Thermoplastic Crossed Axis Helical Gears: Design, Analysis and Manufacture

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Contents

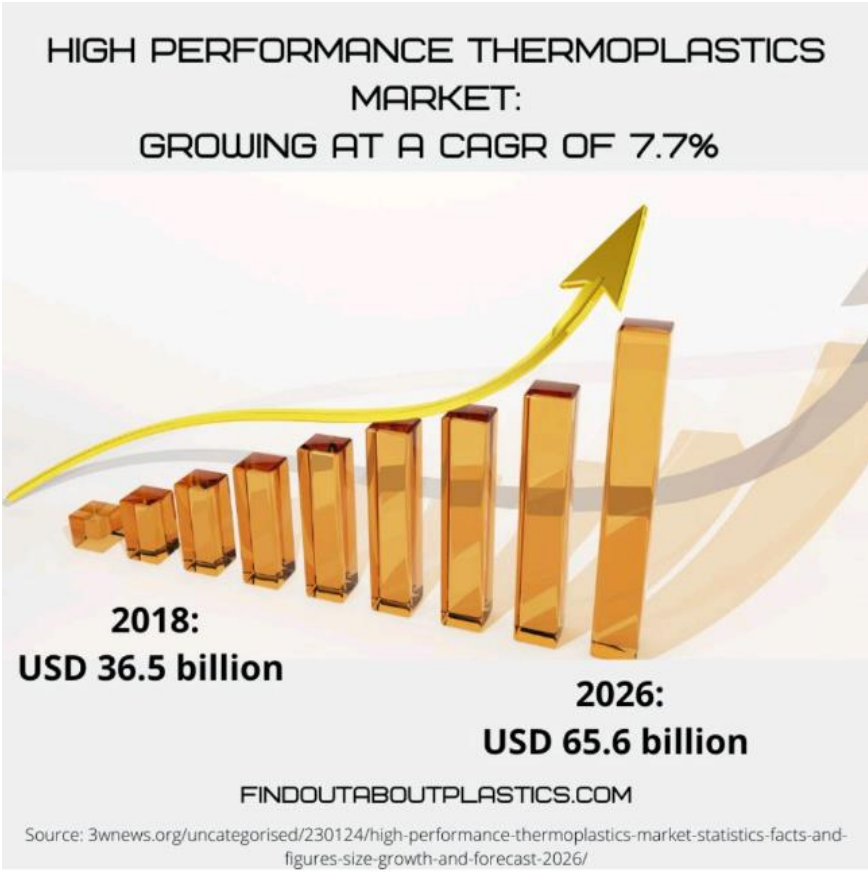
Introduction

- Plastic gears in use for more than 70 years
- R&D increase in the last decade
- R&D activity much lower than on steel gears
- Vast base of potential materials
  - Different types of plastics (POM, PA, PEEK, …)
  - Fillers (glass, carbon, aramide, …)
  - Lubricants (PTFE, MoS2, silicone, …)

- Volume of production:

  Plastic gears >> Steel gears

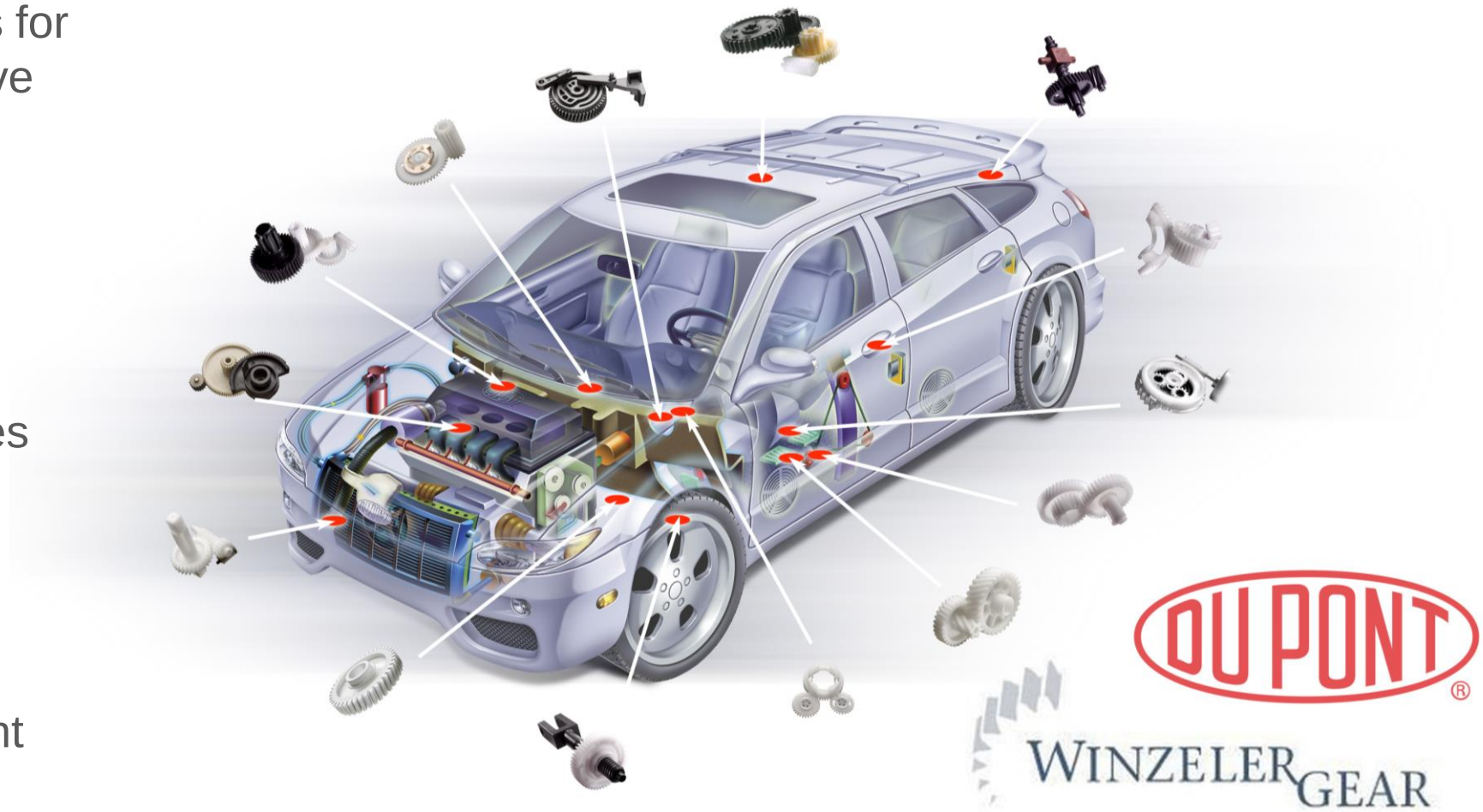
Total market in 2022: 205 billion USD



Actuators for automotive industry

Kitchen appliances

Office equipment

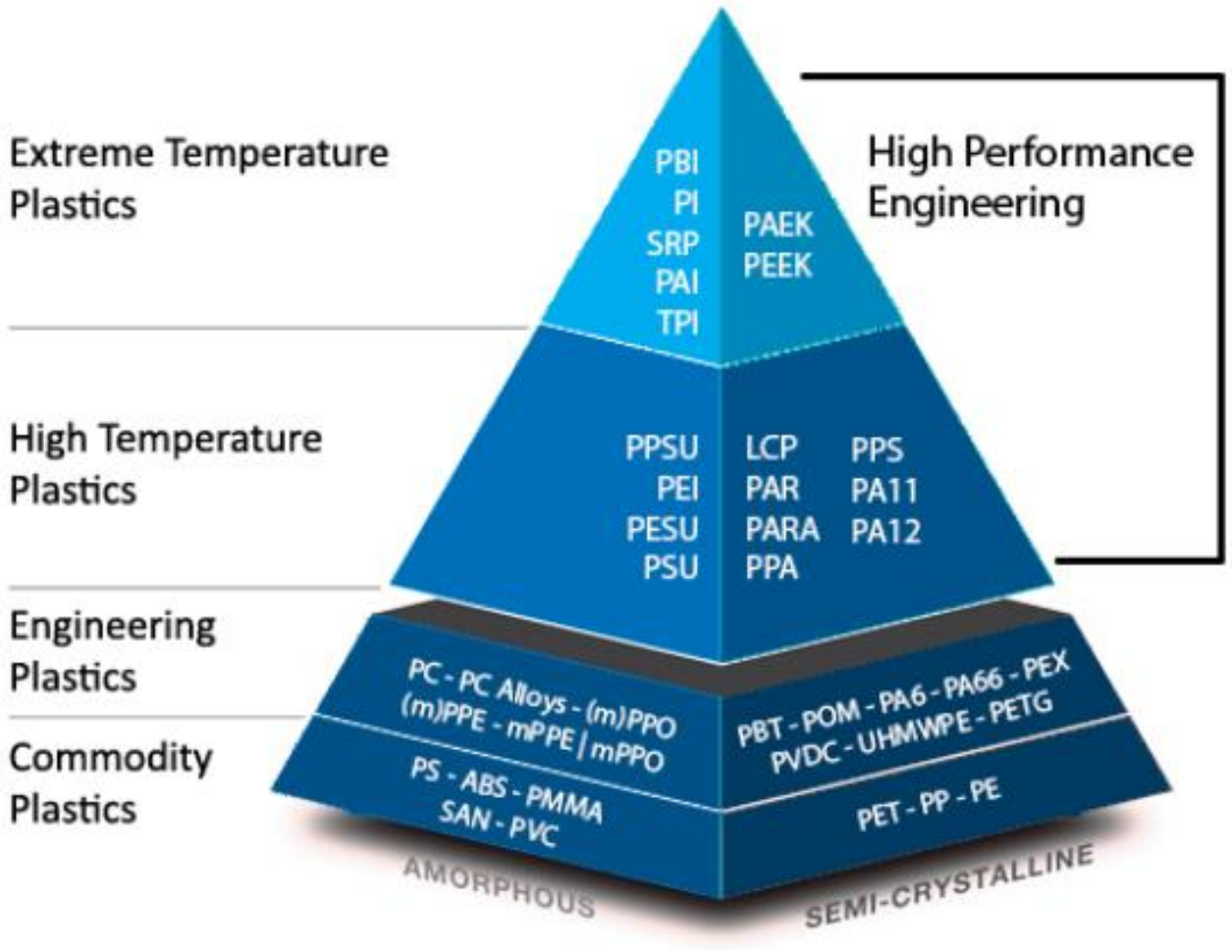


Medical instruments

Industrial robots

Agricultural applications

Image courtesy of Winzeler Gear and DuPont



http://polymers.com.au/thermoplastics/, 16.6.2022.

Advantages

- Low mass and inertia
- No lubrication required
- Corrosion resistance
- Sound and vibration damping
- Design freedom
- Lower cost for serial production

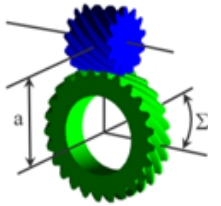
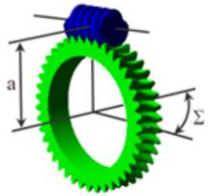
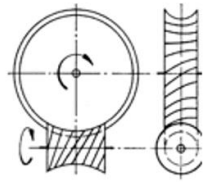
Drawbacks

- Inferior mechanical properties
- Inferior thermal properties
- Lower manufacturing tolerances
- Lower operating temperatures
- Moisture absorption

Optimisation goals

- High strength
- Low wear
- Low noise and vibrations
- Small space

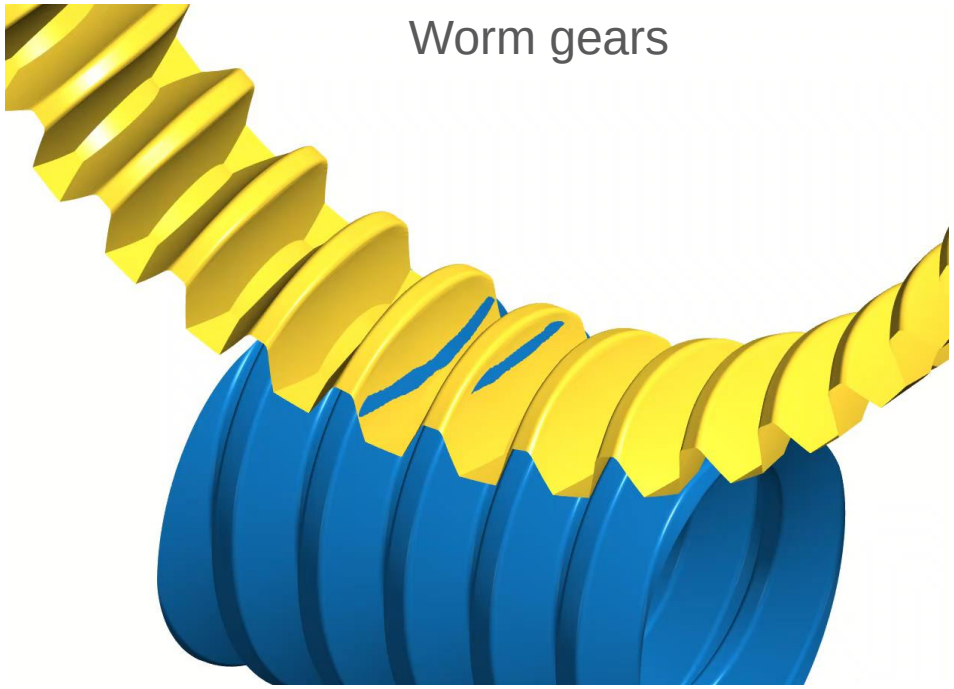
- High transmission ratio
- Fine pitch gearing
- Possible self locking (for small lead angles)

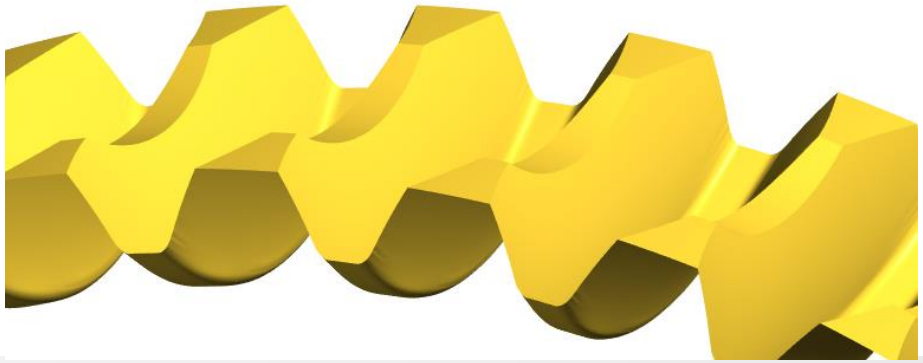
Name	Principle	Basic gear
Crossed axis helical gear set	 a > 0, Σ > 0	Cylindrical worm Cylindrical wheel
Worm gear set	 a > 0, Σ=90°	Cylindrical worm Enveloping wheel
Double enveloping worm gear set	 a > 0, Σ=90°	Enveloping worm Enveloping wheel

Hartmann W.: Berechnungs- und Gestaltungsunterlagen für Maschinenelemente (Calculation and design templates for machine elements), TU Chemnitz, 13th Edition.

