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Special Report 80-28

July 1980

ICE ADHESION TESTS ON COATINGS SUBJECTED TO RAIN EROSION

L. David Minsk

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Screening tests to select icephobic coatings displaying low ice release forces, both before and after exposure to rain erosion in a whirling arm simulator, were performed on approximately 60 commercial materials. A unique linear ball-slide shear test apparatus was designed to provide pure shear forces. No coating survived the erosion test to give an interfacial shear strength as low as 15 psi (103 kPa), an arbitrarily established goal. Several coatings showed shear strengths between 30 and 45 psi (207 and 310 kPa) after rain erosion.

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PREFACE

This report was prepared by L. David Minsk, Research Physical Scientist, Applied Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. This investigation was funded jointly by the Applied Technology Laboratory, U.S. Army Research and Technology Laboratories, AVRADCOM, Fort Eustis, Virginia, and by the U.S. Air Force Flight Dynamics Laboratory, Wright Aeronautical Center, Wright-Patterson AFB, Ohio.

The report was technically reviewed by Dr. George Ashton and Gunars Abele of CRREL. Glenn Durrell and Alan Saracina assisted in performing the ice shear tests and in preparing specimens.

The contents of this report are not to be used for advertising or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products.

ICE ADHESION TESTS ON COATINGS SUBJECTED TO RAIN EROSION

by

L.D. Minsk

INTRODUCTION

Ice accretion on airfoils seriously interferes with aerodynamic performance, and in the case of helicopter rotor blades asymmetric shedding can cause severe, and sometimes catastrophic, vibration or power loss. Heated surfaces have been developed as a method of controlling ice accretions*, but the weight penalty for either utility helicopters (such as the UH-1H) or the cruise missile has fostered a search for a passive coating which will exhibit low adhesion to ice and which will survive the surface erosion resulting from raindrop impaction. Nearly 100 commercially available coatings, offered by industry in response to a CRREL survey, were screened for low ice release force on a pristine surface, followed by subjection of the most promising materials to exposure in the rain erosion simulator at the Air Force Materials Laboratory at the Wright Aeronautical Center. The goal was to find a material which would exhibit an interfacial shear stress of 15 psi (103 kPa) after rain erosion; this value was somewhat arbitrarily chosen as the mean of surface shear forces resulting from centrifugal and viscous drag forces.

DESCRIPTION OF TEST

Apparatus. A number of laboratories have conducted tests to determine the strength of adhesion of ice to various surfaces. These tests generally apply a shear force to ice specimens frozen onto the test surface within a mold. Unless the specimen mold is constrained to move parallel to the test surface, tensile forces can develop that prevent a pure shear failure, affecting reproducibility of the test and contributing to wide scattering of the data. To ensure pure shear failure, a unique device developed at CRREL by Larry Gould of the Technical Services Division was used in the work reported here. It consists of a Lexan mold mounted on the underside of a plate attached to the upper surface of a linear ball slide (Yankee ball slide model Y3-30, Design Components, Medfield, Massachusetts 02052). The mold is positioned directly above the 2-in.^{2} (12.9-cm^2) test specimen, and separated from it by a gap of about 0.08 in. (2 mm) (Fig. 1). The force applied to a load block along the ice/substrate interface is measured by a load cell (Interface SM-250 or SM-50) whose output is fed to a strip chart recorder.

Test specimen. The aluminum test block was dimensioned to meet the

* Werner, J.B. (1975) The development of an advanced anti-wing/deicing capability for U.S. Army helicopters. Vol. II. Ice protection system application to the UH-1H helicopter. USAAMRDL-TR-75-34B. Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia. AD A019049.

requirements for mounting on the whirling arm of the Air Force Materials Laboratory rain erosion simulator*. Block dimensions are 2.435 in. (6.185 cm) base length, 1 in. (2.54 cm) width, and a test surface area of 2 in.^{2} (12.9 cm^2). A hollow was milled in the base to reduce mass. The test surface was machine-finished with an end mill, and a uniform reproducible surface was obtained by sandblasting with an S.S. White Industrial Abrasive Unit Model C, using 50-μm aluminum oxide abrasive powder (White no. 3). The Lexan mold was milled to leave a 2-mm (0.08-in.) lip around the periphery, and a hole was provided on the upper surface for addition of water.

