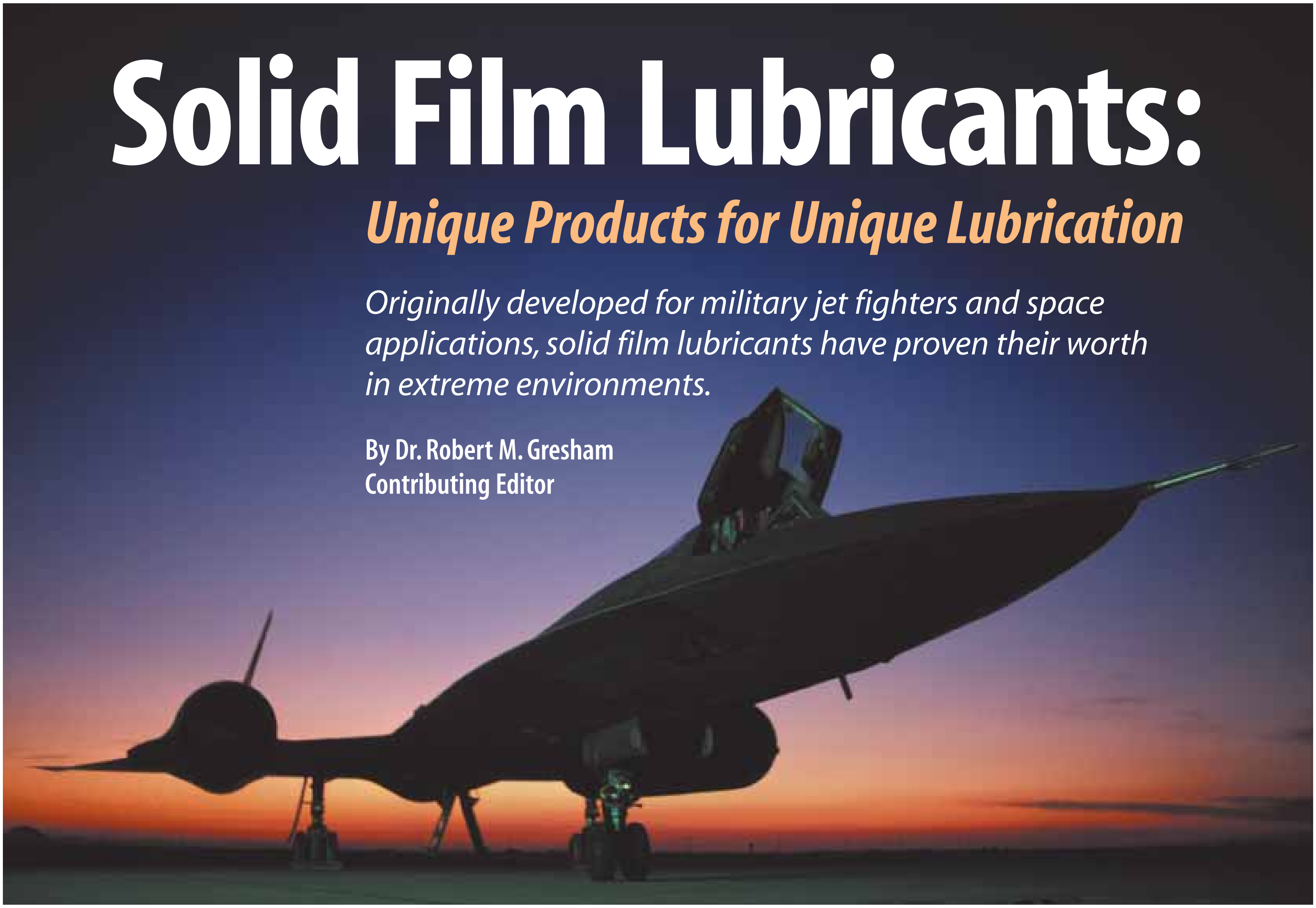

Solid Film Lubricants:

Unique Products for Unique Lubrication

Originally developed for military jet fighters and space applications, solid film lubricants have proven their worth in extreme environments.

