DOE/SF/91001--T5 — MASTER

Program:	Sodium Technology		
AEC Task:	1 — FFTF Support Work — Friction Tests		
Program Manager:	G. W. Meyers	**Project Manager:**	J. G. Asquith
Reporting Period:	GFY 1974	**Category:**	HN 04 01 01.5
General Order:	06507 **Subaccount:** 11100	**189a Number:**	13625

Principal Investigators: R. M. Oliva, P. Horton

AT03 76 SF 91001

I. PROJECT OBJECTIVES

The objective of this program is to conduct friction screening tests in an environment of high-temperature, high-purity liquid sodium or sodium vapor to: (1) develop backup materials, processes, and vendors for core component wear pads, (2) investigate material treatments and coatings for improvement of wear behavior of common LMFBR structural materials, (3) evaluate weld-deposited hardfacings and/or prefabricated bearing materials for use in long-term, high-temperature, high-fluence regions, (4) evaluate bearing materials with a low potential for change in surface composition due to corrosion or mass transfer effects, and (5) develop statistical confidence in friction values for selected material combinations.

II. TECHNICAL PROGRESS DURING FISCAL YEAR 1974

The GFY 1974 effort was a continuation of the friction test program started in GFY 1972. At that time, two test matrices of 18 couples each were tested in sodium to the temperature, surface loading, and wear conditions specified by HEDL (see "Annual Technical Progress Report, Sodium Technology and Cover Gas Seal Development Programs, GFY 1972," AI-AEC-13037). In the following year, GFY 1973, five additional test matrices were completed (see "Annual Technical Progress Report, Sodium Technology and Cover Gas Seal Development Programs, GFY 1973," AI-AEC-13110). During GFY 1974 four more matrices were tested.

Friction testing of each test matrix was performed in liquid sodium (sodium vapor for Matrices 5 and 10) to the HEDL specified temperature and procedural sequence. To assure that the oxygen content on the sodium was at levels below 5 ppm, periodic sodium samples were taken and analyzed per ANL/ST6.

DISCLAIMER

Breakaway (initial movement after dwell at temperature and under load), static (breakaway at each subsequent running cycle), and dynamic (based on average force during the total running cycle) friction coefficients were measured on each couple under the temperatures and contact forces and after the dwell periods. In the sections that follow, these measured values for Matrices 8, 9, 9A, and 10 are tabulated and plotted. The static and dynamic friction coefficients shown were the average values observed over Wear Cycles 2 to 5 with those measured over Cycles 19 to 24. Photographs of couples displaying significant wear or coating depletion are included in each section.

When evaluating the results of each test matrix, it is important to note that a complete understanding of the intended material application, the operating temperature in service, the number of operational cycles, the tolerable friction coefficients in service, the amount of surface deformation (wear permissible over the components anticipated useful lifetime), long-term corrosion resistance, mechanical strength properties, irradiation effects, and ability to withstand thermal cycling are all necessary to properly and sensibly apply the test results. HEDL is performing the final evaluation of the results of these screening tests through the coordination and interpretation of results from all of the friction test programs being currently conducted by AI, HEDL, LMEC, and WARD. To this end, an interim Topical Report is presently being collected by HEDL to present total program results to date. AI has submitted its required input for this document.

Fabrication of test specimens for the eleventh and twelfth test matrices is being initiated.

A brief discussion of each of the four matrices tested in GFY 1974 is presented in the following section.

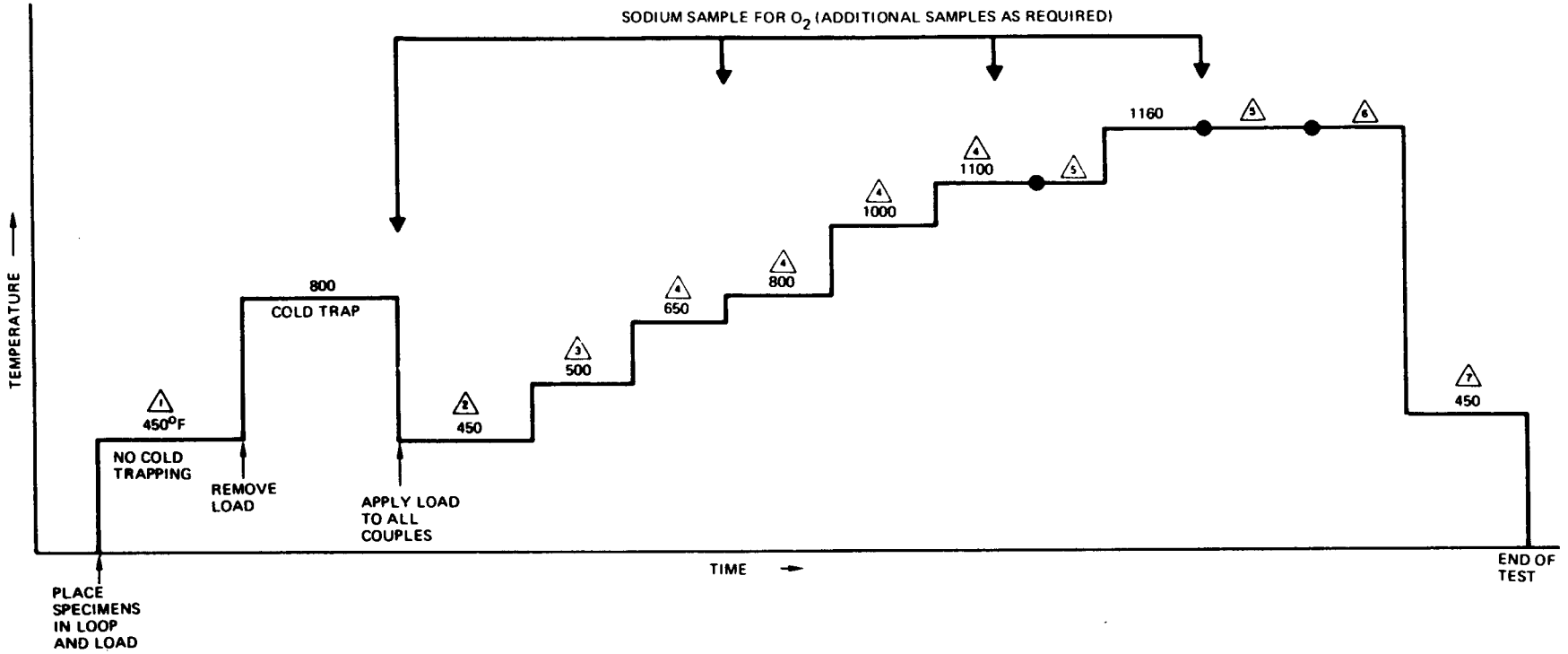
A. FRICTION MATRIX 8

Testing of the eighth friction matrix, Table 1, was completed on October 15, 1973, and followed the temperature test sequence noted on Figure 1. The temperature sequence was performed without incident and without deviation from the noted operational procedures. Sodium samples taken periodically during the test and analyzed for O_2 content per ANL/ST-6 showed that the O_2 level remained below the 5 ppm maximum allowable content.

TABLE 1

FRICTION MATRIX No. 8

	Rider	Plate	Load (psi)	Maximum Temperature (°F)
1.	Aluminized Hastelloy C	Aluminized Hastelloy C	800	1160
2.	Chromized Hastelloy C	Chromized Hastelloy C	800	1160
3.	Chromized Carburized Type 304 SS	Aluminized Inconel 718	800	1160
4.	Chromized-Carburized Hastelloy C	Chromized-Carburized Hastelloy C	800	1160
5.	Aluminized A-286	Aluminized A-286	800	1160
6.	Chromized A-286	Chromized A-286	800	1160
7.	Borided A-286	Borided A-286	800	1160
8.	Chromized-Carburized A-286	Chromized-Carburized A-286	800	1160
9.	Aluminized Type 304 Stainless Steel	Aluminized Inconel 718	800	1160
10.	Chromized Type 304 Stainless Steel	Chromized Type 304 Stainless Steel	800	1160
11.	Borided Type 304 Stainless Steel	Borided Type 304 Stainless Steel	800	1160
12.	Chromized Carburized Type 304 Stainless Steel	Chromized-Carburized Type 304 Stainless Steel	800	1160
13.	Borided Inconel 718	Borided Inconel 718	800	1160
14.	Chromized-Carburized Inconel 718	Chromized-Carburized Inconel 718	800	1160
15.	Chromized Type 304 Stainless Steel	Aluminized Inconel 718	800	1160
16.	Borided A-286	Aluminized Inconel 718	800	1160
17.	A-286	Aluminized Inconel 718	800	500
18.	Type 316 Stainless Steel (annealed)	Aluminized Inconel 718	300	500



1. APPLY LOAD TO ALL COUPLES. RUB 10 CYCLES.
2. AFTER OVERNIGHT DWELL, APPLY 25 WEAR CYCLES.
3. AFTER OVERNIGHT DWELL, APPLY 25 WEAR CYCLES TO ALL BUT COUPLE 17. APPLY 150 CYCLES TO COUPLE 17; DO NOT REMOVE LOAD. REMOVE LOAD FROM COUPLE 18 AFTER CYCLING.
4. AFTER OVERNIGHT DWELL, APPLY 25 CYCLES TO ALL BUT 17 AND 18.
5. AFTER A 3-day MINIMUM DWELL, APPLY 25 CYCLES TO ALL BUT 17 AND 18.
6. DWELL OVERNIGHT UNDER SPECIFIED LOAD (EXCEPT NO. 18). DO NOT APPLY ANY WEAR CYCLES.
7. APPLY LOAD TO NO. 18. DWELL A MINIMUM OF 3 days. APPLY 25 WEAR CYCLES TO EACH COUPLE.

GENERAL TEST CONDITIONS

1. TEMPERATURE CHANGE OF 50°F/hr (MAX.)
2. STABLE TEMPERATURE ±5°F
3. PLUGGING TEMPERATURE AT EACH TEMPERATURE LEVEL
4. O_2 CONTENT TO BE 5 ppm OR LESS THROUGHOUT TEST
5. OVERNIGHT DWELLS TO BE 16 hr MINIMUM

6507-47133C

Figure 1. Temperature Sequence for Eighth Test Matrix

Breakaway, static, and dynamic friction coefficients were measured as required at each temperature level. A summary of these data is shown in Table 2. These various friction coefficients are plotted in Figure 2 to show each couple's friction characteristics vs the combination of temperature and wear cycle accumulation. Photographs taken of select couples after test appear in Figure 3. Test data are also presented in the Summary Table format (specified by HEDL) in Table 3.

The borided couples (No. 7 — borided A-286 vs itself, No. 11 — borided Type 304 stainless steel vs itself, No. 13 — borided Inconel 718 vs itself, and No. 16 — borided A-286 vs aluminized Inconel 718) showed very low friction coefficients below 800°F. Above 800°F, none of the couples displayed static or dynamic friction coefficients above 0.8. However, all were characterized by consistently high breakaway values. Little or no surface deformation occurred on any of the specimens.

The chromized-carburized material, when tested against itself, performed badly, in that significant surface wear and damage was evident on most couples. Three specimens (No. 4 — chromized-carburized Hastelloy C vs itself, No. 8 — chromized-carburized A-286 vs itself, and No. 14 — chromized-carburized Inconel 718 vs itself) showed severe wear on both the riders and plates. An exception to this trend was shown by No. 12 — chromized-carburized Type 304 stainless steel vs itself, which showed little or no wear. A study of the friction plots shows no outstanding friction performance for any of the four couples at any temperature ranges. However, when chromized-carburized Type 304 stainless steel was tested against aluminized Inconel 718 (Couple 3), consistently low friction values resulted over the entire temperature range, and neither part sustained significant wear (a small area at the center of the aluminized Inconel 718 rider was polished, apparently due to a high spot on the surface). Breakaway values at 1100 and 1160°F, and at 450°F (after the high-temperature testing), for this couple were in the range of 1.0 to 1.1.

