Appendix: Static and Kinetic Friction Coefficients for Selected Materials

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THE DEFINITIONS for static and kinetic friction coefficients are given in the Glossary of this Handbook. The friction coefficient between solids sliding, or about to slide, over one another under the influence of a nonzero normal force is a function of several factors whose relative contributions vary on a case-by-case basis:

- Composition of the materials
- Surface finish of each solid
- Nature of the surrounding environment
- Force holding the solids in contact (load)
- Velocity of relative motion
- Nature of the relative motion (for example, unidirectional, back and forth, steady, variable, and so on)
- Nature of the contact (conforming versus nonconforming surfaces)
- Temperature of the interfacial region
- Prior sliding history of the surfaces
- Characteristics of the machine and fixtures in which the materials are affixed

No single source has generated a comprehensive list of friction coefficients for materials under identical testing conditions; therefore, nearly all existing handbooks rely on compilations of data produced under a variety of testing conditions. Readers should be aware of this shortcoming and use the values only as very approximate guides, unless their applications are exactly the same as those methods used in generating the data.

The five tables of friction coefficient values in this Appendix contain both static and kinetic friction coefficients. They are arranged by material type as follows:

- Table 1: metals on metals
- Table 2: ceramics on various materials
- Table 3: polymers on various materials
- Table 4: coatings on various materials
- Table 5: miscellaneous materials

It should be emphasized that the data in the tables are for unlubricated solids at room temperature and in ambient air. The reference list provided with each table lists both the sources of the data for the table and a brief description of the testing conditions used to generate these data, if such information was available in the reference. If accurate friction information is required for a specific application, the use of carefully simulated conditions or instrumentation of the actual machine should be conducted in lieu of using tabulated values because even a small change in contact conditions (for example, sliding speed or relative humidity for some materials) can result in a marked change in the measured or apparent friction coefficient.

Table 1 Friction coefficient data for metals sliding on metals

Metals tested in air at room temperature

Material		Test geometry [a]	Friction coefficient		Ref
Fixed specimen	**Moving specimen**		**Static**	**Kinetic**	
Ag	Ag	IS	0.50	. . .	1
	Au	IS	0.53	. . .	1
	Cu	IS	0.48	. . .	1
	Fe	IS	0.49	. . .	1
Al	Al	IS	0.57	. . .	1
	Ti	IS	0.54	. . .	1
Al, alloy 6061-T6	Al, alloy 6061-T6	FOF	0.42	0.34	2
	Cu	FOF	0.28	0.23	2
	Steel, 1032	FOF	0.35	0.25	2
	Ti-6Al-4V	FOF	0.34	0.29	2
Au	Ag	IS	0.53	. . .	1
	Au	IS	0.49	. . .	1
Brass, 60Cu-40Zn	Steel, tool	POR	. . .	0.24	3
Cd	Cd	IS	0.79	. . .	1
	Fe	IS	0.52	. . .	1
Co	Co	IS	0.56	. . .	1
	Cr	IS	0.41	. . .	1
Cr	Co	IS	0.41	. . .	1
	Cr	IS	0.46	. . .	1
Cu	Co	IS	0.44	. . .	1
	Cr	IS	0.46	. . .	1
	Cu	IS	0.55	. . .	1
	Fe	IS	0.50	. . .	1
	Ni	IS	0.49	. . .	1
	Zn	IS	0.56	. . .	1
Cu, OFHC	Steel, 4619	BOR	. . .	0.82	4
Fe	Co	IS	0.41	. . .	1
	Cr	IS	0.48	. . .	1
	Fe	IS	0.51	. . .	1
	Mg	IS	0.51	. . .	1
	Mo	IS	0.46	. . .	1
	Ti	IS	0.49	. . .	1
	W	IS	0.47	. . .	1
	Zn	IS	0.55	. . .	1
In	In	IS	1.46	. . .	1
Mg	Mg	IS	0.69	. . .	1
Mo	Fe	IS	0.46	. . .	1
	Mo	IS	0.44	. . .	1
Nb	Nb	IS	0.46	. . .	1
Ni	Cr	IS	0.59	. . .	1
	Ni	IS	0.50	. . .	1
	Pt	IS	0.64	. . .	1
Pb	Ag	IS	0.73	. . .	1
	Au	IS	0.61	. . .	1
	Co	IS	0.55	. . .	1
	Cr	IS	0.53	. . .	1
	Fe	IS	0.54	. . .	1
	Pb	IS	0.90	. . .	1
	Steel	SPOF	. . .	0.80	5
Pt	Ni	IS	0.64	. . .	1
	Pt	IS	0.55	. . .	1
Sn	Fe	IS	0.55	. . .	1
	Sn	IS	0.74	. . .	1
Steel	Cu	SPOF	. . .	0.80	5
	Pb	SPOF	. . .	1.40	5

