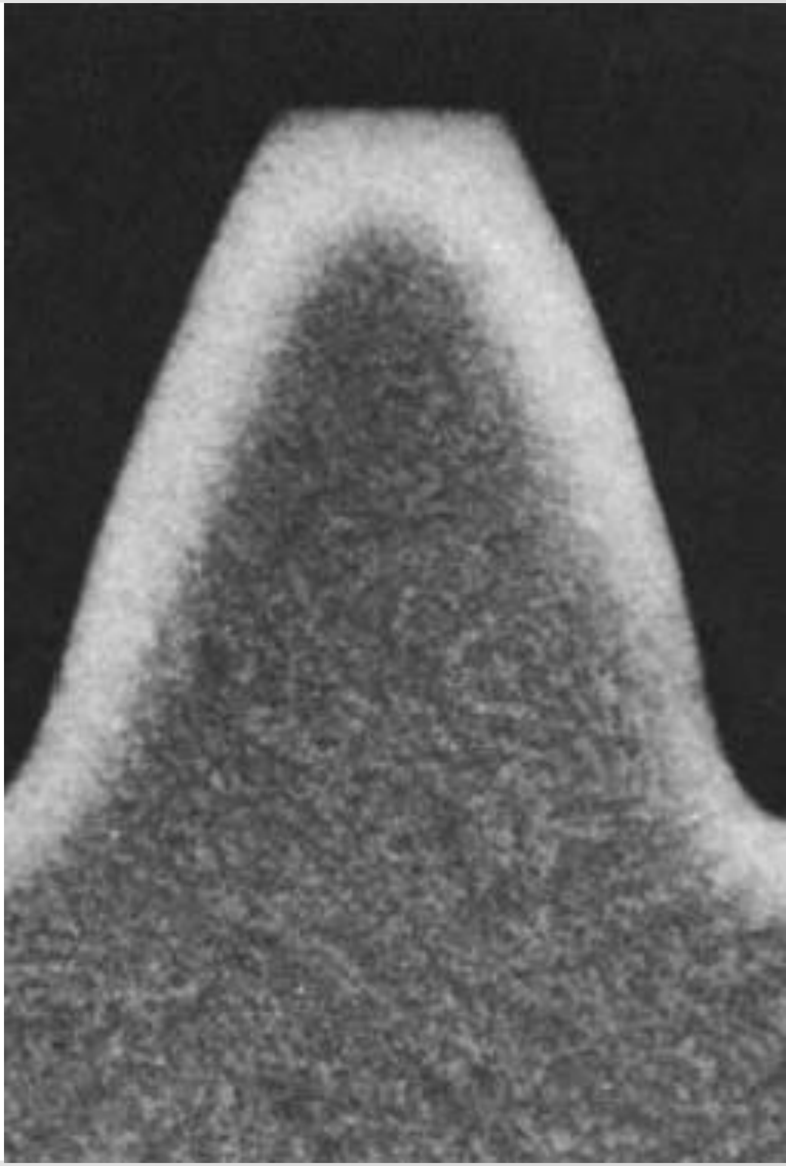
Influence on gear material properties on gear rating

Selected aspects



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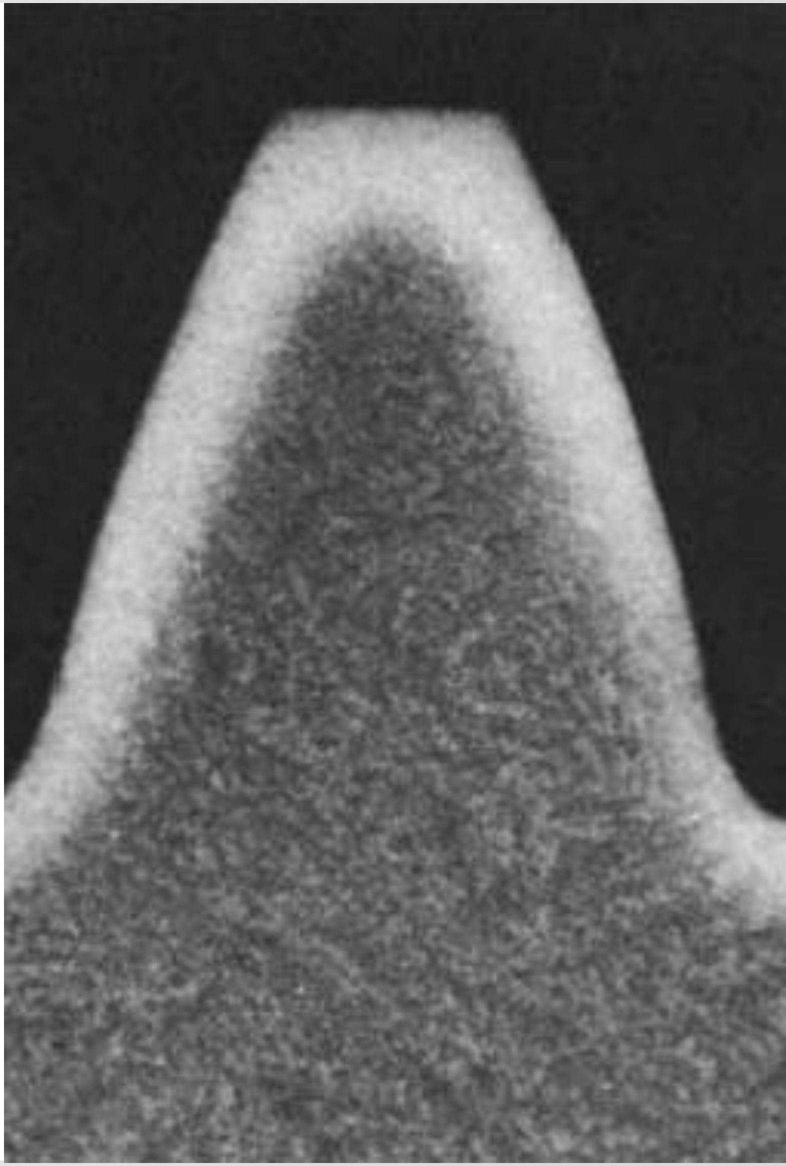
Content



Slope p

ISO 6336: endurance limit in range of 0.85…1.00 of σFlim (ISO 6336-3:2019, Table 3, footnote a)

Values for slope p, for limited life:

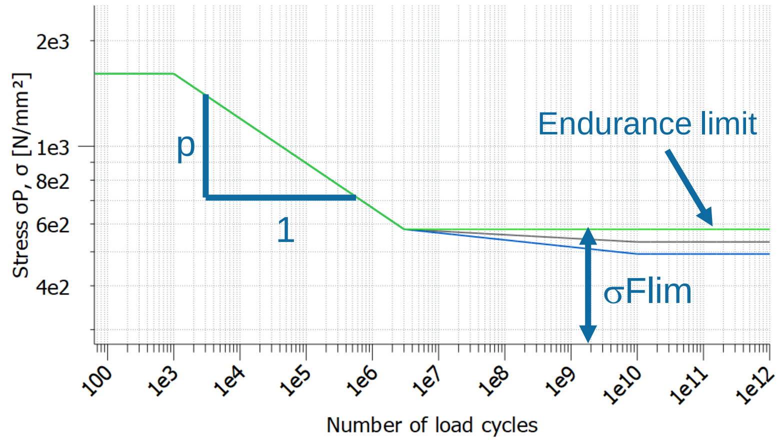
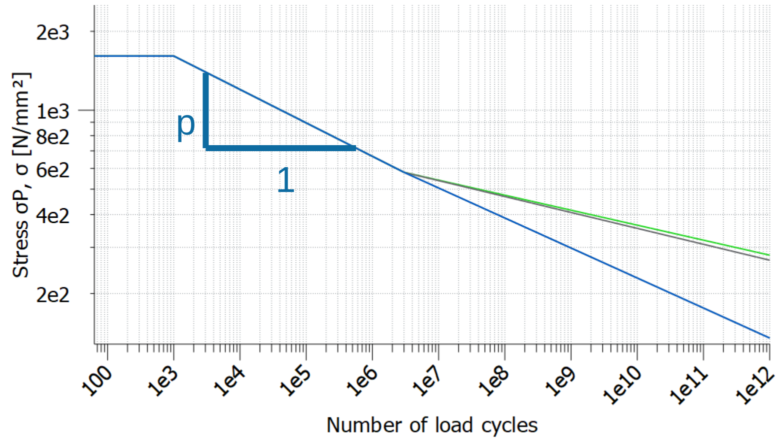


Table A.1 — Exponent *p* of S-N curve and number of load cycles for endurance limit, $N_{\mathrm{L\,ref}}$

Material (acc. ISO 6336-5)	Pitting		Tooth root bending	
	p^a	$N_{\mathrm{L\,ref}}$	p	$N_{\mathrm{L\,ref}}$
St, V, GGG (perl., bai.), GTS (perl.) (limited pitting according to ISO 6336-2)	6,774 8	10×10^6	6,224 9	3×10^6
St, V, GGG (perl., bai.), GTS (perl.) (no pitting according to ISO 6336-2)	6,611 2	50×10^6		
EH, IF (limited pitting according to ISO 6336-2)	6,774 8	10×10^6	8,737 8	3×10^6
EH, IF (no pitting according to ISO 6336-2)	6,611 2	50×10^6		
GG, GGG (ferr.), NT (nitr.), NV (nitr.)	5,709 1	2×10^6	17,035	3×10^6
NV (nitrocar.)	15,716	2×10^6	84,003	3×10^6

[a] Values *p* for pitting are given for the torque; to convert for the stress, these values shall be doubled.



KISSsoft

Calculations in KISSsoft, based on S-N curve

Standard method in KISSsoft, from same S-N curve, for same reliability level	Input: required life H	Input: torque T	Result: safety factor SF, SH
Calculate lifetime, from same S-N curve, for same reliability level	Input: required safety factor SFmin, SHmin	Input: torque T	Result: lifetime HF, HH
Calculate transmittable torque, from same S-N curve, for same reliability level	Input: required safety factor SFmin, SHmin	Input: required lifetime H	Result: transmittable torque T

KISSsoft

Calculation of safety factor

Reference gear		Gear 1		Details
Power	P	92.3209	kW	
Torque	T_1	2000.0000	Nm	
Speed	n_1	440.8000	1/min	
Required service life	H	1234.0000	h	
Application factor	K_A	1.2500		

Standard method in KISSsoft, from same S-N curve, for same reliability level

Input: required life H

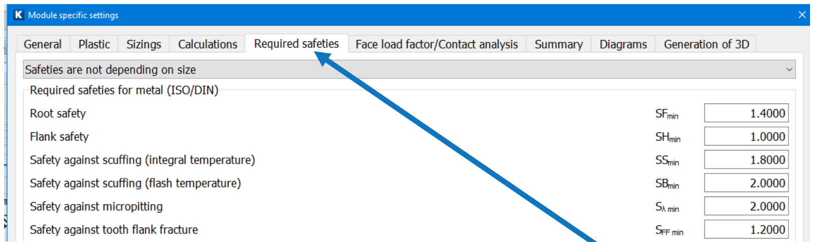
Input: torque T

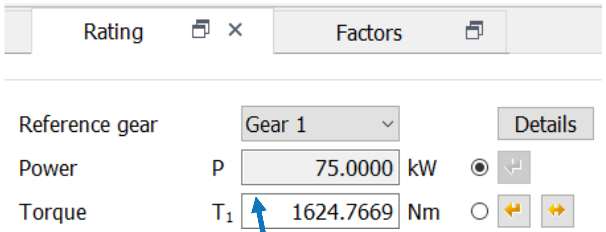
Result: safety factor SF, SH

Contact ratios	$[\varepsilon_{\alpha m}/\varepsilon_{\beta}/\varepsilon_{\gamma m}]$	1.662 / 0.000 / 1.662	
		Gear 1	**Gear 2**
Actual tip circle (mm)	$[d_{ae}]$	164.982	465.018
Root safety	$[S_F]$	2.551	2.459
Flank safety	$[S_H]$	1.333	1.388
Safety of hardened layer, DNV 41.2	$[S_{EHT}]$	1.286	1.286

KISSsoft

Calculation of lifetime



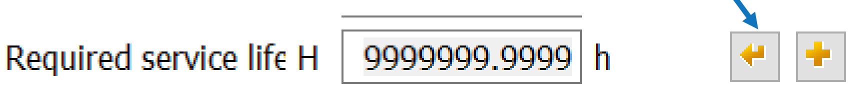


Calculate lifetime, from same S-N curve, for same reliability level

Input: required safety factor SFmin, SHmin

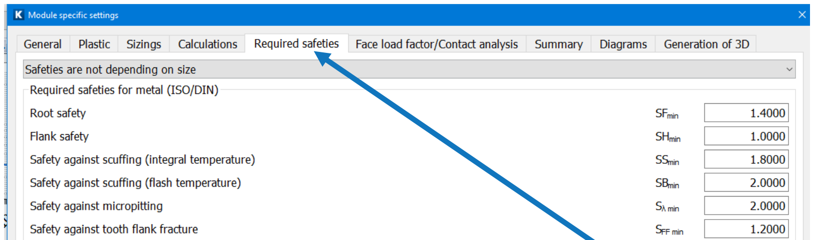
Input: torque T

Result: lifetime HF, HH



KISSsoft

Calculation of transmittable torque



Calculate transmittable torque, from same S-N curve, for same reliability level

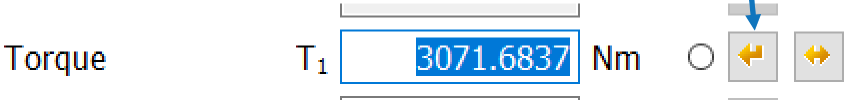
Input:

required safety factor SFmin, SHmin

Input:

required lifetime H

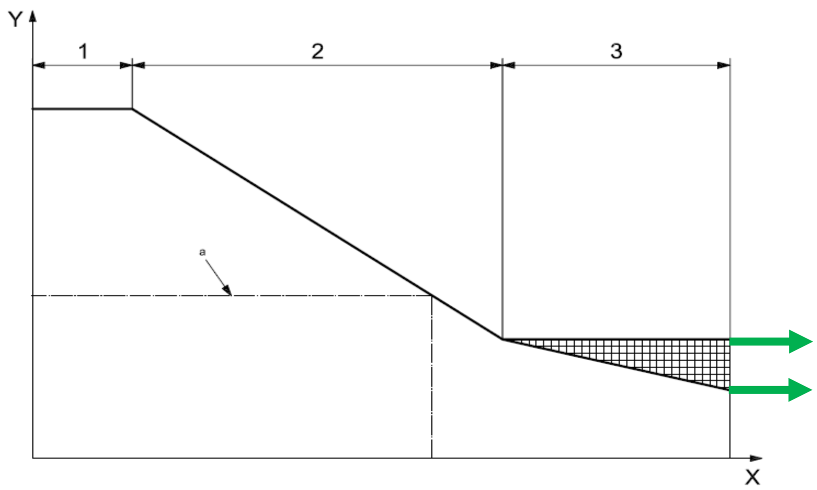
Result:
transmittable torque T



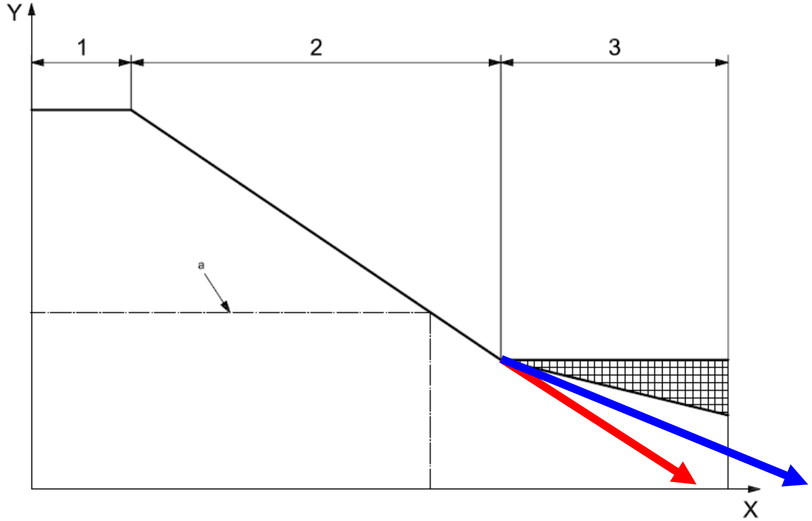
Basic assumption for ISO rating

ISO 6336 assumes that an endurance limit is present, at least if ZNT = YNT = 1.00 in long life domain.

ISO 6336, with endurance limit



Modified S-N curve without endurance limit



Along ISO 6336, parts 2, 5

For steels, pitting

NL ≤ 10e6, static domain, ZNT = 1.6

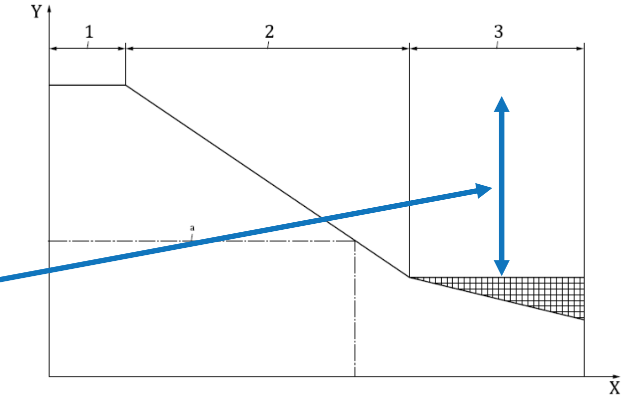
10e6 < NL < 5 * 10e7, limited life, ZNT interpolated

NL = 5 * 10e7, end of limited life domain, ZNT = 1.0

5 * 10e7 < NL < 10e10, long life domain, ZNT = 0.85…1.00

Definition stops at 10e10 cycles

For long life domain, ZNT = 1.00 with optimum lubrication, material, manufacturing and experience. For general purpose gearing: values between 0.85…1.00 may be used.



Key

X number of load cycles, N_L (log)

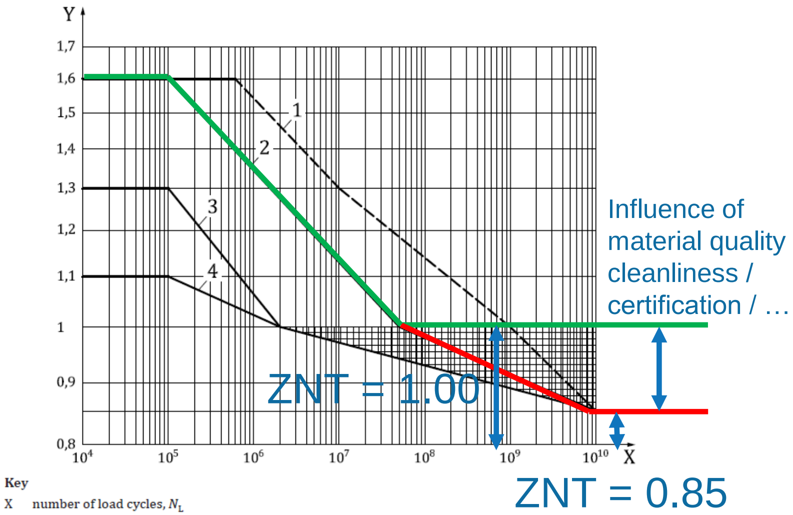
Y permissible contact stress, σ_{HP} (log)

1 static

2 limited life

3 long life

a Example: permissible contact stress, σ_{HP} for a given number of load cycles.



Key

X number of load cycles, N_L

Y life factor, Z_{NT}

1 St, V, GGG (perl., bai.), GTS (perl.), Eh, IF, when limited pitting according to Clause 4 is permitted

2 St, V, GGG (perl., bai.), GTS (perl.), Eh, IF, when no pitting according to Clause 4 is permissible

3 GG, GGG (ferr.), NT (nitr.), NV (nitr.)

4 NV (nitrocar.)

S-N curves

Along ISO 6336, parts 3, 5

For steels, bending (curve 2 for case hardened wrought steel)

NL ≤ 10e3, static domain, YNT = 2.5

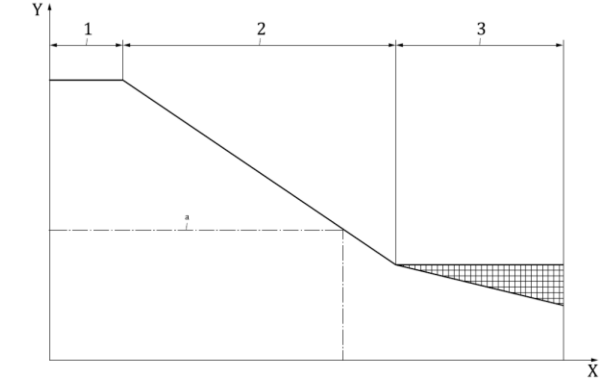
10e3 < NL < 3 * 10e6, limited life, YNT interpolated

NL = 3 * 10e6, end of limited life domain, YNT = 1.0

3 * 10e6 < NL < 10e10, long life domain, YNT = 0.85…1.00

Definition stops at 10e10 cycles

For long life domain, YNT = 1.00 with optimum lubrication, material, manufacturing and experience. For general purpose gearing: values between 0.85…1.00 may be used



Key

X number of load cycles, N_L (log)

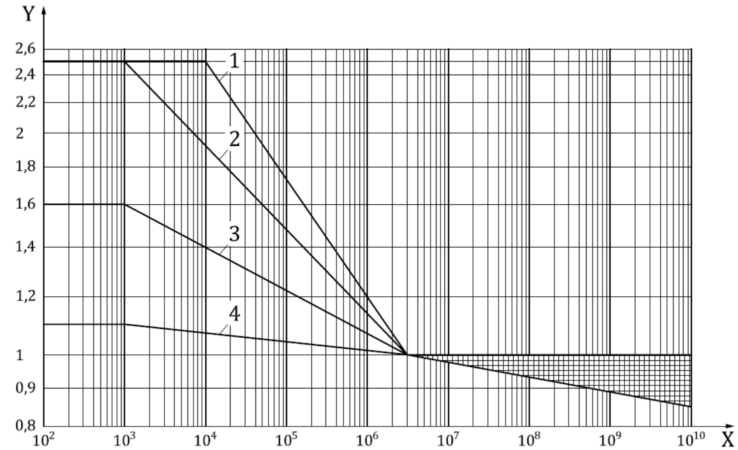
Y permissible bending stress, σ_{FP} (log)

1 static

2 limited life

3 long life

a Example: Permissible bending stress, σ_{FP}, for a given number of load cycles.