The only couple having a chromized surface that did not experience moderate-to-heavy surface wear was No. 2 — chromized Hastelloy C vs itself. Couples No. 6 — chromized A-286 vs itself, and No. 10 — chromized Type 304 stainless steel vs itself, experienced severe wear or surface deformation on both the riders and plates. Moderate wear was evident on Couple No. 15, which matched

TABLE 2

FRICTION TEST No. 8

Rider	Plate	Contact Pressure (psi)	Breakaway(B) Static(S)* Dynamic(D)*	Friction Coefficient										
				450F †	450F ⚠	500F ⚠	650F ⚠	800F ⚠	1000F ⚠	1100F ⚠	1100F ⚠⚠	1160F ⚠	1160F ⚠⚠	450F ⚠⚠
				0-10 Cycles	11-35 Cycles	36-60 Cycles	61-85 Cycles	86-110 Cycles	110-135 Cycles	136-160 Cycles	161-185 Cycles	185-210 Cycles	211-235 Cycles	235-260 Cycles
1. Aluminized Hastelloy C	Aluminized Hastelloy C	800	B	0.30	0.36	0.38	0.43	0.56	0.67	0.88	1.00	1.02	1.24	1.10
			S	0.24	0.40	0.39	0.44	0.38	0.31	0.35	0.26	0.41	0.26	0.40
			D	0.59	0.41	0.43	0.49	0.46	0.46	0.52	0.44	0.59	0.37	0.47
2. Chromized Hastelloy C	Chromized Hastelloy C	800	B	0.50	0.34	0.40	0.45	0.46	0.80	0.93	1.12	1.10	1.44	1.43
			S	0.18	0.32	0.31	0.36	0.59	0.50	0.52	0.48	0.55	0.48	0.54
			D	0.40	0.39	0.34	0.48	0.63	0.69	0.70	0.65	0.65	0.65	0.68
3. Chromized-Carburized 304 SS	Aluminized Inconel 718	800	B	0.35	0.37	0.23	0.28	0.34	0.83	0.69	0.93	1.08	1.06	1.10
			S	0.30	0.30	0.29	0.28	0.39	0.50	0.33	0.29	0.23	0.20	0.45
			D	0.37	0.37	0.37	0.36	0.52	0.58	0.54	0.48	0.37	0.31	0.58
4. Chromized-Carburized Hastelloy C	Chromized Carburized Hastelloy C	800	B	0.30	0.47	0.38	0.55	0.60	0.92	0.80	0.95	1.01	1.08	1.28
			S	0.15	0.51	0.52	0.52	0.56	0.67	0.41	0.46	0.55	0.50	0.59
			D	0.42	0.48	0.48	0.46	0.59	0.69	0.50	0.51	0.63	0.68	0.84
5. Aluminized A-286	Aluminized A-286	800	B	0.47	0.50	0.50	0.48	0.65	0.97	0.76	0.80	0.82	0.96	1.38
			S	0.35	0.30	0.35	0.36	0.33	0.38	0.41	0.30	0.39	0.42	0.53
			D	0.63	0.28	0.45	0.47	0.50	0.56	0.40	0.47	0.56	0.48	0.70
6. Chromized A-286	Chromized A-286	800	B	0.21	0.39	0.33	0.30	0.41	0.86	0.88	0.85	1.25	1.56	>2.0
			S	0.30	0.33	0.32	0.33	0.38	0.50	0.61	0.58	0.75	0.73	0.50
			D	0.58	0.38	0.41	0.40	0.50	0.74	0.72	0.62	0.88	0.96	0.74
7. Borided A-286	Borided A-286	800	B	0.43	0.39	0.34	0.39	0.57	>1.7	>2.0	1.80	1.63	1.72	1.88
			S	0.50	0.33	0.35	0.31	0.36	0.30	0.32	0.23	0.25	0.31	0.65
			D	0.75	0.36	0.40	0.40	0.50	0.34	0.34	0.33	0.31	0.35	0.79
8. Chromize-Carburized A-286	Chromize-Carburized A-286	800	B	0.30	0.37	0.39	0.45	0.43	1.00	1.02	0.91	1.15	1.72	>2.0
			S	0.27	0.33	0.36	0.36	0.42	0.48	0.45	0.47	0.60	0.68	0.44
			D	0.48	0.37	0.45	0.53	0.50	0.55	0.55	0.55	0.73	0.85	0.67
9. Aluminized 304 SS	Aluminized Inconel 718	800	B	0.48	0.48	0.49	0.43	0.50	1.07	1.03	1.00	0.70	1.04	0.94
			S	0.40	0.40	0.39	0.32	0.38	0.51	0.50	0.33	0.35	0.40	0.57
			D	0.75	0.46	0.44	0.43	0.53	0.61	0.49	0.40	0.39	0.50	0.69
10. Chromized 304 SS	Chromized 304 SS	800	B	0.31	0.37	0.23	0.27	0.33	0.78	0.63	0.78	1.02	1.54	>2.0
			S	0.33	0.33	0.31	0.28	0.34	0.45	0.49	0.51	0.70	0.86	0.40
			D	0.48	0.36	0.41	0.41	0.48	0.60	0.41	0.55	0.73	0.83	0.53
11. Borided 304 SS	Borided 304 SS	800	B	0.22	0.13	0.25	0.22	0.25	0.87	1.40	1.80	1.18	1.62	1.68
			S	0.13	0.20	0.16	0.13	0.15	0.22	0.36	0.47	0.77	0.52	0.67
			D	0.37	0.28	0.23	0.27	0.29	0.39	0.40	0.41	0.55	0.69	0.74
12. Chromize-Carburized 304 SS	Chromize-Carburized 304 SS	800	B	0.30	0.50	0.27	0.35	0.38	0.90	0.73	0.60	1.19	1.80	0.90
			S	0.21	0.31	0.32	0.32	0.37	0.41	0.51	0.41	0.65	0.69	0.62
			D	0.43	0.36	0.38	0.36	0.45	0.56	0.64	0.65	0.85	0.81	0.70
13. Borided Inconel 718	Borided Inconel 718	800	B	0.21	0.24	0.23	0.18	0.37	1.07	1.55	>2.0	1.63	1.88	>2.0
			S	0.08	0.18	0.20	0.20	0.20	0.23	0.31	0.25	0.21	0.29	0.82
			D	0.30	0.24	0.26	0.27	0.32	0.31	0.47	0.34	0.30	0.43	0.81
14. Chromize-Carburized Inconel 718	Chromize-Carburized Inconel 718	800	B	0.20	0.26	0.54	0.40	0.40	0.72	0.88	0.97	1.03	1.14	2.00
			S	0.15	0.31	0.42	0.36	0.38	0.39	0.51	0.55	0.50	0.70	0.70
			D	0.35	0.39	0.44	0.42	0.45	0.49	0.57	0.56	0.54	0.58	0.82
15. Chromized 304 SS	Aluminized Inconel 718	800	B	0.30	0.25	0.30	0.25	0.35	0.96	0.92	1.05	1.20	1.48	1.04
			S	0.27	0.31	0.28	0.25	0.30	0.34	0.20	0.27	0.32	0.38	0.51
			D	0.50	0.34	0.33	0.35	0.44	0.44	0.38	0.35	0.40	0.44	0.62
16. Borided A-286	Aluminized Inconel 718	800	B	0.26	0.39	0.32	0.40	0.42	1.08	1.52	1.48	1.54	1.84	1.04
			S	0.20	0.30	0.26	0.29	0.31	0.24	0.43	0.37	0.43	0.40	0.02
			D	0.48	0.36	0.34	0.35	0.38	0.30	0.44	0.38	0.48	0.50	0.71
17. A-286	Aluminized Inconel 718	800	B	0.21	0.30	0.35								1.06
			S	0.28	0.34	0.31§	← No friction cycles run above 500F →							0.54
			D	0.50	0.39	0.43§								0.72
18. 316 SS (Annealed)	Aluminized Inconel 718	300	B	0.15	0.23	0.30								0.73
			S	0.10	0.27	0.26	← Zero load, no friction cycles above 500F →							0.57
			D	0.41	0.40	0.44								0.94

⚠ Measurements made after overnight dwell (minimum)
⚠⚠ Measurements made after 3 day dwell (minimum)
* Average observed during cycles 2-10 and 19-24
† Prior to Cold Trapping
§ 150 cycles run

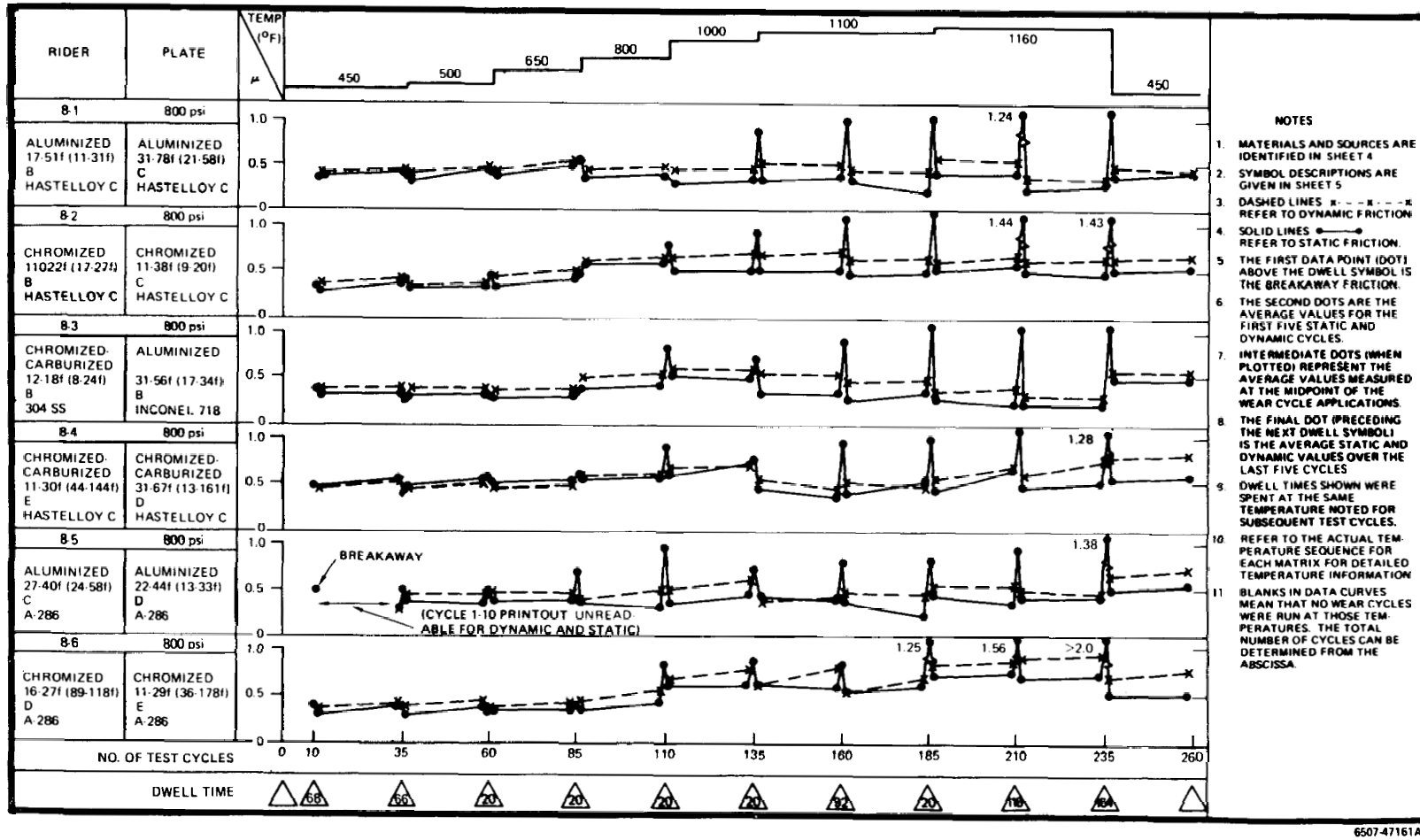


Figure 2. Friction Matrix No. 8 – Friction Coefficients vs Wear Cycles
(Sheet 1 of 5)