By Dr. Robert M. Gresham
Contributing Editor

Solid film lubricants are solid materials with inherent lubricating properties firmly bonded to the surface of substrate. They might be termed "slippery paint."

However, this description does not begin to describe the diversity of products and processes that have evolved over the years. For example, bonding methods include resin bonding, burnishing, sputtering ion deposition, and mechanical impingement.

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From a commercial standpoint, over 95 percent of the solid-film lubricants in use today are resin-bonded. Typical formulations for resin-bonded solid-film lubricants include a lubricating pigment, binder, solvent and additives to improve other properties such as corrosion resistance, aesthetics, etc.

Solid film lubricants are used where conventional lubricants will not do the job. Most commonly, solid film lubricants are found where the environments are extreme or where boundary lubrication is an important property, such as with threaded fasteners, the largest single commercial application.

In many commercial applications using solid film lubricants, other properties, especially corrosion or chemical resistance, can have equal or greater importance compared to lubrication. We will examine formulation considerations, application techniques and typical performance properties.

PIGMENT SELECTION

The primary role of the insoluble solid pigment is lubrication. A wide variety of solid materials with inherent lubricating capability are available for use in solid film lubricants. Generally, this lubricating capability is a result of the inherent crystal structure of the lubricating pigment. The most commonly used are molybdenum disulfide, graphite and polytetrafluoroethylene.

While these are the most common, we also see such materials as tungsten disulfide, boron nitride, antimony oxide, niobium selenide, tin, silver, indium, fluorinated ethylene propylene (FEP), perfluoroalkoxy copolymer (PFA), etc.

The selection of the proper pigment or pigment combination is generally governed by the performance that the solid film lubricant formulation must deliver. No one formulation can satisfy all of the requirements on a cost-effective basis.

Properties that should be considered are coefficient of friction, load-carrying capacity, corrosion resistance (susceptibility to galvanic corrosion), and electrical conductivity. Further, one must consider the environment in which the solid film lubricant must perform. Environmental factors include temperature, pressure, humidity, oxygen content, radiation, etc.

Each of the above solid-lubricant materials has strengths and weaknesses in each area and corresponding compromises must be made. Molybdenum disulfide generally has the highest load-carrying capability with a corresponding low coefficient of friction. However, in an oxidative atmosphere in excess of 400 degrees Celsius. (750 degrees Fahrenheit), it begins to decompose.

Graphite has high-temperature capability in an oxidative environment but tends to promote galvanic corrosion and will not function in high vacuum. The fluorinated polymers such as PTFE generally exhibit a low coefficient of friction and are aesthetically quite suitable for formulations with colored pigments. However, the fluorinated polymers cannot sustain high loading nor do they have good radiation stability.

BINDER SELECTION

As with the pigments, a wide range of resins are available for use as binders or bonding agents in solid-film lubricant formulations. These resins carry names similar to the conventional paint resins, but they are generally of substantially different molecular weight and cross-linking capability.

Nevertheless, the organic bonding agents are divided into two types: A) air-dried, which include acrylics, alkyds, vinyls and acetates and B) thermosets, including phenolics, epoxyphenolics, silicones, epoxies, polyamide-imides, phenoxies, and urethanes. Inorganic bonding agents include silicates, phosphates and ceramics.

As with the lubricating pigment selection, the desired physical properties and environment must be considered when selecting the proper product.

In addition to the above-mentioned physical properties, solvent resistance, corrosion resistance and cure temperature should be considered. For example, the high temperature needed to cure some ceramics may have deleterious effect on the metallurgical properties of the substrate.

In general, the organic air-dry resins are less expensive to apply, are amendable to field application, and due to the low-cure temperature, have no deleterious effects on metallurgical properties. However, air-dry resin systems generally have much lower durability, wear life and solvent resistance.