Key

X number of load cycles, N_L

Y life factor, Y_{NT}

1 GTS (perl.), St, V, GGG (perl. bai.)

2 Eh, IF (root)

3 NT, NV (nitr.), GGG (ferr.), GG

4 NV (nitrocar.)

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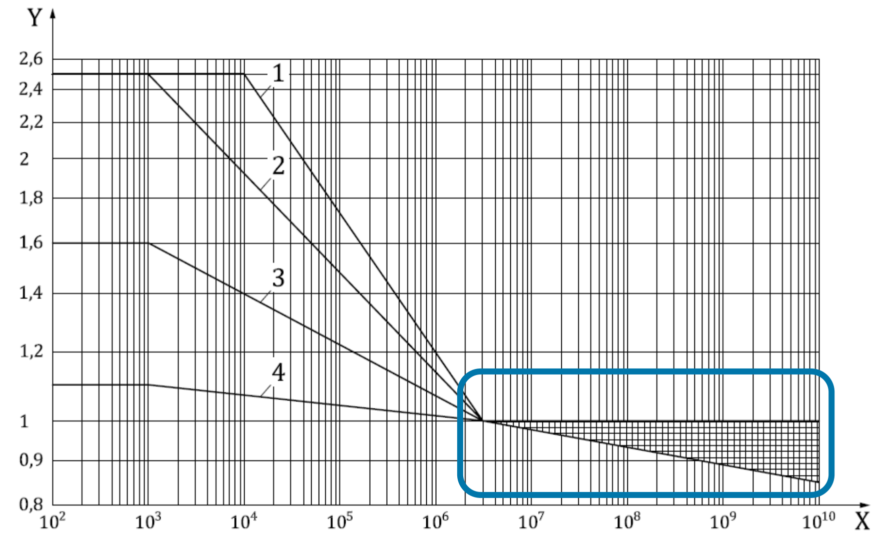
S-N curve is defined through life factor

The life factor accounts for the higher tooth root stress, which may be tolerable for a limited life (number of load cycles), as compared with the allowable stress at 3 × 10e6 cycles

The allowable stress numbers are established for 3 × 10e6 tooth load cycles at R = 99 % reliability



Key

X number of load cycles, N_L

Y life factor, Y_{NT}

1 GTS (perl.), St, V, GGG (perl. bai.)

2 Eh, IF (root)

3 NT, NV (nitr.), GGG (ferr.), GG

4 NV (nitrocar.)

Difference between S-N curve for bearing rating and for gear rating

Gear rating, ISO 6336: R = 99% to start with.

Bearing rating, ISO 281, ISO/TS 16281: R = 90% to start with

Difference

- There is a1 factor to account for R = 95% and other levels → but there is no factor a1 for gear rating! In ISO standard, there is no reliability factor to change the reliability level! But in AGMA standard, there is such a factor, called XR. There is discussion to introduce a reliability level in ISO standard, see below.
- Base value is R = 90% for bearings but R = 99% for gears.
- Gears, ISO 6336: there is always an endurance limit / infinite life domain (horizontal part of S-N curve. But bearings, ISO281, basic rating: NO (!) endurance limit. Only with a23 or aISO factor, we introduce something similar like an endurance limit.

σFlim and σHlim, ISO 6336-5

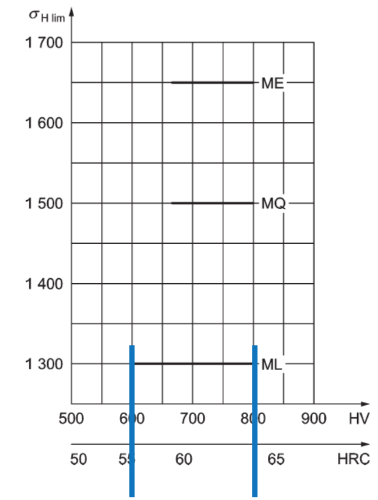
For case hardened wrought steels, the permissible stress level

- Is constant over a hardness range of 600…800 HV or 660…800 HV
- Is a function of material quality grade
- Is only a function of core hardness for root strength for MQ grade (lines a), b), c))

By default, KISSsoft uses MQ material grade to determine σFlim and σHlim

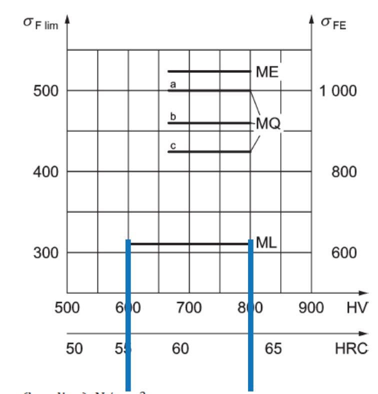
Materials with material grade ML or ME have to be added to the material database by the user.

18CrNiMo7-6, case-hardened, ISO 6336-5 Figure 9/10 (MQ),



Key

$\sigma_{H\,lim}$ allowable stress number (contact), N/mm²
HRC surface hardness
HV surface hardness



Key

$\sigma_{F\,lim}$ nominal stress number (bending), N/mm²
σ_{FE} allowable stress number (bending), N/mm²
HRC surface hardness
HV surface hardness
a Core hardness ≥ 30 HRC.
b Core hardness ≥ 25 HRC Jominy hardenability at J = 12 mm ≥ 28 HRC.
c Core hardness ≥ 25 HRC Jominy hardenability at J = 12 mm < 28 HRC.

Hardness requirements on drawings

Typically, case hardness / surface hardness of case carburized gears is defined as target rang on gear drawings, e.g.

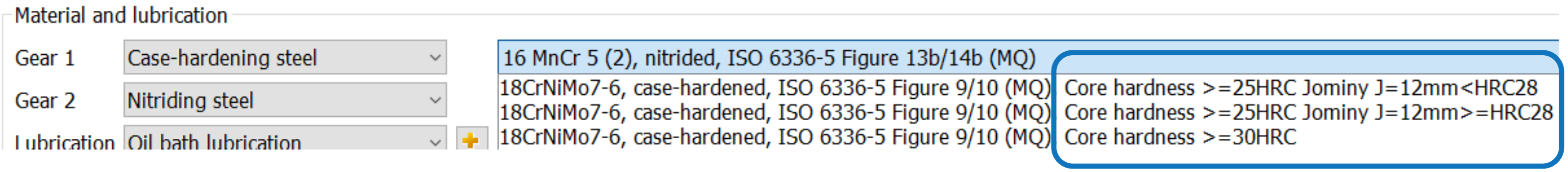
e.g. 58 - 62 HRC for industrial gears

Or 58 - 64 HRC. Here, delta = 6 HRC, is a high tolerance width.

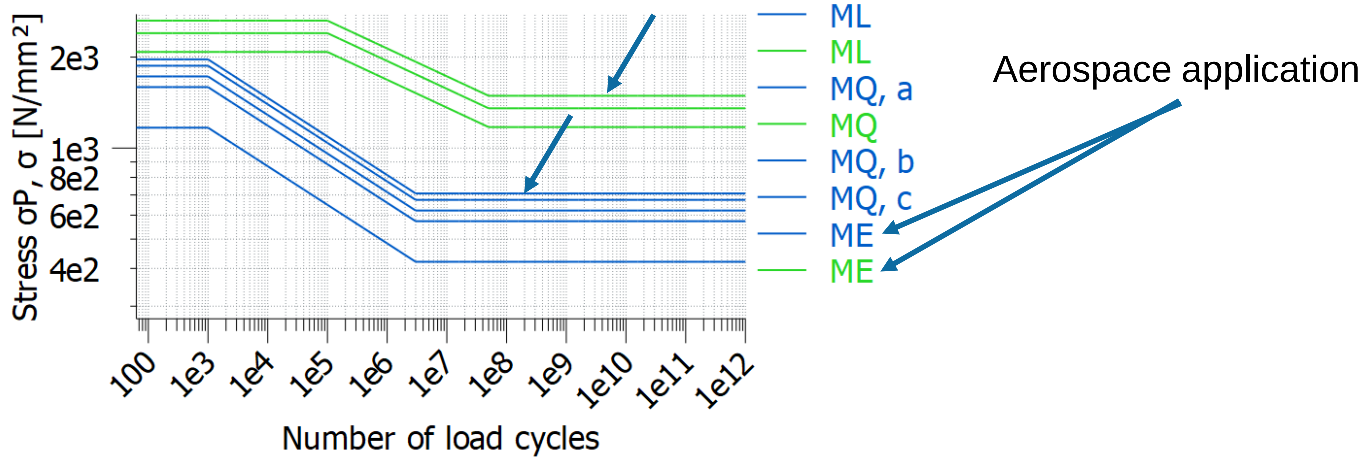
Typical tolerance width are 4 HRC or 3 HRC (for high end gear manufacturing). Also, upper limit is often 63 HRC. I believe it is same for bevel + cylindrical. Also, I see hardness of pinion 1…2 HRC higher than gear.

σFlim and σHlim, ISO 6336-5

S-N curves are by default created for MQ grade. The three different curves a), b) and c) for root S-N curve may be selected from the material data table.



S-N curves for ML and ME grade may also be used. Note that for ML and ME grade, the whole S-N curve (not only the long-life domain) is shifted (in below graphic, ZNT = YNT = 1.00 for long life domain). Green curves = flank, blue curves = root.



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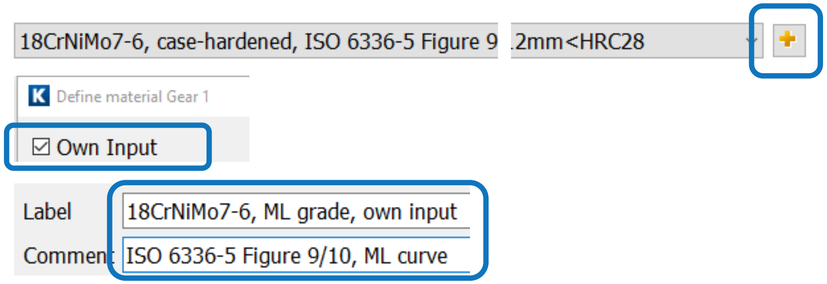
S-N curves

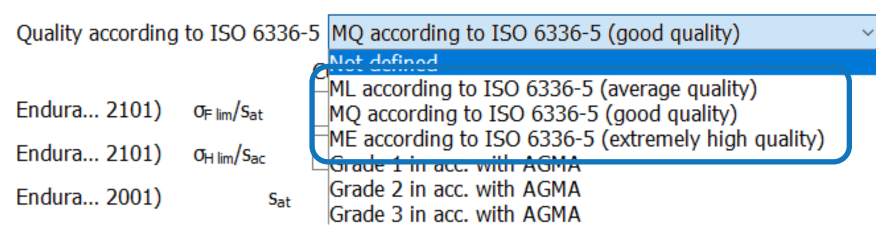
σFlim and σHlim, ISO 6336-5, calculation for other quality grades than MQ

Press “+” button next to material
Activate “Own input” flag

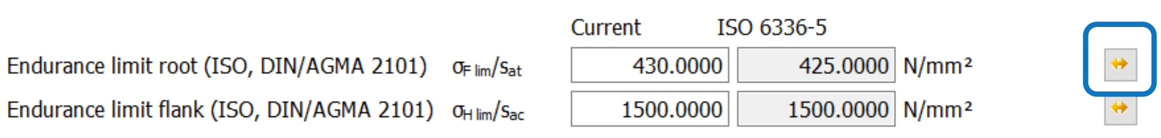


Rename material

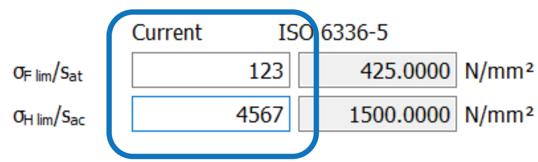
Select material grade from list



Press conversion button
(see next slide)



Or enter values directly



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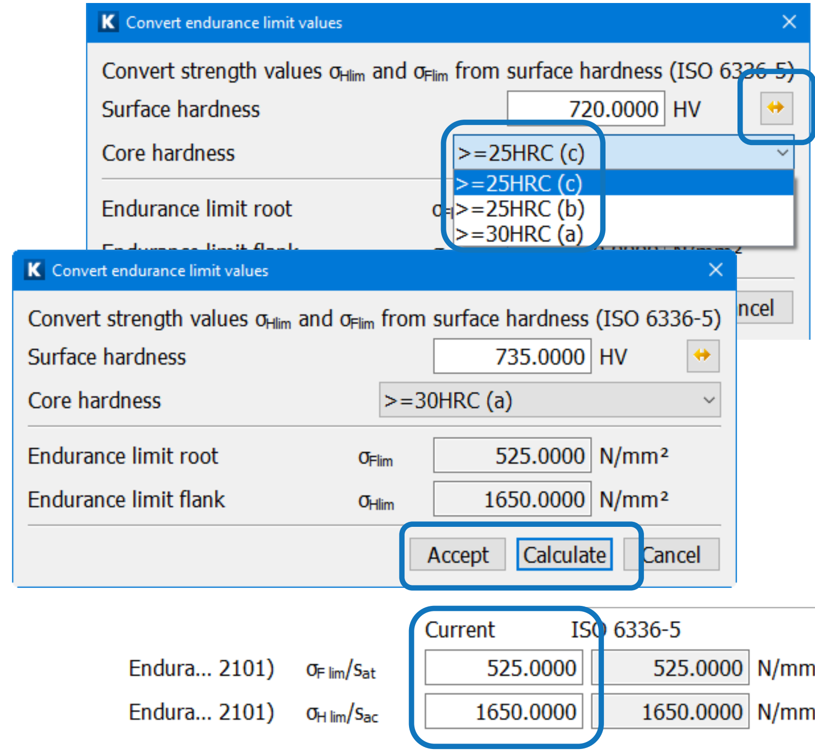
σFlim and σHlim, ISO 6336-5, calculation for other quality grades than MQ



Enter surface hardness in HV or use converstion button to calculate HV value from HRC and other values

Select core hardness / line a), b), c)

Press “Calculate” and “Accept”

Values are then given back to “Current”.

Note that you can overwrite “Current” values manually, reference values are given in column “ISO 6336-5”.

σFlim and σHlim, ISO 6336-5, calculation for other quality grades than MQ

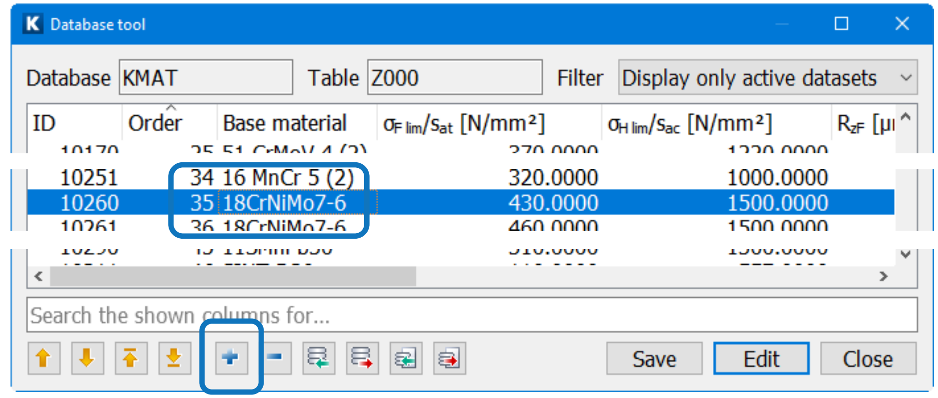
Material can be duplicated in database

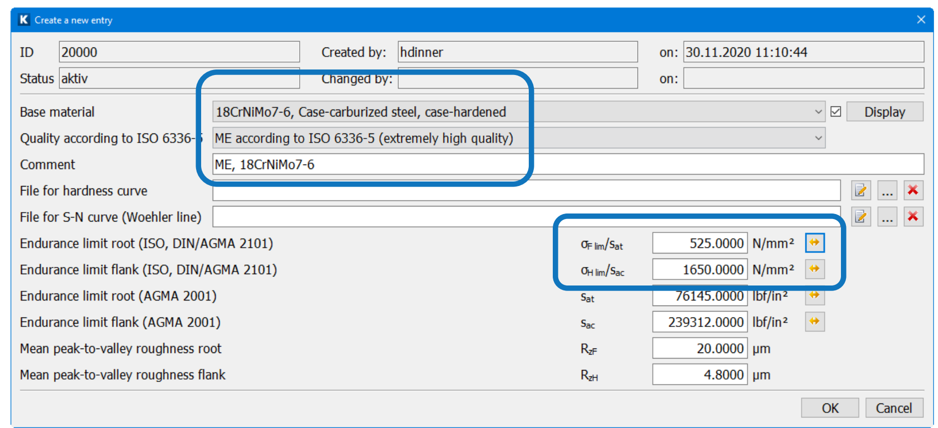
Select an existing material and press “+”

Typically, keep base material (for physical and mechanical properties)

Add comments and enter or

Calculate permissible values. Press “Ok” and “Save” and quite database tool.





Now, the material is available for selection.

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ZNT, YNT, ISO 9085:2002

ZNT and YNT for long life domain are given as function of material quality grade:

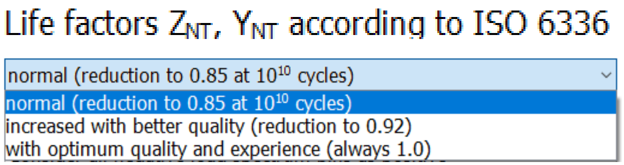
For ML grade, ZNT = YNT = 0.85 for long life domain

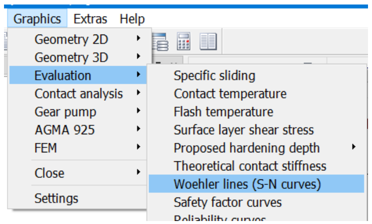
For MQ grade, ZNT = YNT = 0.92 for long life domain

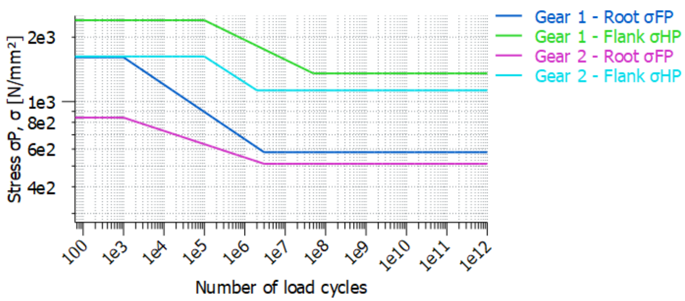
For ME grade, ZNT = YNT = 1.00 for long life domain

KISSsoft usage:

- Select material grade controlling only values for ZNT and YNT (not σFlim or σHlim)
- Graphics “Woehler lines (S-N curves)”
- Direct input of ZNT and YNT for long life not possible







ZNT, YNT, ISO 9085:2002

ZNT and YNT for long life domain are given as function of material quality grade:

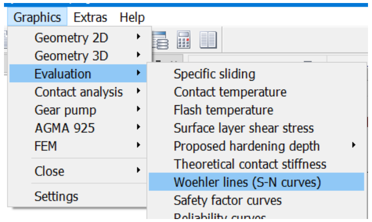
ML grade: ZNT = YNT = 0.85

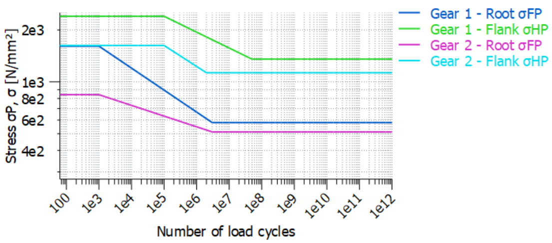
MQ grade: ZNT = YNT = 0.92

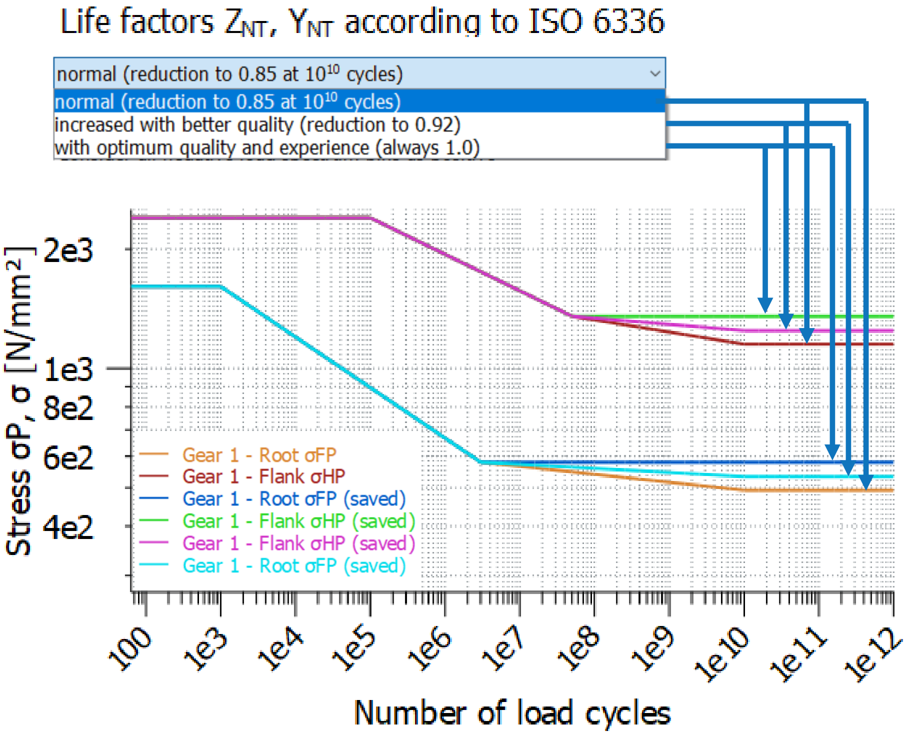
ME grade: ZNT = YNT = 1.00

KISSsoft usage:

- Select material grade controlling only values for ZNT and YNT (not σFlim or σHlim)
- Graphics “Woehler lines (S-N curves)”
- Direct input of ZNT and YNT for long life not possible

