ENDURANCE+ EFFICIENCY

LNP™ LUBRICOMP™ AND LUBRILOY™ COMPOUNDS

A guide to internally lubricated thermoplastic compounds: potential solutions for improved wear and reduced friction

CHEMISTRY THAT MATTERS™

SABIC

Founded in 1976, SABIC is today the first public, global multinational enterprise headquartered in the Middle East. Our products range from bulk commodity chemicals to highly engineered plastics for demanding applications. We are a leading producer of polyethylene, polypropylene, glycols, methanol and fertilizers and the world's third largest polyolefin producer.

SABIC's offerings include Chemicals, Polymers, Specialties, Agri-Nutrients and Metals. In Saudi Arabia, the Netherlands, Spain, the USA, India, China and Japan, our dedicated Technology & Innovation centers research ways to meet our customers' needs with excellence.

INNOVATING FOR CUSTOMER SUCCESS

We believe that SABIC customers deserve the full benefit of every advantage our enterprise can offer. After all, our success is defined by our customers' success. And with more than 80 years of experience pioneering advanced engineering thermoplastics, SABIC is positioned to help create new opportunities for growth and breakthrough applications.

We offer expertise and experience to our customers in a variety of ways:

- Material solutions to help drive innovation and market leadership.
- Design, logistics and processing expertise to spark new ideas and better efficiencies.
- Unwavering commitment to build long-term relationships with ingenuity, trust and continuous improvement.

It's what we strive for and work to deliver… a mutual benefit.

Excellence and nothing less.

INTRODUCTION

SABIC pioneered the creation of internally lubricated thermoplastics

By adding PTFE to nylon 6/6, LNP LUBRICOMP compounds led the way to self lubricating thermoplastic compounds for applications that required reduced wear, lower friction and longer life. The design freedom and ease of fabrication provided by injection molded reinforced thermoplastic composites have helped lead to the replacement of metals requiring wear resistance in many applications in industries as diverse as consumer electronics, business machines, automotive and medical devices. Industrial applications such as pumps, meters, power drives and actuators can also benefit from the inherent lubricating properties of these compounds. Today these compounds are available in multiple resins ranging from polypropylene to PEEK and using a wide variety of fully compounded internal lubricants.

Compared to metal, LUBRICOMP and LUBRILOY compounds offer:

- Elimination of external lubrication
- Reduced weight
- Part consolidation
- Lower power requirements
- Low maintenance
- Reduction/elimination of secondary operations

CONTENTS

APPLICATION DEVELOPMENT AND TECHNICAL SUPPORT

The successful development of any application made from thermoplastic compounds requires input from not only the part designer, but also the material supplier and tooling/process (manufacturing) engineers. SABIC's application development and technical support teams are prepared to provide input in any stage of the design cycle.

To complement these capabilities, our state-of-the-art tribology labs can be used as an application development resource to support customers in their product development effort when characterization of wear and friction are critical to the product design and the success of a new application. By utilizing the development resources and the information outlined in the following pages, customers can gain important information to make design decisions which may shorten the product development cycle and potentially improve the likelihood of success in bringing a new product to market. In the specific area of lubricated materials, SABIC offers:

- Wear and friction application development
- Tribological systems analysis
- Application specific wear and frictional testing
- Thermoplastic limiting pressure-velocity testing
- Thermoplastic gear and bearing design assessment
- Part design reviews and recommendations
- New product development support
- Materials recommendations

Toro irrigation chose LNP K series LUBRICOMP compounds for their water turbine gears and LNP T series LUBRICOMP compounds for their riser seal because they offer the hydrolytic stability and wear resistance in gray water to meet the demanding needs of this commercial golf course sprinkler.

INDUSTRY EXAMPLES OF LUBRICATED COMPOUNDS

CONSUMER ELECTRONICS AND BUSINESS MACHINES

LNP LUBRICOMP internally lubricated composites were initially introduced to fulfill the demanding requirements in the consumer electronics and business machine markets. By adding internal lubricants such as PTFE or PTFE/silicone to tight tolerance but generally poor-wearing materials such as polycarbonate, significant reductions in friction and wear rates allow greater design freedom, part consolidation, and the elimination of external lubricants. Recent requirements for non-halogenated FR and lubricant systems have led to the adoption of polycarbonate-based LUBRILOY alloy in laptop computers and printers.

TYPICAL APPLICATIONS	LUBRICOMP PRODUCTS
Laptop latches, hinges and buttons	LUBRILOY D20001, LUBRILOY DF2041
Printer gear train	LUBRICOMP KL003 and KL004
Fuser gears	LUBRICOMP OFL36
Tape storage chassis	LUBRICOMP DFL34

AUTOMOTIVE APPLICATIONS

The automotive industry's increasing demand for weight and cost reduction make LUBRICOMP and LUBRILOY products excellent candidates for metal replacement. While higher temperature compounds with greater chemical resistance and lubricity for under the hood applications have been traditional spaces for LNP's internally lubricated composites, new demands to further reduce cabin noise have opened opportunities for squeak-reducing compounds.

TYPICAL APPLICATIONS	LUBRICOMP PRODUCTS
Throttle body gears and components	LUBRICOMP RFL36 and UFL36
Transmission thrust washers	LUBRICOMP LCL33E
Electronic actuator gears	LUBRICOMP KL004 and QFL17ES
Damping bands	LUBRILOY R2000A and U2000A-
Leaf spring spacers	LUBRILOY RX99650
Interior components	LUBRICOMP NXCY620, LUBRILOY D2000

INDUSTRY EXAMPLES OF LUBRICATED COMPOUNDS

MEDICAL DEVICES

Medical device and drug delivery manufacturers have embraced the use of LUBRICOMP and LUBRILOY internally lubricated composites to ensure consistent actuation forces without the use of an external lubricant. Low friction, tight tolerance materials with industry- leading formulation management of change processes make SABIC a key partner in this growing market.

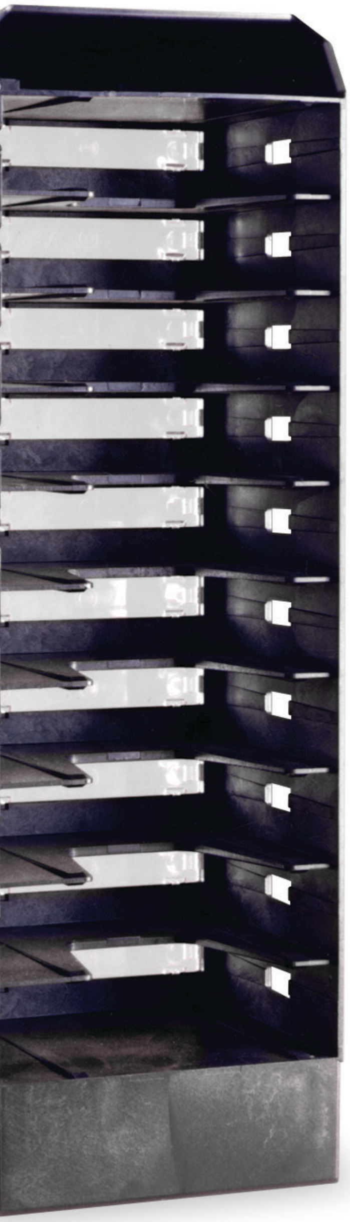
TYPICAL APPLICATIONS	LUBRICOMP PRODUCTS
Drug delivery pens	LUBRILOY D2000AXH, LUBRICOMP WX07423H
Laparoscopic surgery tools	LUBRICOMP EX03599H, DFL34EH, and DL003EXJ
Medical connectors	LUBRICOMP DX07404H
Doors and covers on housings	LUBRILOY D2000AXH

INDUSTRIAL APPLICATIONS

Industrial applications such as pumps, meters, power drives and actuators offer unique potential for metal conversion to LNP LUBRICOMP and LUBRILOY compounds. Typical requirements include high temperature performance, chemical resistance, and excellent load bearing capabilities. Many industrial applications have enjoyed significant cost savings by eliminating bearings and bushings through part consolidation.

TYPICAL APPLICATIONS	LUBRICOMP PRODUCTS
Water meter components	LUBRICOMP CG006, LUBRICOMP PPO and SAN based compounds
Gasoline metering valves	LUBRICOMP OFL36
Irrigation sprinkler turbine gears	LUBRICOMP KAL22M
Industrial gas meter gears	LUBRICOMP WL004
Compressor valve plates	LUBRICOMP LCL33E

WEAR RATE AND FRICTION



Wear rate is defined as the "volumetric loss of material per unit time." The primary wear mechanism characterized for LUBRICOMP compounds is dry sliding, or adhesive, wear. The two surfaces undergo adhesive wear which is characterized by fine particles of material being removed from the surface(s). The presence of melted polymer, large gouges or grooves is an indication of high wear rates and/or that the pressure velocity (PV) limits of the material have been exceeded.

The frictional characteristics of thermoplastics composites do not conform to the classic laws of friction partially due to the low modulus of reinforced thermoplastics compared to metals. In metal/thermoplastic systems the friction is characterized by adhesion and thermoplastic deformation. The combination of these effects often results in higher dynamic frictional values than static values. In general, thermoplastic frictional values are not proportional to load, (friction decreases as load increases) but are proportional to speed.

Storagetek computer cassette feeder, LUBRICOMP compound PDX-D

THE LNP WEAR FACTOR (K_{LNP})

Archard and other investigators contend that wear of an unlubricated surface is proportional to the load multiplied by the distance traveled.

$$W \sim FD$$

$$W \sim FVT$$

Introducing a factor of proportionality (K) and dividing by the bearing area of the test specimen yields:

$$W = K\frac{FVT}{A} \quad \text{or} \quad W = K\frac{F}{A}VT$$

$$W = KPVT$$

The LNP wear factor becomes:

$$K_{LNP} = \frac{W}{PVT} \quad \frac{[in^5 \cdot min]}{ft \cdot lb \cdot hr}$$

where: W = volume wear (in^3 or mm^3)

P = pressure ($lbs./in^2$ or pascals)

V = velocity (ft./min. or m/s)

T = elapsed time (hrs)

WEAR RATE AND FRICTION

The wear (K_{LNP}) factor for a thermoplastic composite is generated by the test procedure described on page 37 of this brochure. This test is a modified version of ASTM D3702. The static and dynamic coefficients of friction are also generated using this test. Once a K factor has been established it can be used by the engineer to calculate wear rates of bearings, gears, etc. However, because wear rate is affected by material types, finishes, hardness, environmental temperature and part design, large errors may result as end use variables begin to differ from those selected for the test procedure. As a relative measure of the performance of one composite versus another at the same operating conditions, the K factors have proven to be highly reliable. Note that PV is used in the calculation of the LNP wear factor, and it is an important variable in wear situations as described in the applications detailed on previous pages of this brochure. A wear factor per unit force (ASTM D3702) can be calculated by dividing the K_{LNP} factors by the contact area of the sample, which is approximately 0.35 in^2.

FRICTION

The coefficient of friction (COF), often symbolized by the Greek letter μ, is a dimensionless scalar value which describes the ratio of the force of friction between two bodies and the force pressing them together. COF can be measured using the thrust washer wear tester or a sliding sled test. COF for a material will vary with the two materials in contact, the nature of the motion between the two surfaces, and condition of the surfaces themselves.

LIMITING PV

The load and velocity capability of a bearing material is expressed by the product of the unit pressure P (psi), based upon projected bearing area and the linear shaft velocity V (ft./min.). The symbol PV will be used to denote this pressure-velocity relationship and can be computed by the equation:

$$PV = \frac{\text{Load (lbf)}}{\text{Projected bearing area (in}^2\text{)}} \times \text{velocity (ft/min)}$$

For a sleeve bearing:

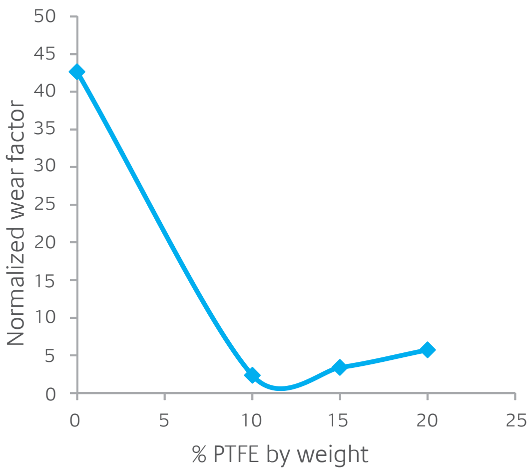
Projected bearing area = bearing length X shaft diameter (inches)

Velocity = π X shaft diameter (in) X RPM/12

A discussion and description of the test method used to generate the limiting PV (LPV) of a compound is discussed on page 40. **It should be noted that this test is a short term test independent of wear rate.** Once the operating parameters of an application exceed approximately one-half of the limiting PV, the wear begins to accelerate. Therefore, the working PV can be approximated by dividing the limiting PV generated by this test method by a factor of two.

PRIMARY LUBRICANTS AND REINFORCEMENTS

FIGURE 1 EFFECT OF PTFE CONTENT ON WEAR



I-Flow sidekick drug dispensing system, LUBRICOMP compound QFL.

PTFE

Polytetrafluoroethylene (PTFE) lubricant compounded into a thermoplastic significantly reduces the wear rate of the composite. PTFE has the lowest coefficient of friction of any known internal lubricant (0.02).

The molecular weight and particle size of the PTFE lubricant used in an LNP LUBRICOMP composite is custom-tailored to yield the optimum improvements for each resin system in wear, friction and PV. PTFE particles in a composite shear to create a PTFE film over the thermoplastic surface. This film then transfers to the mating surface providing a PTFE film on the lubricated composite and the metal or plastic counterface.

In general, PTFE loadings of 10 to 15% by weight provide the lowest wear rates (see figure 1). Higher PTFE loadings have minimal effects on further reduction in wear rate, although frictional coefficients will continue to decrease.