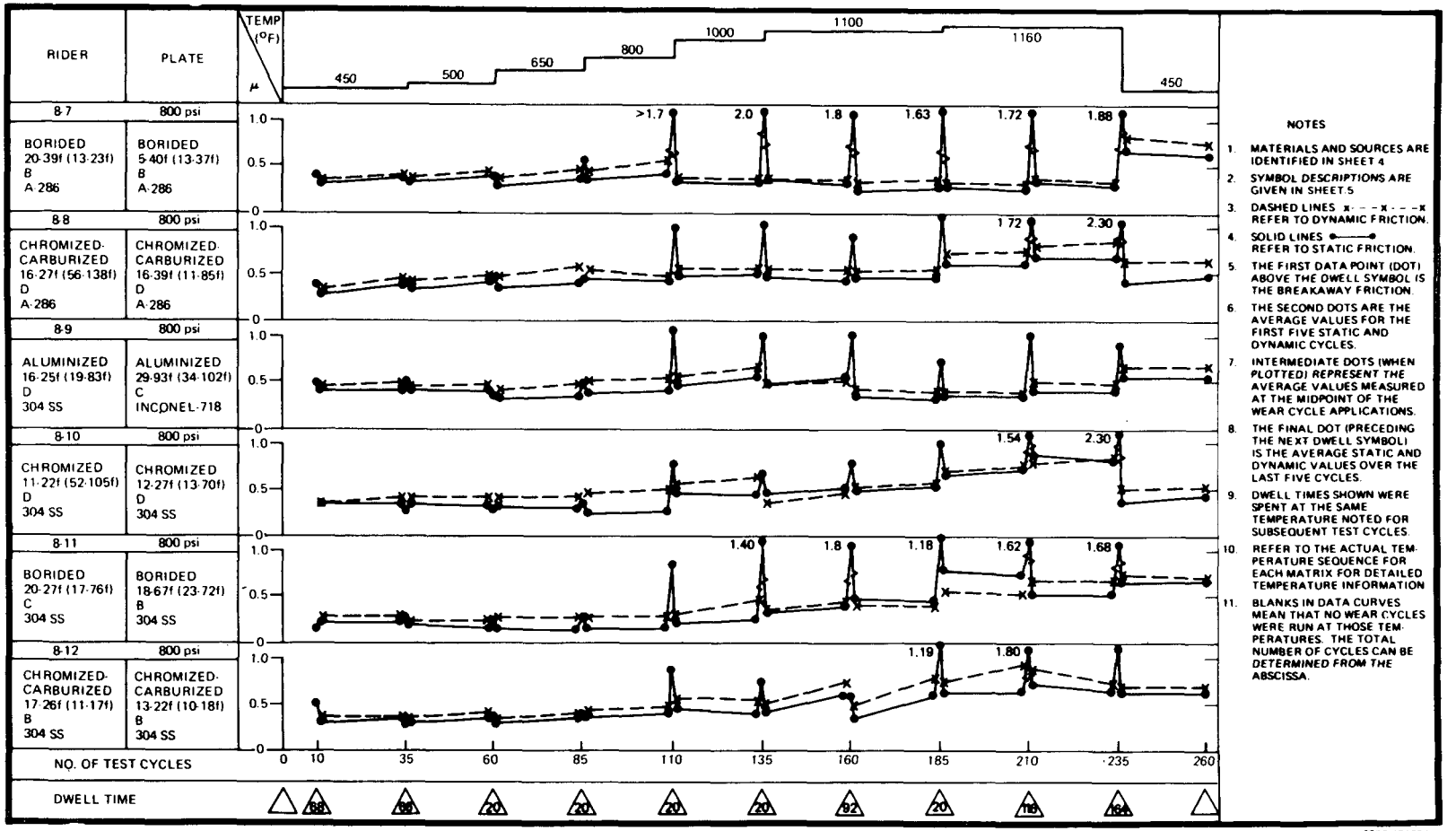


Figure 2. Friction Matrix No. 8 – Friction Coefficients vs Wear Cycles (Sheet 2 of 5)

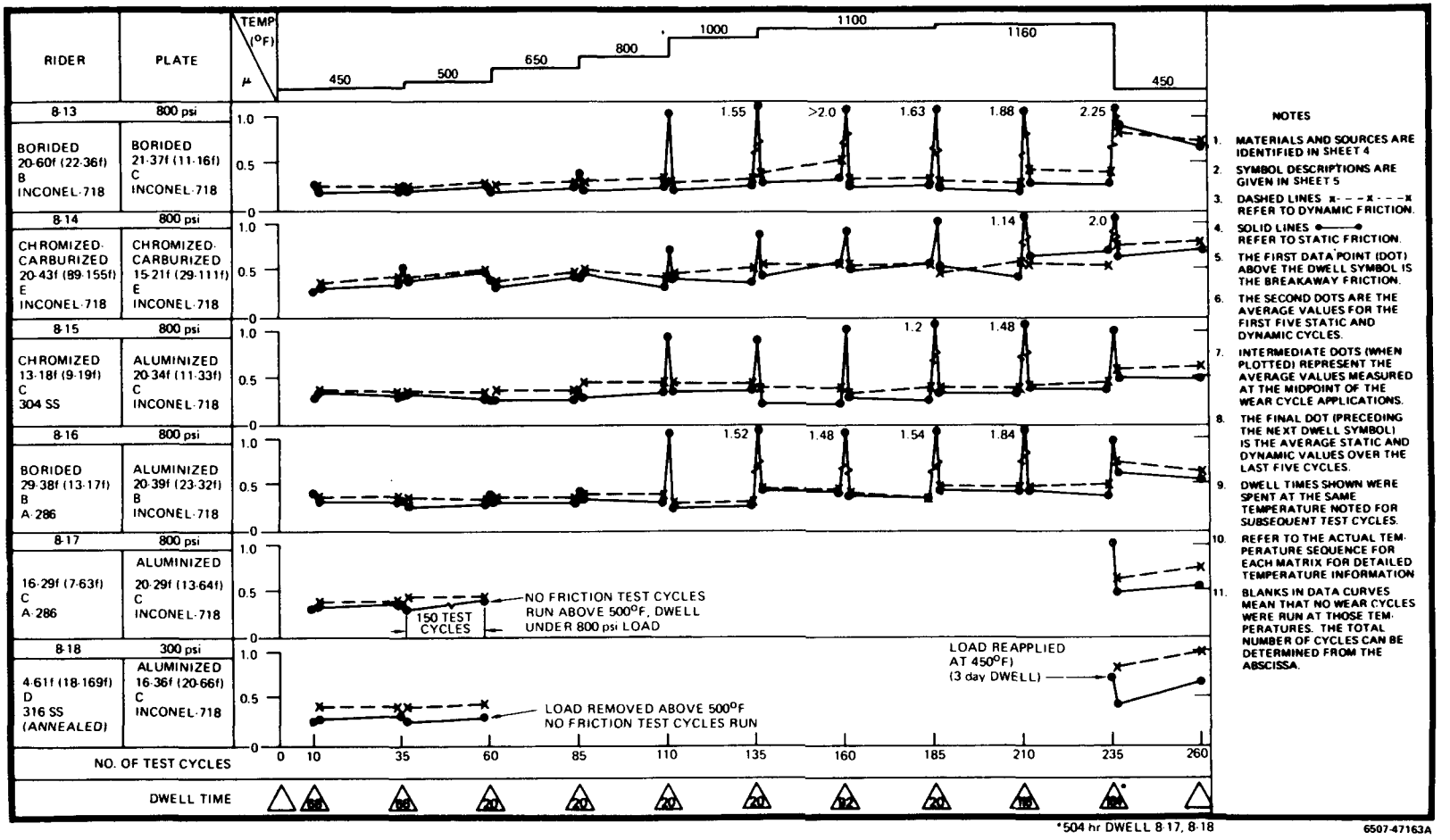


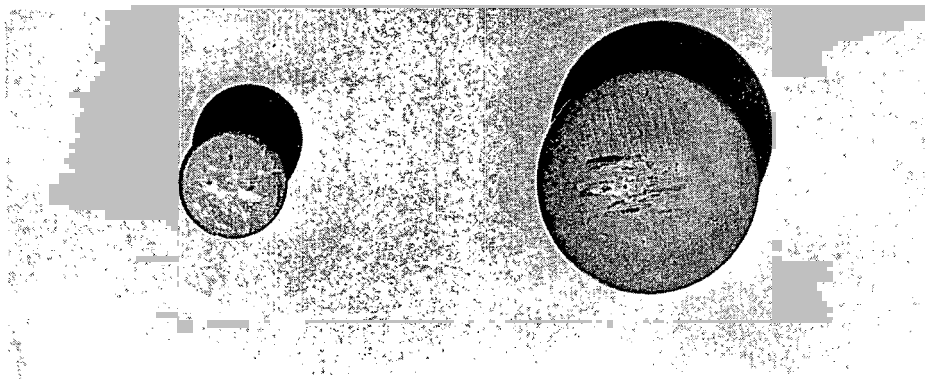
Figure 2. Friction Matrix No. 8 — Friction Coefficients vs Wear Cycles
(Sheet 3 of 5)

Term	Material and Source
A-286	Age-hardened steel with 25% Ni, 15% Cr, and 2% Ti
Aluminize	Diffusion of aluminum into an alloy surface coating. Nickel aluminide rich surface layer in nickel-containing alloys, Chromizing Co.
Aluminum Bronze	Ambco 22, aluminum-bronze alloy 14.1% Al, 4.7% Fe – Ampco Metal Co.
AmCerMet 701-N65	Proprietary nickel-chrome base cermet – Astro-Met Associates
AmCoMo 68-31	Proprietary cobalt-molybdenum base cermet – Astro Met Associates
AM 355	Precipitation-hardened steel with 16% Cr, 4% Ni, and 3% Mo
Ampco 22	See aluminum bronze
Boride	Diffusion of boron into an alloy surface coating. Chromizing Co.
Chromize	Diffusion of chromium into the surface, creating a chrome-rich layer, Chromizing Co.
Chromize-Carburize	Carbon-enriched chrome diffusion process. Outer layer 45% chrome (min.) and 0.5% carbon (min.). Chromizing Co.
CI	Chrome carbide, 15 vol % Inconel 718, applied on Type 316 stainless steel by plasma torch, Union Carbide Corp.
CI-D	Chrome carbide, 15 vol % Inconel, D gun on Type 316 stainless steel, Union Carbide Corp.
CM	Chrome carbide 20 vol % Mo, plasma spray on Type 316 stainless steel, Union Carbide Corp.
CN-1A	Chrome carbide, 15 vol % Nichrome, deposited on Type 316 stainless steel by detonation gun under "hot gun" conditions, Union Carbide Corp.
CN-1B	Chrome carbide, 15 vol % Nichrome, deposited on Type 316 stainless steel by detonation gun under "cooler gun" conditions, Union Carbide Corp.
CN-1P	Chrome carbide, 15 vol % Nichrome, plasma spray on Type 316 stainless steel, Union Carbide Corp.
Colomony 5	Weld-deposited material – nickel-base alloy with 11% Cr, 4% Fe, 3% Si, and 2% B, Wall Colomony Corp.
Cr-Plate	Hard chrome plate, per Federal Specification QQ-C-320, Class II
Cr_3C_2 - 15 Ni	Cr_3C_2 coating, applied by electric spark discharge method, Mech-Electron Corp.
$Cr_{23}C_6$	Chrome carbide ion diffusion coating on Type 316 stainless steel – Endurex Corp.
Electrolize	Proprietary chrome-plating process, Electrolize Corp.
Haynes 90	Iron-base alloy with 27% Cr – Stellite Division of Cabot Corp.
Haynes 273	Weld-deposited material – nickel-base alloy with 5.3% Fe, 17% Mo, and 16% Cr, Stellite Division of Cabot Corp.
Hastelloy C	Nickel-base alloy with 15% Mo and 16% Cr, Union Carbide Corp.
I 718	Inconel 718, International Nickel Corp.
Inconel X-750	Nickel-base alloy with 16% Cr, 7% Fe – International Nickel Corp.
K-ramic	Proprietary ceramic composite coating on Type 316 stainless steel – Kaman Sciences Corp.
K151A	TiC cermet – 81% TiC, 19% Ni, Kennametal Corp.
K165	TiC cermet – 83% TiC, 8.5% Mo, Kennametal Corp.
LC-1C	Detonation gun coating of Cr_3C_2 with 15% NiCr, Union Carbide Corp.
Metco 80NS	Chrome carbide with Nichrome, flame spray, Plasma Technology
Metco 81NS-10	Chrome carbide with Nichrome, flame spray, Plasma Technology
Metco 81VF-NS-12	Chrome carbide with Nichrome, flame spray, Plasma Technology
Metco 430-NS-10	Chrome carbide with nickel aluminide binder, flame spray, Plasma Technology
Ni Resist	High nickel base cast iron (with 30% Ni, 2% C, and 2.5% Si) ASTM A439 Type D3A
Stellite 6	Weld-deposited material – cobalt-base alloy with 27% Cr and 5% W, Stellite Division of Cabot Corp.
Stellite 6B	Wrought material – cobalt-base alloy with 27% Cr and 5% W – Stellite Division of Cabot Corp.
Stellite 1016	Weld-deposited material – cobalt-base alloy with 32% Cr and 17% W, Stellite Division of Cabot Corp.
TiC	Titanium carbide ion-diffusion coating on Type 316 stainless steel – Endurex Corp.
TiC-2	TiC - 10% Mo coating, applied by electric spark discharge method, Mech-Electron Corp.
TiC - 10 Mo	TiC - 10% Mo coating, applied by electric spark discharge method, Mech-Electron Corp. (Same as TiC-2)
TiC - 10 Nb	TiC - 10% Nb coating, applied by electric spark discharge method, Mech-Electron Corp.
TiC - TiN	Titanium carbide - titanium nitride ion-diffusion coating on Type 316 stainless steel – Endurex Corp.
TM	TiC with 15 wt % Mo, applied by plasma spraying, Union Carbide Corp.
TN	TiC with 15 wt % NiCr, applied by plasma spraying, Union Carbide Corp.
Tribaloy 120	NiCoMoSi DuPont coating, flame spray on Type 316 stainless steel, DuPont Corp.
Tribaloy 125	CoMoSiCr DuPont coating, flame spray on Type 316 stainless steel, DuPont Corp.
Tribaloy 400	CoMoSiCr DuPont coating, flame spray on Type 316 stainless steel, DuPont Corp.
Tribaloy 700	NiMoSiCr DuPont coating, weld deposited (WD) or plasma coated (PC) on Type 316 stainless steel – DuPont Corp.
Tribaloy 800	CoMoSiCr DuPont coating, weld deposited (WD) or plasma coated (PC) on Type 316 stainless steel, DuPont Corp.
TZM	Molybdenum alloy, with 99% Mo, 0.5% Ti, and 0.08% Zr
Vitrolube	MoS_2 dry-film lubricant with ceramic binder, coated on Type 316 SS – National Process Industries
17-4 PH	Precipitation-hardened steel with 17% Cr, 4% Ni, and 4% Cu
17-7 PH	Precipitation-hardened steel with 17% Cr, 7% Ni, and 1% Al

