Shell Chemicals

Carilon

Thermoplastic Polymers

EXPAND YOUR HORIZONS

Gear into action

Carilon
Thermoplastic Polymers

Step by Step gear production

Designing

- Configuration and lay-out
- Dimensions and tolerances
- Lubrication

Manufacturing

- Injection molding
- Assembly

Service

- Gear life test
- Wear performance
- Noise performance

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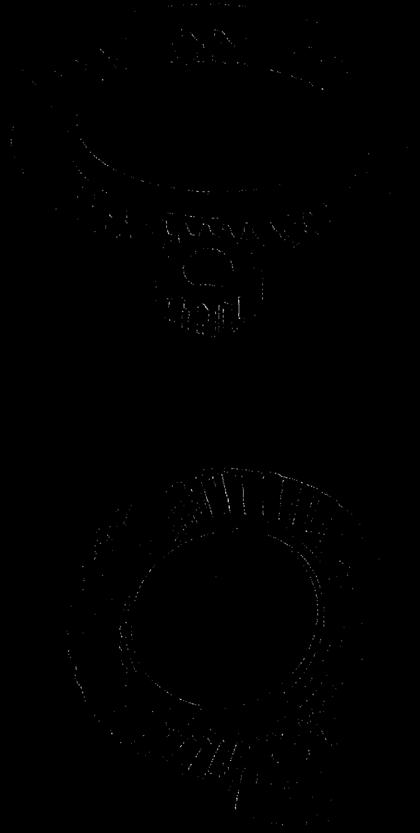
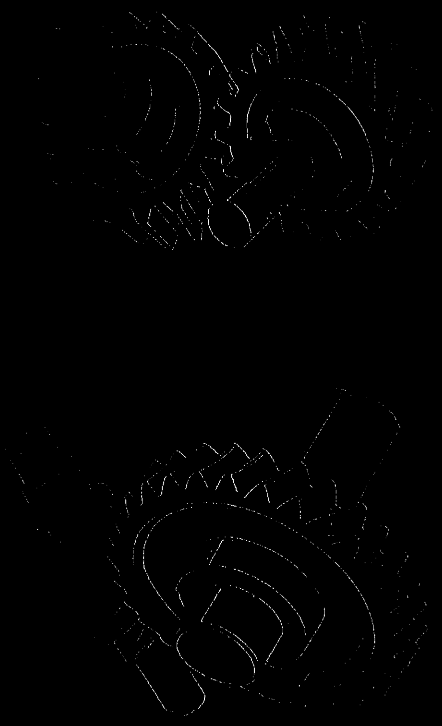
Configuration and lay-out

PARALLEL
SHAFT GEARS



INTERSECTING
SHAFT GEARS



NON-PARALLEL
NON-INTERSECTING
SHAFT GEARS

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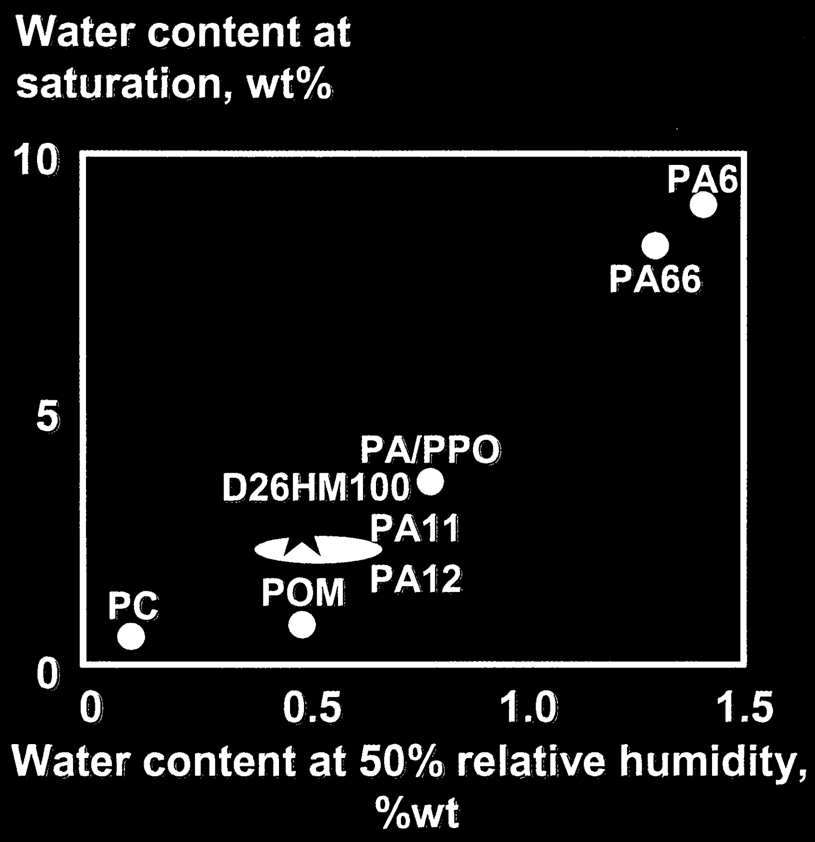
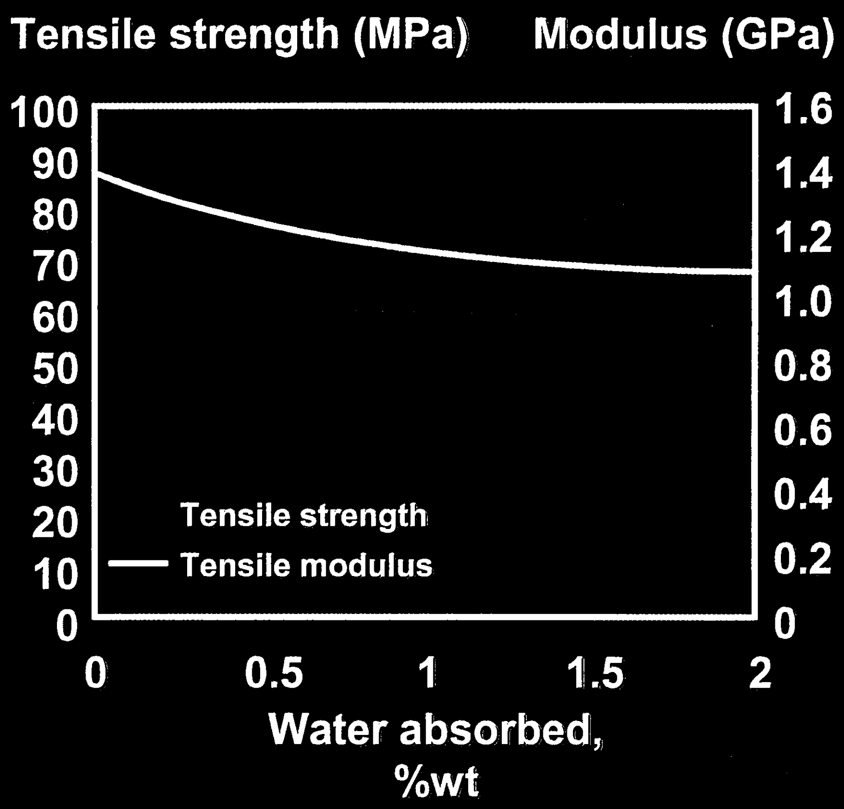
Shell Chemicals

