

# Thermoplastic Crossed Axis Helical Gears: Design, Analysis and Manufacture

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KISSsoft AG

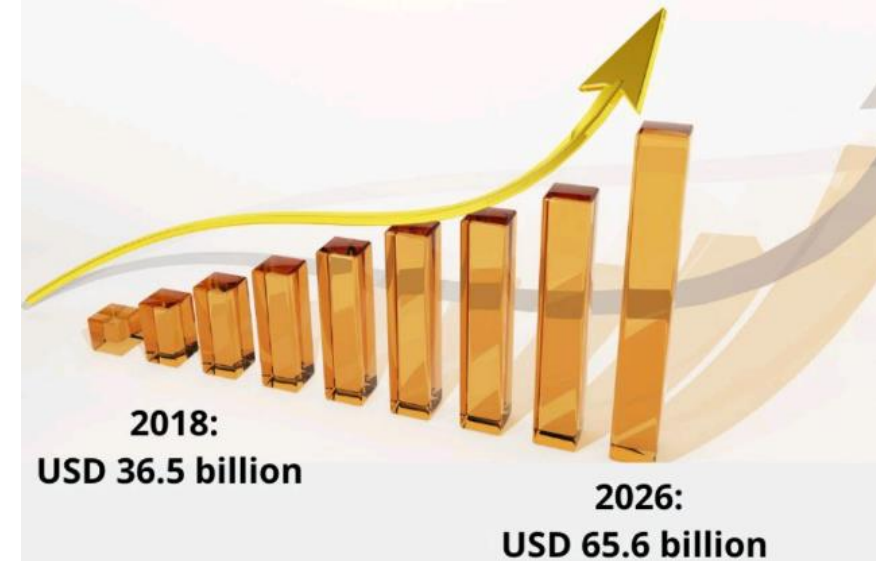


- Introduction
- Typical failure modes
- Efficiency and strength calculation
- Plastic material data
- Backlash calculation
- Manufacturing
- Conclusions

- 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**

**HIGH PERFORMANCE THERMOPLASTICS  
MARKET:  
GROWING AT A CAGR OF 7.7%**



FINDOUTABOUTPLASTICS.COM

Source: [3wnews.org/uncategorised/230124/high-performance-thermoplastics-market-statistics-facts-and-figures-size-growth-and-forecast-2026/](https://3wnews.org/uncategorised/230124/high-performance-thermoplastics-market-statistics-facts-and-figures-size-growth-and-forecast-2026/)

Actuators for  
automotive  
industry

Medical  
instruments

Kitchen  
appliances

Industrial  
robots

Office  
equipment

Agricultural  
applications

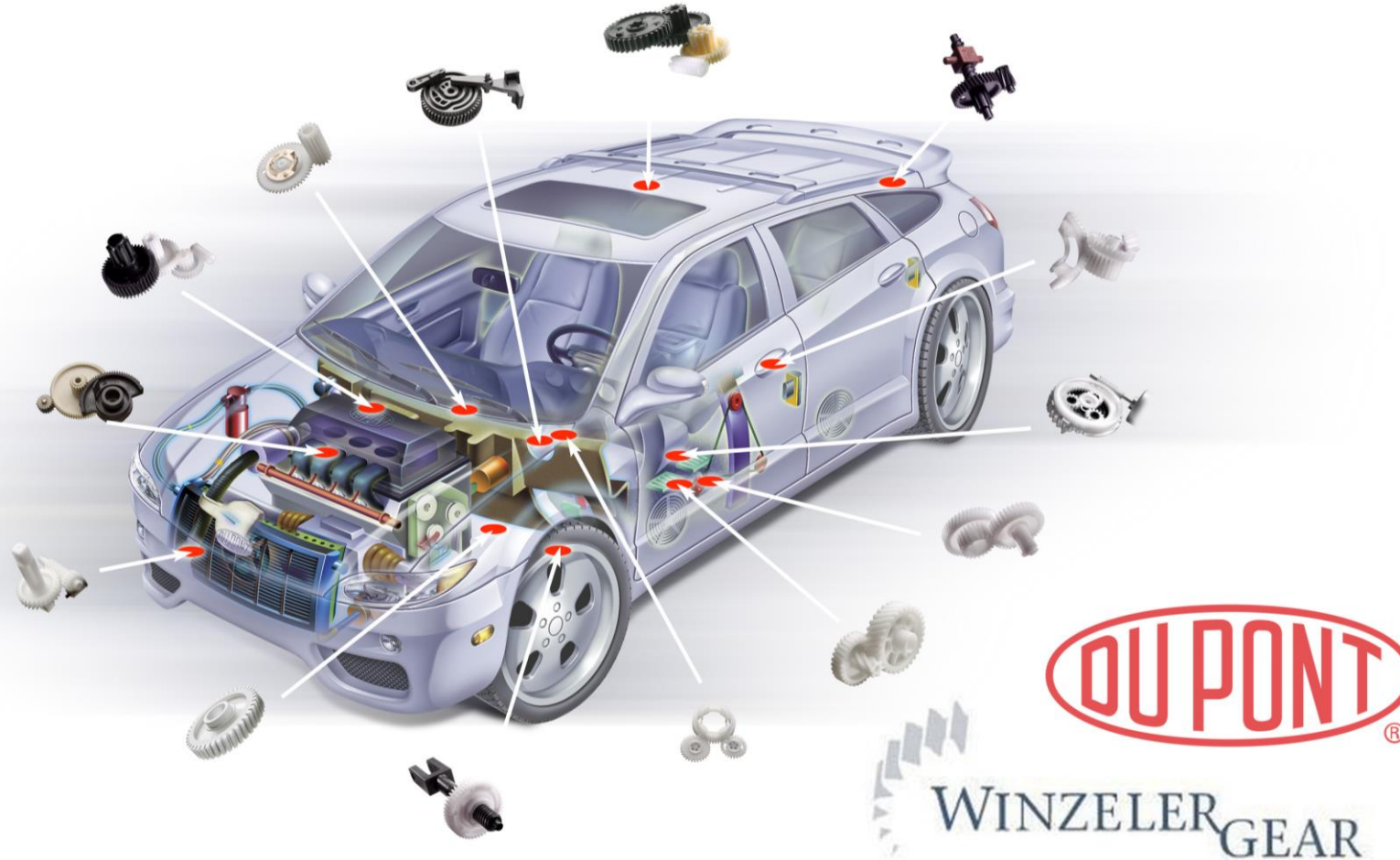
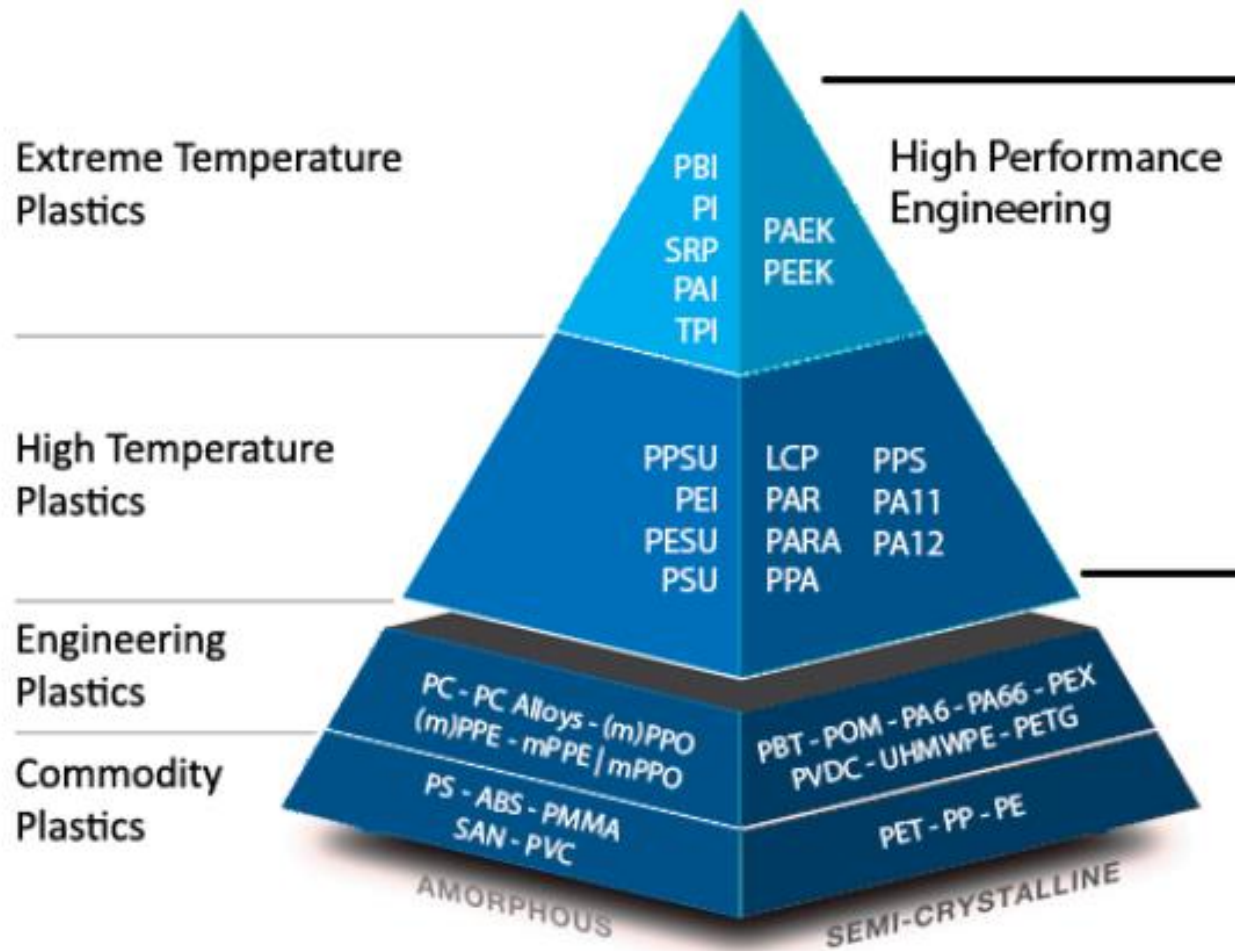


Image courtesy of Winzeler Gear and DuPont



## 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

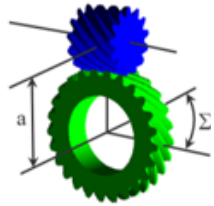
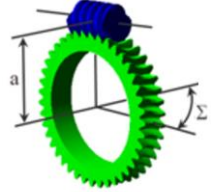
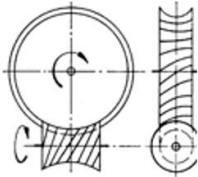
## Optimisation goals

