COLOR • CONDUCTIVE • FILM/SHEET • FLAME RETARDANT
STRUCTURAL • THERMOPLASTIC ELASTOMERS • WEAR

Wear in the World of Plastics

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WEAR AND FRICTION

"My application is wearing out!"

Fatigue? ?

Chemical Attack? ?

Abrasion? ?

Weather/UV Resistance? ?

WEAR AND FRICTION

WEAR AND FRICTION

Be Specific!

Wear – Sliding wear of thermoplastic compounds against a contact surface (steel, aluminum, other thermoplastics, etc.)

Friction – Reducing/controlling the friction in a sliding or moving system

Internally Lubricated Thermoplastics

AGENDA

I. Wear Definitions & Test Methods

II. Friction Definitions & Test Methods

III. Additive Technologies

IV. Application Examples

V. Extreme Conditions – Ultra Wear

WEAR DEFINITIONS

Tribology:

The Science of the mechanisms of friction, lubrication, and wear of interacting surfaces that are in relative motion

WEAR DEFINITIONS

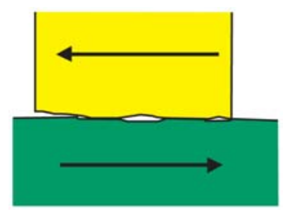
Recall: Sliding surfaces

Wear = Loss of material over time

WEAR DEFINITIONS

Adhesive Wear Mechanism

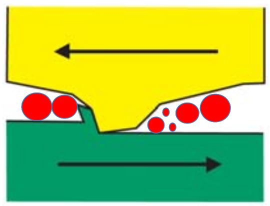
- The primary mechanism for thermoplastic wear
- Characterized by transfer of material from one part to the other caused by frictional heat



WEAR DEFINITIONS

Adhesive Wear Mechanism

- Caused by a hard material scraping or abrading away at a softer material
- Characterized by grooves cut or gouged into the surface
  - Three body



WEAR TESTING

Question: How do you simulate an application and test a material for **long-term** wear resistance?

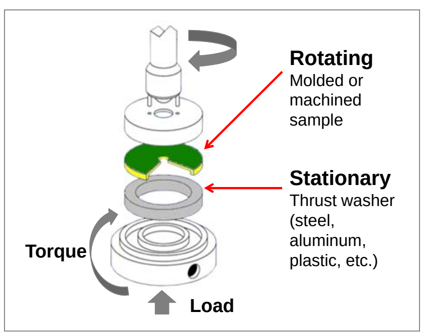
Answer: RTP uses **ASTM D-3702** wear test to quantify the amount of material a sample loses over time under specific conditions (pressure, speed, temperature)

WEAR TESTING

ASTM D-3702 "Thrust Washer" Wear Test

Adjustable:

- Counter-surface (thrust washer)
- Pressure
- Velocity
- Temperature



The best use of this test is to perform comparative screening of multiple candidate materials

WEAR TESTING

- RTP Company has six thrust washer wear testing machines in our wear lab located in Winona, MN
- Equipment is available to perform customer requested testing
- A test isn't always just a test
  - Conditions matter!

WEAR TESTING

Wear factor (K): Used to quantify wear resistance

Lower Value = Better Wear Resistance!

$$K = W/(F \times V \times T)$$

K = Wear Factor: *(in³-min/ft-lb-hr) · 10⁻¹⁰ or (mm³/N-m) · 10⁻⁸*

W = Volume wear: *in³ or mm³*

F = Force: *lb or N*

V = Velocity: *ft/min or m/sec*

T = Elapsed time: *hr or sec* **100 Hour Test!**

WEAR TESTING

Standard Conditions:

- Steel thrust washer
- 40 psi · 50 ft/min
- Ambient temp
- 100 hour test

PV = (Pressure · Velocity)

Conditions often used together to characterize severity of a wear environment

2,000 PV = (40 psi · 50 ft/min)

Typical testing done at 2,000 to 10,000 PV

WEAR TESTING

RTP Wear Brochure

PV (psi*ft./min) Wear Factor (K)