Moisture Sensitivity





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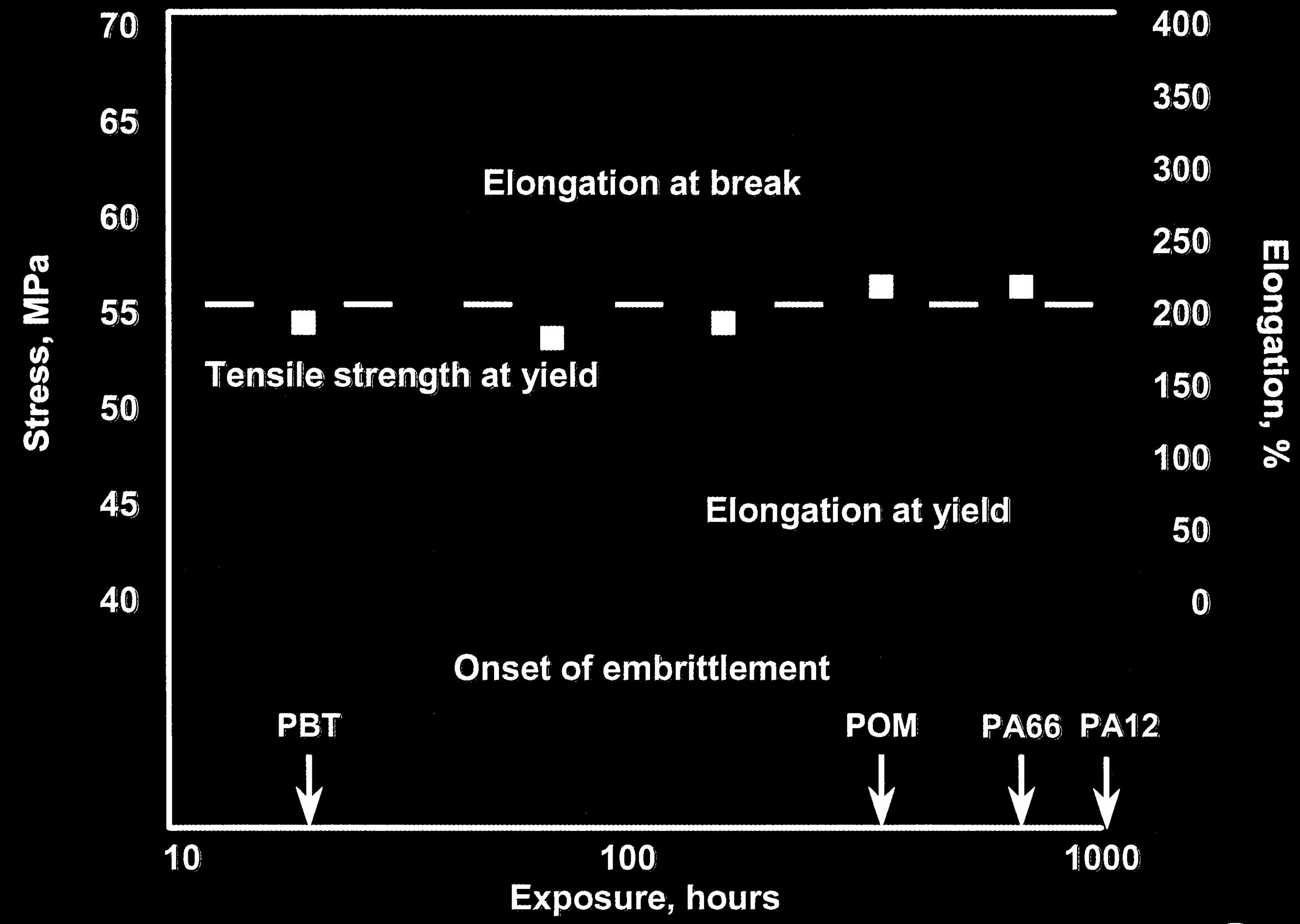
Hydrolytic Stability

Exposure to water at 100°C



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Shell Chemicals

Resistance to common lubricants

Lubricant	Yield Strength Change	Surface Appearance	Weight Change	Volume Change
Motor oil 10W-40	0 %	Dark yellow	0 %	0 %
Chassis Lube	0 %	Yellow	0 %	0%
Automatic Transmis. fluid	0 %	Yellow	0 %	0 %
Hydraulic fluid	0 %	No change	0 %	0 %

CARILON Polymer D26HM100, tested for 2 years at 23°C

Lubricants experience

Longterm W2	Molykote
PG54	Molykote
Polylub GLY 801	Kluber
Albida LX	Shell
Liplex OMB	Shell
Nerita HV	Shell
Tivela CPD A	Shell

Shell Chemicals

Chemical Resistance

	Semi-crystalline							Amorphous		
	PK	PA66	PA12	POM	PBT	PPS	PVDF	PPO	PSU	PC
Hydrocarbons										
aliphatic	+	+	+	+	+	+	+			
aromatic	+	+	+	+	+	+	+			
halogenated	+	+		+		+	+			
Ketones	+	+	+	+	+	+				
Esters/ethers	+	+	+	+	+	+	+			
Aldehydes	+			+	+	+	+			
Aqueous										
water	+		+	+		+	+	+	+	+
weak acids	+					+	+	+	+	+
weak bases	+			+		+		+		+
strong acids							+	+		+
strong bases				+						
salt solutions	+				+		+	+	+	+

+ Resistant   Not Resistant

Note: Relative ranking including temperature effects

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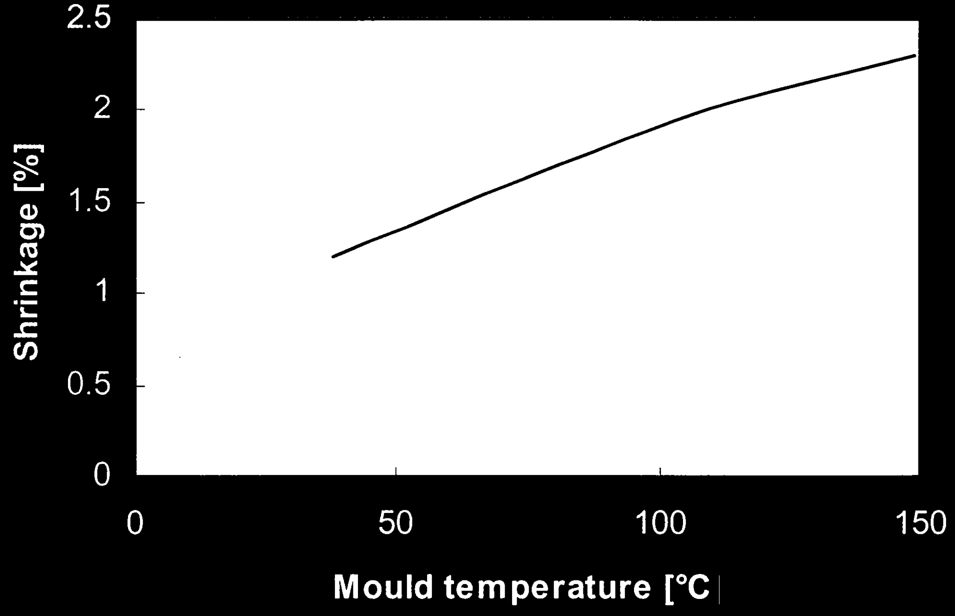
Shrinkage