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

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

# Introduction

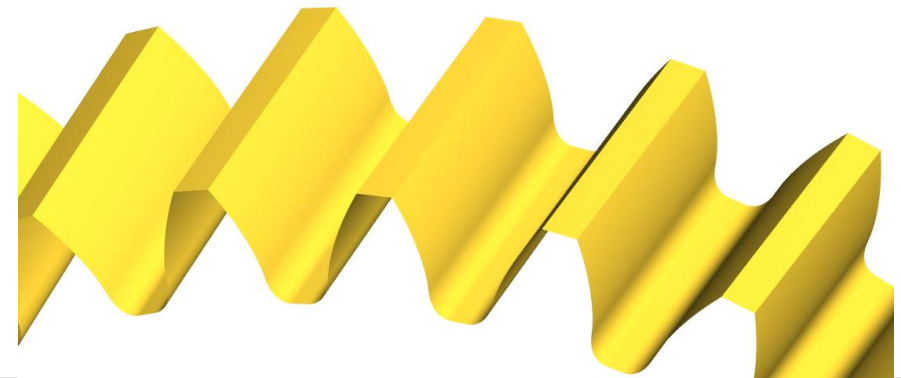
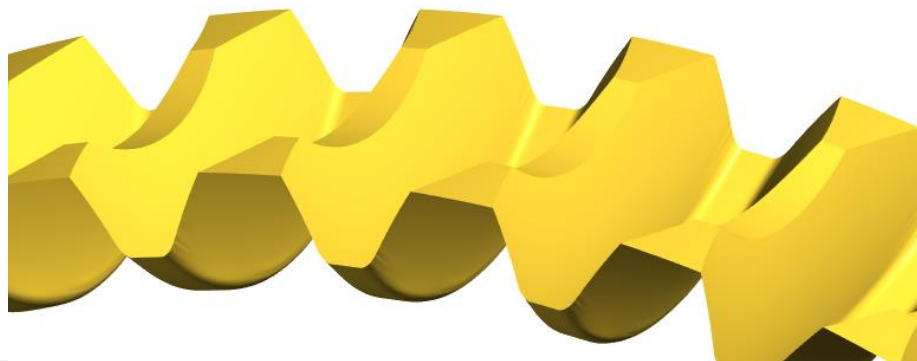
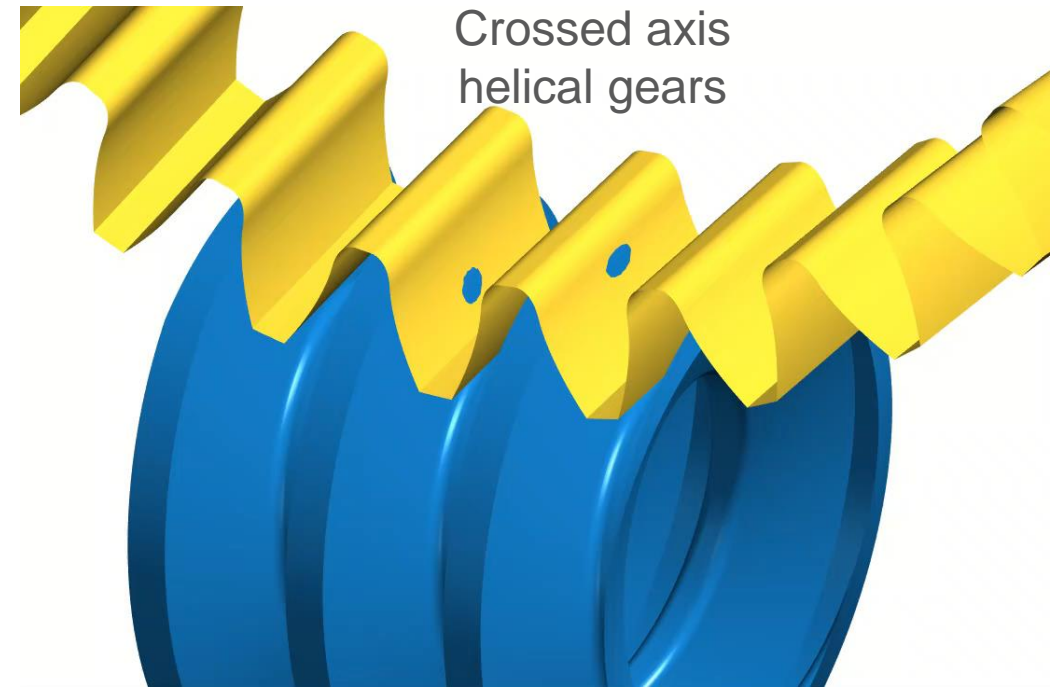
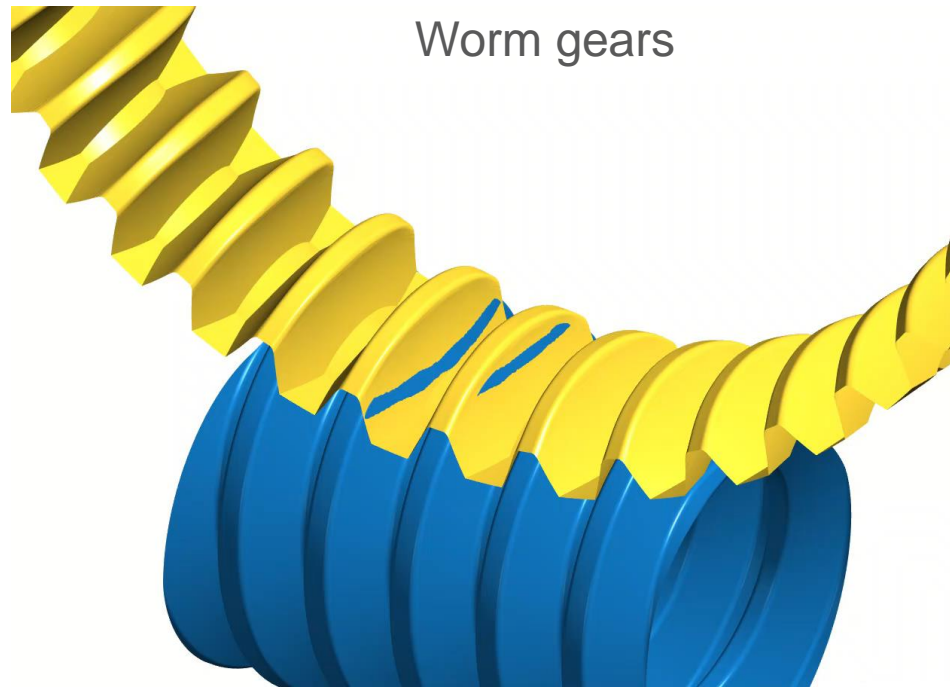
- High transmission ratio
- Fine pitch gearing
- Possible self locking (for small lead angles)

Name	Principle	Basic gear
<p><b>Crossed axis helical gear set</b></p>	 <p><math>a &gt; 0, \Sigma &gt; 0</math></p>	<p>Cylindrical worm Cylindrical wheel</p>
<p><b>Worm gear set</b></p>	 <p><math>a &gt; 0, \Sigma = 90^\circ</math></p>	<p>Cylindrical worm Enveloping wheel</p>
<p><b>Double enveloping worm gear set</b></p>	 <p><math>a &gt; 0, \Sigma = 90^\circ</math></p>	<p>Enveloping worm Enveloping wheel</p>