PRIMARY LUBRICANTS AND REINFORCEMENTS

SILICONE AND PTFE/SI COMBINATIONS

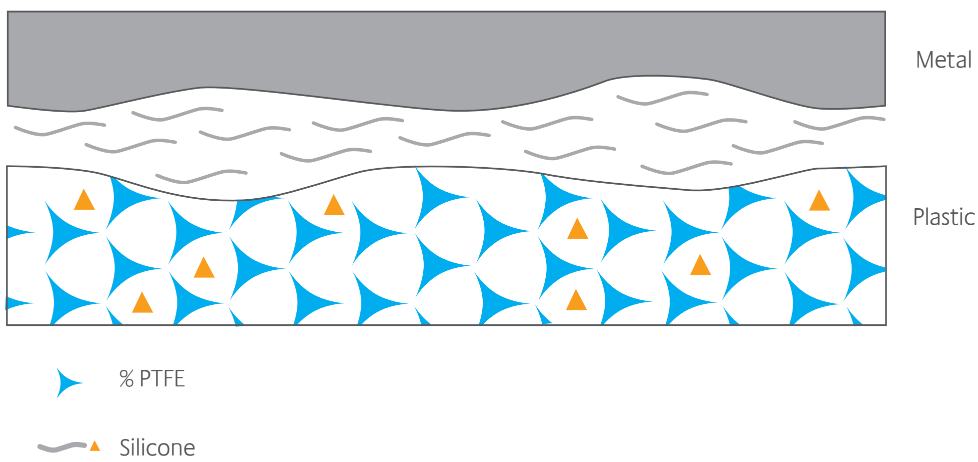
Silicone behaves as a boundary lubricant, and significant reductions in wear rates and coefficients of friction may occur when it is compounded at lower levels into thermoplastics. Silicone migrates to the surface of a molded or extruded part primarily due to the limited compatibility with the base resin. The result is a continuous generation of silicone film which serves as a boundary or mixed film lubricant.

A PTFE/silicone lubricant system provides immediate lubrication from the migratory silicone which acts to help reduce the break-in period experienced with PTFE lubrication alone. PTFE/silicone lubrication provides enhanced wear characteristics at high speeds and higher PV performance compared to PTFE lubrication alone.

LUBRILOY ALLOY TECHNOLOGY

In 1994, SABIC introduced the first in a series of LUBRILOY products, a newly patented lubricant technology. LUBRILOY compounds offer internally lubricated plastic solutions without the use of PTFE or other traditional lubrication packages. This patented alloy technology provides wear performance with lower specific gravity, improved impact, lower mold deposits, and excellent surface finish compared to more traditional loading of PTFE. LUBRILOY compounds are available in PC, POM, PA6.6, PPA, and PPO base resins. Additional lubricants and reinforcements can also be added such as glass, aramid, PTFE, and carbon fiber to enhance wear, friction, abrasion resistance, mechanical strength and conductivity.

FIGURE 2



GRAPHITE POWDERS

Graphite powders are low friction, high temperature solids used to lubricate moving metal parts where boundary lubrication is necessary. When compounded into a thermoplastic, wear factors and coefficients of friction of graphite powders fall in between those of unfilled and PTFE/silicone lubricated grades.

The primary use of graphite lubricated thermoplastics is in applications operating in aqueous environments.

When combined with mineral fillers in low shrinkage amorphous resins (SAN, Styrene, PPO, Polysulfone, etc.) graphite has traditionally been utilized in water meter components.

MOLYBDENUM DISULFIDE (MOLY)

Molybdenum disulfide is another solid lubricant which, when compounded primarily into nylons, reduces wear rates and increases PV limits. In addition to the lubricating qualities imparted to the resin, Moly also acts as a nucleating agent, which enables the molded part to have a very fine crystalline structure. Moly lubricated composites have been traditionally used to reduce "slip-stick" behavior in many bearing applications.

GLASS FIBERS

The addition of glass fiber to a compound improves both short and long term mechanical performance. This property enhancement translates to higher LPV capabilities for glass reinforced composites compared to the unfilled resins in most instances. Wear resistance may also be improved depending on the efficiency of the glass sizing system and fiber aspect ratio. Glass fiber reinforcement generally reduces wear factor of the compound to which it is added, but low aspect ratio glass beads and unsized milled fibers (L/D <20) may actually increase wear factor. All glass reinforcements/fillers increase frictional coefficients and counterface wear. Glass fibers can be used in combination with PTFE or PTFE/silicone. The combination of glass reinforcement with an internal lubricant provides good mechanical strength in conjunction with improved wear resistance.

CARBON FIBERS

Carbon fiber reinforcement provides greater increases in mechanical properties than an equivalent weight percentage of glass fibers. In addition, carbon fibers significantly increase thermal and electrical conductivity. Since the LPV of a thermoplastic is directly related to its thermal conductivity and creep resistance, the increase in operational limits obtained with glass fibers can be further increased with carbon fibers. In addition, the use of carbon fibers translates to coefficients of friction which are lower for carbon fiber reinforced resins than for the unfilled base resin. In general, the greater lubricity of carbon fibers also results in lower counterface wear rates. Electrical conductivity of those fibers translates to the ability to dissipate electrostatic charge build-up in composites containing 10–15% or more carbon fiber reinforcement.

Carbon fiber reinforcement improves the wear resistance of a base resin to a greater degree than an equivalent loading of glass fiber reinforcement.

ARAMID FIBERS

Aramid fibers provide the most lubricity of the reinforcing fibers when added to thermoplastics. Aramid fibers are typically used at levels of 15% by weight or lower and dramatically reduce the wear factor of a thermoplastic resin. Their use, in conjunction with PTFE (with or without silicone), results in further reduction in wear rates and frictional coefficients. The primary advantage of aramid reinforcement is in counterface wear, particularly against soft metals such as brass, aluminum or bronze. Lower counterface wear is significant because the generation of abrasive metal particles can be dramatically reduced, resulting in less wear in the system.

HOW PLASTICS WEAR AGAINST METALS

Similar to the effects of changing the plastic wear specimen, altering the type of metal or the surface finish of the counterface can drastically affect the wear and friction characteristics of plastic composites.

Testing was completed on a variety of reinforced and lubricated composites against cold-rolled 1141 steel, 304 and 440 stainless steel, 70/30 brass, 2024 aluminum alloy and phosphor bronze. Plastic composites were evaluated against several ranges of metal surface finishes from 8 –70 µin. In addition to standard wear and friction data on the plastic composite, metal counterface wear factors were evaluated as well as the change in surface roughness for both plastic and metal components.

SURFACE HARDNESS

SABIC has generated considerable data comparing its plastic compounds to 1141 cold rolled steel. In general, wear can be related to surface hardness. The typical effect of shaft hardness for a given finish of a steel shaft is plotted in figure 3. This curve suggests a decrease in wear rate as hardness increases. This trend has also been demonstrated in moving from harder metal (steel) to softer metals (aluminum, brass, bronze, etc.).

FIGURE 3 EFFECT OF SHAFT HARDNESS ON WEAR OF BEARING MATERIALS LUBRICATED WITH PTFE.

(A) HEAT-STABILIZED NYLON 6/6

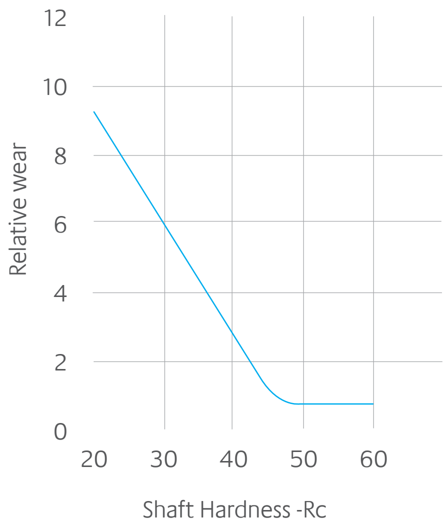
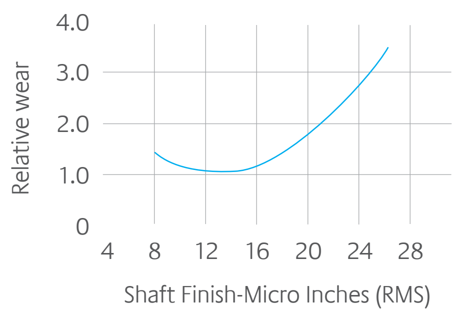


FIGURE 4 EFFECT OF SHAFT FINISH ON WEAR OF BEARING MATERIALS LUBRICATED WITH PTFE.

(A) HEAT-STABILIZED NYLON 6/6



SURFACE ROUGHNESS

Wear is also affected by surface roughness. The lowest wear rates generally occur against metal surfaces with an average roughness of 12–16 μin. (see figure 4). Smoother surface finishes (8–12 μin.) do not efficiently form a PTFE transfer film resulting in higher system wear. With rougher surfaces (50–70 μin.) abrasion becomes the predominant wear mechanism resulting in higher wear rates.

- Wear rates for most of the thermoplastic composites are similar against mild steel, brass and stainless steel with surface finishes of 12–16 μin.
- Lowest wear rates against soft metals such as aluminum and phosphor bronze are provided by unreinforced PTFE lubricated nylon 6/6 and aramid reinforced PTFE lubricated nylon 6/6 composites.
- Overall wear of plastic composites is more sensitive to aluminum surface finish than against any other metal tested.
- Wear rate of glass fiber reinforced PPS against brass and stainless steel is extremely low.
- Wear factors and frictional coefficients are generally higher against 440 stainless steel than against 304.
- Brass counterfaces wear up to 80 times faster than stainless steel mated against glass fiber or carbon fiber reinforced composites.

TABLE 1 WEAR, COEFFICIENTS OF FRICTION, AND LIMITING PV OF REINFORCED AND LUBRICATED THERMOPLASTICS AGAINST STEEL[a]

FAMILY / TRADE NAME	MOVING	K_{LNP} MOVING‡	K_{LNP} STATIONARY‡	COF STATIC	COF DYNAMIC	LPV (FPM-PSI) 10 FPM	LPV (FPM-PSI) 100 FPM	LPV (FPM-PSI) 1000 FPM
ETFE								
LUBRICOMP	2FL24	3	1	0.42	0.43	—	—	—
PVDF								
THERMOCOMP™	5C003	14	0	0.57	0.57	15000	—	—
LUBRICOMP	5CL23	5	0	0.44	0.53	—	—	—
ABS								
LUBRICOMP	AI001XXH	480	0	0.43	0.92	—	—	—
LUBRICOMP	AL003	101	0	0.11	0.22	—	—	—
LUBRICOMP	AL0039	107	0	0.12	0.24	—	—	—
POLYSTYRENE								
LUBRICOMP	CL002	51	1	0.24	0.33	—	—	—
POLYCARBONATE								
THERMOCOMP	D1000	High wear	—	0.50	0.46	—	—	—
LUBRILOY	D2000	38	0	0.22	0.31	6993s	22000	<500
LUBRILOY	D20001	10	0	0.16	0.29	—	9655	—
LUBRILOY	D20009	47	0	0.14	0.23	—	—	—
LUBRILOY	D20009P	50	0	0.23	0.30	—	14100	—
LUBRILOY	D2000AXH	63	1	0.22	0.32	—	—	—
LUBRILOY	D2000I	35	0	0.22	0.32	—	—	—
LUBRILOY	D2000P	44	1	0.16	0.19	5913	10546	—
LUBRICOMP	DI001L	435	0	0.18	0.15	—	—	—
LUBRICOMP	DL001	123	0	0.30	0.47	6000	22000	12000
LUBRICOMP	DL0029E	55	0	0.14	0.20	—	—	—
LUBRICOMP	DL002ER	35	0	0.08	0.24	—	—	—
LUBRICOMP	DL002P	97	0	0.17	0.23	—	—	—
LUBRICOMP	DL003	36	0	0.11	0.25	15000	20000	10500
LUBRICOMP	DL0039EF	7	0	0.18	0.35	—	—	—
LUBRICOMP	DL003EL	15	0	0.24	0.38	—	—	—
LUBRICOMP	DL004	20	0	0.20	0.30	16000	20000	10500
LUBRICOMP	DL0049EF	8	0	0.19	0.32	—	—	—
LUBRICOMP	DP001E	154	0	0.11	0.21	—	—	—
LUBRICOMP	DP003	42	0	0.10	0.26	14000	23000	13000
LUBRICOMP	DP0039	45	0	0.11	0.26	—	—	—
LUBRICOMP	DP003EH	28	0	0.16	0.28	—	—	—
LUBRICOMP	DAL22	21	0	0.18	0.28	—	—	—
LUBRICOMP	DBL32	139	17	0.48	0.42	—	—	—
LUBRICOMP	DBL34	112	12	0.24	0.49	—	—	—
LUBRICOMP	DBL34E	60	6	0.36	0.50	—	—	—
THERMOCOMP	DC006	85	—	0.41	0.39	8000	8500	5500
STAT-KON™	DCL13PXC	79	1	0.36	0.34	—	—	—
LUBRICOMP	DCP32	49	0	0.37	0.36	—	—	—
STAT-KON	DEL22P	15	0	0.52	0.55	—	—	—
STAT-KON	DEL36	38	3	0.34	0.43	—	—	—
LUBRILOY	DF204	179	1	0.39	0.41	—	5250	—
LUBRILOY	DF2041	57	1	0.36	0.43	—	—	—
LUBRICOMP	DFI14	277	5	0.53	0.43	—	—	—
LUBRICOMP	DFL12	126	6	0.44	0.37	—	—	—
LUBRICOMP	DFL22	166	13	0.44	0.38	—	—	—
LUBRICOMP	DFL22ER	100	6	0.50	0.43	—	—	—
LUBRICOMP	DFL23	162	12	0.55	0.50	—	—	—

‡ 10^{-10} in^5-min./ft.-lb.-hr.
[a] AISI 1141 cold rolled steel 18–22 Rockwell C scale, 12–16 micro inch finish, 50 fpm, 40 psi, 70 °F

TABLE 1 CONTINUED   WEAR, COEFFICIENTS OF FRICTION, AND LIMITING PV OF REINFORCED AND LUBRICATED THERMOPLASTICS AGAINST STEEL[a]

