Static Friction Tests with Various Metal Combinations and Special Lubricants

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An inclined-plane apparatus was used in obtaining static friction data for various lubricants with different metal combinations. Special lubricants, such as chlorinated and fluorinated hydrocarbons, were compared with a reference mineral oil. The effect of additives, such as graphite, molybdenum disulfide, zinc oxide, boron nitride, and an oxidized petroleum compound, was investigated. Metal combinations involving stainless steels, carbon steel, cast iron, aluminum alloy, and chromium plate were used.

It was found that the special chlorinated and fluorinated lubricants without additives gave higher friction than the Navy symbol 2110 reference oil. A lubricant containing the oxidized petroleum compound and one containing a silicone grease gave slightly less friction than the reference oil. With a mineral lubricating grease, with dry molydenum disulfide, and with lubricants containing graphite or molybdenum disulfide, the friction was about 50 percent less than with the reference oil. The remaining lubricants gave higher friction than the 2110 reference oil.

In general, the heat-treated stainless-steel combinations gave the lowest friction, whereas the combinations involving cast iron or aluminum alloy gave relatively high friction. Friction was less with lapped and polished surfaces than with ground surfaces.

I. Introduction

Static friction data were obtained for making a practical comparative evaluation of the oiliness of special lubricants when used with various metal combinations. Navy symbol 2110 oil was used as a reference lubricant for comparing the friction obtained with the special lubricants. The work was done at the request of the Naval Ordnance Laboratory, which furnished most of the lubricants and the unmachined metals and specified the metal combinations to be used. The time allotted did not permit a comprehensive investigation, but it is believed that the data may be helpful to those interested in the use of these types of lubricants and metal combinations.

II. Apparatus

An inclined-plane apparatus was used for making the static friction tests. The coefficient of friction, f, is defined as F/W, where F is the tangential force at the sliding surface, and W is the force normal to the surface. As is customary with this type of apparatus, the tangent of the angle with the horizontal when a rider on the incline starts to slide is used as a measure of f. For a given vertically applied load, the magnitude of W changes with the angle of the inclined plane, and the distribution of the load at the sliding surface varies with the angle. However, these variations are not important, as the coefficient of friction was found to be practically independent of load over a wide range.

The testing machine is shown in figure 1. An electric hot plate is mounted on transite between two journals. A handwheel acts through a 100-to-1 reduction gear to give slow tilting of the hot plate. A pointer, perpendicular to the hot plate, indicates on a calibrated scale the tangent of the angle between the surface of the hot plate and the horizontal. The heavy cylindrical weight at one corner of the transite mounting is used to load the reduction gear in one direction, thus eliminating backlash. The plate specimen is fastened to the hot plate with two screws. A loading yoke with a weight pan and weights gives the desired load on the rider specimen. Two steel bars (thicker than the plate specimen), fastened to the hot plate, have several pairs of tapped holes to allow fastening of cross bars at different positions. One of these cross bars (at the left in fig. 1) is pro-