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

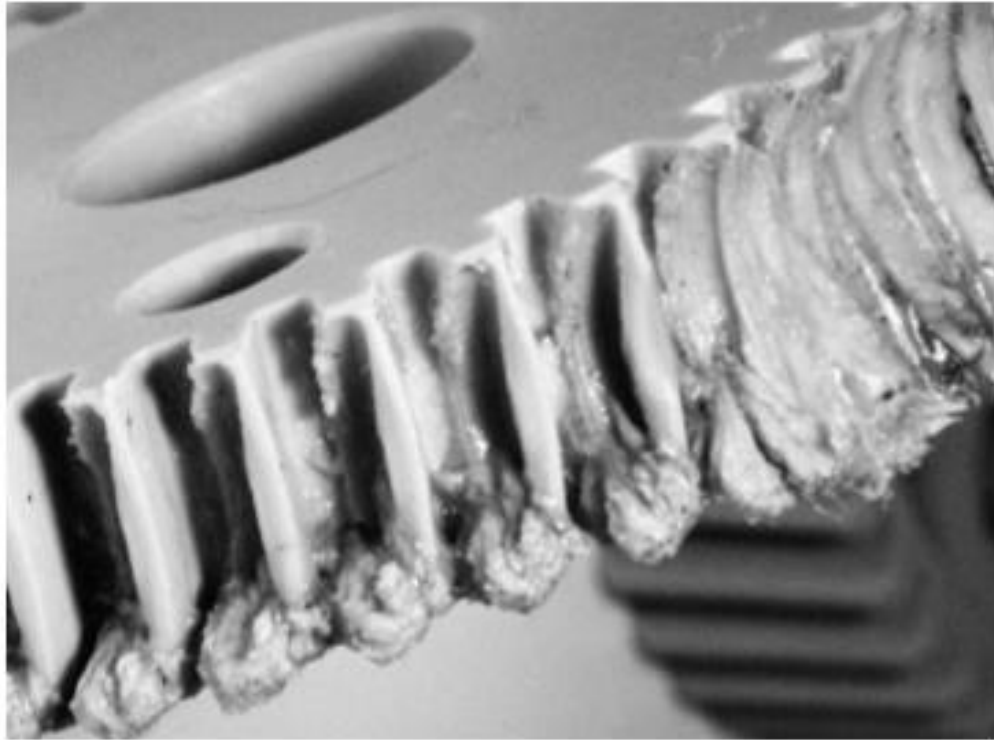


# Introduction / Differences between Cylindrical and Globoidal Worm Wheels

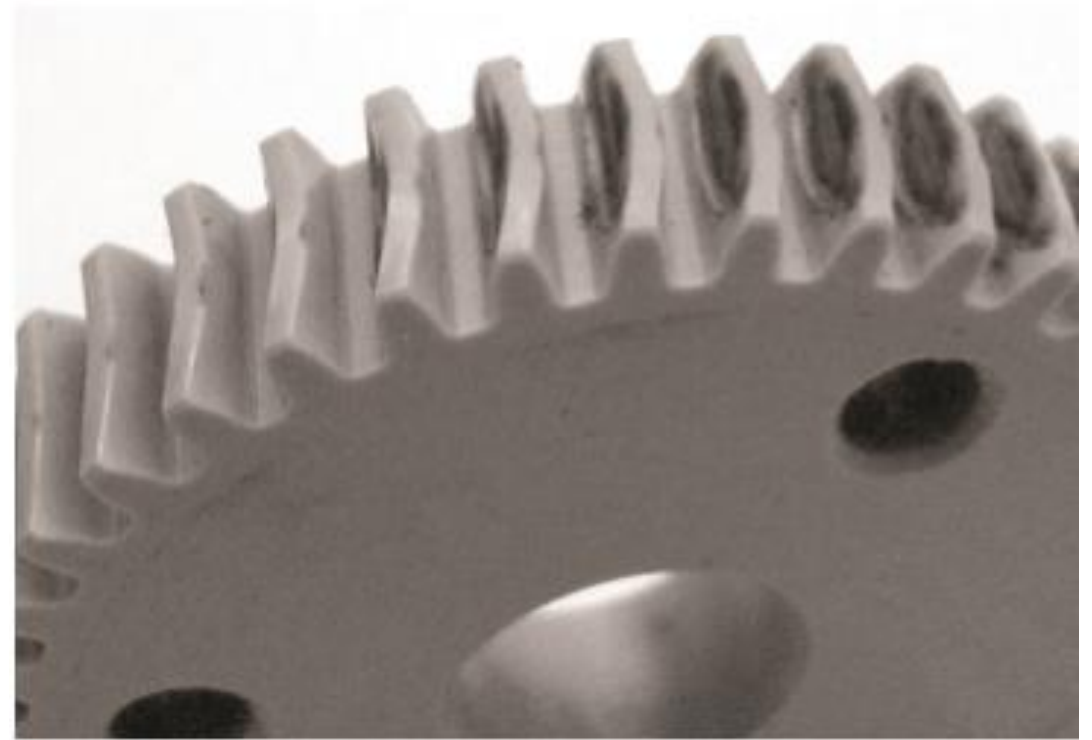


# Typical Failure Modes / Melting and Deformation

Melting



Plastic deformation



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

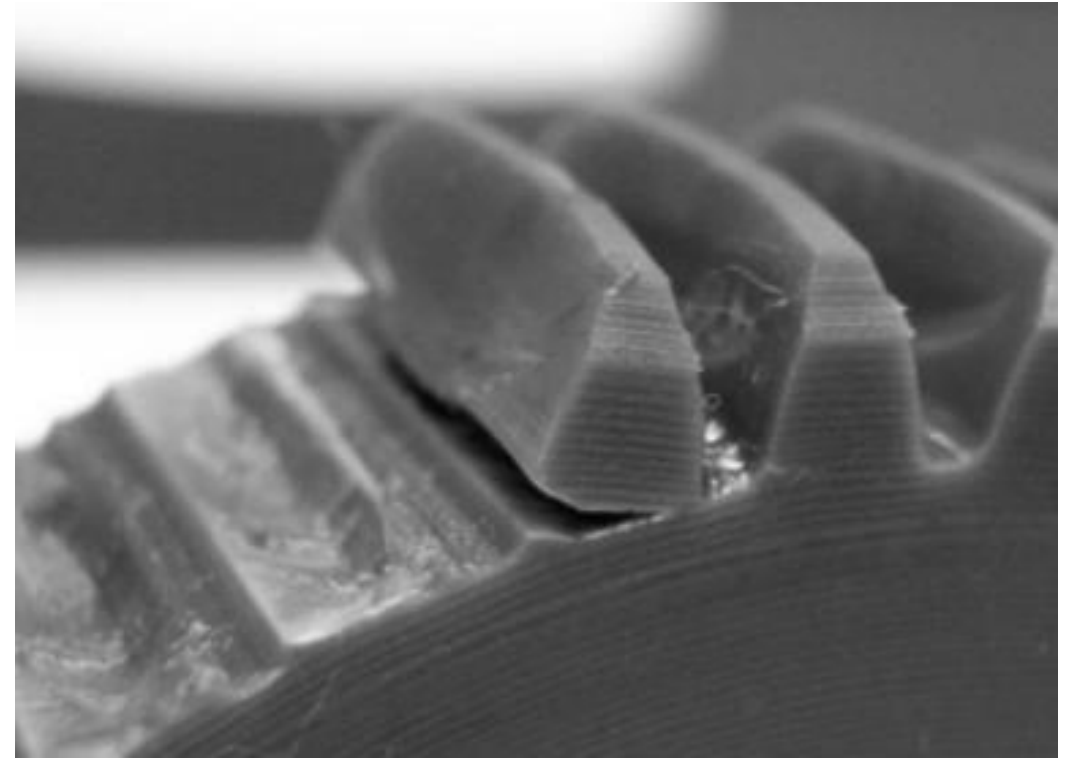


# Typical Failure Modes / Tooth Fracture

Shear failure



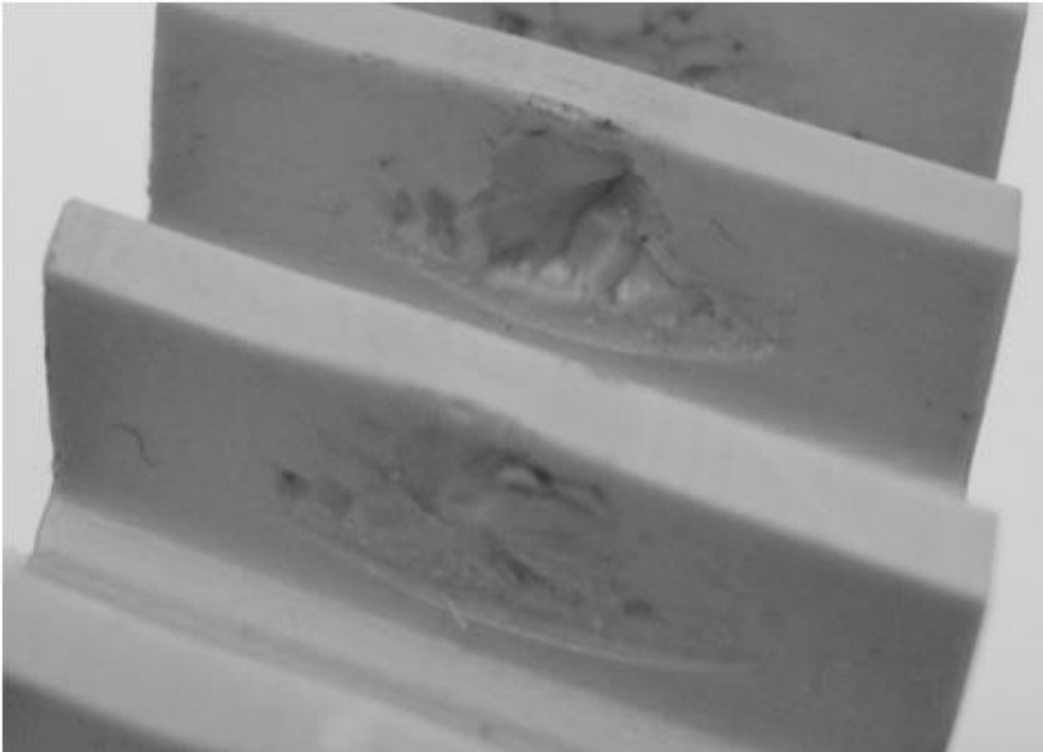
Bending failure



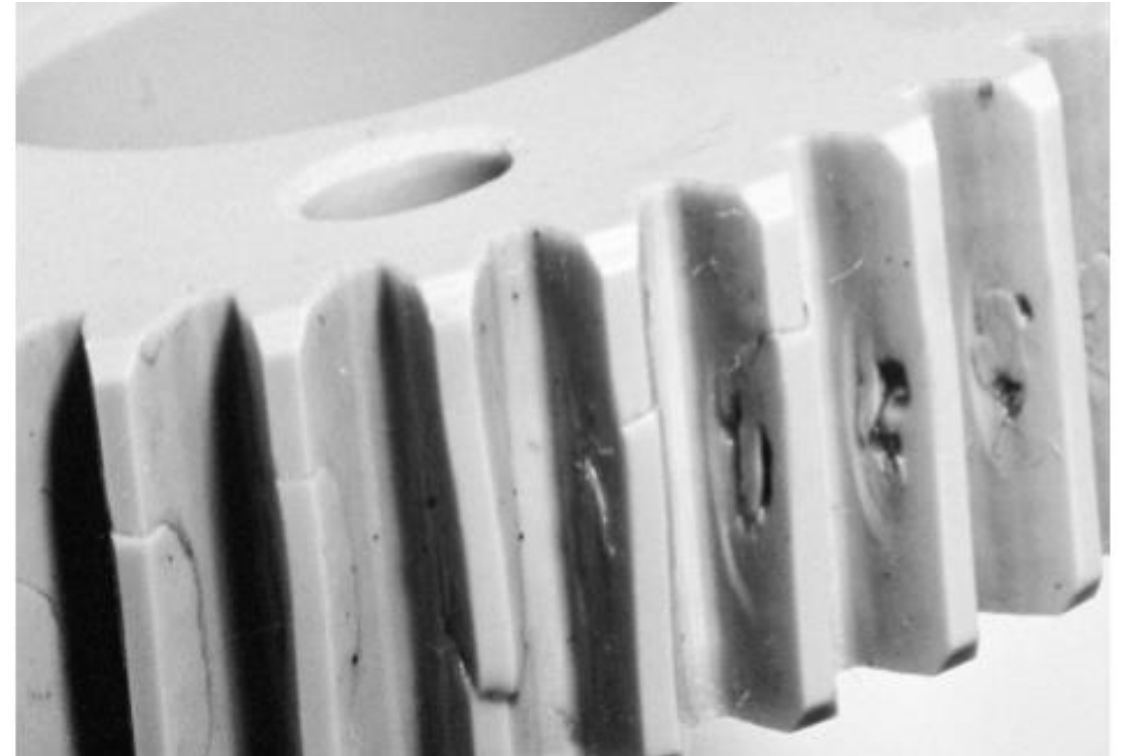
VDI 2736-1, *Thermoplastic gear wheels - Materials, material selection, production methods, production tolerances, form design*, 2014.

# Typical Failure Modes / Pitting and Flank Fracture

Pitting



Flank fracture

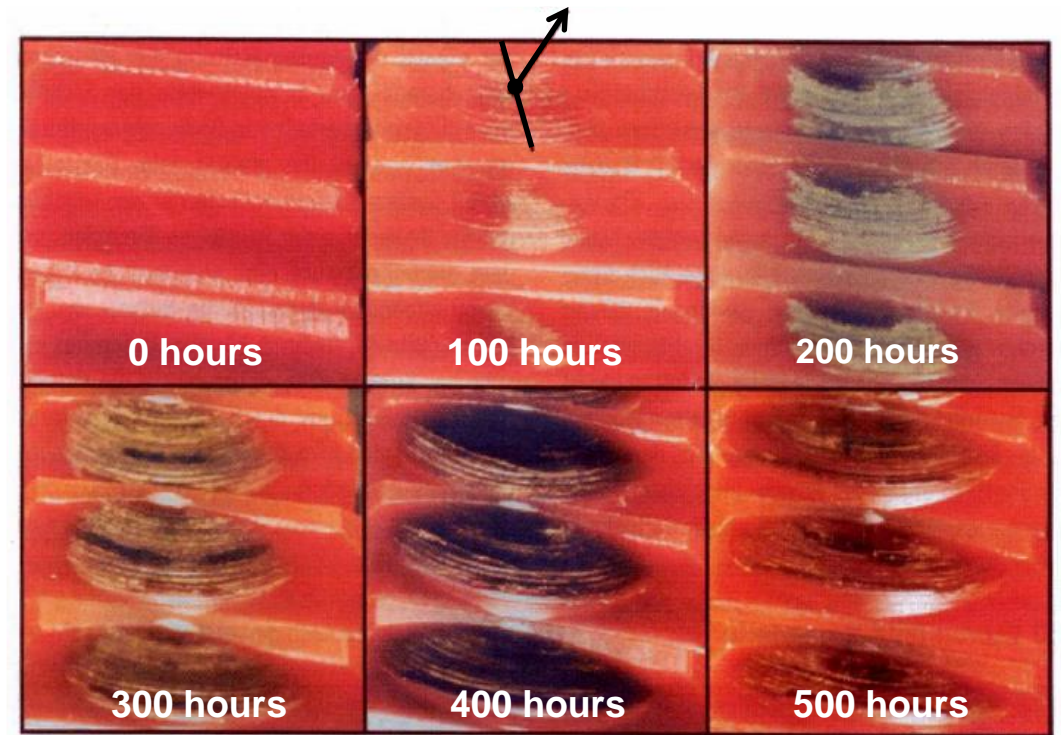


# Typical Failure Modes / Wear

Wear

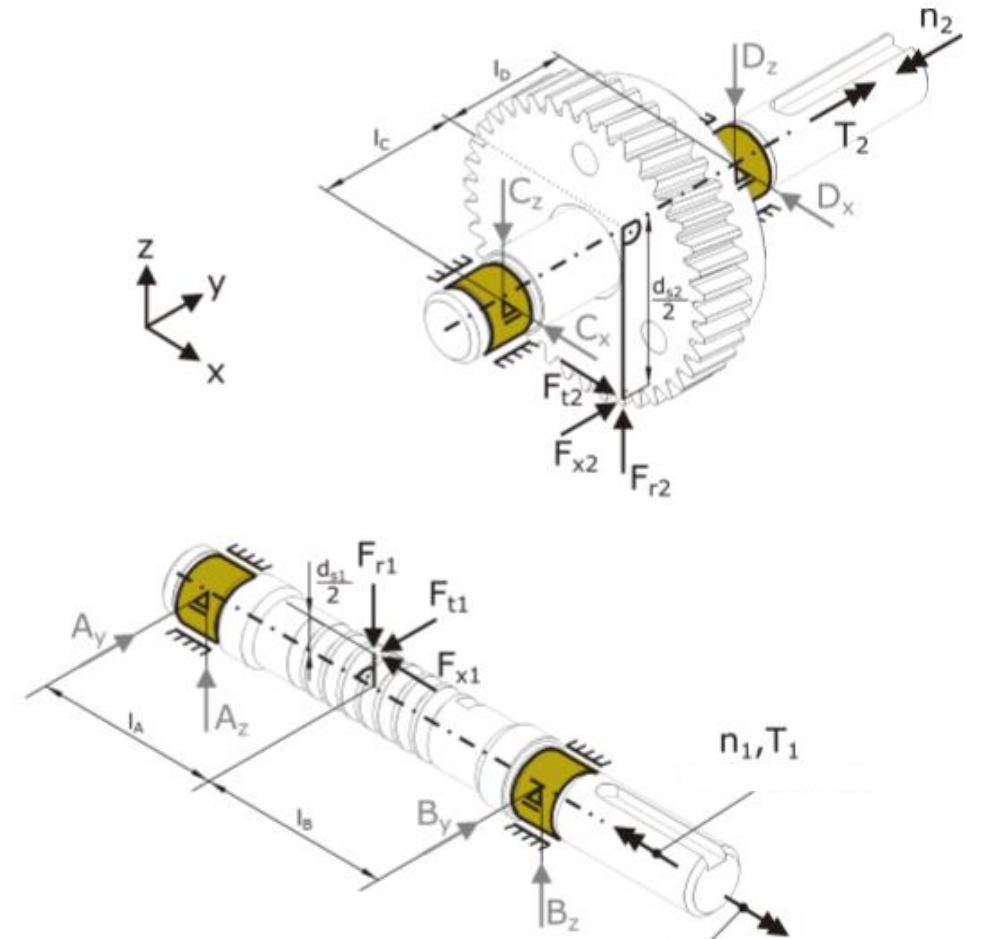
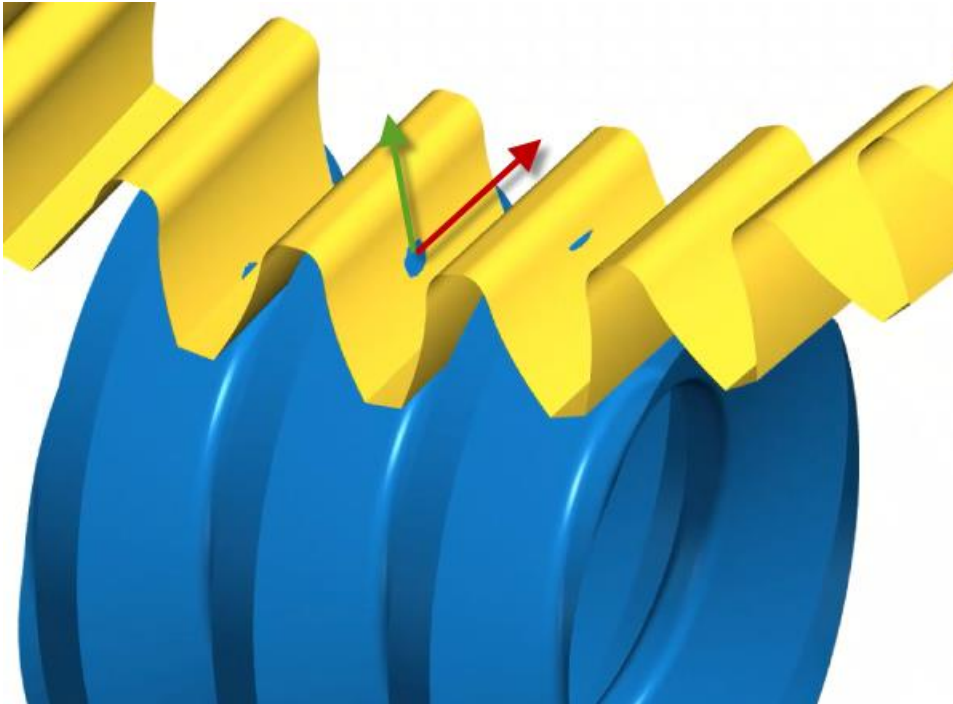