Shrinkage

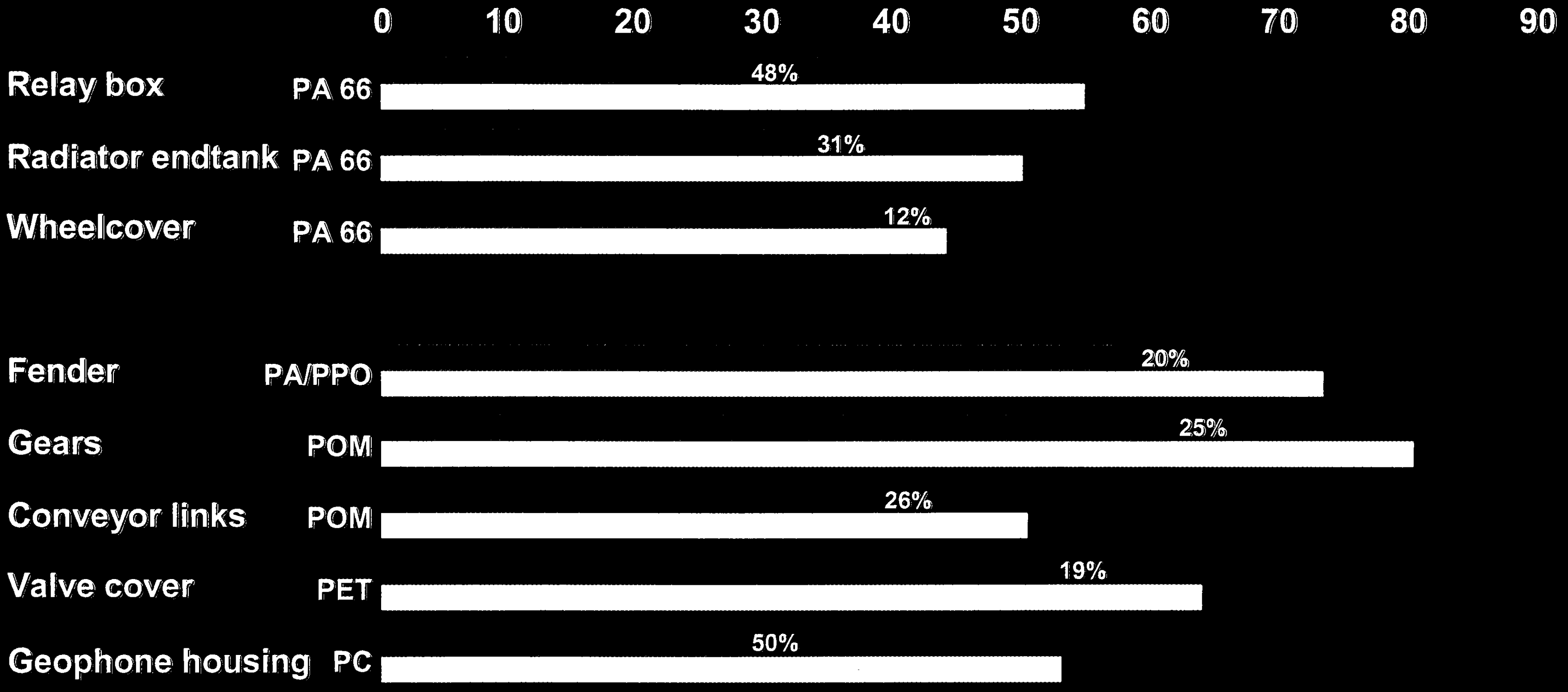
POM	1.9 %
CARILON	2.0 %



CARILON Polymers shrink isotropically

Shell Chemicals

Shorter Cycle Times with CARILON Polymers



Injection moulding cycle times (secs)

CARILON Polymers

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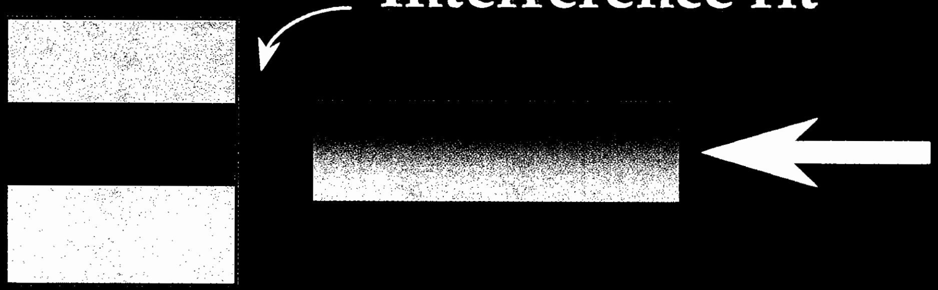
Assembling

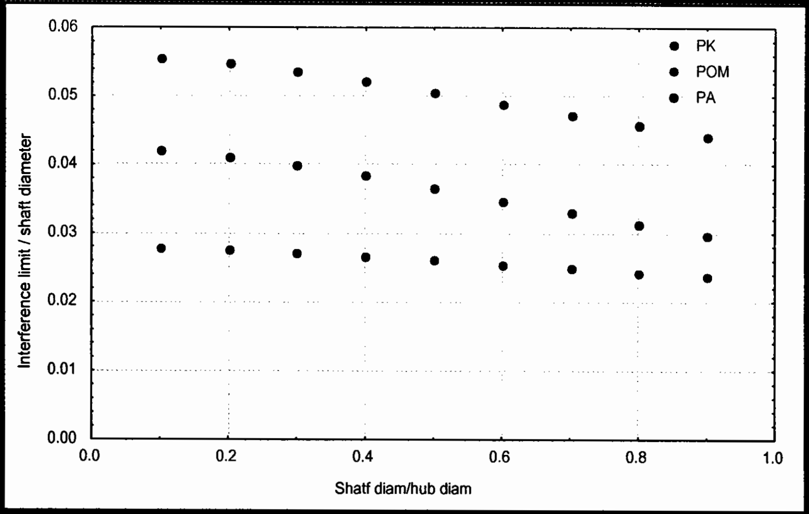


Interference fit

Higher interference limit

↓

Higher contact pressure



Based on Adams Plastics Gearing

Step by Step gear production

Designing

- Configuration and lay-out
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- Gear life test
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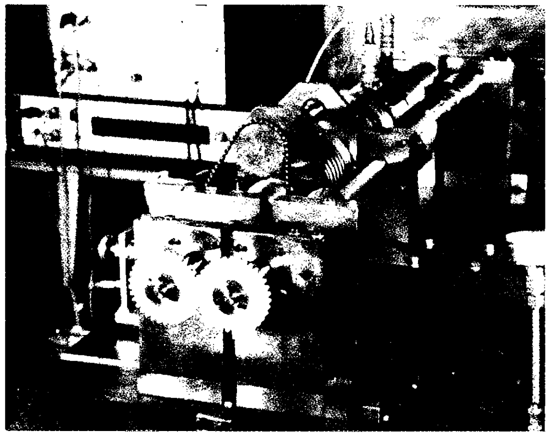
Test conditions

Tested by : Ecole Polytechnique
of the University of Montreal

Geometry : Involute geometry
Driver gear : 33 teeth
Driven gear : 34 teeth
Pitch diameter : 6.99 cm
Pressure angle : 20°



Test : Four square gear tester
All tests on unlubricate gears

Materials : POMco ; PA 6.6 ; PK

Step by Step gear production

Designing

- Configuration and lay-out
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Service

- Gear life test
- Wear performance
- Noise performance

Test conditions : Gear life test

Speed : 1200 rpm
4.4 m/s

Torque : Constant

Failure : When torque could not be transferred

Assessment : Torque to give life from 0.03 to 10 million cycles

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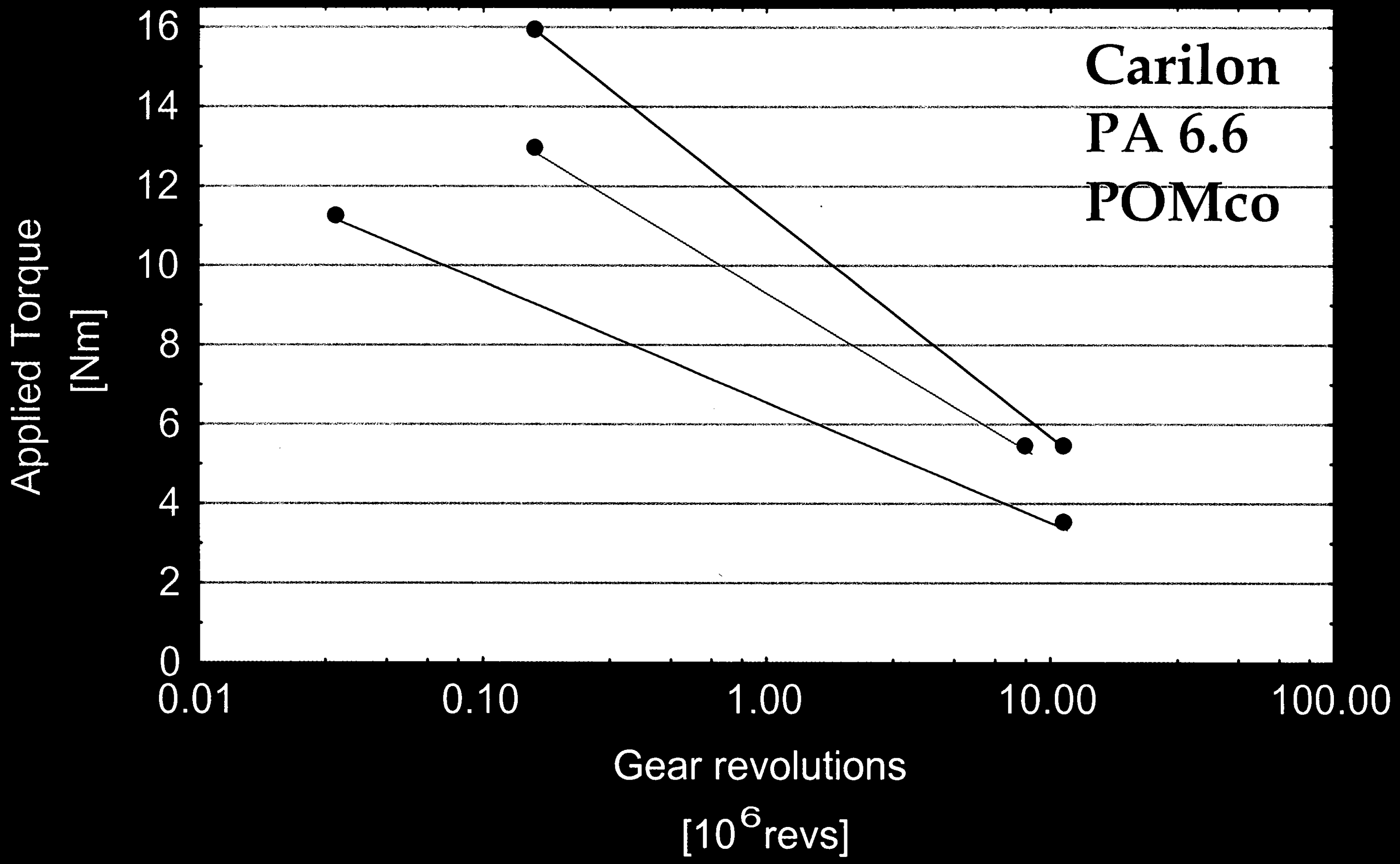
Gear life test