FAMILY / TRADE NAME	MOVING	K_{LNP} MOVING‡	K_{LNP} STATIONARY‡	COF STATIC	COF DYNAMIC	LPV (FPM-PSI)		
						10 FPM	100 FPM	1000 FPM
LUBRICOMP	DFL24	136	1	0.14	0.36	—	—	—
LUBRICOMP	DFL28	129	10	0.53	0.53	—	—	—
LUBRICOMP	DFL28EG	48	3	0.58	0.61	—	—	—
LUBRICOMP	DFL34	82	7	0.45	0.46	—	—	—
LUBRICOMP	DFL349	115	17	0.34	0.42	—	—	—
LUBRICOMP	DFL36	22	4	0.41	0.46	—	—	—
LUBRICOMP	DFL369XF	29	2	0.52	0.51	—	—	—
LUBRICOMP	DFL36ELH	28	1	0.50	0.58	—	—	—
LUBRICOMP	DFL36EU	31	2	0.51	0.47	—	—	—
LUBRICOMP	DFL36G	42	4	0.42	0.49	—	—	—
LUBRICOMP	DFL36L	42	4	0.55	0.52	—	—	—
LUBRICOMP	DFL36P	96	15	0.62	0.48	—	—	—
LUBRICOMP	DFL38	24	1	0.51	0.49	—	—	—
LUBRICOMP	DFL42	29	3	0.50	0.40	—	—	—
LUBRICOMP	DFL44	86	13	0.32	0.48	—	20000	10500
LUBRICOMP	DFP22H	143	8	0.52	0.44	—	—	—
LUBRICOMP	DFP34	49	9	0.53	0.51	—	—	—
LUBRICOMP	DZL34E	91	10	0.53	0.43	—	—	—
STAT-KON	DSL229	184	1	0.18	0.30	—	—	—
PEI								
THERMOCOMP	E1000	High wear	—	0.40	0.51	—	—	—
LUBRICOMP	EL002	185	0	0.30	0.33	—	—	—
LUBRICOMP	EL003	106	0	0.23	0.30	—	—	—
THERMOCOMP	EC006	75	—	0.48	0.52	—	—	—
THERMOCOMP	EC008	70	—	0.46	0.50	—	—	—
LUBRICOMP	ECL36	27	3	0.45	0.38	—	15369	—
LUBRICOMP	EX10404H	13	0	0.29	0.31	—	—	—
THERMOCOMP	EF004	140	—	0.48	0.52	—	—	—
THERMOCOMP	EF006	130	—	0.50	0.55	—	—	—
LUBRICOMP	EFL34HL	61	9	0.53	0.50	—	—	—
LUBRICOMP	EFL36	35	—	0.43	0.46	—	—	—
LUBRICOMP	EFL36	76	3	0.34	0.57	—	—	—
POLYETHYLENE								
LUBRICOMP	FL004	9	0	0.11	0.17	—	—	—
POLYSULFONE								
LUBRICOMP	GL003	25	0	0.13	0.23	—	—	—
LUBRICOMP	GL004	22	0	0.10	0.24	—	—	—
LUBRICOMP	GLF36	55	—	0.36	0.43	20000	—	—
LUBRICOMP	GFL36L	45	8	0.62	0.42	—	—	—
NYLON 11								
LUBRICOMP	HAL23	17	1	0.31	0.40	—	—	—
NYLON 6/12								
LUBRICOMP	IAL12	31	0	0.41	0.46	—	—	—
LUBRICOMP	IBP34	13	0	0.59	0.56	—	—	—
LUBRICOMP	ICL34	15	0	0.33	0.48	—	—	—
LUBRICOMP	IFL21	128	8	0.32	0.37	—	—	—
LUBRICOMP	IFL34	18	0	0.47	0.46	—	—	—
LUBRICOMP	IFL36L	4	0	0.59	0.61	—	—	—
LUBRICOMP	IFP36	12	2	0.52	0.62	—	—	—
PES								
THERMOCOMP	J1000	High wear	—	0.68	0.87	7000	7000	4000

‡ 10^{-10} in^5-min./ft.-lb.-hr.
[a] AISI 1141 cold rolled steel 18–22 Rockwell C scale, 12–16 micro inch finish, 50 fpm, 40 psi, 70 °F

TABLE 1 CONTINUED WEAR, COEFFICIENTS OF FRICTION, AND LIMITING PV OF REINFORCED AND LUBRICATED THERMOPLASTICS AGAINST STEEL[a]

FAMILY / TRADE NAME	MOVING	K_{LNP} MOVING‡	K_{LNP} STATIONARY‡	COF STATIC	COF DYNAMIC	LPV (FPM-PSI)		
						10 FPM	100 FPM	1000 FPM
LUBRICOMP	JL003	23	0	0.12	0.24	—	—	—
LUBRICOMP	JCL36	32	14	0.32	0.36	—	33000	18000
LUBRICOMP	JX91198	4	0	0.34	0.32	—	130000	—
THERMOCOMP	JF006	170	—	0.57	0.52	—	30000	18000
LUBRICOMP	JFL34	58	8	0.63	0.46	—	—	—
LUBRICOMP	JFL36	60	—	0.36	0.46	18000	—	—
ACETAL								
THERMOCOMP	K1000	65	0	0.32	0.48	4000	9563	<2500
LUBRILOY	K2000	10	0	0.24	0.38	—	11500	—
LUBRICOMP	KI001A	110	0	0.30	0.41	—	—	—
LUBRICOMP	KL001	11	0	0.18	0.38	—	—	—
LUBRICOMP	KL002	7	0	0.14	0.30	—	—	—
LUBRICOMP	KL003	10	0	0.18	0.33	—	—	—
LUBRICOMP	KL003LH	14	0	0.14	0.28	—	—	—
LUBRICOMP	KL004	13	0	0.14	0.27	10000	12860	7484
LUBRICOMP	KL004	13	0	0.14	0.30	10000	12860	7860
LUBRICOMP	KL004A	12	0	0.09	0.23	12000	16000	5875
LUBRILOY	KL201	12	0	0.09	0.30	—	11500	—
LUBRICOMP	KP002	9	0	0.18	0.31	—	—	—
LUBRICOMP	KP003A	11	0	0.11	0.21	—	—	—
LUBRICOMP	KP004	9	0	0.14	0.25	8000	15000	12000
LUBRICOMP	KP004A	16	0	0.09	0.26	—	—	—
LUBRICOMP	KP004A	7	0	0.14	0.23	9000	18000	14000
LUBRICOMP	KP004L	9	0	0.15	0.26	—	—	—
LUBRICOMP	KAL22	8	0	0.16	0.23	—	15634	—
LUBRICOMP	KCL34A	69	4	0.32	0.35	—	—	—
STAT-KON	KEP33	202	4	0.31	0.36	—	—	—
THERMOCOMP	KF004	245	—	0.57	0.78	—	—	—
LUBRICOMP	KFL12	836	7	0.45	0.56	—	—	—
LUBRICOMP	KFL32LH	256	9	0.53	0.43	—	—	—
LUBRICOMP	KFL36	235	—	0.40	0.46	—	—	—
LUBRICOMP	KG002	103	0	0.44	0.56	—	—	—
LUBRICOMP	KZL16	920	29	0.44	0.49	—	—	—
LUBRICOMP	KZL34	161	6	0.49	0.43	—	—	—
PEEK								
THERMOCOMP	L1000	123	—	0.49	0.64	—	—	—
LUBRICOMP	LL002	20	0	0.29	0.33	—	—	—
LUBRICOMP	LL003	19	0	0.32	0.43	—	—	—
THERMOCOMP	LC006	55	14	0.32	0.30	—	28000s	—
LUBRICOMP	LCL33	22	0	0.28	0.34	42000	45000	22000
LUBRICOMP	LCL33E	14	1	0.35	0.37	42000	45000	42000
LUBRICOMP	LX91475	13	2	0.29	0.36	—	40000	45000
THERMOCOMP	LF003	111	2	0.57	0.58	—	—	—
LUBRICOMP	LFL36E	73	8	0.64	0.53	—	—	—
POLYPROPYLENE								
THERMOCOMP	M1000	680	0	0.71	0.43	—	—	—
LUBRICOMP	ML004	59	7	0.44	0.61	—	—	—
LUBRICOMP	MFL34SXL	61	1	0.28	0.30	—	—	—
VERTON	MV006S	44	2	0.39	0.36	—	—	—
VERTON	MV00AS	73	5	0.30	0.34	—	—	—

‡ 10^{-10} in^5-min./ft.-lb.-hr.
[a] AISI 1141 cold rolled steel 18–22 Rockwell C scale, 12–16 micro inch finish, 50 fpm, 40 psi, 70 °F

TABLE 1 CONTINUED WEAR, COEFFICIENTS OF FRICTION, AND LIMITING PV OF REINFORCED AND LUBRICATED THERMOPLASTICS AGAINST STEEL[a]

FAMILY / TRADE NAME	MOVING	K_{LNP} MOVING‡	K_{LNP} STATIONARY‡	COF STATIC	COF DYNAMIC	LPV (FPM-PSI) 10 FPM	100 FPM	1000 FPM
PC/ABS								
LUBRICOMP	NL001	854	0	0.27	0.36	—	—	—
PPS								
LUBRICOMP	OL003A	44	0	0.11	0.21	—	—	—
LUBRICOMP	OL004	70	0	0.13	0.22	—	—	—
LUBRICOMP	OL009	2	0	0.14	0.23	—	—	—
THERMOCOMP	OC006	857	287	1.38	1.60	12000	16667	11000
LUBRICOMP	OCL36	27	6	0.36	0.38	27500	—	—
LUBRICOMP	OCP36	33	4	0.21	0.62	60000	72000	370000
LUBRICOMP	OCP36A	15	1	0.30	0.36	—	—	—
STAT-KON	OEP32	6	0	0.41	0.43	—	—	—
THERMOCOMP	OF008	307	32	0.68	0.54	13000	30000	30000
LUBRICOMP	OFL36	34	11	0.39	0.42	27000	30000	30000
NYLON 6								
THERMOCOMP	P1000	200	0	0.50	0.59	25000	2000	<2000
THERMOCOMP	PC006	30	1	0.41	0.48	18000	22000	7500
THERMOCOMP	PF006	95	1	0.55	0.71	10000	8500	6000
LUBRICOMP	PFL34	29	4	0.51	0.46	—	—	—
LUBRICOMP	PFP36	46	3	0.45	0.45	—	—	—
NYLON 6/10								
LUBRICOMP	QL002	35	0	0.26	0.39	—	—	—
LUBRICOMP	QP003XXP	46	0	0.24	0.34	—	—	—
LUBRICOMP	QP004	5	0	0.10	0.26	—	—	—
LUBRICOMP	QAP22S	15	0	0.50	0.36	—	—	—
LUBRICOMP	QCL34	26	0	0.33	0.39	—	—	—
LUBRICOMP	QCL349	444	1	0.28	0.34	—	—	—
LUBRICOMP	QCP36	15	0	0.46	0.46	—	—	—
LUBRICOMP	QFN16	85	0	0.33	0.34	—	—	—
LUBRICOMP	QFL32	49	5	0.38	0.43	—	—	—
NYLON 6/6								
THERMOCOMP	R1000	199	1	0.55	0.65	3000	2500	2500
THERMOCOMP	R10002	47	0	0.64	0.94	—	—	—
LUBRILOY	R2000	50	0	0.27	0.36	26000	20000	—
LUBRILOY	R2000A	12	0	0.27	0.32	35000	30000	—
LUBRICOMP	RI001	104	0	0.27	0.44	—	—	—
LUBRICOMP	RL002	49	0	0.23	0.27	—	—	—
LUBRICOMP	RL003	28	0	0.30	0.32	—	—	—
LUBRICOMP	RL004	16	0	0.21	0.32	14000	17500	8000
LUBRICOMP	RL0049S	28	0	0.11	0.22	—	—	—
LUBRICOMP	RN001S-	103	0	0.55	0.75	—	—	—
LUBRICOMP	RP003	16	1	0.13	0.23	—	—	—
LUBRICOMP	RP004	4	0	0.05	0.20	—	—	—
LUBRICOMP	RP004S	5	0	0.39	0.51	—	—	—
LUBRICOMP	RA004-	62	0	0.50	0.57	—	—	—
LUBRICOMP	RAL22	13	0	0.46	0.55	—	12200	—
LUBRICOMP	RAL22S	12	0	0.26	0.33	—	—	—
LUBRICOMP	RAL23	22	0	0.31	0.37	—	—	—
LUBRICOMP	RAL32	16	0	0.24	0.28	—	—	—
LUBRICOMP	RAP22	23	0	0.26	0.38	—	—	—
LUBRICOMP	RBL36L	33	0	0.58	0.57	—	—	—

‡ 10^{-10} in^5-min./ft.-lb.-hr.
[a] AISI 1141 cold rolled steel 18–22 Rockwell C scale, 12–16 micro inch finish, 50 fpm, 40 psi, 70 °F

TABLE 1 CONTINUED — WEAR, COEFFICIENTS OF FRICTION, AND LIMITING PV OF REINFORCED AND LUBRICATED THERMOPLASTICS AGAINST STEEL[a]

FAMILY / TRADE NAME	MOVING	K_{LNP} MOVING‡	K_{LNP} STATIONARY‡	COF STATIC	COF DYNAMIC	LPV (FPM-PSI) 10 FPM	100 FPM	1000 FPM
LUBRICOMP	RBL36XXJ	41	8	0.44	0.47	—	—	—
THERMOCOMP	RC006	20	1	0.36	0.46	21000	27000	8000
THERMOCOMP	RC006	20	1	0.36	0.46	21000	27000	8000
THERMOCOMP	RC008	14	1	0.30	0.41	22000	27500	8500
LUBRICOMP	RCL26	43	1	0.33	0.41	—	—	—
LUBRICOMP	RCL36	13	1	0.28	0.37	—	—	—
LUBRICOMP	RCL36	10	—	0.25	0.34	—	—	—
LUBRICOMP	RCL36	24	1	0.36	0.34	—	—	—
THERMOCOMP	RF004	80	1	0.52	0.68	—	—	—
THERMOCOMP	RF006	75	1	0.57	0.71	—	—	—
THERMOCOMP	RF006S	148	0	0.41	0.46	12500	10000	7500
LUBRILOY	RF206	46	3	0.40	0.39	—	—	—
LUBRILOY	RF208	41	2	0.32	0.36	—	—	—
LUBRICOMP	RFI12	261	6	0.44	0.47	—	—	—
LUBRICOMP	RFL16	12	0	0.52	0.62	—	—	—
LUBRICOMP	RFL26	6	1	0.59	0.64	—	—	—
LUBRICOMP	RFL33	21	2	0.45	0.40	—	—	—
LUBRICOMP	RFL34	10	1	0.60	0.60	—	—	—
LUBRICOMP	RFL36	12	1	0.46	0.54	17500	20000	17500
LUBRICOMP	RFL36U	5	0	0.61	0.67	—	—	—
LUBRICOMP	RFL449	32	4	0.48	0.45	—	—	—
LUBRICOMP	RFN16	159	—	0.48	0.43	—	—	—
LUBRICOMP	RFN18S	45	1	0.59	0.75	—	—	—
LUBRICOMP	RFP36	11	1	0.48	0.56	17000	20000	7000
LUBRICOMP	RFP38	15	0	0.61	0.65	—	—	—
VERTON™	RVL28	23	0	0.46	0.64	—	—	—
VERTON	RVL29	21	—	0.40	0.39	—	—	—
LUBRILOY	RX05497	10	0	0.16	0.30	3223s	11245	—
LUBRILOY	RX05498	12	0	0.20	0.36	—	—	—
LUBRICOMP	RX06506	11	0	0.39	0.54	—	—	—
THERMOCOMP	RZ006S	119	4	0.36	0.36	—	—	—
NYLON 12								
LUBRICOMP	SP003	14	0	0.14	0.23	—	—	—
LUBRICOMP	SCL36	23	1	0.30	0.41	—	—	—
LUBRICOMP	SCP36	15	0	0.33	0.47	—	—	—
LUBRICOMP	SFP36	14	0	0.53	0.67	—	—	—
POLYURETHANE								
THERMOCOMP	T1000	340	—	0.73	0.84	2000	—	—
LUBRICOMP	TL003	60	—	0.62	0.73	—	—	—
THERMOCOMP	TF006	180	—	0.68	0.78	—	—	—
PPA								
THERMOCOMP	U1000	889	1	0.46	0.48	—	—	—
LUBRILOY	U2000A	18	0	0.22	0.23	—	34600	—
LUBRICOMP	UL002S	18	0	0.09	0.24	—	—	—