Steel, 1032	Al, alloy 6061-T6	FOF	0.47	0.38	2
	Cu	FOF	0.32	0.25	2
	Steel, 1032	FOF	0.31	0.23	2
	Ti-6Al-4V	FOF	0.36	0.32	2
Steel, 52100	Ni_3Al, alloy IC-396M	RSOF	. . .	1.08	6
	Ni_3Al, alloy IC-50	RSOF	. . .	0.70	6
	Steel, 1015 annealed	BOR	. . .	0.74	7
	Steel, dual-phase DP-80	BOR	. . .	0.55	7
	Steel, O2 tool	BOR	. . .	0.49	7
Steel, mild	Steel, mild	BOR	. . .	0.62	3
Steel, M50 tool	Ni_3Al, alloy IC-50	RSOF	. . .	0.68	6
Steel, stainless	Steel, tool	POR	. . .	0.53	3
Steel, stainless 304	Cu	FOF	0.23	0.21	2
Stellite	Steel, tool	POR	. . .	0.60	3
Ti	Al	IS	0.54	. . .	1
	Steel, 17-4 stainless	POF	0.48	0.48	8
	Ti	POF	0.47	0.40	8
	Ti	FOF	0.55	. . .	1
	Ti-6Al-4V	POF	0.43	0.36	8
Ti-6Al-4V	Al, alloy 6061-T6	FOF	0.41	0.38	2
	Cu-Al (bronze)	POF	0.36	0.27	8
	Nitronic 60	POF	0.38	0.31	8
	Steel, 17-4 stainless	POF	0.36	0.31	8
	Steel, Type 440C stainless	POF	0.44	0.37	8
	Stellite 12	POF	0.35	0.29	8
	Stellite 6	POF	0.45	0.36	8
	Ta	POF	0.53	0.53	8
	Ti-6Al-4V	FOF	0.36	0.30	2
	Ti-6Al-4V	POF	0.36	0.31	8
W	Cu	IS	0.41	. . .	1
	Fe	IS	0.47	. . .	1
	W	IS	0.51	. . .	1
Zn	Cu	IS	0.56	. . .	1
	Fe	IS	0.55	. . .	1
	Zn	IS	0.75	. . .	1

(a) Test geometry codes: BOR, flat block pressed against the cylindrical surface of a rotating ring; FOF, flat surface sliding on another flat surface; IS, sliding down an inclined surface; POR, pin sliding against the cylindrical surface of a rotating ring; RSOF, reciprocating, spherically ended pin on a flat surface; SPOF, spherically ended pin on a flat coupon.

Table 2 Friction coefficient data for ceramics sliding on various materials

Specimens tested in air at room temperature

Material		Test geometry[(a)]	Friction coefficient		Ref
Fixed specimen	**Moving specimen**		**Static**	**Kinetic**	
Ag	Alumina	RPOF	. . .	0.37	9
	Zirconia	RPOF	. . .	0.39	9
Al	Alumina	RPOF	. . .	0.75	9
	Zirconia	RPOF	. . .	0.63	9
Alumina	Alumina	SPOD	. . .	0.50	10
	Alumina	SPOD	. . .	0.52	11
	Alumina	SPOD	. . .	0.33	12
	WRA[(b)]	SPOD	. . .	0.53	13
	WRZTA[(c)]	SPOD	. . .	0.50	13
	ZTA[(d)]	SPOD	. . .	0.56	13
Boron carbide	Boron carbide	POD	. . .	0.53	14
Cr	Alumina	RPOF	. . .	0.50	9
	Zirconia	RPOF	. . .	0.61	9
Cu	Alumina	RPOF	. . .	0.43	9

	Zirconia	RPOF	. . .	0.40	9
Fe	Alumina	RPOF		0.45	9
	Zirconia	RPOF	. . .	0.35	9
Glass, tempered	Al, alloy 6061-T6	FOF	0.17	0.14	15
	Steel, 1032	FOF	0.13	0.12	15
	Teflon[e]	FOF	0.10	0.10	15
Silicon carbide	Silicon carbide	SPOD	. . .	0.52	14
	Silicon nitride	SPOD	. . .	0.53	12
	Silicon nitride	SPOD	. . .	0.71	10
	Silicon nitride	SPOD	. . .	0.63	11
Silicon nitride	Silicon carbide	SPOD	. . .	0.54	12
	Silicon carbide	SPOD	. . .	0.67	10
	Silicon carbide	SPOD	. . .	0.84	11
	Silicon nitride	SPOD	. . .	0.17	14
Steel, M50 tool	Boron carbide	POD	. . .	0.29	14
	Silicon carbide	POD	. . .	0.29	14
	Silicon nitride	POD	. . .	0.15	14
	Tungsten carbide	POD	. . .	0.19	14
Ti	Alumina	RPOF	. . .	0.42	9
	Zirconia	RPOF	. . .	0.27	9
Tungsten carbide	Tungsten carbide	POD	. . .	0.34	14

(a) Test geometry codes: FOF, flat surface sliding on another flat surface; POD, pin on disk (pin tip geometry not given); RPOF, reciprocating pin on flat; SPOD, spherically ended pin on flat disk; SPOF, spherically ended pin on a flat coupon.

(b) WRA, silicon carbide whisker-reinforced alumina.

(c) WRZTA, silicon carbide whisker-reinforced, zirconia-toughened alumina.

(d) ZTA, zirconia-toughened alumina.