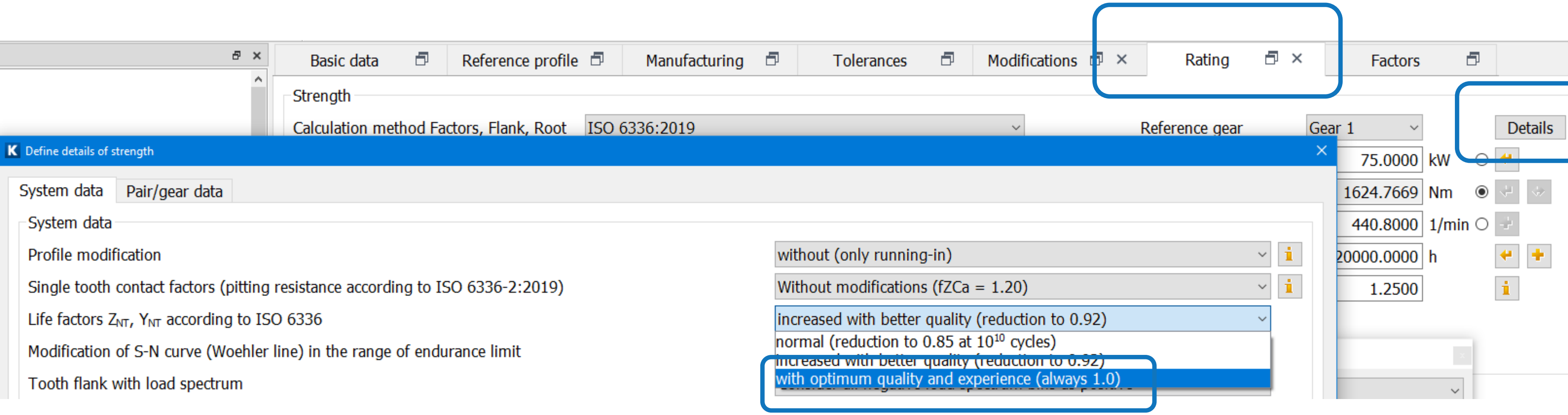






Settings, ALP

In tab “Rating”, button “Details”, select



Modifications

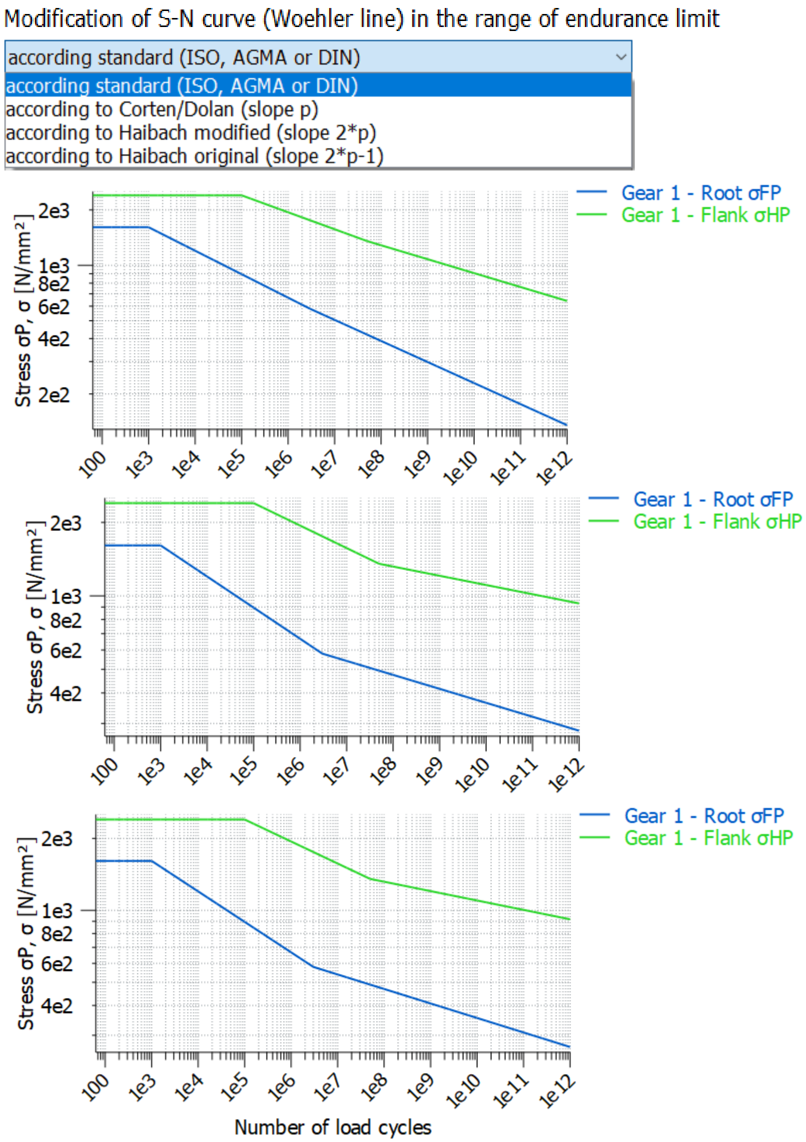
First options are S-N curves as per rating standard, see previous slides → endurance limit / infinite life domain.

“Corten/Dolan”: no long life domain, limited life domain extended → similar to bearing basic rating life

“Haibach modified”: slope exponent p for long life domain: 2 * p.

“Haibach original”: slope exponent p for long life domain: 2 * p – 1.

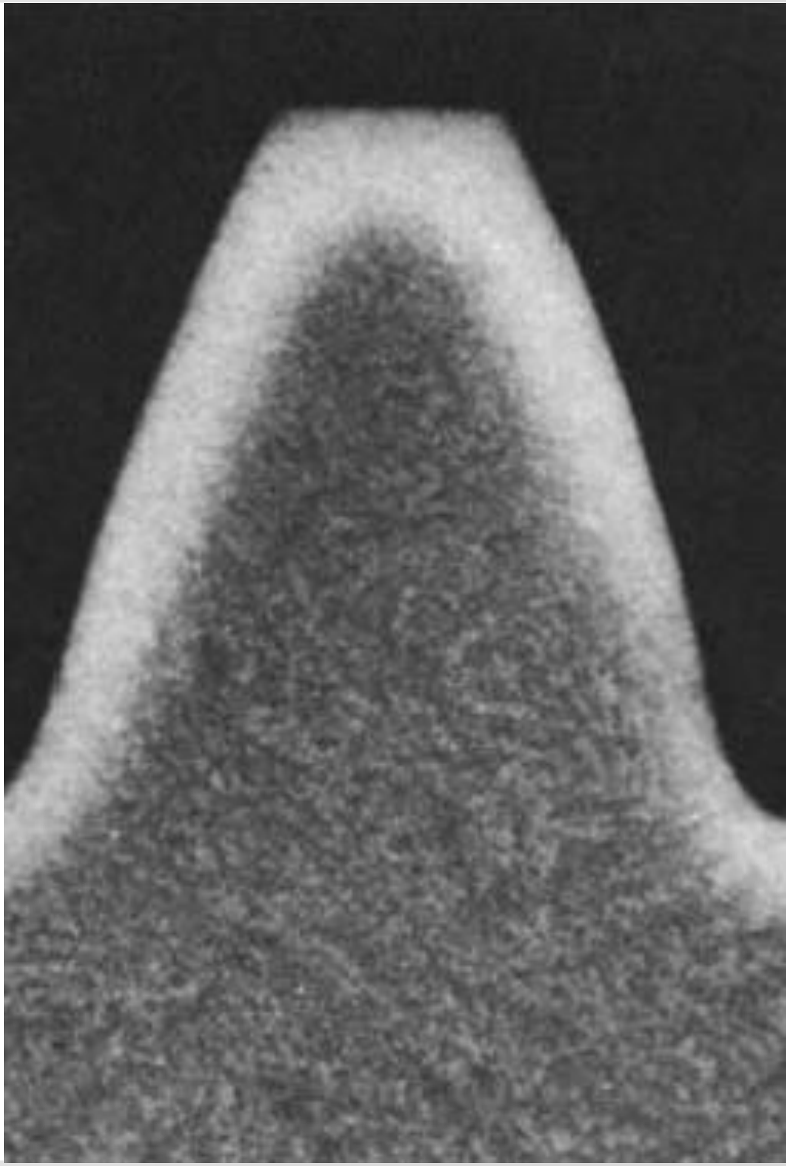
No influence of material quality grade on slope.



KISSsoft

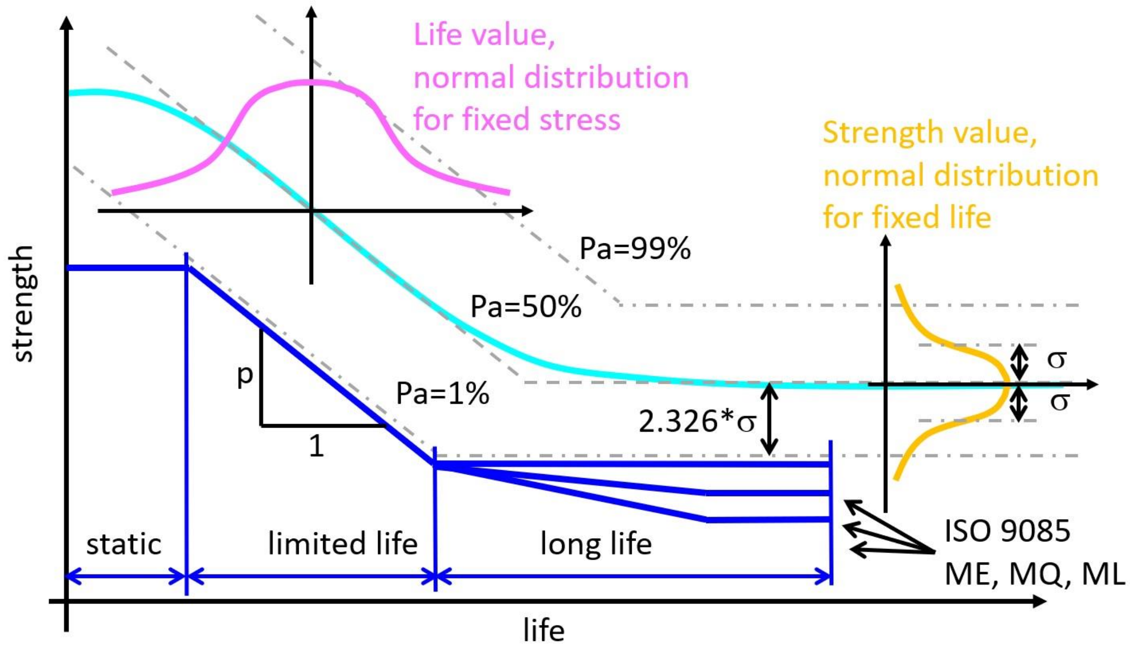
Content

1. S-N curves
2. **Reliability levels**
3. Hardness, hardness depth, material … influence
4. Aerospace gear steels
5. Shot peening
6. Retained Austenite
7. Aspects of KISSsoft usage



Probabilistic approach

S-N curve as per ISO 6336 is based on R = 99% reliability or 1% probability of damage and 0.15 * m_n…0.20 * m_n case depth.



S-N curves are measured for a probability of survival or reliability level of R = 50 %. Correspondingly, the probability of damage is of the same value, R = 50%. They are measured with a scatter in terms of achieved life at a constant stress in the limited life domain (where the curve has a slope p) and a scatter in terms of achieved stress level for long life (where gears in test do not fail anymore), expresses as the standard deviation of the allowable stress number σ. The scatter in terms of achieved life is far greater than the scatter in terms of achieved stress for long life. The below comments are valid for the long-life domain.

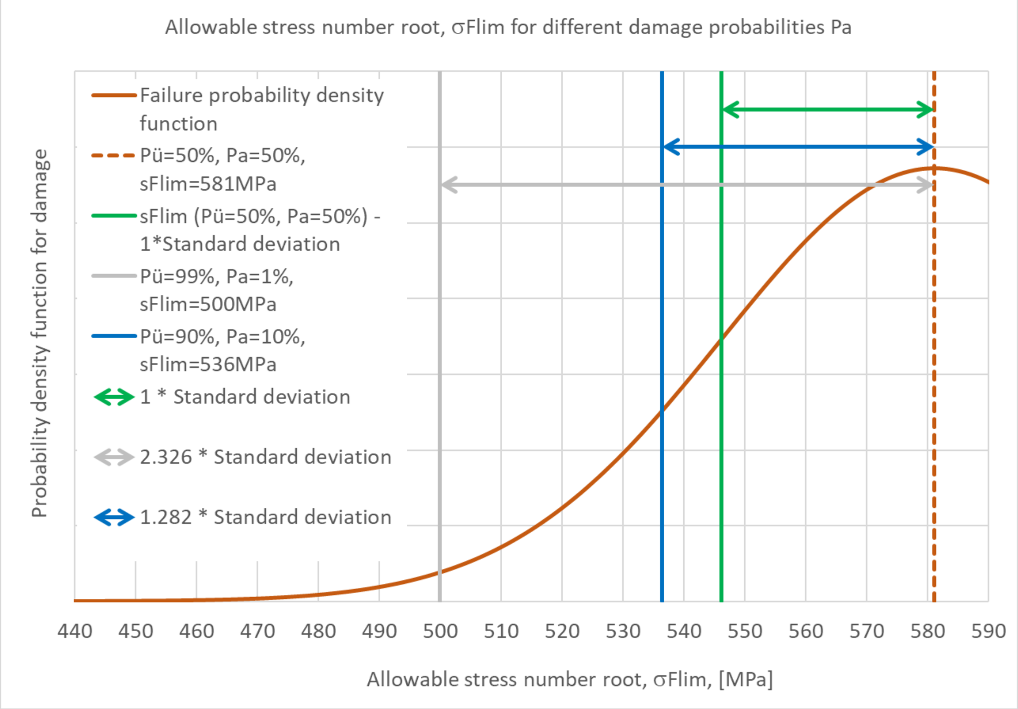
Probabilistic approach

S-N curve as per ISO 6336 is based on 99% reliability or 1% probability of damage and 0.15 * m_n…0.20 * m_n case depth.

For other reliability level than R = 0.99

- ANSI/AGMA 2101: uses reliability factor YZ
- ISO 6336: currently no details given, Hein proposes the introduction of a reliability level factor YZ
- σFlim may be determined from standard deviation of strength measurement data

Requirements of application	Y_Z 1)
Fewer than one failure in 10 000	1.50
Fewer than one failure in 1000	1.25
Fewer than one failure in 100	1.00
Fewer than one failure in 10	0.85 2)
Fewer than one failure in 2	0.70 2) 3)



Probabilistic approach

Conversion of (root) strength from R = 50 % (as measured) to R = 99% (as used in gear rating), factors are based on standard deviation of measured data

For not shot peened gears

σF (R = 99 %) = 0.86 * σF (R = 50 %)

For shot peended gears (slightly higher scattering)

σF (R = 99 %) = 0.92 * σF (R = 50 %)

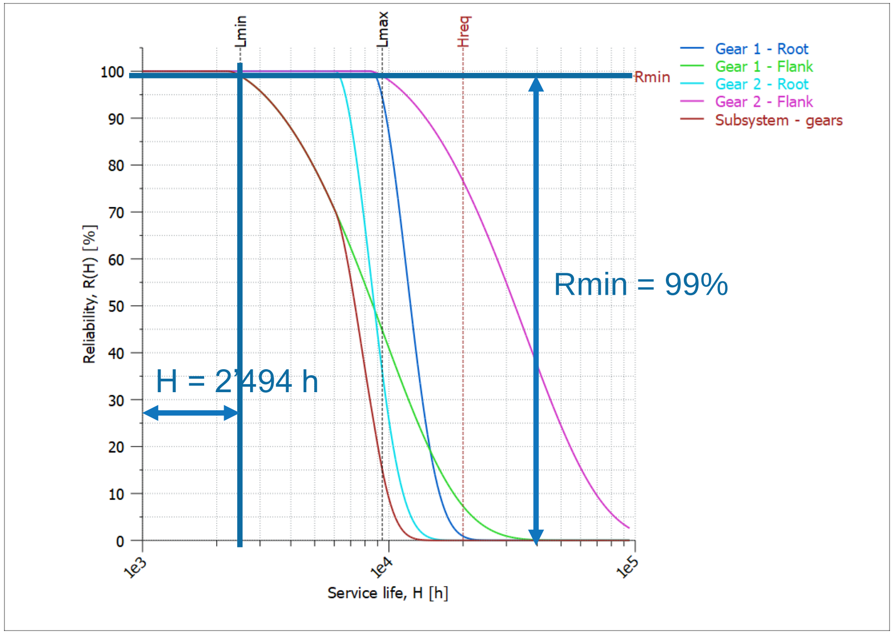
ungestrahlter Zustand: $\sigma_{F\infty 1\%,Lauf} = 0{,}86 \cdot \sigma_{F\infty 50\%,Lauf}$ **(27)**

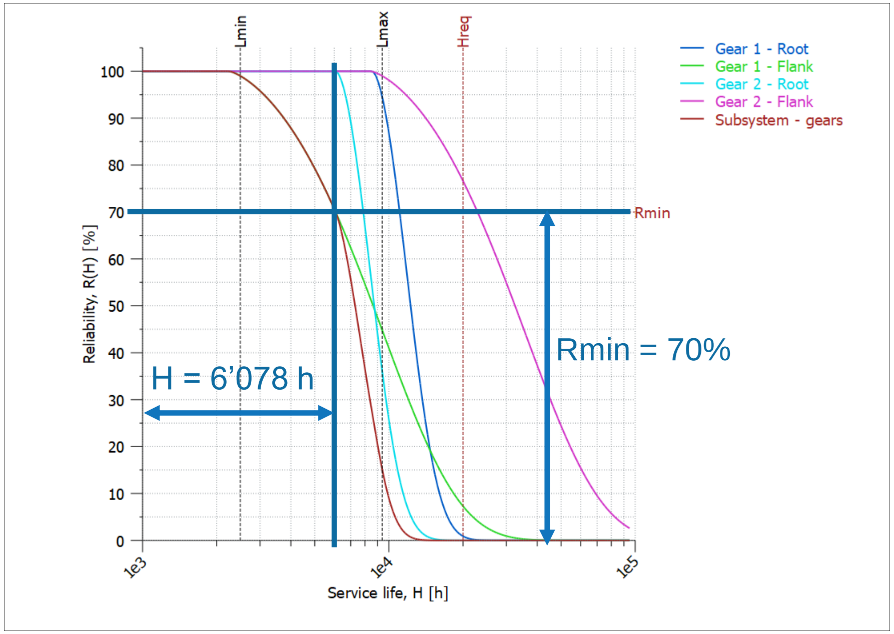
gestrahlter Zustand: $\sigma_{F\infty 1\%,Lauf} = 0{,}92 \cdot \sigma_{F\infty 50\%,Lauf}$ **(28)**

Calculation of component, subsystem and system life for different reliability levels

Required gear system reliability R = 99%
SFmin = 1.40, Shmin = 1.00
Resulting system life H = 2’494 h

Required gear system reliability R = 70%
SFmin = 1.40, Shmin = 1.00
Resulting system life H = 6’078 h

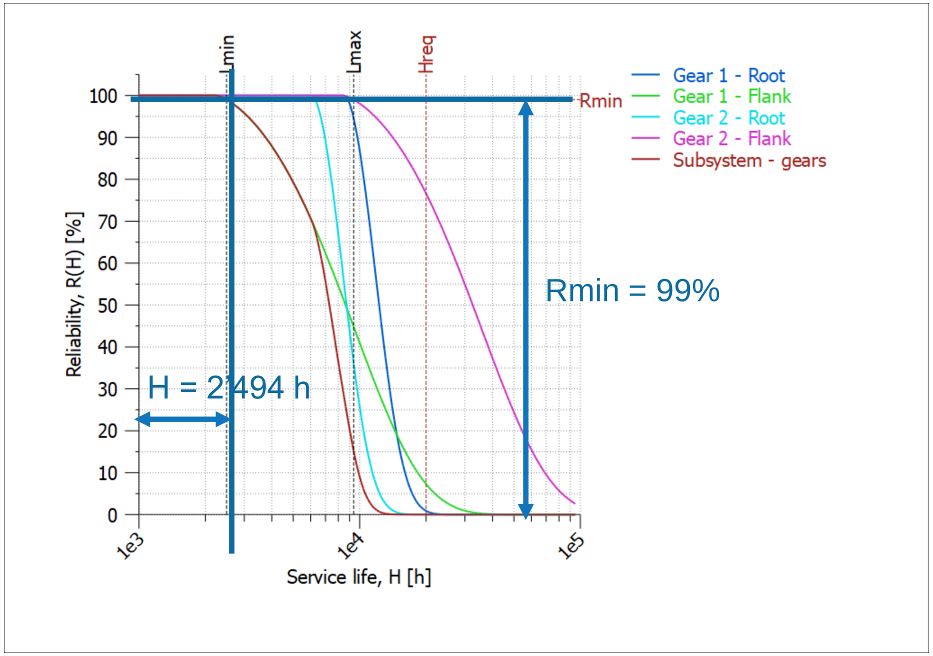


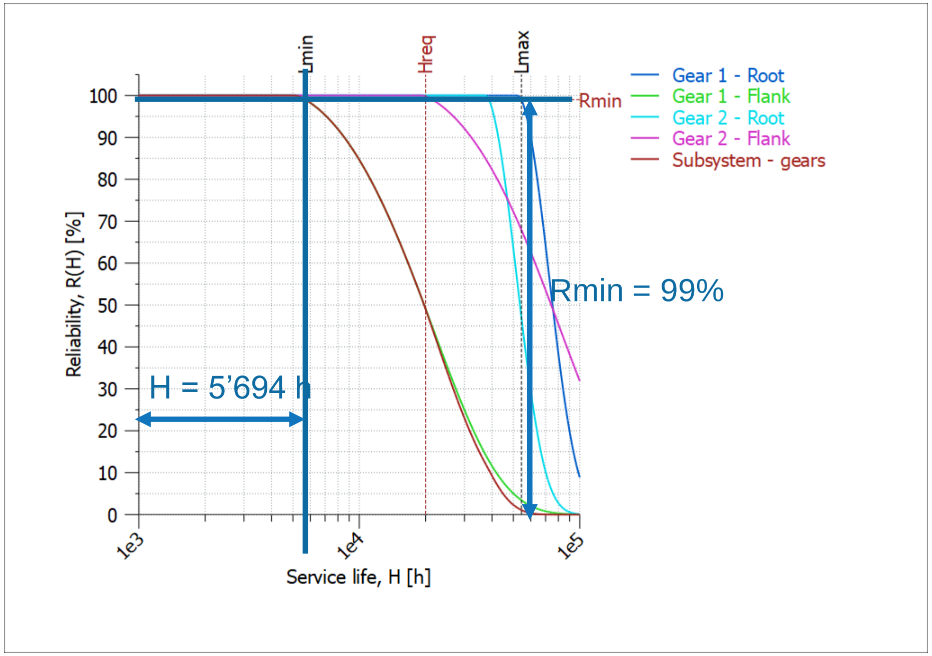


Calculation of component, subsystem and system life for different reliability levels

Required gear system reliability R = 99%
SFmin = 1.40, Shmin = 1.00
Resulting system life H = 2’494 h

Required gear system reliability R = 99%
SFmin = 1.35, Shmin = 0.975
Resulting system life H = 5’694 h





Reliability levels of material and part

Proposed reliability factor YZ, ZZ

Proposal by Geitner / Hein, see M. Hein, Zur ganzheitlichen betriebsfesten Auslegung und Prüfung von Getriebezahnräder, Dissertation, 2018. As a modification for ISO 6336 rating.