‡ 10^{-10} in^5-min./ft.-lb.-hr.
[a] AISI 1141 cold rolled steel 18–22 Rockwell C scale, 12–16 micro inch finish, 50 fpm, 40 psi, 70 °F

TABLE 1 CONTINUED WEAR, COEFFICIENTS OF FRICTION, AND LIMITING PV OF REINFORCED AND LUBRICATED THERMOPLASTICS AGAINST STEEL[a]

FAMILY / TRADE NAME	MOVING	K_{LNP} MOVING‡	K_{LNP} STATIONARY‡	COF STATIC	COF DYNAMIC	LPV (FPM-PSI) 10 FPM	LPV (FPM-PSI) 100 FPM	LPV (FPM-PSI) 1000 FPM
LUBRILOY	UA200A	3	0	0.22	0.25	—	36100	—
LUBRICOMP	UAL22S	11	0	0.18	0.25	—	—	—
THERMOCOMP	UC006H	6	0	0.21	0.27	—	53600	—
LUBRICOMP	UX06427	26	2	0.33	0.34	—	—	—
LUBRICOMP	UCP36S	23	2	0.23	0.34	—	22000	—
THERMOCOMP	UF006H	50	2	0.43	0.48	—	38000	
LUBRICOMP	UFL269SA	85	16	0.47	0.38	—	—	—
LUBRICOMP	UFL36AS	18	1	0.52	0.59	—	—	—
LUBRICOMP	UFL36S	6	0	0.46	0.49	+60000	55600	400000
VERTON	UV00AS	307	11	0.50	0.73	—	—	—
SUPERTOUGH NYLON								
LUBRICOMP	VN001	71	0	0.36	0.79	—	—	—
PBT								
THERMOCOMP	W1000	210	0	0.43	0.57	—	—	—
LUBRICOMP	WI001	93	0	0.45	0.77	—	—	—
LUBRICOMP	WL002	25	0	0.31	0.35	—	—	—
LUBRICOMP	WL003	21	0	0.16	0.25	—	—	—
LUBRICOMP	WL004	58	0	0.24	0.33	—	—	—
LUBRICOMP	WL0049	2	0	0.11	0.23	—	—	—
LUBRICOMP	WP004	16	0	0.13	0.24	—	—	—
LUBRICOMP	WAL34	14	0	0.18	0.21	—	—	—
LUBRICOMP	WBL36L	25	1	0.62	0.66	—	—	—
THERMOCOMP	WC006	24	1	0.27	0.34	18000	22000	10000
LUBRICOMP	WCP36	25	3	0.31	0.35	—	—	—
THERMOCOMP	WF004	105	5	0.50	0.59	—	—	—
THERMOCOMP	WF006I	250	11	0.36	0.48	—	—	—
LUBRICOMP	WFL33	47	4	0.30	0.42	—	—	—
LUBRICOMP	WFL34	40	1	0.21	0.27	—	—	—
LUBRICOMP	WFL34H	35	4	0.47	0.48	—	—	—
LUBRICOMP	WFL36	42	2	0.41	0.57	20000	22000	10000
LUBRICOMP	WFL369	26	2	0.41	0.53	—	—	—
LUBRICOMP	WFP36	136	1	0.42	0.50	—	—	—
MODIFIED PPO								
LUBRILOY	Z2000	121	1	0.19	0.24	—	—	—
LUBRILOY	Z20001	54	0	0.19	0.27	—	—	—
LUBRICOMP	ZL003	12	0	0.20	0.28	—	—	—
LUBRICOMP	ZP001XXP	273	0	0.27	0.30	—	—	—
LUBRICOMP	ZFG26	53	16	0.89	0.62	—	—	—
LUBRICOMP	ZFL31XXC	101	12	0.27	0.40	—	—	—
LUBRICOMP	ZFL34	94	22	0.59	0.44	—	—	—
LUBRICOMP	ZX05506	174	18	0.34	0.34	—	—	—

‡ 10^{-10} in^5-min./ft.-lb.-hr.
[a] AISI 1141 cold rolled steel 18–22 Rockwell C scale, 12–16 micro inch finish, 50 fpm, 40 psi, 70 °F

HOW PLASTICS WEAR AGAINST METALS

TABLE 1A PLASTIC VS. ALUMINUM AT 50FPM 40PSI

FAMILY / TRADE NAME	MOVING	K_{LNP} MOVING‡	K_{LNP} STATIONARY‡	COF STATIC	COF DYNAMIC
POLYCARBONATE					
LUBRILOY	D2000	91	2	0.11	0.18
LUBRILOY	D20001	55	0	0.09	0.21
LUBRILOY	D20009P	16	0	0.14	0.23
LUBRILOY	D2000P	7	0	0.11	0.27
LUBRILOY	DF204	High wear	445	0.41	0.48
LUBRICOMP	DFL34	995	132	0.36	0.34
ACETAL					
LUBRILOY	K2000	High wear	2514	0.23	0.25
LUBRILOY	KL201	23	0	0.14	0.30
LUBRICOMP	KL004A	18	0	0.07	0.21
LUBRICOMP	KAL22	25	4	0.14	0.25
PEEK					
LUBRICOMP	LCL33E	58	3	0.32	0.30
PPS					
LUBRICOMP	OCL36	3	1	0.21	0.21
NYLON 6/6					
LUBRILOY	R2000	269	0	0.27	0.39
LUBRILOY	R2000A	13	0	0.07	0.23
LUBRILOY	RX05497	19	0	0.14	0.21
LUBRICOMP	RL004	29	6	0.14	0.21
LUBRICOMP	RP004	7	0	0.11	0.18
LUBRICOMP	RAL32	48	9	0.25	0.36
LUBRICOMP	RCL36	175	95	0.27	0.27
LUBRILOY	RF206	563	8	0.16	0.25
LUBRICOMP	RFL36	320	175	0.34	0.41
PPA					
LUBRILOY	U2000A	107	0	0.23	0.16
LUBRILOY	UA200A	13	0	0.18	0.18
LUBRICOMP	UL002S	8	0	0.05	0.18
LUBRICOMP	UCL36S	7	1	0.25	0.26
PBT					
LUBRICOMP	WFL33	High wear	2912	0.34	0.34

‡ 10^{-10} in^5-min./ft.-lb.-hr.

TABLE 2 WEAR BEHAVIOR OF THERMOPLASTIC COMPOSITES AND AISI 1141 STEEL AS A FUNCTION OF THE STEEL SURFACE FINISH AT 50FPM 40PSI

TRADE NAME	MOVING	Finish (Ra)	K_{LNP} MOVING‡	K_{LNP} STATIONARY‡	COF STATIC	COF DYNAMIC
NYLON 6/6						
LUBRICOMP	RL004	8 to 12	16	0	0.11	0.23
LUBRICOMP	RL004	12 to 16	16	0	0.21	0.32
LUBRICOMP	RL004	50 to 70	24	0	0.25	0.30
LUBRICOMP	RAL32	8 to 12	18	0	0.41	0.48
LUBRICOMP	RAL32	12 to 16	16	0	0.24	0.28
LUBRICOMP	RAL32	50 to 70	14	0	0.25	0.27
THERMOCOMP	RF006	8 to 12	142	2	0.36	0.48
THERMOCOMP	RF006	12 to 16	75	1	0.57	0.71
THERMOCOMP	RF006	50 to 70	100	1	0.50	0.64
THERMOCOMP	RC006	8 to 12	36	2	0.30	0.32
THERMOCOMP	RC006	12 to 16	20	1	0.36	0.46
THERMOCOMP	RC006	50 to 70	30	1	0.39	0.48
LUBRICOMP	RFL36	8 to 12	30	1	0.46	0.59
LUBRICOMP	RFL36	12 to 16	12	1	0.46	0.54
LUBRICOMP	RFL36	50 to 70	16	1	0.39	0.46
LUBRICOMP	RFP36	8 to 12	20	1	0.46	0.59
LUBRICOMP	RFP36	12 to 16	11	1	0.48	0.56
LUBRICOMP	RFP36	50 to 70	20	1	0.36	0.43
LUBRICOMP	RCL36	8 to 12	24	1	0.36	0.34
LUBRICOMP	RCL36	12 to 16	13	1	0.28	0.37
LUBRICOMP	RCL36	50 to 70	27	1	0.27	0.34
PPS						
LUBRICOMP	OFL36	8 to 16	28	3	0.46	0.41
LUBRICOMP	OFL36	12 to 16	34	11	0.39	0.42

‡ 10^{-10} in^5-min./ft.-lb.-hr.

HOW PLASTICS WEAR AGAINST METALS

TABLE 3 WEAR BEHAVIOR OF THERMOPLASTIC COMPOSITES AND AISI 304 STAINLESS STEEL AS A FUNCTION OF THE STEEL SURFACE FINISH AT 50FPM 40PSI

TRADE NAME	MOVING	Finish (Ra)	K_{LNP} MOVING‡	K_{LNP} STATIONARY‡	COF STATIC	COF DYNAMIC
NYLON 6/6						
LUBRICOMP	RL004	8 to 16	7	0	0.11	0.21
LUBRICOMP	RL004	50 to 70	13	0	0.09	0.21
LUBRICOMP	RAL32	8 to 16	18	0	0.18	0.25
LUBRICOMP	RAL32	50 to 70	37	0	0.16	0.25
LUBRICOMP	RCL36	8 to 16	17	0	0.39	0.73
LUBRICOMP	RCL36	50 to 70	17	0	0.36	0.68
LUBRICOMP	RFL36	8 to 16	12	0	0.39	0.41
LUBRICOMP	RFL36	50 to 70	13	0	0.30	0.34
LUBRICOMP	RFP36	8 to 16	15	0	0.39	0.46
LUBRICOMP	RFP36	50 to 70	26	7	0.34	0.41
POLYCARBONATE						
LUBRICOMP	DFL36	8 to 16	16	0	0.23	0.36
LUBRICOMP	DFL36	50 to 70	29	1	0.21	0.34
PPS						
LUBRICOMP	OFL36	8 to 16	4	0	0.23	0.39
LUBRICOMP	OFL36	50 to 70	8	1	0.23	0.34

TABLE 4 WEAR BEHAVIOR OF THERMOPLASTIC COMPOSITES AND AISI 440 STAINLESS STEEL AS A FUNCTION OF THE STEEL SURFACE FINISH AT 50FPM 40PSI

TRADE NAME	MOVING	Finish (Ra)	K_{LNP} MOVING‡	K_{LNP} STATIONARY‡	COF STATIC	COF DYNAMIC
NYLON 6/6						
LUBRICOMP	RL004	8 to 16	7	0	0.23	0.27
LUBRICOMP	RL004	50 to 70	12	0	0.18	0.25
LUBRICOMP	RAL32	8 to 16	8	0	0.23	0.30
LUBRICOMP	RAL32	50 to 70	23	0	0.18	0.27
LUBRICOMP	RCL36	8 to 16	16	0	0.23	0.52
LUBRICOMP	RCL36	50 to 70	45	0	0.34	0.48
LUBRICOMP	RFL36	8 to 16	22	0	0.23	0.48
LUBRICOMP	RFL36	50 to 70	16	0	0.30	0.34
LUBRICOMP	RFP36	8 to 16	60	4	0.32	0.73
LUBRICOMP	RFP36	50 to 70	18	0	0.23	0.36
POLYCARBONATE						
LUBRICOMP	DFL36	8 to 16	24	1	0.46	0.46
LUBRICOMP	DFL36	50 to 70	50	1	0.43	0.52
PPS						
LUBRICOMP	OFL36	8 to 16	11	0	0.30	0.34
LUBRICOMP	OFL36	50 to 70	8	0	0.34	0.36

‡ 10^{-10} in^5-min./ft.-lb.-hr.

TABLE 5 WEAR BEHAVIOR OF THERMOPLASTIC COMPOSITES AND 70/30 BRASS AS A FUNCTION OF THE BRASS SURFACE FINISH AT 50FPM 40PSI

TRADE NAME	MOVING	Finish (Ra)	K_{LNP} MOVING‡	K_{LNP} STATIONARY‡	COF STATIC	COF DYNAMIC
NYLON 6/6						
LUBRICOMP	RL004	8 to 16	8	0	0.14	0.21
LUBRICOMP	RL004	50 to 70	21	0	0.11	0.21
LUBRICOMP	RAL32	8 to 16	16	0	0.23	0.32
LUBRICOMP	RAL32	50 to 70	34	1	0.25	0.03
LUBRICOMP	RCL36	8 to 16	18	5	0.34	0.34
LUBRICOMP	RCL36	50 to 70	13	6	0.30	0.32
LUBRICOMP	RFL36	8 to 16	21	11	0.41	0.34
LUBRICOMP	RFL36	50 to 70	18	14	0.34	0.34
LUBRICOMP	RFP36	8 to 16	19	3	0.41	0.39
LUBRICOMP	RFP36	50 to 70	18	12	0.43	0.41
POLYCARBONATE						
LUBRICOMP	DFL36	8 to 16	22	8	0.23	0.39
LUBRICOMP	DFL36	50 to 70	12	4	0.23	0.34

TABLE 6 WEAR AND COEFFICIENTS OF FRICTION AGAINST ALUMINUM ALLOY 2024 AS A FUNCTION OF SURFACE AT 50FPM 40PSI

TRADE NAME	MOVING	Finish (Ra)	K_{LNP} MOVING‡	K_{LNP} STATIONARY‡	COF STATIC	COF DYNAMIC
NYLON 6/6						
LUBRICOMP	RL004	8 to 12	High wear	—	0.00	0.00
LUBRICOMP	RL004	12 to 16	29	6	0.14	0.21
LUBRICOMP	RL004	50 to 70	105	6	0.18	0.23
LUBRICOMP	RAL32	12 to 16	48	9	0.25	0.36
LUBRICOMP	RAL32	50 to 70	128	5	0.21	0.39
LUBRICOMP	RFL36	8 to 12	High wear	166	0.34	0.41
LUBRICOMP	RFL36	12 to 16	320	175	0.34	0.41
LUBRICOMP	RFL36	50 to 70	High wear	75	0.32	0.43
LUBRICOMP	RCL36	8 to 12	247	144	0.27	0.30
LUBRICOMP	RCL36	12 to 16	175	95	0.27	0.27
LUBRICOMP	RCL36	50 to 70	247	151	0.27	0.30

‡ 10^{-10} in^5-min./ft.-lb.-hr.