Figure 2. Friction Matrix No. 8 – Friction Coefficients vs wear Cycles (Coating Material Identification)
(Sheet 4 of 5)

Term	Description
A	Very low wear or essentially no wear
AR	As received
ARDB	As received, dry brush
ARWB	As received, wet brush
B	Low wear (have visible shiny spots, but have no physical surface damage)
B17-4PH	Base material was precipitation-hardened steel with 17% Cr, 4% Ni, and 4% Cu
B304	Base materials was Type 304 stainless steel
B316	Base material was Type 316 stainless steel
B I 718	Base material was Inconel 718
C	Medium wear (slightly scratched)
CDB	Cleaned, dry brush
CWB	Cleaned, wet brush
D	High wear (scratched, along with a few deep cuts)
E	Very high wear (heavily scratched, with or without welding spots)
ESD	Electric spark discharge process by Mech-Electron Corp.
FS	Flame sprayed
ND	Nondimensional finish. Tyrco wheel process, surface rms < 16
PC	Plasma coated (sprayed)
WD	Weld deposit
xxxf	Pre-test surface finish (i.e., 100 f = 100 roms)
(xxxf)	Post-test surface roughness [i.e. (100f) = 100 rms)]
16	Surface finish was 16 rms (or better) ground finish

Figure 2. Friction Matrix No. 8 — Friction Coefficients vs Wear Cycles (Coating Material Identification)
(Sheet 5 of 5

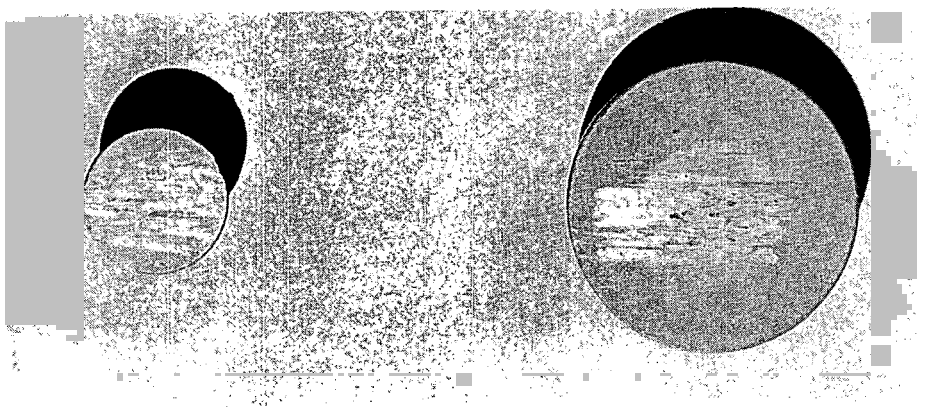


CHROMIZED-CARBURIZED HASTELLOY C

CHROMIZED-CARBURIZED HASTELLOY C

COUPLE 4

6507-51260

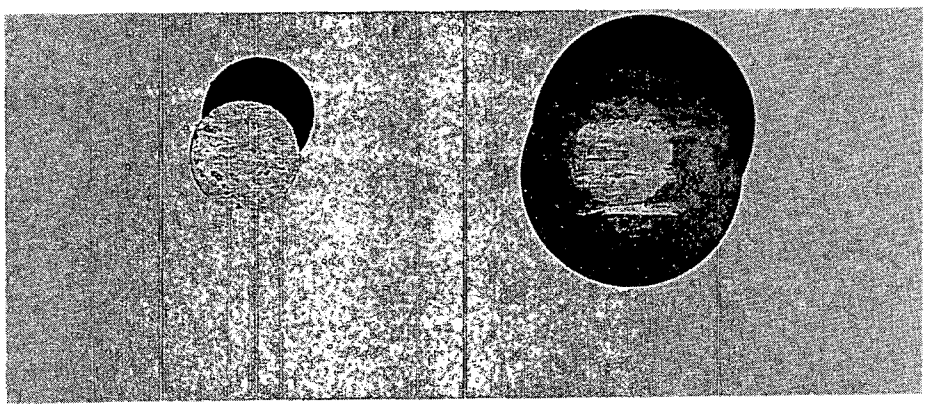


CHROMIZED-CARBURIZED A-286

CHROMIZED-CARBURIZED A-286

COUPLE 8

6507-51272



CHROMIZED-CARBURIZED INCONEL 718

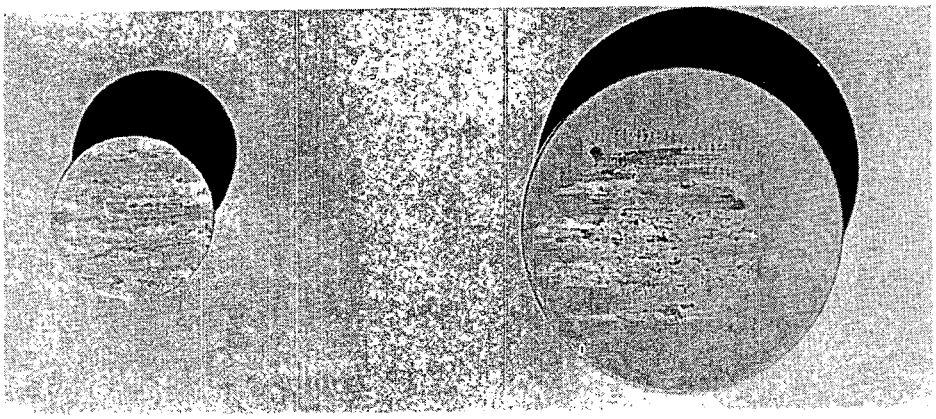
CHROMIZED-CARBURIZED INCONEL 718

COUPLE 14

6507-51263

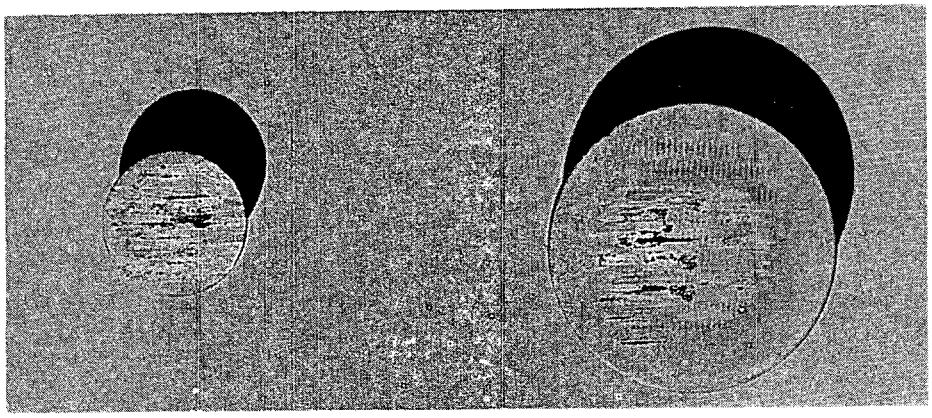
6507-51396

Figure 3. Matrix 8 – Friction Test Specimens
(Sheet 1 of 3)



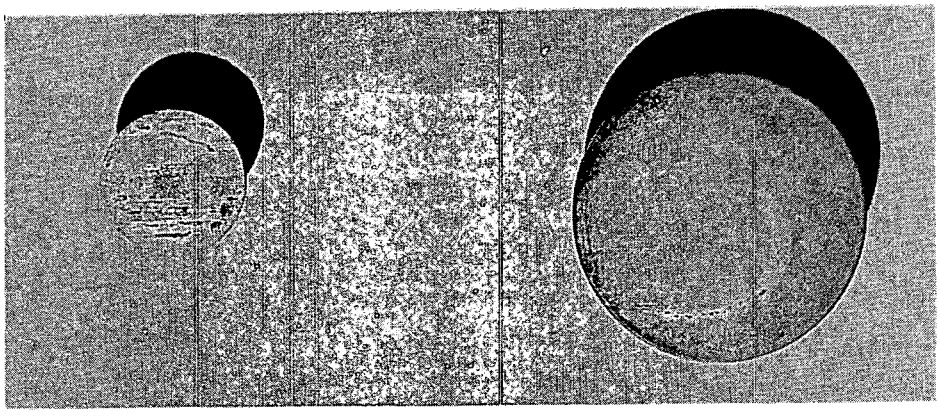
CHROMIZED A-286 — CHROMIZED A-286

COUPLE 6 — 6507-51271



CHROMIZED TYPE 304 SS — CHROMIZED TYPE 304 SS

COUPLE 10 — 6507-51259

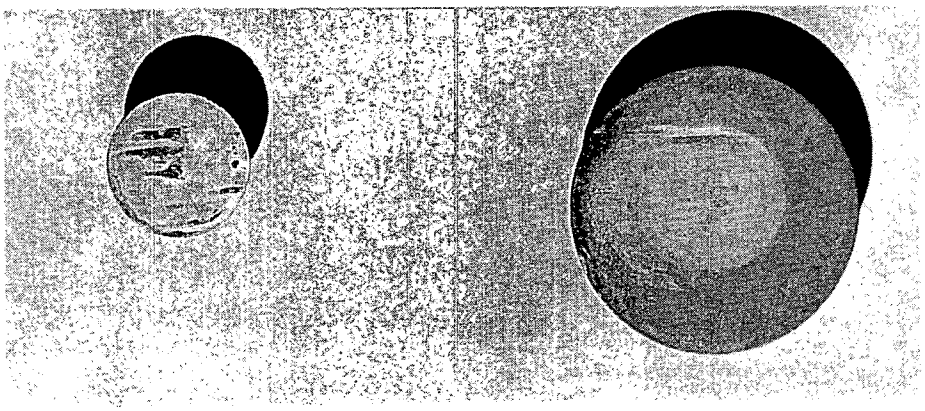


CHROMIZED TYPE 304 SS — ALUMINIZED INCONEL 718

COUPLE 15 — 6507-51269

6507-51397

Figure 3. Matrix 8 — Friction Test Specimens
(Sheet 2 of 3)