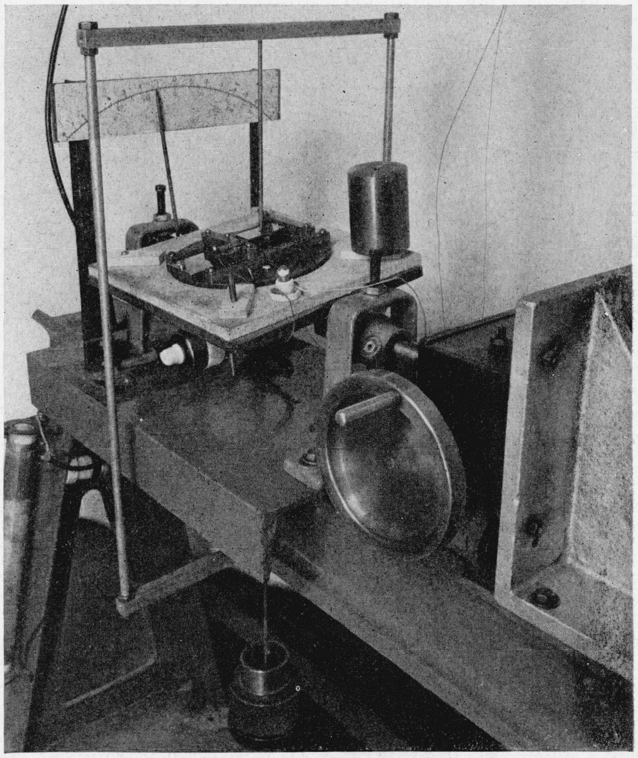

Figure 1. *Static friction machine.*

vided with an electrically insulated screw and needle that are connected in series with a dry cell, lamp, and rider. Connection from the lamp to the rider is made with a No. 38 copper wire in such a way as not to influence movement of the rider. When the rider contacts the needle, the completed circuit is indicated by the signal lamp. The temperature, controlled manually, is measured by a thermocouple fastened to the plate specimen.

Typical test specimens are shown in figure 2. The plate dimensions are ⅜ in. by 2 in. by 7 in., and the rider dimensions are ½ by 1 by 2 in. Each rider has a cone-shaped depression formed in the center of its upper surface for locating the point of the loading yoke. The central portion of the underside of each rider is undercut so as to leave a bearing surface ⅛ by 1 in. at each end. The tapped holes for fastening the thermocouple to the plates and the screws for fastening the signal light wire to the riders are shown in figure 2. The rider and plate shown in the background were finished by grinding. After the plate shown in the foreground was ground, it was lapped, and the contacting surfaces of the rider were finished by lapping and polishing.

III. Metal Combinations

The code numbers and descriptions of the plate specimens are given in the following tabulation.

Code No.	Material	Hardness, Rockwell C	Roughness, (rms)	Remarks
			μ *in.*	
431	431 stainless steel	42	9	Dry-ground.
431–L	do	42	1	Dry-ground and lapped.
440C–L	440C stainless steel	54	1	Do.
214	214 Alcoa alloy		4	Kerosine-ground.
214–L	do		3	Kerosine-ground and lapped.
2–L	cast iron		2	Oil-ground and lapped.

The code numbers and descriptions of the rider specimens are given in the following tabulation.

Code No.	Material	Hardness, Rockwell C	Roughness, (rms)	Remarks
			μ *in.*	
416S	416 stainless steel [a]	49	3	Dry-ground.
416S–LP	do. [a]	49		Dry-ground, lapped and polished.
3C–LP	Chromium plate			Do.
304	304 stainless steel		5	Dry-ground.
304–LP	do			Dry-ground, lapped and polished.
1050–LP	1050 steel			Do.

[a] Sulfurized for free machining.

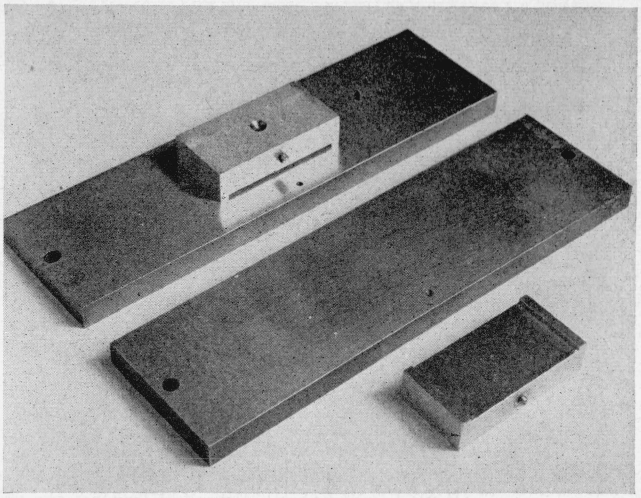

Figure 2. *Static friction machine specimens.*

The specimens of stainless steel 431, 440C, and 416 were hardened by heating to 1,850° F and quenching in oil, and tempered by heating at 500° F for 1 hr and cooling in air.

The sharp edges of the ⅛ by 1-in. contact surfaces of the riders were stoned and polished to prevent any shaving effect.

The values of roughness given are in microinches (rms) as determined by an Abbot Profilometer. With the lapped cast iron (2–L) the open pores gave erratic high readings above 2 μ in., but examination with an interference microscope indicated a roughness of about 2 μ in., if the pores were neglected. With the ground riders, roughness was measured on the backs of the specimens, which were ground in the same manner as the contacting surfaces. It is assumed that the lapped and polished surfaces of the riders had a roughness less than 1 μ in. In the code numbers, L means lapped, and LP means lapped and polished.

