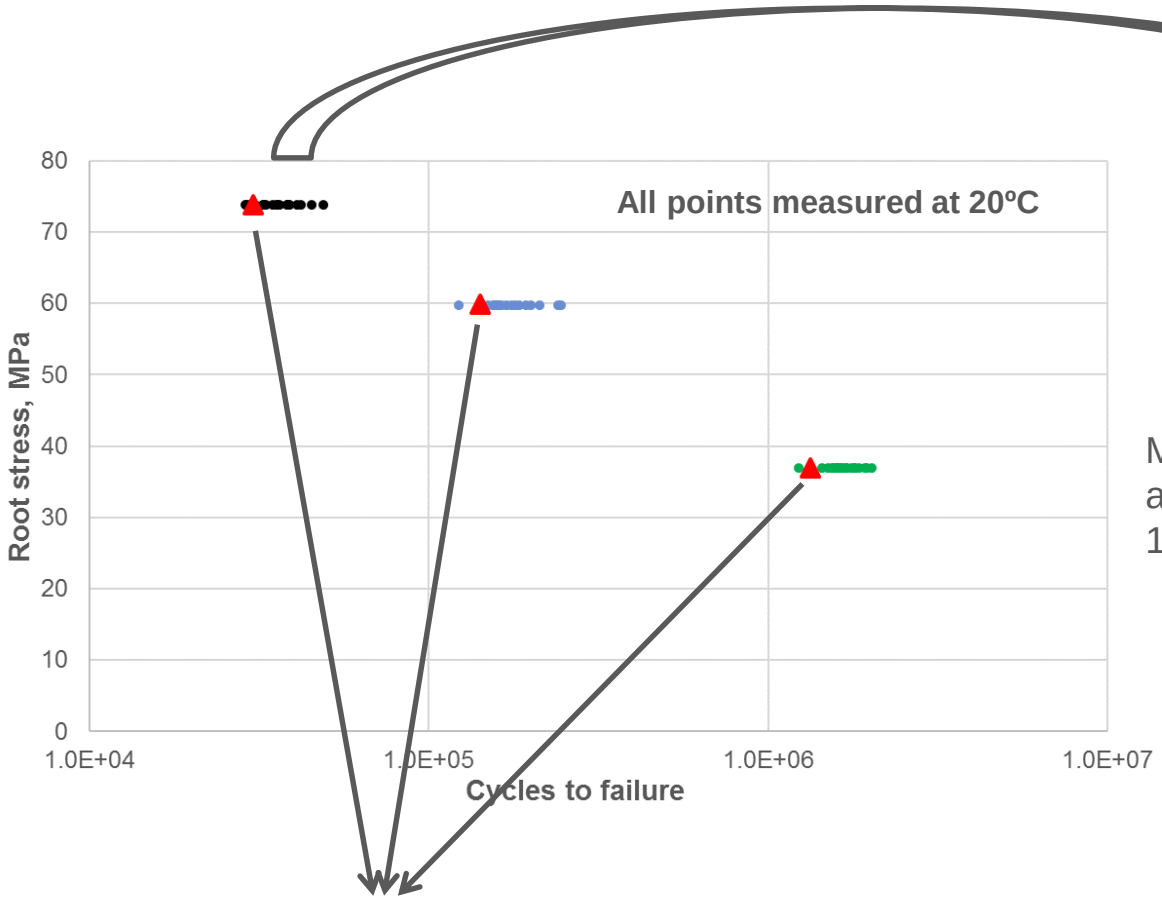
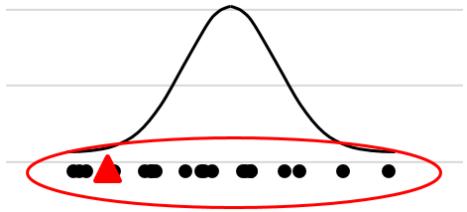
Summary of merge and group functions



Merged points ▲ **grouped** together to form S-N curve at **20ºC**



Measured points ● **merged** together and statistically shifted to 10% to form 1 point ▲ on the S-N curve

```
-- Tooth root strength sigFlim [N/mm2] -
-- SigFlim values noted with * were measu
:TABLE FUNCTION FootSigFlim
      INPUT X ZahnTempFuss TREAT LINEAR
      INPUT Y Lastwechsel    TREAT LOG
DATA
              20      80
0.000E+00   41.5    27.7
1.000E+05   41.5*   27.7
3.400E+05   34.6*   27.7
3.600E+05   31.2*   27.7
4.700E+05   30.6    27.7*
6.000E+05   30.1    24.2*
8.200E+05   29.4    20.8*
1.770E+06   27.9    19.1*
2.000E+06   27.7*   17.3*
2.001E+06    0.0     0.0
1.000E+99    0.0     0.0
END
```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Calculating permissible stresses

The calculated permissible stresses are **calculation method dependent**.