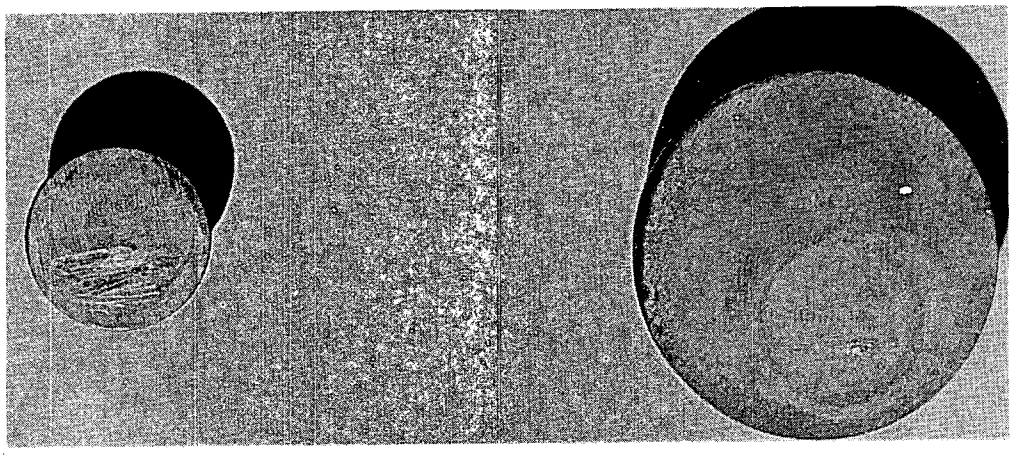


ALUMINIZED TYPE 304 SS

ALUMINIZED INCONEL 718

COUPLE 9

6507-51273

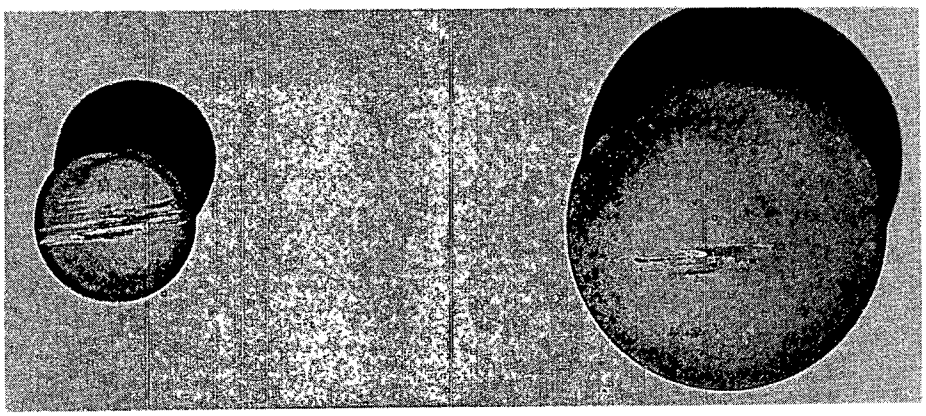


A-286

ALUMINIZED INCONEL 718

COUPLE 17

6507-51262



TYPE 316 SS (ANNEALED)

ALUMINIZED INCONEL 718

COUPLE 18

6507-51264

6507-51398

Figure 3. Matrix 8 – Friction Test Specimens
(Sheet 3 of 3)

TABLE 3

DATA SUMMARY – FRICTION TEST 8
(Sheet 1 of 6)

Test			Test Conditions						Friction Results							Comments
Number	Materials		Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in. /sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Static Friction			Dynamic Friction			
	Pin	Plate								Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
8-1	Aluminized Hastelloy C	Aluminized Hastelloy C	450	157.1/800	0.07	d/2	35/17.5	68	0.36	0.36	0.42	0.42	0.38	0.43	0.43	Previous experience includes 10/5 at 450° prior to cold trapping
							260/130	164	1.10	0.40	0.43	0.43	0.52	0.52	0.45	Rubbing experience includes prior 35/17.5 at 450° F plus 200/100 at other temp. levels
	17-51f (11-31f)	31-78f (21-58f)	800				110/55	20	0.56	0.40	0.40	0.39	0.40	0.48	0.48	Rubbing experience includes 85/42.5 at lower temperature levels
			1160				210/105	20	1.02	0.45	0.45	0.42	0.54	0.59	0.58	Rubbing experience includes 185/92.5 at lower temp. levels
							235/117.5	116	1.24	0.24	0.27	0.27	0.43	0.43	0.36	Rubbing experience includes 185/92.5 at lower temp. levels plus 25/12.5 at prior 1160°F
8-2	Chromized Hastelloy C	Chromized Hastelloy C	450				35/17.5	68	0.34	0.30	0.38	0.38	0.31	0.42	0.42	
							260/130	164	1.43	0.51	0.56	0.56	0.62	0.69	0.69	
	11-22f (17-27f)	11-38f (9-20f)	800				110/55	20	0.46	0.52	0.59	0.59	0.55	0.65	0.65	Same as 8-1
			1160				210/105	20	1.18	0.49	0.57	0.57	0.58	0.68	0.68	
							235/117.5	116	1.44	0.46	0.50	0.46	0.58	0.66	0.66	
8-3	Chromize-Carburized 304 SS	Aluminized 718 1	450				35/17.5	68	0.37	0.33	0.33	0.31	0.36	0.38	0.38	
							260/130	164	1.10	0.50	0.50	0.50	0.60	0.60	0.58	
	12-18f (8-24f)	31-56f (17-34f)	800				110/55	20	0.56	0.35	0.40	0.40	0.46	0.54	0.54	Same as 8-1
			1160	157.1/800	0.07	d/2	210/105	20	1.24	(1)	0.37	0.36	0.43	0.37	0.36	
							235/117.5	116	1.06	0.52	0.52	0.20	0.40	0.40	0.31	

(1) Initial static friction data unreadable on chart paper.

TABLE 3

DATA SUMMARY – FRICTION TEST 8
(Sheet 2 of 6)

Test			Test Conditions						Friction Results							Comments
Number	Materials		Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in. /sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Break-away Friction	Static Friction			Dynamic Friction			
	Pin	Plate								Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
8-4	Chromize-Carburized Hastelloy C	Chromize-Carburized Hastelloy C	450	157.1/800	0.07	d/2	35/17.5	68	0.47	0.38	0.55	0.55	0.37	0.52	0.52	
							260/130	164	1.28	0.64	0.64	0.60	0.79	0.86	0.86	
	11-20f (44-144f)	31-67f (13-161f)	800				110/55	20	0.60	0.48	0.58	0.58	0.52	0.59	0.59	Same as 8-1
			1160				210/105	20	1.01	0.48	0.67	0.67	0.54 (2)	0.70	0.70	
							235/117.5	116	1.08	0.59	0.59	0.52	0.60	0.77	0.77	
8-5	Aluminized A-286	Aluminized A-286	450				35/17.5	68	0.50	(1)	0.30	0.30	(1)	0.28	0.28	
							260/130	164	1.38	0.52	0.56	0.56	0.64	0.73	0.73	
	27-40f (24-58f)	22-44f (13-33f)	800				110/55	20	0.65	0.41	0.41	0.30	0.49	0.50	0.50	Same as 8-1
			1160				210/105	20	0.82	0.59	0.59	0.35	0.58	0.58	0.55	
							235/117.5	116	0.96	0.56	0.56	0.42	0.50	0.50	0.47	
8-6	Chromized A-286	Chromized A-286	450				35/17.5	68	0.39	0.19	0.37	0.37	0.33	0.40	0.40	
							260/130	164	>2.0	0.51	0.51	0.50	0.71	0.79	0.79	
	16-27f (89-118f)	11-29f (36-178f)	800				110/55	20	0.41	0.34	0.41	0.41	0.36	0.55	0.55	Same as 8-1
			1160	157.1/800	0.07	d/2	210/105	20	1.25	0.77	0.77	0.77	0.77	0.89	0.89	
							235/117.5	116	1.56	1.13	1.13	0.75	0.84	0.99	0.99	

(1) Initial values unreadable on chart paper.
(2) Squeaky during first 10 cycles.

TABLE 3

DATA SUMMARY – FRICTION TEST 8
(Sheet 3 of 6)

Test			Test Conditions						Friction Results							Comments
Number	Materials		Temperature (° F)	Load/ Pressure (lb)/(psi)	Average Velocity (in. /sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Break-away Friction	Static Friction			Dynamic Friction			
	Pin	Plate								Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
8-7	Borided A-286	Borided A-286	450	157.1/800	0.07	d/2	35/17.5	68	0.39	0.36	0.36	0.35	0.35	0.38	0.38	
							260/130	164	1.88	0.73	0.73	0.62	0.72	0.82	0.76	
	20-39f (13-23f)	5-40f (13-37f)	800				110/55	20	0.57	0.36	0.39	0.39	0.36	0.56	0.56	Same as 8-1
			1160				210/105	20	1.63	0.53	0.53	0.34	0.32	0.32	0.31	
							235/117.5	116	1.72	0.53	0.53	0.29	0.33	0.36	0.34	
8-8	Chromize-Carburized A-286	Chromize-Carburized A-286	450				35/17	68	0.37	(1)	0.38	0.38	0.32	0.42	0.42	
							260/130	164	2.3	0.48	0.48	0.48	0.59	0.67	0.67	
	16-27f (56-138f)	16-29f (11-85f)	800				110/55	20	0.43	0.41	0.43	0.41	0.48	0.54	0.46	Same as 8-1
			1160				210/105	20	1.15	0.70	0.70	0.60	0.71	0.78	0.78	
							235/117.5	116	1.72	1.30	1.30	0.68	0.82	0.88	0.88	
8-9	Aluminized 304 SS	Aluminized 718f	450				35/17.5	68	0.48	0.37	0.41	0.41	0.39	0.48	0.48	
							260/130	164	0.94	0.63	0.63	0.56	0.66	0.70	0.70	
	16-25f (19-83f)	29-93f (34-102f)	800				110/55	20	0.50	0.39	0.40	0.40	0.47	0.54	0.54	Same as 8-1
			1160	157.1/800	0.07	d/2	210/105	20	0.70	0.54	0.54	0.35	0.43	0.43	0.38	
							235/117.5	116	1.04	0.48	0.48	0.40	0.53	0.53	0.48	

(1) Value unreadable on chart paper

TABLE 3

DATA SUMMARY – FRICTION TEST 8
(Sheet 4 of 6)