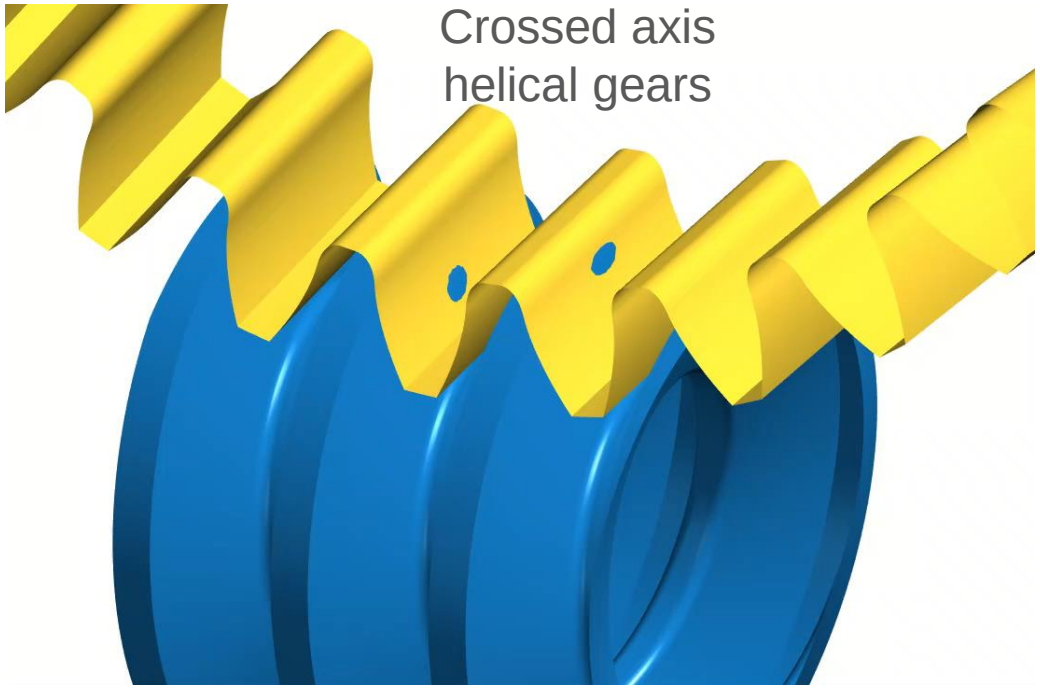
Introduction / Differences between Cylindrical and Globoidal Worm Wheels

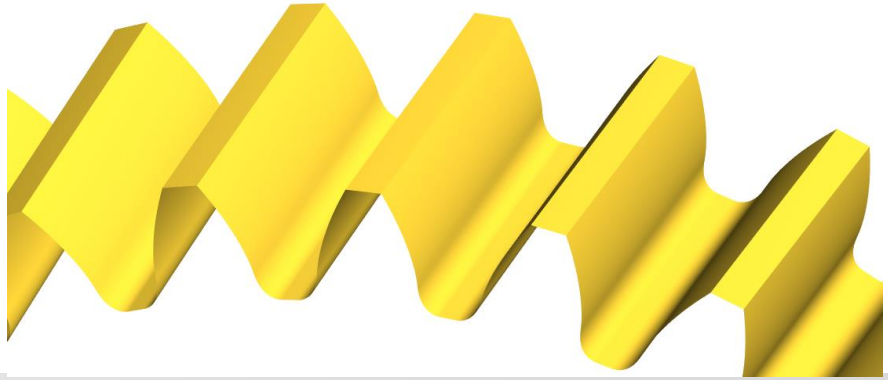
Worm gears





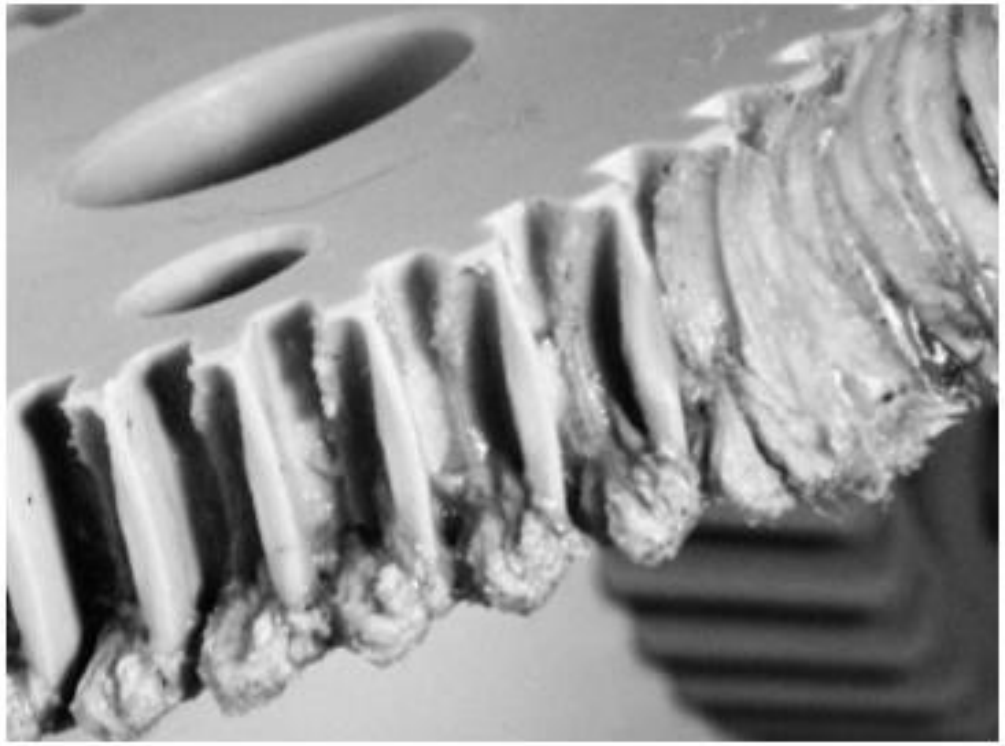
Crossed axis helical gears



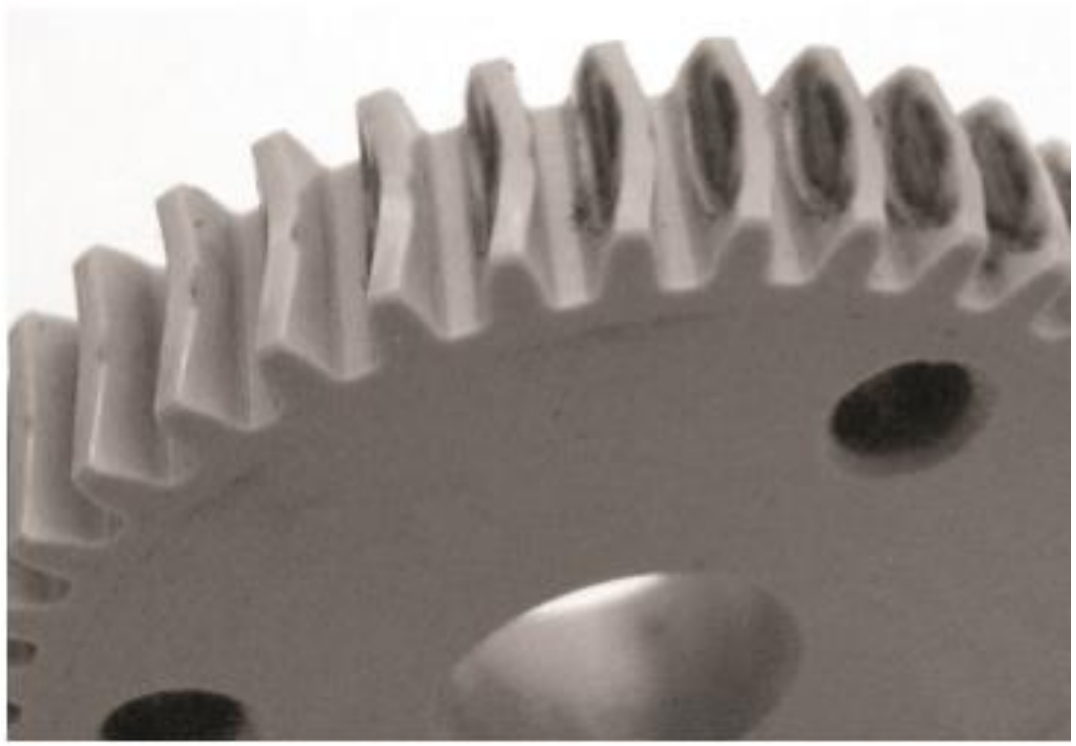


Typical Failure Modes / Melting and Deformation

Melting



Plastic deformation

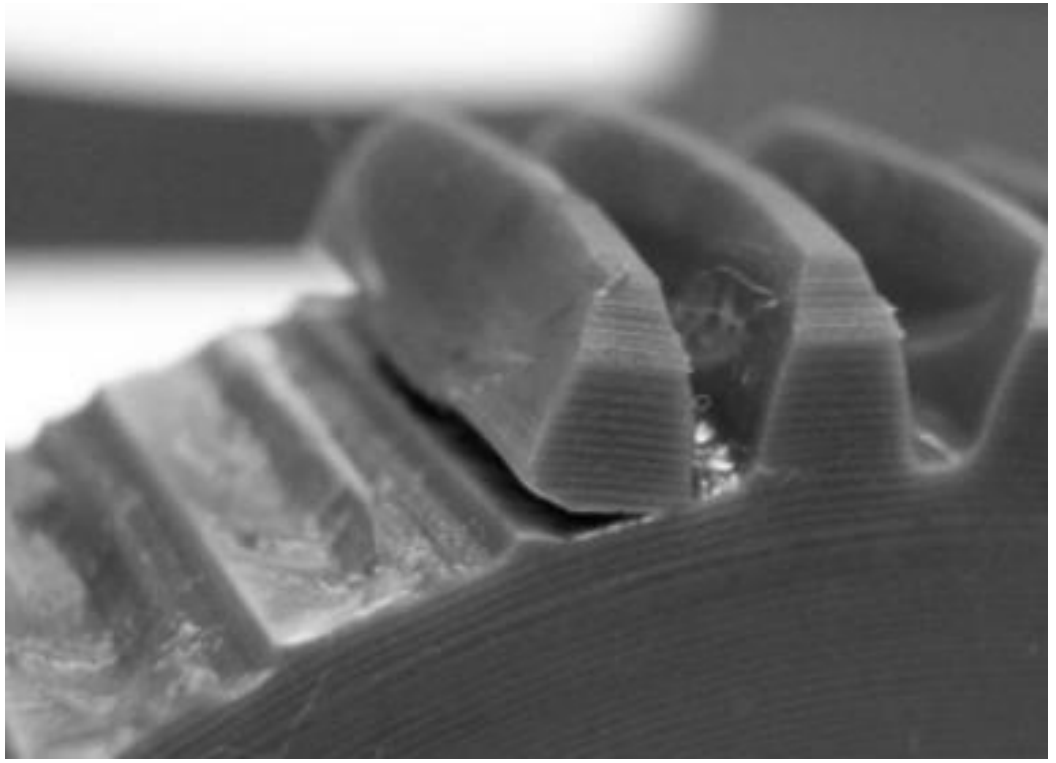


VDI 2736-1, Thermoplastic gear wheels - Materials, material selection, production methods, production tolerances, form design, 2014.