A cast iron plate with grids was used to charge a similar lead-tin-alloy plate, which was then rinsed and used to lap the test specimens. This method prevented charging of the specimens with abrasives. After lapping the riders were polished on 4/0 polishing paper resting on a surface plate.

The specimen combinations used in these tests are listed in the following tabulation.

Rider	Plate
416S	431.
304	214.
416S–LP	431–L and 440C–L.
3C–LP	431–L and 214–L.
304–LP	214–L.
1050–LP	2–L.

IV. Lubricants

The lubricants used in this investigation are listed in the following tabulation.

Series No.	Code No.	Lubricant
	7	Navy symbol 2110 oil (SAE 10).
1	13	Chlorinated hydrocarbon.
1	14	Organic phosphate ester.
1	15	Fluorinated hydrocarbon S (medium viscosity).
2	16	Fluorinated hydrocarbon S+1% commercial additive, oxidized petroleum compound.
2	17	Fluorinated hydrocarbon S+1% molybdenum disulfide.
3	18	Fluorinated hydrocarbon FS (light viscosity).
3	19	Fluorinated hydrocarbon S+1% graphite.
3	20	Perfluorokerosene.
4	21	Fluorinated hydrocarbon FS+0.5% copper phthalocyanine.
4	22	Silicone DC–200 (100 centistokes at 25° C).
4	23	Fluorinated hydrocarbon FS+2% silicone grease DC–44 (medium).
4	24	Fluorinated hydrocarbon KEL–F.
4	25	Fluorinated hydrocarbon FS+5% fluorinated grease (light).
5	26	Grease G (23.5% sodium soap).
5	27	Grease G+5% molybdenum disulfide.
5	28	Molybdenum disulfide (dry).
5	29	2110 oil+1% molybdenum disulfide.
5	30	Fluorinated hydrocarbon FS+1% zinc oxide.
6	31	Fluorinated hydrocarbon S+2% molybdenum disulfide concentrate.
6	32	Fluorinated hydrocarbon S+0.75% boron nitride (amorphous).

Lubricant 7 was selected as the reference oil for comparing the frictional characteristics of the samples, most of which were furnished by the Naval Ordnance Laboratory. The lubricants were received in groups and each group was assigned a series number.

V. Test Procedure

For cleaning the test specimens, five solvents were used in the following order: Stoddard solvent; carbon tetrachloride; benzene, cp; acetone, cp; ethyl alcohol, 95 percent. Absorbent cotton was used for scrubbing the specimens with the first two solvents. This was followed by rinsing with the other three and drying with clean cotton.

The liquid lubricants were applied to the plates and riders by means of small clean cotton swabs. Grease samples were applied with a finger tip and dry molybdenum disulfide by dusting.

With the plate horizontal, the rider was placed in position, contacting the insulated needle, and the load was applied. The needle was retracted 0.006 in. (¼ turn of the screw), and the plate was tilted slowly until the rider moved sufficiently to contact the needle and light the signal lamp. The tangent of the angle of tilt was recorded. A second reading was obtained by leveling the plate, retracting the needle another 0.006 in., and again tilting the plate until the signal lamp was lighted. This was repeated, usually until eight readings were obtained, giving a total movement of the rider of 0.048 in. This procedure and series of readings were considered as one test. Between tests the specimens were cleaned and the needle was returned to its original position so that the next lubricant could be tested on the same area of the plate specimen. Because of the variation in static friction resulting from such things as the presence of the oxide films, microscopic irregularities of the metal surfaces, and contamination from the atmosphere, tests with the reference oil (Navy symbol 2110) were made in conjunction with each series of special lubricants. For example, with series No. 1 and one needle bar position, tests were made with lubricants in the following order of Code Nos.: 7, 7, 13, 7, 14, 7, 15, 7. After all the lubricants of a series had been tested at one plate area, the needle bar was moved to another position, the rider was lapped and polished again, and the series was tested at the new plate area. In general, these comparative tests were made at three different areas of the plate specimens. With each new surface area, two or more tests were made with the 2110 oil to assure reasonable reproducibility before testing the series of lubricants. After three areas had been used on a plate specimen, it was lapped again before being used with the next series of lubricants.