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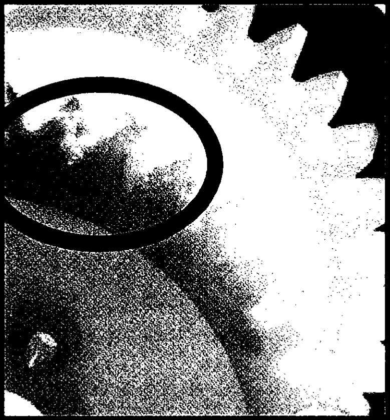
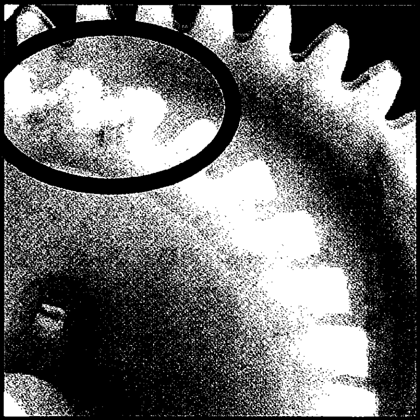
Failure mode



PA 6.6



POMco

CARILON
Polymer

Shell Chemicals

Step by Step gear production

Designing

- Configuration and lay-out
- Dimensions and tolerances
- Lubrication

Manufacturing

- Injection molding
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Service

- Gear life test
- Wear performance
- Noise performance

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Test conditions : Wear performance

Speed : 1200 rpm
4.4 m/s

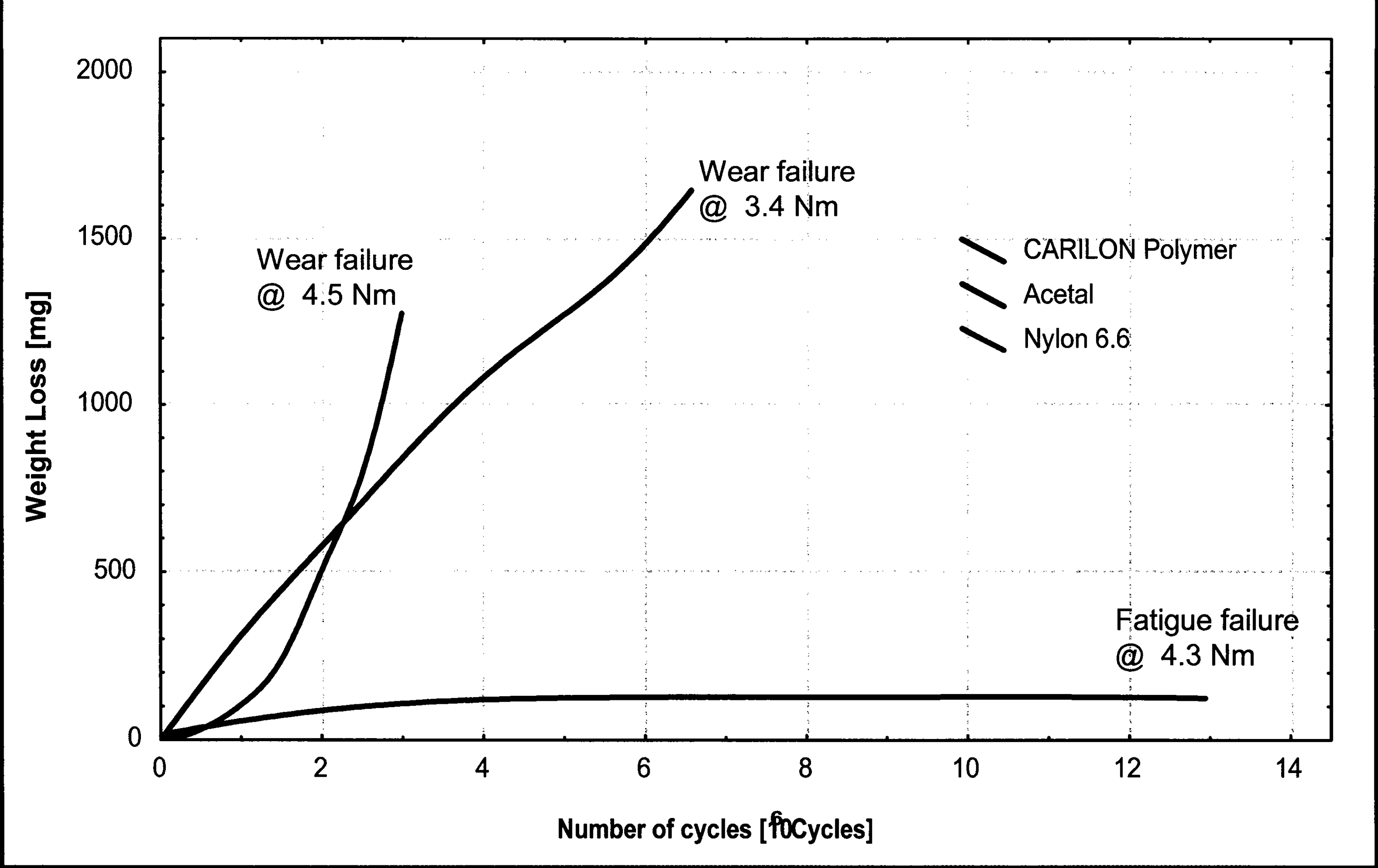
Torque : Low torque (from life test)
High torque (from life test)