Contact line



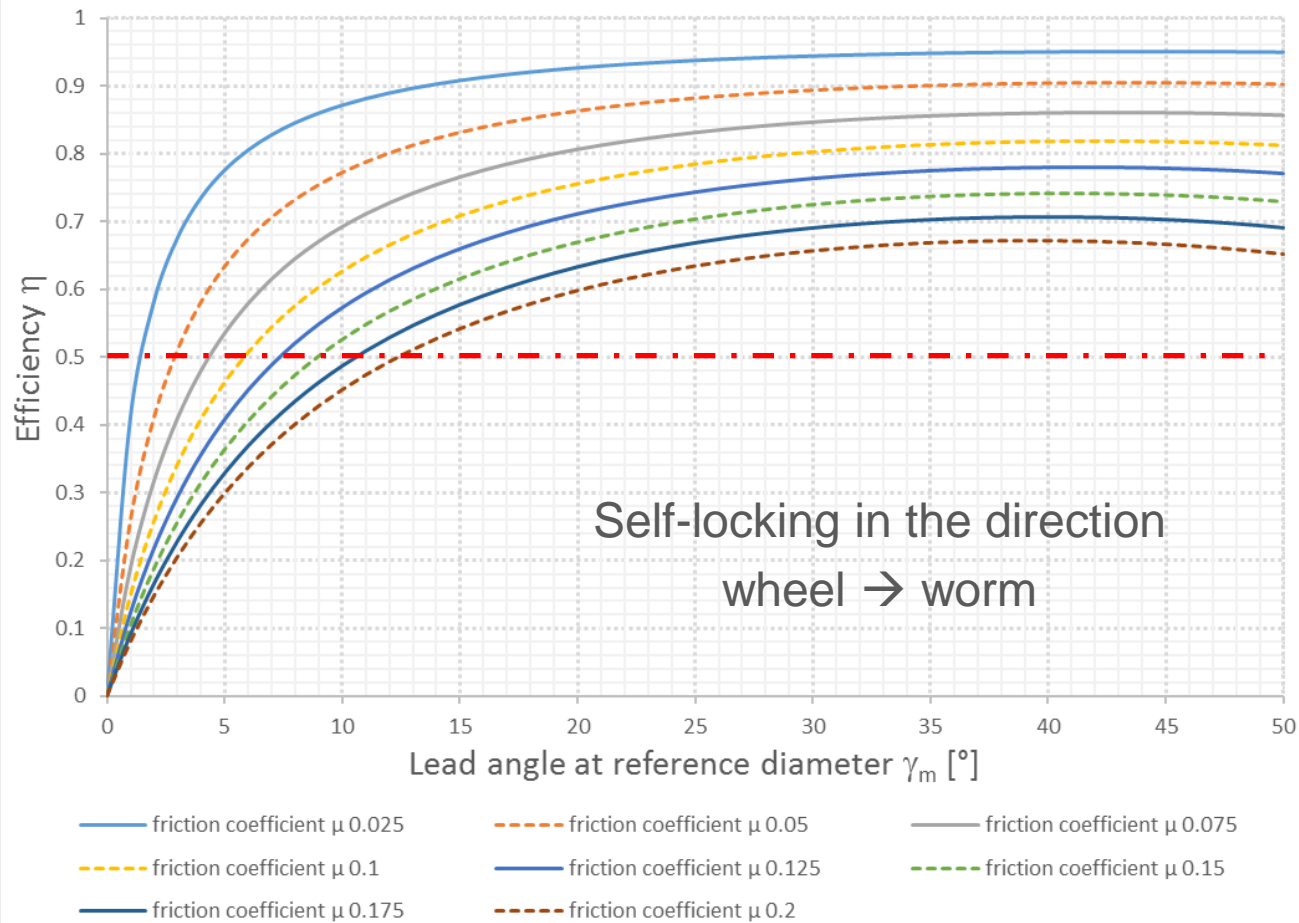
VDI 2736-1, *Thermoplastic gear wheels - Materials, material selection, production methods, production tolerances, form design*, 2014.  
Predki W., Barton P., *Load Carrying Capacity of Screw Helical Gears with Steel Pinions and Plastic Wheels*, *Gear Technology* July/August 2004.

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





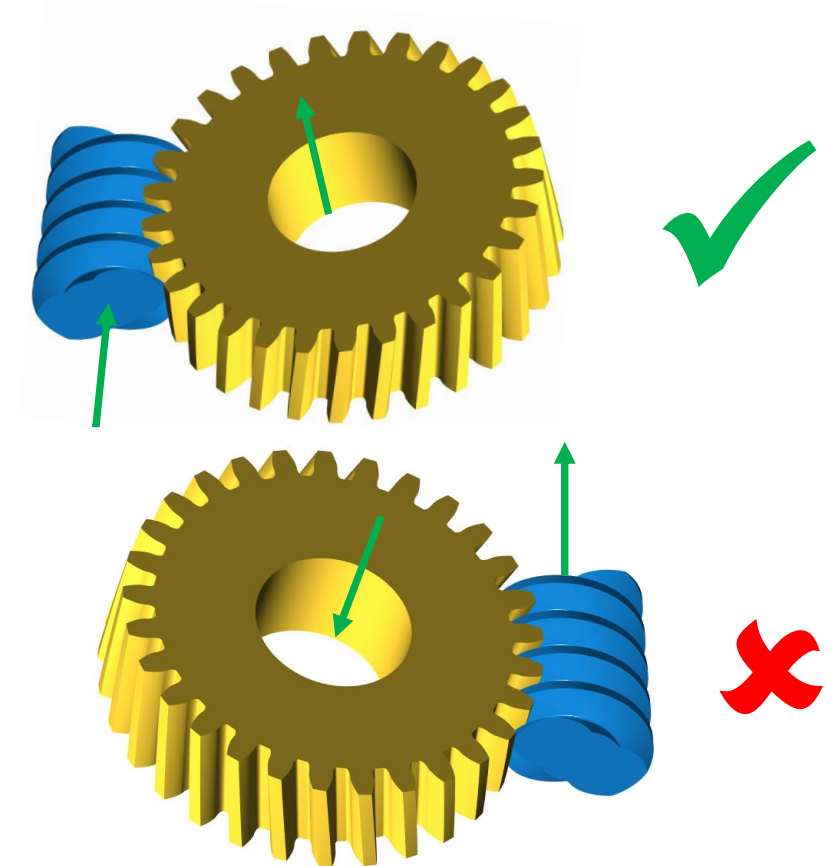
## Efficiency $\eta$ - Worm driving (input)



## Efficiency for $\Sigma = 90$

$$\eta_z = \frac{\tan \beta_{s,b}}{\tan(\beta_{s,b} + \varrho^*)}$$

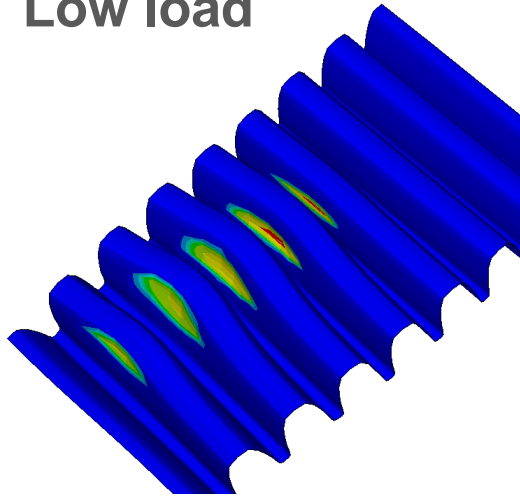
$$\varrho^* = \tan^{-1} \frac{\mu}{\cos \alpha_{sn}}$$



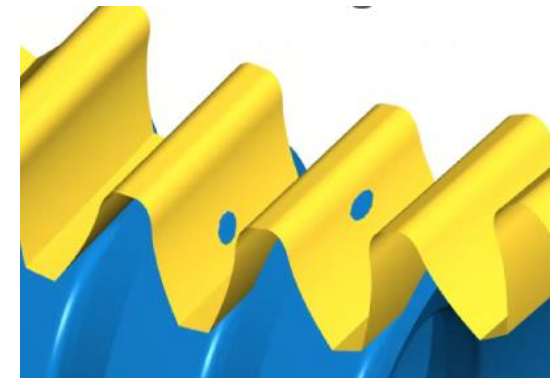
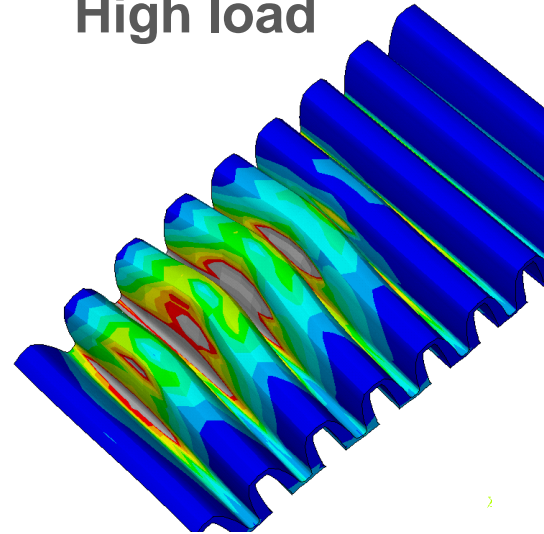