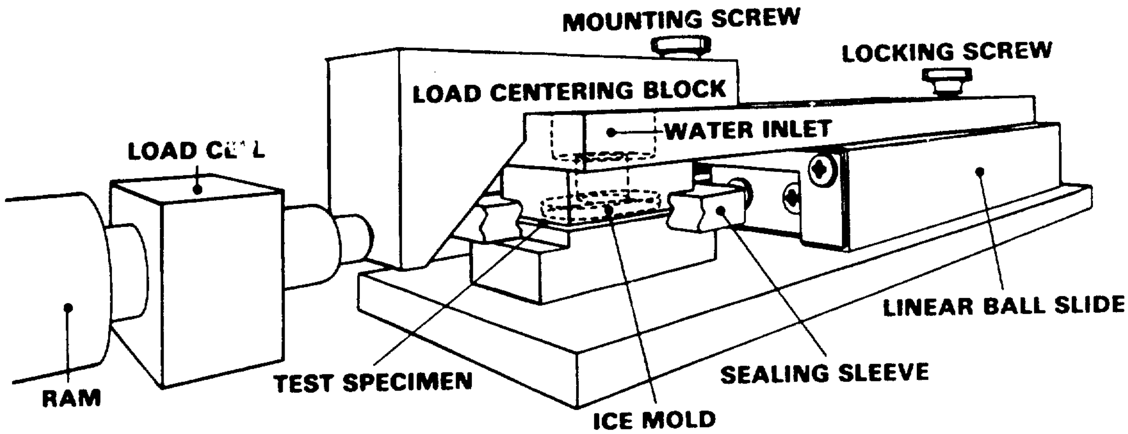

Figure 1. Shear test apparatus.

Sample preparation. The freshly abraded surface of an aluminum specimen was washed with detergent to remove the fine abrasive powder, wiped dry, and then wiped with toluene immediately prior to application of the test coating. Application can be accomplished by spray, wipe, or brush methods, depending on the form of the material; coatings too viscous for spraying were applied by brush in these tests. All specimens with the test coatings were placed in a dust-free enclosure until removed to the coldroom for mounting on the shear test apparatus (Fig. 2).

Test procedure. The aluminum specimen block was mounted on the base plate of the shear test apparatus with two machine screws; the Lexan mold was mounted on the top (sliding) plate with two machine screws. The mold was positioned directly above the specimen, and a silicone rubber gasket (pre-positioned on the mold) was slid over the opening between the two parts to prevent water leakage. The slider was locked with a set screw and the entire apparatus was allowed to stabilize at coldroom temperature (-10°C for all tests reported here). Following this, deaired, distilled water at

* Hurley, C.J. and G.F. Schmitt, Jr. (1970) Development and calibration of a Mach 1.2 rain erosion test apparatus. Technical Report AFML-TR-70-240, Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio.