Subject to the reservations given in 5.3.2.1 and 5.3.2.2, Equation (5) is to be used for this calculation:

$$\sigma_{FP} = \frac{(\sigma_{F\,lim} \cdot Y_{ST}) \cdot Y_{NT}}{S_{F\,min}} \cdot Y_Z \cdot Y_{\delta relT} \cdot Y_{RrelT} \cdot Y_X = \frac{\sigma_{FG}}{S_{F\,min}} \quad (5)$$

where

(...)

Y_Z is the reliability factor (see Clause 16), which accounts the considered reliability level;

Table 4 – Reliability factor, Y_Z

Material [a]	Y_{NT}	Reliability, R, % 50	90	95	97	99	99.5	99.9	99.95	99.99
Eh, peened [b]	1	1.08	1.04	1.024	1.012	1	0.99	0.974	0.967	0.95
	1.2	1.07	1.03	1.02	1.01	1	0.99	0.98	0.97	0.96
	1.8	1.04	1.02	1.011	1.007	1	0.996	0.99	0.985	0.978
	2.3	1.08	1.04	1.024	1.015	1	0.99	0.974	0.968	0.95
Eh, unpeened [b]	1	1.14	1.06	1.04	1.03	1	0.98	0.95	0.94	0.92
	1.2	1.08	1.03	1.02	1.01	1	0.99	0.98	0.97	0.96
	1.8	1.04	1.02	1.011	1.007	1	0.966	0.99	0.985	0.978
	2.3	1.04	1.02	1.013	1.008	1	0.995	0.99	0.98	0.97
V, unpeened [b]	1	1.11	1.05	1.03	1.02	1	0.99	0.96	0.95	0.93

[a] See ISO 6336-1:2006, Table 2 for an explanation of the abbreviations used.
[b] In the tooth root area.

The permissible contact stress is calculated from

$$\sigma_{HP} = \frac{\sigma_{H\,lim} \cdot Z_{NT}}{S_{H\,min}} \cdot Z_Z \cdot Z_L \cdot Z_v \cdot Z_R \cdot Z_W \cdot Z_x = \frac{\sigma_{HG}}{S_{H\,min}} \quad (6)$$

where

(...)

Z_Z is the reliability factor (see Clause 15), which accounts the considered reliability level;

Table 4 – Reliability factor, Z_Z

Material [a]	Z_{NT}	Reliability, R, % 50	90	95	97	99	99.5	99.9	99.95	99.99
Eh	1	1.09	1.04	1.03	1.02	1	0.99	0.97	0.96	0.95
	> 1	1.11	1.06	1.04	1.03	1	0.98	0.94	0.93	0.89
V	1	1.11	1.05	1.03	1.02	1	0.99	0.96	0.95	0.93
	> 1	1.19	1.10	1.07	1.05	1	0.97	0.91	0.88	0.83
St	1	1.11	1.05	1.03	1.02	1	0.99	0.96	0.95	0.93

[a] See ISO 6336-1:2006, Table 2 for an explanation of the abbreviations used.

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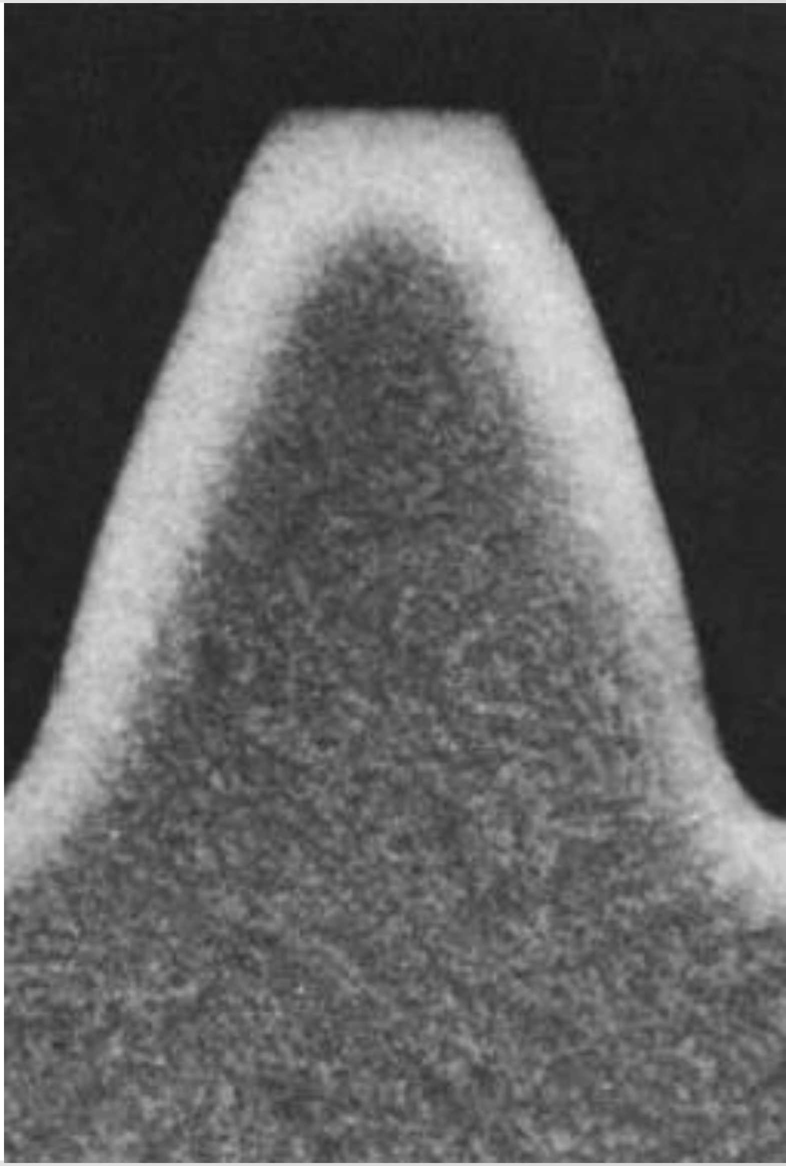
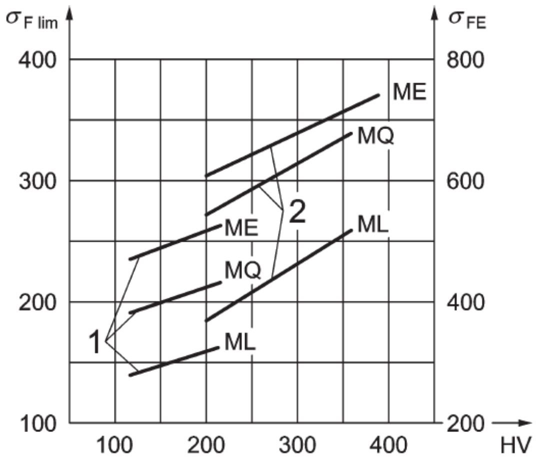


Hardness: of case, influence on strength as per ISO rating

Standards for gear rating: no specific materials but material classes

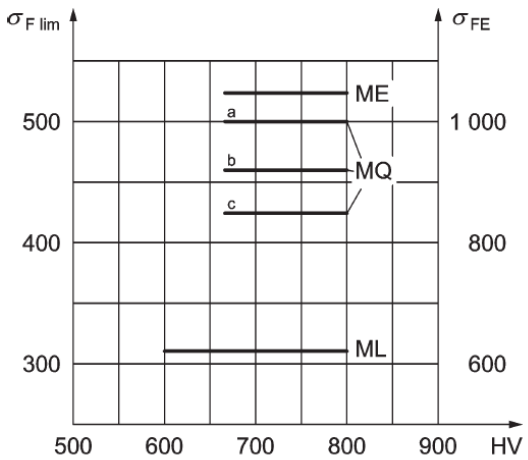
For through hardened wrought steels, fatigue limit of root is a linear function of the hardness

$\Delta\ \sigma$ Flim / ΔHV = constant



For case hardened wrought steels, fatigue limit of root is a constant function of the case hardness. Values shown in ISO 6336-5 are for 0.15 * mn…0.20 * mn case depth.

σ Flim = constant



Hardness: relationship to flank and root strength

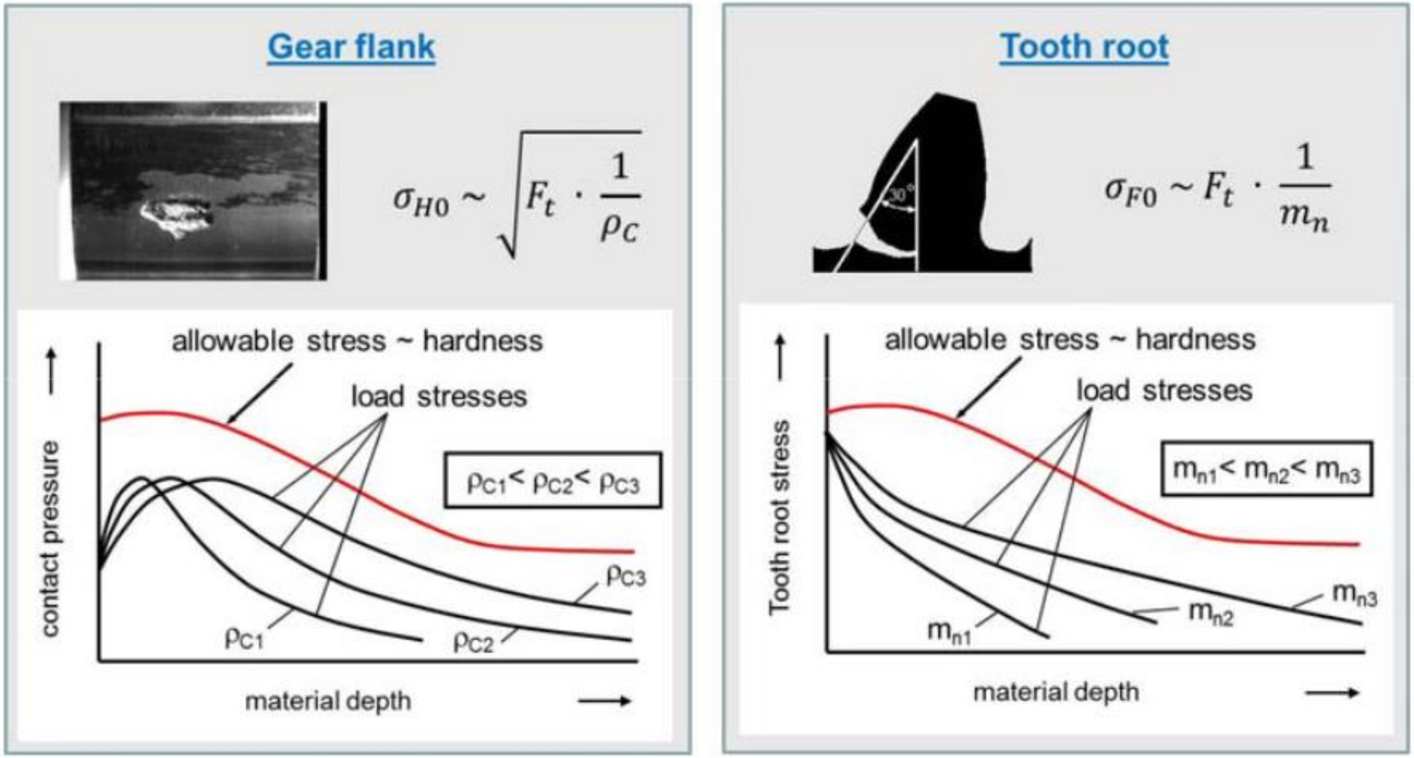


Figure 5. Comparison of gear flank contact pressure (left) and tooth root stress (right) vs. the allowable stress over material depth depending on the gear size represented by the curvature ρ_C and module m_n for a given tangential driving force F_t [7].

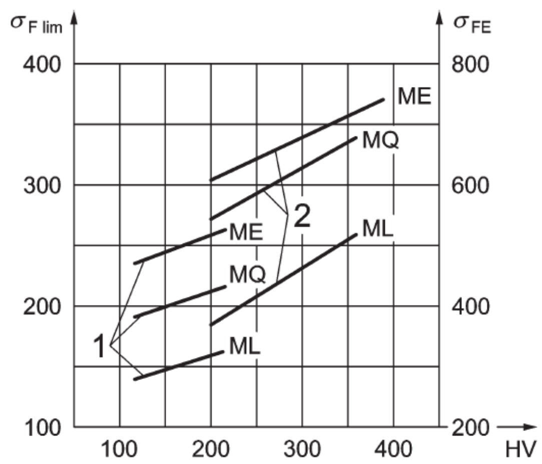
Tobie, T.; Höhn, B.-R.; Stahl, K. Tooth flank breakage—Influences on subsurface initiated fatigue failuresof case hardened gears. In Proceedings of the ASME 2013 International Design Engineering TechnicalConferences and Computers and Information in Engineering Conference, IDETC/CIE 2013, DETC2013-12183,Portland, OR, USA, 4–7 August 2013

Hardness: of case, influence on strength as per ISO rating

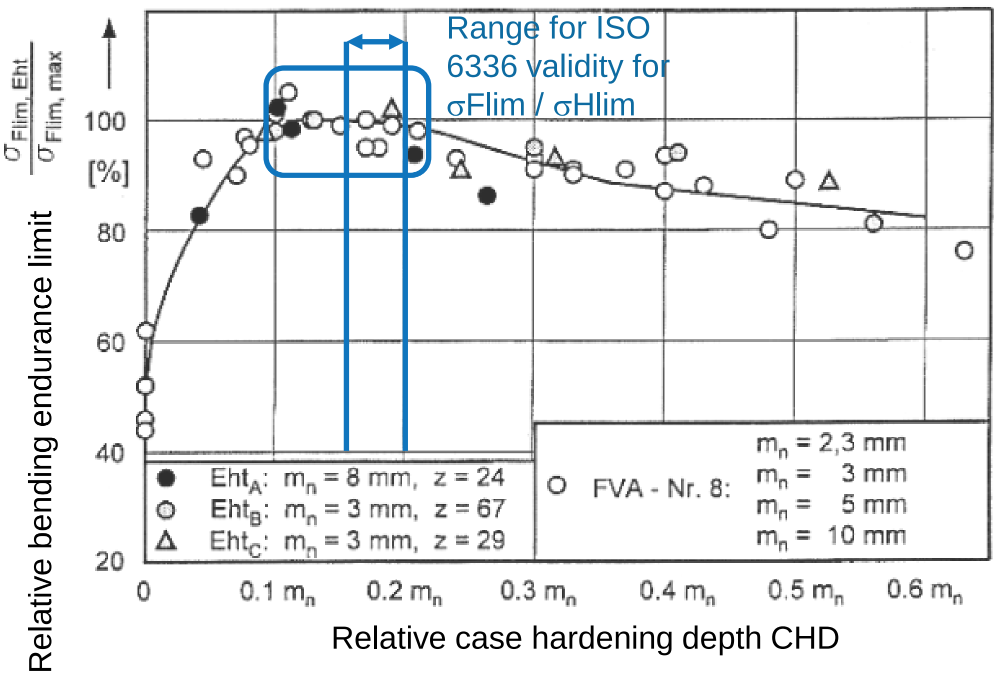
Standards for gear rating: no specific materials but material classes

For through hardened wrought steels, fatigue limit of root is a linear function of the hardness

$\Delta\ \sigma$ Flim / ΔHV = constant



Fatigue limit, root, normalized to maximum value vs. relative case hardness depth, CHD ~ mn, T. Tobie, Zur Grübchen- und Zahnfusstragfähigkeit einsatzgehärteter Zahräder, Dissertation, TU München, 2001



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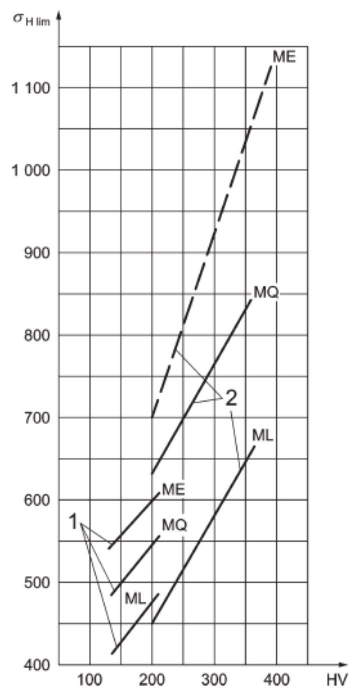
Hardness: of case, influence on strength as per ISO rating

Standards for gear rating: no specific materials but material classes

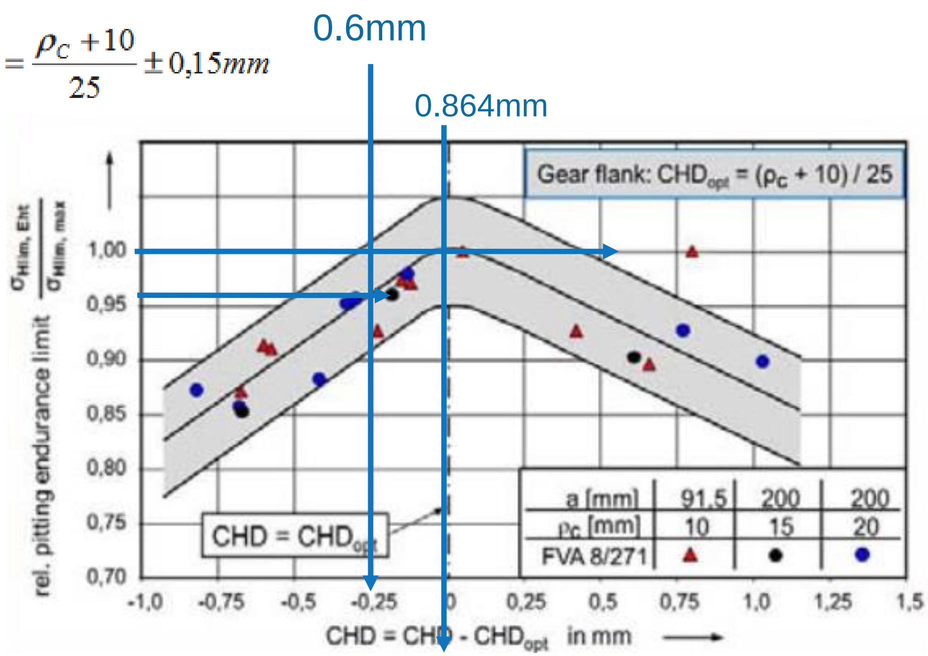
For through hardened wrought steels, fatigue limit of flank is a linear function of the hardness

$\Delta\ \sigma$ Hlim / ΔHV = constant



Fatigue limit, flank, normalized to maximum value vs. relative case hardness depth, CHDopt = (ρc + 10) / 25, T. Tobie, Zur Grübchen- und Zahnfusstragfähigkeit einsatzgehärteter Zahräder, Dissertation, TU München, 2001

$$X_{Grenz} = \frac{\rho_C + 10}{25} \pm 0{,}15mm$$



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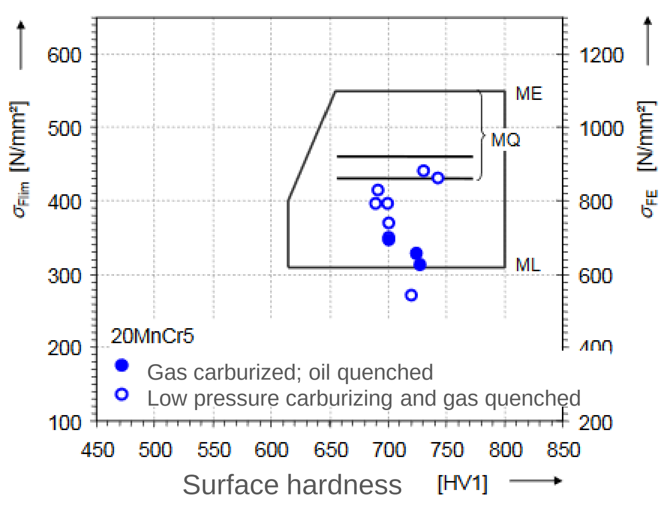
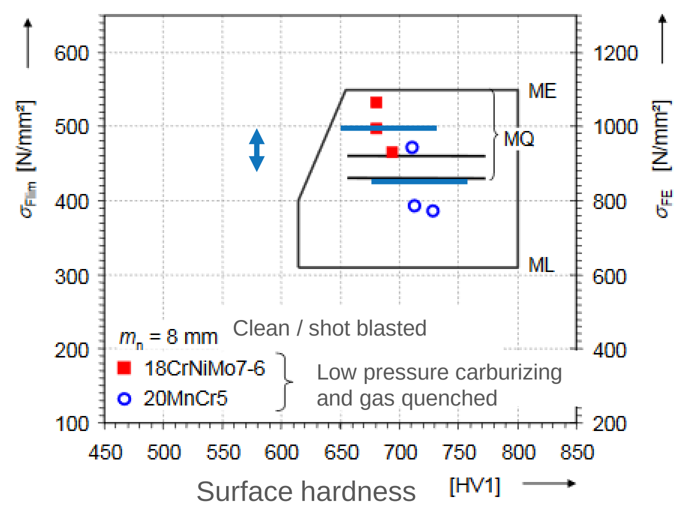
Hardness: of case, influence on strength

Material and heat treatment however have an influence

Root strength, same material (20MnCr5), two heat treatments (two types of case carburizing processes)



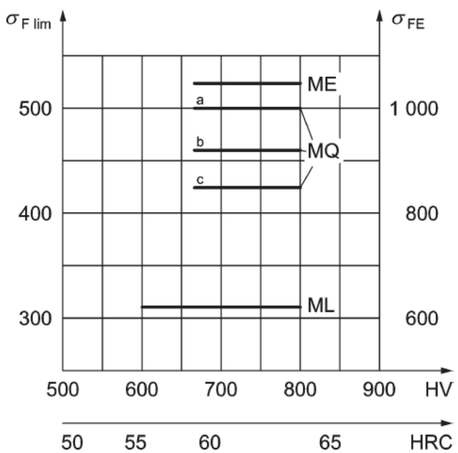
Root strength, same heat treatment (low pressure carburizing and gas quenching), two materials (18CrNiMo7-6 vs. 20MnCr5). Difference is about half as much as the change from MQ to ME level.