- As the load increases, the contact point extends to a contact ellipse

**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

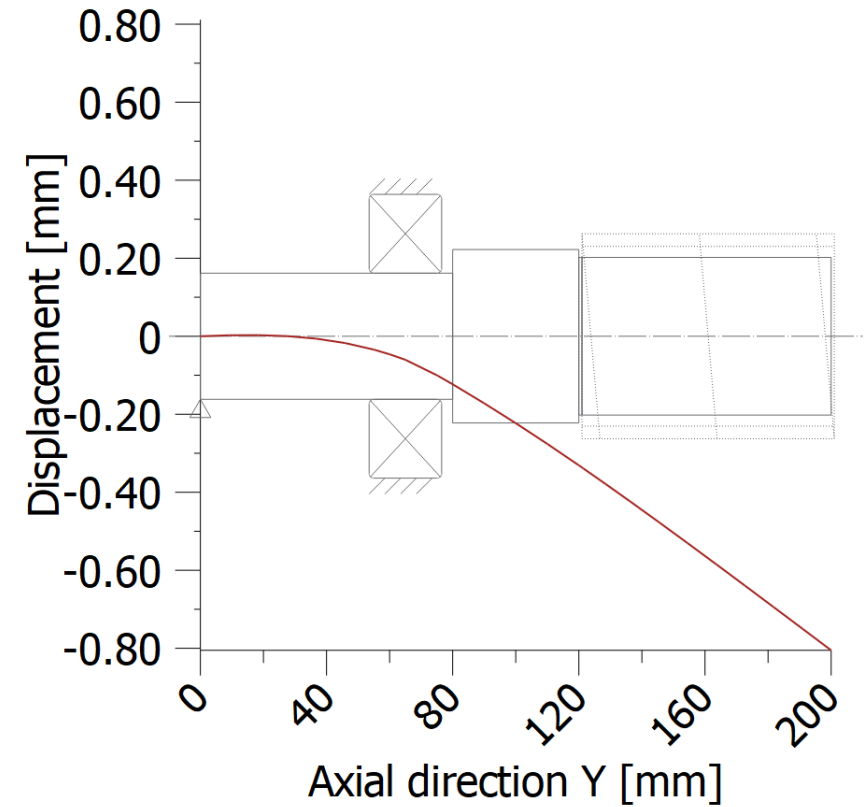
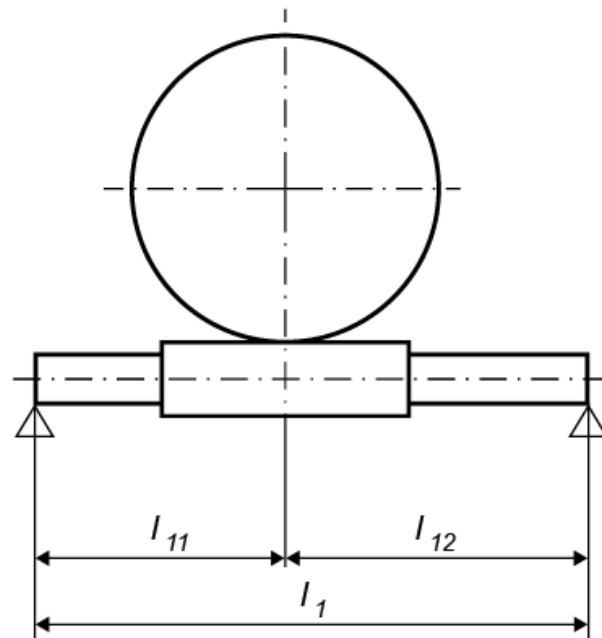
ICS 21.200, 83.080.20		VDI-RICHTLINIEN		Mai 2014 May 2014	
VEREIN DEUTSCHER INGENIEURE	Thermoplastische Zahnräder Schraubradgetriebe Paarung Zylinderschnecke Schrägstirnrad Tragfähigkeitsberechnung Thermoplastic gear wheels Crossed helical gears Mating cylindrical worm with helical gear Calculation of 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.			
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VDI-Gesellschaft Produkt- und Prozessgestaltung (GPP) Fachbereich Getriebe und Maschinenelemente					
VDI-Handbuch Getriebetechnik II: Gleichförmig übersetzte Getriebe					

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678.01 : 678.02 (083.132)		VDI-RICHTLINIEN		Januar 1981	
VEREIN DEUTSCHER INGENIEURE	Zahnräder aus thermoplastischen Kunststoffen	VDI 2545	- 2. Juli 1981		
Gear wheels made from thermoplastics					
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VDI-Gesellschaft Kunststofftechnik					
VDI-Handbuch Kunststofftechnik VDI/VDE-Handbuch Feinwerktechnik VDI-Handbuch Getriebetechnik II VDI-Handbuch Konstruktion					Register-Nr. 3 Register-Nr. 5

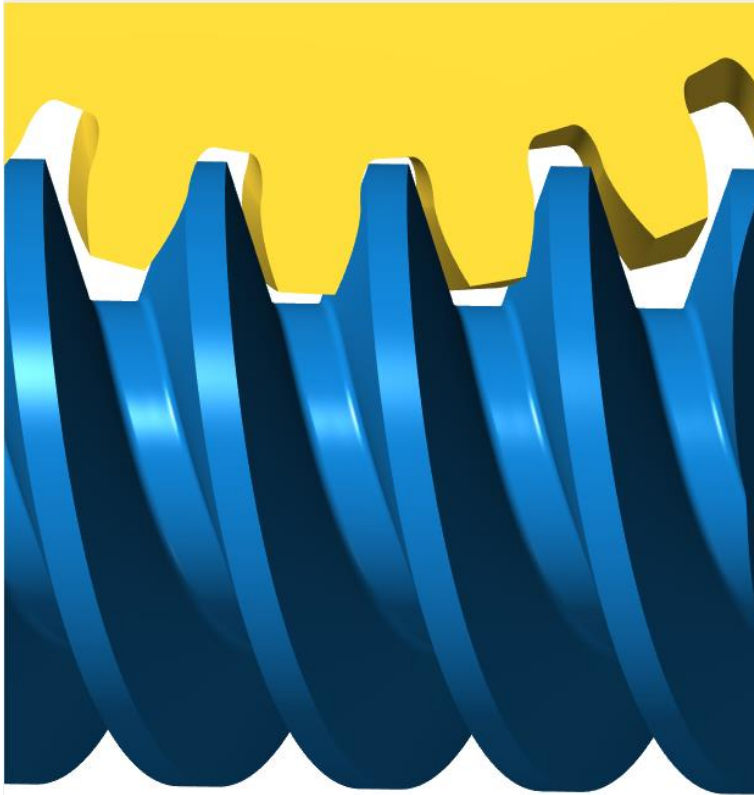
Vervielfältigung – auch für innerbetriebliche Zwecke – nicht gestattet

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

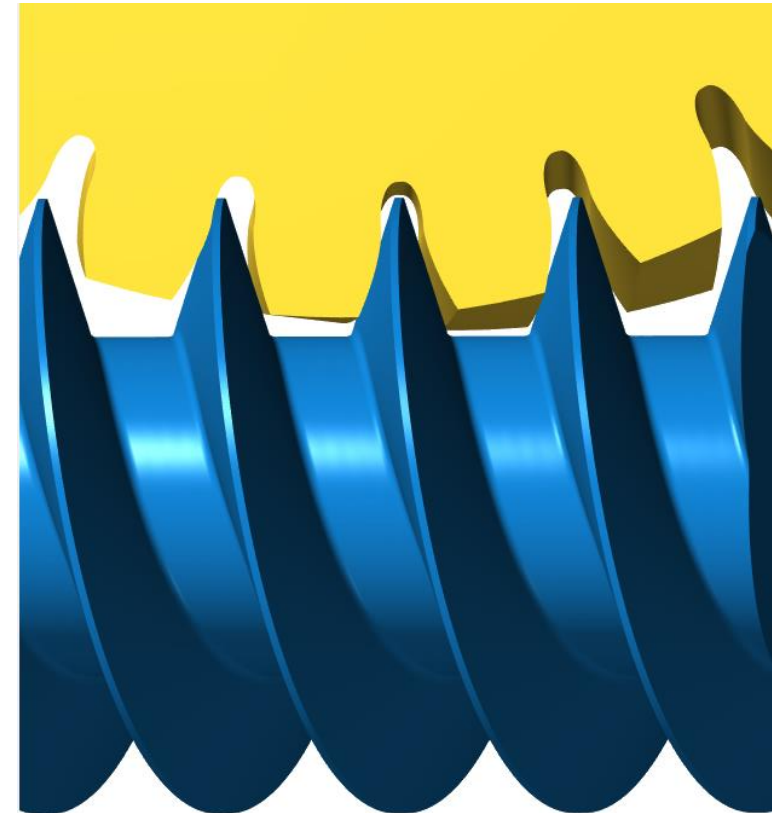


- Increasing the tooth thickness of plastic gear – strength is increased
- Decreasing the tooth thickness of the metal gear – strength is decreased

**Typical tooth thickness (50%-50%)**

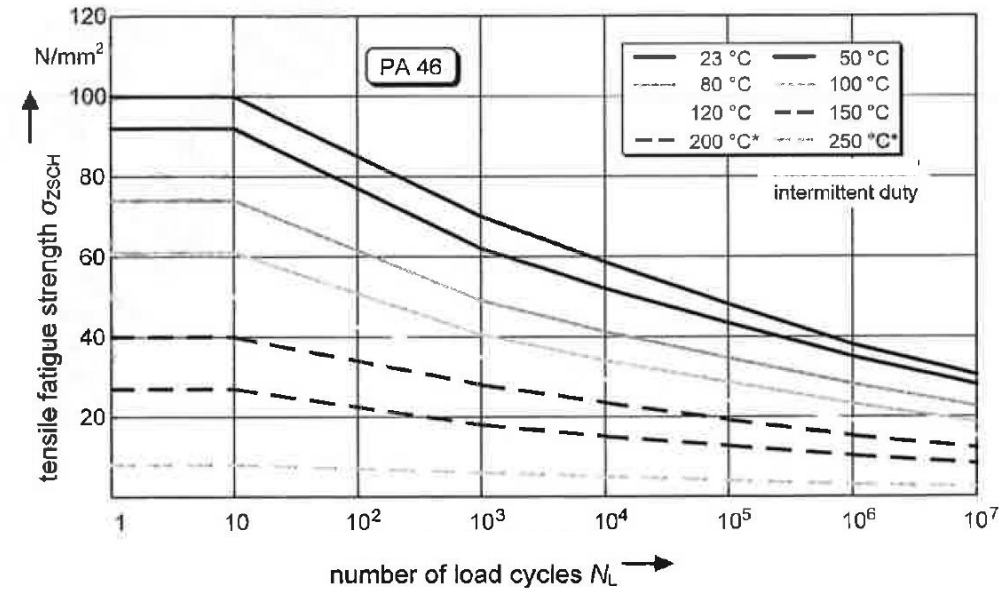
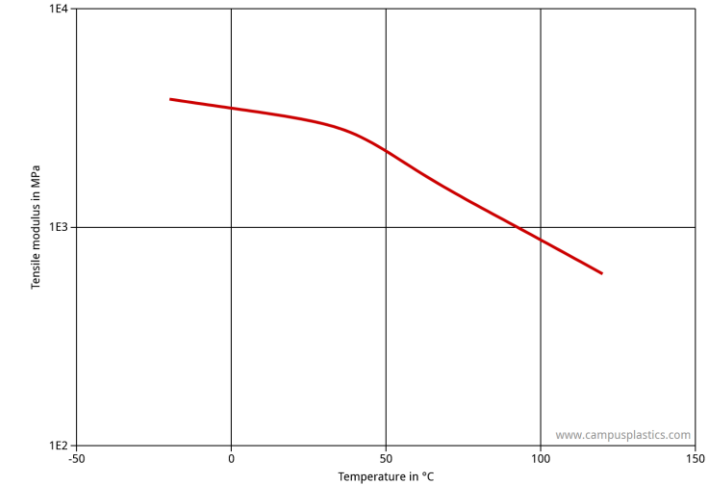
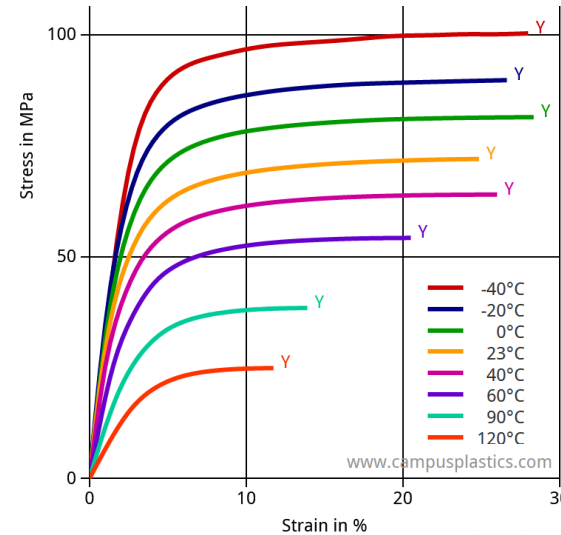