Test			Test Conditions						Friction Results							
	Materials									Static Friction			Dynamic Friction			
Number	Pin	Plate	Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in./sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	Comments
8-10	Chromized 304SS	Chromized 304SS	450	157./800	0.07	d/2	35/17.5	68	0.37	0.32	0.33	0.33	0.36	0.36	0.33	
							260/130	164	2.30	0.53	0.53	0.43	0.51	0.54	0.54	
	11-22f (52-105f)	12-27f (13-70f)	800				110/55	20	0.33	0.34	0.37	0.37	0.42	0.50	0.50	Same as 8-1
			1600				210/105	20	1.02	0.99	0.99	0.72	0.69	0.76	0.76	
							235/117.5	116	1.54	1.03	1.03	0.83	0.87	0.87	0.86	
8-11	Borided 304SS	Borided 304SS	450				35/17.5	68	0.13	0.30	0.30	0.21	0.31	0.31	0.28	
							260/130	164	1.68	0.71	0.71	0.70	0.84	0.84	0.73	
	20-27f (17-76f)	18-67f (23-72f)	800				110/55	20	0.25	0.19	0.19	0.16	0.28	0.30	0.30	Same as 8-1
			1600				210/105	20	1.18	0.84	0.84	0.75	0.58	0.58	0.53	
							235/117.5	116	1.62	0.50	0.5	0.52	0.66	0.69	0.68	
8-12	Chromize-Carburized 304SS	Chromize-Carburized 304SS	450				35/17.5	68	0.50	0.32	0.33	0.33	0.33	0.37	0.37	
							260/130	164	0.90	0.61	0.62	0.62	0.71	0.71	0.70	
	17-26f (11-17f)	13-22f (10-18f)	800				110/55	20	0.38	0.36	0.39	0.39	0.40	0.47	0.47	Same as 8-1
			1160	157.1/800	0.07	d/2	210/105	20	1.19	0.72	0.72	0.64	0.66	0.94	0.94	
							235/117.5	116	1.80	0.81	0.81	0.65	0.81	0.89	0.73	

TABLE 3

DATA SUMMARY – FRICTION TEST 8
(Sheet 5 of 6)

Test			Test Conditions						Friction Results							Comments
Number	Materials		Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in. /sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Break-away Friction	Static Friction			Dynamic Friction			
	Pin	Plate								Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
8-13	Borided 718 I	Borided 718 I	450	157.1/800	0.07	d/2	35/17.5	68	0.24	0.20	0.20	0.18	0.22	0.24	0.24	
							260/130	164	2.25	0.96	0.96	0.70	0.89	0.89	0.77	
	20-60f (22-36f)	21-37f (11-16f)	800				110/55	20	0.37	0.22	0.22	0.22	0.18	0.34	0.34	Same as 8-1
			1160				210/105	20	1.63	0.50	0.50	0.19	0.32	0.32	0.30	
							235/17.5	116	1.88	0.51	0.51	0.28	0.41	0.43	0.42	
8-14	Chromize-Carburized 718 I	Chromize-Carburized 718 I	450				35/17.5	68	0.26	0.30	0.34	0.34	0.33	0.42	0.42	
							260/130	164	2.0	0.70	0.73	0.73	0.74	0.84	0.84	
	20-43f (89-155f)	15-21f (29-111f)	800				110/55	20	0.40	0.47	0.47	0.30	0.46	0.50	0.41	Same as 8-1
			1160				210/105	20	1.03	0.61	0.61	0.43	0.62	0.62	0.60	
							235/117.5	116	1.14	0.71	0.72	0.72	0.56	0.58	0.57	
8-15	Chromized 304SS	Aluminized 718 I	450				35/17.5	68	0.25	0.31	0.32	0.29	0.32	0.35	0.32	
							260/130	164	1.04	0.49	0.52	0.52	0.60	0.60	0.63	
	13-18f (9-19f)	20-34f (11-33f)	800				110/55	20	0.35	0.30	0.32	0.32	0.40	0.44	0.44	Same as 8-1
			1160	157.1/800	0.07	d/2	210/105	20	1.20	0.53	0.53	0.32	0.36	0.40	0.39	
							235/117.5	116	1.48	0.53	0.53	0.37	0.37	0.46	0.46	

TABLE 3

DATA SUMMARY – FRICTION TEST 8
(Sheet 6 of 6)

Test			Test Conditions						Friction Results							Comments
	Materials									Static Friction			Dynamic Friction			
Number	Pin	Plate	Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in. /sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
8-16	Borided A-286	Aluminized 718 I	450	157.1/800	0.07	d/2	35/17.5	68	0.39	0.40	0.40	0.30	0.43	0.43	0.36	
							260/130	164	1.04	0.71	0.71	0.58	0.69	0.76	0.67	
	29-38f (13-17f)	20-39f (23-32f)	800				110/55	20	0.42	0.41	0.41	0.30	0.38	0.38	0.38	Same as 8-1
			1160				210/105	20	1.54	0.81	0.81	0.44	0.48	0.48	0.47	
							235/117.5	116	1.84	0.86	0.86	0.38	0.47	0.52	0.52	
8-17	A-286	Aluminized 718 I	450				35/17.5	68	0.30	0.31	0.37	0.37	0.34	0.40	0.40	Rubbing experience includes 10/5 at 450°F prior to cold trapping
							210/105	504	1.06	0.61	0.61	0.58	0.69	0.78	0.78	Rubbing experience includes prior 35/17.5 at 450°F plus 150/75 at 500°F
	16-20f (7-63f)	20-29f (13-64f)	500(1)	157.1/800			185/92.5	70	0.35	0.37	0.40	0.40	0.35	0.48	0.48	Rubbing experience includes 35/17.5 at 450°F
8-18	Annealed 316SS	Aluminized 718 I	450	58.9/300			35/17.5	68	0.23	0.29	0.29	0.29	0.37	0.41	0.41	Rubbing experience includes 10/5 at 450°F prior to cold trapping
							85/42.5	504	0.73	0.90	0.90	0.70	0.98	1.02	1.02	Rubbing experience includes prior 35/17.5 at 450°F plus 25/12.5 at 500°F
	4-61f (18-169f)	16-36f (20-66f)	500(2)	58.9/300	0.07	d/2	60/30	70	0.30	0.30	0.30	0.30	0.45	0.47	0	Rubbing experience includes 35/17.5 at 450°F

(1) No cycles run above 500°F. 150 total cycles run at 500°F. Load remained on couple at all temperatures above 500°F.
(2) No cycles or data taken above 500°F. Load removed above 500°F.

chromized Type 304 stainless steel against aluminized Inconel 718. In this case, the chromized rider experienced the damage, and the aluminized plate was relatively unaffected. Of this group, Couple No. 15 was the best performer, as far as friction was concerned, inasmuch as it displayed static and dynamic friction coefficients at 0.4 or less over the entire temperature range. Breakaway values at high temperature, however, were as high as 1.48.

Seven couples evaluated aluminized coatings on one or both test parts. Generally, the static and dynamic friction coefficients did not exceed 0.5, over the bulk of the entire temperature range, but all showed the undesirable high-temperature breakaway peaks. No wear was evident on Couple No. 1 — aluminized Hastelloy C vs itself, or on Couple No. 16 — borided A-286 vs aluminized Inconel 718. Light wear occurred on both the rider and plate of Couple No. 5 — aluminized A-286 vs itself; while, on Couple No. 9, moderate wear occurred on the aluminized Type 304 stainless-steel rider, but not on the aluminized Inconel 718 plate. The remaining couples [No. 15 — chromized Type 304 stainless steel vs aluminized Inconel 718, No. 17 — A-286 vs aluminized Inconel 718, and No. 18 — Type 316 stainless steel (annealed) vs aluminized Inconel 718] all sustained moderate to heavy surface damage, but primarily on the nonaluminized surface only. All of the preceding observations of wear are based on visual inspection and evaluation. No metallurgical examinations were made of the coating condition or depth, or of the type and extent of wear.

B. FRICTION MATRIX 9

The ninth test matrix, Table 4, was tested to the temperature sequence shown in Figure 4. Testing was performed without deviation from the noted operational procedures. Sodium samples, taken periodically during the test and analyzed for oxygen content per ANL/ST-6, showed that the oxygen level remained below the 5-ppm maximum allowable content.

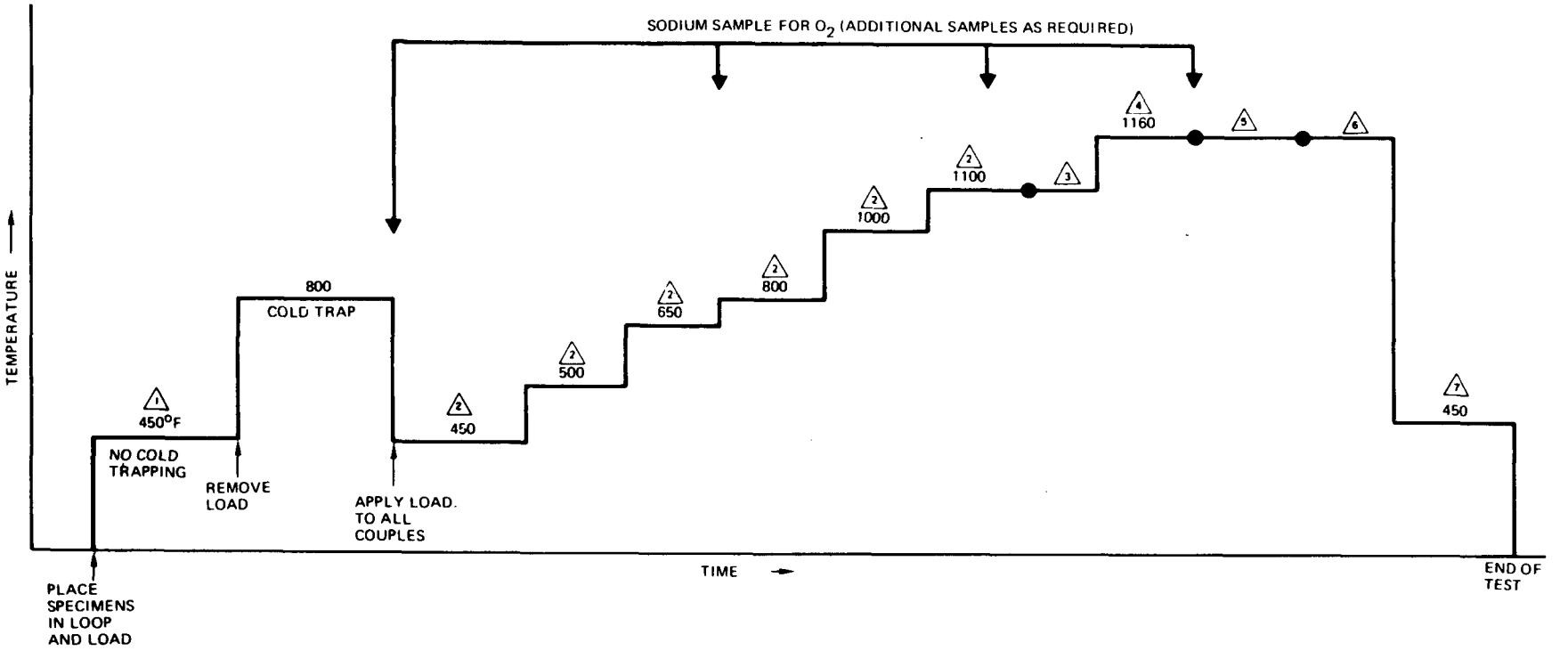
Breakaway, static, and dynamic friction coefficients were measured, as required, at each temperature level. The breakaway friction coefficient was computed, using the value of the load which was required to initiate movement on the first wear cycle following the dwell period. The static and dynamic friction coefficients were computed, using the average of the values observed during Wear Cycles 2 and 5 with those measured during Cycle 20 to 25. When

TABLE 4

FRICTION MATRIX NO. 9

Couple No.	Rider	Plate	Load (psi)
1	Tribaloy 400 (WD)	Tribaloy 400 (WD)	800
2	Tribaloy 800 (PC)	Tribaloy 800 (PC)	800
3	Tribaloy 700 (PC)	Tribaloy 700 (PC)	800
4	Tribaloy 700 (PC)	Tribaloy 700 (PC)	300
5	Tribaloy 400 (WD)	Inconel 718	800
6	Tribaloy 800 (PC)	Inconel 718	800
7	Tribaloy 800 (PC)	Aluminized I 718	800
8	Tribaloy 800 (PC)	Stellite 6B	800
9	Aluminized I 718	Tribaloy 400 (WD)	800
10*	Chromized/Carburized 304 SS	Aluminized I 718	300
11	Stellite 6B	Aluminized I 718	800
12*	Borided A-286	Borided A-286	300
13*	Chromized/Carburized 304 SS	Chromized/Carburized 304 SS	300
14*	Borided A-286	Aluminized I 718	300
15*	Aluminized Hastelloy C	Aluminized Hastelloy C	300
16	Tribaloy 700 (WD)	Tribaloy 700 (WD)	800
17	Tribaloy 700 (WD)	Inconel 718	800
18	Tribaloy 700 (WD)	Aluminized I 718	800

*Couples repeated from Matrix 8
(WD) Weld Deposited
(PC) Plasma Coated



1. APPLY LOAD TO COUPLES, RUB 10 CYCLES
2. AFTER OVERNIGHT DWELL, APPLY 25 WEAR CYCLES
3. AFTER 3-day DWELL MINIMUM, APPLY 25 CYCLES
4. AFTER OVERNIGHT DWELL, APPLY 25 CYCLES
5. AFTER 3-day DWELL MINIMUM, APPLY 25 CYCLES
6. DWELL OVERNIGHT (16-hr MINIMUM) UNDER SPECIFIED LOAD. DO NOT APPLY ANY WEAR CYCLES
7. AFTER A 3-day MINIMUM DWELL, APPLY 25 CYCLES

GENERAL TEST CONDITIONS

1. TEMPERATURE CHANGE OF 50°F/hr (MAX.)
2. STABLE TEMPERATURE ±5°F
3. PLUGGING TEMPERATURE AT EACH TEMPERATURE LEVEL
4. O_2 CONTENT TO BE 5 ppm OR LESS THROUGHOUT TEST
5. OVERNIGHT DWELLS TO BE 16 hr MINIMUM

6507-47133D

Figure 4. Temperature Sequence for Ninth Test Matrix

these various friction coefficients were plotted to show each couple's friction characteristics vs the combination of temperature and wear cycle accumulation, much higher than expected friction coefficients were indicated, when compared with the results on the same material combinations in previous matrices. Consequently, a comprehensive review of the calibration, operation procedures, data reduction, and data interpretation was made.