(e) Teflon, polytetrafluoroethylene

Table 3 Friction coefficient data for polymers sliding on various materials

Specimens tested in air at room temperature

Material[a]		Test geometry[b]	Friction coefficient		Ref
Fixed specimen	**Moving specimen**		**Static**	**Kinetic**	
Polymers sliding on polymers					
Acetal	Acetal	TW	0.06	0.07	16
Nylon 6/6	Nylon 6/6	TW	0.06	0.07	16
PMMA	PMMA	NSp	0.80	. . .	17
Polyester PBT	Polyester PBT	TW	0.17	0.24	16
Polystyrene	Polystyrene	NSp	0.50	. . .	17
Polyethylene	Polyethylene	NSp	0.20	. . .	17
Teflon	Teflon	NSp	0.04	. . .	17
	Teflon	FOF	0.08	0.07	18
Dissimilar pairs with the polymer as the fixed specimen					
Nylon 6 (cast)	Steel, mild	TPOD	. . .	0.35	19
(extruded)	Steel, mild	TPOD	. . .	0.37	19
Nylon 6/6	Polycarbonate	TW	0.25	0.04	16
Nylon 6/6 (+ PTFE)	Steel, mild	TPOD	. . .	0.35	19
PA 66	Steel, 52100	BOR	. . .	0.57	20
PA 66 (+ 15% PTFE)	Steel, 52100	BOR	. . .	0.13	20
PA 66 (PTFE/glass)	Steel, 52100	BOR	. . .	0.31	20
PEEK	Steel, 52100	BOR	. . .	0.49	20
PEEK (+ 15% PTFE)	Steel, 52100	BOR	. . .	0.18	20
PEEK (PTFE/glass)	Steel, 52100	BOR	. . .	0.20	20
PEI	Steel, 52100	BOR	. . .	0.43	20
PEI (+ 15% PTFE)	Steel, 52100	BOR	. . .	0.21	20
PEI (PTFE/glass)	Steel, 52100	BOR	. . .	0.21	20
PETP	Steel, 52100	BOR	. . .	0.68	20
PETP (+ 15% PTFE)	Steel, 52100	BOR	. . .	0.14	20

PETP (PTFE/glass)	Steel, 52100	BOR	. . .	0.18	20
Polyurethane[c]	Steel, mild	TPOD	. . .	0.51	19
Polyurethane[d]	Steel, mild	TPOD	. . .	0.35	19
POM	Steel, 52100	BOR	. . .	0.45	20
POM (+ 15% PTFE)	Steel, 52100	BOR	. . .	0.21	20
POM (PTFE/glass)	Steel, 52100	BOR	. . .	0.23	20
PPS	Steel, 52100	BOR	. . .	0.70	20
PPS (+ 15% PTFE)	Steel, 52100	BOR	. . .	0.30	20
PPS (PTFE/glass)	Steel, 52100	BOR	. . .	0.39	20
Teflon	Al, alloy 6061-T6	FOF	0.24	0.19	18
	Cr plate	FOF	0.09	0.08	18
	Cu	FOF	0.13	0.11	18
	Ni (0.001 P)	FOF	0.15	0.12	18
	Steel, 1032	FOF	0.27	0.27	18
	Ti-6Al-4V	FOF	0.17	0.14	18
	TiN (Magnagold)	FOF	0.15	0.12	18
UHMWPE	Steel, mild	TOPD	. . .	0.14	19
Dissimilar pairs with the polymer as the moving specimen					
Steel, carbon	ABS resin	POF	0.40	0.27	21
Steel, mild	ABS	TW	0.30	0.35	16
	ABS + 15% PTFE	TW	0.13	0.16	16
	Acetal	TW	0.14	0.21	16
Steel, 52100	Acetal	POD	. . .	0.31	22
	HDPE	POD	. . .	0.25	22
Steel, carbon	HDPE	POF	0.36	0.23	21
	LDPE	POF	0.48	0.28	21
Steel, 52100	Lexan 101	POD	. . .	0.60	22
Steel, mild	Nylon (amorphous)	TW	0.23	0.32	16
Steel, carbon	Nylon 6	POF	0.54	0.37	21
Steel, mild	Nylon 6	TW	0.22	0.26	16
Steel, carbon	Nylon 6/6	POF	0.53	0.38	21
Steel, mild	Nylon 6/6	TW	0.20	0.28	16
Steel, carbon	Nylon 6/10	POF	0.53	0.38	21
Steel, mild	Nylon 6/10	TW	0.23	0.31	16
	Nylon 6/12	TW	0.24	0.31	16
	PEEK (Victrex)	TW	0.20	0.25	16
Steel, carbon	Phenol formaldehyde	POF	0.51	0.44	21
Steel, 52100	PMMA	POD	. . .	0.68	22
Steel, carbon	PMMA	POF	0.64	0.50	21
Steel, mild	Polycarbonate	TW	0.31	0.38	16
	Polyesther PBT	TW	0.19	0.25	16
	Polyethylene	TW	0.09	0.13	16
Steel, carbon	Polyimide	POF	0.46	0.34	21
	Polyoxylmethylene	POF	0.30	0.17	21
	Polypropylene	POF	0.36	0.26	21
Steel, mild	Polypropylene	TW	0.08	0.11	16
Steel, carbon	Polystyrene	POF	0.43	0.37	21
Steel, mild	Polystyrene	TW	0.28	0.32	16
	Polysulfone	TW	0.29	0.37	16
Steel, carbon	PVC	POF	0.53	0.38	21
	PTFE	POF	0.37	0.09	21
Al, alloy 6061-T6	Teflon	FOF	0.19	0.18	18
Cr plate	Teflon	FOF	0.21	0.19	18
Glass, tempered	Teflon	FOF	0.10	0.10	18
Ni (0.001 P)	Teflon	FOF	0.22	0.19	18
Steel, 1032	Teflon	FOF	0.18	0.16	18
Ti-6Al-4V	Teflon	FOF	0.23	0.21	18
TiN (Magnagold)	Teflon	FOF	0.16	0.11	18