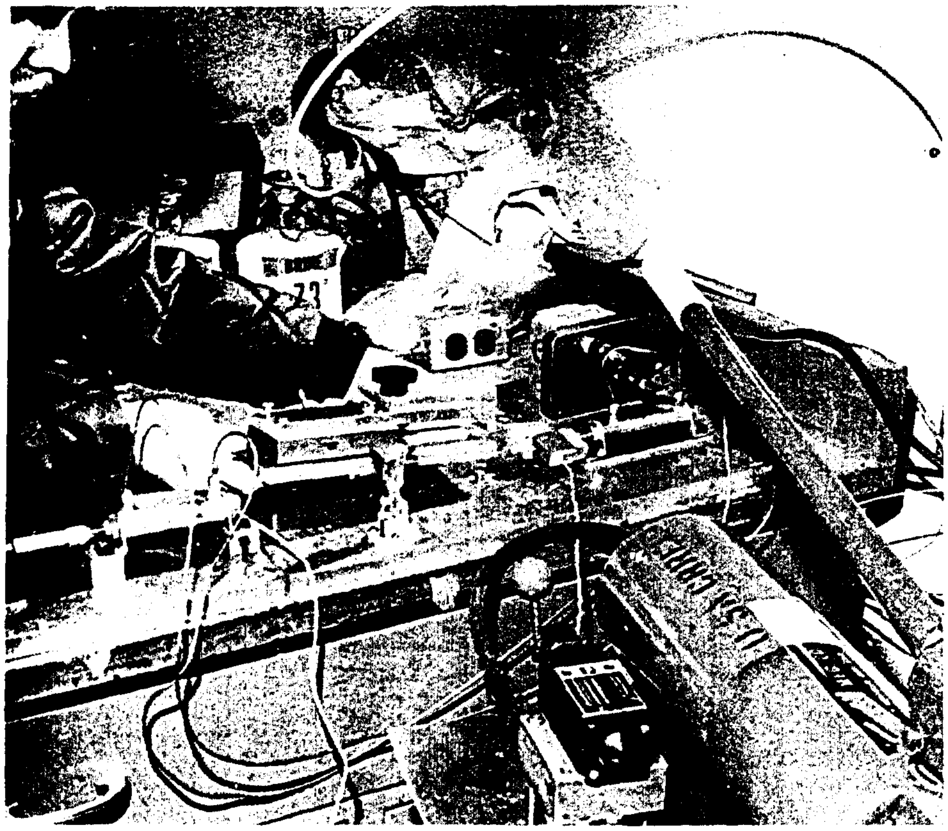

Figure 2. Placing the shear test apparatus on the load application fixture; hydraulic cylinder and strain gauge are to the immediate right of the slide. A separate fixture with hydraulic cylinder and strain gauge, partially visible at left below the technician's hand, was designed for conducting shear tests on flat plates.

room temperature was poured through the holes in both the top plate and the Lexan mold, and the apparatus was tilted slightly in a rolling motion to allow any air trapped in the 1- to 2-mm gap between the specimen and the mold to escape. Sufficient water was added to ensure complete coverage of the test surface, and, if necessary, additional water was added to bring the ice level to the top of the mold. Generally, specimens were prepared in the afternoon and tested the following morning. The frozen specimen in its slide support was carefully placed on the indexing pins of the shear test apparatus, a fixture mounted on the top plate to permit load application in line with the ice/substrate interface, and a hydraulic cylinder was actuated to drive the load cell against the slider. Output was read on a strip chart recorder. Cylinder travel speed was controlled by a flow-control valve (Sperry Vickers Model FCG) and was adjusted for a speed of 0.1 in./s (0.25 cm/s).

Rain erosion. Specimens in most tests were exposed for 10 minutes at a speed of 500 mph (805 km/hr) to rainfall at a rate of 1 in./hr (2.54 cm/hr), with a median droplet size of 1.8 mm (0.071 in.). Most coatings failed this severe condition; therefore one group of specimens was exposed to a 300-mph (483-km/hr) speed for 5 minutes. This group of tests was not considered valid, however, since the rain erosion simulator had been calibrated for droplet impaction conditions occurring at 500 mph, and it was not known how many of the droplets actually struck the specimen at the lower speed. Nonetheless, the ice release forces measured at the lower speed were tabulated in the results.