Failure : When torque could not be transferred

Assessment : Weight loss

Shell Chemicals

Wear resistance of unlubricated gears at low torque levels



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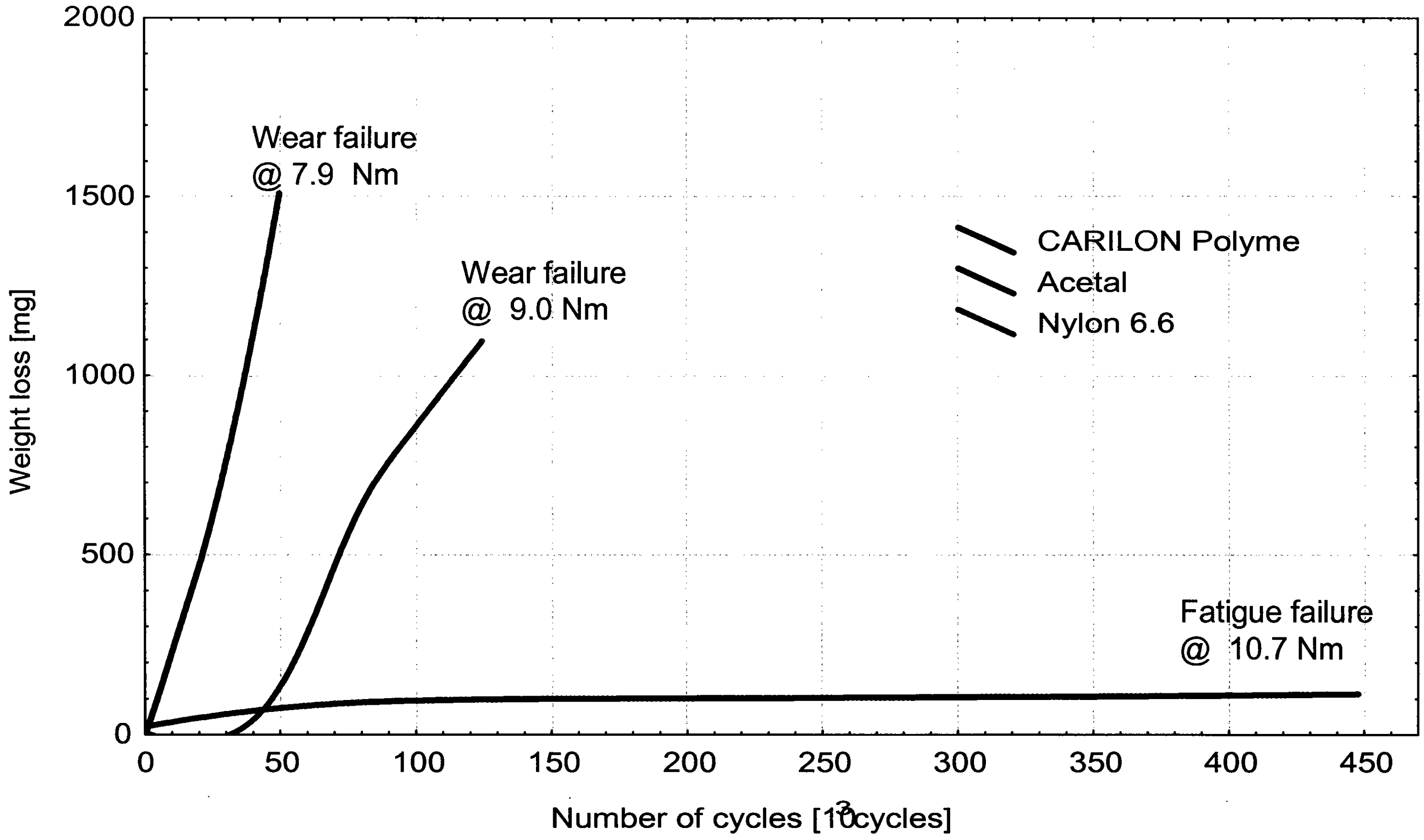
Wear resistance of unlubricated gears at high torque levels



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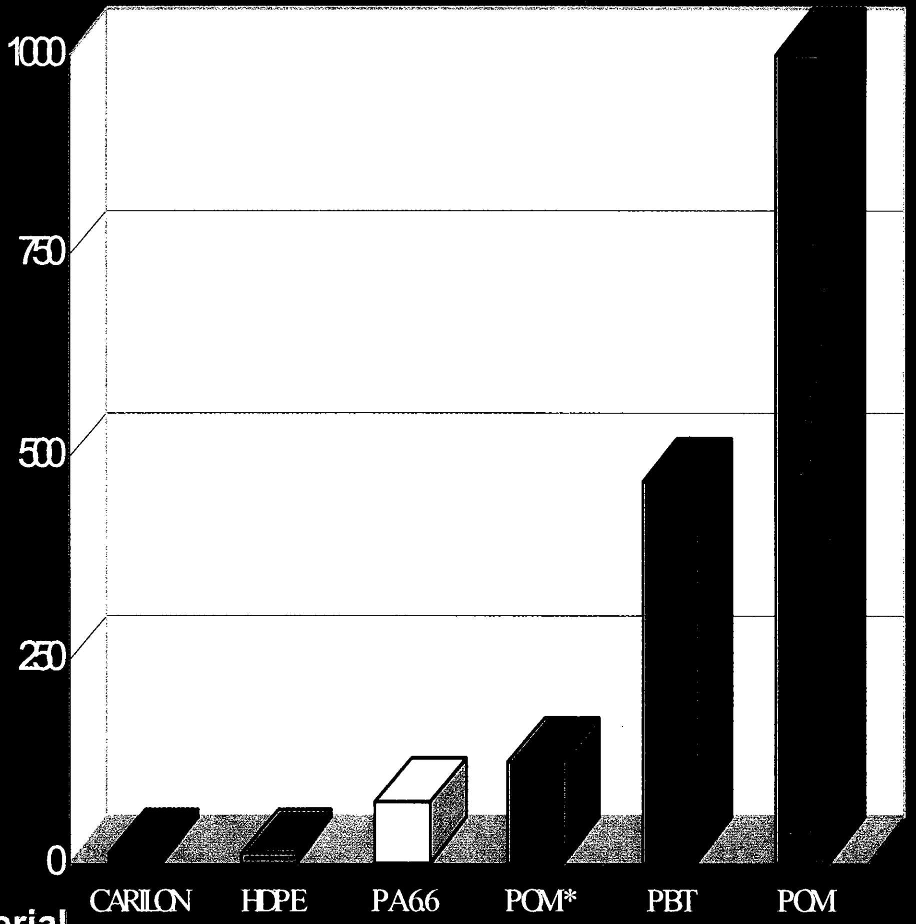
Polymer-Polymer Wear

Polymer Pair	Wear Factor $10^{-15} m^3/Nm$
CARILON	10
HDPE	10
PA 66	74
POM* (PTFE modified)	125
PBT	467
POM	>1000



Pin On Disk Method, Pin & Disk of Similar Material
Velocity 0.2 m/sec, Pressure 2.0 MPa

Wear in gear combination

Pin Disk	POM	PA 6	Carilon Polymer
POM	1800	0.5	0.2
CARILON Polymer	2.9	0.7	18.4

- : unit of wear

Pin on disk test (speed 0.25m/s, pressure 5MPa)

Step by Step gear production

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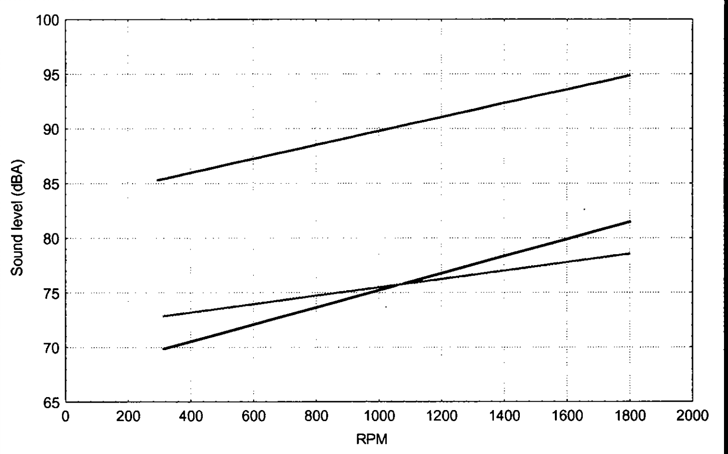
- Wear performance
- Noise performance