(a) ABS, acrylonitrile butadiene styrene; HDPE, high-density polyethylene; LPDE, low-density polyethylene; Lexan, trademark of the General Electric Co. (polycarbonate); nylon, one of a group of polyamide resins (see also PA); PA, polyamide; PBT, polybutylene terephthalate; PEEK, polyetheretherketone; PEI, polyetherimide; PETP, polyethylene terephthalate; PMMA, polymethylmethacrylate; POM, polyoxymethylene; PPS, polyphenylene sulphide; PTFE, polytetrafluoroethylene; PVC, polyvinyl chloride; UHMWPE, ultra high molecular weight polyethylene; Magnagold, product of General Magnaplate, Inc.; Teflon, trademark of E.I. Du Pont de Nemours & Co., Inc. (PTFE).

(b) Test geometry codes: BOR, flat block-on-rotating ring; FOF, flat surface sliding on another flat surface; NSp, not specified; POD, pin on disk; POF, pin on flat; TPOD, triple pin-on-disk; TW, thrust washer test.

(c) Green polyurethane.

(d) Cream-colored polyurethane

Table 4 Friction coefficient data for coatings sliding on various materials

Specimens tested in air at room temperature

Material		Test geometry[(a)]	Friction coefficient		Ref
Fixed specimen	**Moving specimen**		**Static**	**Kinetic**	
Al, alloy 6061-T6	Cr plate	FOF	0.27	0.22	23
	Ni (0.001 P) plate	FOF	0.33	0.25	23
	TiN (Magnagold)[(c)]	FOF	0.25	0.22	23
Au, electroplate	60Pd-40Ag, plate	POF	. . .	2.40	24
	60Pd-40Au, plate	POF	. . .	0.30	24
	70Au-30Ag, plate	POF	. . .	3.00	24
	80Pd-20Au, plate	POF	. . .	1.80	24
	99Au-1 Co, plate	POF	. . .	2.40	24
	Au plate	POF	. . .	2.80	24
	Au-0.6 Co, plate	POF	. . .	0.40	24
	Pd plate	POF	. . .	0.60	24
Cr plate	Al, alloy 6061-T6	FOF	0.20	0.19	23
	Ni (0.001 P) plate	FOF	0.19	0.17	23
	Steel, 1032	FOF	0.20	0.17	23
	Teflon[(b)]	FOF	0.21	0.19	23
	Ti-6A1-4V	FOF	0.38	0.33	23
Niobium carbide, coating	Niobium carbide, coating	FOF	0.19	0.13	25
Ni (0.001 P) plate	Al, alloy 6061-T6	FOF	0.26	0.23	23
	Cr plate	FOF	0.41	0.36	23
	Ni (0.001 P) plate	FOF	0.32	0.28	23
	Steel, 1032	FOF	0.35	0.31	23
	Steel, D2 tool	FOF	0.43	0.33	23
	Teflon[(b)]	FOF	0.22	0.19	23
	TiN (Magnagold)[(c)]	FOF	0.33	0.26	23
Steel	Cu film on steel	SPOD	0.30	. . .	26
	In film on Ag	SPOD	0.10	. . .	26
	In film on steel	SPOD	0.08	. . .	26
	Pb film on Cu	SPOD	0.18	. . .	26
Steel, 1032	Cr plate	FOF	0.25	0.21	23
	Ni (0.001 P) plate	FOF	0.37	0.30	23
	TiN (Magnagold)[(c)]	FOF	0.31	0.28	23
Steel, type 440C stainless	TiC on type 304 stainless	POD	0.12	0.17	27
	TiN on type 304 stainless	POD	0.50	0.75	27
Steel, bearing	Chrome carbide	POD	. . .	0.79	28
	SiC (CVD)[(d)]	POD	. . .	0.23	28
	TiC (CVD)[(d)]	POD	. . .	0.25	28
	TiN (CVD)[(d)]	POD	. . .	0.49	28
Steel, stainless	Al_2O_3, plasma-sprayed	Ams	. . .	0.13-0.30	29
	Cr plate	Ams	. . .	0.30-0.38	29
	Cr_2O_3, plasma-sprayed	Ams	. . .	0.14-0.15	29
	TiO_2, plasma sprayed	Ams	. . .	0.10-0.15	29
	WC-12 Co, plasma-sprayed	Ams	. . .	0.11-0.13	29
Teflon[(b)]	Cr plate	FOF	0.09	0.08	23
	Ni (0.001 P) plate	FOF	0.15	0.12	23
	TiN (Magnagold)[(c)]	FOF	0.15	0.12	23
TiC on type 44OC stainless steel	Al	POD	0.50	0.85	27

	Ti	POD	0.65	0.80	27
	TiC on type 440C stainless steel	POD	0.22	0.20	27
	TiN on type 440C stainless steel	POD	0.25	0.20	27
TiN on type 440C stainless steel	Al	POD	0.27	0.40	27
	Steel, type 304 stainless	POD	0.29	0.41	27
	Ti	POD	0.50	0.76	27
	TiC on type 440C stainless steel	POD	0.05	0.06	27
	TiN on type 440C stainless steel	POD	0.65	0.45	27
TiN (Magnagold)[c]	Al, alloy 6061-T6	FOF	0.30	0.26	23
	Steel, 1032	FOF	0.38	0.31	23
	Teflon[b]	FOF	0.16	0.11	23
	Ti-6Al-4V	FOF	0.26	0.23	23
	TiN (Magnagold)[c]	FOF	0.25	0.21	23

(a) Ams, Amsler circumferential, rotating disk-on-disk machine; FOF, flat surface sliding on another flat surface; POD, pin on disk; POF, pin on flat; SPOD, spherically ended pin-on-flat disk.