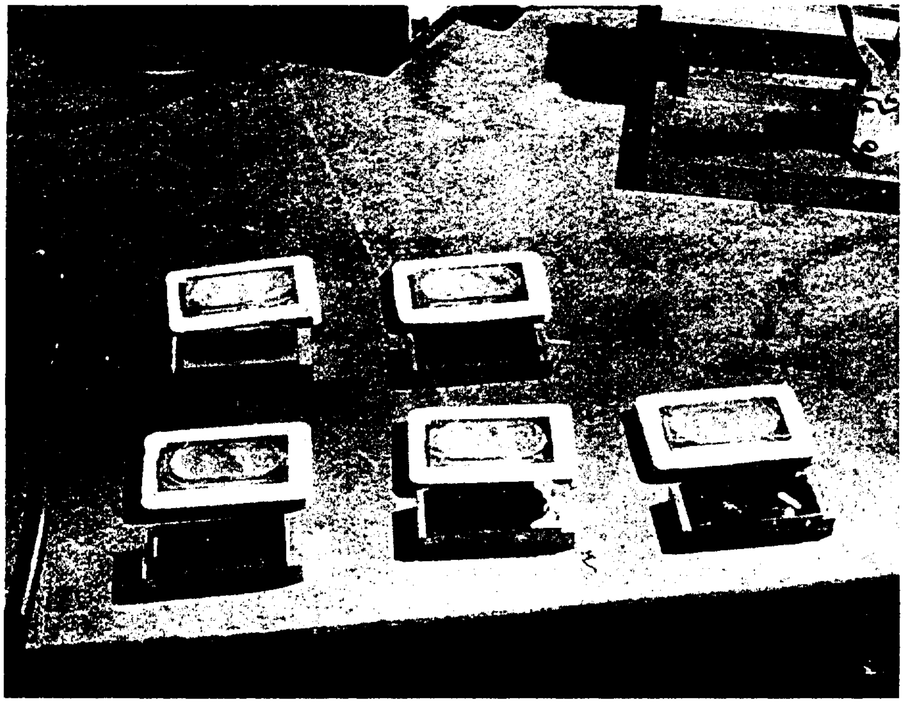

Figure 3. Appearance of test specimens following ice release. Adhesive failures left a clean surface; high energy surfaces (those to which ice bonded strongly) failed partially cohesively, exemplified by the specimen in lower center on which some ice can be seen.

EXPERIMENTAL RESULTS

Two replicates of each test surface were run for both the pristine coatings and for those that were subjected to the rain erosion test. This small number did not permit any valid statistical tests of dispersion, but were justified on the grounds that a large number of candidate coatings needed to be screened and a selection made in a rather short time for three or four coatings to be used on in-flight tests. The ice release values, expressed as shear stress in psi, are presented in Table 1. Ice did not break cleanly from all test surfaces; some specimens exhibited cohesional failure, with a portion of the ice remaining on the surface. These are indicated by a listing of the proportion of the surface remaining ice-covered in the columns titled "Ice Residue" in Table 1. Figure 3 shows typical ice failures, with ice residues visible in the two specimens at the lower right.

Table 1. Ice release shear stress values for new and rain-eroded icephobic coatings.

Coating	Shear stress new (psi)	300 mph, erosion Shear stress (psi)	300 mph, erosion Ice residue	500 mph, erosion Trial 1 Shear stress (psi)	500 mph, erosion Trial 2 Shear stress (psi)	500 mph, erosion Trial 2 Ice residue
Allied Chemical CM-1	>19					
Armstrong E-72300-3N	< 1	43	1/3	65		
Carborundum Dilectrix	51	54	1/8			
Contour XA-1876	< 1					
Cramolin Carbo Spray	53					
Cramolin Plastik	78					
Dexter 0709-A05M	< 1	68	1/8	81*		
Dexter 0709 Micolon	>19					
Dow Corning E-2460-40-1	< 1	44	1/2	60		
Dow Corning E-3382-100	< 1	55	1/4	52		
Dow Corning R-4-3117	1			80*		
Dow Corning 09-6500MST	1.5	54	1/8	57		
Du Pont Vydax AR	68					
Du Pont Vydax 550	75					
Easton STST	40					
GE G661	1			44		
GE G666	3					
GE G671	2			78		
GE 117-8441-B	< 1	69		42		
GE 117-8499	< 1			81*		
GE 124-5964	45					
GE RTV 158	15			45	22	1/8
GE RTV 619		20	1/4		28	1/8
GE SS 4044	50*					
GE SS 4124	50*					
GE SS 4191	30					
GE Viscasil 100,000	< 1					
General PG 405	< 1	65	1/10	83*		
Greenchem MR 218	< 1					
Greenchem MR 515	< 1					
Groendyk 8604	11					
Kantstik LM	45					
Kro-Lon	10					
MES-5	47					
Meyer Sno-Flo	47					
M & H 1604	50					
Miller-Stephenson MS 122	43					
Miller-Stephenson MS 136	57					
Peterson TFE #4	50					
Phillips Ryton PR-01	> 9	53	1/8			
RAE 127L	< 1	63	1/3	55		
Repcon	25					
Rilsan Nylon 11	17					
Rilsan RDP-21	< 1					
Seize-no-More	< 1			81*		
StanChem 85X-162	8	45	1/3	32		
Sterling Astrocoat 7100	>18					
SWS 951	2					
SWS Silgan H-621	1					
SWS Silgan H-622	1	54	1/3			
SWS Silgan J-500	2	< 1		46	23	clean
SWS Silgan J-501	28					
3M SJ-8581	54	48	1/8	31		
Tuf-lube Teflon	18					
Tullanox LC410	66					
Union Carbide Grafoil	48					
Vulkem Urethane #450	>19					
Xylan 1010	15					
Xylan 1014	< 1					
Xylan 1052	2					
Xylan 8450	< 1					
Bare metal (Aluminum)	81*					