Typical Failure Modes / Tooth Fracture

Shear failure

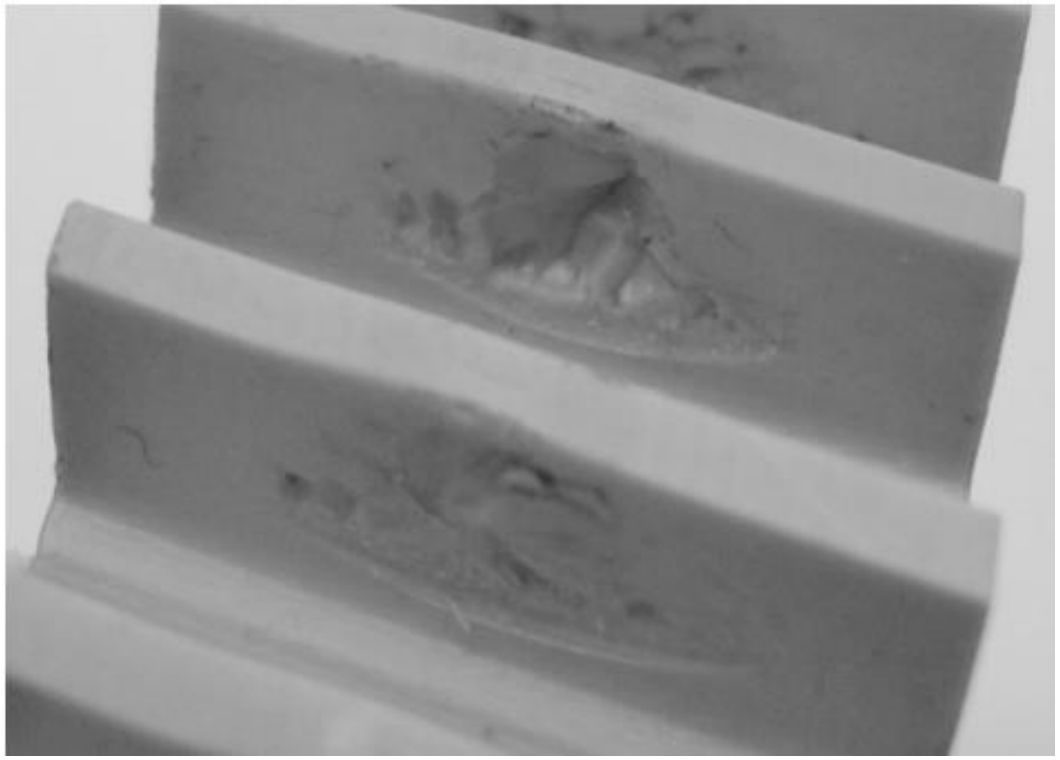
Bending failure



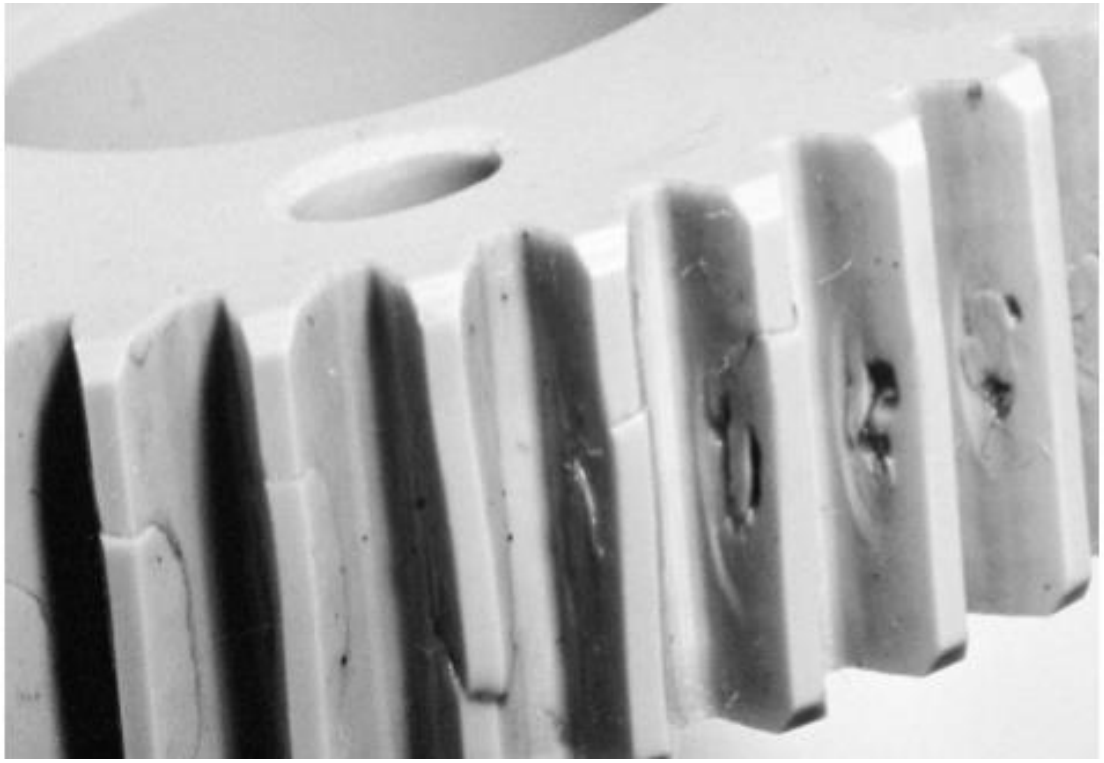
VDI 2736-1, Thermoplastic gear wheels - Materials, material selection, production methods, production tolerances, form design, 2014.

Typical Failure Modes / Pitting and Flank Fracture

Pitting



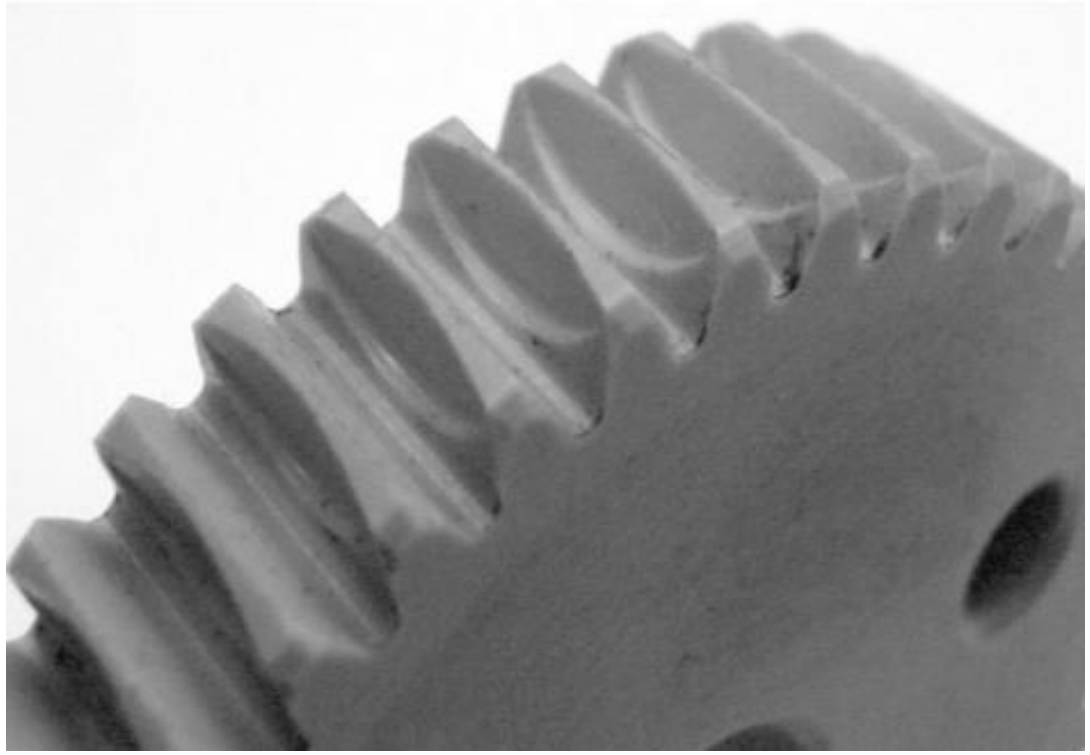
Flank fracture



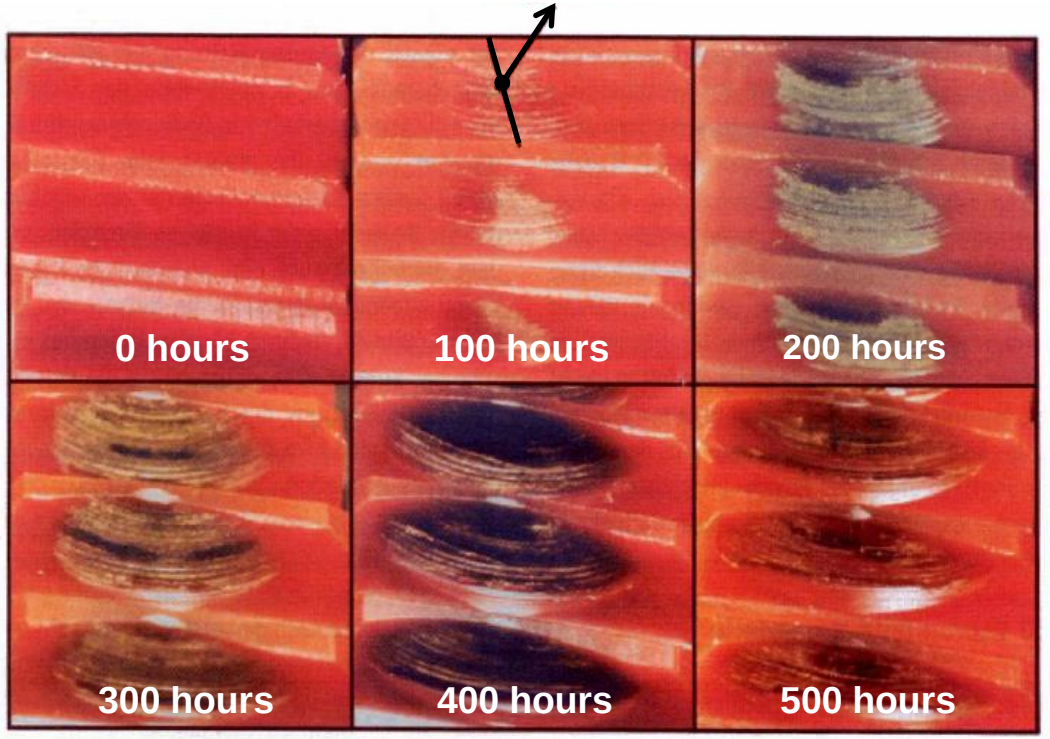
VDI 2736-1, Thermoplastic gear wheels - Materials, material selection, production methods, production tolerances, form design, 2014.