(b) Teflon is a registered trademark of E.I. Du Pont de Nemours & Co., Inc. (polytetrafluoroethylene).

(c) Magnagold is a product of General Magnaplate, Inc.

(d) CVD, chemical vapor deposition

Table 5 Friction coefficient data for miscellaneous materials

Specimens tested in air at room temperature

Material		Test geometry[a]	Friction coefficient		Ref
Fixed specimen	**Moving specimen**		**Static**	**Kinetic**	
Brick	Wood	UnSp	0.6	. . .	30
Cotton thread	Cotton thread	UnSp	0.3	. . .	30
Diamond	Diamond	UnSp	0.1	. . .	30
Explosives[b]					
HMX[c]	Glass	RPOF	. . .	0.55	31
PETN[d]	Glass	RPOF	. . .	0.40	31
RDX[e]	Glass	RPOF	. . .	0.35	31
Lead azide [$Pb(N_3)_2$]	Glass	RPOF	. . .	0.28	31
Silver azide (AgN_3)	Glass	RPOF	. . .	0.40	31
Glass, tempered	Al, alloy 6061-T6	FOF	0.17	0.14	32
	Steel, 1032	FOF	0.13	0.12	32
	Teflon[f]	FOF	0.10	0.10	32
Glass, thin fiber	Brass	StOD	. . .	0.16-0.26	33
	Graphite	StOD	. . .	0.15	33
	Porcelain	StOD	. . .	0.36	33
	Steel, stainless	StOD	. . .	0.31	33
	Teflon[f]	StOD	. . .	0.10	33
Glass, clean	Glass (clean)	UnSp	0.9-1.0	. . .	30
Graphite, molded	Al, alloy 2024	FOF	0.16	. . .	34
	Al, alloy 2219	FOF	0.22	. . .	34
	Graphite, extruded	FOF	0.20	0.17	34
	Graphite, molded	FOF	0.18	0.14	34
	Inconel X-750[g]	FOF	0.16	. . .	34
	Steel, type 304 stainless	FOF	0.18	. . .	34
	Steel, type 347 stainless	FOF	0.19	. . .	34
Graphite (clean)	Graphite (clean)	UnSp	0.10	. . .	30
Graphite (outgassed)	Graphite (outgassed)	UnSp	0.5-0.8	. . .	30
Hickory wood, waxed	Snow	UnSp	. . .	0.14	35
Ice	Bronze	UnSp	. . .	0.02	35
	Ebonite	UnSp	. . .	0.02	35
	Ice	UnSp	0.05-0.15	. . .	35
	Ice	UnSp	. . .	0.02	35
	Ice	FOF	>0.01	>0.01	32
Leather	Metal (clean)	UnSp	0.6	. . .	30
Metal	Glass (clean)	UnSp	0.5-0.7	. . .	30

Mica (cleaved)	Mica (cleaved)	UnSp	1.0	. . .	30
Mica (contaminated)	Mica (contaminated)	UnSp	0.2-0.4	. . .	30
Nylon fibers	Nylon fibers	UnSp	0.15-0.25	. . .	30
Paper, copier	Paper, copier	FOF	0.28	0.26	32
Sapphire	Sapphire	UnSp	0.2	. . .	30
Silk fibers	Silk fibers	UnSp	0.2-0.3	. . .	30
Steel (clean)	Graphite	UnSp	0.1	. . .	30
Wood (clean)	Metals	UnSp	0.2-0.6	. . .	30
	Wood (clean)	UnSp	0.25-0.5	. . .	30

(a) FOF, flat surface sliding on another flat surface; RPOF, reciprocating pin-on-flat; StOD, strand wrapped over a drum; UnSp, unspecified method.

(b) Explosives reported here were tested as reciprocating, single-crystal, flat-ended pin-on-moving flat.

(c) HMX, cyclotetramethylene tetranitramine;

(d) PETN, pentaerithritol tetranitrate.

(e) RDX, cyclotrimethylene trinitramine.

(f) Teflon is a registered trademark of E.I. Du Pont de Nemours & Co., Inc.

(g) Inconel is a product of INCO, Inc.