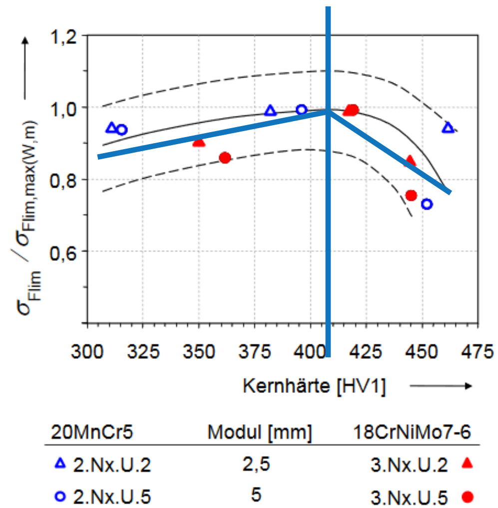


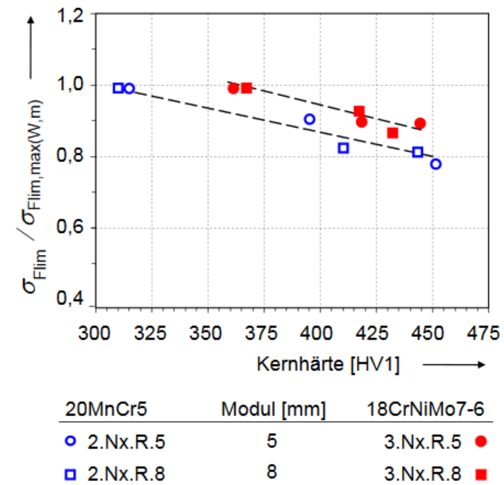
Stenico, Werkstoffmechanische Untersuchungen zur Zahnfußtragfähigkeit einsatzgehärteter Zahnräder, Dissertation, TUM, 2007

KISSsoft

Core hardness







- Left: Core hardness ≥ 30 HRC (300 HV) gives highest root strength
- Middle: Core hardness ~ 400 HV gives highest root strength, not cleaned gear
- Right: Core hardness > 30 HRC (300 HV), shot / clean blasted gear, root strength drops

Stenico, Werkstoffmechanische Untersuchungen zur Zahnfußtragfähigkeit einsatzgehärteter Zahnräder, Dissertation, TUM, 2007

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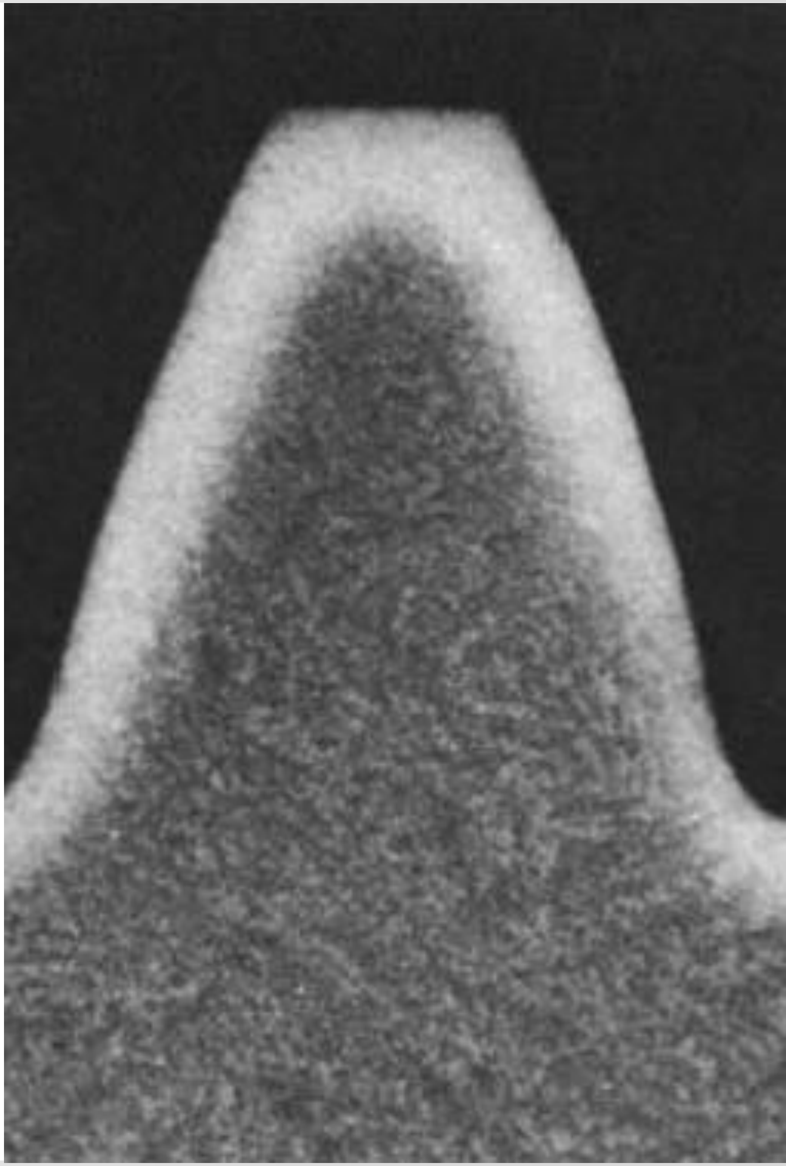


AISI 9310

External gears: case hardened by carburization.

Internal gears: through hardening or case hardening by nitriding or carburization. Material quality ISO 6336-5, ME. Single vacuum melted (SVM) or double vacuum melted (DVM) or consumable electrode melted (CVM).

Commonly used material: case carburized VAR or VIM-VAR AISI 9310

Material	AMS specification (http://www.asminternational.org/)	Typical surface hardness in HRC	Typical core hardness in HRC	Typical applications
AISI 9310	6265/6260	58…64	32…42	RGB, AGB, actuators
VASCO X2M	None	60…64	36…44	RGB, high temperature
CarTech ® Pyrowear® 53 Alloy	6308	59…64	36…44	RGB, high temperature
CarTech® Pryowear® 675 Stainless				
CarTech® Ferrium® C61TM Alloy				
CarTech® Ferrium® C64® Alloy	6509			
CBS600	6255	58…62	34…42	High temperature
	AISI 8620			
Nitralloy N		Nitrided		
Super Nitralloy		Nitrided		
M-50NiL				

KISSsoft

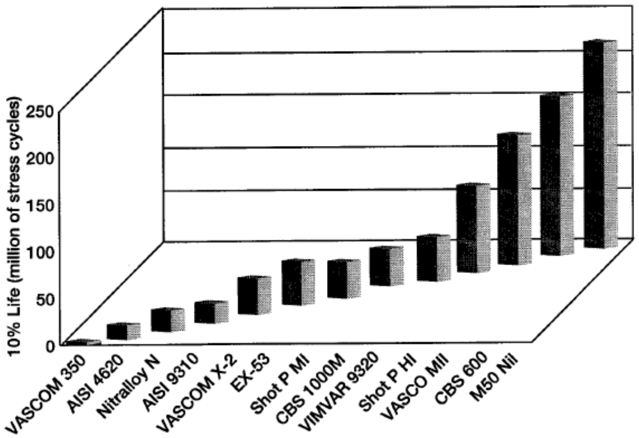
Gear materials, some aspects

AISI 9310

AISI 9310 alloy steel is a low alloy steel containing molybdenum, nickel and chromium. It is a carburizing steel which has high hardenability, high core hardness together with high fatigue strength. The premium quality of alloy 9310 make it ideally suited for critical aircraft engine gears.

NASA Technical Memorandum 102529, Bearing and Gear Steels for Aerospace Applications

Steel	Relative life increase, pitting
VAR AISI 9310	1.0
VAR AISI 9310, shot peened	1.6
VIM-VAR AISI 9310	2.5
VAR Carpenter EX-53	2.1
CVM CBS 600	1.4
CVM CBS 1000	2.1
CVM VASCO X-2	2.0
CVM Super Nitralloy (5Ni-2A1)	1.3
VIM-VAR AISI M-50 (forged)	3.2
VIM-VAR AISI M-50 (ausforged)	2.4
VIM-VAR M-50 NiL	11.5



KISSsoft

Gear materials, some aspects

Vasco X-2 is a high-temperature gear material. This material has an operating temperature limit of 315 ° C and has been shown to have good gear 1oad-carrylng capacity when properly heat treated. The material has a high chromium content (4.9 percent) that oxidizes on the surface and can cause soft spots when the material is carburized and hardened. A special process has been developed that eliminates these soft spots when the process is closely followed (Ref. 29). Several groups of Vasco X-2 with different heat treatments were surface fatigue tested in the NASA gear test facility. All groups except the group with the special processing gave poor results (Ref. 30). Vasco X-2 has a lower fracture toughness than AISI 9310 and is subject to tooth fracture after a fatigue spall. Further, there is a suggestion that this material as well as some of the other higher alloy carburized steels may be susceptible to stress corrosion under certain environmental conditions. As a result, where the material Is subject to a corrosive environment, stress corrosion testing should be performed before committing these types of materials to application.

CarTech ® Pyrowear® 53 Alloy, AMS 6308: A premium quality alloy carburizing gear steel that has resisted softening at elevated service temperatures. It is double vacuum processed by vacuum induction melting followed by vacuum arc remelting to provide optimum metallurgical quality. Based on its combination of high-temperature performance, deep hardenability, and excellent toughness and fatigue resistance, this alloy finds application in demanding helicopter and aerospace drivetrain components.

CarTech® Pryowear® 675 Stainless: A carburizing, corrosion resistant steel that provides a case hardness in excess of HRC 60 combined with a tough, ductile core. The corrosion resistance of carburized Pyrowear 675 stainless is similar to that of Type 440C stainless while core toughness is similar to AISI 9310. Provides excellent hot hardness capability.

CarTech® Ferrium® C61TM Alloy: A premium quality carburizing steel that offers high core strength, high fatigue strength, high temperature resistance and high hardenability. The alloy has achieved carburized case hardness of 60-62 HRC but provides ultra-high core properties for demanding shaft and gear applications. The high tempering temperature (900° F) offers a 400-600° F increase in thermal stability relative to conventional gear steels. It is well suited to low-pressure carburization at high temperature to reduce manufacturing time and expense while providing reliable carburization profiles. The material does not require a separate hardening/quenching process

CarTech® Ferrium® C64® Alloy: A premium quality carburizing steel that offers high core strength, high fatigue strength, high temperature resistance and high hardenability. It is processed by vacuum induction melting followed by vacuum arc remelting. It can achieve carburized case hardness of 62-64 HRC (exceeding that of conventional gear steels such as 8620, 9310, etc.) and also provides ultra-high core properties for demanding shaft and gear applications. The high tempering temperature (925° F) offers a 400-600° F increase in thermal stability relative to conventional gear steels. The alloy benefits from low-pressure carburization at high temperature in order to reduce manufacturing time and expense while providing reliable carburization profiles. It is direct gas quenched using moderate pressures which reduces the amount of distortion and eliminates the need for a separate hardening/quenching process. Typical applications include power transmission shafts, gears and other demanding applications in aerospace, energy, and racing/off-road/mission-critical vehicles and other industries where weight savings, compactness, high temperature resistance and high surface fatigue resistance are valued. Specifications: AMS 6509

Gear materials, some aspects

CBS 600 material is a low- to medium-alloy steel that can be carburlzed and hardened to glve a hard case of Rockwell HRC 60 with a core of Rockwell HRC 38. The CBS 600 has a medium fracture toughness that can cause fracture failures after a surface fatigue spall has occurred.

Nitralloy N is a 1ow-alloy nitriding steel that has been used for several years as a gear material. It can be used for applications requiring temperatures of 204 to 232 ° C. A modified Nitralloy N called Super Nitralloy or 5NI-2AI Nitralloy was used In the U.S. supersonic aircraft program for gears. It can be used for gear applications requiring temperatures to 260 ° C.

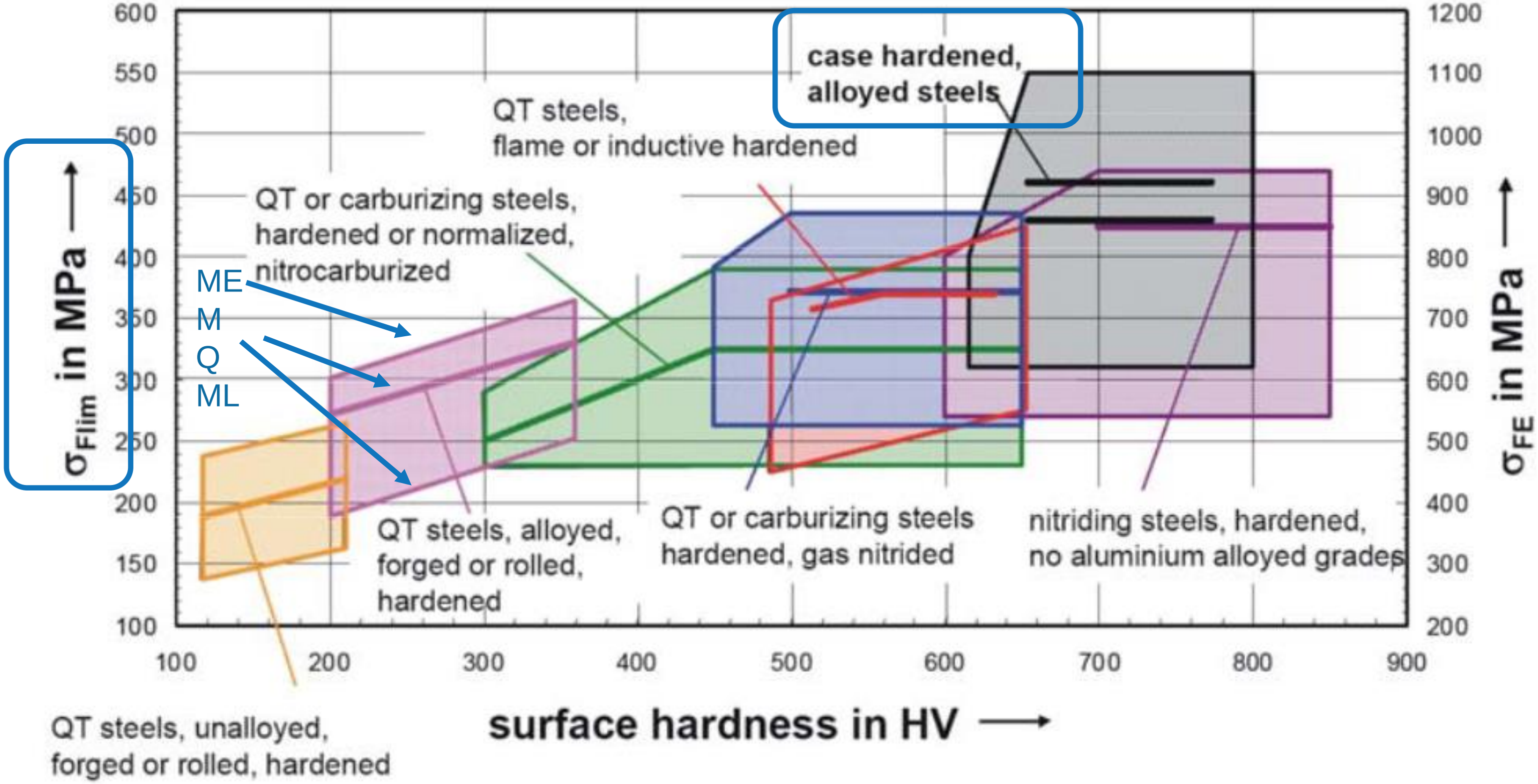
M50-NiL: This material exhibits all the benefits of AISI 9310 and, In addition, the VIM-VAR M-5ONiL has over II times the pitting fatigue life of VAR AISI 9310 and over 4 times that of VIM-VAR AISI 9310. The VIM-VAR M-5ONiL was also shown to have good reslstance to fracture through a fatigue spall in a gear tooth

Major carburizing steels for medium to large size gears (below table is not specifically for aerospace industry)

Steel Grade	Standard		Alloy Addition in wt %								Region
			C	Si	Mn	P	S	Cr	Mo	Ni	
20MnCr5	EN 10084 (1.7147)	min.	0.17	-	1.10	-	-	1.00	-	-	Western Europe
		max.	0.22	0.40	1.40	0.035	0.035	1.30			
18CrNiMo7-6	EN 10084 (1.6587)	min.	0.15	-	0.50	-	-	1.50	0.25	1.40	
		max.	0.21	0.40	0.90	0.025	0.035	1.80	0.35	1.70	
15CrNi6	EN 10084 (1.5919)	min.	0.14	-	0.40	-	-	1.40	-	1.40	France, Germany
		max.	0.19	0.40	0.60	0.035	0.035	1.70		1.70	
17NiCrMo6-5	EN 10084 (1.6566)	min.	0.14	-	0.60	-	-	0.80	0.15	1.20	Italy, France
		max.	0.20	0.40	0.90	0.025	0.035	1.10	0.25	1.50	
SAE 8620	SAE J1249	min.	0.18	0.15	0.70	-	-	0.40	0.15	0.40	North America
		max.	0.23	0.35	0.90	0.030	0.040	0.60	0.25	0.70	
SAE 9310	SAE J1249	min.	0.08	0.15	0.45	-	-	1.00	0.08	3.00	
		max.	0.13	0.35	0.65	0.025	0.040	1.40	0.15	3.50	
20CrMnTi	GB T 3077-1999	min.	0.17	0.17	0.80	-	-	1.00	0.00	-	China
		max.	0.23	0.37	1.10	0.035	0.035	1.30	0.15	0.30	
20CrMnMo	GB T 3077-1999	min.	0.17	0.17	0.90	-	-	1.10	0.20	-	
		max.	0.23	0.37	1.20	0.025	0.035	1.40	0.30	0.30	
SCM420	JIS	min.	0.18	0.15	0.60	-	-	0.90	0.15	-	Japan
		max.	0.23	0.35	0.85	0.030	0.030	1.20	0.30		

T. Tobie et al., Optimizing Gear Performance by Alloy Modification of Carburizing Steels, Metals 2017

Tooth root load carrying capacity, allowable bending stress numbers, ISO 6336-5, for ML, MQ, ME level. Note that with nitriding you can reach higher hardness but not higher strength compared to case carburizing, but nitriding gears are resistant in higher temperature.



T. Tobie et al., Optimizing Gear Performance by Alloy Modification of Carburizing Steels, Metals 2017

AGMA 926, pertaining mainly to AISI 9310

Aerospace Grades

1: aircraft quality, using AGMA 2000 series grade 1 material data, typically air melted. Conforming to ANSI/SAE AMS 2301 quality level. (consider as MQ grade)

2: premium aircraft quality, using AGMA 2000 series grade 2 material data, typically single vacuum melted (SVM). Conforming to ANSI/SAE AMS 2300 quality level. (not clear whether this is corresponding to ME grade)

3: ultra-premium aircraft quality, using AGMA 2000 series grade 3 material data, typically double vacuum melted (DVM). Conforming to ANSI/SAE AMS 2300 quality level (should be ME grade or higher).

Higher material requirements than in AGMA 2000 apply

Table 1 - Typical aerospace carburizing steels

Material	AMS spec	Typical hardness[1]		Typical applications
		Surface, HRC[2]	Core, HRC	
AISI 9310	6265/6260	58-64	32-42	Main drive, accessory, actuators
33V	6427/6411	58-62	42-48	Actuators
VASCO X2M[3]	(None)	60-64	36-44	Main drive, high temperature[4]
HP 9-4-30	6526	58-60	48-52	Actuators
PYROWEAR 53[3]	6308	59-64	36-44	Main drive, high temperature[4]
CBS600	6255	58-62	34-42	High temperature[4]

NOTES:

1) Drawing specified hardness limits are based on performance considerations and are normally narrower than the full range shown in this table.

2) Rockwell hardness scale (HRC) is shown for direct comparison only. In general, that scale is not specifically recommended for measurement where other, more appropriate hardness scales are commonly used.

3) Proprietary material designation.

4) High temperature property - capable of operating somewhat below the tempering temperature for indefinite periods.

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AGMA 911, Design Guidelines for Aerospace Gearing

Table 15 – Typical aerospace gear materials

Material	AMS Spec	Heat treatment*	Typical hardness Case, HRC**	Typical hardness Core, HRC	Typical applications
Alloy steel:					
AISI 9310	6265/6260	C–H	58–62	34–42	Main drive, Accessory, actuators
4330M	6427	C–H	58–62	42–48	Actuators
VASCO X2M***	N/A	C–H	58–62	38–44	Main drive, High temperature
HP 9–4–30	6526	C–H	58–60	48–52	Actuators
PYROWEAR 53***	6308	C–H	59–64	36–42	Main drive, High temperature
M50NiL	6278	C–H	58–62	35–45	High temperature
CBS600	6255	C–H	58–62	34–42	High temperature
Nitralloy 135M	6471	TH–N	60–64	34–42	Accessory drive
Nitralloy N	6475	TH–N	60–64	38–44	Accessory drive
AISI 4340	6414	TH–N	48–53	27–35	Accessory drive
AISI 4340	6414	TH	–	34–48	Accessory drive
300M	6419	TH	–	52–55	Actuators
Stainless steel:					
PH13–8 MO	5629	PH	–	34–45	Accessory drive
Custom 455	5617	ST	–	44–48	Actuators
Bronze:					
C63000	4640	ST	–	(100HRB)	Worm gear Actuators

NOTES –

* C–H = Carburize and harden
TH–N = Through harden and nitride
TH = Through harden
PH = Precipitation harden
ST = Solution heat treat

** Rockwell hardness scales (HRC and HRB) are shown for direct comparison only. In general, those scales are not specifically recommended for measurement where other, more accurate hardness scales are commonly used.