HOW PLASTICS WEAR AGAINST PLASTICS

Wear characteristics of one plastic against another vary widely, even among those materials with good natural lubricity. When an application calls for plastic-on-plastic bearings, shafts, gears or other wear members, the combination must be chosen carefully. In plastic on metal wear, the non-rigid nature of plastics yields unexpected wear results. Frictional forces are not proportional to load. Friction increases with increasing speed and the static coefficient is lower than the dynamic. In plastic-on-plastic wear where two non-rigid materials are mated, additional inconsistencies occur. As a result, selection of a suitable plastic-on-plastic wear combination can only be assured by conducting actual wear testing, since acceptable combinations cannot be predicted. Historical plastic-on-plastic wear testing has suggested that a composite will not wear well against itself. Although it is easier to find acceptable wear combinations which use dissimilar materials, more recent test data indicates that composites do exist which wear well against themselves.

In plastic-on-plastic wear testing, a molded plastic counterface is substituted for the stationary metal counterface. Test conditions are identical to plastic-on-metal wear testing. Wear testing of a plastic composite against itself has indicated a trend of higher wear rate on the moving sample. This effect is usually minimal and is not expected to be significant in actual applications for plastic-on-plastic wear

- The use of PTFE lubrication may reduce wear rates in both similar and dissimilar resins
- A carbon fiber reinforced composite wearing against a glass fiber reinforced composite generally results in higher wear rates in the carbon fiber composite due to the higher hardness of glass fibers
- Against a fiber reinforced composite, the mating material should contain PTFE lubrication
- Coefficients of friction in plastic-on-plastic wear systems are lower than in plastic-on-metal wear systems

Trunk deck lid actuator gears, LUBRICOMP KFL and RL compound

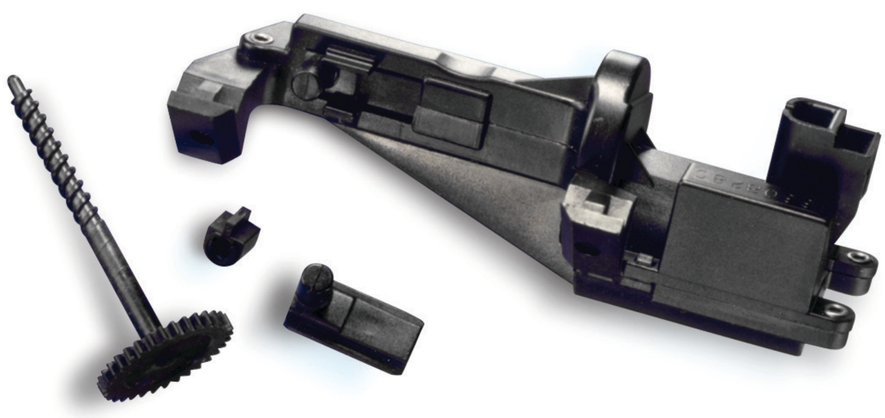


TABLE 7 WEAR FACTOR AND COEFFICIENTS OF FRICTION FOR PLASTIC-ON-PLASTIC

FAMILY / MOVING TRADE NAME	MOVING WEAR SAMPLE	STATIONARY TRADE NAME	STATIONARY COUNTERFACE	K_{LNP} MOVING‡	K_{LNP} STATIONARY‡	COF STATIC	COF DYNAMIC
ABS							
THERMOCOMP	A1000	THERMOCOMP	D1000	PV	PV	0.00	0.00
THERMOCOMP	A1000	LUBRILOY	D2000	PV	high wear	0.18	0.16
THERMOCOMP	AF006	THERMOCOMP	D1000	high wear	1017	0.14	0.18
THERMOCOMP	AF006	LUBRILOY	D2000	high wear	1071	0.18	0.16
POLYCARBONATE							
THERMOCOMP	D1000	THERMOCOMP	D1000	high wear	high wear	0.25	0.80
THERMOCOMP	D1000	LUBRILOY	D2000	3	22	0.14	0.14
LUBRILOY	D2000	THERMOCOMP	D1000	49	1	0.09	0.07
LUBRILOY	D2000	LUBRILOY	D2000	PV	PV	0.16	0.18
LUBRILOY	D2000	LUBRICOMP	DFL36	82	25	0.09	0.11
LUBRILOY	D20001	LUBRILOY	D20001	PV	PV	0.00	0.00
LUBRILOY	D20009P	LUBRILOY	D20009P	PV	PV	0.27	0.18
LUBRILOY	D2000P	THERMOCOMP	D1000	22	23	0.11	0.11
LUBRILOY	D2000P	LUBRILOY	D2000P	PV	PV	0.00	0.00
LUBRILOY	D2000P	THERMOCOMP	DF006	18	0	0.09	0.01
LUBRILOY	D2000P	THERMOCOMP	K1000A	11	18	0.11	0.14
LUBRICOMP	DCL32	LUBRICOMP	DCL32	1029	482	0.27	0.32
LUBRICOMP	DCL32	THERMOCOMP	DF002	high wear	55	0.27	0.32
LUBRICOMP	DCL32	LUBRICOMP	DFL32	1068	245	0.25	0.27
STAT-KON	DE002	LUBRICOMP	DCL32	1098	high wear	0.59	0.50
STAT-KON	DE002	THERMOCOMP	DF002	PV	PV	0.00	0.00
STAT-KON	DE002	LUBRICOMP	DFL32	high wear	997	0.46	0.30
STAT-KON	DE0039	LUBRICOMP	RCP36	159	72	0.18	0.21
STAT-KON	DEL26	LUBRICOMP	RCP36	455	119	0.18	0.23
STAT-KON	DEL42EXC	LUBRICOMP	RCL36	651	74	0.25	0.16
THERMOCOMP	DF004	THERMOCOMP	DF004	high wear	high wear	0.68	0.73
THERMOCOMP	DF006	THERMOCOMP	D1000	high wear	PV	0.16	0.57
THERMOCOMP	DF006	LUBRILOY	D2000	2	104	0.07	0.11
THERMOCOMP	DF006	LUBRICOMP	DFL36	300	500	0.18	0.27
THERMOCOMP	DF006	LUBRICOMP	DL003	30	216	0.07	0.11
THERMOCOMP	DF006	THERMOCOMP	RF006	high wear	high wear	0.36	0.62
THERMOCOMP	DF006	LEXAN™	WR2210	5	85	0.09	0.11
LUBRILOY	DF204	LUBRILOY	DF204	high wear	high wear	0.25	0.18
LUBRILOY	DF2041	LUBRILOY	DF2041	PV	PV	0.00	0.00
LUBRILOY	DF206XXH	LUBRILOY	DF206XXH	high wear	high wear	0.25	0.16
LUBRICOMP	DFL34	LUBRICOMP	KL004A	145	high wear	0.05	0.21
LUBRICOMP	DFL34	LUBRICOMP	WFL36	137	80	0.16	0.16
LUBRICOMP	DFL36	THERMOCOMP	D1000	841	228	0.25	0.18
LUBRICOMP	DFL36	LUBRILOY	D2000	2	133	0.07	0.11
LUBRICOMP	DFL36	LUBRICOMP	DFL36	310	350	0.14	0.18
LUBRICOMP	DFL36	LUBRICOMP	QFL36	18	18	0.09	0.18
LUBRICOMP	DFL44	THERMOCOMP	D1000	310	108	0.09	0.18
LUBRICOMP	DFP36	LUBRICOMP	QFP36	41	20	0.09	0.16
LUBRICOMP	DL003	VALOX™	325E	51	14	0.09	0.05
LUBRICOMP	DL003	THERMOCOMP	D1000	152	113	0.14	0.09
LUBRICOMP	DL003	LUBRILOY	D2000	155	36	0.14	0.16
LUBRICOMP	DL003	THERMOCOMP	DF006	134	2	0.07	0.11

‡ 10^{-10} in^5-min./ft.-lb.-hr.

HOW PLASTICS WEAR AGAINST PLASTICS

TABLE 7 CONTINUED WEAR FACTOR AND COEFFICIENTS OF FRICTION FOR PLASTIC-ON-PLASTIC

FAMILY / MOVING TRADE NAME	MOVING WEAR SAMPLE	STATIONARY TRADE NAME	STATIONARY COUNTERFACE	K_{LNP} MOVING‡	K_{LNP} STATIONARY‡	COF STATIC	COF DYNAMIC
LUBRICOMP	DL003	LUBRICOMP	DFL36	114	1	0.05	0.11
LUBRICOMP	DL003	LUBRICOMP	DL003	57	73	0.14	0.09
LUBRICOMP	DL003	THERMOCOMP	RF006	25	26	0.05	0.16
LUBRICOMP	DL003	LUBRICOMP	RFL36S	42	21	0.05	0.16
LUBRICOMP	DP003	VALOX	325E	46	27	0.07	0.07
LUBRICOMP	DP003	VALOX	325E	47	23	0.07	0.05
STAT-KON	DSL229	LUBRICOMP	DCL33E	746	143	0.02	0.18
PEI							
LUBRICOMP	EFL36	ULTEM™	1000	84	753	0.23	0.25
LUBRICOMP	EFL36	LUBRICOMP	EFL36	218	173	0.23	0.18
LUBRICOMP	EFL36	LUBRICOMP	JFL36	160	50	0.23	0.18
LUBRICOMP	EFL36	LUBRICOMP	UFL36S	203	300	0.27	0.25
LUBRICOMP	EFL36	LUBRICOMP	WFL36	339	139	0.27	0.23
NYLON 6/12							
LUBRICOMP	IFL36	LUBRICOMP	IFL36	7	5	0.14	0.11
PES							
LUBRICOMP	JFL36	LUBRICOMP	EFL36	112	330	0.27	0.16
LUBRICOMP	JFL36	LUBRICOMP	JFL36	107	83	0.25	0.14
LUBRICOMP	JFL36	LUBRICOMP	OFL36	47	177	0.21	0.16
LUBRICOMP	JFL36	LUBRICOMP	UFL36S	113	265	0.36	0.25
ACETAL							
THERMOCOMP	K1000	THERMOCOMP	D1000	high wear	228	0.07	0.05
THERMOCOMP	K1000	THERMOCOMP	R1000	60	50	0.09	0.14
THERMOCOMP	K1000	LUBRILOY	R2000	high wear	1099	0.09	0.23
THERMOCOMP	K1000A	THERMOCOMP	D1000	high wear	232	0.09	0.07
THERMOCOMP	K1000A	LUBRILOY	D2000	2	10	0.11	0.14
THERMOCOMP	K1000A	LUBRICOMP	DL003	high wear	28	0.09	0.11
THERMOCOMP	K1000A	THERMOCOMP	K1000A	high wear	high wear	0.14	0.09
LUBRILOY	K2000	THERMOCOMP	D1000	high wear	283	0.14	0.14
LUBRILOY	K2000	LUBRILOY	D2000	high wear	25	0.11	0.16
LUBRILOY	K2000	THERMOCOMP	K1000A	PV failure	211	0.18	0.21
LUBRILOY	K2000	LUBRILOY	K2000	high wear	high wear	0.23	0.25
LUBRILOY	K2000	LUBRILOY	R2000	PV failure	PV failure	0.00	0.00
LUBRICOMP	KFL32R	VERTON	RV00AES	19	14	0.14	0.14
LUBRICOMP	KFL-4542	VERTON	RV00AES	16	13	0.09	0.11
LUBRICOMP	KI001XXJ	LUBRICOMP	KI001XXJ	114	287	0.14	0.16
LUBRICOMP	KL002	LUBRICOMP	KL002	high wear	high wear	0.23	0.27
LUBRICOMP	KL003	ULTEM	1000	high wear	high wear	0.05	0.11
LUBRICOMP	KL003	LUBRICOMP	KP004	5	25	0.09	0.21
LUBRICOMP	KL004	THERMOCOMP	D1000	380	26	0.14	0.09
LUBRICOMP	KL004	LUBRILOY	D2000	50	20	0.11	0.18
LUBRICOMP	KL004	LUBRILOY	D2000	PV	18	0.11	0.18
LUBRICOMP	KL004	LUBRICOMP	DFL36	high wear	10	0.21	0.25
LUBRICOMP	KL004	LUBRICOMP	KL004	high wear	high wear	0.18	0.21
LUBRICOMP	KL004A	LUBRICOMP	KL004A	1129	838	0.23	0.25
LUBRICOMP	KL004A	LUBRICOMP	RAL22	5	15	0.05	0.21
LUBRICOMP	KL004A	LUBRICOMP	RAL22	7	16	0.05	0.21
LUBRILOY	KL201	THERMOCOMP	D1000	high wear	220	0.09	0.09

‡ 10^{-10} in^5-min./ft.-lb.-hr.