References

1. E. Rabinowicz, *ASLE Trans.,* Vol 14, 1971, p 198; plate sliding on plate at 50% relative humidity
2. "Friction Data Guide," General Magnaplate Corporation, 1988; TMI Model 98-5 slip and friction tester, 1.96 N (0.200 kgf) load, ground specimens, 54% relative humidity, average of five tests
3. J.F. Archard, *ASME Wear Control Handbook,* M.B. Peterson and W.O. Winer, Ed., American Society of Mechanical Engineers, 1980, p 38; pin-on-rotating ring, 3.9 N (0.40 kgf) load, 1.8 m/s (350 ft/min) velocity
4. A.W. Ruff, L.K. Ives, and W.A. Glaeser, *Fundamentals of Friction and Wear of Materials,* ASM International, 1981, p 235; flat block-on-rotating 35 mm ($1\frac{3}{8}$ in.) diameter ring, 10 N (1.02 kgf) load, 0.2 m/s (40 ft/min) velocity
5. F.P. Bowden and D. Tabor, *The Friction and Lubrication of Solids,* Oxford Press, 1986, p 127; sphere-on-flat, unspecified load and velocity
6. P.J. Blau and C.E. DeVore, *Tribol. Int.,* Vol 23 (No. 4), 1990, p 226; reciprocating ball-on-flat, 10 Hz, 25 N (2.6 kgf) load, 10 mm stroke
7. P.J. Blau, *J. Tribology,* Vol 107, 1985, p 483; flat block-on-rotating 35 mm ($1\frac{3}{8}$ in.) diameter ring, 133 N (13.6 kgf) load, 5.0 cm/s (2.0 in./s) velocity
8. K.G. Budinski, *Proceedings of Wear of Materials,* American Society of Mechanical Engineers, 1991, p 289; modified ASTM G 98 galling test procedure
9. K. Demizu, R. Wadabayashim, and H. Ishigaki, *Tribol. Trans.,* Vol 33 (No. 4), 1990, p 505; 1.5 mm (0.060 in.) radius pin reciprocating on a flat, 4 N (0.4 kgf) load, 0.17 mm/s (0.0067 in./s) velocity, 50% relative humidity
10. P.J. Blau, Oak Ridge National Laboratory
11. P.J. Blau, Oak Ridge National Laboratory, 1.0 N (0.10 kgf) load and 0.1 m/s (20 ft/min) velocity
12. P.J. Blau, Oak Ridge National Laboratory, 10 N (1.0 kgf) load and 0.1 m/s (20 ft/min) velocity
13. C.S. Yust, *Tribology of Composite Materials,* P.K. Rohatgi, P.J. Blau, and C.S. Yust, Ed., ASM International, 1990, p 27; 9.5 mm ($\frac{3}{8}$ in.) diameter sphere-on-disk, 2 to 9 N (0.2 to 0.9 kgf) load, 0.3 m/s (60 ft/min) velocity
14. B. Bhushan and B.K. Gupta, table in *Handbook of Tribology,* Mc-Graw-Hill, 1991; 20 N (2.0 kgf), 3 mm/s (0.12 in./s) velocity
15. "Friction Data Guide," General Magnaplate Corporation, 1988; TMI Model 98-5 slip and friction tester, 1.96 N (0.200 kgf) load, ground specimens, 54% relative humidity, average of five tests

16. "Lubricomp(R) Internally-Lubricated Reinforced Thermoplastics and Fluoropolymer Composites," Bulletin 254-688, ICI Advanced Materials; thrust washer apparatus, 0.28 MPa (40 psi), 0.25 m/s (50 ft/min), after running-in for one full rotation
17. F.P. Bowden and D. Tabor, Appendix IV, *The Friction and Lubrication of Solids,* Oxford Press, 1986; unspecified testing conditions
18. "Friction Data Guide," General Magnaplate Corporation, 1988; TMI Model 98-5 slip and friction tester, 1.96 N (0.200 kgf) load, ground specimens, 54% relative humidity, average of five tests
19. J.M. Thorp, *Tribol. Int.,* Vol 15 (No. 2), 1982, p 69; three-pin-on-rotating disk apparatus, 0.1 m/s (20 ft/min)
20. J.W.M. Mens and A.W.J. de Gee, *Wear,* Vol 149, 1991, p 255; flat block-on-rotating ring, 1.5 MPa (0.22 ksi) pressure, 150 N (15 kgf) load, 0.1 m/s (20 ft/min) velocity
21. R.P. Steijn, *Metall. Eng. Quart.,* Vol 7, 1967, p 9; 12.7 mm (0.500 in.) diameter ball-on-flat, 9.8 N (1.0 kgf) load, 0.01 mm/s (4×10^{-4} in./s) velocity
22. N.P. Suh, *Tribophysics,* Prentice-Hall, 1986, p 226; pin-on-disk, 4.4 N (0.45 kgf) load, 3.3 cm/s (1.3 in./s) velocity, 65% relative humidity
23. "Friction Data Guide," General Magnaplate Corporation, 1988; TMI Model 98-5 slip and friction tester, 1.96 N (0.200 kgf) load, ground specimens, 54% relative humidity, average of five tests
24. M. Antler and E.T. Ratcliff, *Proceedings of the Holm Conference on Electrical Contacts,* 1982, p 19; sphere-on-reciprocating flat, 0.49 N (0.050 kgf) load, 1.0 mm/s (0.039 in./s) velocity
25. M.J. Manjoine, *Bearing and Seal Design in Nuclear Power Machinery,* American Society of Mechanical Engineers, 1967; flat plate-on-flat plate, 28 MPa (4.1 ksi) contact pressure, 0.25 mm/s (0.010 in./s) velocity
26. F.P. Bowden and D. Tabor, *The Friction and Lubrication of Solids,* Oxford Press, 1986, p 127; sphere-on-flat, low-speed sliding, 39.2 N (4 kgf) load
27. B. Bhushan and B.K. Gupta, *Handbook of Tribology,* McGraw-Hill, 1991, Table 14.16a; pin-on-disk, 12 N (1.2 kgf) load, 14 to 16 cm/s (0.55 to 0.63 in./s) velocity
28. B. Bhushan and B.K. Gupta, *Handbook of Tribology,* McGraw-Hill, 1991, Table 14.65; pin-on-disk, 5 N (0.5 kgf) load, 1.0 cm/s (0.39 in./s) velocity, 50% relative humidity
29. B. Bhushan and B.K. Gupta, *Handbook of Tribology,* McGraw-Hill, 1991, Table 14.12; Amsler disk machine, 400 rev/min, 250 N (26 kgf) load
30. F.P. Bowden and D. Tabor, Appendix IV, *The Friction and Lubrication of Solids,* Oxford Press, 1986; method unspecified
31. J.K.A. Amuzu, B.J. Briscoe, and M.M. Chaudhri, *J. Phys. D, Appl. Phys.,* Vol 9, 1976, p 133; reciprocating, single-crystal flat sliding on smooth fired glass surfaces, range 5 to 20 gf (0.049 to 0.1962 N load), 0.20 mm/s (0.008 in./s) velocity
32. "Friction Data Guide" General Magnaplate Corporation, 1988; TMI Model 98-5 slip and friction tester, 1.96 N (0.200 kgf) load, ground specimens, 54% relative humidity, average of five tests
33. P.K. Gupta, *J. Am. Ceram. Soc.,* Vol 74 (No. 7), 1991, p 1692; strand lying on a rotating drum, 1.96 N (0.200 kgf) load, 8.5 mm/s (0.33 in./s) velocity
34. M.J. Manjoine, *Bearing and Seal Design in Nuclear Power Machinery,* American Society of Mechanical Engineers, 1967; flat plate-on-flat plate, 28 MPa (4.1 ksi) contact pressure, 0.25 mm/s (0.010 in./s) velocity
35. F.P Bowden and D. Tabor, *The Friction and Lubrication of Solids,* Oxford Press, 1986; unspecified method, 4.0 m/s (790 ft/min) at 0 °C