*No release.

Supplementing this information is a table of important properties of the materials tested (Appendix A) and a list of the manufacturers (Appendix B).

RECOMMENDATIONS

Coatings recommended for further laboratory and field evaluation are:

General Electric 117-8441-B
General Electric RTV 158
General Electic RTV 619
SWS Silgan J-500
StanChem 85X-162
3M SJ-8581

Several other coatings with higher shear strength values are recommended for further testing with a larger number of replicates in order to obtain statistically significant values. These include:

Dow Corning E-2460-40-1
Dow Corning E-3382-10C
Dow Corning 09-6500 MST
RAE 127L

All the icephobic coatings listed above, with two exceptions, are silicone-based polymers. The exceptions are RAE 127L, a wax paste, and 3M SJ-8581, a polyurethane tape. The polyurethane test results were unexpected; the rain-eroded surface displayed lower values of ice release shear strength than the fresh surface. Though this could be a real effect resulting from surface modification, such as cold flow under the peening action of droplet impact, more ice release tests and surface characterization should be undertaken.

APPENDIX A: PROPERTIES OF COATINGS TESTED

PRODUCT NAME	MANUFACTURER	FORM	COMPOSITION	VISCOSITY	PENETRATION	APPLICATION METHOD	DILUTION OF MIX	DILUENTS (SOLVENTS)	CURE	FLASH POINT
CM-1	Allied Chemical Company	Powder coating	Hexafluoro iso-butylene-vinylidene fluoride copolymer			Powder coating				Non-flam-mable
ATI-Kote 550	American Technical Industries	Liq.	2-part aliphatic polyurethane			Brush, spray, roller	4 polyol, 1 isocy-anate	Phosphoric acid (10%), methylene chloride	hard 24 hr, fully cured 7 days,	100F (38C)
E-72300-3S	Armstrong Products Co.	Coated plate	Epoxy			Dip, spray		Acetone		
Cramolin 'R'	Caig Laboratories Inc.	Liq.	Cramolin (red) fluid, Freon TF	.694 cp		Spray		Trichloro-trifluoro-ethane	None	182°C
Cramolin Plastik	Caig Laboratories Inc.	Liq.	59% trichlorotri-fluoroethane, 41% acrylic resin			Spray		Trichloro-trifluoro-ethane		180°C
Cramolin Graphite	Caig Laboratories Inc.	Liq.	Graphite			Spray				
XA-1876	Contour Chemical Company	Liq.								
Acrothane White 975-W-426	Cook Paint and Varnish Co.	Paint	Acrylic urethane enamel, 2-part			Spray, brush	4A:1B	Reducer 255-C-157	4 hrs (open air)	45°F
6709-A05M Cockbottom Black 4109-W02M Micolon IV-W black	Dexter Corporation	Coated plate								
Dilectrix	Dilectrix Corp.	Sheet	Teflon TFE	None			None	None		None