TABLE 7 CONTINUED WEAR FACTOR AND COEFFICIENTS OF FRICTION FOR PLASTIC-ON-PLASTIC

FAMILY / MOVING TRADE NAME	MOVING WEAR SAMPLE	STATIONARY TRADE NAME	STATIONARY COUNTERFACE	K_{LNP} MOVING‡	K_{LNP} STATIONARY‡	COF STATIC	COF DYNAMIC
LUBRILOY	KL201	LUBRILOY	D2000	high wear	30	0.09	0.16
LUBRILOY	KL201	LUBRILOY	KL201	high wear	high wear	0.16	0.18
LUBRICOMP	KP004	LUBRICOMP	KP004	92	106	0.09	0.16
PEEK							
LUBRICOMP	LCL33E	LUBRICOMP	LCL33E	309	323	0.30	0.32
LUBRICOMP	LCL33E	LUBRICOMP	OCL36	301	108	0.39	0.27
LUBRICOMP	LCL33E	LUBRICOMP	UCL36S	385	71	0.23	0.30
POLYPROPYLENE							
VERTON	MV008S	VERTON	MV008S	176	139	0.16	0.18
VERTON	MV008S	VERTON	MV008S	high wear	high wear	0.18	0.39
PPS							
LUBRICOMP	OCL36	LUBRICOMP	LCL33E	124	179	0.18	0.23
LUBRICOMP	OCL36	LUBRICOMP	OCL36	27	24	0.16	0.14
LUBRICOMP	OCL36	LUBRICOMP	UCL36S	161	89	0.16	0.18
LUBRICOMP	OCP36	LUBRICOMP	OCP36	62	84	0.23	0.21
LUBRICOMP	OCP36A	LUBRICOMP	RP004	1	64	0.09	0.21
LUBRICOMP	OFG26A	LUBRICOMP	OFL36	710	750	0.30	0.27
LUBRICOMP	OFL36	LUBRICOMP	EFL36	36	114	0.11	0.21
LUBRICOMP	OFL36	LUBRICOMP	JFL36	92	23	0.18	0.14
LUBRICOMP	OFL36	LUBRICOMP	OCL36	31	207	0.14	0.14
LUBRICOMP	OFL36	THERMOCOMP	OF006I	790	391	0.36	0.41
LUBRICOMP	OFL36	LUBRICOMP	OFL36	68	92	0.07	0.18
LUBRICOMP	OFL36	LUBRICOMP	OFL36	878	645	0.21	0.21
LUBRICOMP	OFL36	LUBRICOMP	RFL36	50	186	0.09	0.25
LUBRICOMP	OFL36	LUBRICOMP	UFL36S	259	236	0.34	0.25
LUBRICOMP	OFL36	LUBRICOMP	WFL36	33	92	0.18	0.21
LUBRICOMP	OFP36A	ULTEM	1000	499	high wear	0.41	0.25
LUBRICOMP	OFP36A	ULTEM	1000	high wear	high wear	0.09	0.21
LUBRICOMP	OFP36A	LUBRICOMP	RP004	12	552	0.23	0.36
NYLON 6/10							
LUBRICOMP	QAP22S	LUBRICOMP	QAP22S	3	5	0.16	0.16
LUBRICOMP	QFL36	LUBRICOMP	DCL33E	56	362	0.21	0.25
NYLON 6/6							
THERMOCOMP	R1000	LUBRILOY	D2000	76	PV	0.14	0.16
THERMOCOMP	R1000	LUBRILOY	R2000	23	50	0.18	0.21
LUBRILOY	R2000	THERMOCOMP	D1000	PV failure	PV failure	0.00	0.00
LUBRILOY	R2000	LUBRILOY	D2000	314	PV failure	0.18	0.25
LUBRILOY	R2000	THERMOCOMP	R1000	45	27	0.16	0.21
LUBRILOY	R2000	LUBRILOY	R2000	12	9	0.16	0.21
LUBRILOY	R2000	LUBRILOY	R2000P	56	56	0.18	0.23
LUBRILOY	R2000	LUBRILOY	RF206	high wear	184	0.11	0.14
LUBRILOY	R2000A	THERMOCOMP	D1000	high wear	high wear	0.16	0.23
LUBRILOY	R2000A	LUBRILOY	D2000	90	117	0.16	0.14
LUBRILOY	R2000A	THERMOCOMP	R1000	8	38	0.05	0.18
LUBRILOY	R2000A	LUBRILOY	R2000	55	36	0.16	0.23
LUBRILOY	R2000A	LUBRILOY	R2000P	58	68	0.14	0.23
LUBRILOY	R2000A	LUBRILOY	RF206	76	4	0.09	0.16
LUBRILOY	RA	THERMOCOMP	D1000	high wear	high wear	0.18	0.34

‡ 10^{-10} in^5-min./ft.-lb.-hr.

HOW PLASTICS WEAR AGAINST PLASTICS

TABLE 7 CONTINUED WEAR FACTOR AND COEFFICIENTS OF FRICTION FOR PLASTIC-ON-PLASTIC

FAMILY / MOVING TRADE NAME	MOVING WEAR SAMPLE	STATIONARY TRADE NAME	STATIONARY COUNTERFACE	K_{LNP} MOVING‡	K_{LNP} STATIONARY‡	COF STATIC	COF DYNAMIC
LUBRILOY	RA	LUBRILOY	D2000	15	41	0.11	0.14
LUBRICOMP	RA004	LUBRICOMP	RA004	69	100	0.30	0.32
LUBRICOMP	RAL22	THERMOCOMP	D1000	210	high wear	0.21	0.18
LUBRICOMP	RAL22	LUBRILOY	D2000	15	8	0.11	0.18
LUBRICOMP	RAL22	LUBRICOMP	RAL22	58	73	0.11	0.34
LUBRICOMP	RAL22	LUBRICOMP	RCL36	314	34	0.23	0.30
THERMOCOMP	RC006	THERMOCOMP	RC006	20	13	0.34	0.30
THERMOCOMP	RC006	LUBRICOMP	RL004	7	24	0.09	0.13
LUBRICOMP	RCL36	LUBRICOMP	RCL36	43	39	0.23	0.39
THERMOCOMP	RF006	THERMOCOMP	D1000	546	high wear	0.23	0.21
THERMOCOMP	RF006	LUBRILOY	D2000	12	17	0.09	0.11
THERMOCOMP	RF006	THERMOCOMP	KF006	162	high wear	0.32	0.43
THERMOCOMP	RF006	THERMOCOMP	RF006	1057	1025	0.27	0.34
THERMOCOMP	RF006	LUBRICOMP	RFL36	787	639	0.36	0.41
THERMOCOMP	RF006S	LUBRICOMP	DFL34	10	62	0.14	0.05
LUBRILOY	RF206	THERMOCOMP	D1000	648	high wear	0.14	0.16
LUBRILOY	RF206	LUBRILOY	D2000	10	130	0.09	0.11
LUBRILOY	RF206	VERTON	MV008S	601	413	0.18	0.21
LUBRILOY	RF206	VERTON	MV00AS	366	54	0.16	0.18
LUBRILOY	RF206	LUBRILOY	R2000	168	high wear	0.21	0.23
LUBRILOY	RF206	LUBRILOY	R2000P	28	290	0.07	0.16
LUBRILOY	RF206	LUBRILOY	RF206	305	327	0.11	0.27
LUBRILOY	RF206	THERMOCOMP	WF006	787	252	0.18	0.23
LUBRICOMP	RFL36	THERMOCOMP	D1000	608	high wear	0.18	0.36
LUBRICOMP	RFL36	LUBRILOY	D2000	14	42	0.09	0.14
LUBRICOMP	RFL36	LUBRICOMP	EFL36	152	87	0.07	0.23
LUBRICOMP	RFL36	LUBRICOMP	RFL36	48	35	0.09	0.23
LUBRICOMP	RFL36	LUBRICOMP	UFL36S	51	61	0.25	0.21
LUBRICOMP	RFN16	VERTON	MV008	112	140	0.34	0.27
LUBRICOMP	RL004	THERMOCOMP	D1000	517	high wear	0.23	0.16
LUBRICOMP	RL004	LUBRILOY	D2000	25	13	0.09	0.16
LUBRICOMP	RL004	LUBRICOMP	KL004	17	18	0.10	0.23
LUBRICOMP	RP004	LUBRICOMP	KP004	20	14	0.09	0.25
LUBRICOMP	RP004	VERTON	RV007E	10	1	0.11	0.14
LUBRICOMP	RP004	THERMOCOMP	WF006	16	3	0.11	0.14
LUBRICOMP	RP004	THERMOCOMP	WF008	25	1	0.11	0.14
VERTON	RV00AE	LUBRICOMP	DFL34	595	high wear	0.11	0.18
VERTON	RV00AE	LUBRICOMP	KL004	14	31	0.05	0.16
VERTON	RV00AE	LUBRILOY	RF208	44	310	0.16	0.16
VERTON	RV00AE	LUBRICOMP	RFL36	14	138	0.14	0.18
VERTON	RV00AE	LUBRICOMP	RL004	13	64	0.02	0.16
VERTON	RV00AE	VERTON	RV00AES	246	362	0.41	0.30
VERTON	RV00AE	VERTON	RVL29	550	521	0.32	0.34
VERTON	RV00AE	LUBRICOMP	UFL36S	54	438	0.25	0.25
VERTON	RV00AE	LUBRICOMP	WFL34	21	218	0.05	0.18
VERTON	RV00AES	LUBRICOMP	RFN16	121	1080	0.36	0.41
VERTON	RV00AES	VERTON	RVL28	383	602	0.32	0.32
VERTON	RVL28	VERTON	RVL28	100	96	0.16	0.25

‡ 10^{-10} in^5-min./ft.-lb.-hr.

TABLE 7 CONTINUED WEAR FACTOR AND COEFFICIENTS OF FRICTION FOR PLASTIC-ON-PLASTIC

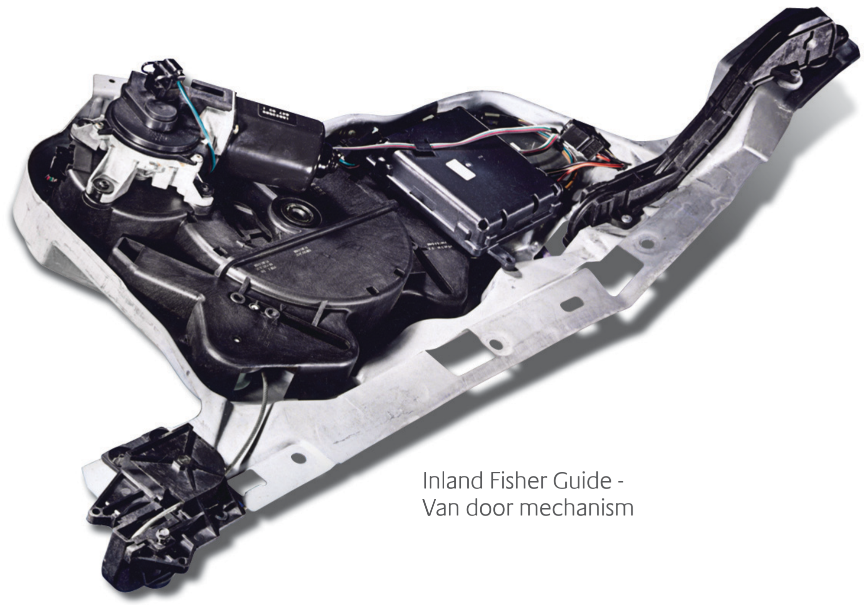
FAMILY / MOVING TRADE NAME	MOVING WEAR SAMPLE	STATIONARY TRADE NAME	STATIONARY COUNTERFACE	K_{LNP} MOVING‡	K_{LNP} STATIONARY‡	COF STATIC	COF DYNAMIC
VERTON	RVL29	THERMOCOMP	RF006S	PV failure	PV failure	0.00	0.00
LUBRILOY	RX05497	THERMOCOMP	K1000A	PV failure	PV failure	0.00	0.00
LUBRILOY	RX05497	LUBRILOY	K2000	13	12	0.09	0.16
LUBRILOY	RX05497	LUBRICOMP	KL004	4	18	0.11	0.16
LUBRILOY	RX05497	LUBRILOY	KL201	17	10	0.11	0.18
LUBRILOY	RX05497	THERMOCOMP	R1000	PV failure	PV failure	0.00	0.00
LUBRILOY	RX05497	THERMOCOMP	RF006	25	74	0.11	0.14
LUBRILOY	RX05497	LUBRILOY	RF206	42	30	0.11	0.16
LUBRILOY	RX05497	LUBRILOY	RX05498	103	70	0.14	0.32
LUBRILOY	RX05498	LUBRILOY	RX05498	282	213	0.09	0.10
NYLON 12							
LUBRICOMP	SX06511	LUBRICOMP	SX06511	78	62	0.09	0.21
PPA							
LUBRILOY	U2000A	LUBRILOY	U2000A	high wear	high wear	0.09	0.11
LUBRILOY	UA200A	LUBRILOY	UA200A	27	27	0.18	0.18
LUBRICOMP	UCL36S	LUBRICOMP	LCL33E	394	366	0.18	0.25
LUBRICOMP	UCL36S	LUBRICOMP	OCL36	60	96	0.11	0.23
LUBRICOMP	UCL36S	LUBRICOMP	UCL36S	16	10	0.21	0.23
THERMOCOMP	UF006H	LUBRICOMP	UFL36S	301	81	0.09	0.23
LUBRICOMP	UFL36S	LUBRICOMP	EFL36	264	216	0.25	0.23
LUBRICOMP	UFL36S	LUBRICOMP	OFL36	242	275	0.11	0.27
LUBRICOMP	UFL36S	LUBRICOMP	OFL36	292	278	0.18	0.32
LUBRICOMP	UFL36S	THERMOCOMP	UF006	295	101	0.11	0.23
LUBRICOMP	UFL36S	LUBRICOMP	UFL36S	264	240	0.11	0.23
PBT							
THERMOCOMP	WF006	THERMOCOMP	RF006S	high wear	999	0.23	0.30
THERMOCOMP	WF006	THERMOCOMP	WF006	high wear	high wear	0.34	0.30
LUBRICOMP	WFL36	LUBRICOMP	DCL33E	64	148	0.23	0.27
LUBRICOMP	WFL36	LUBRICOMP	DFL34	109	111	0.05	0.16
LUBRICOMP	WFL36	LUBRICOMP	KL004	2	29	0.02	0.18
LUBRICOMP	WFL36	LUBRICOMP	RFL36	87	66	0.14	0.18
LUBRICOMP	WFL36	LUBRICOMP	WFL36	194	181	0.05	0.18

‡ 10^{-10} in^5-min./ft.-lb.-hr.

ELEVATED TEMPERATURE WEAR

Elevated temperature wear testing is performed using the thrust washer test apparatus with test samples enclosed in an environmental chamber. Using this test, thermoplastic wear factors and friction coefficients can be tested up to 500 °F (260 °C). In many cases thermoplastic wear factor and frictional coefficients increase with increasing test temperature. Composites for elevated temperature wear applications usually contain fibrous reinforcement especially crystalline resins which, when unreinforced, have low heat distortion temperatures. In fiber reinforced systems, carbon fibers with their higher thermal conductivity and lower thermal expansion generally produce materials with better elevated temperature wear rates and bearing capabilities.