References

REFERENCES/TEST CONDITIONS (Table 1 Friction coefficient data for metals sliding on metals)

1. E. Rabinowicz, *ASLE Trans.,* Vol 14, 1971, p 198; plate sliding on plate at 50% relative humidity

2. "Friction Data Guide," General Magnaplate Corporation, 1988; TMI Model 98-5 slip and friction tester, 1.96 N (0.200 kgf) load, ground specimens, 54% relative humidity, average of five tests
3. J.F. Archard, *ASME Wear Control Handbook,* M.B. Peterson and W.O. Winer, Ed., American Society of Mechanical Engineers, 1980, p 38; pin-on-rotating ring, 3.9 N (0.40 kgf) load, 1.8 m/s (350 ft/min) velocity
4. A.W. Ruff, L.K. Ives, and W.A. Glaeser, *Fundamentals of Friction and Wear of Materials,* ASM International, 1981, p 235; flat block-on-rotating 35 mm ($1\frac{3}{8}$ in.) diameter ring, 10 N (1.02 kgf) load, 0.2 m/s (40 ft/min) velocity
5. F.P. Bowden and D. Tabor, *The Friction and Lubrication of Solids,* Oxford Press, 1986, p 127; sphere-on-flat, unspecified load and velocity
6. P.J. Blau and C.E. DeVore, *Tribol. Int.,* Vol 23 (No. 4), 1990, p 226; reciprocating ball-on-flat, 10 Hz, 25 N (2.6 kgf) load, 10 mm stroke
7. P.J. Blau, *J. Tribology,* Vol 107, 1985, p 483; flat block-on-rotating 35 mm ($1\frac{3}{8}$ in.) diameter ring, 133 N (13.6 kgf) load, 5.0 cm/s (2.0 in./s) velocity
8. K.G. Budinski, *Proceedings of Wear of Materials,* American Society of Mechanical Engineers, 1991, p 289; modified ASTM G 98 galling test procedure

REFERENCES/TEST CONDITIONS (Table 2 Friction coefficient data for ceramics sliding on various materials)

9. K. Demizu, R. Wadabayashim, and H. Ishigaki, *Tribol. Trans.,* Vol 33 (No. 4), 1990, p 505; 1.5 mm (0.060 in.) radius pin reciprocating on a flat, 4 N (0.4 kgf) load, 0.17 mm/s (0.0067 in./s) velocity, 50% relative humidity
10. P.J. Blau, Oak Ridge National Laboratory
11. P.J. Blau, Oak Ridge National Laboratory, 1.0 N (0.10 kgf) load and 0.1 m/s (20 ft/min) velocity
12. P.J. Blau, Oak Ridge National Laboratory, 10 N (1.0 kgf) load and 0.1 m/s (20 ft/min) velocity
13. C.S. Yust, *Tribology of Composite Materials,* P.K. Rohatgi, P.J. Blau, and C.S. Yust, Ed., ASM International, 1990, p 27; 9.5 mm ($\frac{3}{8}$ in.) diameter sphere-on-disk, 2 to 9 N (0.2 to 0.9 kgf) load, 0.3 m/s (60 ft/min) velocity
14. B. Bhushan and B.K. Gupta, table in *Handbook of Tribology,* Mc-Graw-Hill, 1991; 20 N (2.0 kgf), 3 mm/s (0.12 in./s) velocity
15. "Friction Data Guide," General Magnaplate Corporation, 1988; TMI Model 98-5 slip and friction tester, 1.96 N (0.200 kgf) load, ground specimens, 54% relative humidity, average of five tests