*** Proprietary material designation.

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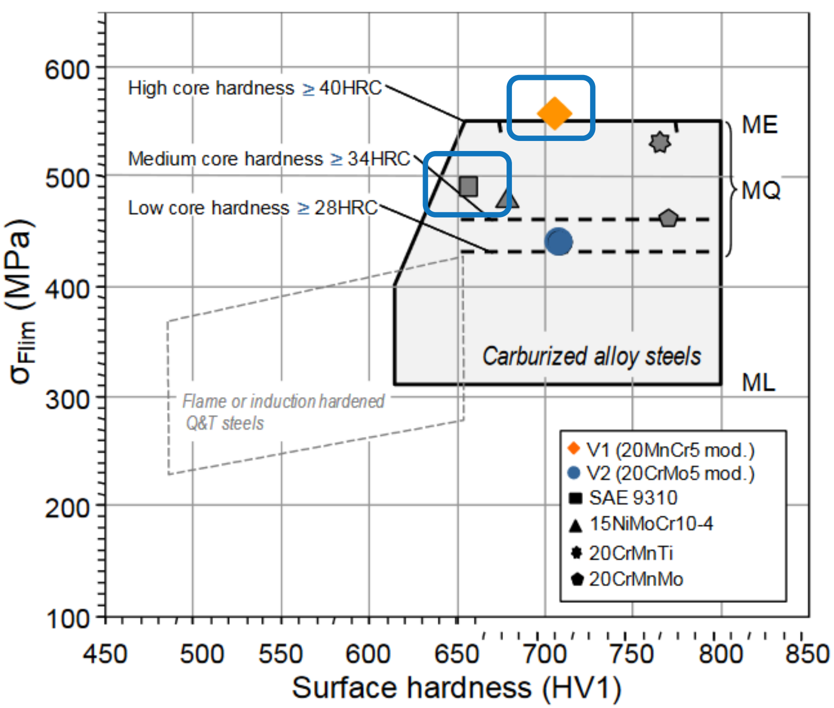
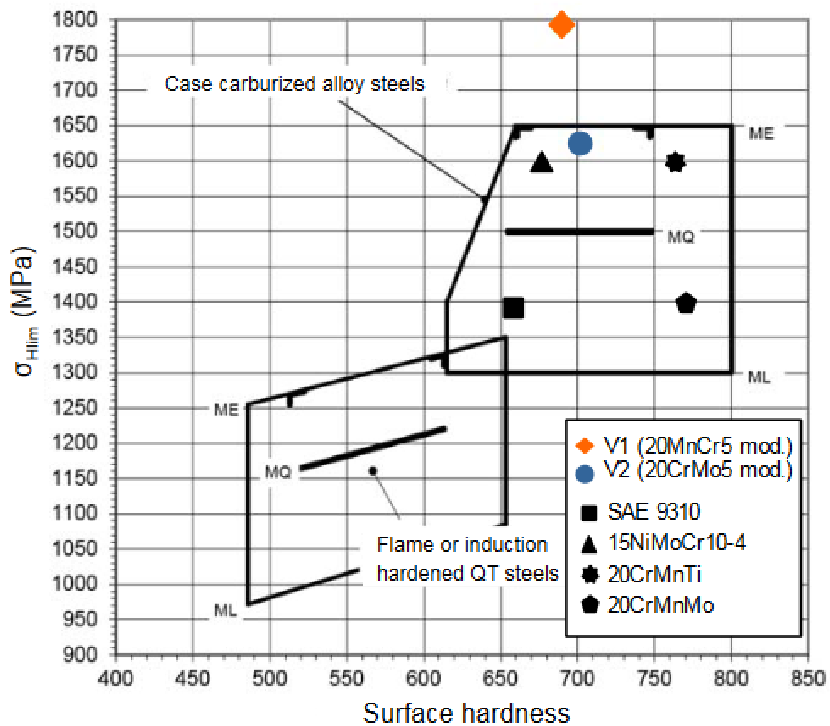
SAE 9310 vs. newly developed steels

Potential for modified case carburizing steel is investigated. It shows that modifying well known steels (20MnCr5) has the potential to result in materials surpassing SAE9310. T. Tobie et l., Optimizing Gear Performance by Alloy Modification of Carburizing Steels, Metals, 2017





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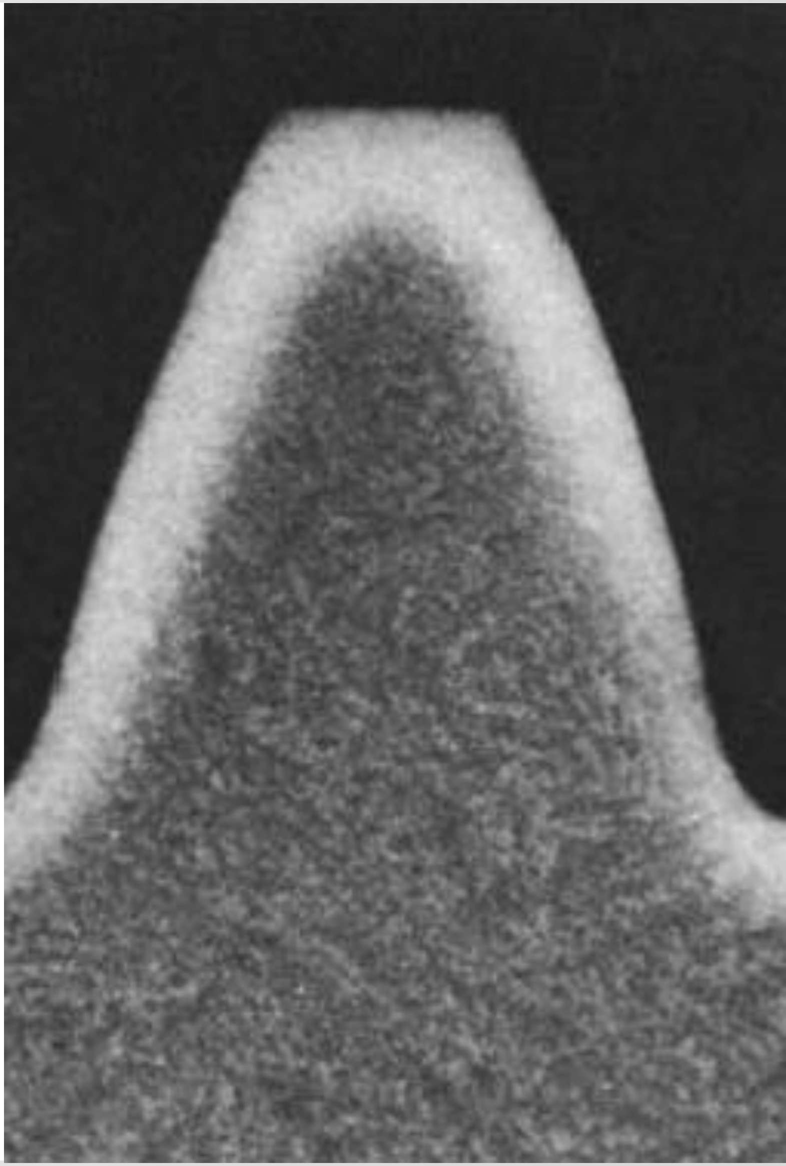


Effects of shot peening [36]

Near surface residual compressive stresses ↑

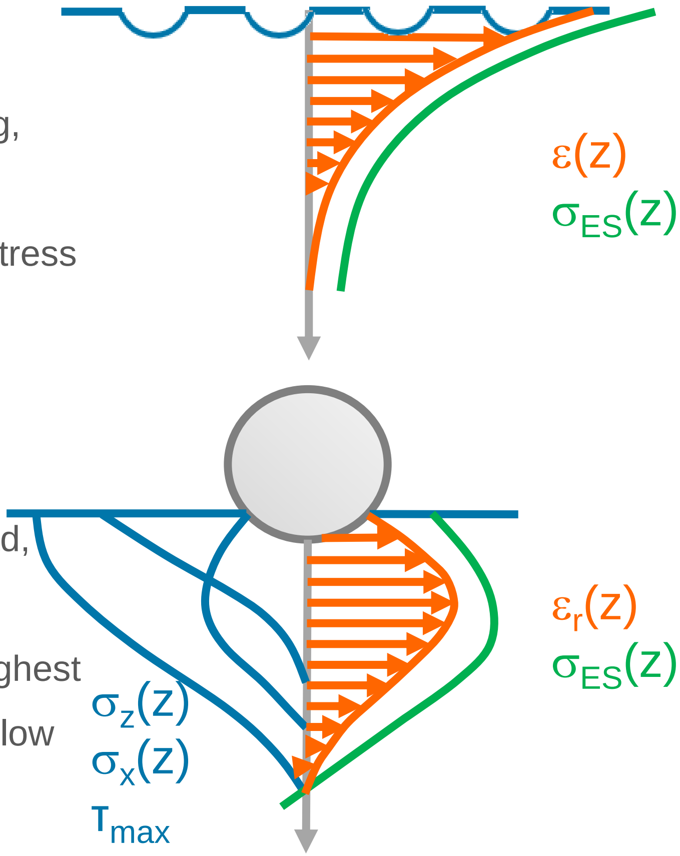
Retained austenite content ↓

Surface roughness ↑

Work strengthening / structure dislocation ↑

After shot peening, surface plastified, highest residual stress at surface

Under contact load, elastic stresses superimposed, highest residual stress below surface



Values for technology factor YT

ISO 6336-5 allows for strength increase of

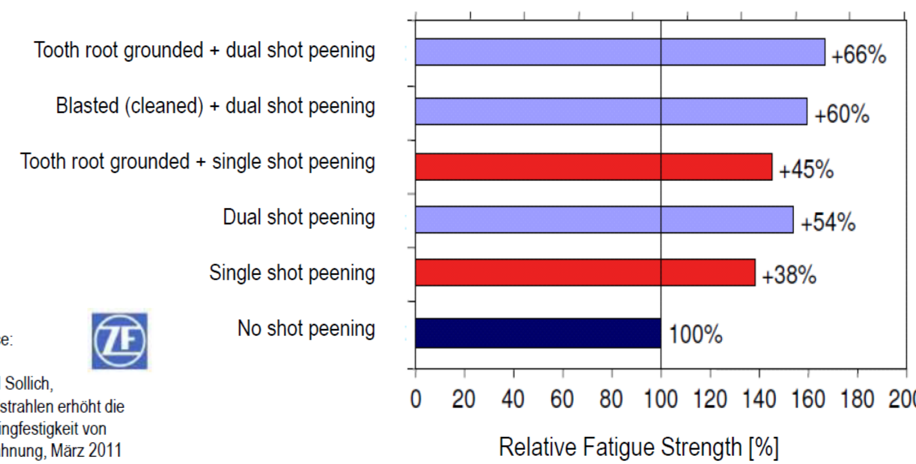
- 0% in case of ML material quality grade
- 10% in case of MQ material quality grade
- 5% in case of ME material quality grade

Lloyd’s Register of Shipping allows for strength increase of 20%

Higher values are reported in literature, using highly controlled processes, for “automotive” size, case carburized gears,


Kind permission, The Metal Improvement Company, LLC

Planetary Gears – Material ZF7B
Dual Shot Peening (2 different shot media @ 2 different intensities)



Source:

Alfred Sollich, Kugelstrahlen erhöht die Schwingfestigkeit von Verzahnung, März 2011

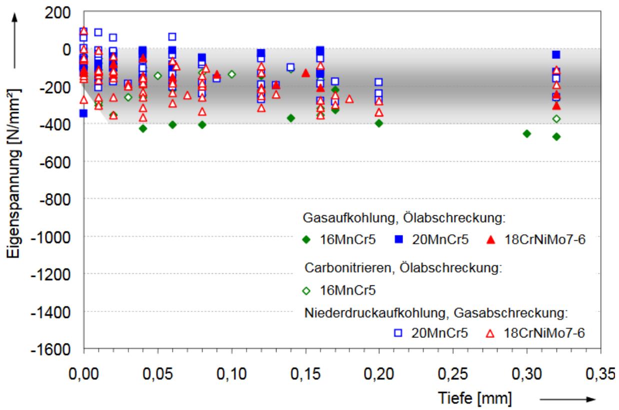
Residual stress state

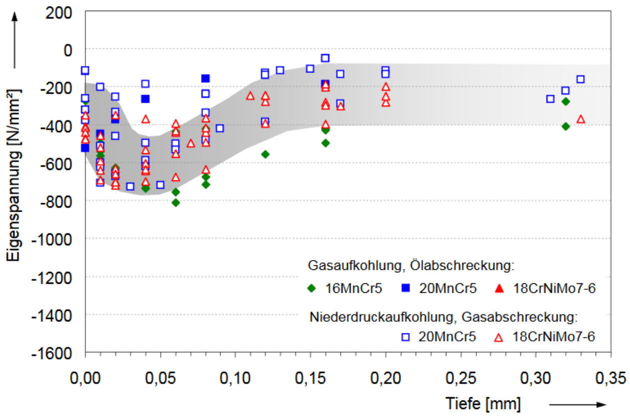
Before shot blasting / cleaning

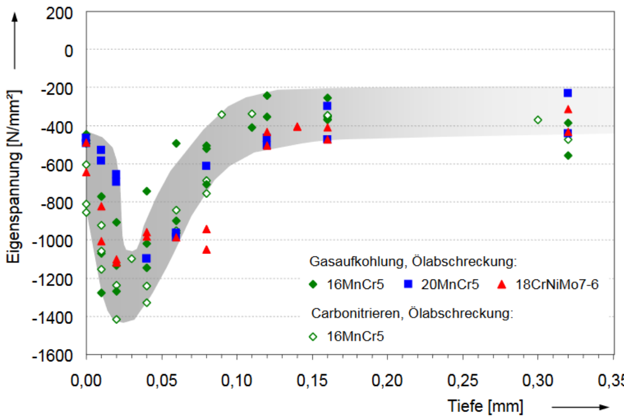
After shot blasting / cleaning

After controlled shot peening

"Eigenspannung" = residual stress, "Tiefe" = depth from surface. For different materials and different case carburizing processes







Stenico, Werkstoffmechanische Untersuchungen zur Zahnfußtragfähigkeit einsatzgehärteter Zahnräder, Dissertation, TUM, 2007

Residual stress state and strength increase

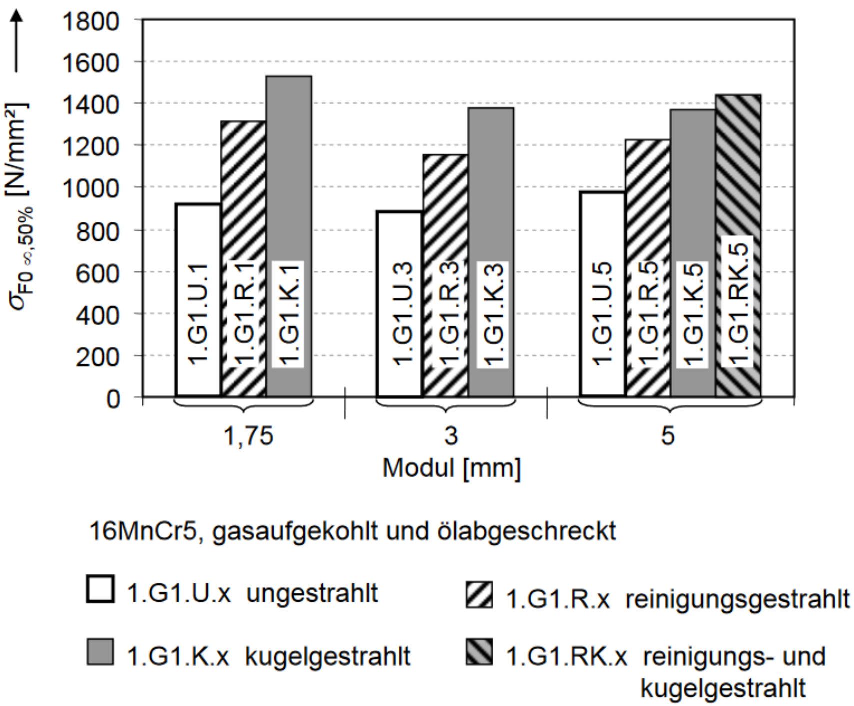
"ungestrahlt" = no treatment

"reinigungsgestrahlt" = shot blasted for cleaning

"kugelgestrahlt" = shot peened

"reinigungs- und kugelgestrahlt" = shot blasted for cleaning and shot peened

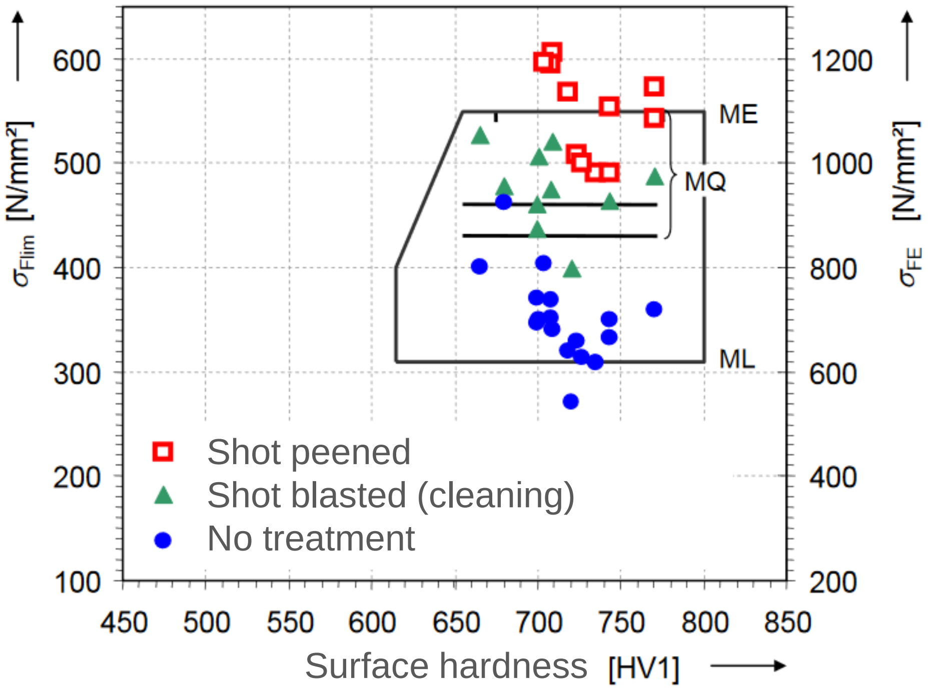
"gasaufgekohlt und ölabgeschreckt" = gas carburized, oil quenched



Stenico, Werkstoffmechanische Untersuchungen zur Zahnfußtragfähigkeit einsatzgehärteter Zahnräder, Dissertation, TUM, 2007

Issues and questions

- Effectiveness for large gears?
- Effectiveness for gears under alternating bending, lower effectiveness is reported
- Introduction of a shot peening factor ZS is proposed
- Strength values as per ISO 6336-5 require a mechanical cleaning of gears by a shot blasting (not a shot peening) process



Stenico, Werkstoffmechanische Untersuchungen zur Zahnfußtragfähigkeit einsatzgehärteter Zahnräder, Dissertation, TUM, 2007

Process definition

SAE AMS2430 for Aerospace applications, SAE J2441 for Automotive / Industrial application

SAE Aerospace
An SAE International Group

AEROSPACE MATERIAL SPECIFICATION

SAE AMS2430	REV. R
Issued 1948-09 Revised 2010-01 Superseding AMS2430P	

Shot Peening, Automatic

RATIONALE

AMS2430R was issued to add 4.4.3.

1. SCOPE

1.1 Form

This specification covers the engineering requirements for automatic peening of surfaces of parts by impingement of metallic shot, glass beads, or ceramic shot.

1.2 Application

To induce residual compressive stress in surface layers of parts, thereby increasing fatigue strength and resistance to stress-corrosion cracking but usage is not limited to such applications.

2. APPLICABLE DOCUMENTS

The issue of the following documents in effect on the date of the purchase order forms a part of this specification to the extent specified herein. The supplier may work to a subsequent revision of a document unless a specific document issue is specified. When the referenced document has been cancelled and no superseding document has been specified, the last published issue of that document shall apply.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

AMS2431	Peening Media, General Requirements
AMS-S-13165	Shot Peening of Metal Parts
SAE J442	Test Strip, Holder, and Gage for Shot Peening
SAE J443	Procedures for Using Standard Shot Peening Test Strip
SAE J2277	Shot Peening Coverage

SAE The Engineering Society For Advancing Mobility Land Sea Air and Space
INTERNATIONAL
400 Commonwealth Drive, Warrendale, PA 15096-0001

SURFACE VEHICLE STANDARD

SAE J2441	ISSUED AUG2000
Issued 2000-08	

Submitted for recognition as an American National Standard

Shot Peening

1. *Scope*

1.1 Form—This SAE Standard covers the engineering requirements for peening surfaces of parts by impingement of metallic shot, glass beads, or ceramic shot.

1.2 Application—To induce residual compressive stress in surface layers of parts, thereby increasing fatigue strength and resistance to stress-corrosion cracking.

2. *References*

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply. The applicable issue of other publications shall be the latest revision.

2.1.1 SAE Publications—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J441—Cut Wire Shot
SAE J442—Test Strip, Holder, and Gage for Shot Peening
SAE J443—Procedures for Using Standard Shot Peening Test Strip
SAE J444—Cast Shot and Grit Size Specifications Peening and Cleaning
SAE J445—Metallic Shot and Grit Mechanical Testing
SAE J827—High-Carbon Cast-Steel Shot
SAE J1173—Size Classification and Characteristics of Glass Beads for Peening
SAE J1830—Ceramic
SAE J2175—Specifications for Low Carbon Cast Steel Shot
SAE J2277—Shot Peening Coverage

2.1.2 ASTM Publications—Available from ASTM, 100 Barr Harbor Drive West Conshohocken, PA 19428-2959.

ASTM E 18—Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials
ASTM E 11—Standard Specification for Wire Cloth and Sieves for Testing Purposes

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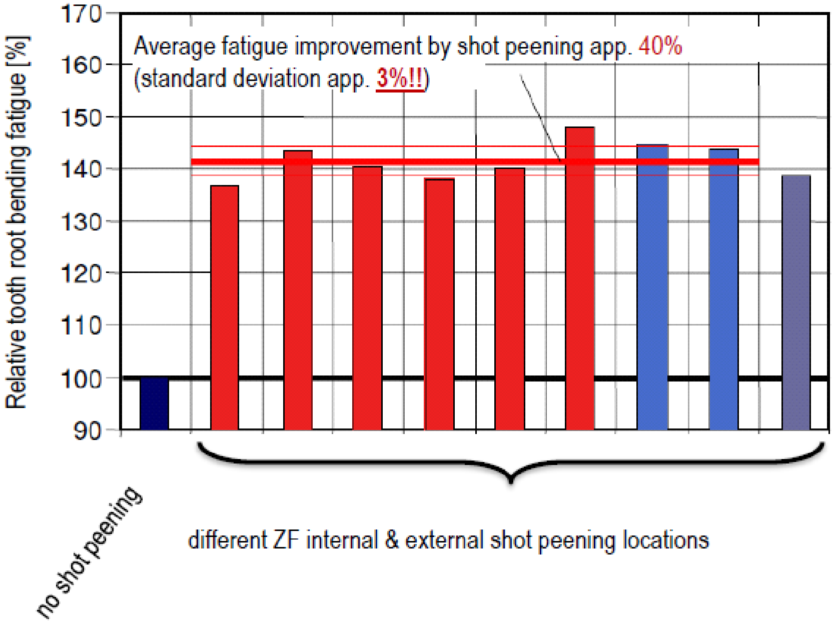
Issues and questions

1. NASA TM 107428, Gear and Transmission Research at NASA Lewis Research Center



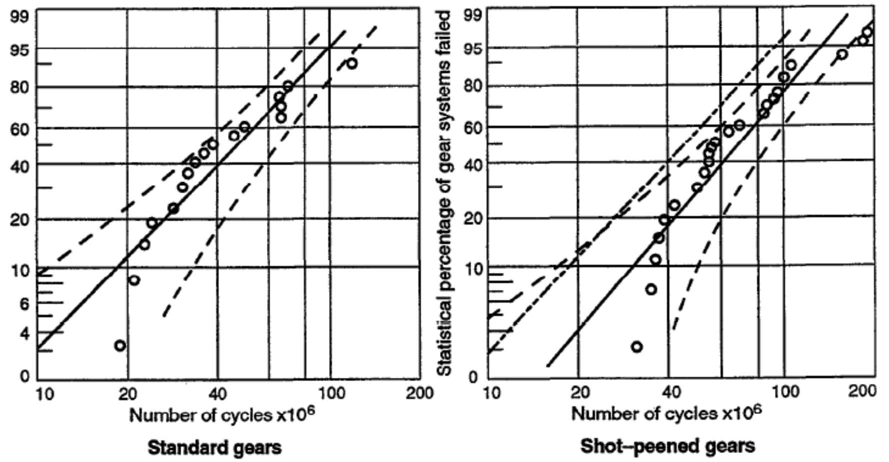
Shot peening, flank

AGMA 911: life increase of approximately factor 1.60.