VI. Test Results

Some preliminary testing was done in order to study reproducibility and the effects of temperature and load. The effect of temperature was small and was within probable experimental error for the range of 80° to 120° F. Tests with loads of 5, 10, and 15 lb. indicated that variation in the load had no effect on the coefficient of friction, that is, the tangent of the angle when sliding occurred. This was checked later with the 2110 reference oil and special lubricants 16 and 17, with the 416S–LP rider on the 431–L plate. All the values of coefficient of friction reported herein were obtained at a nominal temperature of 100° F and with a 10-lb. load (40 lb/in.[2] average).

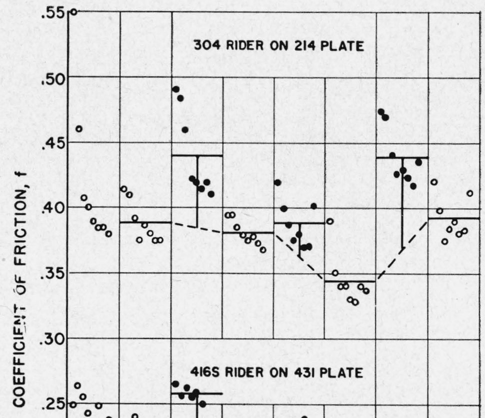

FIGURE 3. *Representative friction data at 10-lb load and 100° F, with ground surfaces.*

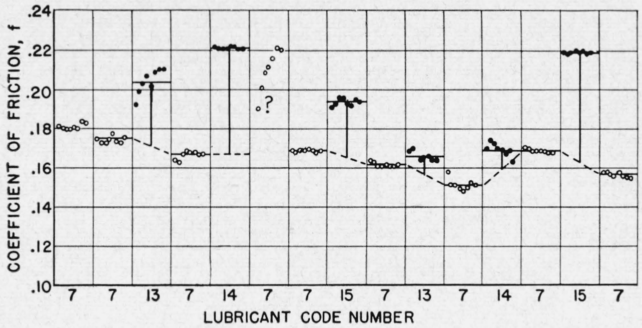

FIGURE 4. *Representative friction data at 10-lb load and 100° F, with 416S–LP rider on 431–L plate (first series of lubricants).*

Some tests were made with ground surfaces on the metal specimens. Typical data for the 2110 reference oil and lubricants 13, 14, and 15 are shown in figure 3. The horizontal lines represent the averages for each group of data obtained in a test. The averages for the reference oil are connected by broken lines from which vertical lines are drawn to the averages for the special lubricants.

Due to the large spread of data on ground surfaces and the fact that lapped or lapped-and-polished surfaces are more easily reproduced and are more commonly used for machine parts involving small clearances, subsequent tests were made with lapped plates and lapped-and-polished riders. The lapping and polishing processes have already been described.

Figure 4 shows typical data for the first series of lubricants with the 416S lapped-and-polished stainless-steel rider on the 431 lapped stainless steel plate. Where a test was obviously not representative it was ignored, as indicated by the question mark for one of the tests with oil 7. Otherwise, the spread of data in figure 4 is much less than in figure 3.

Representative data for the second and fifth series of lubricants are shown in figures 5 and 6, respectively.

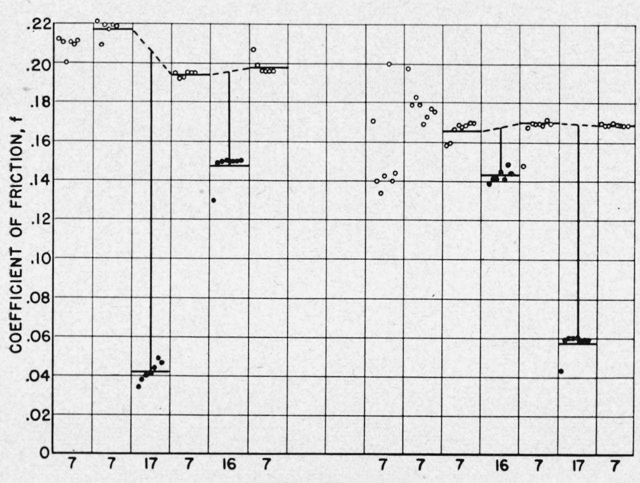

FIGURE 5. *Representative friction data at 10-lb load and 100° F, with 416S–LP rider on 431–L plate, at two locations on the plate (second series of lubricants).*

The data for all the lubricants with this particular metal combination are given in table 1. These were obtained from plots similar to figures 4, 5, and 6. The position number refers to the position of the needle bar, and hence each different position means a different location of the rider on the plate specimen. The spread of data is indicated by giving the maximum and minimum readings for each test, and the average corresponds to the horizontal mean lines as in figures 4, 5, and 6. The percentage increase in friction corresponds to the vertical lines connecting the means to the broken lines for the 2110 reference oil. The percentage increase is indicated as negative when the friction is less than with the reference oil. The reference values of f used for the 2110 oil in connection with each special lubricant test is given in the last column.