		Safety factor lifetime calculation method		
		VDI 2736 (YF C)	**VDI 2545 (YF C)**	**VDI 2545 (YF B)**
Permissible stress calculation method	**VDI 2736 (YF C)**	1.00 (254 h)	1.12 (529 h)	0.99 (247 h)
	VDI 2545 (YF C)	0.89 (125 h)	1.00 (254 h)	0.89 (122 h)
	VDI 2545 (YF B)	1.00 (260 h)	1.12 (570 h)	1.00 (254 h)

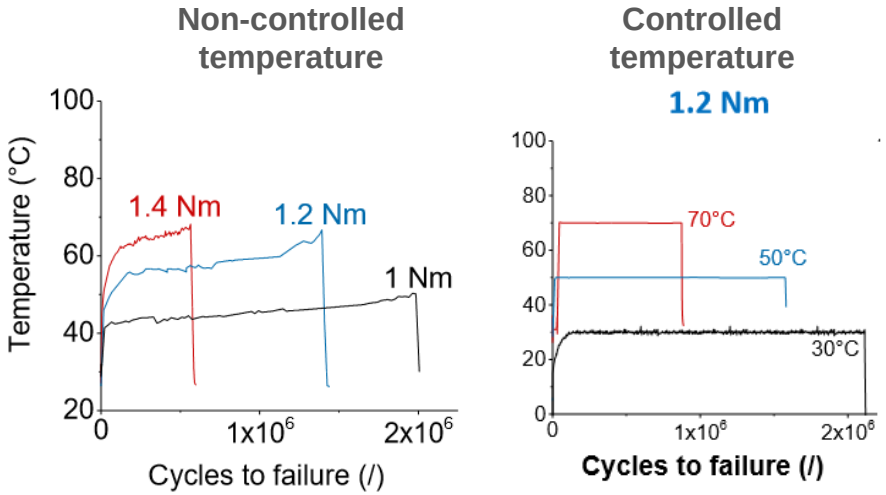
Calculated safety factors and achieved lifetime with SF = 1 (steel/POM, 350 rpm, 20 ºC, 10^6 cycles).

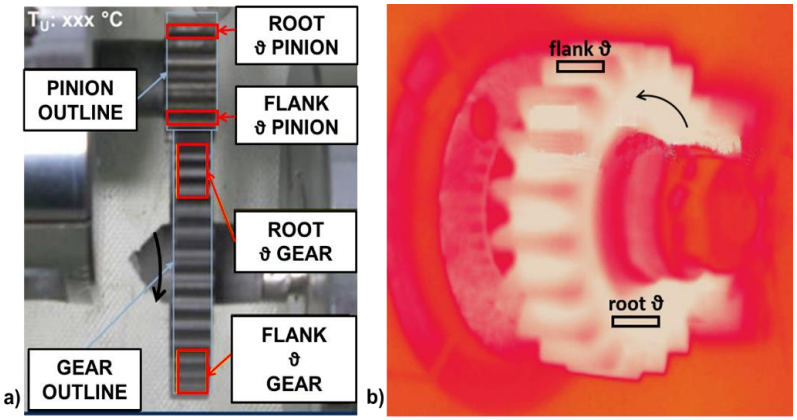
The same calculation method should be used for permissible stress calculation and for the calculation of safety factors!

What and how to measure during testing

	Root failure	Flank failure	Wear factor	Heat transfer coefficients
Torque and speed	yes	yes	yes	yes
Cycles to failure	yes	yes	yes	no
Root temperature, failed	yes	no	no	yes
Root temperature, counter	no	no	no	yes
Flank temperature, failed	no	yes	yes	yes
Flank temperature, counter	no	no*SP/yes*PP	no	yes
Local linear wear or mass	no	no	yes	no

***SP** – steel/plastic combination, ***PP** – for plastic/plastic combination





SOURCE: Kalin M. et. al: Temperature dependent tribological behaviour of polymer (POM) gears, 2017. Industriekreis final report, Lehrstuhl für Kunststofftechnik Universität Erlangen-Nürnberg, 2010.

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Additional options

It is also possible to calculate and combine permissible stresses from **different** test geometries – testing in actual applications. However, the material of failed gear must be the same!