PRODUCT NAME	MANUFACTURER	FORM	COMPOSITION	VISCOSITY	PENETRATION	APPLICATION METHOD	DILUTION OR MIX	DILUENTS (SOLVENTS)	CURE	FLASH POINT
117-8499-B	General Electric Co.	Grease	Silica-thickened trifluoropropyl-methyl polysiloxane		250-300	Spray		MEK, acetone; chlorinated solvents fairly good, aromatics only fair		None
117-8441-B	General Electric Co.	Liq.	Cyanoethanol silicone and dimethyl silicone			Brush, wipe, spray	None	Toluene and acetone	None	None
SS419 (SS4192C) catalyst and SS45259C accelerator)	General Electric Co.	Liq.	Toluene soln of a curable dimethyl polysiloxane			Brush, wipe	1:3 silicone: diluent	Toluene, ketones, heptane, xylene, chlorinated hydrocarbons		
124-5964	General Electric Co.	Liq.	30% cationic emulsion of special silicone fluid			Wipe, brush	None or 1:1	Water		None
SS4290	General Electric Co.	Liq.	Silicone release							
Viscasil 100,000	General Electric Co.	Liq.	Polydimethyl-siloxane	100,000 cs		Brush, wipe				P-M closed-cup, 500F (260C)
GE 697	General Electric Co.	Grease	Polydimethyl-siloxane		260-320	Brush, spray, dip		1,1,1, tri-chloroethane, mineral spirits	None	None
RTV 619	General Electric Co.	Paste	Silicone	500 cps		Spray, brush, dip		Naphtha, methylethyl ketone, tri-chloroethylene	1-2 day at 25°C 15 min at 150°C	None
Tufram PG 405	General Magnaplate	Coated plate	not stated							
MR 218 MR 515	Greenchem Products	Liq. Liq.	Silicone			Spray, brush wipe			1 min (open air)	

PRODUCT NAME	MANUFACTURER	FORM	COMPOSITION	VISCOSITY	PENETRATION	APPLICATION METHOD	DILUTION OR MIX	DILUENTS (SOLVENTS)	CURE	FLASH POINT
R-4-3117	Dow Corning	Liq.	Silicone resin			Spray, dip, brush, flow	40% solids soln	Cellosolve acetate	24 hr @ 77F (25C) 50% RH; 30 m @ 168F (75C)	
E-2460-40-1	Dow Corning	Liq.	Cationic silicone oil							
E-3382-100	Dow Corning	Liq.	2-part cationic silicone oil							
09-6500 MST	Dow Corning	Liq.								
DC 5 compound	Dow Corning	Paste	Silicone		210-230	Brush, wipe			None	None
Vydax 550	E.I. du Pont de Nemours & Co.	Liq.	Fluorotelomer dispersion in Freon TF			Spray				
Vydax AR	duPont	Liq.	Fluorotelomer							
STST	Easton R.S. Corp.	Paste	Hard and soft waxes emulsified in water with small amt. HMW silicone oil and phosphate ester			Spray, wipe	None			
Betacote 91	Essex Chemical Corp.	Liq.	Urethane	45-55		Brush, spray			4-6 hrs	
G 661	General Electric Co.	Paste	Silica-filled polydimethyl siloxane fluid		200-300	Brush, wipe, trowel (spray diluted soln)	1:1 (spray)	Non-polar, e.g. toluene	None (grease)	N.A.
RTV 158	General Electric Co.	Paste	Acetoxy-cure silicone		N.A.	Wipe or brush	10% soln	hexane	12 hr @ 25C (77F) 50% RH	250C (400F) TAG closed cup
G 671	General Electric Co.	Grease	Mica-filled silica-thickened methyl alkyl silicone		250-300	Brush, wipe, trowel (spray diluted soln)	1:1 (spray)	Non-polar or chlorinated, e.g., hexane; also aromatics. No polar solvents, no MEK.	None	None

