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LIGHT LOAD FRICTION COEFFICIENT
AND WEAR STUDY OF THREE BONDED
SOLID LUBRICANTS

Technological Spinoff Report

D. P. Pope, Project Leader

Project Team:
Guy Titsworth
Edward Swink

August 1974

Prepared for the
United States Atomic Energy Commission
Under Contract Number AT(29-1)-613 USAEC

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**Kansas City
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Printed in the United States of America

Available from the National Technical
Information Service, U. S. Department of
Commerce, 5285 Port Royal Road, Springfield,
Virginia 22151.

Price: Paper Copy \$4.00
Microfiche \$1.45

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LIGHT LOAD FRICTION COEFFICIENT AND WEAR STUDY OF THREE BONDED SOLID LUBRICANTS

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August 1974

Prepared by D. P. Pope, D/822

Light load coefficient and wear life data were compiled for Electrofilm 77S, 4396, and 4396S bonded dry film lubricants. Static and dynamic friction performance was studied using a tribometer specially designed to test bonded films. Mean and standard deviations were calculated for comparison. Electrofilm 77S, the data indicated, was better for light load applications.

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THE BENDIX CORPORATION

KANSAS CITY DIVISION

KANSAS CITY, MISSOURI

A prime contractor for the
Atomic Energy Commission

Contract Number AT(29-1)-613 USAEC

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SUMMARY

Bonded dry film lubricants 77-S, 4396-S, and 4396 marketed by the Electro-film Corporation were tested to determine their friction and wear characteristics at light load operating conditions. The data was obtained using a light-load tribometer designed at Bendix.

Samples coated with the lubricants were prepared identically. Static and dynamic friction coefficient data were obtained against rough and smooth rollers. Wear characteristics were obtained against the smooth rollers only.

Lubricant 77-S exhibited a lower static coefficient than the other lubricants. The static coefficient for all three lubricants was lower on the smooth rollers.

The dynamic friction coefficient for lubricant 77-S also tends to be lower than for the other two lubricants. All lubricants exhibited lower friction on the rough rollers.

Wear tests suggest lubricant 77-S has significantly less predictable wear characteristics than the other two lubricants.

Future work will include an investigation into the cause of the friction increases encountered during wear tests on smooth rollers. This study will be the subject of a future report.

DISCUSSION

SCOPE AND PURPOSE

Three commercially-marketed, bonded, thin film lubricants were tested for friction coefficient and wear life characteristics. The objective was to gather light load performance data that could be correlated to design requirements for Bendix's small precision electromechanical mechanisms.

The data was obtained using a tribometer especially designed at Bendix for testing bonded dry films under light load operating conditions.

ACTIVITY

Lubricants Tested

Electrofilm 77-S is a coating which contains moly-disulphide and graphite in a thermosetting resin that cures in one hour at 375°F (190.5°C). The manufacturer advertises that particular attention has been paid to new, high adhesion thermosetting resins, micron-size solid lubricants, milling techniques, and new plasticizers and solvents.

Electrofilm 4396 is an organic, thermosetting, resin-bonded solid film lubricant of approximately 90 percent molybdenum sulfide (MoSO_2) and 10 percent graphite by weight, cured at 350 to 375°F (176 to 191°C) for one hour. This lubricant is more frequently used at Bendix when the high cure temperature is permissible.

Electrofilm 4396-S is similar to 4396, but the clay suspending agents are omitted.

These three lubricants were selected for testing and comparison based on the initial finding of an earlier study, BDX-613-883.

Test Equipment Description

A tribometer was used to measure the friction and wear life characteristics during this lubricant evaluation (Figure 1). The tester consists of two rollers mounted on shafts driven by a variable speed motor through a spiral helical gear train. The rollers can rotate in the same or opposite direction. When using the tribometer, a bar coated with the test lubricant is placed on the rollers. The friction interface reaction comes solely from the force of the rollers against the bar (Figure 2).

Figure 1. Tribometer Used in Friction Testing

Figure 2. Schematic of Tribometer

Testing of Lubricants

Coefficient of Friction Testing

Samples for six test bar assemblies (Figure 3) were spray coated with each lubricant 0.0002 to 0.0005 inch (5.08 to 12.7 μm) thick and cured to manufacturers' specifications. Before application of the lubricant the samples, made from 302 stainless steel condition B, were vapor blasted with Number 500 size Al_2O_3 grit.