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Table 1 – Properties of Common Lubricating Pigments

Pigment Capability (psi)	Color Stability	Load-Carrying Partical Size	Thermal Suitability	Typical Sensitivity	Vacuum	Moisture
Molybdenum Disulfide	Gray-Black	> 100,000	Good < 750° F	2-6 microns	Yes	Detrimental
Graphite	Gray-Black	< 50,000	Excellent < 1,200° F	2.5-10 microns	No	Necessary
Polytetra-fluoroethylene (PTFE)	White	< 6,000	Fair < 500° F	Sub-micron	Yes	No Effect

The oven-cured thermoset resins usually have outstanding durability, solvent resistance and wear life but, like all other organics, are subject to radiation damage, vacuum outgassing, limited high-temperature applicability and liquid oxygen incompatibility.

The inorganic binder systems generally have outstanding radiation resistance suitable for extremely high vacuum and high temperature and are compatible with liquid oxygen environments. However, these materials have limited wear life and durability and are often difficult to apply.

PIGMENT/BINDER RATIO

A major consideration in the formulation of solid-film lubricant products is the pigment/binder ratio or the amount of lubricating solids to resin solids. Again, the performance requirements and environment are of prime importance. Low pigment-to-binder ratio products have higher coefficients of friction, appear glossy, tend to be hard and durable and have excellent corrosion resistance.

High pigment-to-binder ratio products, on the other hand, generally have a low coefficient of friction, a dull soft powdery appearance and less corrosion resistance. Thus, the right pigment-to-binder ratio is necessary to achieve the optimum performance.

Table 2 – The Effect of Pretreatment on Wear Life

Pretreatment	LFW-1 Test ASTM D-2714 Cycles to Failure
None	Failure on Loading
Vapor Degrease/Sand Blast	20,000
Vapor Degrease/Sand Blast Phos.	672,000

Clearly, the preferred pretreatment of degreasing, sand blasting and phosphating provides the necessary base to achieve the ultimate performance of the solid-film lubricant.

SOLVENT SELECTION

Solvent selection is generally governed by the evaporation rate and solubility of the resin system. However, other factors must also be included such as flash point, evaporation rate, toxicity, EPA and OSHA regulations, shipping and storage considerations etc. Most modern solid film lubricants, due to the 1993 Clean Air Act, have been reformulated to utilize resins that can be dispersed in a water-based system. As a result, solvent based systems are used when no other alternative is available.

ADDITIVES

Finally, A additives also can be used in bonded solid-film lubricant formulations to enhance a variety of properties such as aesthetics, ease of application, corrosion resistance, etc. Such additives include dispersants, anti-settling agents, wetting agents, flow agents, corrosion inhibitors and colored pigments or dyes. Generally, these additives are similar to those typically used in the paint industry for similar purposes.

APPLICATION OF RESIN-BONDED PRODUCTS

Once the product has been selected for the desired application, the final step is to apply the product properly. Generally speaking, 80 percent of failures of solid-film lubricants are due to poor surface pretreatment or other misapplication. To demonstrate the importance of proper pretreatment, the comparison in Table 2 was performed.

Three identical Timken T54148 test races were coated with a commercially available phenolic-bonded molybdenum disulfide/graphite-containing product. Coating thicknesses, cure times and temperatures for all three races were identical. The tests were conducted on an LFW-1 test machine (ASTM D-2714) at 72 rpm and 630-Ib load, which corresponds to approximately 100,000 psi.

The only difference between the specimens, therefore, was the surface pretreatment. The first specimen was vapor degreased and coated with solid-film lubricant. The second was degreased and grit blasted with 220-mesh aluminum oxide before coating. The third was degreased, grit blasted and phosphated with a manganese phosphate conforming to DOD-P-16232 before coating.