Basic data | Test data | Data extrapolation | DAT file

Calculation

Damage probability		10.0000	%	Statistical method: Normal distribution
Merge temperature deviation	$\Delta\theta_{merge}$	8.0000	°C	
Root/flank stress merge deviation	$\Delta\sigma/\sigma$	5.0000	%	
Group temperature deviation	$\Delta\theta_{group}$	5.0000	°C	

Test gear measurements

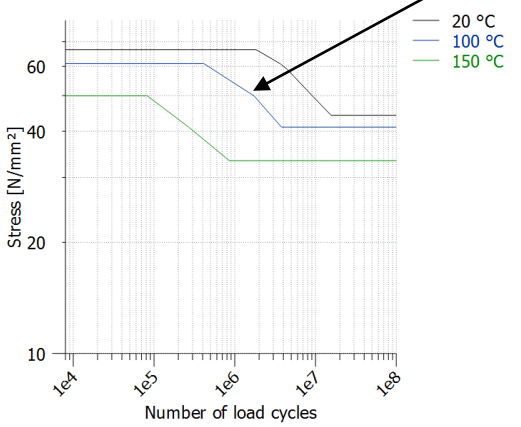
	Status	Test gear file	Failed gear	Failure mode	Counter gear
1	inactive	4Gears2.Z16	2	No failure	1
2	inactive	4Gears1.Z16	2	No failure	1
3	active	3Gears2.Z15	2	Root	3
4	active	3Gears1.Z15	2	Root	3
5	active	3Gears8.Z15	2	Root	3
6	active	3Gears5.Z15	2	Root	3
7	active	3Gears6.Z15	2	Root	3
8	active	3Gears4.Z15	2	Root	3

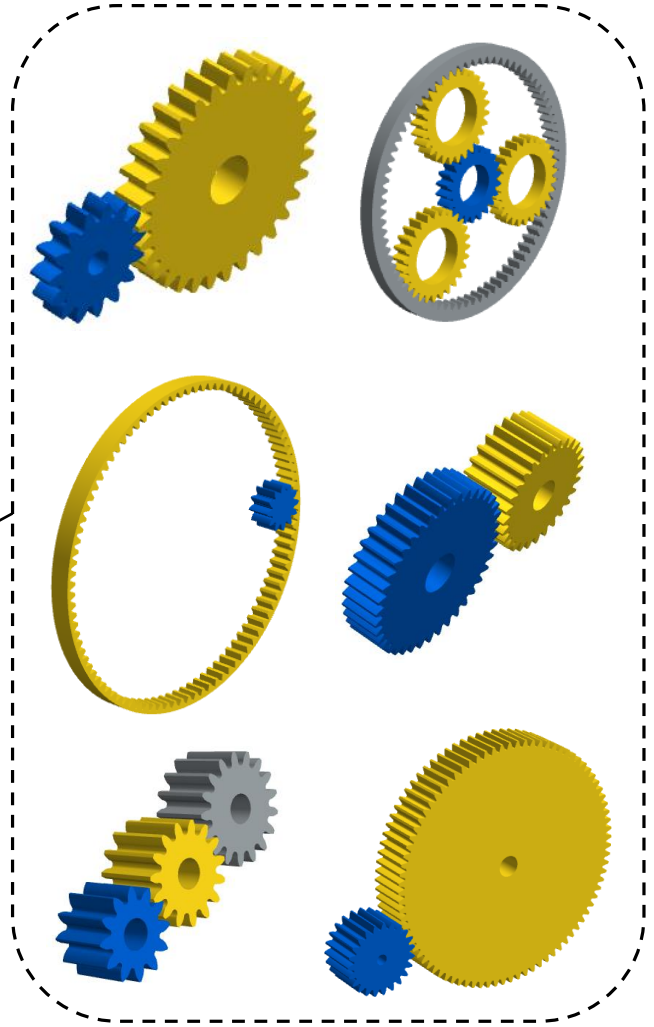
Module specific settings

Minimum number of data points for merging		2	
Minimum number of data points for grouping		2	
Allowable cycles to failure deviation		30.0000	%
Allowable speed deviation		5.0000	%
Stress correction factor of reference test gear	Y_{ST}	2.0000	
Root safety	SF_{min}	1.0000	
Flank safety	SH_{min}	1.0000	
Power-on time		100.0000	%
Housing heat-transfer resistance	$R_{\lambda,G}$	0.0000	K*m²/W
Housing heat-dissipating surface	A_G	0.0100	m²

☐ Single test file
☐ Calculate wear coefficient from worn test gear
☑ Display permissible root/flank stresses in LOG scale

OK | Cancel





Possible KS files: Z12, Z14, Z15, Z16

Thank you!