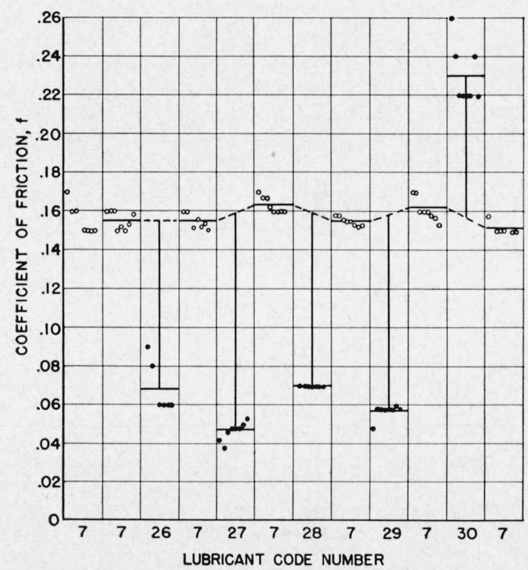

FIGURE 6. *Representative friction data at 10-lb load and 100° F, with 416S–LP rider on 431–L plate (fifth series of lubricants).*

TABLE 1. *Static friction data at 10-lb. load and 100° F. for 416 stainless steel (416S–LP) on 431 stainless steel (431–L)*

Test No.	Position No.	Lubricant Code No.	f (tangent)			Percentage increase [a]	f 2110 Oil
			Maximum	Minimum	Average		
61	7	13	0.210	0.192	0.204	19	0.172
68	7	13	.190	.184	.186	19	.156
78	5	13	.160	.146	.153	10	.138
63	7	14	.222	.221	.221	32	.167
72	7	14	.220	.218	.219	34	.163
80	5	14	.190	.178	.182	34	.136
66	7	15	.196	.191	.194	17	.166
70	7	15	.174	.164	.169	6	.160
76	5	15	.141	.138	.139	−2	.142
213	3	16	.167	.162	.165	−13	.186
221	5	16	.150	.130	.147	−25	.196
226	7	16	.149	.139	.143	−15	.168
215	3	17	.089	.078	.086	−52	.179
219	5	17	.049	.034	.042	−80	.205
228	7	17	.060	.043	.057	−67	.170
353	3	18	.219	.194	.203	18	.172

[a] Percentage increase in average f relative to tests with 2110 oil.

TABLE 1. *Static friction data at 10-lb. load and 100° F. for 416 stainless steel (416S–LP) on 431 stainless steel (431–L)*—Continued

Test No.	Position No.	Lubricant Code No.	f (tangent) Maximum	f (tangent) Minimum	f (tangent) Average	Percentage increase [a]	f 2110 Oil
365	5	18	.171	.160	.164	3	.159
371	7	18	.154	.137	.142	−1	.144
355	3	19	.087	.077	.079	−52	.164
363	5	19	.081	.069	.071	−57	.166
369	7	19	.101	.070	.078	−49	.152
357	3	20	.176	.168	.170	8	.158
361	5	20	.171	.166	.167	0	.167
373	7	20	.160	.149	.152	7	.142
503	3	21	.240	.190	.222	29	.172
519	5	21	.230	.200	.216	27	.170
529	7	21	.170	.150	.160	−5	.168
505	3	22	.240	.190	.215	26	.171
515	5	22	.211	.179	.195	5	.185
531	7	22	.220	.180	.200	15	.164
507	3	23	.124	.105	.118	−28	.164
517	5	23	.130	.106	.125	−28	.174
527	7	23	.160	.100	.130	−24	.172
509	3	24	.220	.200	.215	31	.164
521	5	24	.180	.170	.177	−1	.178
533	7	24	.230	.220	.225	36	.166
511	3	25	.170	.166	.168	11	.152
523	5	25	.190	.176	.179	1	.178
535	7	25	.190	.180	.181	−1	.182
575	3	26	.090	.060	.068	−56	.155
597	5	26	.130	.070	.090	−45	.165
603	7	26	.100	.040	.058	−62	.154
577	3	27	.053	.038	.047	−70	.159
599	5	27	.060	.036	.052	−68	.163
605	7	27	.040	.030	.037	−77	.158
579	3	28	.070	.070	.070	−56	.159
591	5	28	.094	.086	.090	−46	.167
607	7	28	.100	.070	.090	−40	.149
581	3	29	.060	.048	.057	−64	.158
593	5	29	.049	.030	.045	−73	.165
609	7	29	.052	.050	.052	−64	.143
583	3	30	.260	.220	.230	47	.156
595	5	30	.230	.200	.212	30	.163
611	7	30	.160	.150	.159	12	.142
625	3	31	.050	.040	.049	−68	.151
634	5	31	.070	.048	.058	−58	.138
638	7	31	.070	.050	.067	−57	.156
627	3	32	.210	.190	.198	32	.150
631	5	32	.210	.198	.200	24	.161
640	7	32	.198	.180	.184	16	.158