Figure 3. Test Bar Assembly (Bar Weight 36 g)

Two sets of 303 stainless steel (condition B) rollers were used. One set had a smooth (8-16 RMS) surface finish and the other set had a rough (16-32 RMS) surface finish. The friction tests were performed in the following sequence.

Test Number	Test Type	Test Method	Roller
1	Static	Force Transducer	Rough
2	Static	Force Transducer	Smooth
3	Dynamic	Force Transducer	Rough
4	Dynamic	Force Transducer	Smooth
5	Dynamic	Oscillation	Rough
6	Dynamic	Oscillation	Smooth

Three of the six test bar assemblies for each lubricant were subjected to a 1-3-5 test sequence and the remaining three test bars with a 2-4-6 sequence so that half the samples were tested on smooth rollers and half on rough rollers. Lubricant 77-S consistently performed better than either 4396 or 4396-S.

These were the tests used.

Static Friction, Force Transducer Method. The rollers remain stationary while the force transducer is advanced against the end of the test bar assembly until the bar slips on the rollers. A force signature is recorded on a Visicorder and the static friction coefficient is calculated as $\mu_s = P/W$, where P is the break-away force and W is the weight of the bar (Tables 1 through 3). A typical recorder force signature is shown in Figure 4.

Figure 4. Typical Static Friction Visicorder Signature

Table 1. Static Friction Data

Lubricant	Roller Finish	Sample	Coefficient of Friction				
77-S	Smooth	1	0.109	0.128	0.123	0.120	0.140
		2	0.111	0.142	0.142	0.109	0.109
		3	0.111	0.136	0.125	0.136	0.123
4396	Smooth	7	0.134	0.128	0.128	0.117	0.125
		8	0.134	0.178	0.201	0.142	0.117
		9	0.128	0.123	0.150	0.145	0.142
4396-S	Smooth	13	0.106	0.111	0.139	0.134	0.117
		14	0.142	0.150	0.136	0.139	0.148
		15	0.145	0.136	0.145	0.136	0.139
77-S	Rough	4	0.125	0.120	0.128	0.097	0.134
		5	0.142	0.114	0.145	0.123	0.103
		6	0.123	0.117	0.106	0.103	0.123
4396	Rough	10	0.198	0.128	0.162	0.145	0.106
		11	0.201	0.240	0.217	0.120	0.189
		12	0.150	0.153	0.153	0.153	0.150
4396-S	Rough	16	0.139	0.114	0.142	0.134	0.111
		17	0.167	0.134	0.156	0.156	0.148
		18	0.167	0.167	0.148	0.164	0.195

Table 2. Means and Standard Deviations Calculated From Table 1.

Lubricant	Roller Finish								
	Smooth			Rough			Smooth and Rough		
	$\bar{X}$		σ	$\bar{X}$		σ	$\bar{X}$		σ
77-S	0.124	(B)	0.013	0.120	(A)	0.014	0.122	(G)	0.013
4396	0.139	(D)	0.023	0.165	(F)	0.037	0.152	(I)	0.032
4396-S	0.135	(C)	0.013	0.149	(E)	0.022	0.142	(H)	0.019
All Lubes	0.133	(J)	0.018	0.145	(K)	0.032			

Table 3. Separation of Means for Static Function Data (Means underlined are statistically alike.)

A	B	C	D	E	F
<u>0.120</u>	<u>0.124</u>	<u>0.135</u>	0.139	<u>0.149</u>	<u>0.165</u>
<hr/>					
<hr/>					
G	H	I			
<u>0.122</u>	<u>0.142</u>	<u>0.152</u>			
J	K				
<u>0.133</u>	<u>0.145</u>				

Dynamic Friction, Force Transducer Method. The test bar assembly is placed on the rollers with one end touching the force transducer. The driven rollers force the bar against the transducer. The dynamic friction coefficient is calculated as $\mu_D = P/W$, where P is the force against the transducer and W is the weight of the bar (Tables 4 through 7). A typical Visicorder force signature is shown in Figure 5.