Test conditions : Noise performance

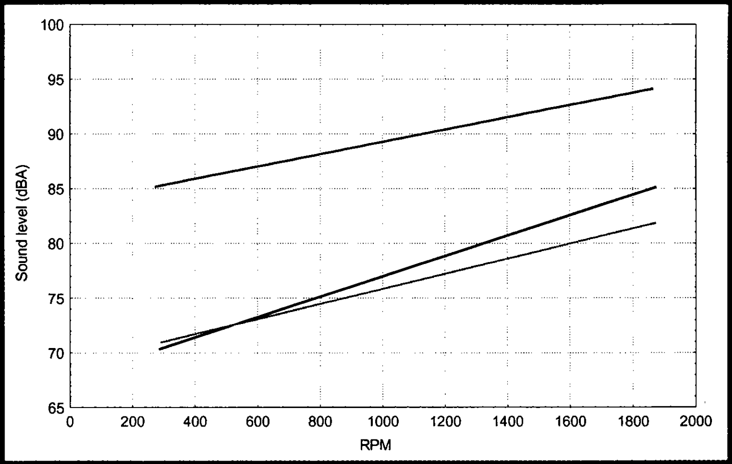
Torque : 3.4 Nm ; 5.7 Nm ; 7.9 Nm

Assessment : Noise generation as function of speed

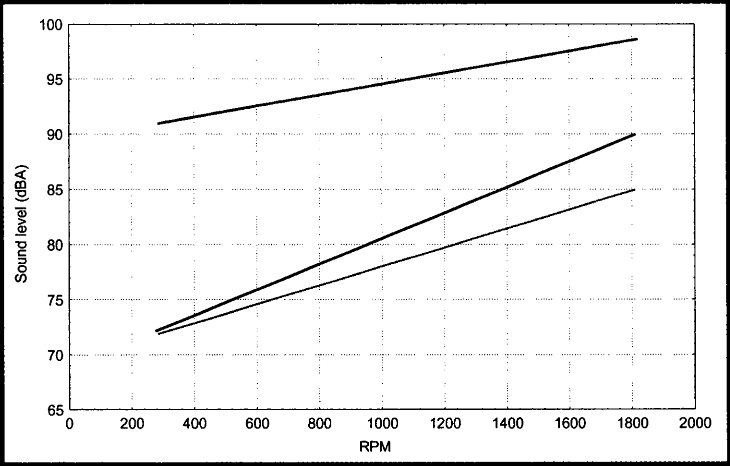
Noise generation



3.4 Nm



5.7 Nm



7.9 Nm

— PK
— POMco
— PA 6.6

Conclusions

- Dimensions and tolerances
- Lubrication
- Injection molding
- Assembly
- Gear life test
- Wear performance
- Noise performance

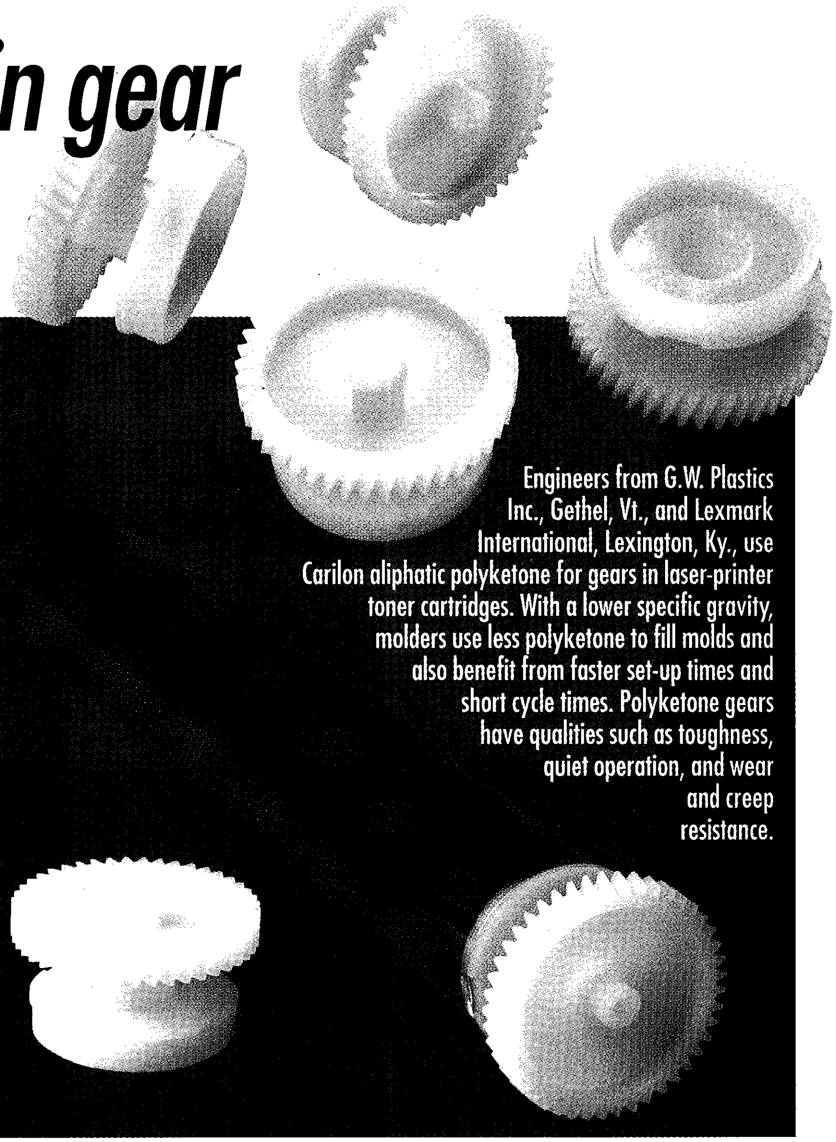
Reprinted from ***MACHINE DESIGN*** SEPTEMBER 11, 1997

EDITED BY DAVID S. HOTTER

Polymers get in gear

New developments in polyketone chemistry boost gear performance.

JOHN W. KELLEY
Staff Research Engineer
Shell Chemical Company
Houston, Tex.

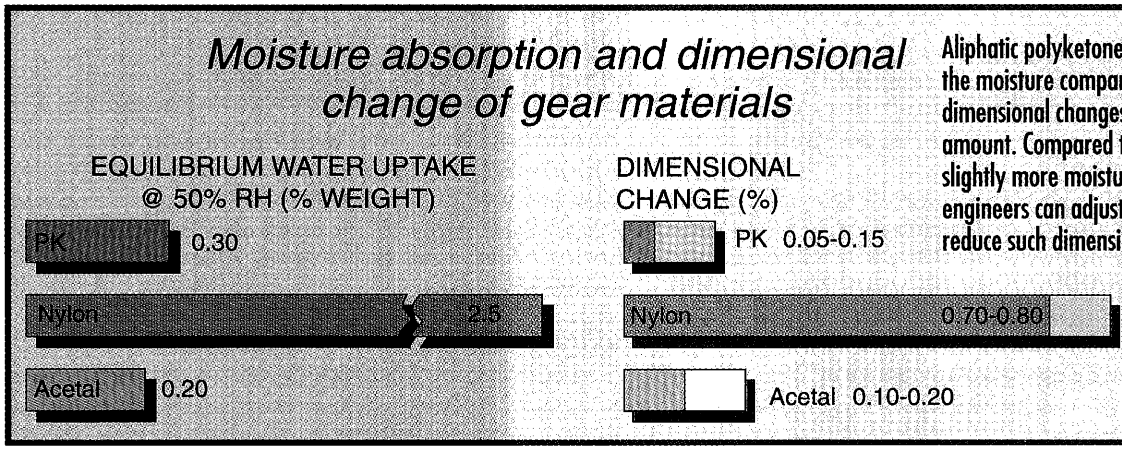


Engineers from G.W. Plastics Inc., Gethel, Vt., and Lexmark International, Lexington, Ky., use Carilon aliphatic polyketone for gears in laser-printer toner cartridges. With a lower specific gravity, molders use less polyketone to fill molds and also benefit from faster set-up times and short cycle times. Polyketone gears have qualities such as toughness, quiet operation, and wear and creep resistance.

Engineers use plastic gears for a wide variety of applications in automobiles, computers, electronics, and medical equipment. They provide a lightweight, low-cost means of transmitting power. With less mass and lower inertia, smaller power controls are needed to move plastic gears during both start-up and normal running. Neat (unfilled) polymer gears often require no lubrication, and those that do can be compounded with internal lubricants such as polytetrafluoroethylene and silicon.

Engineers have traditionally used nylons and acetals for plastic gears. While both of these materials have attractive qualities, they also suffer from drawbacks such as excessive running noise and moisture absorption. Aliphatic polyketone (PK) resins, the latest in polymer developments, now offer a unique balance of mechanical, tribological, acoustical, chemical, and injection-molding qualities.