PRODUCT NAME	MANUFACTURER	FORM	COMPOSITION	VISCOSITY	PENETRATION	APPLICATION METHOD	DILUTION OR MIX	DILUENTS (SOLVENTS)	CURE	FLASH POINT
8604 Rubber	Groendyk	Sheet	Silicone rubber, 60 durometer							
Vulkem 450	The Master Mechanics Co.	Coated plate	Modified polyurethane rubber			Spray, squeegee, roller, brush, trowel	None			
1604 Ice repellent	m&h Laboratories, Inc.	Liq.	Silicone			Spray				
Sno-Flo	Meyer Products Co.	Paint				Brush, spray	None			
MS-122	Miller-Stephenson Chemical Co.	Liq.	Contains Vydax AR			Spray	None			None
MS-136	Miller-Stephenson Chemical Co.	Liq.	Contains Vydax AR			Spray	None			None
MS-S-143	Miller-Stephenson Chemical Co.		Fluorocarbon			Brush, spray, dip			Fast drying	Non-flammable
TFE no. 4	Peterson Chemical Corp.		2-part epoxy with Teflon particles			Brush, roller spray	mix 1:1 A:B		7 days @ 70F (21C) 40 min @ 150F (66C)	
Ryton PR-01	Phillips Chemical	Coated plate	Polyphenylene sulfide			Spray			72 hrs at 315 C, 30 min at 455°C	
M.E.S. 5	Rever	Liq.				Spray				
RDP-21/Rilprim P-104	Rilsan Corp.	Coated plate	Polyamide							
Nylon 11	Rilsan Corp.		Polyamide				None	Mineral acids	None	

PRODUCT NAME	MANUFACTURER	FORM	COMPOSITION	VISCOSITY	PENETRATION	APPLICATION METHOD	DILUTION OR MIX	DILUENTS (SOLVENTS)	CURE	FLASH POINT
RAE 127L	Royal Aircraft Establishment		Gelled wax paste			Brush	None	Water	10 sec gel time	
Kant Stik LM	Specialty Products Co.		Mixture of fatty acid and esterified organic acid in aqueous soln			Brush, wipe, spray	None	Water		None
StanChem 85X-162 clear	StanChem, Inc.		Silicone, 42% solids	20-26 sec. Z_2 @ 77oF		Spray	5:1 diluent: silicone	MEK, butyl acetate, butyl alcohol, xylene, toluene or 1,1,1-trichloroethane	30 min @ 250F	105-110F TAG open cup
Astrocoat 7100	Sterling Lacquer Manufacturing Co.		Urethane			Spray, brush	25-50% Astrocoat thinner	85/15 methylethyl ketone/ dimethylformamide	45-60 min at 50% RH	
Seize-no-more	Stoner's Ink					Spray				
SWS 951	SWS Silicones Corp.		Silicone						7 days @ 77F (25C) 50% RH	
Silgan J-501	SWS Silicones Corp.		Silicone dispersion			Spray, dip, brush			24 hr @ 51°F 77F (25 C) 50% RH	
Silgan J-500	SWS Silicones Corp.		Silicone	300 poise		Spray, dip, brush			24 hrs	
Silgan H-622	SWS Silicones Corp.		2-part silicone polymer	15,000 cp		Flow	20:1,H622: CN by wt.		24 hr (7 days complete)	
Silgan H-621/ CN cat.	SWS Silicones Corp.		2-part silicone polymer	30,000 cp		Flow	20:1 CN catalyst		24 hrs	
SJ-8581	3M Company		Polyurethane film, 0.014" thick	NA	NA	tape	NA	NA	NA	NA

PRODUCT NAME	MANUFACTURER	FORM	COMPOSITION	VISCOSITY	PENETRATION	APPLICATION METHOD	DILUTION OR MIX	DILUENTS (SOLVENTS)	CURE	FLASH POINT
SJ-8561	3M Company	Sheet	Polyurethane tape							
Kro-Lon	TFB, Inc.	Coated plate	Chrome/Teflon			Electolytic plating				
Tullanox LC 410	Tulco, Inc.	Liq.	Fumed amorphous silica powder and organic silicone-like compound in liquid hydro-carbon							
Repcon rain repellent(for glass and plastic)	Unelko Corp.		Activated isomeric polymers			Wipe		Isopropyl alcohol	1 min	70F (21C)
Xylan 8450	Whitford Corp.	Coated plate	Fluorocarbon			Spray				
Xylan 1014		Coated plate	Fluorocarbon/ polyimide			Spray		ethyl acetate, dimethyl formamide	32-40 min @284-650F (140-344C)	
Xylan 1052		Coated plate	Fluorocarbon/ epoxy			Spray		ethyl acetate dimethyl forma-mide	(same)	
Xylan 1010		Coated plate	Fluorocarbon			Spray				
Xim Glid Air	Xim Products	Liq.				Spray				
Grafoil	Union Carbide Corp.	Sheet	Graphite							