[a] Percentage increase in average *f* relative to tests with 2110 oil.

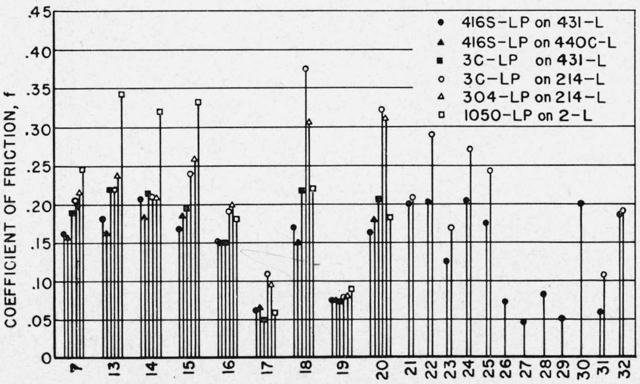

FIGURE 7. *Summary of friction data for various lubricants with different metal combinations, at 10-lb load and 100° F.*

Tables 2, 3, 4, 5, and 6 present similar data for the other metal combinations.

The data in the above tables are summarized in figure 7. The average values of *f* for lubricant 7 (2110 reference oil) and special lubricants 13 to 20 are given for six metal combinations. The averages for lubricants 21 to 25 and 31 and 32 are given for the two metal combinations used with them. Lubricants 26 to 30 were prepared at this Bureau and were tested with one metal combination only.

TABLE 2. *Static friction data at 10-lb load and 100° F, for 416 stainless steel (416S–LP) on 440C stainless steel (440C–L)*

Test No.	Position No.	Lubricant Code No.	f (tangent) Maximum	f (tangent) Minimum	f (tangent) Average	Percentage increase [a]	f 2110 oil
86	5	13	0.163	0.158	0.160	7	0.150
92	7	13	.180	.159	.166	15	.144
88	5	14	.189	.179	.183	22	.150
94	7	14	.188	.182	.185	23	.150
84	5	15	.184	.180	.181	19	.152
96	7	15	.195	.184	.188	24	.152
233	7	16	.170	.163	.167	−5	.176
241	5	16	.174	.160	.165	−7	.178
245	3	16	.124	.121	.122	−25	.162
235	7	17	.097	.091	.095	−49	.175
239	5	17	.064	.052	.060	−66	.179
247	3	17	.044	.029	.039	−76	.160
377	7	18	.161	.147	.154	3	.149
390	5	18	.169	.130	.138	−1	.139
397	3	18	.179	.148	.158	11	.142
379	7	19	.085	.070	.074	−50	.148
386	5	19	.081	.070	.072	−50	.144
399	3	19	.096	.070	.081	−43	.143
382	7	20	.190	.170	.184	15	.160
388	5	20	.200	.169	.192	41	.136
395	3	20	.170	.158	.162	17	.139

[a] Percentage increase in average *f* relative to tests with 2110 oil.