- Elevated temperature wear and LPV capabilities are defined by the thermal properties of the thermoplastic resin
- The addition of internal lubricants enhances elevated temperature wear performance
- High temperature crystalline based composites show the lowest wear rates for thermoplastic resins at elevated temperatures
- PEEK based composites are the only thermoplastics tested exhibiting acceptable wear rates at 500 °F (260 °C)



Inland Fisher Guide - Van door mechanism

TABLE 8 ELEVATED TEMPERATURE WEAR AND FRICTION DATA FOR ENGINEERING PLASTICS AGAINST STEEL[a]

FAMILY / TRADE NAME	MOVING	STATIONARY	TEMP (°C)	K_{LNP} MOVING‡	K_{LNP} STATIONARY‡	COF STATIC	COF DYNAMIC
POLYCARBONATE							
LUBRICOMP	DFL23	Steel	65	61	0	0.25	0.39
LUBRICOMP	DFL23	Steel	95	199	5	1.32	0.50
LUBRICOMP	DFL34	Steel	65	116	4	0.46	0.43
LUBRICOMP	DFL34	Steel	95	Melted	—	0.00	0.00
PEI							
LUBRICOMP	ECL36	Steel	163	33	<1	0.30	0.46
LUBRICOMP	ECL36	Steel	177	26	0	0.25	0.36
LUBRICOMP	EFL36	410 SS	121	128	5	0.55	0.52
LUBRICOMP	EFL36	440 SS	121	120	4	0.55	0.55
LUBRICOMP	EFL36	Steel	95	40	—	0.62	0.75
LUBRICOMP	EFL36	Steel	150	100	—	0.73	0.87
LUBRICOMP	EFL36	Steel	163	120	3	0.18	0.25
LUBRICOMP	EFL36	Steel	177	128	1	0.23	0.32
LUBRICOMP	EFL36	Steel	205	Melted	—	0.00	0.00
PES							
LUBRICOMP	JCL36	Steel	95	97	20	0.55	0.66
LUBRICOMP	JCL36	Steel	121	18	3	0.39	0.57
LUBRICOMP	JCL36	Steel	135	14	3	0.39	0.50
LUBRICOMP	JCL36	Steel	150	Melted	—	—	—
LUBRICOMP	JFL36	1161 SS	356	196	29	0.78	1.02
LUBRICOMP	JFL36	Steel	95	120	—	0.62	0.68
LUBRICOMP	JFL36	Steel	121	94	6	0.30	0.36
LUBRICOMP	JFL36	Steel	135	72	5	0.25	0.36
LUBRICOMP	JFL36	Steel	150	Melted	—	0.00	0.00
PEEK							
LUBRICOMP	LCL33	Steel	302	97	0	1.87	1.50
LUBRICOMP	LCL33	Steel	315	PV	PV	—	—
LUBRICOMP	LCL33E	A390 Aluminum	177	113	2.142	0.23	0.26
LUBRICOMP	LCL33E	Steel	150	35	0	0.16	0.34
LUBRICOMP	LCL33E	Steel	260	58	0	0.25	0.46
LUBRICOMP	LCL33E	Steel	302	65	1	0.16	0.68
LUBRICOMP	LCL33E	Steel	315	Melted	—	—	—
LUBRICOMP	LX91475	Steel	150	35	—	0.23	0.48
PPS							
LUBRICOMP	OCL36	Steel	95	20	12.9	0.64	0.71
LUBRICOMP	OCL36	Steel	150	68	0.16	0.80	0.89
LUBRICOMP	OCL36	Steel	205	71	0.14	0.80	0.89
LUBRICOMP	OCL36	Steel	260	PV	—	0.00	0.00
LUBRICOMP	OCP36	Steel	150	31	0	0.25	0.39
LUBRICOMP	OCP36	Steel	177	51	2	0.16	0.23
LUBRICOMP	OCP36	Steel	205	37	1	0.27	0.39

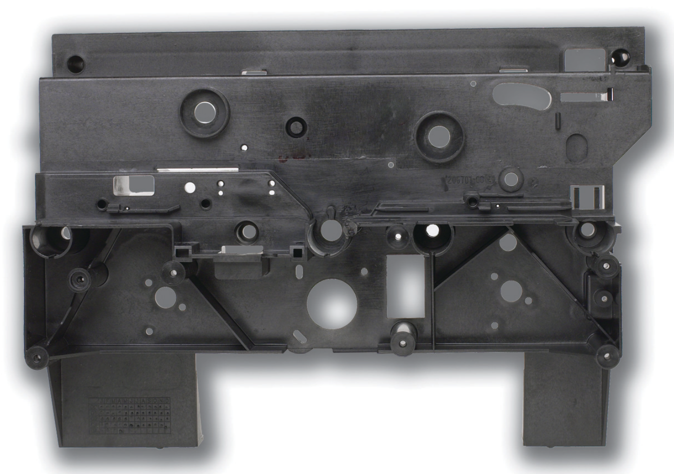
‡ 10^{-10} in^5-min./ft.-lb.-hr.
[a] AISI 1141 cold rolled steel, 18–22 Rockwell C scale, 12–16 micro inch finish unless otherwise noted

ELEVATED TEMPERATURE WEAR

TABLE 8 CONTINUED ELEVATED TEMPERATURE WEAR AND FRICTION DATA FOR ENGINEERING PLASTICS AGAINST STEEL[a]

FAMILY / TRADE NAME	MOVING	STATIONARY	TEMP (°C)	K_{LNP} MOVING‡	K_{LNP} STATIONARY‡	COF STATIC	COF DYNAMIC
LUBRICOMP	OCP36	Steel	260	156	0	0.57	0.46
LUBRICOMP	OFL36	Steel	95	154	13.5	0.75	0.87
LUBRICOMP	OFL36	Steel	150	332	12.2	0.66	0.84
LUBRICOMP	OFL36	Steel	205	Failed	0	0.68	0.91
LUBRICOMP	OFL36	Steel	205	280	4.6	0.78	0.84
LUBRICOMP	OL009	Steel	150	7	0	0.09	0.14
LUBRICOMP	OL009	Steel	205	16	0	0.11	0.16
LUBRICOMP	OL009	Steel	260	Melted	—	0.00	0.00
NYLON 6/6							
LUBRICOMP	RFL36	Steel	95	60	3.9	0.66	0.78
LUBRICOMP	RFL36	Steel	150	294	5.3	0.82	0.73
LUBRICOMP	RFL36	Steel	205	706	3.9	0.84	0.91
PPA							
LUBRICOMP	UFL269SA	1161 SS	356	222	4	0.65	0.73
LUBRICOMP	UFL36S	Steel	150	46	2	0.39	0.48
LUBRICOMP	UFL36S	Steel	150 in ATF	74	0	0.32	0.30
PBT							
LUBRICOMP	WFL36	304 SS	100	35	1	0.32	0.48
LUBRICOMP	WFL36	304 SS	125	43	1	0.27	0.39
LUBRICOMP	WFL36	304 SS	150	38	1	0.32	0.43

‡ 10^{-10} in^5-min./ft.-lb.-hr.
[a] AISI 1141 cold rolled steel, 18–22 Rockwell C scale, 12–16 micro inch finish unless otherwise noted



Zebra Technologies chose LNP LUBRICOMP compounds for their newest printer chassis because it offered the structural integrity, wear resistance, and dimensional stability necessary to support high volume, long term card printing quality and accuracy.

TABLE 8A ELEVATED TEMPERATURE WEAR AND FRICTION DATA FOR ENGINEERING PLASTICS AGAINST OTHER PLASTICS

FAMILY / TRADE NAME	MOVING	STATIONARY TRADE NAME	STATIONARY	TEMP./ COND.	K_{LNP} MOVING‡	K_{LNP} STATIONARY‡	COF STATIC	COF DYNAMIC
PEI								
LUBRICOMP	EFL36	LUBRICOMP	OFL36	121	13	15	0.21	0.14
LUBRICOMP	EFL36	LUBRICOMP	EFL36	150	148	159	0.21	0.16
LUBRICOMP	EFL36	LUBRICOMP	JFL36	150	88	62	0.16	0.14
LUBRICOMP	EFL36	LUBRICOMP	OFL36	150	18	25	0.16	0.14
LUBRICOMP	EFL36	LUBRICOMP	UFL36S	150	108	120	0.16	0.14
PES								
THERMOCOMP	JF006E	LUBRICOMP	EFL36	121	34	205	0.30	0.16
THERMOCOMP	JF006E	LUBRICOMP	JFL36	121	98	507	0.21	0.18
LUBRICOMP	JFL36	LUBRICOMP	OFL36	121	7	39	0.32	0.32
LUBRICOMP	JFL36	LUBRICOMP	EFL36	150	89	226	0.16	0.16
LUBRICOMP	JFL36	LUBRICOMP	OFL36	150	24	22	0.16	0.16
LUBRICOMP	JFL36	LUBRICOMP	UFL36S	150	90	140	0.21	0.21
PEEK								
LUBRICOMP	LCL33E	LUBRICOMP	LCL33E	150	55	49	0.21	0.27
LUBRICOMP	LCL33E	LUBRICOMP	OCL36	150	62	79	0.11	0.25
LUBRICOMP	LCL33E	LUBRICOMP	UCL36S	150	56	337	0.16	0.23
PPS								
LUBRICOMP	OFL36	LUBRICOMP	EFL36	150	25	39	0.16	0.14
LUBRICOMP	OFL36	LUBRICOMP	JFL36	150	18	45	0.14	1.37
LUBRICOMP	OFL36	LUBRICOMP	OFL36	150	19	19	0.18	0.11
LUBRICOMP	OFL36	LUBRICOMP	UFL36S	150	78	87	0.18	0.18
PPA								
LUBRICOMP	UCL36S	LUBRICOMP	OCL36	150	271	276	0.18	0.23
THERMOCOMP	UF006H	LUBRICOMP	EFL36	121	53	232	0.21	0.18
THERMOCOMP	UF006H	LUBRICOMP	EFL36	121	220	324	0.23	0.21
LUBRICOMP	UFL36S	LUBRICOMP	EFL36	150	107	152	0.21	0.18
LUBRICOMP	UFL36S	LUBRICOMP	OFL36	150	282	213	0.18	0.21
LUBRICOMP	UFL36S	LUBRICOMP	UFL36S	150	348	493	0.16	0.11
THERMOCOMP	UX93847	LUBRICOMP	EFL36	121	84	274	0.21	0.25

‡ 10^{-10} in^5-min./ft.-lb.-hr.

DESIGN PROPERTIES OF REINFORCED AND INTERNALLY LUBRICATED THERMOPLASTICS

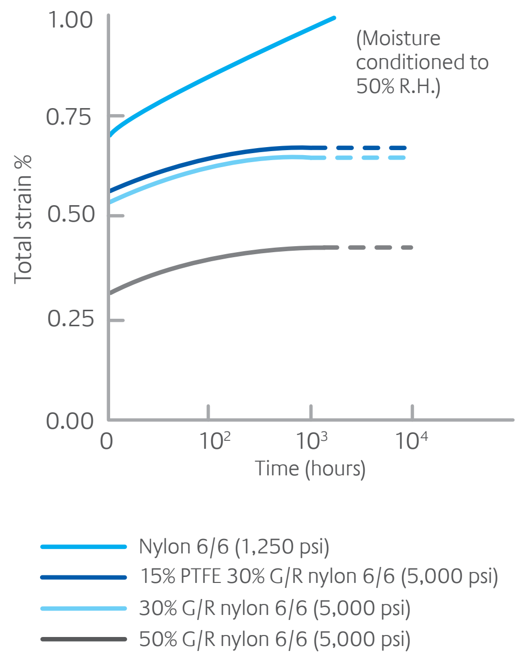
SHORT TERM

In general, the addition of properly sized reinforcing fibers such as carbon or glass will result in dramatic increases in strength, stiffness and thermal properties, while the solid internal lubricants act as fillers and reduce the properties of an unmodified or reinforced resin by an amount approximately equal to the volume % of lubricant. The liquid silicone discussed previously is used at relatively low volume content and has only a modest effect on mechanical and thermal properties. The thermal properties remain unchanged or are lowered slightly.

LONG TERM

Equally important to plastics engineers and designers are the long-term mechanical properties. The two long-term properties most frequently used to compare and evaluate thermoplastic compounds are flexural creep and fatigue endurance limit (see figure 5). For more information on long-term properties, see the SABIC publication on "Long-Term Behavior of Reinforced Thermoplastics."

FIGURE 5 FLEXURAL CREEP NYLON 6/6 AND COMPOSITES AT 75 °F (24 °C)



TEST METHODS

FIGURE 6 THRUST WASHER TEST APPARATUS

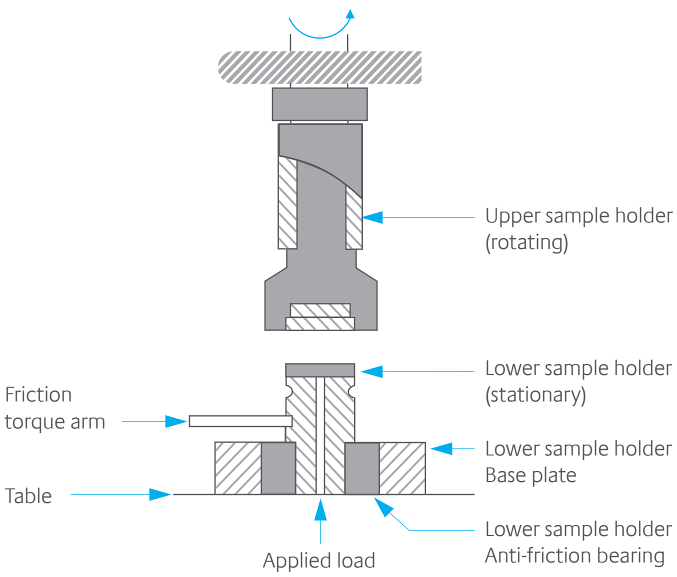
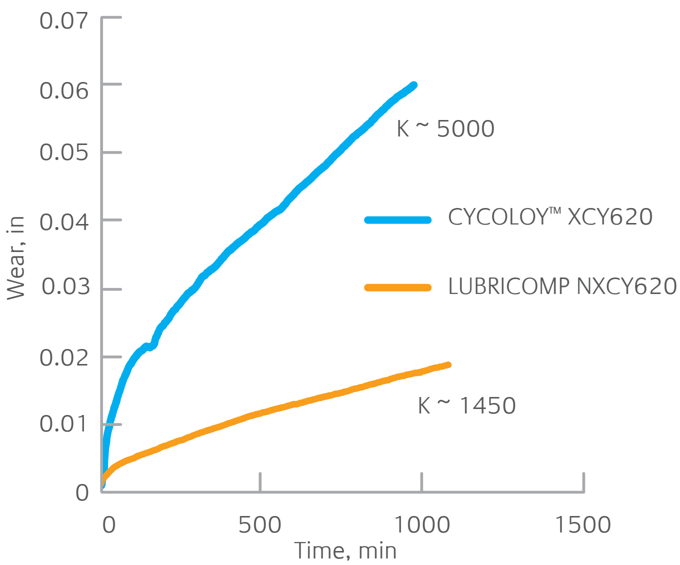


FIGURE 7 WEAR VS TIME



WEAR

Wear tests at SABIC are generally conducted with a thrust washer test apparatus. The thermoplastic thrust washer is mounted in an anti-friction bearing equipped with a torque arm (figure 6).