**Optimized tooth thickness (30%-70%)**



# Material Properties

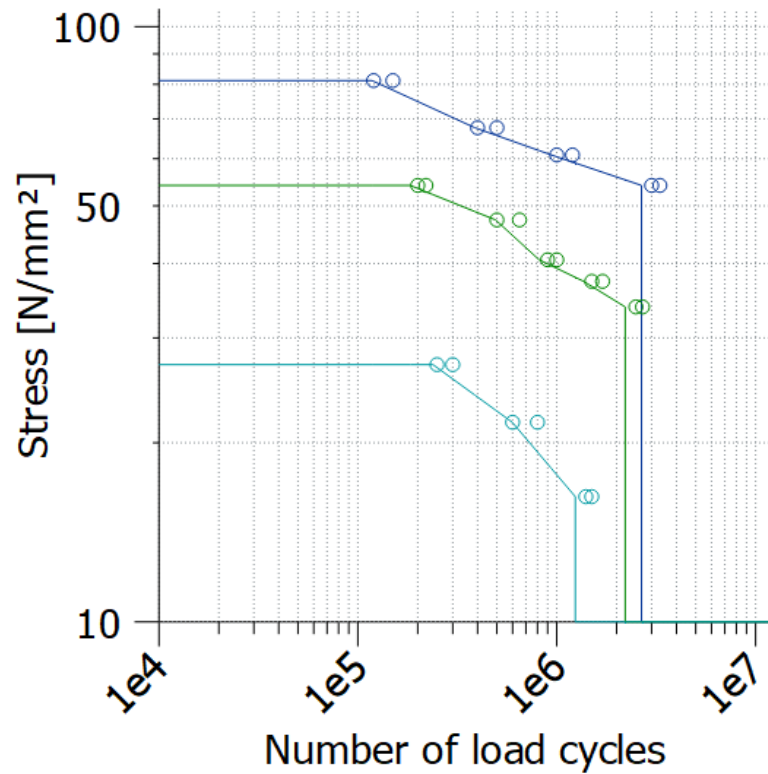
- Young's modulus
  - Ultimate and yield tensile strength
  - Poisson ratio
  - Coefficient of thermal expansion
  - Water/humidity absorption
- 
- SN curves for root and flank
  - SN curves for shear



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**

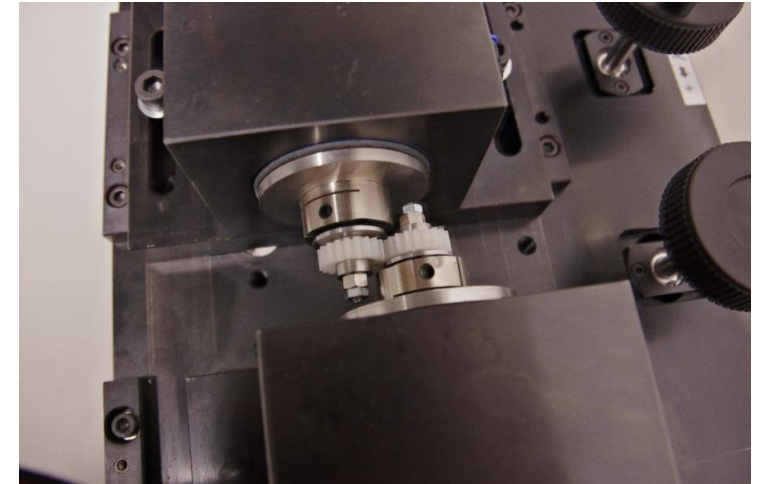
Material nam: Polymer\_example  
 Comment: Enter...  
 Data source: Measurements  
 Material type: Thermoplastic PA  
 Type...ment: untreated  
 Material grou: Not on the list

Density  $\rho_{mat}$ : 1320.0000 kg/m<sup>3</sup>  
 Poisson's ratio  $\nu$ : 0.4000  
 Specific heat capacity  $c_M$ : 0.0000 J/(kg·K)  
 Specific heat conductivity  $\lambda_M$ : 0.0000 W/(m·K)  
 Coefficient ...al expansion  $\alpha$ : 75.0000 10<sup>-6</sup>/°C  
 Absorption of water/humidi  $w_{VOL}$ : 0.0900 %

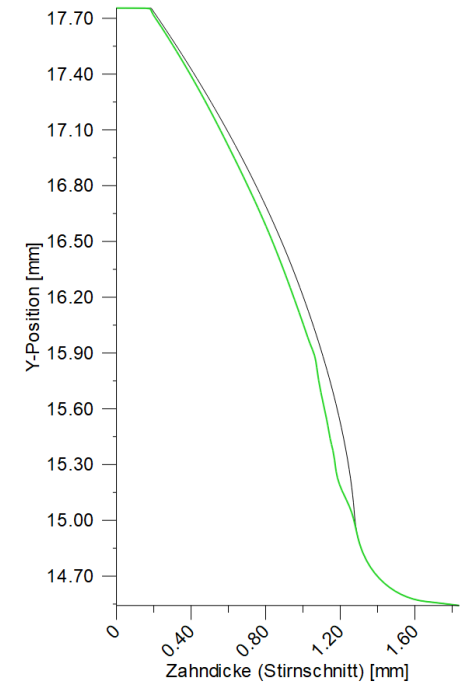
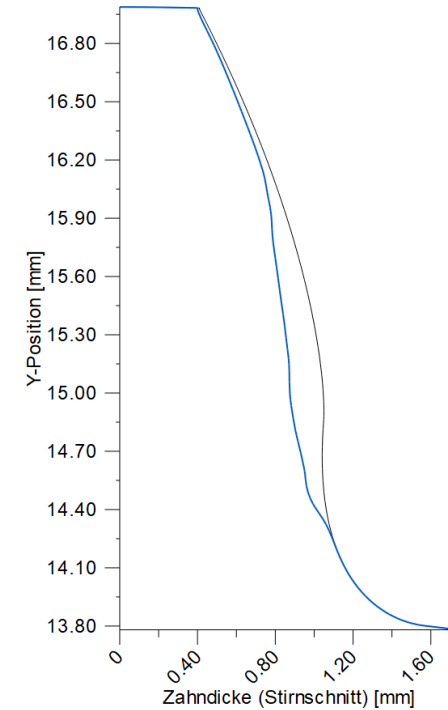
Data available also for dry material (for PA6, ...)

**Tribological properties**

	Oil	Grease	Dry
Coefficient of friction $\mu$	0.0400	0.0900	0.3200
Wear coefficient $k_w$	0.0000	0.0000	0.0000
Temperature dependent wear coefficient	No	No	No



- 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  $90^\circ$
  - 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

Influences due to inaccuracy at manufacturing

Consider manufacturing error according to DIN 3967
  Consider axis deviation error  
 Consider runout error
  Reduce tolerance ranges

	Gear 1	Gear 2	
Runout error	41.000000	58.000000	µm <input type="checkbox"/>

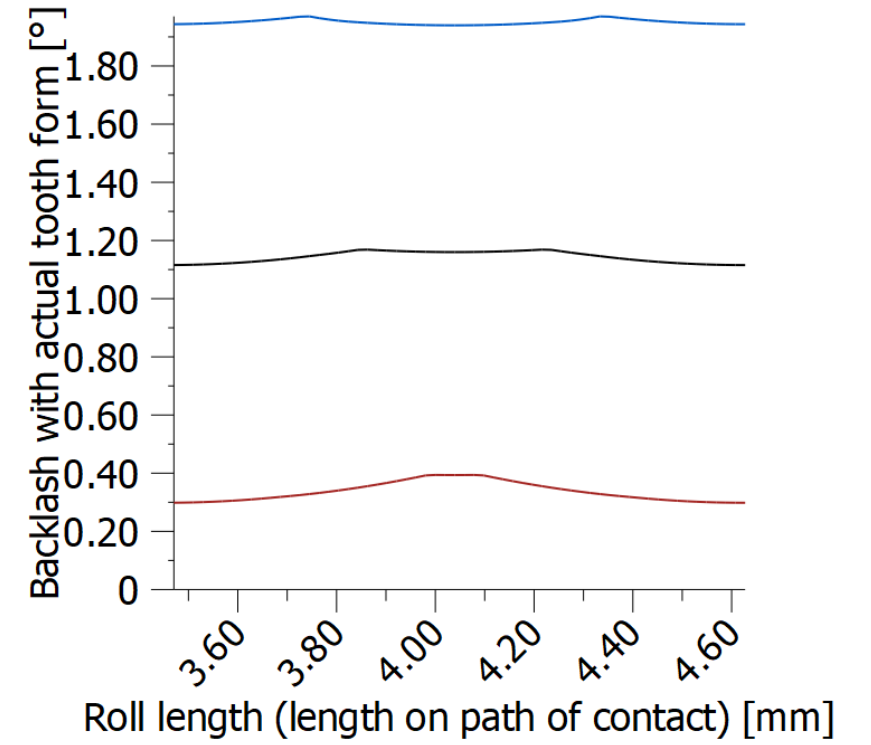
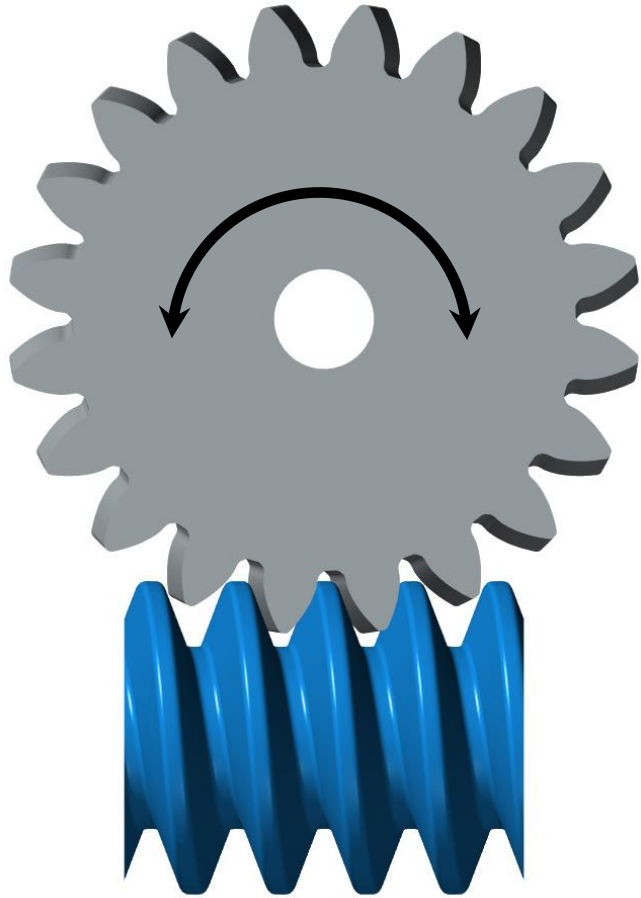
Influences during operation

		min	max		Gear 1	Gear 2	
Reference temperature	$T_{ref}$	20.000000 °C					
Temperature range housing	$T_C$	-40.000000	55.000000	°C	Relative water absorption during swelling $w_{VOL}$	0.000000	0.000000 %
Temperature range gears	$T_R$	-40.000000	55.000000	°C	Swelling coefficient according to	DIN 3967	<input checked="" type="checkbox"/>
Permissible temperature difference	$\Delta T = T_R - T_C$	0.000000	10.000000	Δ°C	Swelling coefficient	0.333333	