Typical Failure Modes / Wear

Wear

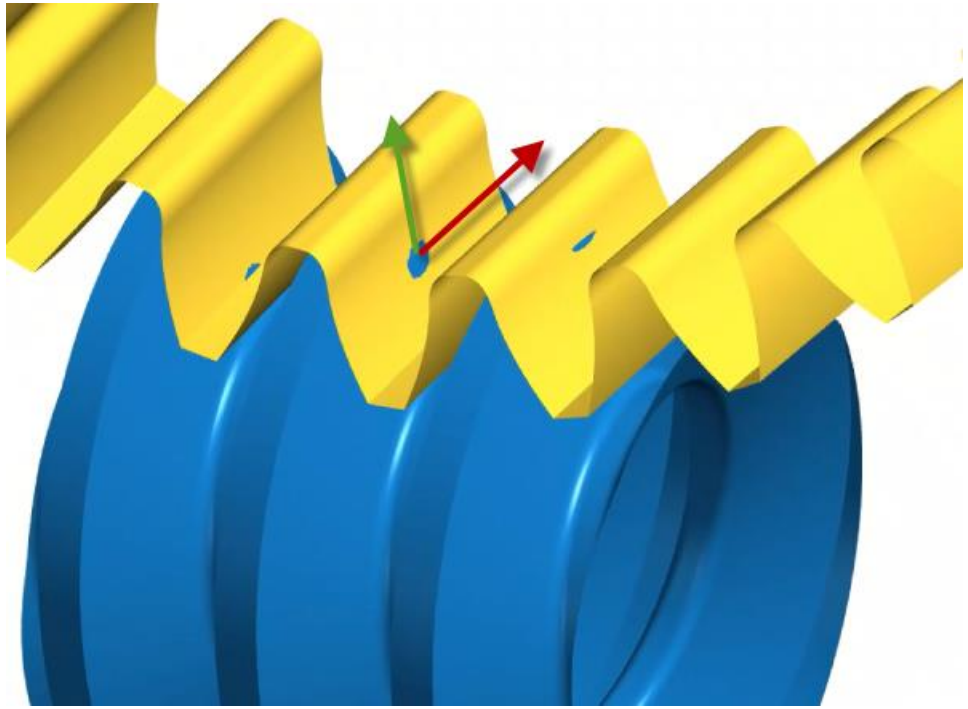


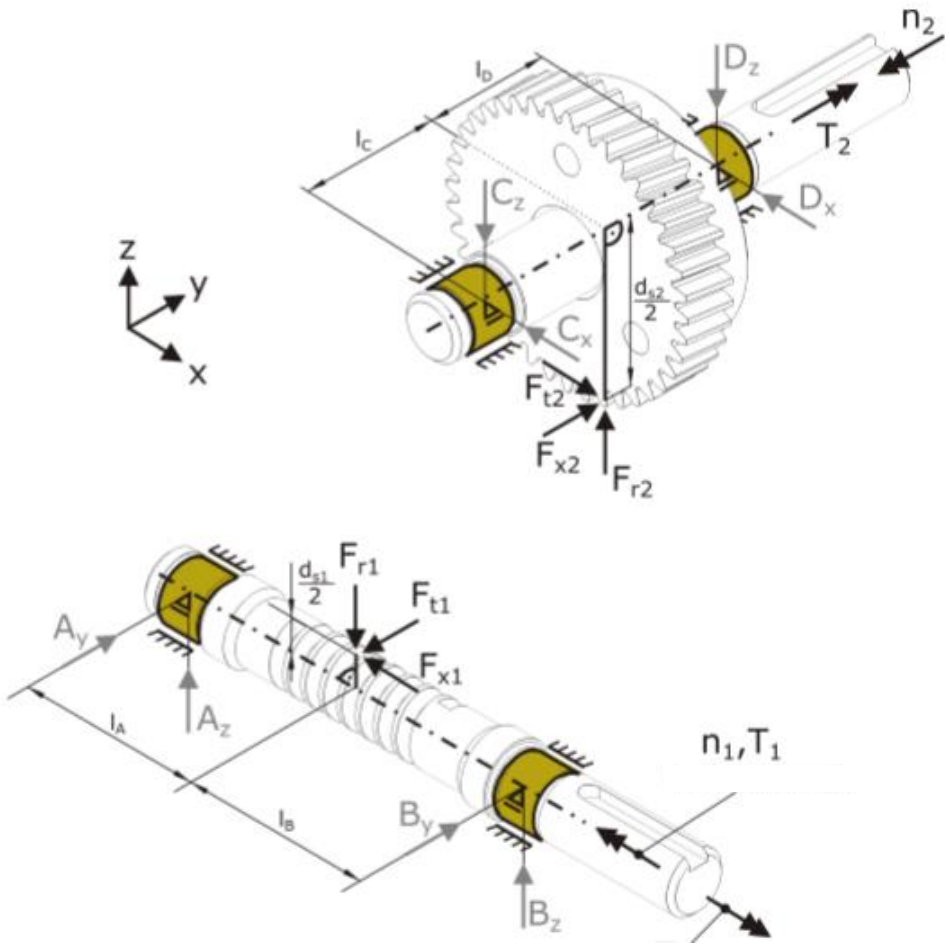
Contact line



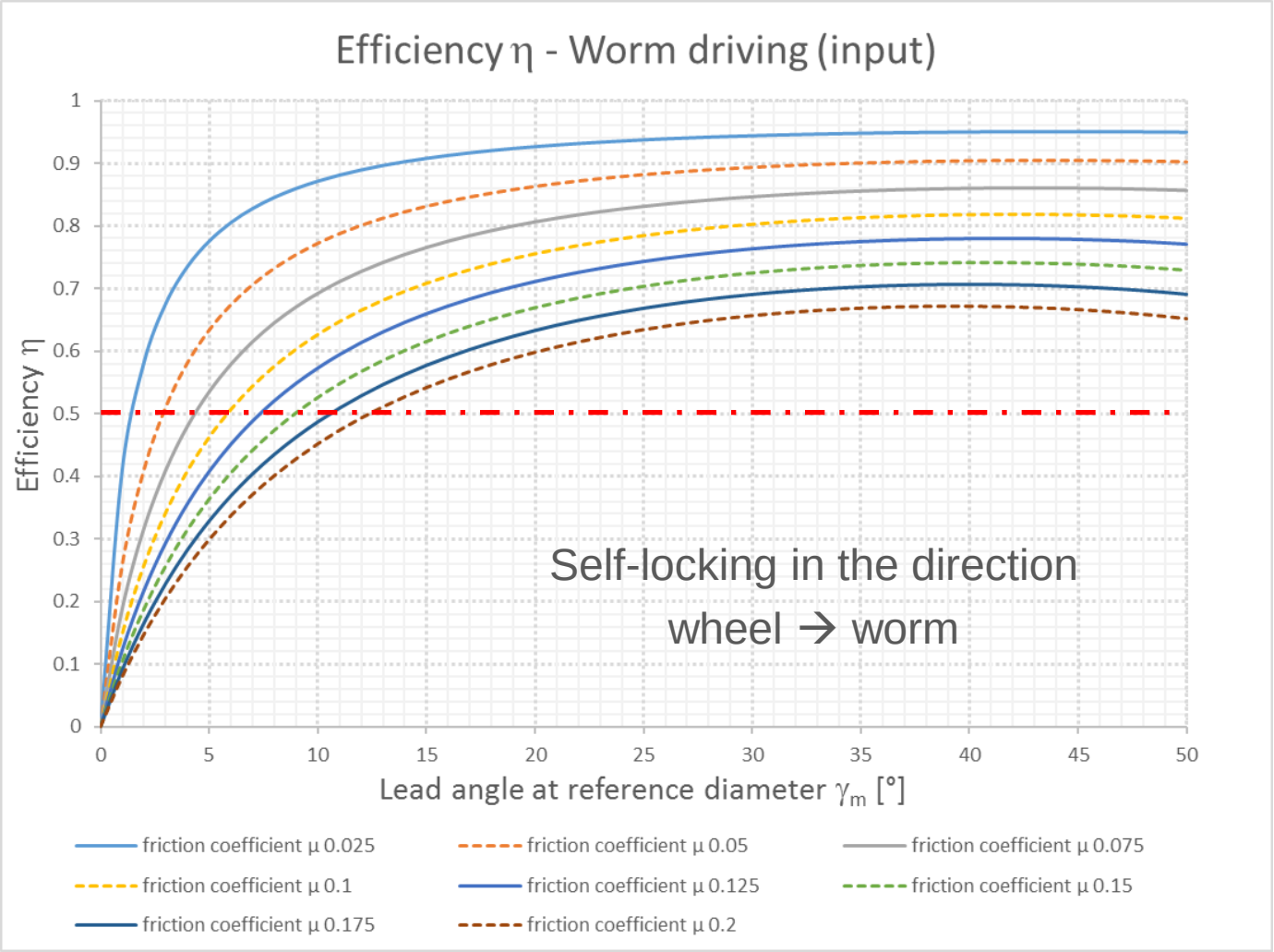
VDI 2736-1, Thermoplastic gear wheels - Materials, material selection, production methods, production tolerances, form design, 2014.
Predki W., Barton P., Load Carrying Capacity of Screw Helical Gears with Steel Pinions and Plastic Wheels, Gear Technology July/August 2004.

- Sliding + rolling in the profile direction
- Sliding in the flank line direction



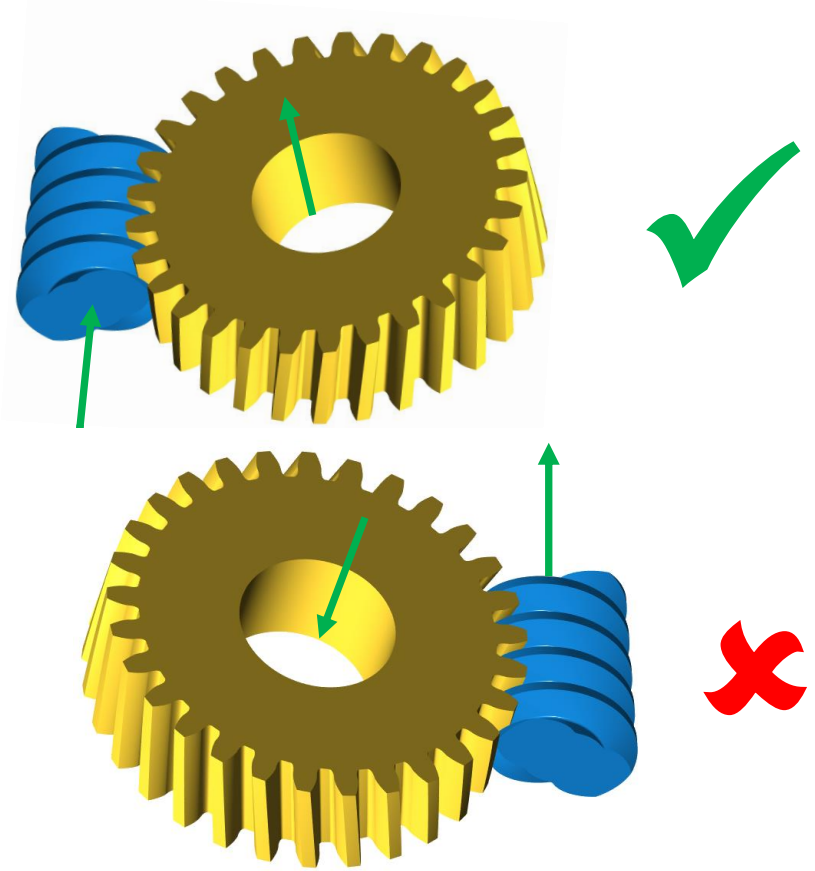


Pech M.: Tragfähigkeit und Zahnverformung von Schraubradgetrieben der Werkstoffpaarung Stahl/Kunststoff, Lehrstuhl für Maschinenelemente, Getriebe und Kraftfahrzeuge, Bochum, 2011.



Efficiency for Σ = 90

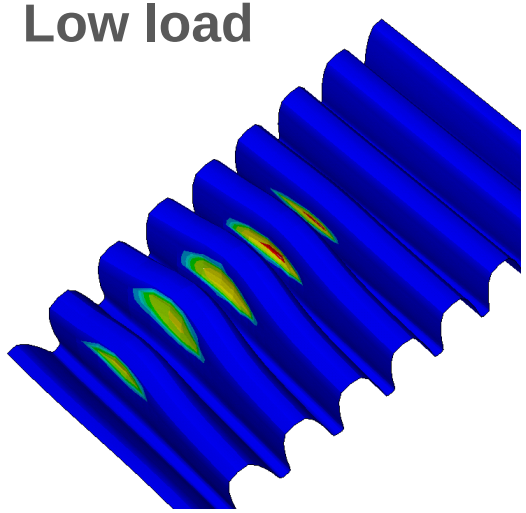
$$\eta_Z = \frac{\tan \beta_{s,b}}{\tan\left(\beta_{s,b} + \varrho^*\right)} \qquad \varrho^* = \tan^{-1} \frac{\mu}{\cos \alpha_{sn}}$$



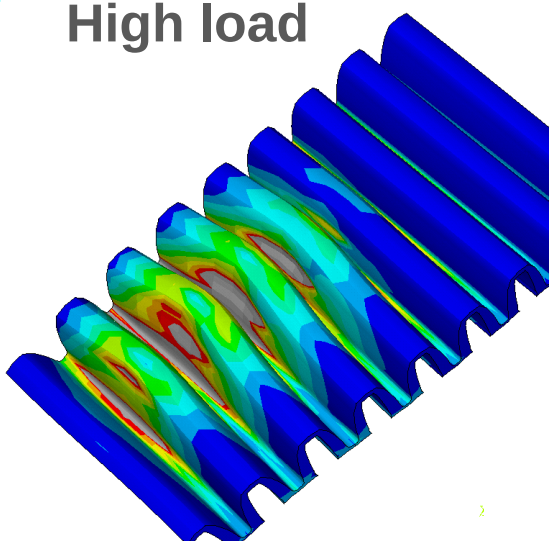
Strength Calculation

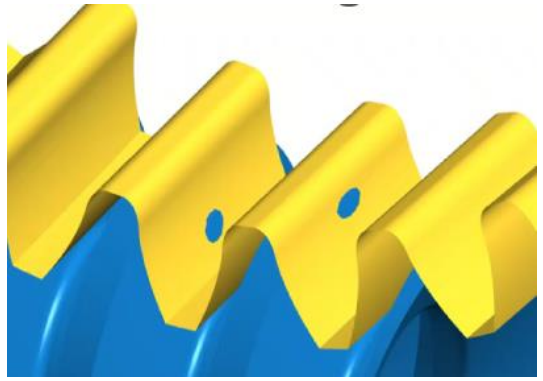
- As the load increases, the contact point extends to a contact ellipse

Low load



High load



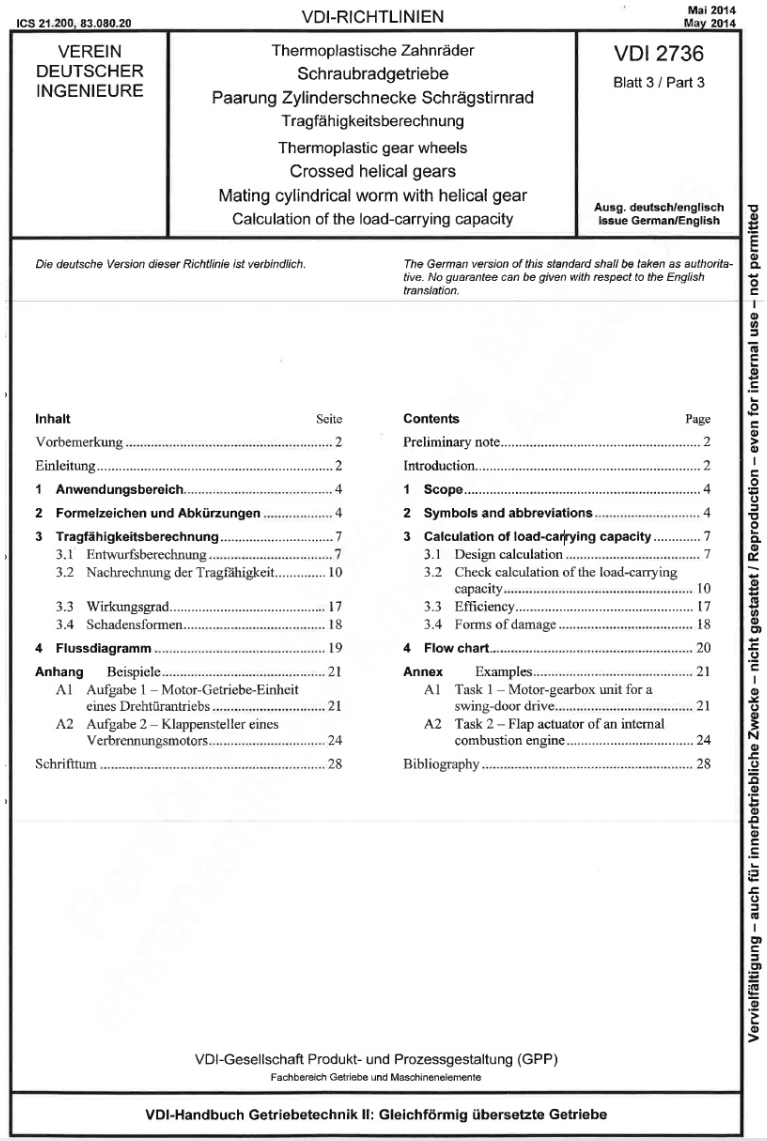


- Increase in load carrying capacity
  - Steel/bronze: 400%
  - Steel/plastic: 20%

Barton, P.: Tragfähigkeit von Schraubrad- und Schneckengetrieben der Werkstoffpaarung Stahl/Kunststoff, Ruhr Universität Bochum, Deutschland, 2000.

Strength Calculation

- VDI 2736-3
  - Shear
  - Pitting
  - Efficiency
  - Limitations
- VDI 2545
  - Bending
  - Pitting



ICS 21.200, 83.080.20 — VDI-RICHTLINIEN — Mai 2014 / May 2014

VEREIN DEUTSCHER INGENIEURE

Thermoplastische Zahnräder
Schraubradgetriebe
Paarung Zylinderschnecke Schrägstirnrad
Tragfähigkeitsberechnung

Thermoplastic gear wheels
Crossed helical gears
Mating cylindrical worm with helical gear
Calculation of the load-carrying capacity

VDI 2736
Blatt 3 / Part 3

Ausg. deutsch/englisch
Issue German/English

Die deutsche Version dieser Richtlinie ist verbindlich.

The German version of this standard shall be taken as authoritative. No guarantee can be given with respect to the English translation.