APPENDIX B: MANUFACTURERS OF COATINGS TESTED

Allied Chemical Co.
P.O. Box 1057R
Morristown, NJ 07960
201-455-2000

American Technical Industries
P.O. Box 399
Stoughton, MA 02072
617-828-4480

Armstrong Products Company
P.O. Box 657
Warsaw, IN 46580
219-267-3226

Caig Laboratories
P.O. Box 64
Escondido, CA 92025
714-743-7143

Dilectrix Corporation
69 Allen Blvd.
Farmingdale, LI, NY 11735
516-249-6419

Contour Chemical Company
3 Draper Street
Woburn, MA 01801
617-935-5910

Cook Paint and Varnish
P.O. Box 389
Kansas City, MO 64141
816-471-4800

The Dexter Corporation
Midland Division
One Elm Street
Windsor Locks, CT 06096
203-623-9801

Dow Corning Corporation
Fluids and Lubricants Research
Midland, MI 48640
Mr. Joseph W.Keil
517-496-4407

E.I. du Pont de Nemours & Co., Inc.
Organic Chemical Department
Dyes and Chemicals Division
Wilmington, DE 19898
302-774-2421

Easton R.S. Corp.
4907 Farragut Road
Brooklyn, NY
212-629-0920

Essex Chemical Corporation
Jamestown Finishes Division
125 Blackstone Avenue
Jamestown, NY 14701
716-665-6313

Frekote Inc.
P.O. Box 825
Boca Raton, FL 33432
305-395-3083

General Electric Company
Silicone Products Department
Waterford, NY 12188
Mr. John H. Wright
518-237-3330

General Magnaplate Corporation
1331 U.S. Route 1
Linden, NJ 07036
201-862-6200

Greenchem Products
3035 Hartzell Street
Wilmette, IL 60091
312-251-0507

Groendyk Manufacturing Company
P.O. Box 276
Buchanan, VA 24066
703-254-1010

MAMECO International
4475 East 175th Street
Cleveland, OH 44128
216-752-4400

Meyer Products, Inc.
18513 Euclid Avenue
Cleveland, OH 44112
216-486-1313

M & H Laboratories
2705 Archer Ave.
Chicago, IL 60608
312-842-2132

Miller-Stephenson Chemical Co., Inc.
P.O. Box 950
Danbury, CT 06810
203-743-4447

Peterson Chemical Corporation
Box 191
Sheboygan, WI 53081
414-458-5555

Phillips Chemical Company
Plastics Technical Center
Bartlesville, OK 74004
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Rever Manufacturing Corp.
32470 Gratiot
Roseville, MI 48066

Royal Aircraft Establishment
Materials Department
Bldg. R.178
Farnborough, Herts, England
Mr. J. H. Sewell

Specialty Products
15 Exchange Place
Jersey City, NJ 07302
201-434-4700

StanChem Inc.
East Berlin, CT 06023
Frank E. Flood
203-828-0571

Sterling Lacquer Manufacturing Company
3150 Brannon Ave.
St. Louis, MO 63139
314-776-4450

Stoner's Ink
Quarryville, PA 17566
717-786-7355

SWS Silicones Corporation
P.O. Box 428
Adrian, MI 49221
517-263-5711

TFB, Inc.
1900 South Navajo Street
Denver, CO 80223
303-936-7101

3M Company
Industrial Specialties Division
St. Paul, MN 55101
Government Representative: D.B. Shepardson
1101-15th St., NW
Washington, DC 20005
202-331-6946

Tulco, Inc.
Talbot Mills Industrial Park
Faulkner Street
North Billerica, MA 01862
617-667-9686

Unelko Corporation
727 E. 110th St.
Chicago, IL 60628
312-468-1700

Union Carbide Corporation
230 Park Avenue
New York, NY 10017
212-551-2345

Whitford Corporation
West Chester, PA 19380
215-436-0600