Housing material

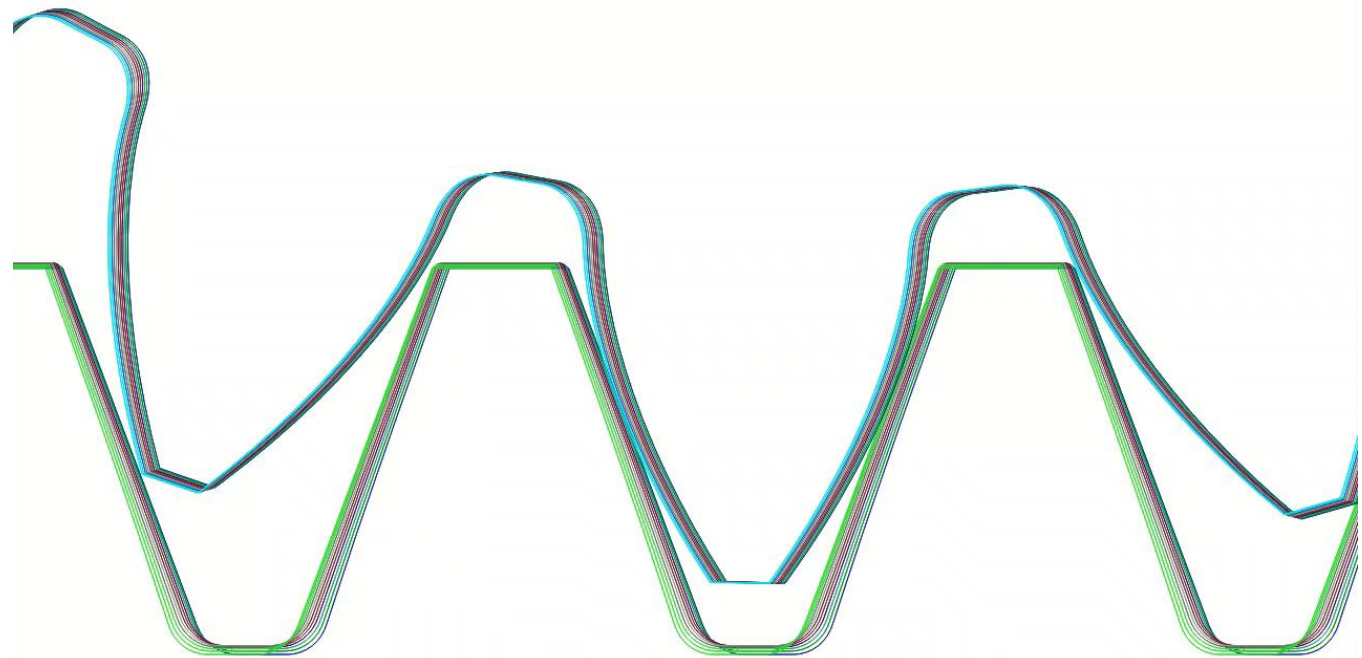
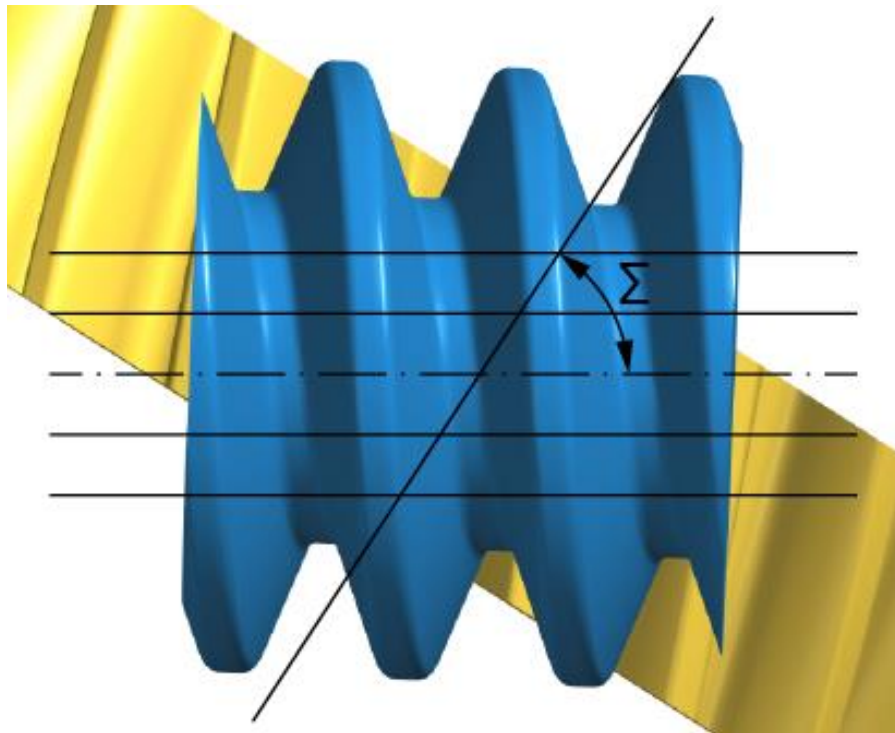
Housing material	Thermoplastic (POM, PPA, etc.)	POM (VDI2736), untreated	<input type="checkbox"/>
Coefficient of thermal expansion	$\alpha_C$	110.000000	$10^{-6}/^{\circ}C$
Relative water absorption during swelling	$w_{VOL}$	0.000000	% <input type="checkbox"/>
Swelling coefficient according to	DIN 3967		
Swelling coefficient	0.333333		

# Backlash Calculation



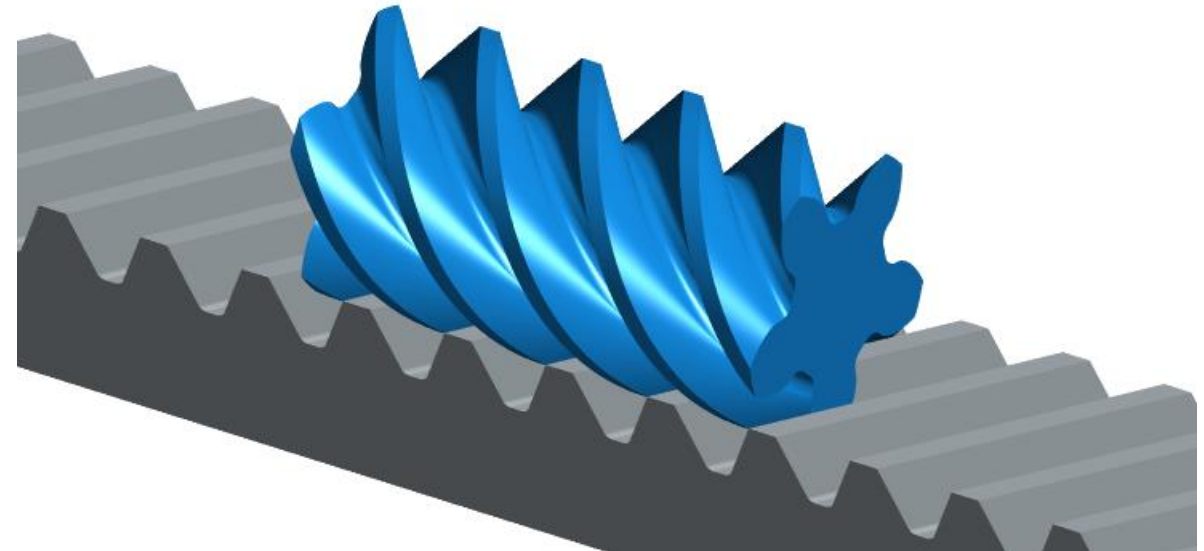
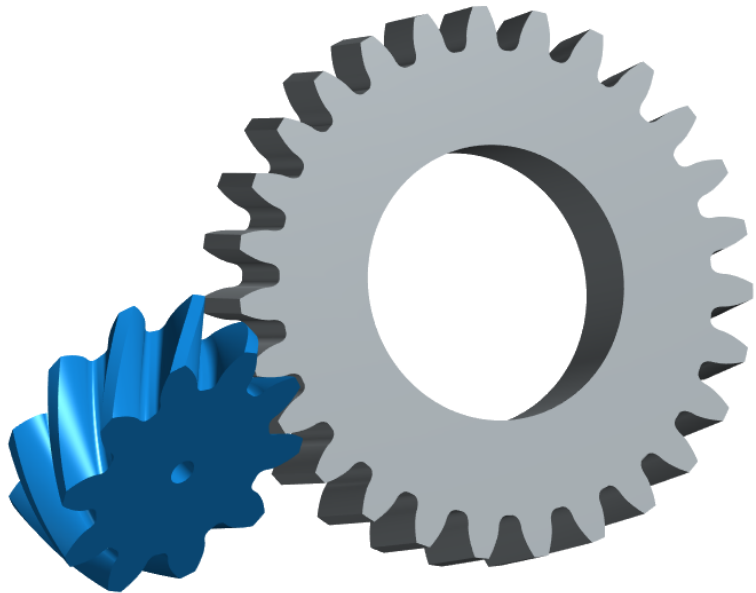
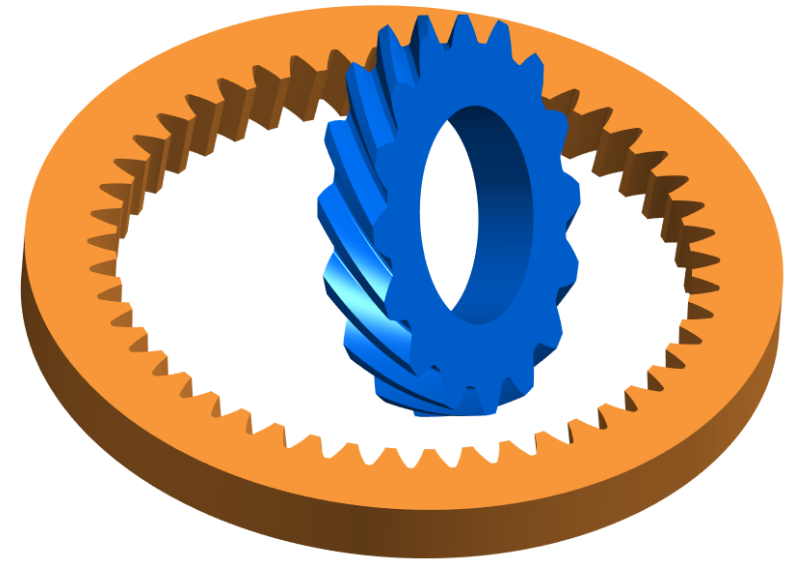
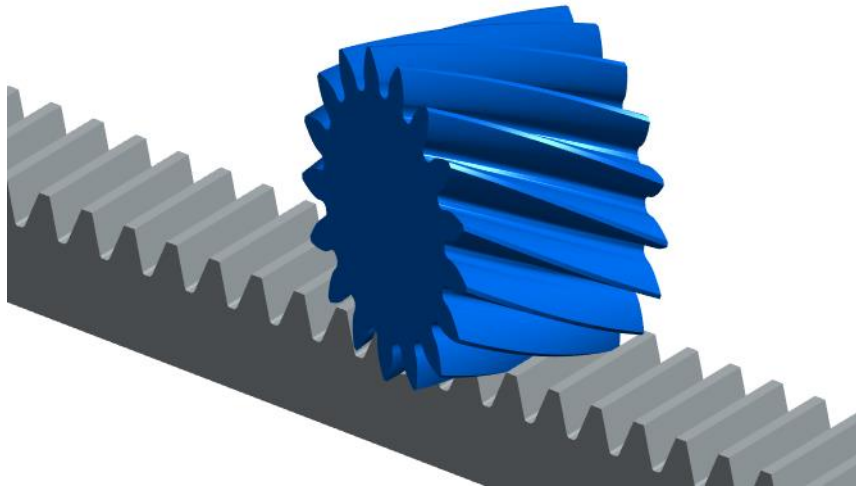
- Angle - Highest backlash (d.i, sn.i, a.e)
- Angle - Mean backlash (d.m, sn.m, a.m)
- Angle - Lowest backlash (d.e, sn.e, a.i)

# Meshing with Sections

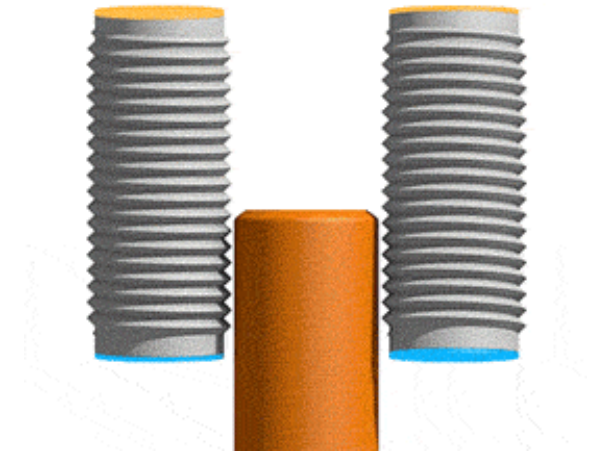
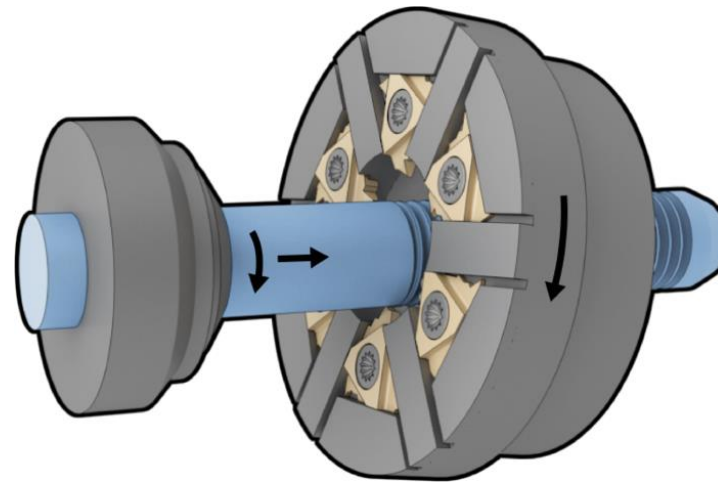