Inhalt Seite

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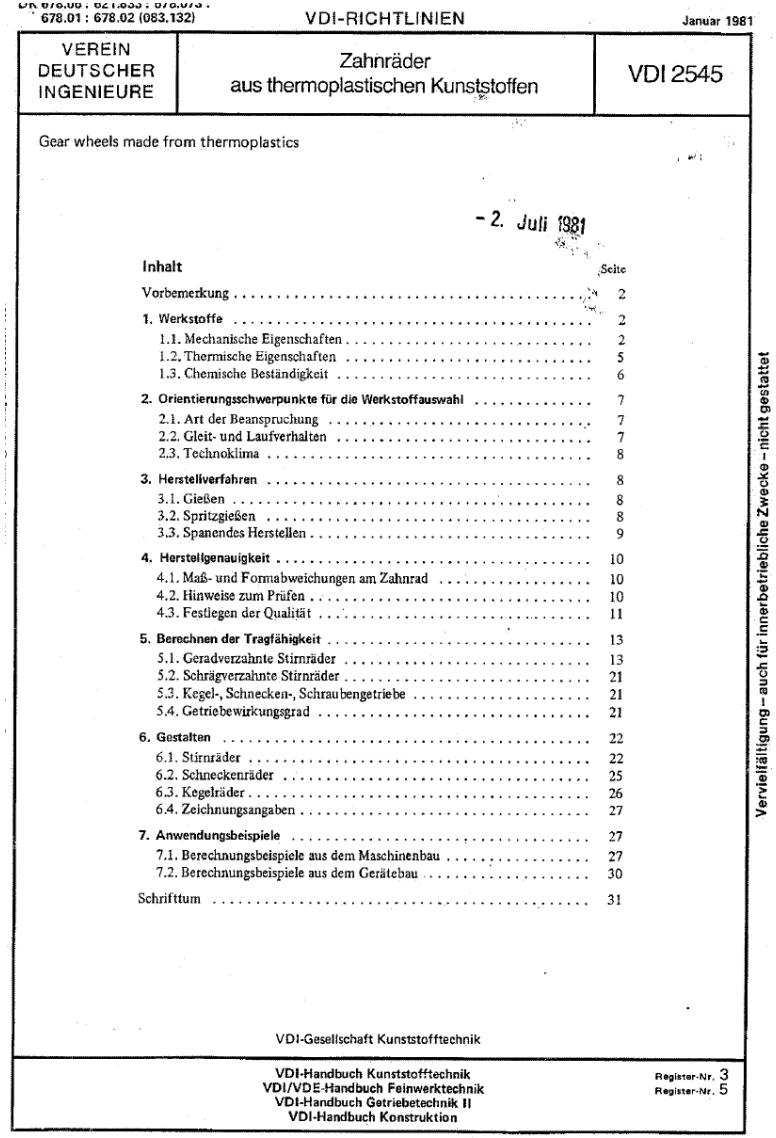
VDI-Gesellschaft Produkt- und Prozessgestaltung (GPP)
Fachbereich Getriebe und Maschinenelemente

VDI-Handbuch Getriebetechnik II: Gleichförmig übersetzte Getriebe



DK 678.01 : 678.02 (083.132) — VDI-RICHTLINIEN — Januar 1981

VEREIN DEUTSCHER INGENIEURE

Zahnräder
aus thermoplastischen Kunststoffen

VDI 2545

Gear wheels made from thermoplastics

– 2. Juli 1981

Inhalt Seite

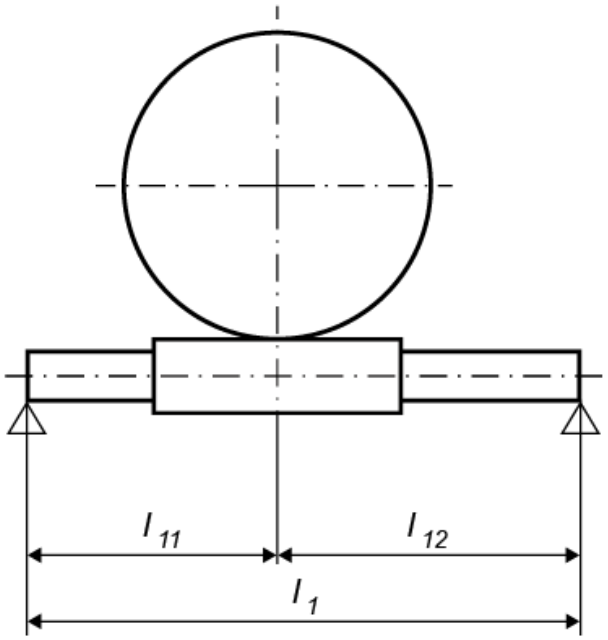
VDI-Gesellschaft Kunststofftechnik

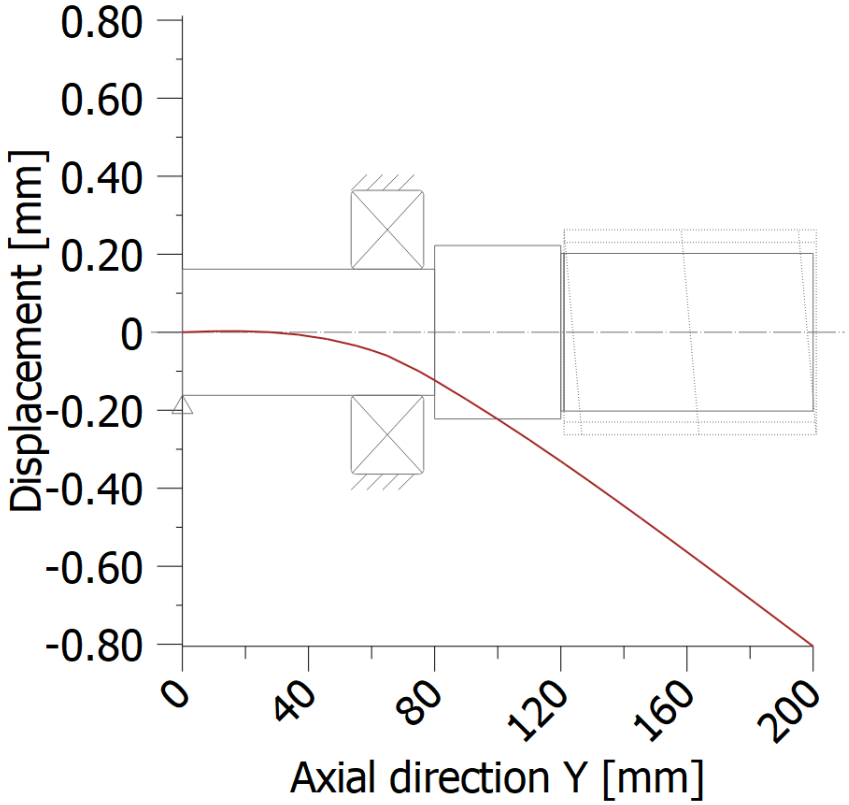
VDI-Handbuch Kunststofftechnik
VDI/VDE-Handbuch Feinwerktechnik
VDI-Handbuch Getriebetechnik II
VDI-Handbuch Konstruktion

Register-Nr. 3
Register-Nr. 5

Total Gear Solutions Gleason

- Should be checked in case of small worm diameter
  - Shaft module
  - FEM
  - Worm module

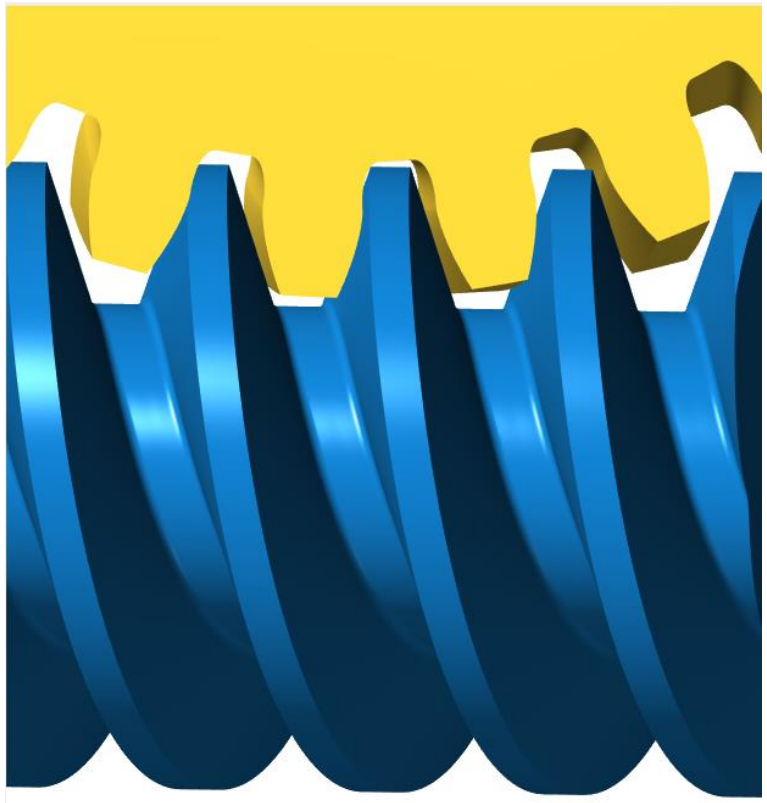




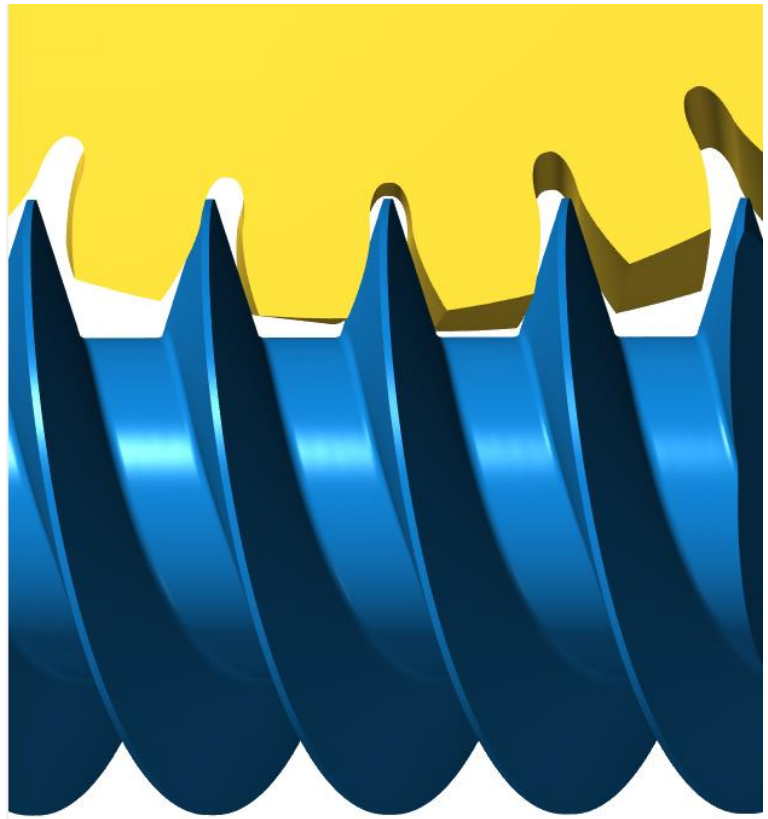
Strength Calculation / Tooth Thickness Optimization

- Increasing the tooth thickness of plastic gear – strength is increased
- Decreasing the tooth thickness of the metal gear – strength is decreased

Typical tooth thickness (50%-50%)

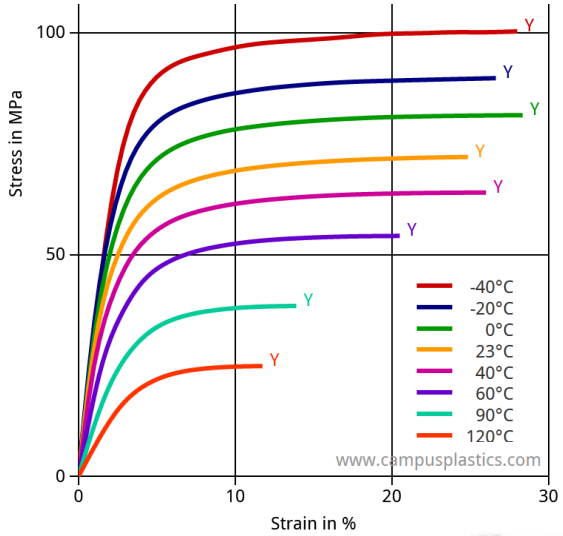


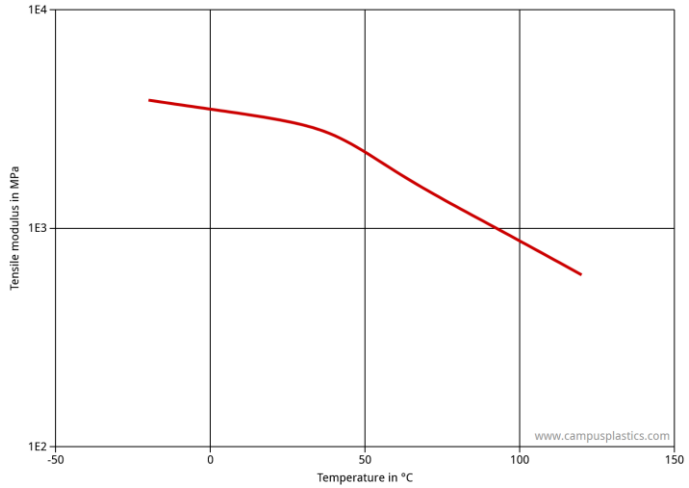
Optimized tooth thickness (30%-70%)