Nylon 6/6 (RTP 200 Series)						Load (lb)	Speed (ft/min)	PV	PV (SI)	Wear Factor (K)	K (SI)	µk
RTP 0200	-	-	-	-	-	8	50	2000	(70)	901	(1811)	0.66
RTP 0200	-	-	-	-	-	10	100	5000	(175)	95	(191)	0.91
RTP 0200	-	-	-	-	-	40	50	10000	(350)	191	(384)	0.60
RTP 0200 SI 2	-	-	-	-	2	8	50	2000	(70)	639	(1284)	0.54
RTP 0200 SI 2	-	-	-	-	2	10	100	5000	(175)	181	(364)	0.78
RTP 0200 SI 2	-	-	-	-	2	40	50	10000	(350)	85	(171)	0.77
RTP 0200 TFE 5	-	-	-	5	-	8	50	2000	(70)	957	(1924)	0.61
RTP 0200 TFE 5	-	-	-	5	-	10	100	5000	(175)	427	(858)	0.77
RTP 0200 TFE 5	-	-	-	5	-	20	100	10000	(350)	76	(153)	0.59
RTP 0200 TFE 10	-	-	-	10	-	8	50	2000	(70)	341	(685)	0.31
RTP 0200 TFE 10	-	-	-	10	-	10	100	5000	(175)	171	(344)	0.28
RTP 0200 TFE 10	-	-	-	10	-	40	50	10000	(350)	156	(314)	0.29
RTP 0200 TFE 18 SI 2	-	-	-	18	2	8	50	2000	(70)	11	(22)	0.20
RTP 0200 TFE 18 SI 2	-	-	-	18	2	10	100	5000	(175)	59	(119)	0.36
RTP 0200 TFE 18 SI 2	-	-	-	18	2	40	50	10000	(350)	18	(36)	0.19

- Excellent Wear Resistance (K= < 75) - Good Wear Resistance (K = 75 – 200) - Fair Wear Resistance (K = 200 – 400)

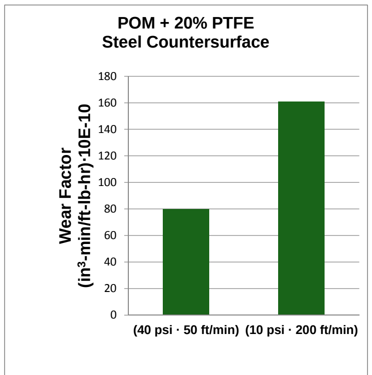
WEAR TESTING

Question: Does an equivalent PV always result in the same data?

Standard Conditions: PV = 2,000
- P = 40psi
- V = 200 ft./min

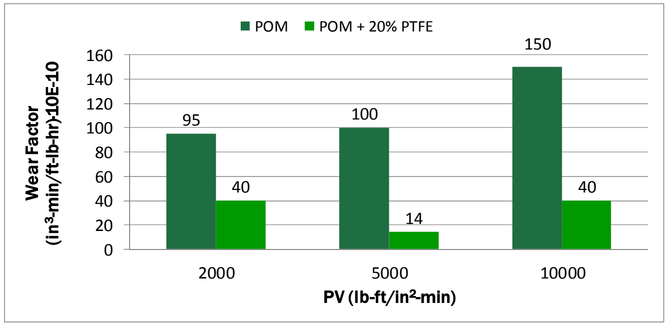
Non-Standard Conditions: PV = 2,000
- P = 10psi
- V = 200 ft./min

Answer: No…Wear factor will change based on individual conditions



WEAR TESTING

Question: What happens when PV is increased? Does Wear Factor (K) also increase?