# Crossed Axis Helical Gear Configurations

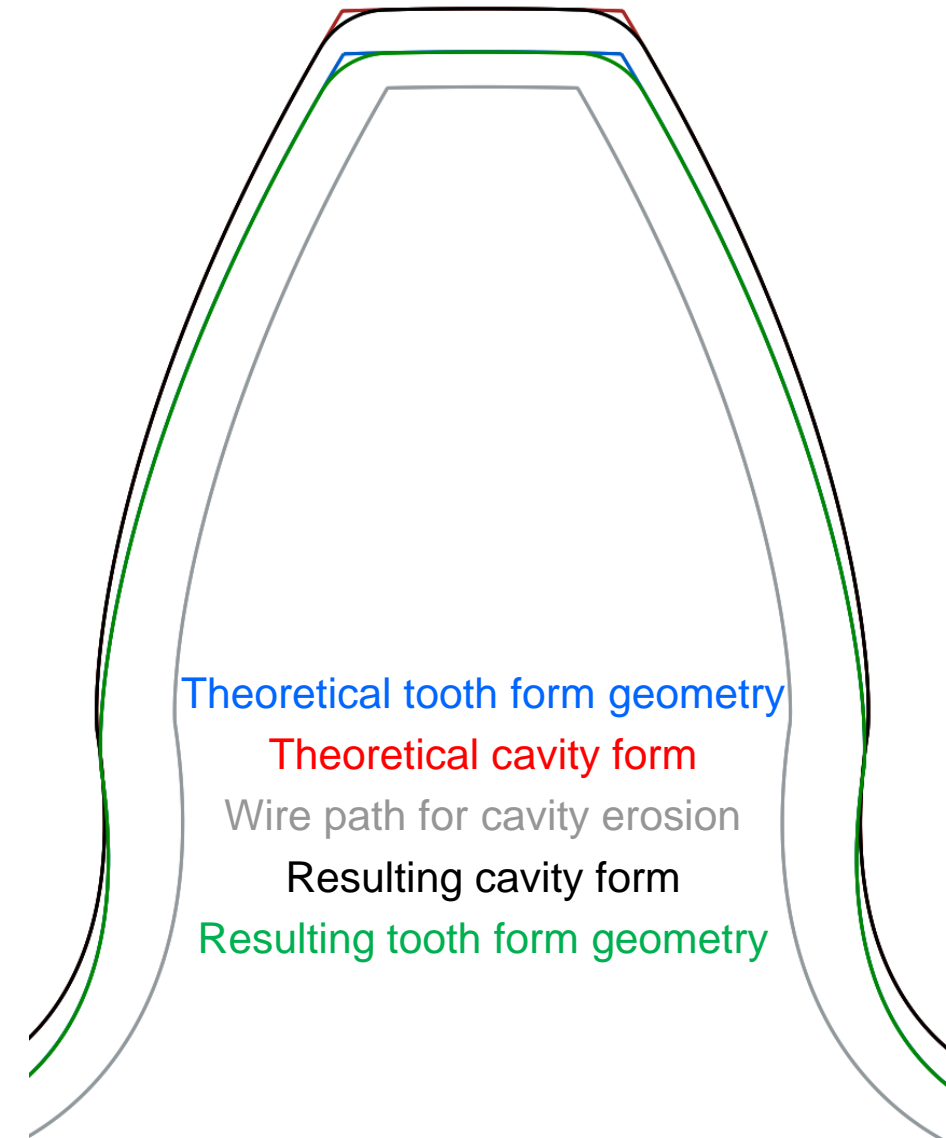
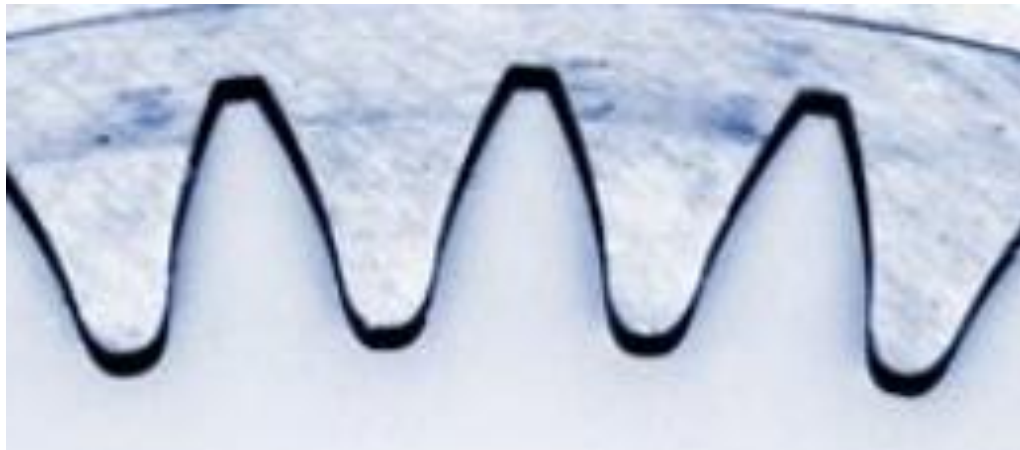


- Worm cutting (turning or whirling)
- Worm rolling
- Worm injection moulding
  
- Gear wheel injection moulding
- Gear wheel cutting

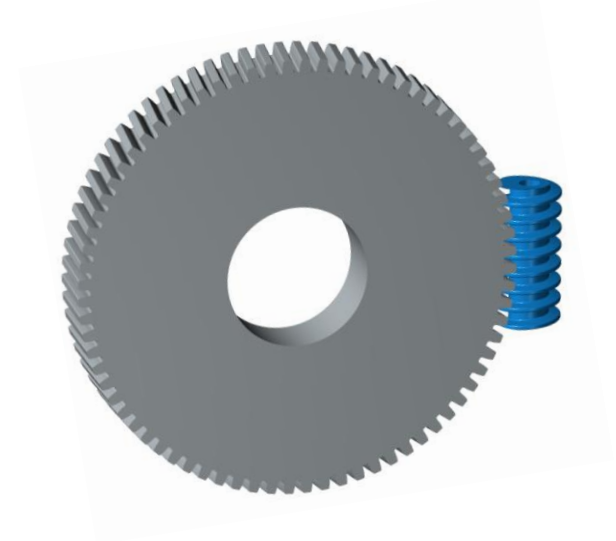
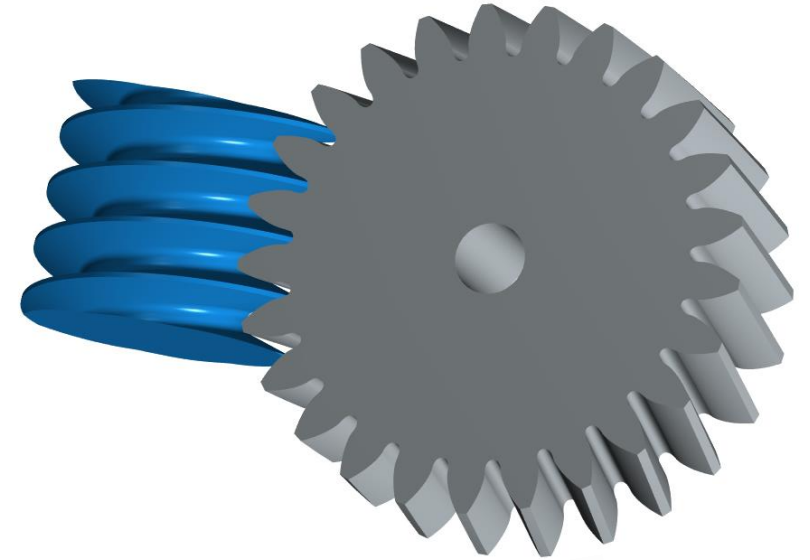
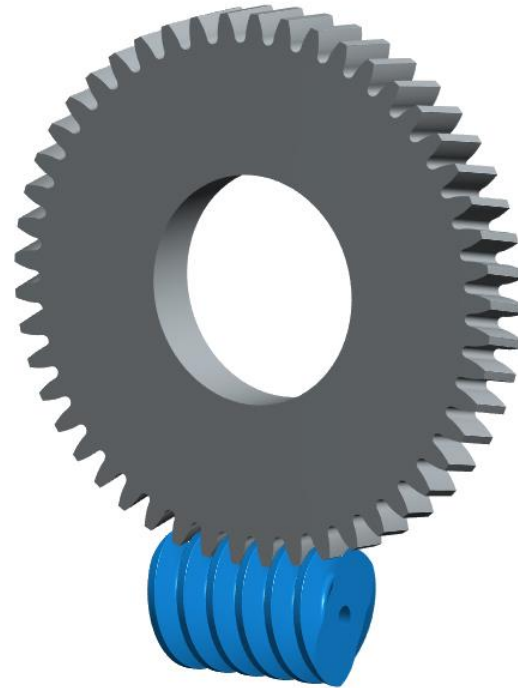
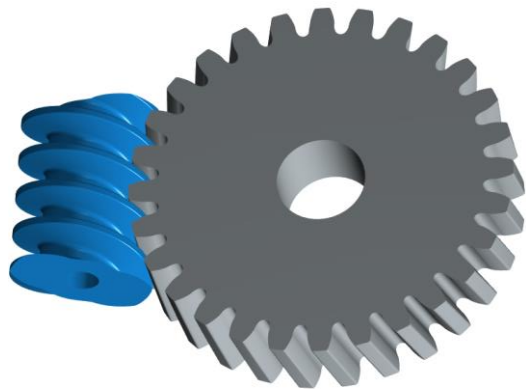


[www.profiroll.com](http://www.profiroll.com), <https://www.manufacturingguide.com>, <https://blog.igus.de/herstellung-gewindespindel/> 16.6.2022.

- Compensation for mould shrinkage
- Compensation for wire erosion



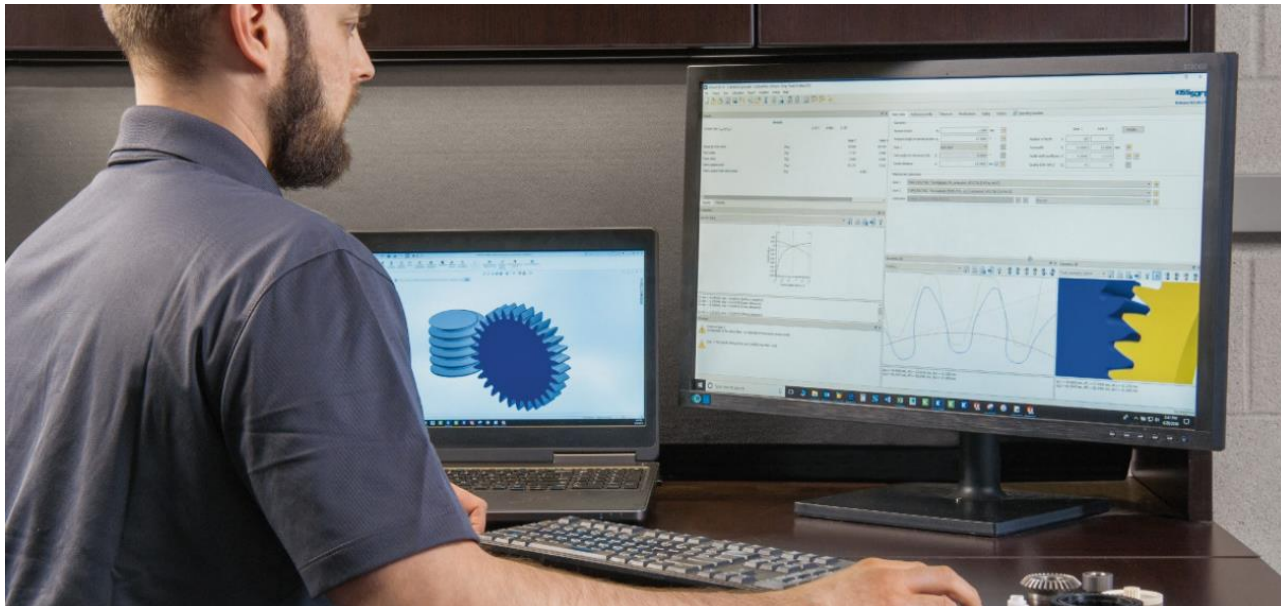
- 50+ engineering projects on crossed helical axis gears
- Coffee machine
- Car mirror application
- Window regulator
- Wash machine opener
- Lock application
- Roof opening mechanism
- Head rest application
- Positioning system
- ...





# 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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