A comparison of the pre- and post-test calibrations revealed that a dramatic change in transducer sensitivity occurred at an undetermined point in time following the pretest calibration. Assuming the change to be a step change, the subsequent data would be high by a factor of 2.56. Insufficient information existed to establish, with any real certainty, the time or rate of change of instrument sensitivity. Consequently, it was decided jointly by AI and HEDL to run an additional test matrix, 9A, to obtain sufficient information to establish a correction factor to be used with the Matrix 9 data. HEDL specified the 9A matrix composition utilizing the reuse of twelve couples (1, 2, 3, 5, 6, 7, 8, 9, 10, 13, 17, and 18) from the ninth matrix. The use of so many "repeat" couples in Matrix 9A was intended not only to generate sufficient information to provide a correction factor for the Matrix 9 tests, but also to provide the first bit of statistical data concerning specimens of identical material composition.

Subsequent testing of Matrix 9A (as discussed in the next section) showed that a step change in the calibration occurred after the pretest calibration but before start of the test. Therefore, all Matrix 9 data were corrected by a factor of 2.56 and are presented accordingly in this section.

A tabulation of the revised Matrix 9 data is given in Table 5. Plots of the friction coefficients vs temperature levels appear in Figure 5. Photographs taken after test of the three most severely worn specimens appear in Figure 6. Test data are also presented in the summary table format (specified by HEDL) in Table 6.

In general, the Tribaloy materials demonstrated excellent wear characteristics. The only evidence of any surface deformation was that which could be described as a surface "polishing," wherein high spots were smoothed out.

TABLE 5
DATA SUMMARY – FRICTION TEST 9
(Sheet 1 of 2)

Couple	Rider	Plate	Contact Pressure (psi)	Breakaway(B) Static(S)* Dynamic(D)*	Friction Coefficient										
					450°F§	450°F ⚠	500°F ⚠	650°F ⚠	800°F ⚠	1000°F ⚠	1100°F ⚠	1100°F ⚠	1160°F ⚠	1160°F ⚠	450°F ⚠
					0-10 Cycles	11-35 Cycles	36-60 Cycles	61-85 Cycles	86-110 Cycles	110-135 Cycles	136-160 Cycles	161-185 Cycles	185-210 Cycles	211-235 Cycles	235-260 Cycles
1	Tribaloy 400 (WD)	Tribaloy 400 (WD)	800	B	-	0.16	0.22	0.26	0.34	0.44	>0.78	0.78	0.73	1.02	0.33
				S	0.20	0.18	0.27	0.23	0.34	0.38	0.46	0.44	0.38	0.47	0.30
				D	0.25	0.23	0.31	0.30	0.37	0.43	0.47	0.48	0.43	0.48	0.45
2	Tribaloy 800 (PC)	Tribaloy 800 (PC)	800	B	-	0.17	0.28	0.25	0.29	0.54	0.88	0.65	0.68	1.02	>0.78
				S	0.39	0.22	0.29	0.23	0.21	0.22	0.24	0.25	0.29	0.31	0.36
				D	0.49	0.29	0.34	0.29	0.25	0.29	0.37	0.32	0.30	0.34	0.43
3	Tribaloy 700 (PC)	Tribaloy 700 (PC)	800	B	-	0.14	0.17	0.22	0.36	0.66	1.21	1.07	0.98	0.94	1.17
				S	0.39	0.14	0.17	0.20	0.30	0.40	0.45	0.45	0.42	0.45	0.66
				D	0.47	0.22	0.27	0.26	0.34	0.46	0.55	0.53	0.48	0.52	0.71
4	Tribaloy 700 (PC)	Tribaloy 700 (PC)	300	B	-	0.18	0.22	0.18	0.25	0.56	0.74	0.38	0.25	0.39	0.47
				S	0.58	0.18	0.22	0.22	0.22	0.23	0.19	0.32	0.30	0.29	0.36
				D	0.65	0.29	0.37	0.39	0.33	0.33	0.34	0.38	0.35	0.38	0.59
5	Tribaloy 400 (WD)	Inconel 718	800	B	-	>0.35	0.28	0.47	0.33	0.48	0.84	0.69	0.57	0.88	0.39
				S	0.50	0.25	0.27	0.47	0.46	0.46	0.42	0.44	0.29	0.34	0.46
				D	0.64	0.40	0.34	0.52	0.50	0.57	0.45	0.45	0.45	0.47	0.57
6	Tribaloy 800 (PC)	Inconel 718	800	B	-	0.21	0.20	0.22	0.25	0.40	0.82	0.43	0.63	0.86	0.66
				S	0.37	0.25	0.27	0.28	0.30	0.39	0.46	0.43	0.40	0.48	0.50
				D	0.42	0.32	0.32	0.32	0.34	0.44	0.52	0.53	0.45	0.50	0.58
7	Tribaloy 800 (PC)	Aluminized I 718	800	B	-	0.18	0.27	0.23	0.31	0.54	0.82	0.74	0.26	0.88	0.51
				S	0.26	0.27	0.29	0.28	0.28	0.25	0.28	0.21	0.28	0.35	0.40
				D	0.38	0.30	0.33	0.32	0.34	0.32	0.39	0.28	0.39	0.49	0.53
8	Tribaloy 800 (PC)	Stellite 6B	800	B	-	0.20	0.18	0.23	0.26	0.44	0.70	0.44	0.59	0.72	0.48
				S	0.20	0.13	0.14	0.19	0.25	0.31	0.35	0.36	0.18	0.30	0.34
				D	0.23	0.27	0.21	0.23	0.31	0.36	0.43	0.40	0.23	0.27	0.39
9	Aluminized I 718	Tribaloy 400 (WD)	800	B	-	0.18	0.27	0.26	0.31	0.57	0.47	0.94	0.82	1.09	0.76
				S	0.37	0.23	0.29	0.32	0.32	0.37	0.43	0.43	0.46	0.41	0.46
				D	0.41	0.35	0.34	0.35	0.36	0.42	0.52	0.56	0.52	0.53	0.55
10†	Chromized-Carburized Type 304 SS	Aluminized I 718	300	B	-	0.25	0.23	0.38	0.34	0.60	0.78	0.56	0.54	0.70	0.66
				S	0.22	0.30	0.38	0.30	0.39	0.20	0.15	0.21	0.10	0.13	0.30
				D	0.29	0.43	0.45	0.35	0.43	0.41	0.33	0.34	0.18	0.29	0.54
11	Stellite 6B	Aluminized I 718	800	B	-	0.23	0.23	0.26	0.25	0.45	0.66	0.63	0.58	0.81	0.51
				S	0.35	0.19	0.23	0.20	0.22	0.24	0.29	0.35	0.28	0.25	0.33
				D	0.41	0.35	0.34	0.26	0.32	0.36	0.42	0.39	0.31	0.39	0.56
12†	Borided A-286	Borided A-286	300	B	-	0.14	0.21	0.21	0.23	0.48	0.76	0.66	0.55	0.82	0.82
				S	0.20	0.21	0.20	0.19	0.14	0.18	0.20	0.21	0.20	0.20	0.32
				D	0.32	0.30	0.33	0.27	0.23	0.36	0.32	0.36	0.31	0.36	0.59

TABLE 5

DATA SUMMARY – FRICTION TEST 9
(Sheet 2 of 2)

Couple	Rider	Plate	Contact Pressure (psi)	Breakaway(B) Static(S)* Dynamic(D)*	Friction Coefficient										
					450°F§	450°F ⚠	500°F ⚠	650°F ⚠	800°F ⚠	1000°F ⚠	1100°F ⚠	1100°F ⚠⚠	1160°F ⚠	1160°F ⚠⚠	450°F ⚠⚠
					0-10 Cycles	11-35 Cycles	36-60 Cycles	61-85 Cycles	86-110 Cycles	110-135 Cycles	136-160 Cycles	161-185 Cycles	185-210 Cycles	211-235 Cycles	235-260 Cycles
13†	Chromized-Carburized Type 304 SS	Chromized-Carburized Type 304 SS	300	B	-	0.14	0.17	0.22	0.29	0.59	1.37	1.41	1.02	1.21	0.43
				S	0.07	0.15	0.15	0.22	0.30	0.50	0.35	0.34	0.38	0.40	0.38
				D	0.18	0.23	0.25	0.28	0.38	0.56	0.54	0.43	0.41	0.52	0.63
14†	Borided A-286	Aluminized I 718	300	B	-	0.08	0.09	0.08	0.19	0.44	0.64	0.59	0.55	0.88	0.64
				S	0.16	0.06	0.11	0.10	0.17	0.19	0.16	0.14	0.21	0.18	0.32
				D	0.32	0.19	0.25	0.22	0.23	0.30	0.27	0.28	0.30	0.27	0.48
15†	Aluminized Hastelloy C	Aluminized Hastelloy C	300	B	-	0.14	0.13	0.16	0.27	0.47	1.02	0.84	0.68	1.25	1.09
				S	0.13	0.11	0.09	0.16	0.30	0.25	0.30	0.32	0.39	0.36	0.37
				D	0.33	0.21	0.13	0.26	0.43	0.40	0.41	0.47	0.48	0.55	0.59
16	Tribaloy 700 (WD)	Tribaloy 700 (WD)	800	B	-	0.13	0.23	0.27	0.34	0.59	1.09	1.11	0.90	1.33	0.50
				S	0.25	0.19	0.23	0.30	0.33	0.32	0.29	0.30	0.30	0.36	0.56
				D	0.34	0.25	0.29	0.34	0.39	0.40	0.45	0.36	0.36	0.45	0.58
17	Tribaloy 700 (WD)	Inconel 718	800	B	-	0.23	0.35	0.23	0.35	0.50	0.80	0.67	0.68	0.86	0.53
				S	0.31	0.34	0.39	0.39	0.41	0.45	0.36	0.18	0.29	0.38	0.48
				D	0.51	0.39	0.45	0.47	0.42	0.53	0.45	0.20	0.37	0.47	0.55
18	Tribaloy 700 (WD)	Aluminized I 718	800	B	-	0.19	0.24	0.26	0.27	0.46	0.66	0.66	0.70	1.17	0.48
				S	0.29	0.23	0.30	0.28	0.29	0.29	0.23	0.23	0.26	0.36	0.37
				D	0.37	0.30	0.36	0.30	0.36	0.42	0.40	0.36	0.31	0.38	0.43