TABLE 3. *Static friction data at 10-lb load and 100° F, for chromium plate (3C–LP) on 431 stainless steel (431–L)*

Test No.	Position No.	Lubricant Code No.	f (tangent) Maximum	f (tangent) Minimum	f (tangent) Average	Percentage increase [a]	f 2110 oil
155	3	13	0.278	0.214	0.252	15	0.219
165	5	13	.210	.201	.205	40	.146
175	7	13	.210	.200	.202	19	.170
157	3	14	.242	.221	.237	12	.212
167	5	14	.217	.207	.211	37	.154
171	7	14	.211	.196	.199	21	.164
159	3	15	.233	.209	.226	24	.182
163	5	15	.166	.157	.161	13	.143
173	7	15	.199	.190	.195	14	.171
269	7	16	.172	.168	.170	−19	.210
278	5	16	.171	.110	.150	−13	.175
283	3	16	.139	.121	.130	−37	.207
271	7	17	.058	.050	.053	−74	.205
276	5	17	.061	.039	.056	−68	.173
285	3	17	.050	.032	.044	−78	.204
429	7	18	.239	.198	.213	10	.193
441	5	18	.270	.238	.253	17	.216
448	3	18	.196	.174	.184	8	.171
431	7	19	.098	.078	.084	−58	.200
437	5	19	.077	.070	.072	−67	.220
450	3	19	.080	.070	.073	−58	.175
433	7	20	.216	.200	.206	6	.194
439	5	20	.243	.238	.240	11	.216
446	3	20	.184	.178	.179	−4	.187

[a] Percentage increase in average *f* relative to tests with 2110 oil.

TABLE 4. *Static friction data at 10-lb load and 100°F, for chromium plate (3C–LP) on 214 Alcoa alloy (214–L)*

Test No.	Position No.	Lubricant code No.	*f* (tangent)			Percentage increase [a]	*f* 2110 oil
			Maximum	Minimum	Average		
179	7	13	0.239	0.182	0.221	12	0.198
190	5	13	.248	.187	.221	19	.186
200	3	13	.230	.199	.215	7	.201
182	7	14	.211	.200	.204	9	.188
192	5	14	.228	.199	.211	10	.191
196	3	14	.231	.200	.214	3	.207
184	7	15	.230	.199	.214	14	.188
188	5	15	.346	.267	.296	58	.187
198	3	15	.223	.196	.212	3	.206
289	3	16	.211	.172	.192	−4	.200
299	5	16	.200	.180	.185	−15	.218
303	7	16	.200	.180	.192	−10	.214
326	3	17	.068	.048	.062	−71	.214
297	5	17	.200	.174	.195	−12	.245
305	7	17	.137	.049	.077	−63	.210
454	3	18	.367	.253	.292	36	.214
467	5	18	.460	.340	.406	79	.226
473	7	18	.470	.360	.425	109	.203
456	3	19	.084	.080	.080	−58	.192
463	5	19	.090	.073	.082	−60	.204
475	7	19	.090	.078	.081	−62	.216
458	3	20	.420	.300	.355	70	.209
465	5	20	.430	.216	.310	41	.220
471	7	20	.420	.196	.303	52	.200
539	7	21	.260	.220	.242	17	.206
555	5	21	.220	.190	.200	2	.197
565	3	21	.190	.170	.180	−16	.214
541	7	22	.330	.320	.323	63	.198
551	5	22	.290	.270	.279	28	.217
567	3	22	.270	.260	.265	26	.210
543	7	23	.180	.150	.169	−11	.190
553	5	23	.180	.150	.169	−21	.213
563	3	23	.190	.140	.165	−25	.221
545	7	24	.280	.230	.261	33	.196
557	5	24	.300	.260	.284	46	.195
569	3	24	.270	.250	.265	35	.196
547	7	25	.260	.220	.245	32	.185
559	5	25	.280	.230	.256	27	.202
571	3	25	.234	.220	.225	18	.190
645	7	31	.140	.040	.111	−49	.219
653	5	31	.120	.070	.099	−52	.206
657	3	31	.140	.070	.114	−37	.181
647	7	32	.212	.196	.201	0	.201
651	5	32	.230	.180	.195	−4	.204
659	3	32	.180	.170	.173	−14	.201

[a] Percentage increase in average *f* relative to tests with 2110 oil.