Dynamic Friction, Oscillation Method. With the rollers rotating in opposite directions, the bar is displaced from the central position and released. If the roller speed is always sufficient to maintain slip between itself and the bar, the bar will oscillate in a harmonic motion until damping decays its displacement from center (Figure 6). The dynamic friction coefficient is calculated as

$$\mu_D = \frac{H}{\frac{gT^2}{4\pi^2} + h}$$

where T is the time period of oscillation and g is acceleration of gravity 386 in/sec² (9.2 m/sec²). The time period of oscillation was determined by using a photocell and Visicorder arrangement (Tables 8 through 10).

Table 4. Force Transducer Method Dynamic Friction Data

Lubricant	Roller Finish	Sample	Friction Coefficient After Lapsed Running Time (Seconds)			
			1	3	10	20
77-S	Smooth	1	0.228	0.253	0.265	0.279
		2	0.214	0.226	0.240	0.253
		3	0.200	0.214	0.228	0.242
4396	Smooth	7	0.220	0.231	0.240	0.248
		8	0.240	0.234	0.245	0.251
		9	0.242	0.251	0.259	0.267
4396-S	Smooth	13	0.259	0.265	0.270	0.276
		14	0.256	0.259	0.270	0.281
		15	0.251	0.265	0.270	0.276
77-S	Rough	4	0.212	0.201	0.201	0.203
		5	0.195	0.195	0.192	0.201
		6	0.203	0.198	0.195	0.203
4396	Rough	10	0.220	0.209	0.189	0.184
		11	0.209	0.201	0.203	0.206
		12	0.212	0.201	0.178	0.184
4396-S	Rough	16	0.181	0.187	0.178	0.195
		17	0.195	0.192	0.198	0.201
		18	0.214	0.203	0.198	0.201

Table 5. Comparison by Lubricant, Time, and Roller Finish of Data Presented in Table 4

Smooth	1 Second		3 Seconds		10 Seconds		20 Seconds		1 Through 20	
	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ
77-S	0.216	0.011	0.231	0.020	0.244	0.019	0.258	0.019	0.237	0.022
4396	0.234	0.012	0.239	0.011	0.248	0.010	0.255	0.010	0.244	0.013
4396-S	0.255	0.004	0.263	0.0035	0.270	0.000	0.278	0.003	0.267	0.009
All	0.235	0.010	0.244	0.013	0.254	0.012	0.264	0.0126	0.249	0.020
Rough	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ
77-S	0.203	0.0085	0.198	0.003	0.196	0.0046	0.202	0.001	0.200	0.009
4396	0.214	0.0057	0.204	0.0046	0.190	0.0125	0.191	0.0127	0.200	0.013
4396-S	0.197	0.0166	0.194	0.008	0.191	0.0115	0.199	0.0035	0.195	0.010
All	0.205	0.011	0.199	0.0057	0.192	0.010	0.198	0.0076	0.198	0.010

Table 6. Separation of Means for Smooth Roller Data Presented in Table 5

Identification	Time (Seconds)			
	1	3	10	20
77-S	0.216	0.231	0.244	0.258
4396	0.234	0.239	0.248	0.255
4396-S	0.255	0.263	0.270	0.277
All Lubes	0.235	0.244	0.254	0.264
At 1 Second	77-S 0.216	4396 0.234	4396-S 0.255	
At 3 Seconds	77-S 0.231	4396 0.239	4396-S 0.263	
At 10 Seconds	77-S 0.244	4396 0.248	4396-S 0.270	
At 20 Seconds	4396 0.255	77-S 0.258	4396-S 0.277	
Data for 1, 3, 10, 22, and 20 Seconds Com- bined	77-S 0.237	4396 0.244	4396-S 0.267	
All data combined 0.249.				

Table 7. Separation of Means for Rough Roller Data Presented in Table 5

Identification	Time (Seconds)			
	1	3	10	20
77-S	0.196	0.198	0.202	0.203
4396	0.190	0.191	0.203	0.217
4396-S	0.191	0.194	0.197	0.199
All Lubes	0.192	0.198	0.199	0.205
At 1 Second	4396-S 0.197	77-S 0.203	4396 0.217	
At 3 Seconds	4396-S 0.194	77-S 0.198	4396 0.203	
At 10 Seconds	4396 0.190	4396-S 0.191	77-S 0.196	
At 20 Seconds	4396 0.191	4396-S 0.199	77-S 0.202	
Data for 1, 3, 10, and 20 Combined	4396-S 0.195	77-S 0.200	4396 0.200	
All Data Combined	Rough Roller 0.198		Smooth Roller 0.249

Figure 5. Typical Dynamic Friction Visicorder Signature Using a Force Transducer Against a Smooth (Left) and Rough (Right) Roller

Figure 6. Schematic of Oscillation Mode of Friction Measurement

Wear Testing

After friction testing was completed, two test bar assemblies for each lubricant were subjected to a 10 minute wear test. The friction was monitored continually during the test using the force transducer method. After the first 10 minutes, the bar was moved slightly and the test was repeated. A range of wear performance was plotted for the lubricants for each test bar (Figures 7 and 8).