Wear per ASTM D 3702 against C1018 Steel

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I. Wear Definitions & Test Methods

II. Friction Definitions & Test Methods

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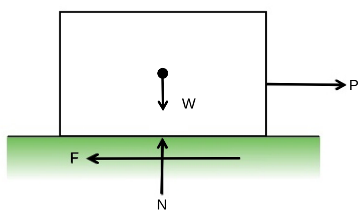
FRICTION DEFINITIONS

Coefficient of Friction (μ)

Ratio of the force of friction between two bodies and the force pressing them together

$\mu = F/N$



FRICTION DEFINITIONS

Coefficient of Friction (μ)

Static coefficient of friction (μ_s) = Fx/Fy
Fx = Force to *initiate* motion
Fy = Normal force holding surfaces together

Dynamic coefficient of friction (μ_k) = Fx/Fy
Fx = Force to *sustain* motion
Fy = Normal force holding surfaces tog

FRICTION DEFINITIONS

- In most non-plastic materials
  - $\mu_s > \mu_k$
- Thermoplastics are somewhat unique
  - $\mu_k > \mu_s$
- May cause "slip/stick" – *Glide Factor*[SM]
- If $\mu_k >> \mu_s$ you may have squeaking

FRICTION TESTING

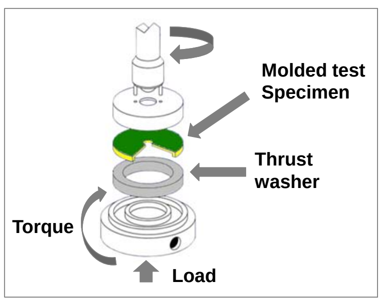
ASTM D 1894 "sled test"

- Coefficient of friction testing
- Does not determine wear resistance
- Can show slip/stick

FRICTION TESTING

RTP Modified ASTM D3702 Friction Test

- Oscillating motion used to measure Friction coefficients and *Glide Factor*[SM]
- *Glide Factor*[SM] is used to quantify the difference between μ_s and μ_k in order to reduce/eliminate stick/slip
- Used to generate friction data for optimal material selection in medical devices



TESTING REVIEW

Question: How does RTP measure wear resistance?

Answer: ASTM D3702 Thrust Washer wear test; Wear Factor (K)

Question: How does RTP measure Friction?

Answer 1: ASTM D1894 "Sled Test"
(Static and Dynamic Coefficient of Friction)

Answer 2: Modified ASTM D3702 Thrust washer friction test.
(Glide Factor[SM])

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ADDITIVE TECHNOLOGIES

ADDITIVE TECHNOLOGIES

PTFE – Polytetrafluoroethylene (5-20%)

Workhorse additive – solid white powder

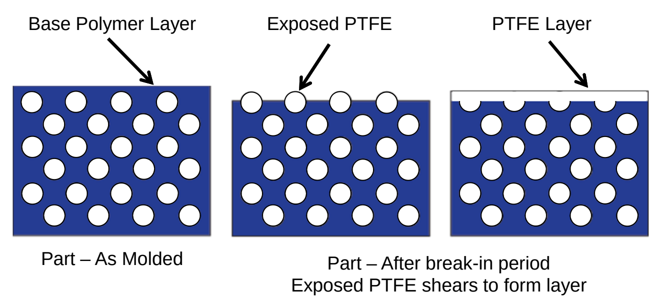
Compatible with nearly all thermoplastic resins

Limitations:

- Fluorine content
- Die plate-out
- Relatively high loadings
- Cost fluctuation

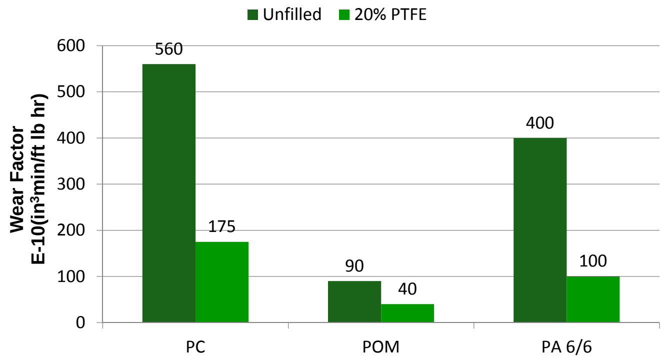
ADDITIVE TECHNOLOGIES

PTFE Wear Mechanism



ADDITIVE TECHNOLOGIES

Unfilled vs. PTFE Wear Factor



Wear factor against Steel; PV = 2000

APPLICATION EXAMPLE

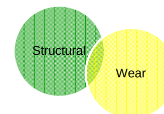
Laser Printer Fuser Gears

Requirements:

- High Operating Temperatures
- Good wear Resistance

Solution:

- Glass fiber reinforced and PTFE lubricated PPS



ADDITIVE TECHNOLOGIES

ADDITIVE TECHNOLOGIES

Silicone – Polydimethylsiloxane (1-3%)

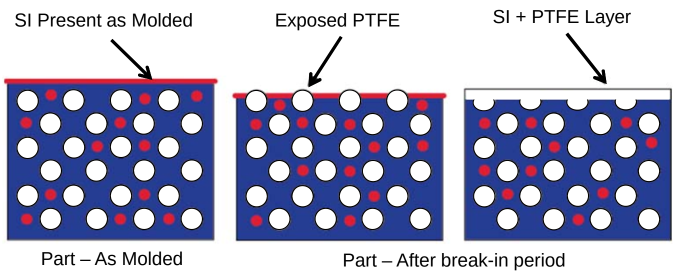
- Boundary lubricant which migrates to the surface over time
  - Migration rate is viscosity dependent
- Excellent friction reducer
- Best in high speed/low load applications

Limitations:

- Limited use in decorated parts
  - Poor adhesion of paint or print inks
- Bad for electrical applications
  - Can foul contacts

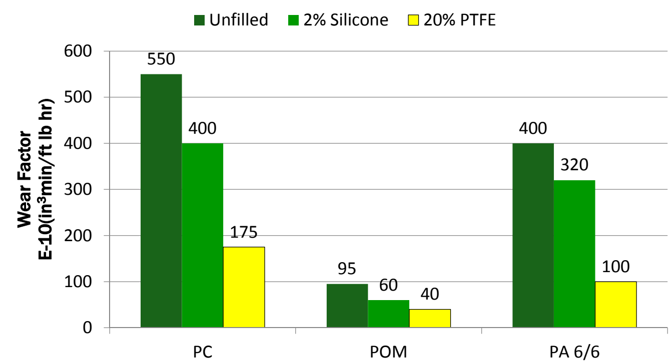
ADDITIVE TECHNOLOGIES

PTFE + Silicone Wear Mechanism



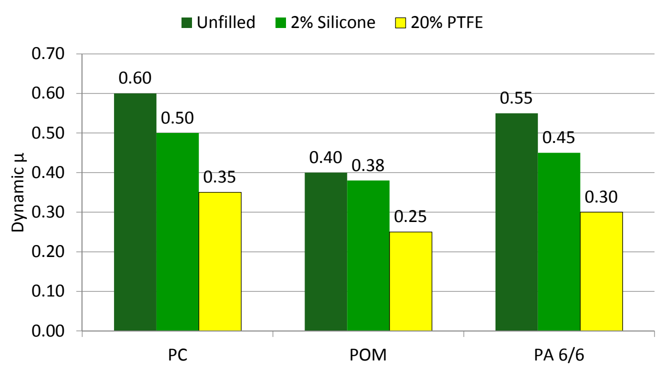
ADDITIVE TECHNOLOGIES

Wear Resistance with PTFE and Silicone



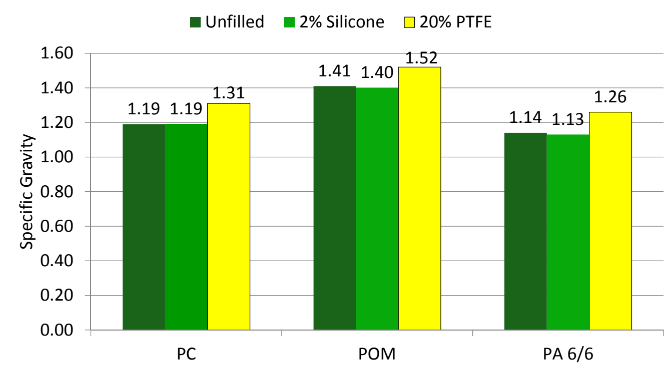
ADDITIVE TECHNOLOGIES

Friction Reduction with PTFE and Silicone



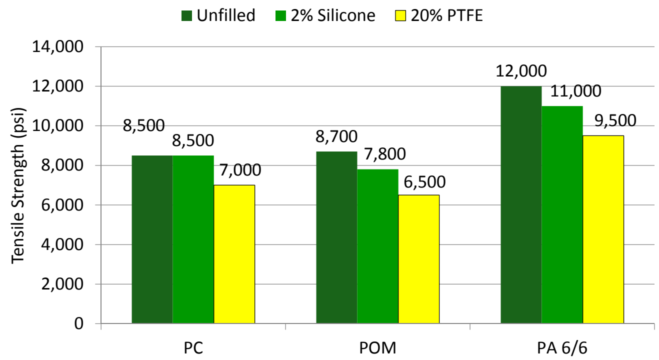
ADDITIVE TECHNOLOGIES

Specific Gravity Differences with PTFE and Silicone



ADDITIVE TECHNOLOGIES

Tensile Strength with PTFE and Silicone



ADDITIVE TECHNOLOGIES

	PC			PA 6/6			POM		
	Unfilled	PTFE (20%)	Silicone (2%)	Unfilled	PTFE (20%)	Silicone (2%)	Unfilled	PTFE (20%)	Silicone (2%)
Specific Gravity	1.19	1.31	1.19	1.14	1.26	1.13	1.41	1.52	1.40