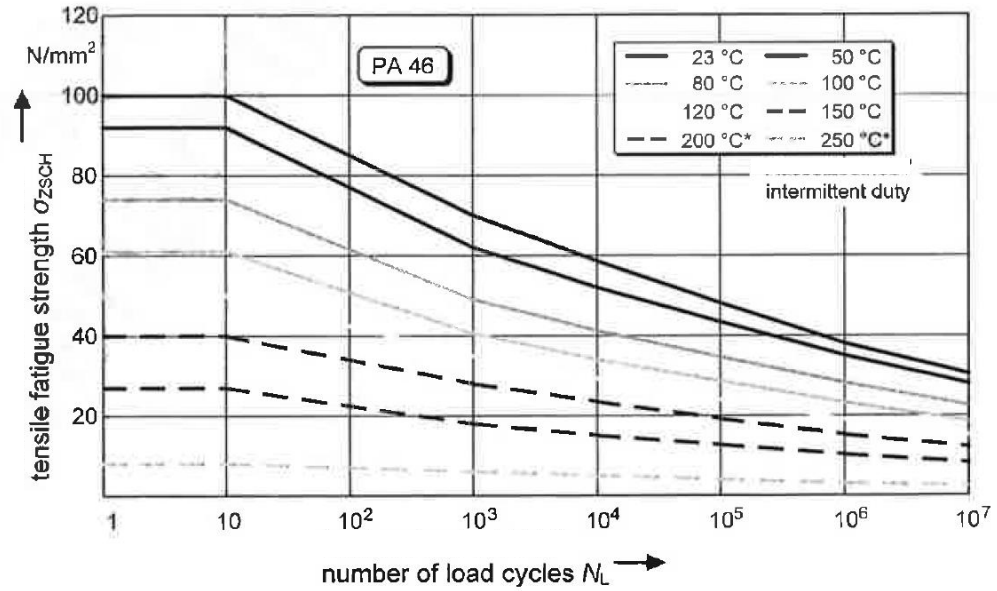
Material Properties

- Youngs modulus
- Ultimate and yield tensile strength
- Poisson ratio
- Coefficient of thermal expansion
- Water/humidity absorption



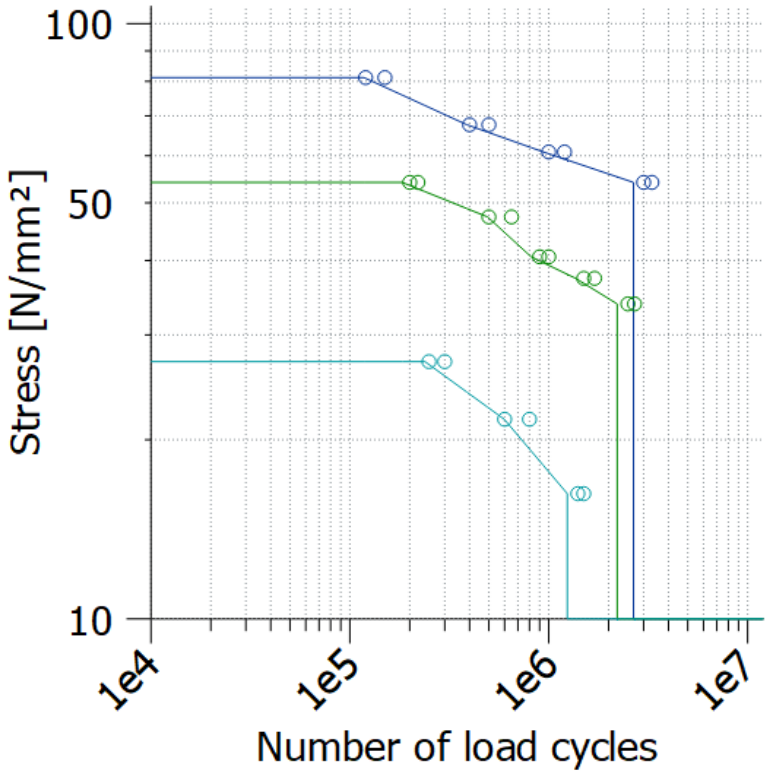


- SN curves for root and flank
- SN curves for shear



VDI 2736-3, Thermoplastic gear wheels - Crossed helical gears, 2014.

- Adding plastic materials to KISSsoft
- Evaluating measured SN data



Basic data | Test data | Data extrapolation | Material DAT file

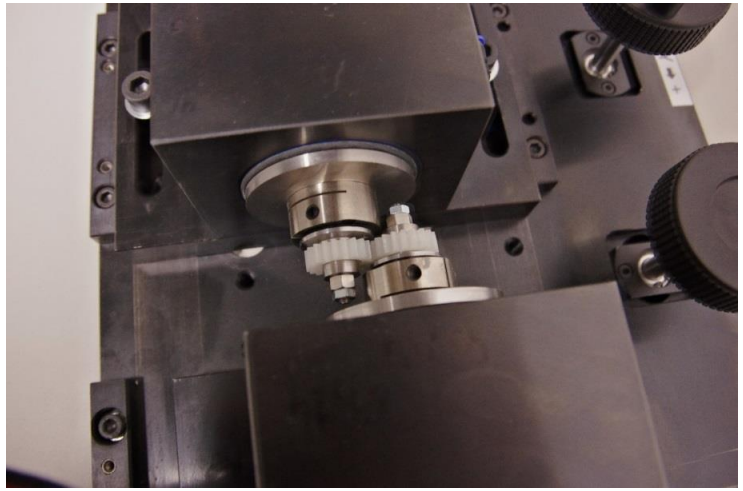
General

Material nam	Polymer_example	Density	ρ_{mat}	1320.0000	kg/m³
Comment	Enter...	Poisson's ratio	v	0.4000	
Data source	Measurements	Specific heat capacity	c_M	0.0000	J/(kg·K)
Material type	Thermoplastic PA	Specific heat conductivity	λ_M	0.0000	W/(m·K)
Type...ment	untreated	Coefficient ...al expansion	α	75.0000	10^{-6}/°C
Material grou	Not on the list	Absorption of water/humidi	w_{VOL}	0.0900	%

☐ Data available also for dry material (for PA6, ...)

Tribological properties

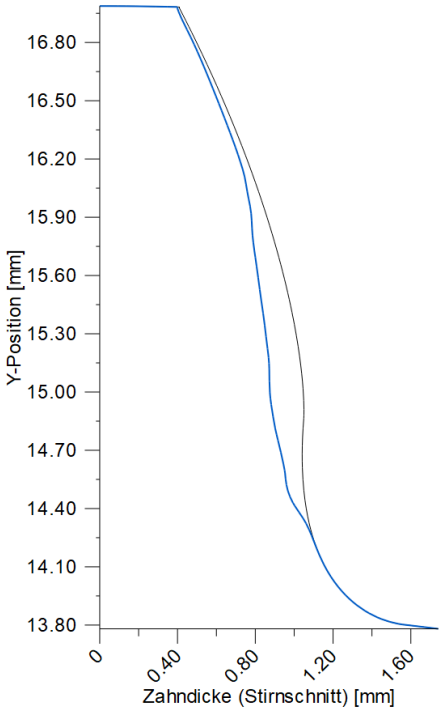
		Oil	Grease	Dry	
Coefficient of friction	μ	0.0400	0.0900	0.3200	
Wear coefficient	k_W	0.0000	0.0000	0.0000	mm³/Nm/10^6
Temperature dependent wear coefficient		No	No	No	

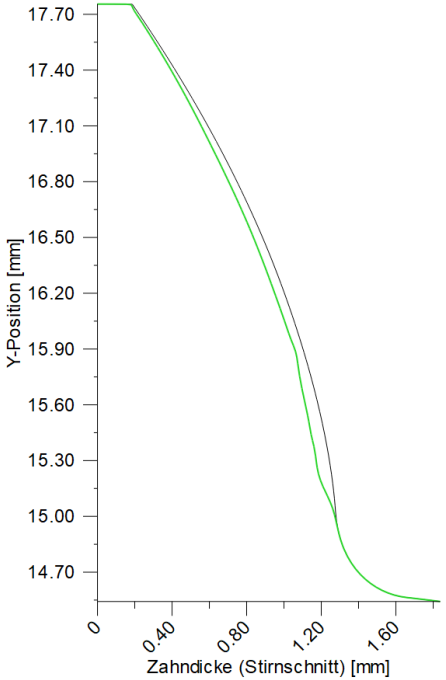


Wear Calculation / According to Pech

- Calculation of plastic deformation, wear intensity and total wear
- Calculation of COF, efficiency, lubricant temperature and gear temperatures

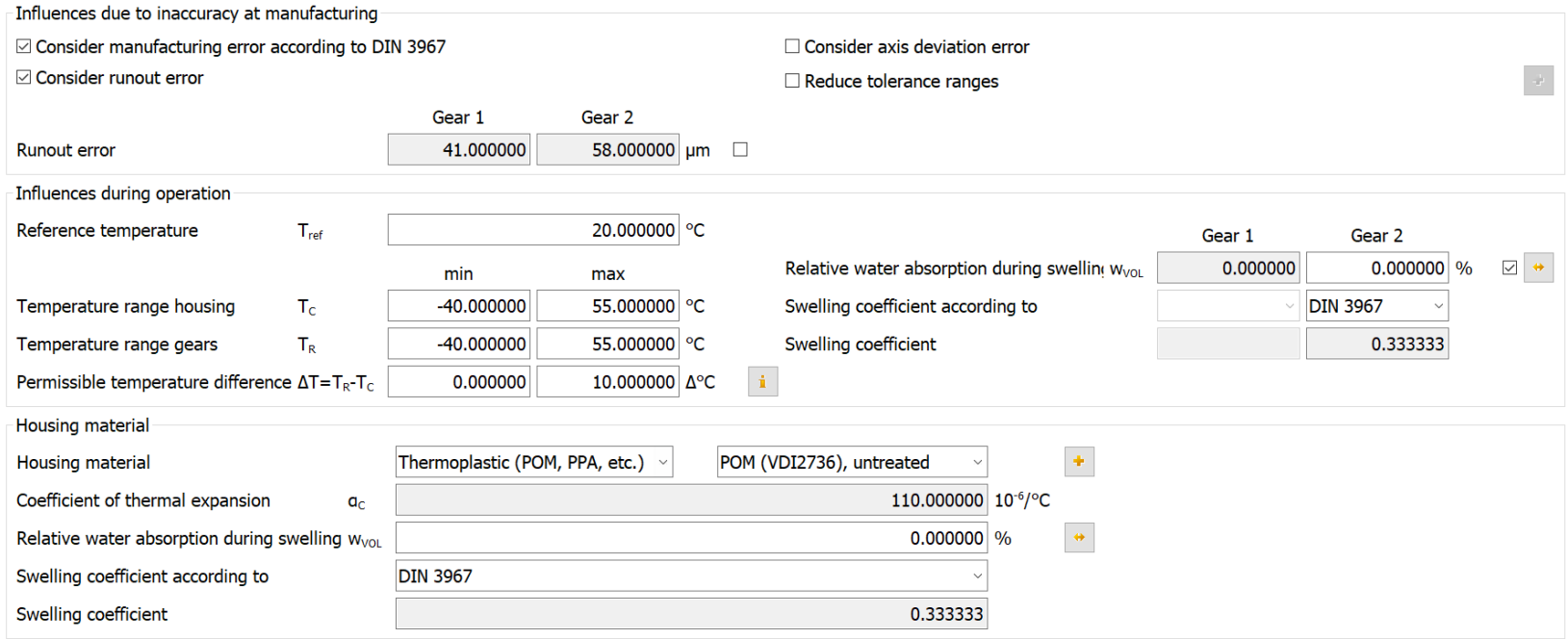
- The following limitations apply for the calculation:
  - Shaft angle of 90°
  - Grease lubrication
  - Driving gear: worm
  - Material of worm: steel
  - Material of worm gear: POM, PEEK, PEEK+30% CF or PA46