NASA reports increase in the range of factor 2.00 Townsend et al., Improvement in Surface Fatigue Life of Hardened Gears by High-Intensity Shot Peening, NASA Technical Memorandum 105678, Davis (ed.), Gear Materials, Properties, and Manufacture, 2005 ASM; see also Townsend et al., Effect of Shot Penning on Surface Fatigue Life of Carburized and Hardened AISI 9310 Spur Gears

FVA research project 185 reports strength increase by 0…10%. Repair of gears with grinding temper a possibility.

Root: strength increase, see figure



Comparison of surface (pitting) fatigue lives of standard ground and shot-peened carburized and hardened CVM AISI 9310 steel spur gears:

Speed – 10 000 RPM
Lubricant – synthetic paraffinic oil
Gear temperature – 77°C (170°F)

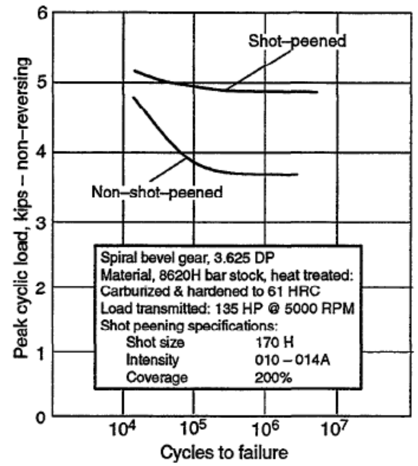
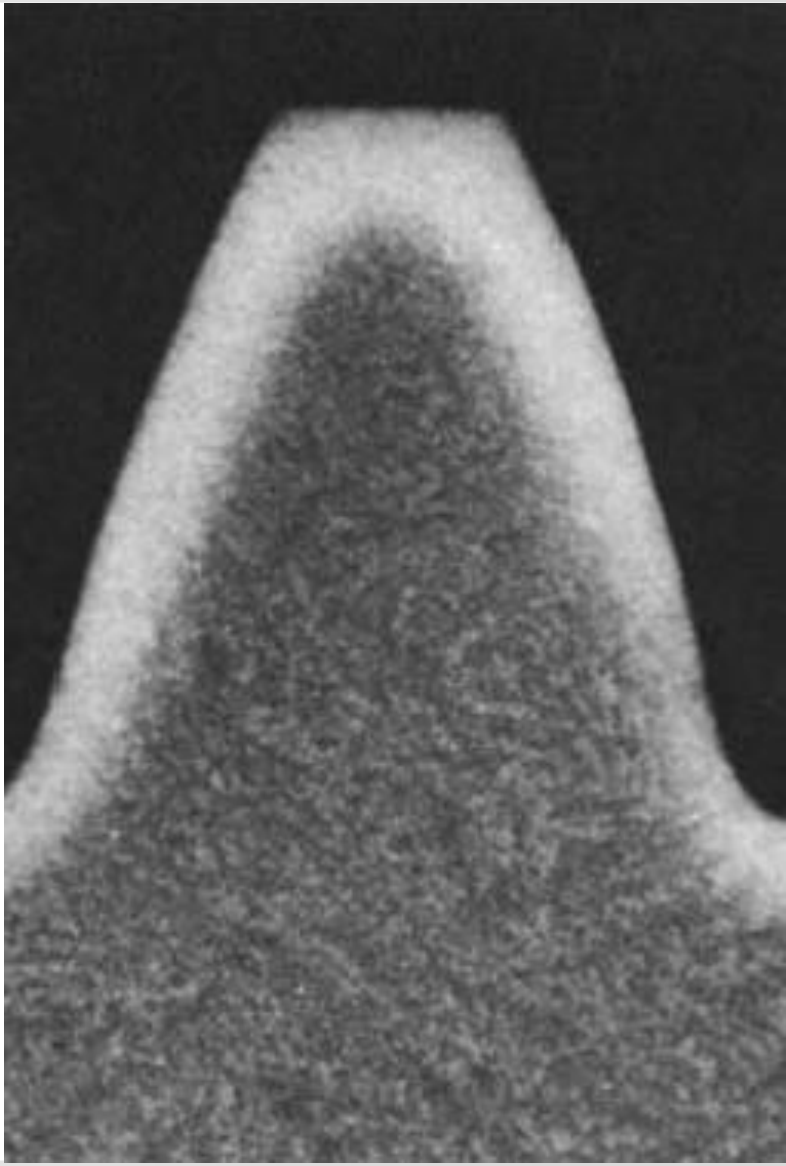


Figure 24 – Increase in fatigue resistance of spiral bevel gear [15]

Content

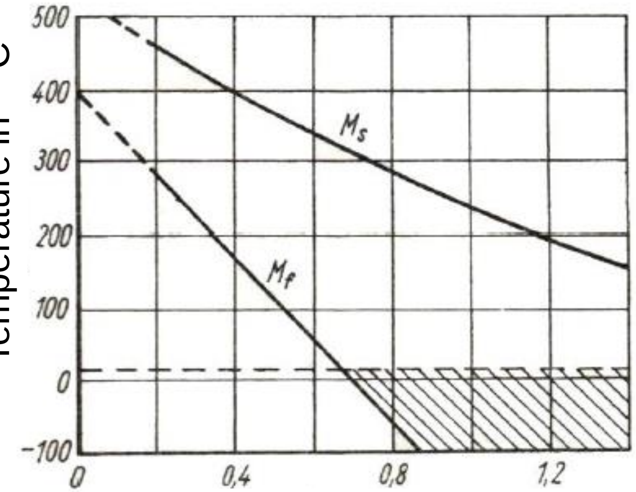


Retained austenite level

Some comments
Herring, A Discussion of Retained Austenite, IndustrialHeating.com 2005

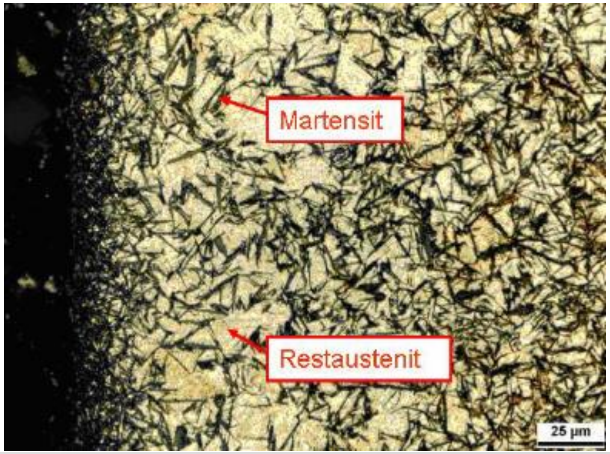
- Austenite that does not transform to Martensite during quenching → retained Austenite. 100% transformation occurs only if cooling to Martensite finish temperature is done, below room temperature.
- Retained Austenite content is a function of carbon content, alloy content, quench temperature, post treatment
- Transformation from Austenite to Martensite leads to volume increase by about 4% → internal stresses
- Martensite: hard, strong, brittle. Austenite: soft, tough. When properly combined, both beneficial properties are combined.
- Retained Austenite can improve rolling contact fatigue, its ductility delays crack growth. And retained Austenite transforms under external stress to Martensite, inducing compressive residual stresses, delaying crack growth.

Temperature in ° C



Carbon content in %

Martensite start and finish temperature



After heat treatment, before shot peening

Davis (ed.), Gear Materials, Properties, and Manufacture, 2005 ASM, Herring, A Discussion of Retained Austenite, IndustrialHeating.com 2005

- More Austenite → tougher, better for low cycle fatigue.
- Less Austenite → harder, better for high cycle fatigue.
- Shot peening leads to stress induced Austenite to Martensite conversion by about -5%.
- Target about 4-15% retained Austenite. Refer to e.g. AGMA 926. Strength drops for higher than 15% level.
- Cryogenic treatment after heat treatment results in very low retained Austenite content.

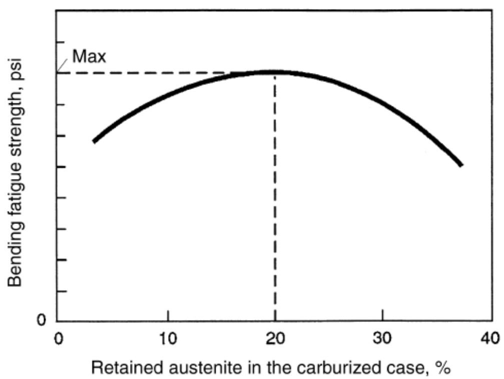
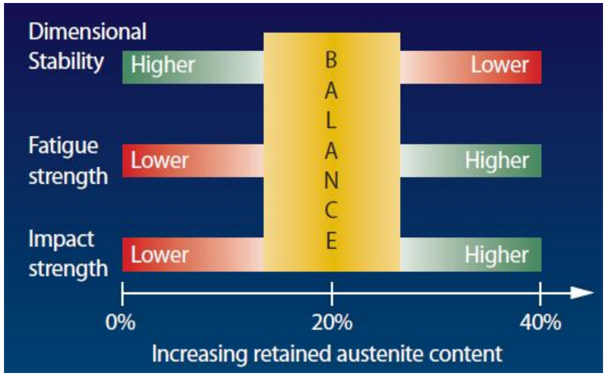


Fig. 29 Influence of retained austenite on bending fatigue strength



Retained Austenite and Its Effect on Gear Performance. After carburizing and hardening, it is possible that some retained austenite may exist near the surface of the gear teeth. Steels containing nickel are especially susceptible to such austenite retention. The retained austenite is not generally considered harmful to gear life when present in the amount not exceeding 15 to 20% by volume. In fact, retained austenite present between 15 to 20% by volume seems to increase bending fatigue resistance of gear teeth (Fig. 29). On the other hand, retained austenite in the martensitic microstructure of the case lowers the surface hardness, which is not at all desirable for contact fatigue life. Also, a high percentage of retained austenite (above 20% by volume) is found to be detrimental during the service life of gears where the volume accompanying austenite-martensite transformation causes dimensional change in gear tooth geometry. Furthermore, martensite formed in this manner is untempered and brittle and may accelerate crack formation in the case. Hence, it is essential to control the amount of retained austenite for maximum service life of gears. Recent research indicates that finely dispersed, retained austenite in the amount of up to 15% is not detrimental to the contact fatigue (pitting) life of gears. Retained austenite above 20% may cause "grind burn," discussed later in this chapter, particularly if the gears are ground on wet gear grinding machines with vitrified aluminum oxide wheels.

Retained austenite level

Some aspects related to gearing

- Gas carburized and oil quenched gears show lower retained Austenite level of about 5% vs. low pressure carburized / carbonitrided gears of about 15%.
- Root and flank strength is a function of retained Austenite level, 20% indicates a good compromise.
- Root strength seems to be fairly independent of austenising temperature Stenico, Werkstoffmechanische Untersuchungen zur Zahnfusstragfähigkeit einsatzgehärteter Zahnräder, Dissertation, 2007

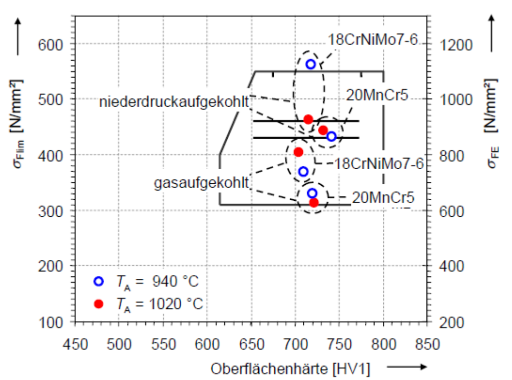
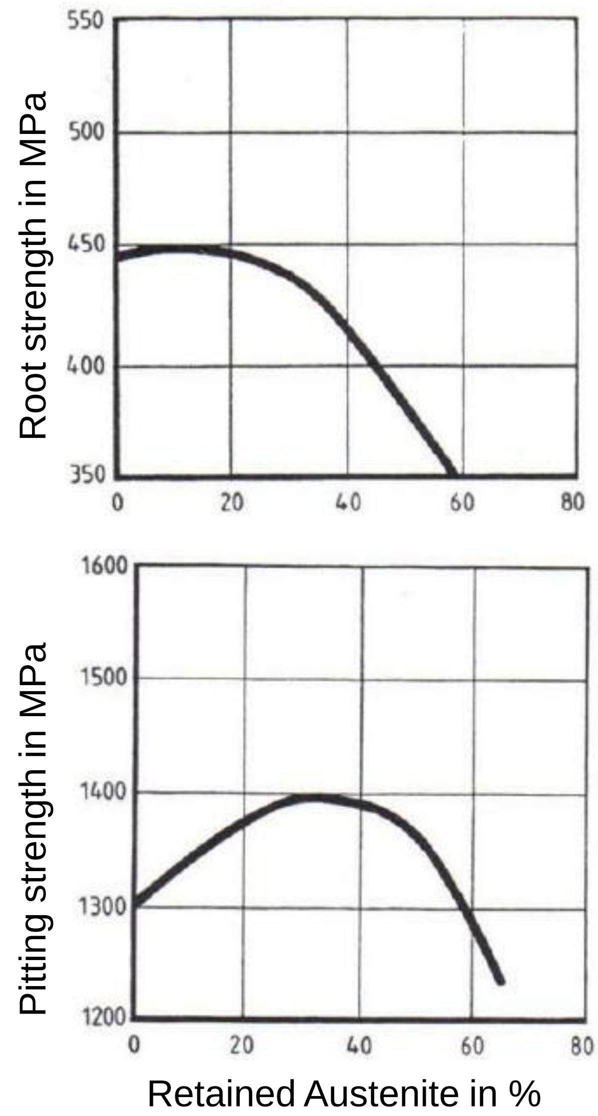


Bild 46 Kennwerte zur Zahnfußdauerfestigkeit der ungestrahlten Prüfvarianten bei Variation der Austenitisierungstemperatur T_A: Einordnung in das Kennfeld der Norm DIN 3990 [2]



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Retained austenite level

After heat treatment, before shot peening

Aerospace → Gear class (A)

10% max. retained Austenite in the case. Davis (ed.), Gear Materials, Properties, and Manufacture, 2005 ASM

“... A number of standard heat treatments in gear applications require the retained austenite to be in range of 15-20%. On the other hand, in aerospace applications, other … require the retained austenite to be reduced to less than 4% by sub-zero cooling …” Abudaia et al., Characterization of Retained Austenite in Case Carburized Gears and Its Influence on Fatigue Performance, Gear Technology, 2003

Table 9 Hardness and microstructure requirements in case and core for different classes of carburized and hardened gears

			Hardness		Microstructure	
Gear class(a)	Process	Material	Case surface (Knoop 500 g)	Core HRC	Area of part	Requirement
A	Carburize and harden	Carburizing grade	720 min on tooth surfaces 710 min at root fillet areas	34–44	Case	High-carbon refined tempered martensite. Retained austenite 10% max. Continuous carbide network or cracks are not acceptable. Scattered carbides are acceptable provided the max carbide particle size does not exceed 0.005 mm (0.0002 in.) in any direction. Transformation products such as bainite, pearlite, proeutectoid ferrite, or cementite not permitted in excess of the amount. No white martensite (untempered) permitted.
					Core	Low carbon (tempered) martensite. No blocky ferrite, pearlite, or bainite. Ferrite patches not to exceed 1.6 mm ($^1/_{16}$ in.) in width or length as measured at 250× magnification. Excessive banding not permitted.
B	Carburize and harden	Carburizing grade	690 min (all areas)	30–44	Case	High-carbon tempered martensite. Retained austenite 20% max. No continuous carbide network is acceptable. Scattered carbides are acceptable provided the maximum carbide particle size does not exceed 0.010 mm (0.0004 in.) in any direction. Surface oxidation not to exceed 0.013 mm (0.0005 in.). Transformation products not permitted in excess of the amount shown. No white martensite permitted.
					Core	Essentially low-carbon martensite with some transformation products permissible. Ferrite patches up to 3.18 mm ($^1/_8$ in.) wide and length permissible as measured at 250×. Excessive banding not permitted.
C	Carburize and harden	Carburizing grade	630 min (all areas)	28–45	Case and core	Defects such as laps and cracks are not permitted. Retained austenite, 30% max. Case depth shall meet drawing requirements. Excessive inclusions that may affect the function of the part shall be cause for rejection.

(a) A, critical applications where a gear failure may result in loss of life; B, not as critical as A but still requires high reliability; C, industrial application

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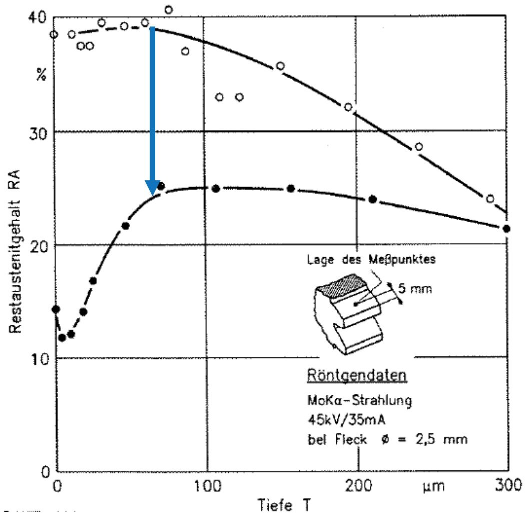
Effect of shot peening on retained Austenite



Significant reduction of retained Austenite

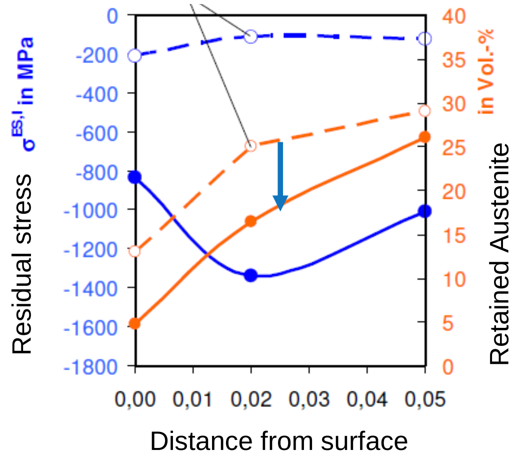
FVA research report 185, Zahnflanken Kugelstrahlen

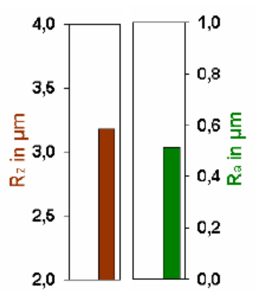
Shot peening leads to stress induced Austenite to Martensite conversion by about -5%

Sollich, Kugelstrahlen, Steigerung der Schwingfestigkeit von Verzahnungen, Festkolloquium Braunschweig 2011

Influence of shot peening Results of a DoE investigation

Status before shot peening, case carburized





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Retained austenite level

Effect on scuffing risk

Retained austenite level has considerable influence on scuffing risk, ISO 6336-21.

For retained Austenite content of 15%, value of XW = 1.00 applies.

Input in KISSsoft:

System data | Pair/gear data

Pair data

Relative structural factor (scuffing) X_{WrelT} 1.0000

Gear material	X_W
Through-hardened steel	1,00
Phosphated steel	1,25
Copper-plated steel	1,50
Bath and gas nitrided steel	1,50
Case carburized steel:	
— average austenite content less than 10 %	1,15
— average austenite content 10 % to 20 %	1,00
— average austenite content greater than 20 % to 30 %	0,85
Austenitic steel (stainless steel)	0,45

Table 4 Mean scuffing temperature for synthetic lubricants typically used for operating carburized gears in aerospace applications

Lubricant	Mean scuffing temperature, T_S °C	Mean scuffing temperature, T_S °F
MIL-L-6081 (grade 1005)	129	264
MIL-L-7808	205	400
MIL-L-23699	220	425
DERD2487	225	440
DERD2497	240	465
DOD-L-85734	260	500
Mobil SHC624	280	540
Dexron II	290	550

Source: Ref 20

KISSsoft

ISO 6336-5:2016

Examples, influence of shot peening on retained Austenite level

Gear Version	Variante	KG DL 1	KG SR 1	KG DL 2	KG DL 3	KG DL 4
SP-method (nozzle / wheel)	Strahlverfahren	Druckluft-strahlen	Schleuder-radstrahlen	Druckluft-strahlen	Druckluft-strahlen	Druckluft-strahlen
Material	Werkstoff	16 MnCr 5	16 MnCr 5	16 MnCr 5	17 CrNiMo 6	17 CrNiMo 6
Initial content of RA	Ausgangsgefüge	RA ≃ 40%	RA ≃ 40%	RA ≃ 18%	RA ≃ 44%	RA ≃ 25%
	nach dem Kugelstrahlen: after shot peening:					
Content of RA after SP	Gefüge	RA = 14%	RA = 26%	RA << 5%	RA = 11%	RA < 5%
Average roughness	mittlere Rauhtiefe	$R_z \simeq 2{,}5\ \mu m$	$R_z \simeq 3\ \mu m$	$R_z \simeq 2{,}2\ \mu m$	$R_z \simeq 2{,}5\ \mu m$	$R_z \simeq 2{,}8\ \mu m$
Residual surface stress	Eigenspannungen an der Oberfläche	$\sigma_{E,A} \simeq -980\ N/mm^2$	$\sigma_{E,A} \simeq -1200\ N/mm^2$	$\sigma_{E,A} \simeq -780\ N/mm^2$	$\sigma_{E,A} \simeq -1000\ N/mm^2$	$\sigma_{E,A} \simeq -770\ N/mm^2$
Hardness increase	Härteanstieg ΔH	≃ 160 HV10	≃ 50 HV10	≃ 90 HV10	≃ 160 HV10	≃ 170 HV10

Bild 54: Werkstoff- und Gefügevarianten mit charakteristischen Kennwerten nach dem Kugelstrahlen

ISO 6336-5:2016

Note the comment on salvaging by shot peening where Austenite is transformed to Martensite again.