Tensile Strength (psi)	8,500	7,000	8,500	12,000	9,500	11,000	8,700	6,500	7,800
Flexural Modulus (psi)	340,000	320,000	350,000	400,000	400,000	400,000	350,000	300,000	350,000
Notched Impact (ft-lb/in)	7.5	3.5	10.5	1.0	1.0	1.0	1.5	1.0	1.5

APPLICATION EXAMPLE

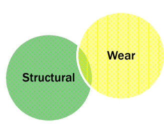
Garage Door Opener Limit Switch

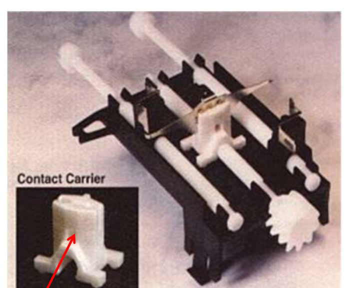
Requirements

- Dimensional stability
- Good strength and stiffness

Solution

- Silicone lubricated PC





Not Transparent! More on this later…

APPLICATION EXAMPLE

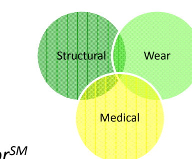
Drug Delivery Pen Components

Requirements

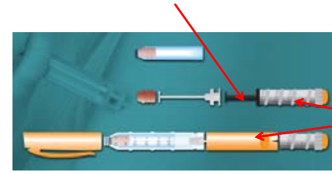
- Good strength, dimensional stability, eliminate secondary lubricant application and no slip/stick

Solution(s)

- Optimal Plastic "Friction Pairs" with low *Glide Factor*SM



Fiber reinforced and internally lubricated PC or PBT



Internally lubricated POM or PBT

ADDITIVE TECHNOLOGIES

PTFE

Silicone

PFPE

ADDITIVE TECHNOLOGIES

PFPE – Perfluoropolyether Oil (< 1%)

- Thermally stable up to PEEK processing temps
- Differentiates RTP Company from others
- Synergy with PTFE
- Specific gravity benefits

Limitations:

- Limited effectiveness in amorphous resins
- Needs PTFE "kick" to deliver optimum friction reduction