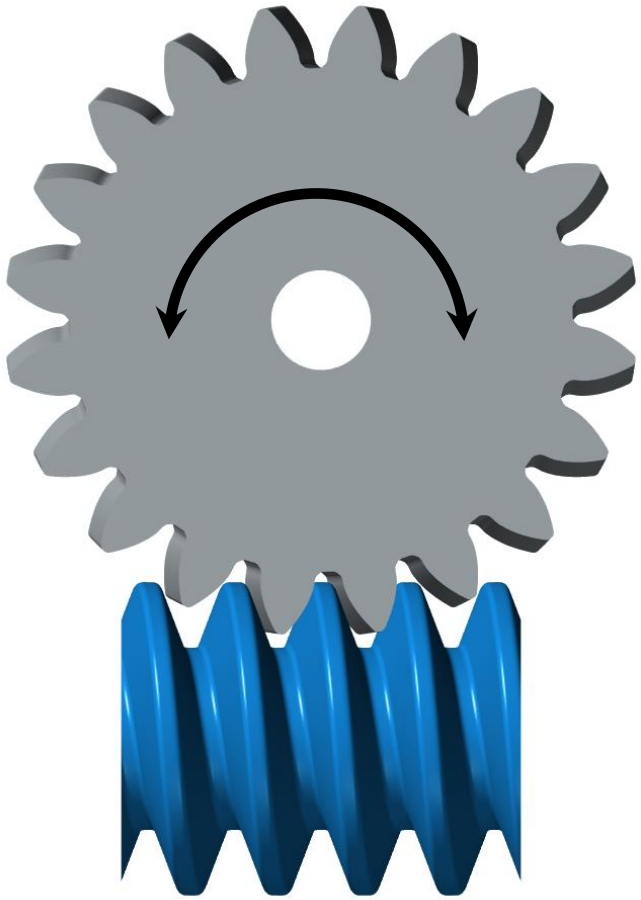


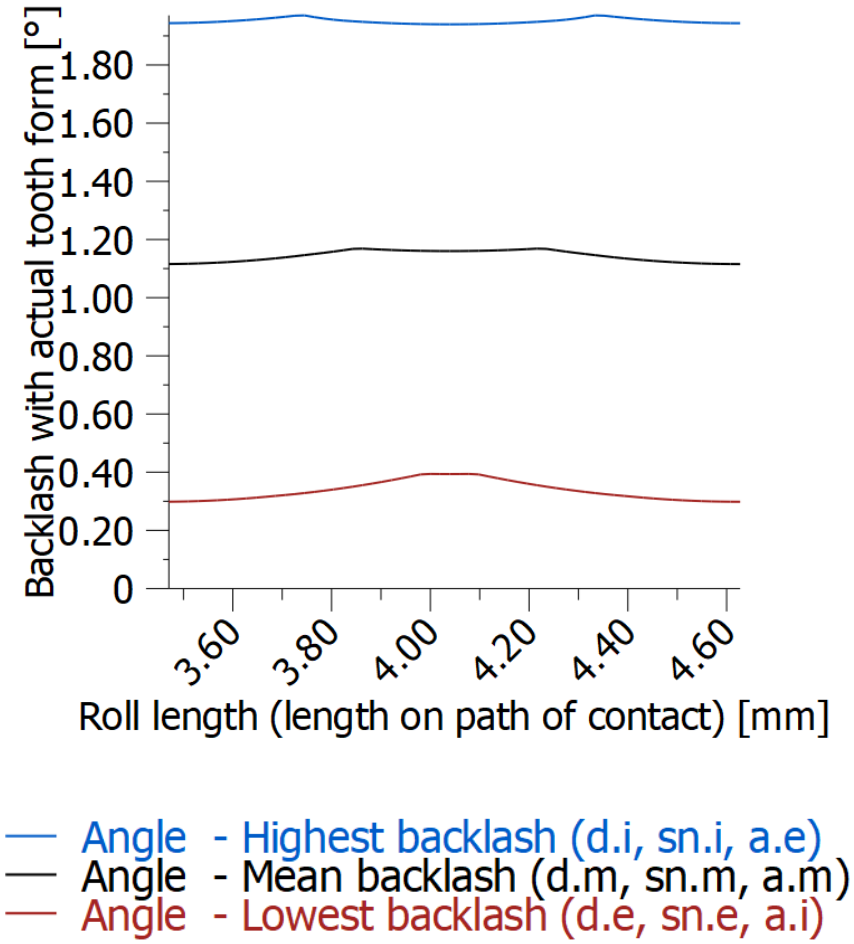
Operating Backlash

- Nominal backlash
- Acceptance backlash (manufacturing deviations, mounting errors, runout)
- Operating backlash
  - Housing temperature change
  - Housing water absorption
  - Housing material
  - Gears temperature change
  - Gears water absorption