ACCOMPLISHMENTS

Based upon the statistical analysis of the friction coefficient and wear measurements gathered during this study, the following conclusions are made regarding the performance of lubricants 77-S, 4396-S, and 4396.

Table 8. Oscillation Method Dynamic Friction Data

Lubricant	Roller Finish	Sample	Coefficient of Friction
77-S	Smooth	1	0.163
		2	0.169
		3	0.152
4396	Smooth	7	0.173
		8	0.188
		9	0.186
4396-S	Smooth	13	0.202
		14	0.206
		15	0.201
77-S	Rough	4	0.122
		5	0.138
		6	0.124
4396	Rough	10	0.191
		11	0.162
		12	0.202
4396-S	Rough	16	0.165
		17	0.143
		18	0.165

Table 9. Means and Standard Deviations Calculated From Table 8

Lubricant	Roller Finish								
	Smooth			Rough			Smooth and Rough		
	$\bar{X}$		σ	$\bar{X}$		σ	$\bar{X}$		σ
77-S	0.161	(B)	0.009	0.128	(A)	0.009	0.145	(G)	0.020
4396	0.182	(D)	0.008	0.169	(F)	0.019	0.175	(I)	0.015
4396-S	0.203	(C)	0.003	0.157	(E)	0.012	0.180	(H)	0.026
All Lubes	0.182	(J)	0.019	0.152	(K)	0.022			

Table 10. Separation of Means for Oscillation Method Dynamic Friction Data.
(Means underlined are statistically alike.)

A	E	B	F	D	C
<u>0.128</u>	<u>0.157</u>	<u>0.161</u>	<u>0.169</u>	<u>0.182</u>	0.203
G	I	H			
<u>0.145</u>	<u>0.175</u>	0.180			
K	J				
<u>0.152</u>	<u>0.182</u>

Figure 7. Range of Wear Tests 1 and 2

Figure 8. Range of Wear Tests for All Three Tests

Static

- Lubricant 77-S exhibited approximately a 20 percent lower static friction coefficient than lubricants 4396 and 4396-S.
- The static friction coefficient generally was lower during the smooth roller tests.
- At the one-second wear time, lubricant 77-S exhibited approximately 10 percent lower friction than the other lubricants during tests on the smooth rollers. No significant difference appeared in the lubricants' performance results at the other times or during tests on the rough rollers. These facts suggest that possibly during the earlier stages of run-in for bonded lubricant systems (that lose the wear debris) the lubricant solids at the friction interface are depleted, thus exposing more higher-friction bonding material at the point of rubbing.

Dynamic (Oscillation Method)

- The average friction coefficient using this method was approximately 20 percent lower during the rough roller tests.
- Lubricant 77-S against the rough rollers exhibited approximately a 20 percent lower dynamic friction coefficient than against the smooth rollers and lubricants 4396 and 4396-S against either roller.

Dynamic (Force Transducer Method)

- Rough rollers resulted in approximately 20 percent lower friction when data for all lubricants and all wear times were combined.
- The friction coefficients increased significantly as time of wear increased for the smooth rollers but were similar for the rough rollers.

Wear Tests

The results indicate all lubricants degrade during operation with the faster increase in the friction coefficient occurring during early operation. This would not be true when the film was broken, allowing metal to metal contact of the mating parts.

The overall data seems to indicate that lubricant 77-S is slightly better in light load, moderate wear applications than lubricants 4396 and 4396-S. However, because lubricant 77-S is thinner and slower drying than the other two lubricants, it is prone to settle in the spray reservoir, run during application, and present handling problems until the solvent evaporates. Additional experience and equipment will be needed at this facility before 77-S can be satisfactorily controlled for production.

FUTURE WORK

Further study of the cause of the friction increases encountered during run-in against smooth rollers will be the subject of a future report.