APPLICATION EXAMPLE

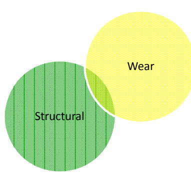
Agricultural Pump

Requirements

- Chemical and Wear Resistance

Solution

- PFPE lubricated PP



APPLICATION EXAMPLE

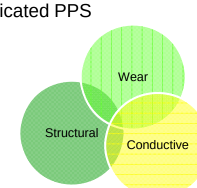
Universal Conveyor Roller

Requirements

- Strength, conductivity and wear resistance (must be silicone-free)

Solution

- Carbon fiber reinforced and PTFE/ PFPE lubricated PPS

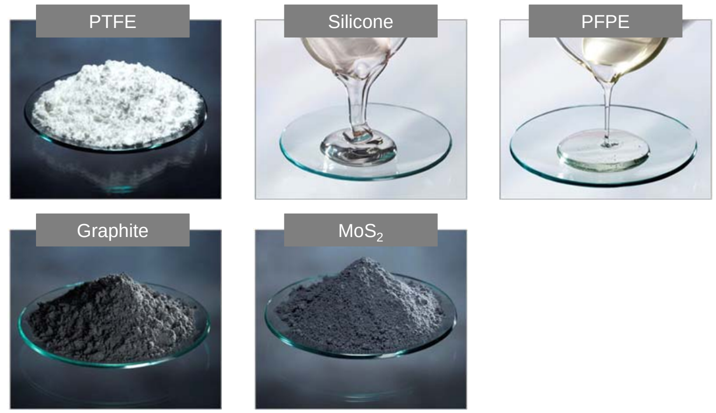


ADDITIVE TECHNOLOGIES

Additives Reduce Clarity!

- PC with APWA+
- PC with PTFE
- PC with PFPE
- PC with Silicone
- Natural PC

ADDITIVE TECHNOLOGIES



ADDITIVE TECHNOLOGIES

Graphite Powder (5-30%)
- Aqueous environments
- Excellent temperature resistance
- Black color

Molybdenum Disulfide – MoS_2 (1-5%)
- Nucleating agent in nylons: creates harder surface
- High affinity to metal:
  - Smoother mating metal surface = lower wear

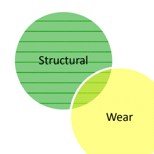
Limitations:
- Limited use
- Dark color limits colorability
- Sloughing type additives

APPLICATION EXAMPLE

Water Meter Valve

Requirements
- Dimensional stability, potable water contact - NSF listed

Solution
- Graphite lubricated PS and SAN



ADDITIVE TECHNOLOGIES

ADDITIVE TECHNOLOGIES

Reinforcing Fibers and Wear Resistance

Glass Fiber

- Improved bearing capabilities/wear resistance
- Very abrasive

Carbon Fiber

- Higher bearing capabilities
- Excellent thermal resistance
- Conductive
- Less abrasive

Aramid Fiber

- Little strength improvement
- Very gentle to mating surface

ADDITIVE TECHNOLOGIES

Fibers protect the polymer, but may be abrasive against the mating material

Glass

Carbon

Aramid

Aluminum Contact Surface

APPLICATION EXAMPLE

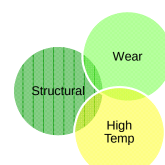
Copier Bushings

Requirements

- High HDT and good wear resistance

Solution

- Aramid fiber reinforced and PTFE lubricated PPA



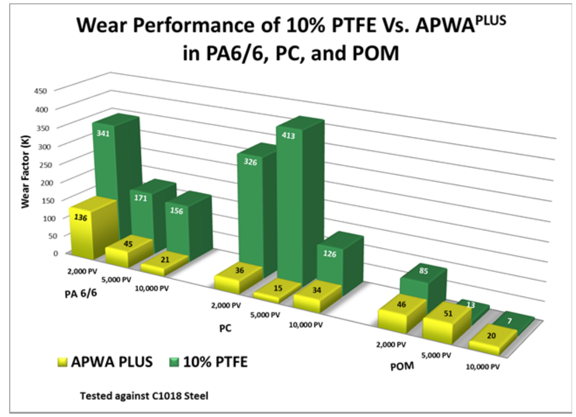
ADDITIVE TECHNOLOGIES

APWA^{PLUS}: All Polymeric Wear Alloy

A Unique Polymer Alloy Technology Offering:

- Improved wear and friction performance
  - Especially effective in plastic vs. plastic wear
- Good retention of base resin physical properties
- Lower specific gravity than PTFE
- Reduction/Elimination of plate-out associated with PTFE

ADDITIVE TECHNOLOGIES



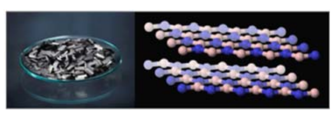
ADDITIVE TECHNOLOGIES

Additive Synergies

10/10/10 – Carbon Fiber/Graphite Powder/PTFE
Typical additive package for high load bearing/high temp. applications

Aramid Fiber/PTFE
Excellent wear package that is gentle on the mating surface

Carbon Fiber/Ceramic Additive
Non-PTFE solution, good for very demanding conditions



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EXTREME CONDITIONS

What happens when your application has a PV higher than 10,000?

High Temperature
High Loads (500+ psi)
High Speeds
Chemical Resistance

Excellent Mechanical Properties
Injection Molded Parts

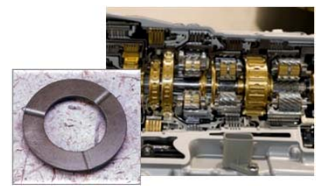
100 ft/min tests	*200 ft/min tests*
10,000 PV: 100 psi	*10,000 PV: 50 psi*
25,000 PV: 250 psi	*25,000 PV: 125 psi*
50,000 PV: 500 psi	*50,000 PV: 250 psi*

EXTREME CONDITIONS

Ultra Wear Products Developed for Demanding applications

Transmission Seal
High Load Thrust Washers
Pipe Gaskets

Off-Shore Drilling
Construction Vehicles
Oil and Gas Industry



EXTREME CONDITIONS

1. **Develop a series of high performance RTP products ideal for "Ultra" testing**

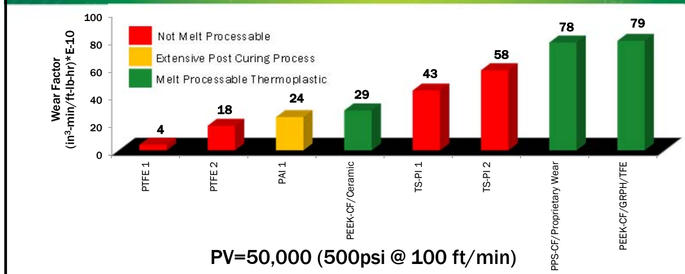
Resins
- PEEK
- PPS
- PPA

Additives
- Carbon Fiber
- Graphite
- Aramid Fiber
- PTFE
- Ceramic
- MoS_2

2. **Compare RTP Ultra Products with industry leading wear resistant materials**

- Rulon® J
- Rulon® LR
- Torlon® 4301
- Torlon® 4630
- Vespel® SP-21
- Vespel® SP-211
- Stanyl® TW371

EXTREME CONDITIONS



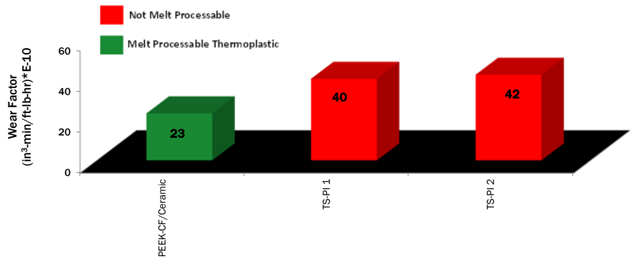
PV=50,000 (500psi @ 100 ft/min)