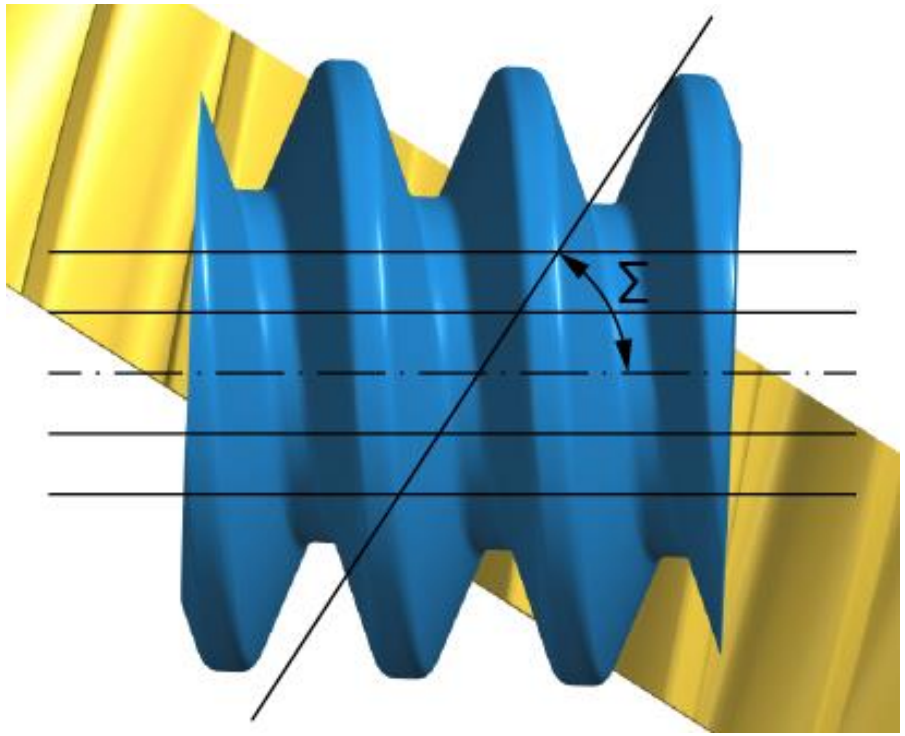


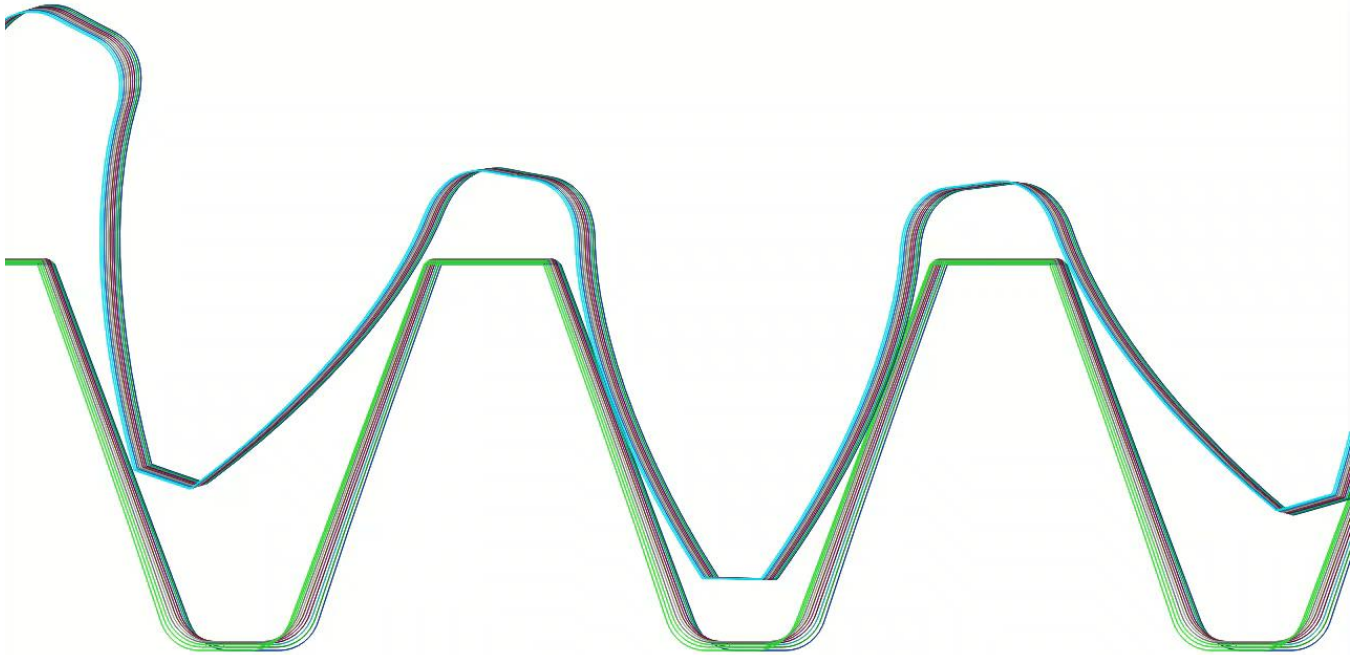
Backlash Calculation



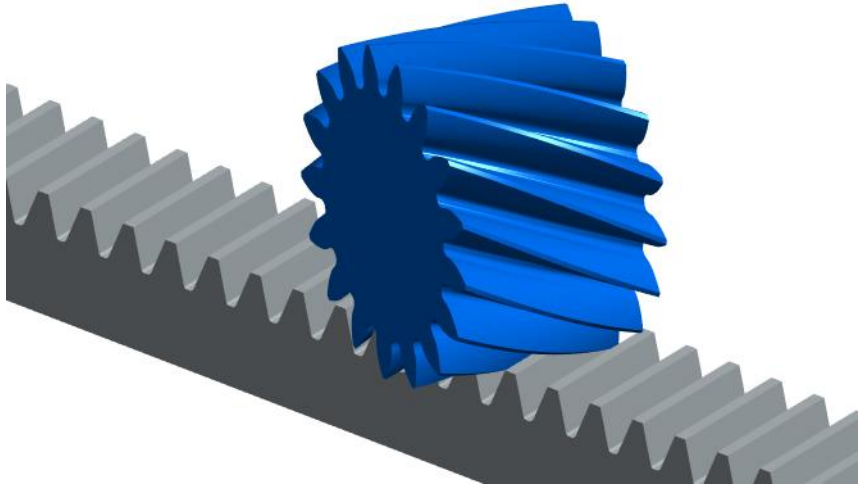


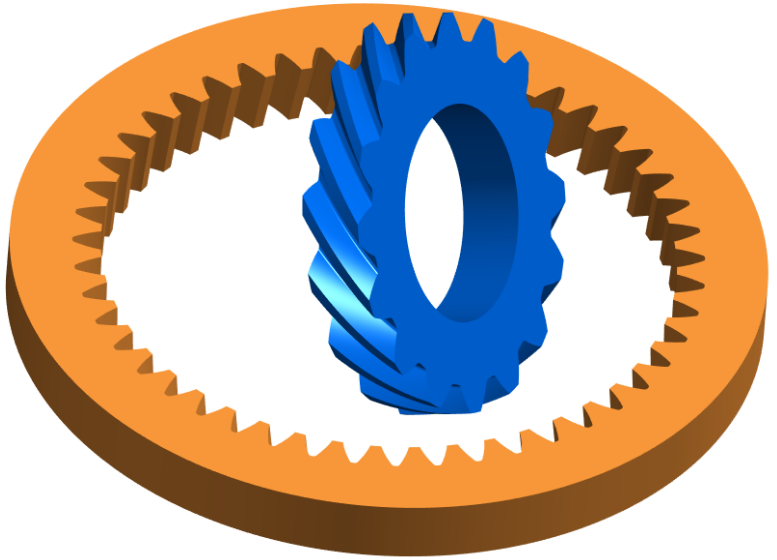
Meshing with Sections

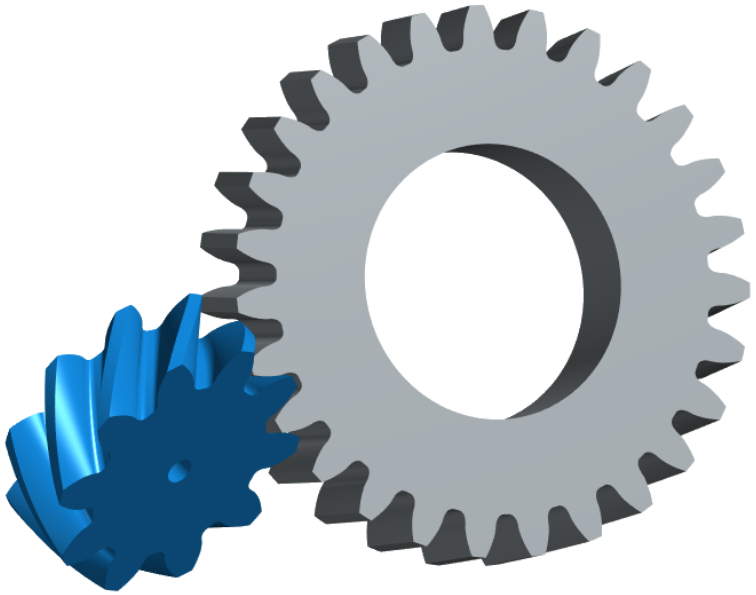


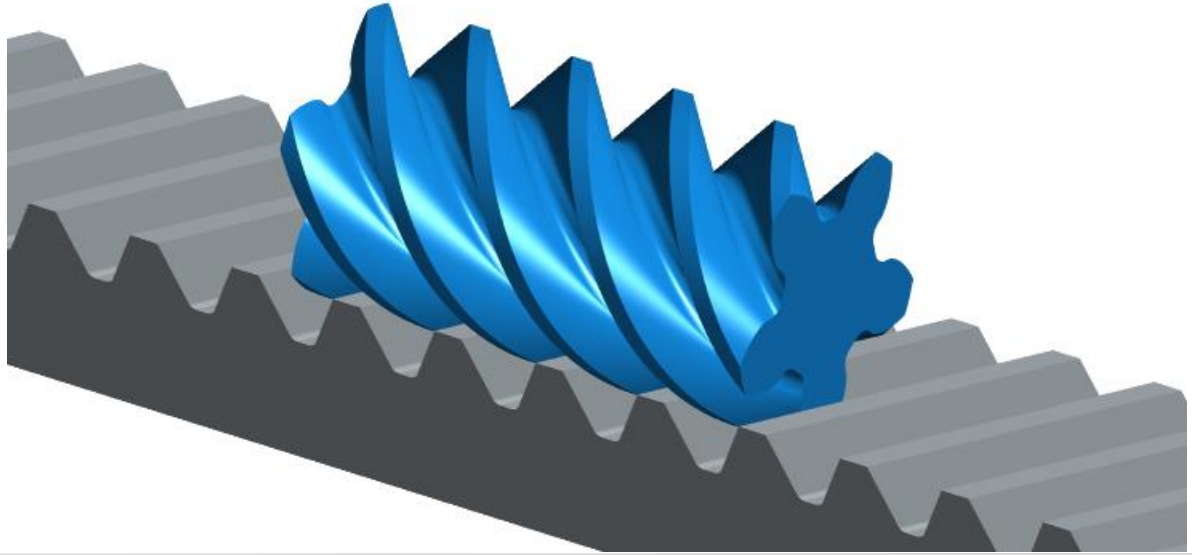


Crossed Axis Helical Gear Configurations





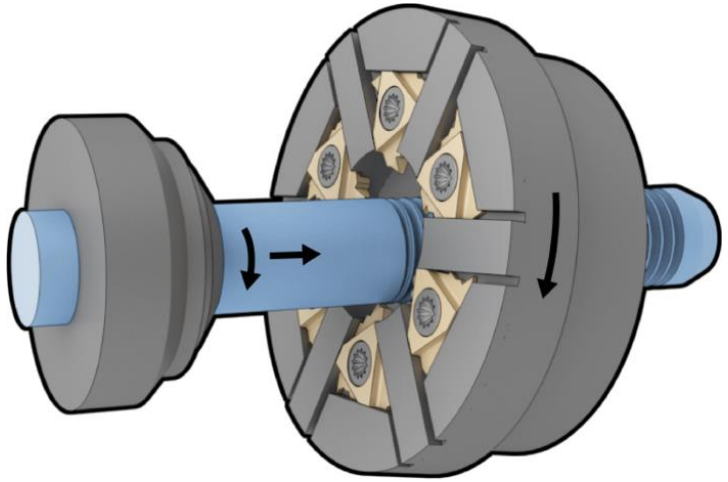


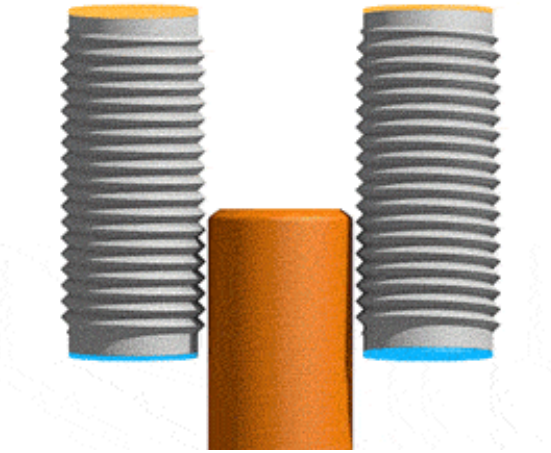


Manufacturing

- Worm cutting (turning or whirling)
- Worm rolling
- Worm injection moulding

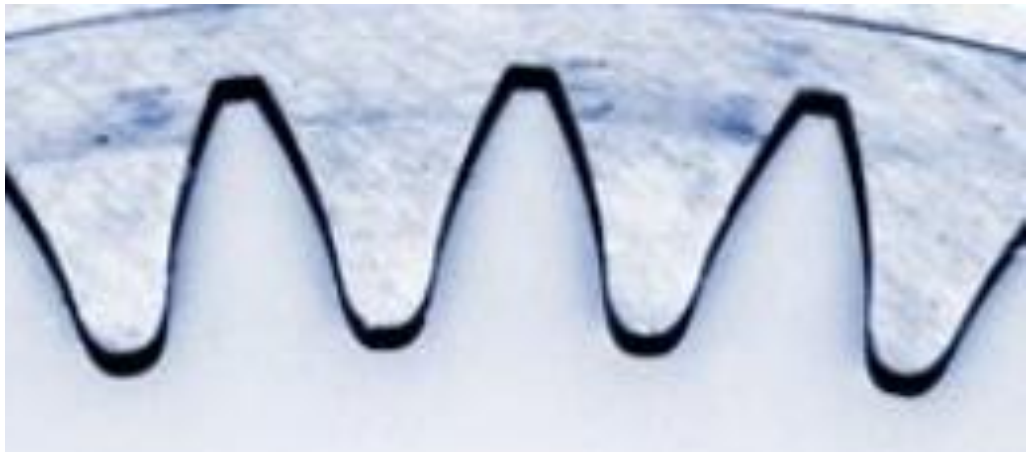
- Gear wheel injection moulding
- Gear wheel cutting

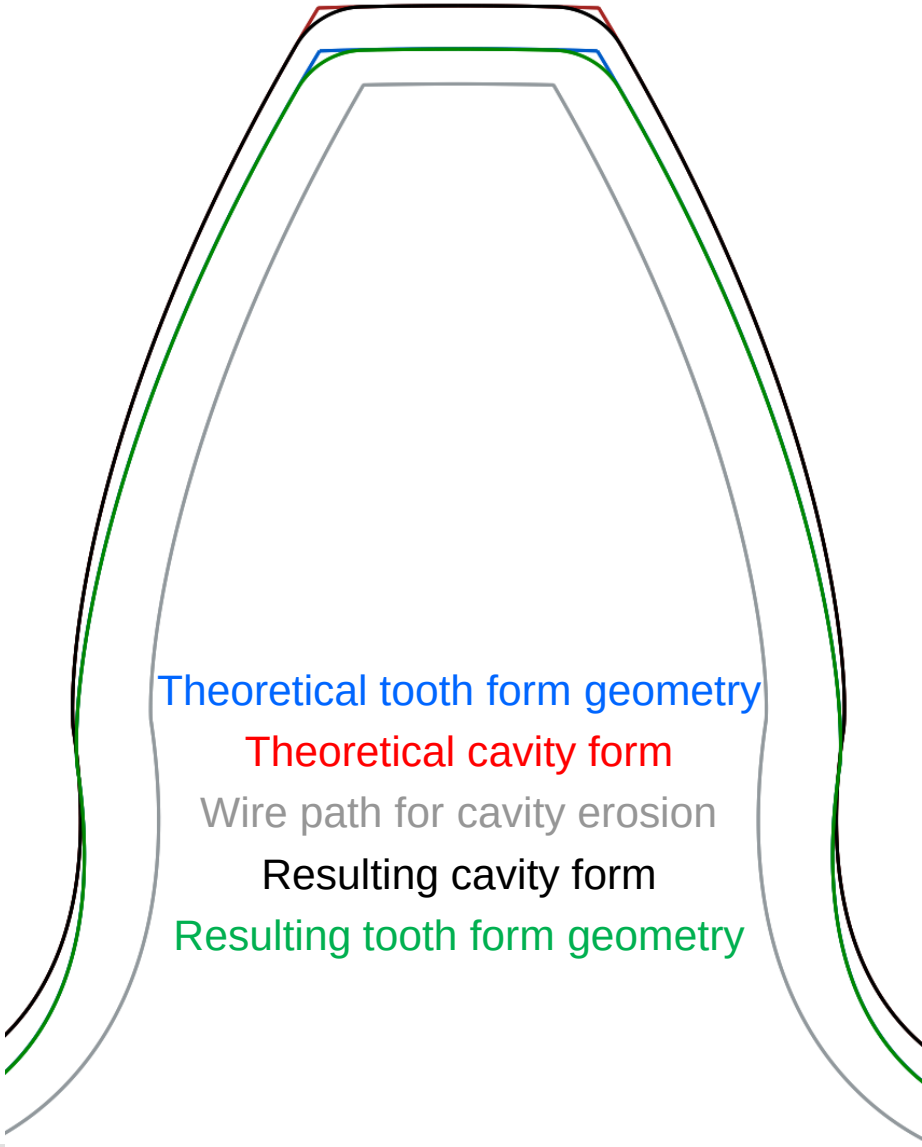




www.profiroll.com, https://www.manufacturingguide.com, https://blog.igus.de/herstellung-gewindespindel/ 16.6.2022.

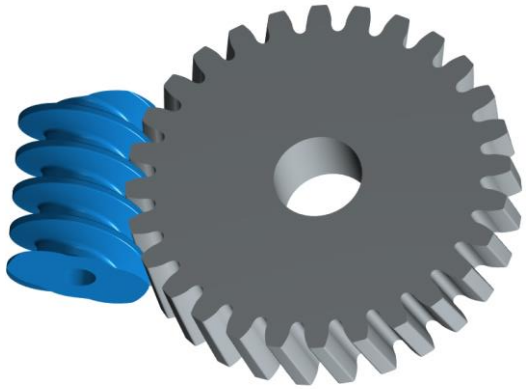
- Compensation for mould shrinkage
- Compensation for wire erosion

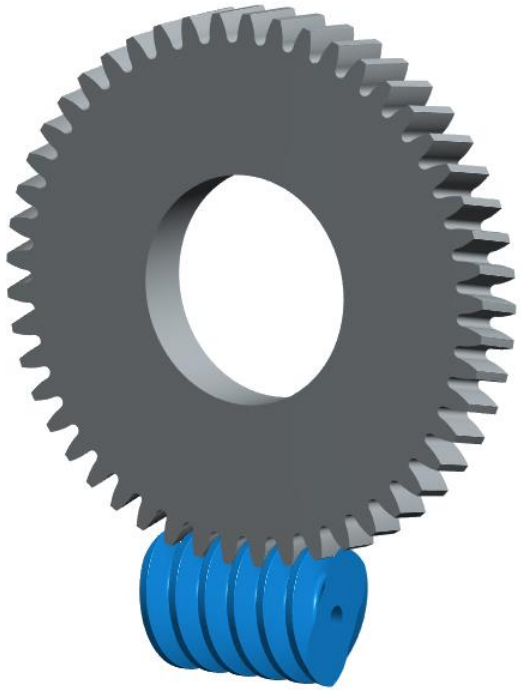


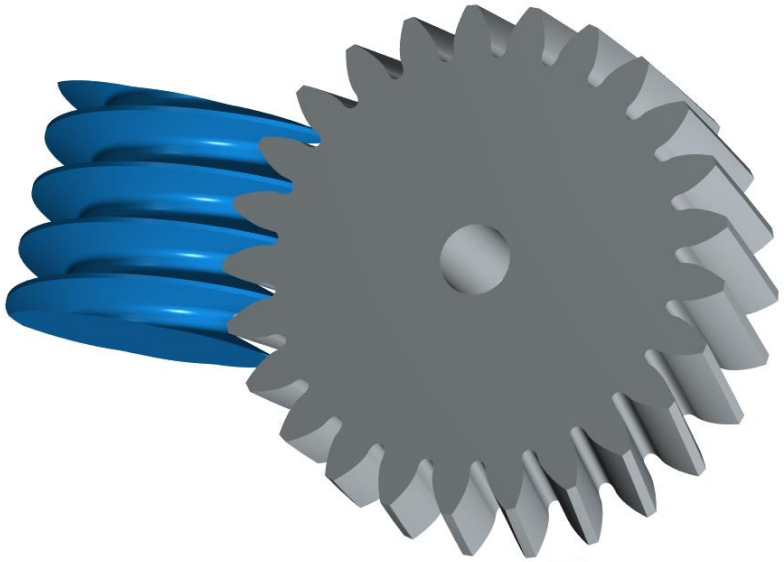


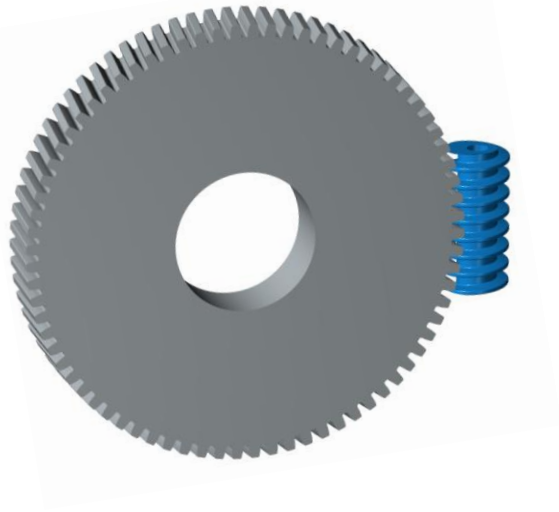
Engineering Projects and Services

- 50+ engineering projects on crossed helical axis gears
- Coffee machine
- Car mirror application
- Window regulator
- Wash machine opener
- Lock application
- Roof opening mechanism
- Head rest application
- Positioning system
- ...



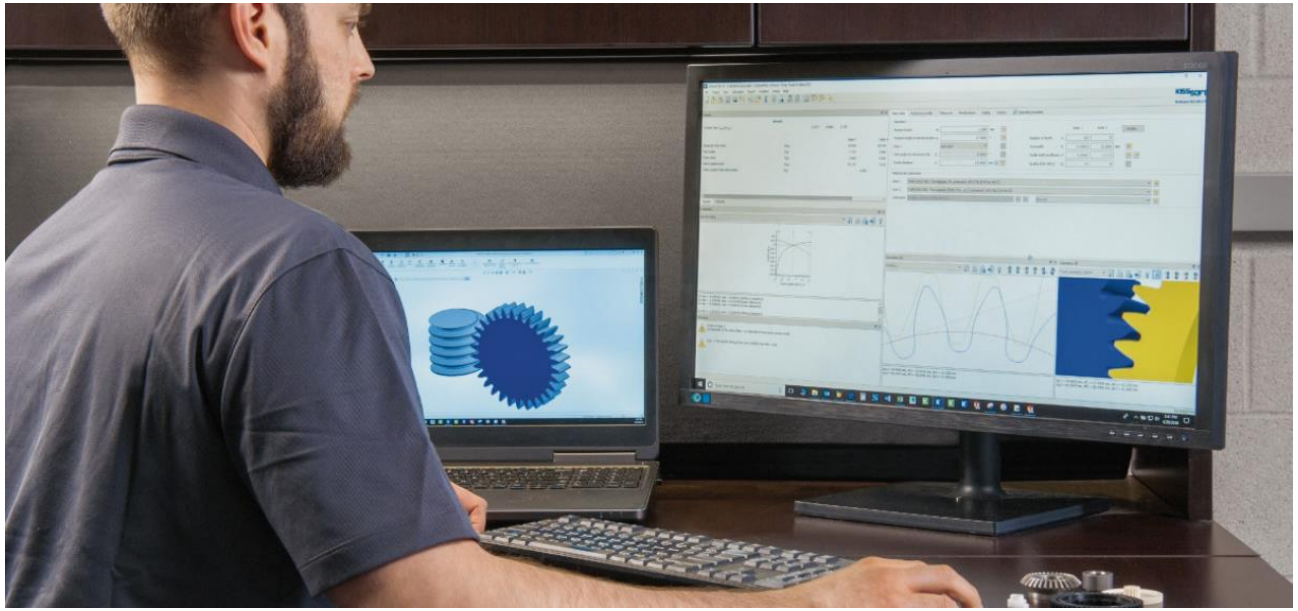






Conclusions

- Wide range of potential applications for crossed axis helical gears
- Different challenges for the design and optimization
- Design tools and experience is accessible, yet hard to find



Thank you for your attention

Thermoplastic Crossed Axis Helical Gears

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KISSsoft AG