The raised portion of the thrust washer bears against a counterface. The standard counterface used is a dry, cold-rolled, carbon-steel wear ring with 12 to 16 micro inch finish, 18 to 22 Rockwell C scale hardness at room temperature. Each evaluation is conducted with a new wear ring which has been cleaned and weighed on an analytical balance. Frictional torque is continuously monitored.

The test duration is dependent upon the period required to achieve 360 degree contact between the raised portion of the thrust washer and the wear ring. The average wear factor and duration of this break-in period are listed. Reported wear factors for each compound are based on equilibrium wear rate independent of break-in wear.

Volume wear is calculated as follows

$$W = \frac{\text{Weight loss}}{\text{Density}}$$

Where W is volume wear (in^3), weight loss is in milligrams, and density is in grams/cm^3.

This volume is used for calculation of LNP wear factor (K_{LNP}):

$$K_{LNP} = \frac{W}{PVT}$$

W = volume wear (in^3)
V = velocity (ft./min.)
P = pressure (lbs./in^2)
T = elapsed time (hrs)

Two types of thrust washer wear testers are used at SABIC. The original test design requires a manual measurement of the weight loss of both the test sample and the counterface at regular intervals. This data is used to calculate the wear factor and is generally an average of 6 to 7 readings taken once every 24 hours during the test. Wear factors generated on this equipment is used in this brochure and on datasheets.

TEST METHODS

A newer version of the this test uses real time data collection to measure the change in total thickness of the wear sample and counterface together, and uses that change to calculated the wear factor for the system. This method allows for a shorter test duration and larger data sample. The wear factor generated from this type of test is a system wear factor combining both the wear of the test specimen and the counterface. See figure 7 for a graph of wear vs time as collected on this type of equipment.

These newer testers can also collect data using a pin on disc configuration, and collect data in a rotary oscillation mode.

FRICTION

Coefficient of friction data can also be measured with the thrust washer test apparatus. The test specimen is “run in” against the standard wear ring until 360 degree contact between the raised portion of the thrust washer and wear ring is achieved. Temperature of the test specimen is then allowed to stabilize at the test conditions, generally 40 psi, 50 ft./min., room temperature, and dry. After thermal equilibrium occurs, the dynamic frictional torque generated is measured with the torque arm mounted on the anti-friction bearing. The average of a minimum of five readings is taken. The newer thrust washer wear machines with instrumented data collection can also measure the coefficient of friction in real time and a chart of friction vs. time can be created. (See figure 8).

Coefficient of friction can also be measured using a sliding sled test like ASTM D1894. These tests involve pulling a flat test sample across another flat surface (counterface) and measuring the force required to get the plaque moving and the force required to keep in moving. Since the normal force applied to the sample and the sample area is known, the coefficients of friction can be calculated. These tests are done at low loads and speed without a break-in period, and the data measured is generally different than that collected using a thrust washer test. This data can be useful for press-fit calculations or applications that only see a small number of actuations. (Figures 9a and 9b)

FIGURE 8 FRICTION VS TIME

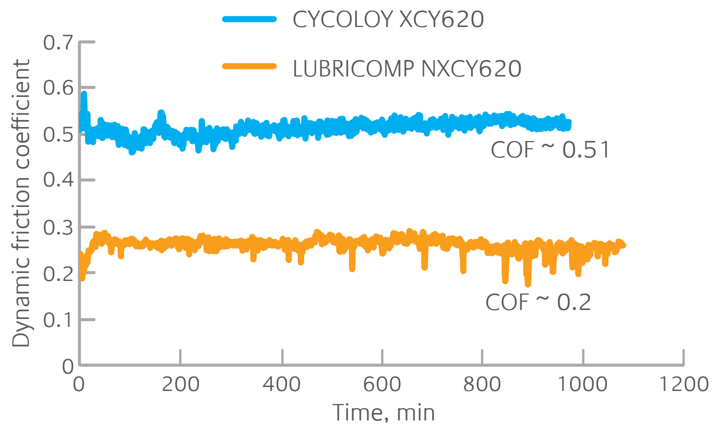


FIGURE 9A SLIDING SLED COF VS STEEL 3 LB SLED

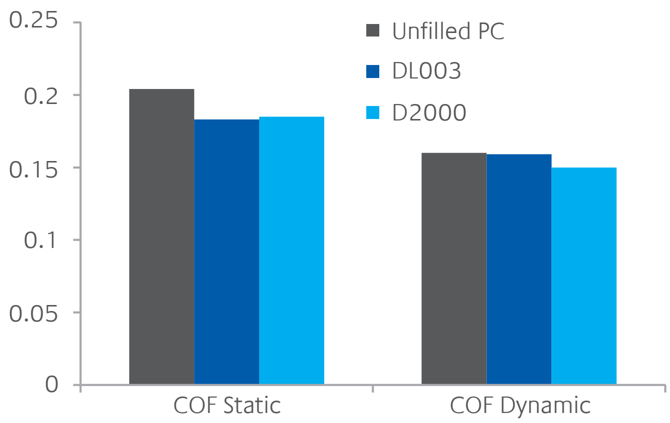


FIGURE 9B SLIDING SLED COF VS STEEL 3 LB SLED

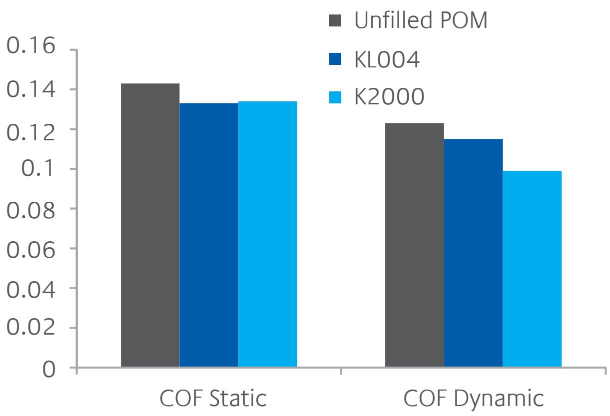
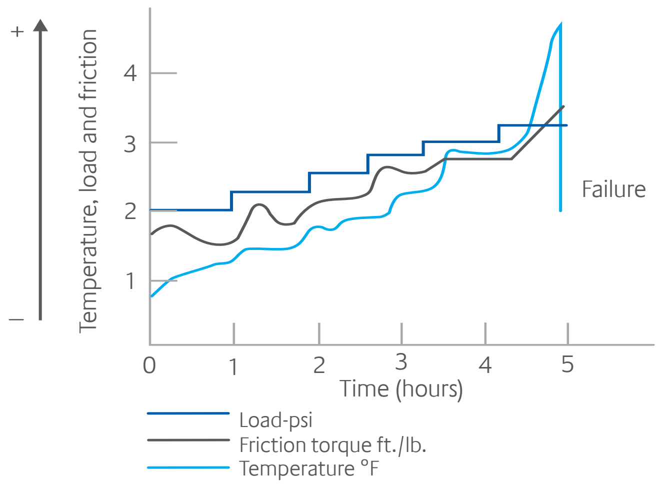


FIGURE 10 LOAD STEPPING TEST



LIMITING PV

To determine the limiting PV for a composition, a sample cylindrical half bearing, generally a 1” x 1” x 0.060” wall is installed in an anti-friction bearing mounted in the test apparatus. The anti-friction bearing holder is equipped with a torque arm. Load is applied through the anti-friction bearing to the test bearing. The shaft can be rotated at surface velocities from 10 to 1000 ft./min. The load (psi), velocity (ft/min), friction torque (lb-ft), and temperature (°F) at the bearing holder 0.125 in from the rubbing surfaces are continuously monitored. A minimum of three velocities are selected to cover a practical range, i.e. 10, 100, and 1000 ft./min. At each velocity, a load-stepping test is conducted. Friction torque and bearing temperature, which are plotted continuously, are allowed to reach equilibrium at each loading (Figure 10). The equilibrium condition is maintained for approximately 30 min., and then the load is increased.

At an advanced load increment, the friction, torque and/or temperature will not stabilize. The slope of the curve will increase sharply in the friction/torque and/or temperature plot. The increase in temperature and/or torque will result in bearing failure. The pressure limits at several velocities provide a curve of the limiting PV capability of the bearing material.

TEST METHODS

PV MAPPING

Since the wear factor and the coefficient of friction for a pair of materials can be affected by changes in the load, relative speeds and temperature, it can be useful to do tests at multiple speeds and velocity combinations. The resulting data can be plotted to show a more compete performance envelope for a material. Modern thrust washer wear testers can collect much of this data automatically. Examples of "PV Maps" for LUBRICOMP UFL36S are shown in figures 11a, 11b and 11c.

FIGURE 11A WEAR FACTOR VS STEEL

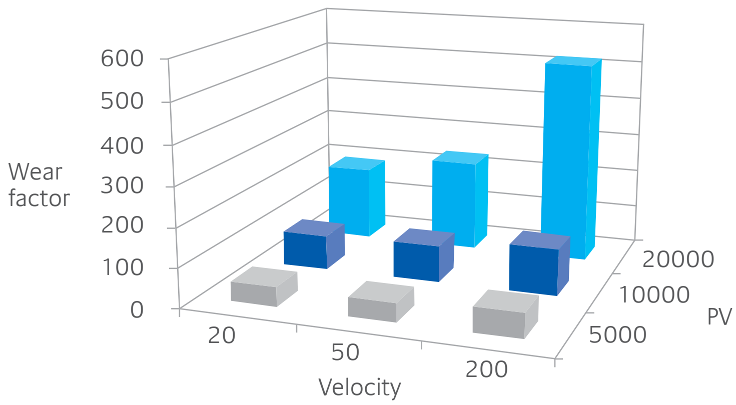


FIGURE 11B TEMPERATURE (COUNTERFACE)

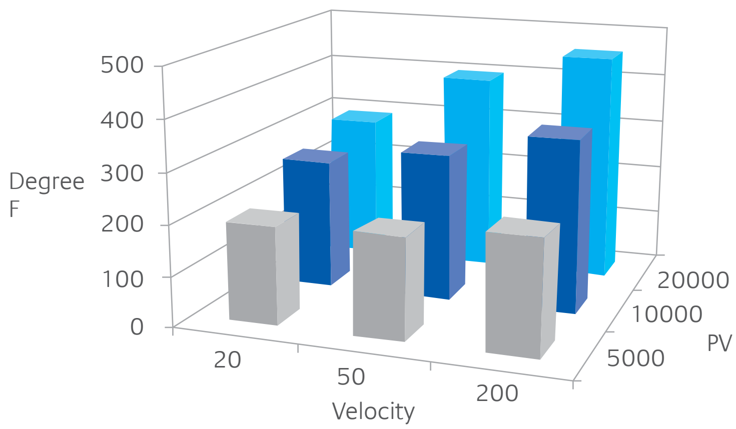
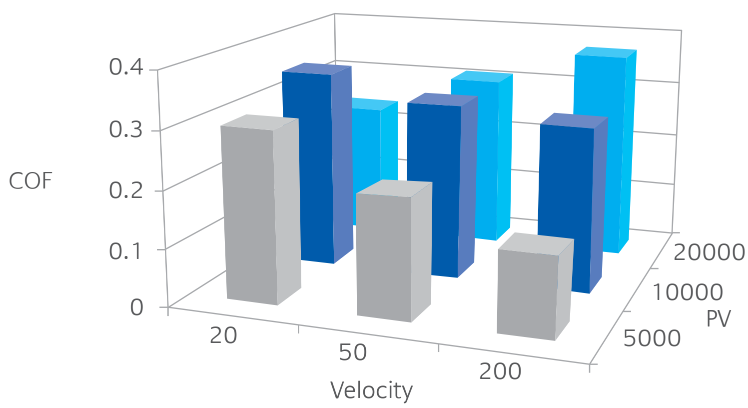


FIGURE 11C DYNAMIC COF



LNP WEAR TESTING CAPABILITIES

THRUST WASHER TEST

Based on ASTM D3702, thrust washer wear testing places a rotating thermoplastic disk in contact with a stationary ring-shaped counterface (metal or plastic). The standard test is run for 5 to 7 days, and the weight loss and coefficients of friction are recorded every 24 hours. Standard test conditions are 50 fpm and 40 psi at 70 °F, but custom testing is available.

SABIC GEAR WEAR TESTING

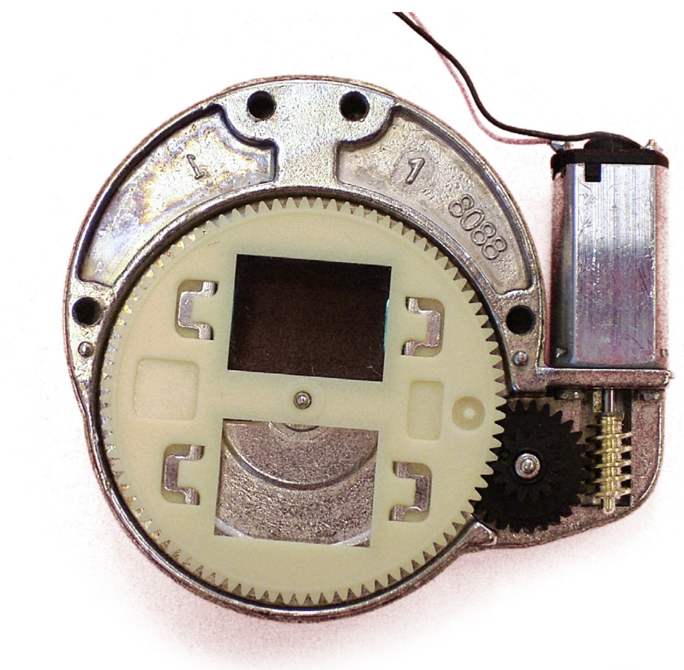
This test, developed by SABIC, places two molded plastic gears in contact and measures the wear of the gear set as they run at different speeds (0 to 4000 rpm) or loads (0.60 in.-lbs.) The wear is determined by using optical angle encoders to measure the change in rotational position of the gears. Data are presented as wear (in.) vs. cycles or time.

LIMITING PRESSURE VELOCITY (LPV)

This test is a measure of a material's ability to act as a bearing. A rotating steel shaft is placed inside a thermoplastic journal bearing, to which a load is applied. The temperature of the bearing is measured. As the temperature equilibrates, the load is increased. This load stepping continues until the bearing melts or seizes. The pressure velocity product between the last measurement and the failure point is listed as the Limiting PV (psi-fpm) of the material at the specific speed tested, usually 10, 100 or 1000 fpm.

SLIDING SLED FRICTION TESTING (ASTM D1894)

A weighted thermoplastic sample is pulled at a constant speed over a metals or plastic counterface. The dynamic and static coefficients are measured. These data are useful in determining coefficient of friction for applications that see a limited amount of contact (press fits, assemblies.)



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