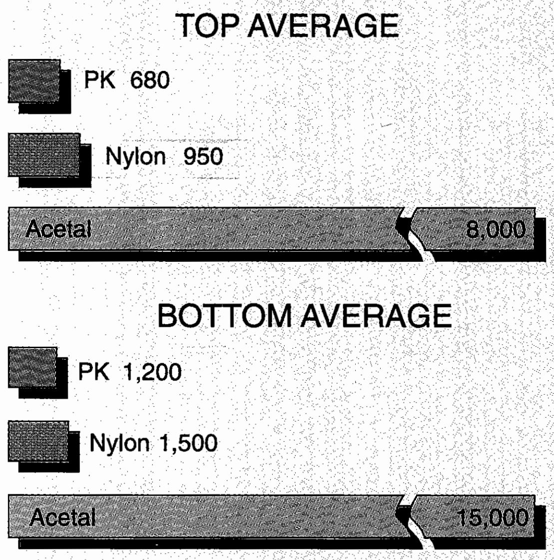
The new family of resins, called Carilon, resists chemicals such as automotive fluids and lubricants, organic solvents, corrosive salts, and water. With absorption qualities similar to acetal, PK absorbs less moisture than nylon and with only minor dimensional changes. What's more, any dimen-



Aliphatic polyketones absorb one-eighth the moisture compared to nylon, reducing dimensional changes by nearly the same amount. Compared to acetal, PKs absorb slightly more moisture. However, engineers can adjust molding conditions to reduce such dimensional change.

Wear factors for polymer thrust washers run against each other

Tests run at $PV = 1{,}000$ ($P = 50$ psi, $V = 20$ ft/min)
Average wear factor (10^{-10} in.^{3} min/ft-lb-hr)



PK outperforms nylon and acetal in wear-resistance tests of like polymers run against another in pure sliding or rolling contact.

sional changes can be compensated for in the mold design and by adjusting molding conditions. This doesn't affect gear performance because of PK's wide molding window. Additional qualities include high impact strength, short cycle times, and low shrinkage after removing parts from molds.

WEARING OUT

Noise, fatigue resistance, and wear are critical properties for engineers designing plastic gears. Gears act as cantilevered beams, thereby making flexural strength and stiffness critical to performance. Gear-tooth dynamics vary from mainly rolling contact to pure sliding, depending on geometry, so polymers must also resist frictional forces under point, line, or area contact.

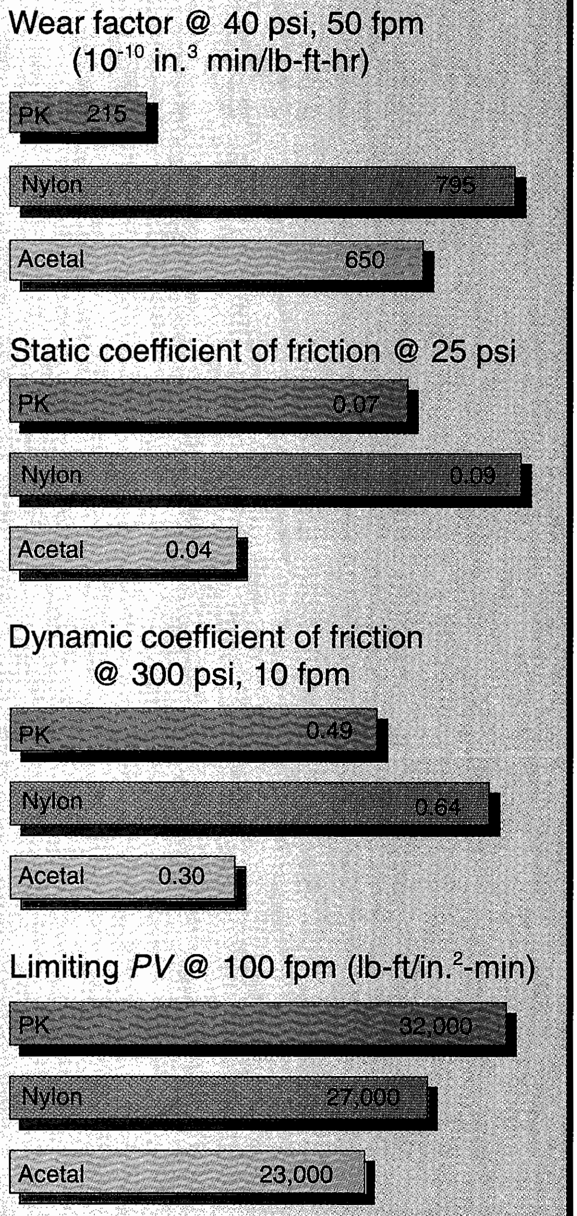
Because molding gears from plastic is a relatively new technology and gear tooth dynamics are complex, designers have limited data on the load-carrying capacity and wear qualities of resins. Therefore, they rely heavily on gear-testing results to choose the best polymer.

For example, tests run over a range of rpm and applied torque show that PK gear pairs generate up to 16% less noise than pairs of acetal gears and from 3% less to 3% more noise than nylon pairs, depending on running speed. Tests also show that PK outperforms nylon and has equivalent to slightly less fatigue resistance than acetal.

Engineers also use comparative life-testing on like-polymer pairs of spur gears injection molded from PK, nylon and acetal to determine wear resistance. Carilon polymer gear pairs don't show any significant wear even after reaching their full fatigue lives. Comparatively, acetal and nylon gear pairs wear and fail prematurely, often due to high friction and low wear resistance. Polyketones also outperform nylon and acetal when run against metal, where sliding contact contributes to wear.

Tribological performance among common gear resins

(from testing polymer thrust washers on steel)



Wear tests run against steel thrust washers in pure sliding contact show that PK has better wear resistance than nylon and acetal.

STALLING FOR TIME

In many applications, plastic gears find themselves held in a stalled position when rotation stops. After sudden stops or starts, meshing teeth experience a near-instantaneous maximum load, which may last only a very short time or for long periods. Such stalled conditions occur in actuator and timer applications at cycle extremes in temperatures ranging from -40 to 80°C.

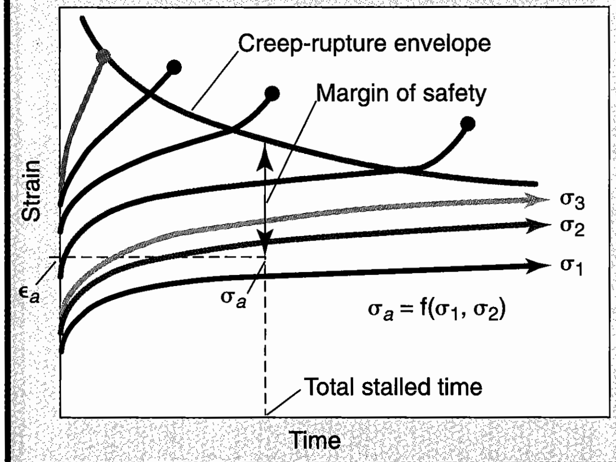
As a stalled condition begins, high strain rates can damage gear teeth with impactlike deformations. Therefore, designers look for plastic resins with enough impact resistance to meet such demanding conditions.

Generally, ductile polymers, such as PK and nylon, have more impact resistance than nonductile polymers such as acetal. Engineers use the Notched Izod impact test (ASTM D-256) to measure impact resistance. The approximate Notched Izod impact values at 23°C for PK, acetal, and nylon are 4.5, 1.0, and 2.1 ft-lb/in., respectively. At -40°C, the approximate Notch Izod impact values are 0.9, 0.8, and 0.5 ft-lb/in., respectively. Therefore, PK has significantly better impact resistance than acetal and nylon at 23°C, and continues to outperform the other resins at -40°C.

In stalled conditions, mating gear teeth also experience creep deformation — time-dependent deformation under static or quasi-static loading. This creep deformation is analogous to the creep deformation experienced in tensile and bending creep testing. As gear teeth creep more by remaining stalled, they may rupture in the same way that materials fail under the conditions in creep-rupture testing.

It takes time to relieve the effects of creep strain. Strain builds up in actuators and timers, particularly when gears remain stalled longer than they cycle. Gears fail from creep rupture when creep strain accumulates and reaches material limits. Comparative charts show that PK has better creep resistance than

Designing ductile-polymer gears for stalled conditions



Getting a solid gear-tooth design

Engineers strive to design plastic gears with teeth that don't fail over the expected life of the gear. Experience shows that plastic gears have several different modes for failing, including wear, mechanical fatigue, mechanical fracture, pitting, local tooth-surface softening, and global tooth thermal softening.