Compound	Wear Factor (in³-min/ft-lb-hr)*E-10	Dynamic μ
PTFE 1	4	0.15
PTFE 2	18	0.16
PAI 1	24	0.12
PEEK-CF/Ceramic	29	0.06
TS-PI 1	43	0.14
TS-PI 2	58	0.15
PPS-CF/Proprietary Wear	78	0.24
PEEK-CF/GRPH/TFE	79	0.16
PAI 2	105	0.18
PEEK-AF/TFE	119	0.18
PEEK-CF/GRPH/TFE (CGP)	133	0.23

Compound	Wear Factor (in³-min/ft-lb-hr)*E-10	Dynamic μ
PPS-CF/TFE	134	0.26
PPS-AF/TFE	Wear Limit	NA
PPS-GF/TFE	Wear Limit	NA
PEEK-CF/TFE	Wear Limit	NA
PEEK-CF/AF/TFE	Wear Limit	NA
PEEK-CF/GRPH/TFE/PFPE	Wear Limit	NA
PEEK-CF/PFPE	Wear Limit	NA
PPA-CF/TFE	Wear Limit	NA
PPA-CF/Proprietary Wear	Wear Limit	NA
PPA-CF/AF/TFE/SI	Wear Limit	NA
PA 46 - TFE	Wear Limit	NA

Wear per ASTM D-3702 against Steel

EXTREME CONDITIONS



Disc Material	Wear Factor (in³-min/ft-lb-hr)*E-10	Dynamic µ
PEEK-CF/Ceramic	23	0.05
TS-PI 1	40	0.10
TS-PI 2	42	0.07
PTFE 1	Wear Limit	NA
PAI 1	Wear Limit	NA
PPS-CF/Proprietary Wear	Wear Limit	NA

Wear per ASTM D-3702 against Steel at **400°F; PV = 100,000**

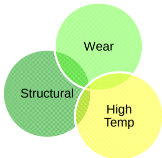
EXTREME CONDITIONS

	Torlon 4301 (PAI)	Vespel SP-21 (TS PI)	Rulon J (PTFE)	Stanyl TW371 (PA46)	RTP 1300 AR 15 TFE 15 (PPS)	RTP 4085 TFE 15 (PPA)	RTP 2285 HF TFE 15 (PEEK)	RTP 2299 X 125404 A (PEEK)
Manufacturer	Solvay	DuPont	St. Gobain	DSM	RTP	RTP	RTP	RTP
Polymer	PAI	TS PI	PTFE	PA 4/6	PPS	PPA	PEEK	PEEK
Generic Description	PTFE/Grph	Grph	PI Pwdr	PTFE	AF/PTFE	CF/PTFE	CF/PTFE	CF/Ceramic
Strength	G	G	P	F	F	E	E	G
Stiffness	G	G	P	P	F	E	E	G
~ Cont. Use Temperature	>500°F (260°C)	>600°F (316°C)	~550°F (290°C)	~350°F (177°C)	~400°F (205°C)	~375°F (190°C)	~475°F (246°C)	~475°F (246°C)
Chem. Resistance	E	E	E	P	E	G	E	E
Processing	17 Day Cure	Parts Only	Parts Only	G	G	G	G	G
Friction	G	G	E	G	E	F	G	G
Wear resistance	E	E	E	G	G	G	G	E
Moisture sensitivity	P	G	E	P	E	G	G	G

APPLICATION EXAMPLE

AC Compressor Scroll Seal

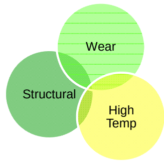
- Requirements
  - High temperature, chemical and wear resistance
- Solution
  - Carbon fiber reinforced and PTFE/Graphite lubricated PEEK



APPLICATION EXAMPLE

Transmission Seal Rings/Thrust Washers

- Requirements
  - Ability to survive extremely high PV conditions with external lubrication
- Solution
  - Carbon fiber reinforced, internally lubricated PEEK



WEAR AND FRICTION

ADDITIONAL INFORMATION

Wear Factor (K) and friction coefficient (μ_K) for common tribological compounds:
www.rtpcompany.com/info/wear

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Thank You!

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