Limit of 30% is in line with above recommendation of 25%.

ISO 6336-5:2016(E)

Table 5 *(continued)*

Item	Requirement	ML	MQ	ME
10.2	Surface structure: The desired structure has less than 10 % bainite determined by metallographic inspection	No specification	Recommended. Martensite, essentially fine acicular, as shown by a representative test bar.	Required. Martensite, fine acicular, as shown by a representative test bar.
10.3	Carbide precipitation	Semi-continuous carbide network permitted in accordance with Figure 20 a). On representative test bar.	Discontinuous carbides permitted in accordance with Figure 20 b). Discontinuous carbides differ from semicontinuous carbide network in such a way that they do not delineate the grain structure. Maximum length of any carbide is 0,02 mm. (On representative test bar, if used.)	Dispersed carbides permitted in accordance with Figure 20 c). Maximum size of any carbide is 0,01 mm. Inspection of representative test bar in accordance with 6.5.
10.4	Residual austenite. Determined by metallographic inspection. [h]	No specification	Up to 30 % on inspection of companion heat treatment batch test piece.	Up to 30 %, finely dispersed. Inspection of representative test bar in accordance with 6.5.
			If outside specification, salvage may be possible by controlled shot-peening in accordance with 6.7, or other appropriate procedures.	

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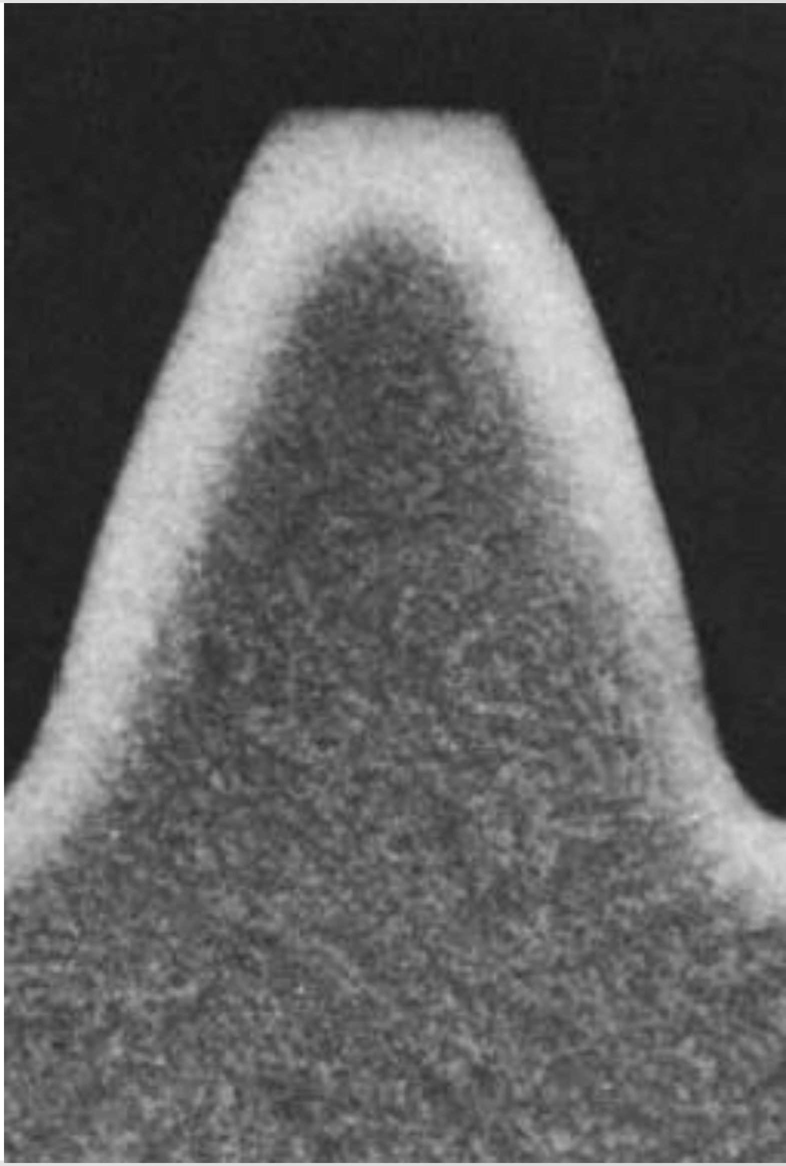


Mean stress influence factor YM

Along ISO 6336-3, Annex B (informative)

ISO 6336-5: YM = 0.70 for reverse bending. Note that this is not necessarily conservative.

The mean stress influence factor, Y_M, can be calculated as follows:

$$Y_M = \frac{1}{1 - R \cdot \frac{1-M}{1+M}} \qquad \text{(B.1)}$$

where

R is the stress ratio;

M considers the mean stress influence on the endurance (or static) strength amplitudes, and is defined as the reduction of the endurance strength amplitude for a certain increase of the mean stress divided by that increase of the mean stress (the values listed in Table B.1 may be used for M, see explanation below).

To simplify, for designs with the same load applied both on forward- and back-flank, R may be assumed to equal –1,2. For designs with considerably different loads on the forward- and back-flank, R may be assumed to be as follows:

$$R = -1{,}2 \cdot \frac{F_{\text{Rlow}}}{F_{\text{Rhigh}}} \qquad \text{(B.2)}$$

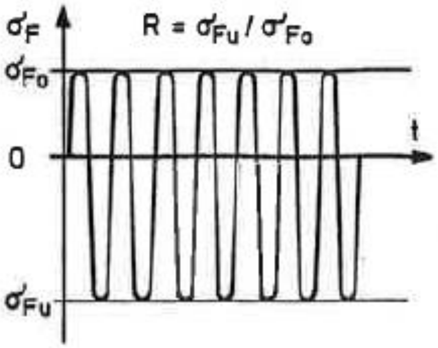
where

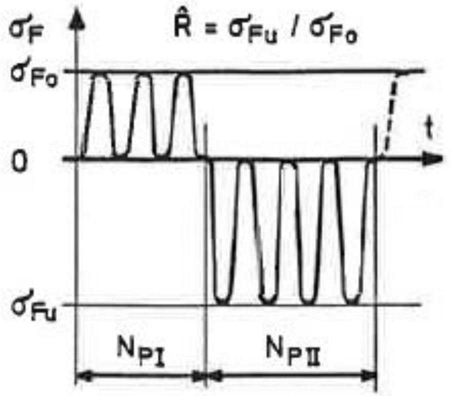
F_{Rhigh} is the load per unit facewidth of the higher loaded flank

F_{Rlow} is the load per unit facewidth of the lower loaded flank

Table B.1 — Mean stress ratio, *M*

	Endurance limit	Static strength
Case hardened	0,8 – 0,15 Y_S	0,7
Case hardened and shot peened	0,4	0,6
Nitrided	0,3	0,3
Induction or flame hardened	0,4	0,6
Not surface hardened steels	0,3	0,5
Cast steels	0,4	0,6



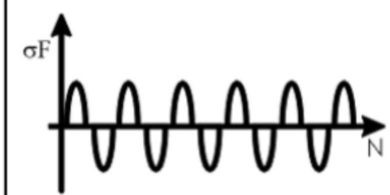
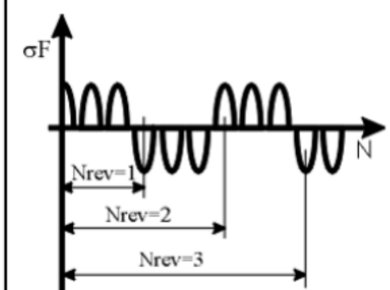


Mean stress influence factor YM for periodic load reversal

In case of periodical change of loading direction

Calculate YM as a function of the number of load reversal.

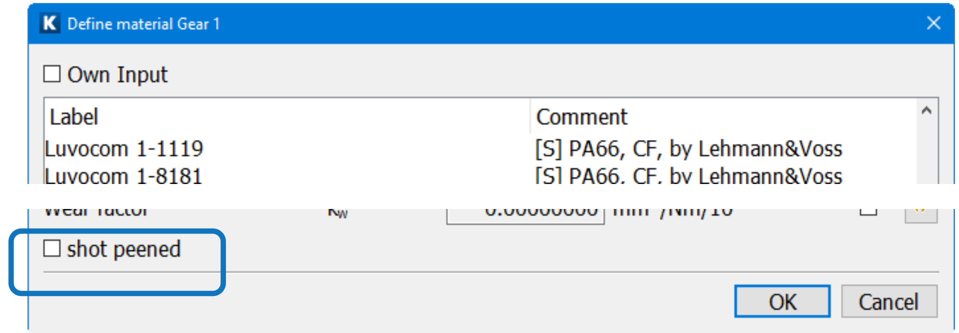
For case carburized gears, a 30% strength loss is quickly achieved in case of load reversals.

Operating Mode	Alternating Bending Factor (Mean Stress Influence Factor) Y_M	Load Direction
Pulsating	1	
Alternating	0.7 [1] 0.65 [2]	
Oscillating	$0.85 - 0.15 \cdot \frac{\log N_{rev}}{6}$ [1] $0.85 - 0.20 \cdot \frac{\log N_{rev}}{6}$ [2] $(1 \leq N_{rev} \leq 10^6)$ 0.7 [1] 0.65 [2] $(N_{rev} \geq 10^6)$	

(1) Linke, H.: Stirnradverzahnung, Carl Hanser Verlag, 1996.
(2) Linke, H.: Stirnradverzahnung, Carl Hanser Verlag, 2010.

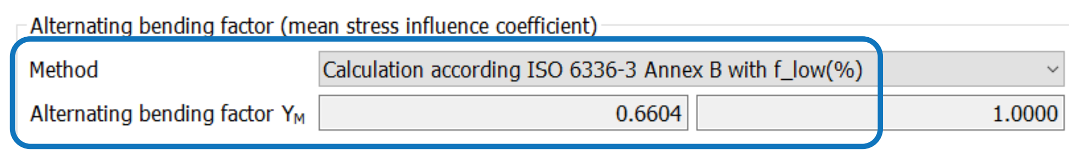
KISSsoft

Flag “shot peening”



Note that the flag “shot peened” in material details is not related to YT factor.

It is related to YM factor if YM is calculated along Annex B to ISO 6336-3. If flag “shot peened” is active, then, second line in Table B.1 is used.



Then, M and subsequently YM is not a function of YS but constant.

	Endurance limit	Static strength
Case hardened	0,8 – 0,15 Y_S	0,7
Case hardened and shot peened	0,4	0,6
Nitrided	0,3	0,3
Induction or flame hardened	0,4	0,6
Not surface hardened steels	0,3	0,5
Cast steels	0,4	0,6

KISSsoft

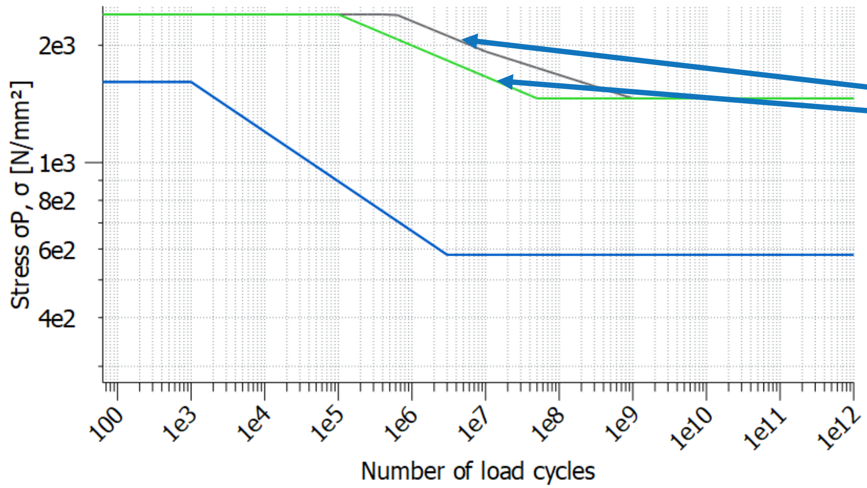
Flag «Limited pitting is permitted»

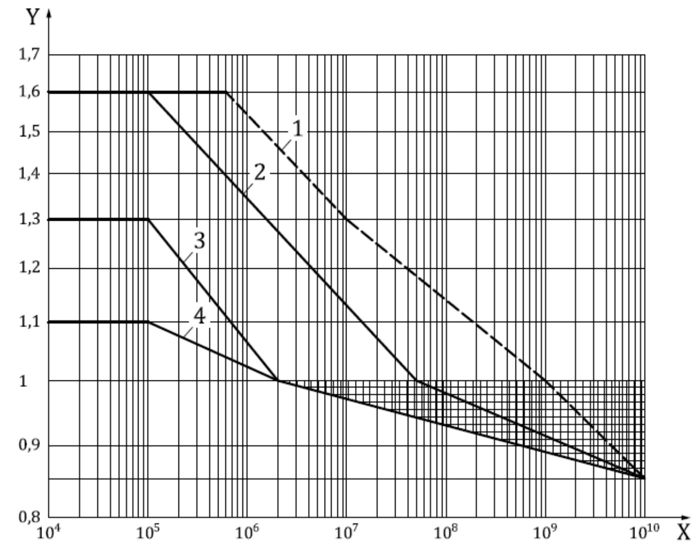
Even after study of literature, it is not clear what the extent of «limited pitting» is.

In tab «Rating», button «Details», the corresponding flag may be set.

☑ Limited pitting is permitted

Then, the curve (1) is used instead of curve (2).





Key

X number of load cycles, N_L

Y life factor, Z_{NT}

1 St, V, GGG (perl., bai.), GTS (perl.), Eh, IF, when limited pitting according to Clause 4 is permitted

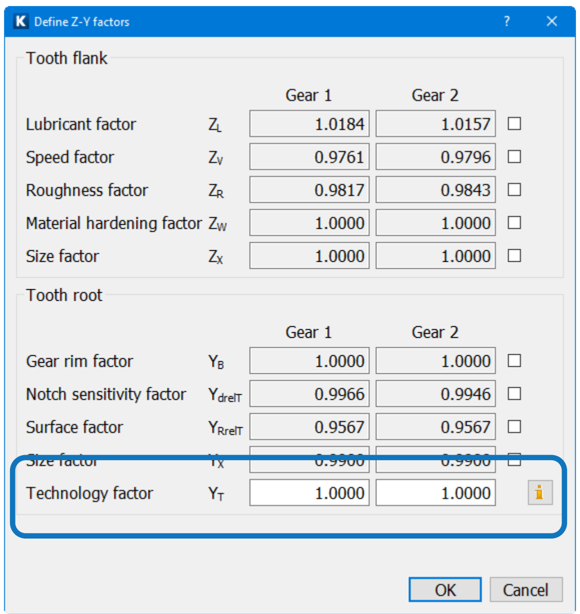
2 St, V, GGG (perl., bai.), GTS (perl.), Eh, IF, when no pitting according to Clause 4 is permissible

3 GG, GGG (ferr.), NT (nitr.), NV (nitr.)

4 NV (nitrocar.)

Input of technology factor YT

YT needs to be defined by the user, it is never automatically set in KISSsoft. In put is in tab “Factors”, button “Z-Y factors”. Note that the factor only applies for root strength. To consider the effect of e.g. shot peening of the flank, directly manipulate the S-N curve.



Technology factor Y_T according to ISO 6336-5	
Treatment of the tooth root area	**Technology factor Y_T** (only for case-hardened gears)
Shot-peening (Quality MQ)	1.10
Shot-peening (Quality ME)	1.05

Technology factor Y_T according to Linke	
Treatment of the tooth root area	**Technology factor Y_T**
Shot-peening applies for case-hardened or carbonitrided tooth forms; not ground in the hardened layer	1.20
Rolling Applies for flame or induction hardened tooth forms; not ground into the hardened layer	1.30
Grinding applies for case-hardened or carbonitrided tooth forms	General: 0.70 with CBN grinding discs: 1.00
Cutting Machining does not apply for ground tooth form	1.00

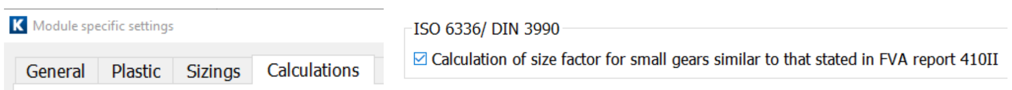
Technology factor Y_T according to Lloyd's rules	
Design factor Y_D in Lloyd's rules	**Technology factor Y_T = 1.00/Y_D**
Controlled shot-peening (Y_D = 0.83)	1.205
Shrunk on gears, approx. (Y_D = 1.25)	0.800
Shrunk on gears, by formula	$Y_T = \frac{1}{1 + \frac{0.2 \cdot d_S^2 \cdot d \cdot P_R \cdot b}{F_T \cdot \sigma_{F\,lim}(d_f^2 - d_S^2)}}$ d_S: Shrink diameter (mm) P_R: Radial pressure (N/mm²)

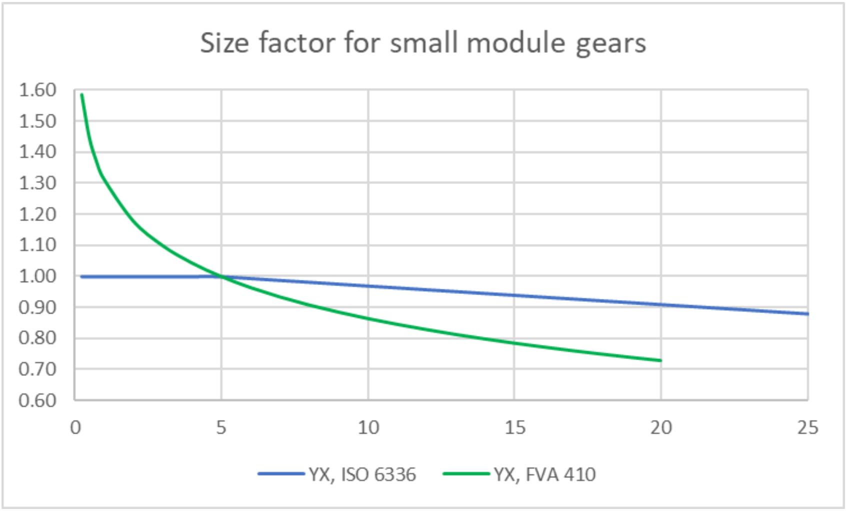
Technology factor Y_T according to GOST
See GOST 21354-87, Table 13, Normally 1.00

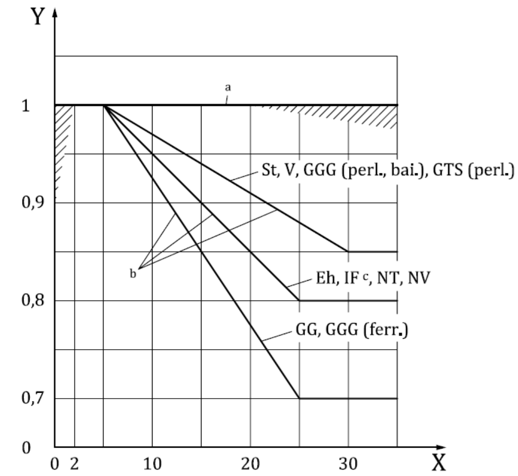
Influence of size on specific strength

Material flaws increase with increasing size. Rating standards are known to be conservative for small gears.

FVA project 410 proposes different approach for YX factor. Set below flag in the module specific settings.







Key

X normal module, m_n, mm

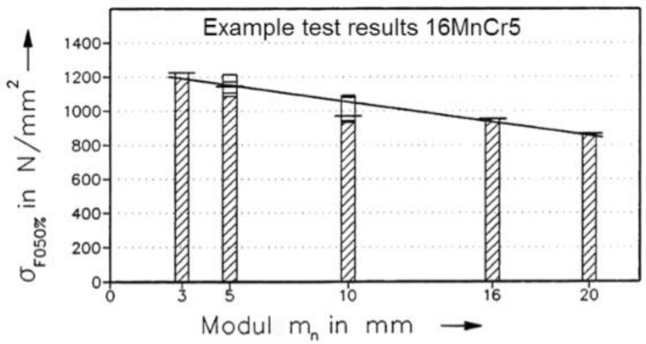
Y size factor, Y_X

a Static stress (all materials).

b Reference stress.

c (root).

ISO 6336



Steutzger, M. Größeneinfluß auf die Zahnfußfestigkeit, Forschungsvereinigung Antriebstechnik e.V.,Frankfurt am Main, Forschungsvorhaben Nr. 162, Heft 529. 1997

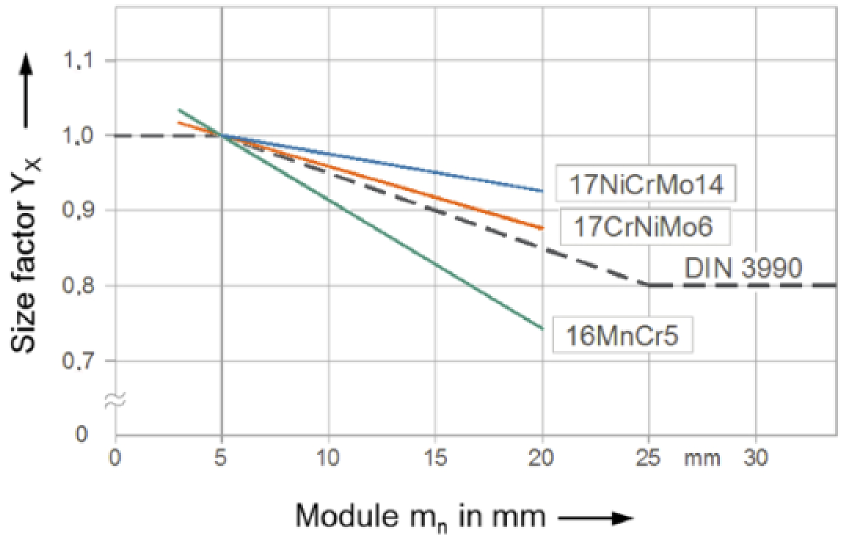
Influence of material on specific strength

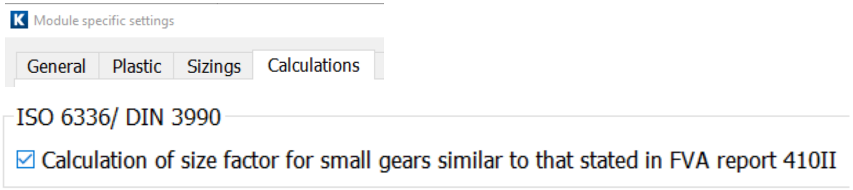
Material flaws increase with increasing size

Rating standards are known to be conservative for small gears

FVA project 410 proposes different approach for YX factor

To change calculation method for YX, set below flag in the module specific settings.





Thank you for your kind attention

Sharing Knowledge

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