REFERENCES/TEST CONDITIONS (Table 3 Friction coefficient data for polymers sliding on various materials)

16. "Lubricomp(R) Internally-Lubricated Reinforced Thermoplastics and Fluoropolymer Composites," Bulletin 254-688, ICI Advanced Materials; thrust washer apparatus, 0.28 MPa (40 psi), 0.25 m/s (50 ft/min), after running-in for one full rotation
17. F.P. Bowden and D. Tabor, Appendix IV, *The Friction and Lubrication of Solids,* Oxford Press, 1986; unspecified testing conditions
18. "Friction Data Guide," General Magnaplate Corporation, 1988; TMI Model 98-5 slip and friction tester, 1.96 N (0.200 kgf) load, ground specimens, 54% relative humidity, average of five tests
19. J.M. Thorp, *Tribol. Int.,* Vol 15 (No. 2), 1982, p 69; three-pin-on-rotating disk apparatus, 0.1 m/s (20 ft/min)
20. J.W.M. Mens and A.W.J. de Gee, *Wear,* Vol 149, 1991, p 255; flat block-on-rotating ring, 1.5 MPa (0.22 ksi) pressure, 150 N (15 kgf) load, 0.1 m/s (20 ft/min) velocity
21. R.P. Steijn, *Metall. Eng. Quart.,* Vol 7, 1967, p 9; 12.7 mm (0.500 in.) diameter ball-on-flat, 9.8 N (1.0 kgf) load, 0.01 mm/s (4×10^{-4} in./s) velocity
22. N.P. Suh, *Tribophysics,* Prentice-Hall, 1986, p 226; pin-on-disk, 4.4 N (0.45 kgf) load, 3.3 cm/s (1.3 in./s) velocity, 65% relative humidity

REFERENCES/TEST CONDITIONS (Table 4 Friction coefficient data for coatings sliding on various materials)

23. "Friction Data Guide," General Magnaplate Corporation, 1988; TMI Model 98-5 slip and friction tester, 1.96 N (0.200 kgf) load, ground specimens, 54% relative humidity, average of five tests
24. M. Antler and E.T. Ratcliff, *Proceedings of the Holm Conference on Electrical Contacts,* 1982, p 19; sphere-on-reciprocating flat, 0.49 N (0.050 kgf) load, 1.0 mm/s (0.039 in./s) velocity
25. M.J. Manjoine, *Bearing and Seal Design in Nuclear Power Machinery,* American Society of Mechanical Engineers, 1967; flat plate-on-flat plate, 28 MPa (4.1 ksi) contact pressure, 0.25 mm/s (0.010 in./s) velocity
26. F.P. Bowden and D. Tabor, *The Friction and Lubrication of Solids,* Oxford Press, 1986, p 127; sphere-on-flat, low-speed sliding, 39.2 N (4 kgf) load
27. B. Bhushan and B.K. Gupta, *Handbook of Tribology,* McGraw-Hill, 1991, Table 14.16a; pin-on-disk, 12 N (1.2 kgf) load, 14 to 16 cm/s (0.55 to 0.63 in./s) velocity
28. B. Bhushan and B.K. Gupta, *Handbook of Tribology,* McGraw-Hill, 1991, Table 14.65; pin-on-disk, 5 N (0.5 kgf) load, 1.0 cm/s (0.39 in./s) velocity, 50% relative humidity
29. B. Bhushan and B.K. Gupta, *Handbook of Tribology,* McGraw-Hill, 1991, Table 14.12; Amsler disk machine, 400 rev/min, 250 N (26 kgf) load

REFERENCES/TEST CONDITIONS (Table 5 Friction coefficient data for miscellaneous materials)

30. F.P. Bowden and D. Tabor, Appendix IV, *The Friction and Lubrication of Solids,* Oxford Press, 1986; method unspecified
31. J.K.A. Amuzu, B.J. Briscoe, and M.M. Chaudhri, *J. Phys. D, Appl. Phys.,* Vol 9, 1976, p 133; reciprocating, single-crystal flat sliding on smooth fired glass surfaces, range 5 to 20 gf (0.049 to 0.1962 N load), 0.20 mm/s (0.008 in./s) velocity
32. "Friction Data Guide" General Magnaplate Corporation, 1988; TMI Model 98-5 slip and friction tester, 1.96 N (0.200 kgf) load, ground specimens, 54% relative humidity, average of five tests
33. P.K. Gupta, *J. Am. Ceram. Soc.,* Vol 74 (No. 7), 1991, p 1692; strand lying on a rotating drum, 1.96 N (0.200 kgf) load, 8.5 mm/s (0.33 in./s) velocity
34. M.J. Manjoine, *Bearing and Seal Design in Nuclear Power Machinery,* American Society of Mechanical Engineers, 1967; flat plate-on-flat plate, 28 MPa (4.1 ksi) contact pressure, 0.25 mm/s (0.010 in./s) velocity
35. F.P Bowden and D. Tabor, *The Friction and Lubrication of Solids,* Oxford Press, 1986; unspecified method, 4.0 m/s (790 ft/min) at 0 °C