TABLE 5. *Static friction data at 10-lb load and 100° F, for 304 stainless steel (304–LP) on 214 Alcoa alloy (214–L)*

Test No.	Position No.	Lubricant Code No.	*f* (tangent)			Percentage increase [a]	*f* 2110 Oil
			Maximum	Minimum	Average		
108	7	13	0.223	0.182	0.214	1	0.212
116	5	13	.232	.217	.223	8	.206
148	3	13	.293	.237	.277	14	.239
110	7	14	.211	.196	.200	−7	.216
118	5	14	.222	.201	.208	0	.207
150	3	14	.233	.216	.221	−8	.238
112	7	15	.219	.181	.208	2	.203
125	5	15	.307	.252	.285	26	.217
146	3	15	.316	.272	.289	27	.227
309	7	16	.234	.192	.210	−7	.226
317	5	16	.180	.176	.179	−19	.220
321	3	16	.226	.205	.215	−12	.245
311	7	17	.180	.120	.168	−21	.214
315	5	17	.060	.040	.057	−75	.227
323	3	17	.070	.045	.060	−75	.240
403	3	18	.310	.250	.277	31	.211
414	5	18	.360	.250	.309	47	.210
422	7	18	.350	.298	.325	78	.183
405	3	19	.082	.070	.072	−64	.201
412	5	19	.122	.083	.092	−59	.222
424	7	19	.085	.073	.078	−58	.185
407	3	20	.367	.250	.311	50	.207
416	5	20	.380	.319	.359	64	.219
420	7	20	.290	.250	.258	39	.185

[a] Percentage increase in average *f* relative to tests with 2110 oil.

TABLE 6. *Static friction data at 10-lb load and 100° F, for 1050 steel (1050–LP) on cast iron (2–L)*

Test No.	Position No.	Lubricant Code No.	*f* (tangent)			Percentage increase [a]	*f* 2110 Oil
			Maximum	Minimum	Average		
130	5	13	0.360	0.326	0.340	19	0.286
138	7	13	.357	.317	.344	18	.292
132	5	14	.378	.292	.318	10	.290
140	7	14	.386	.297	.324	6	.305
134	5	15	.367	.329	.353	19	.298
142	7	15	.318	.308	.312	4	.302
251	3	16	.173	.148	.160	−23	.207
259	5	16	.192	.171	.177	−43	.308
263	7	16	.210	.192	.198	−13	.227
253	3	17	.078	.060	.070	−67	.213
257	5	17	.088	.038	.057	−81	.299
265	7	17	.082	.045	.057	−76	.237
479	7	18	.240	.220	.222	25	.178
491	5	18	.220	.168	.189	10	.172
497	3	18	.270	.240	.249	23	.202
481	7	19	.090	.090	.090	−51	.186
487	5	19	.085	.074	.078	−59	.191
499	5	19	.100	.090	.098	−60	.246
483	7	20	.210	.194	.201	14	.176
489	5	20	.200	.196	.198	4	.190
495	3	20	.150	.150	.150	−13	.173

[a] Percentage increase in average *f* relative to tests with 2110 oil.

VII. Conclusion

For static friction under the conditions used for these tests, the following indications have been obtained:

1. Polished surfaces sliding on lapped surfaces tend to give lower friction and less variation than ground surfaces sliding on ground surfaces.

2. For the metal specimens tested, with most of the lubricants, the heat-treated stainless steel combinations gave the lowest friction. The chromium-plated rider on the heat-treated stainless steel plate also gave correspondingly low friction with lubricants 16, 17, and 19. For the chromium-plated rider and the 304 stainless steel rider on the Alcoa 214 alloy plate, and for the 1050 steel rider on the cast iron plate, the relative friction varied greatly with the lubricant. Each of these combinations gave high friction with one or more lubricants while giving low friction with other lubricants.

3. The lubricants containing molybdenum disulfide gave the lowest friction, whereas mineral lubricating grease, dry molybdenum disulfide, and the lubricant containing graphite gave friction nearly as low. With the above lubricants the friction was about 50 to 60 percent less than with the 2110 reference oil. The lubricant containing an oxidized petroleum compound and the one containing a silicone grease gave slightly less friction than the 2110 oil. The chlorinated and fluorinated lubricants without additives and the remaining special lubricants gave higher friction than the 2110 reference oil.

These relative evaluations of friction apply only for static conditions as used in these tests. Any significance with respect to kinetic boundary lubrication is questionable, except possibly in those cases where the velocity approaches zero.

WASHINGTON, October 9, 1950.