Typically, gear teeth are designed against these failures using materials with adequate allowable stresses, values which are derived from life-testing gears made from different resins. Engineers typically design gear teeth by treating each individual tooth as a cantilever beam subjected to bending stress and assuming only single pairs of teeth are in contact. This gear-tooth design methodology is based on the Lewis gear-tooth bending stress equation:

$$\sigma_b = (FP_d)/(fY)$$

where F is the tangential force transmitted at the pitch point.

P_d = pitch diameter
f = face width of the gear
Y = Lewis tooth-form factor

The force transmitted at the pitch point can be calculated from the required service torque, T, as follows:

$$F = 2T/D_d$$

where D_d is the diametral pitch of the gear.

Combining the two formulae and solving for the transmitted torque, T, results in:

$$T = (\sigma_a D_d f Y)/(2P_d)$$

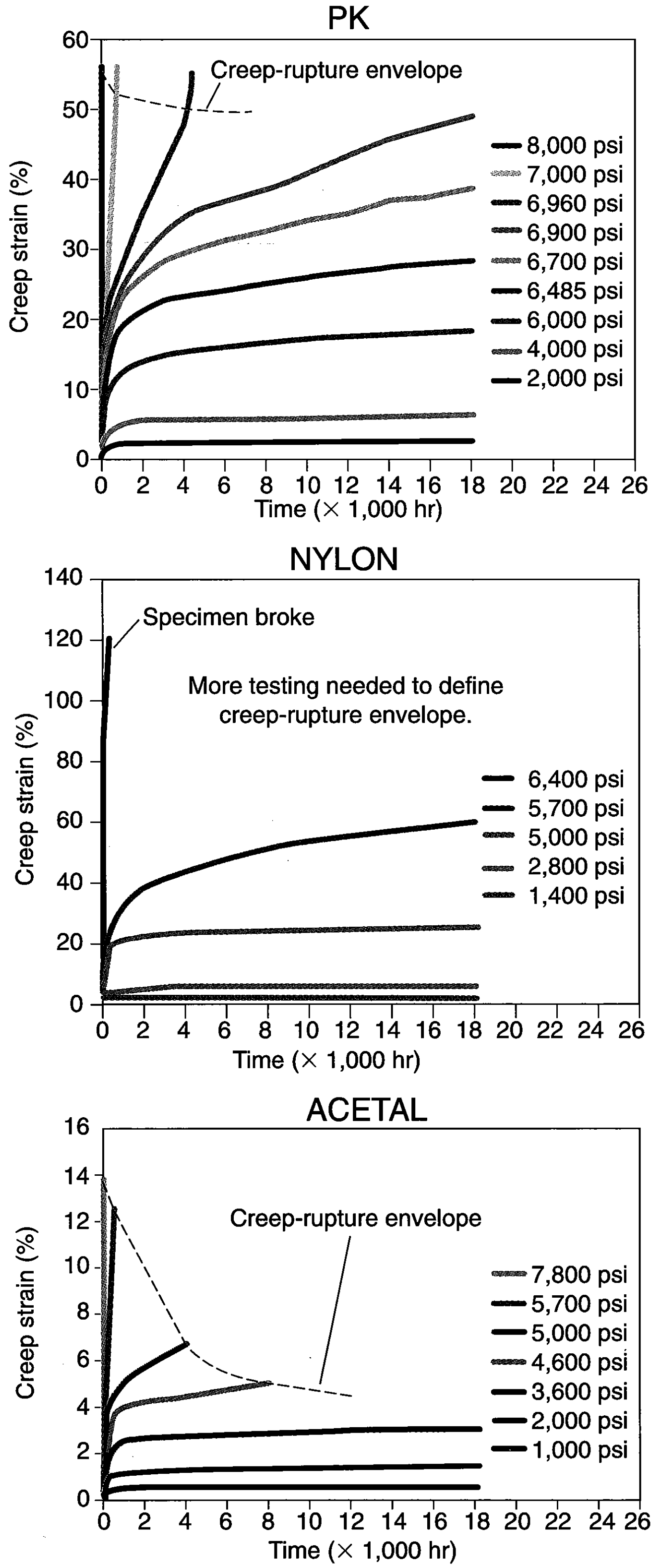
where σ_a, an allowable stress, has been substituted for σ_b.

The allowable stress, σ_a, is an appropriate strength value which has been adjusted for safety. Gear testing of a specific resin yields the appropriate strength value. In gear design, engineers adjust the tooth geometry, controlled by D_d, P_d, f, and Y, until they reach the required service torque, T.

Designing gear teeth for gears run into or held in a stalled condition presents a challenge, but the equations derived above can still be used to design these types of gear teeth. However, defining a value for σ_a from the results of gear life-testing of stalled gears is not possible because this static-creep life-testing is not readily available. Instead, values from bending creep and tensile creep/creep-rupture testing are used, since they are available for most polymers used in plastic gearing. It is possible to interchange these properties because the time-dependent deformation (creep deformation) resulting from a constant tensile or bending stress simulates the same deformation experienced by gear teeth under stalled conditions.

Gear designers still need to derive the allowable stress, σ_a, from the results of tensile creep/creep-rupture testing, because the equipment used to run bending creep tests doesn't run to failure. First, determine the total time that a gear will remain under stalled conditions. Once that time is known, use tensile creep/creep-rupture test results for each specific polymer.

Next, plot the data with creep strain on the vertical axis and time on the horizontal axis. Then locate the required total stalled time and move up the graph until reaching an appropriate strain level ϵ_a with a large enough margin of safety (distance away from the creep-rupture envelope) to protect against creep-rupture. If ϵ_a doesn't directly fall on a strain versus time curve and σ_a can't be directly read, interpolate the allowable stress level between curves. Using this resulting σ_a value, modify tooth geometry (D_d, P_d, f and Y) to meet the required service torque T.



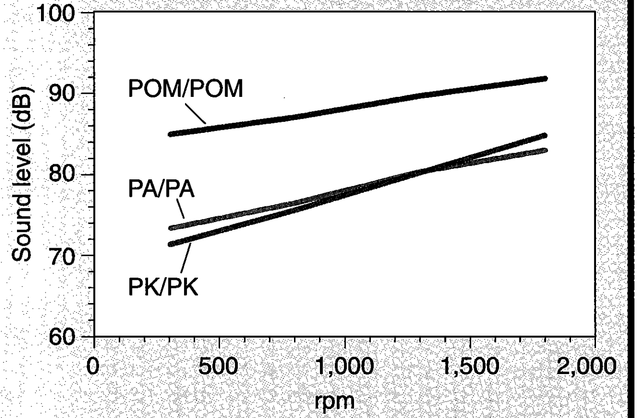
Creep behavior in polymers

at 23°C and 50% RH

Keep quiet!

Spur-gear noise data at 2.5 lb-ft torque

(12 diametral pitch, 20° pressure angle, unlubricated, polymer-on-polymer gears)



PK gears produce less noise than acetal and slightly less or slightly more noise than nylon, depending on gear speed.

A resin's ductility is defined by the shape of its creep-rupture envelope. A ductile plastic has less slope in its envelope, covering a broad range of strain values. Nonductile polymers, on the other hand, have more slope in its envelope over a very narrow band of strain levels. As in standard creep testing, gear teeth experience primary creep deformation (initial part of the curve with large slope) and secondary creep (second part of curve with smaller slope). In addition, ductile polymers, such as PK and nylon, undergo tertiary creep — part of the curve where slope increases again.

acetal, but not as good as nylon.

Ductile and nonductile polymers behave differently under creep conditions. Ductile polymers experience primary, secondary, and tertiary creep deformation before creep rupture, while nonductile polymers experience only primary and secondary creep deformation before creep rupture.

Ductile polymers will experience larger creep deformation than nonductile polymers. Therefore, nonductile polymers are more creep resistant than ductile polymers. However, ductile polymers are known to be more creep-rupture resistant than nonductile ones. That is, for a given load, nonductile versions could creep-rupture significantly earlier in time than ductile polymers, as seen in the magnitude, shape, and slope of the creep-rupture envelopes for each type of polymer. ■