Table 2 summarizes the results. While this example is specific for bearing steel in particular test, similar results are obtained on the wide variety of substrates, pretreatments and solid-film lubricants encountered in real applications.

METHODS OF APPLICATION

The methods of applying resin-bonded solid film lubricants are basically identical to those of other paint-like materials. However, resin-bonded solid film lubricants generally need a very tightly controlled film thickness.

Unlike conventional paints, the normal recommended thickness is in the range of 0.0002 in and 0.0005 in for optimum wear and lubrication performance. However, other performance factors can require compromise. For example, a thickness of 0.0005 in to 0.00020 in may be needed for optimum corrosion resistance.

The major factors which govern the selection of methods of application of solid film lubricants include the number of parts, size of parts, types of parts, film thickness, tolerance, functional areas to be coated, including masking and over-spray allowances.

Once these parameters have been defined, it can be determined whether the coating should be applied by conventional spray equipment, electrostatic spray, dipping, roll coating, brush coating, etc. Generally, spray application with multiple coats provides the best lubrication.

Performance properties of typical bonded solid film lubricants are listed in Table 3. While this table is by no means inclusive of all products commercially available, it provides insight into properties that can be expected. **<<**

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Table 3 – Performance Properties of Typical Solid-Film Lubricants

	ORGANIC						INORGANIC		
	THERMO SET				AIR DRY				
SPECIFICATION:	MIL-L-8937	MIL-L-46010			MIL-L-23398	MIL-L-46009	MIL-L81329	AMS2525A	AMS2526A
Composition:									
Lubricant	MoS_2	MoS_2/ Metallic Oxide	MoS_2/ Graphite	PTFE	MoS_2	MoS_2/ Graphite	MoS_2/ Graphite	Graphite	MoS_2
Binder	Phenolic	Epoxy	Silicone	Phenolic			Silicate	—	—
Application:	Spray	Spray	Spray	Spray	Spray	Aerosol	Spray		Impingement
Cure:	149°C	204°C	260°C	204°C	Ambient	Ambient	204°C	149°C	149°F
Compatibility:									
LOX	N/A	N/A	N/A	N/A	N/A	N/A	X	X	X
OZ	N/A	N/A	N/A	N/A	N/A	N/A	X	X	X
Rocket Fuel	X	N/A	L	N/A	N/A	N/A	L	X	X
Jet Fuel	X	X	X	X	X	L	X	X	X
Hydrocarbons	X	X	X	X	X	L	X	X	X
Solvents	X	X	X	X	X	L	X	X	X
Radiation:	Fair	N/A	N/A	N/A	N/A	—	V.G.	V.G.	V.G.
Operating Temp.									
Air (High)	260°C	260°C	371°C	260°C	176°C	204°C	649°C	+1093°C	400°C
Air (Low)	-220°C	-220°C	-157°F	-220°C	-220°C	-185°C	-240°C	-240°C	-220°C
Vacuum	10^{-4}Pa	10^{-7}Pa	10^{-7}Pa	N/A	N/A	N/A	10^{-5}Pa	10^{-7}Pa	10^{-7}Pa
Load Capacity[2]									
Force Test	2500 lbs. gage Falex	2500 lbs. gage Falex	2500 lbs. gage Falex	150 lb. LFW-1	2500 lbs. gage Falex	2500 lbs. gage Falex	— —	— —	— —
Wear Life[2]									
Load	1000 lbs. gage	1000 lbs. gage	1000 lbs. gage	150 lb.	1000 lbs. gage	—	1000 lbs. gage	50	50
Test	Falex	Falex	Falex	LFW-1	Falex		Falex	Falex	Falex
Time	60 min.	450 min.	60 min.	120,000	120 min.	—	70 min.	2 min.	5 min.
Coefficient of Friction	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Corrosion Resistance	G	V.G.	F	E	G	—	F	—	—

1) X = Compatible; L = Low; N/A = Not Applicable 2) Falex tests are all designed for English units and are, therefore, reported as such.