*Average observed during Cycles 2 to 10 and 19 to 24
(WD) Weld Deposited (PC) Plasma Coated
†Couples repeated from Matrix 8
§Prior to cold trapping

⚠ Measurements made after overnight dwell (16-hr minimum)
⚠⚠ Measurements made after 3-day dwell (minimum)

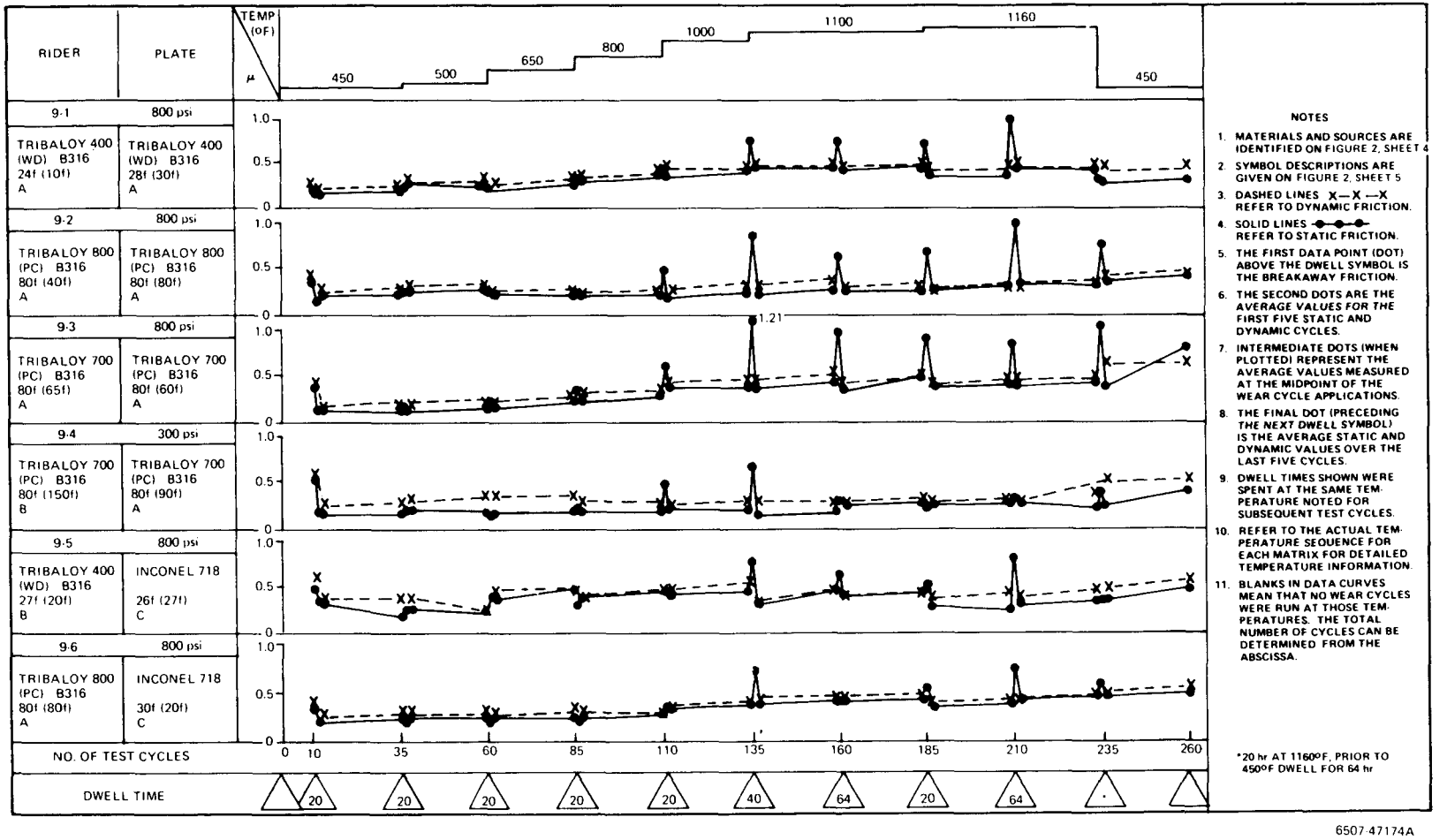


Figure 5. Friction Matrix No. 9 – Friction Coefficients vs Wear Cycles (Sheet 1 of 3)

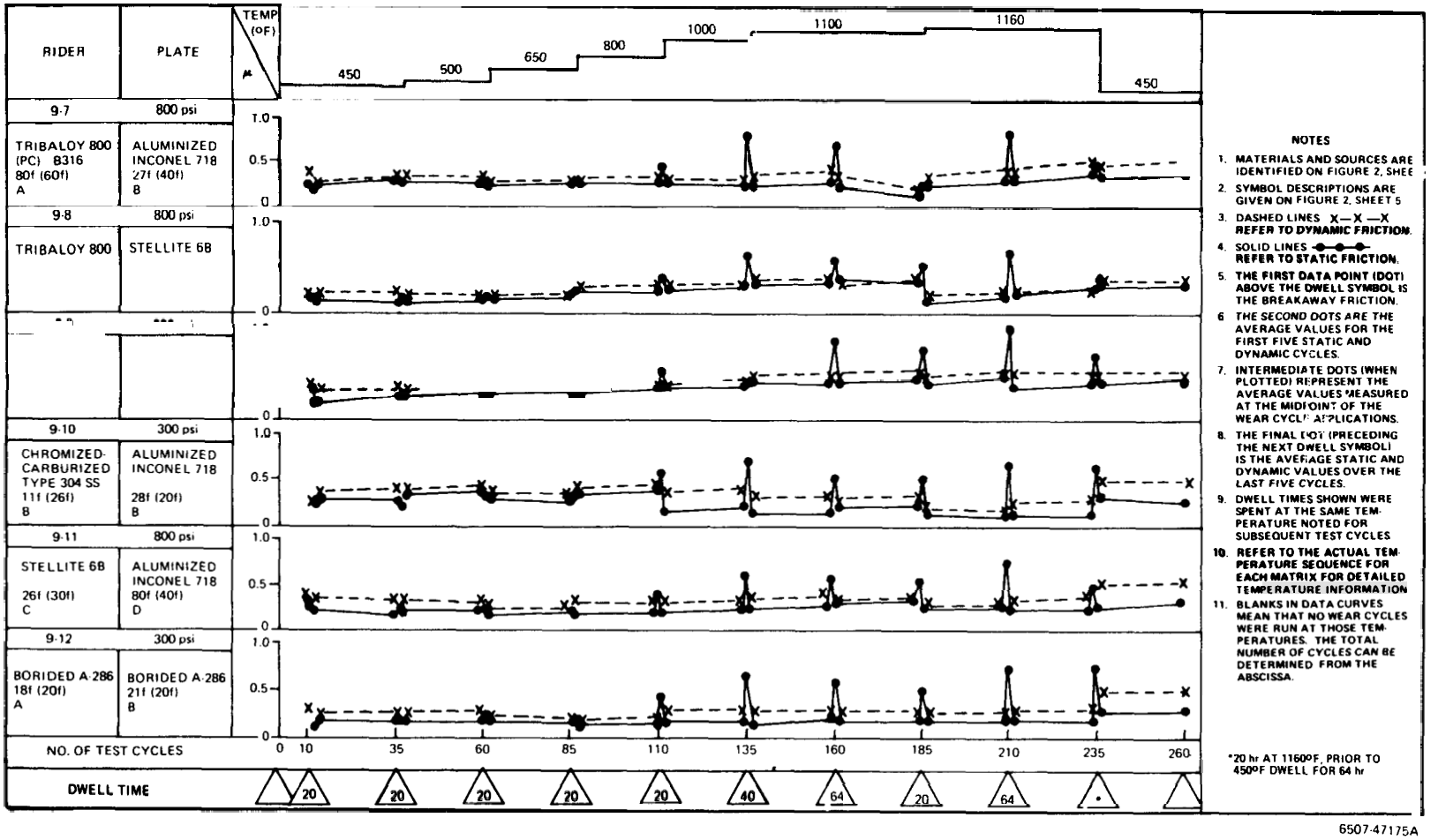


Figure 5. Friction Matrix No. 9 — Friction Coefficients vs Wear Cycles
(Sheet 2 of 3)

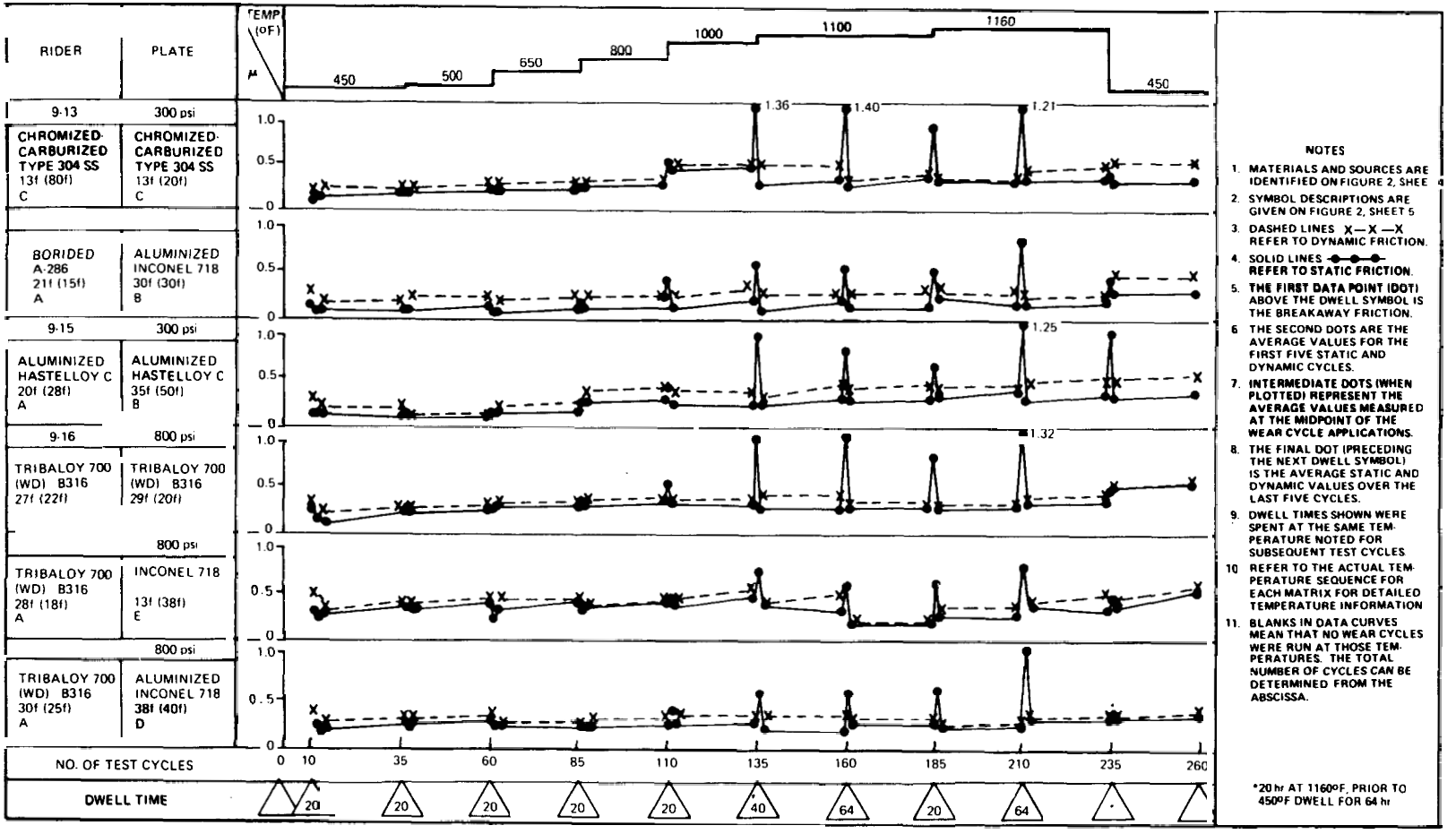


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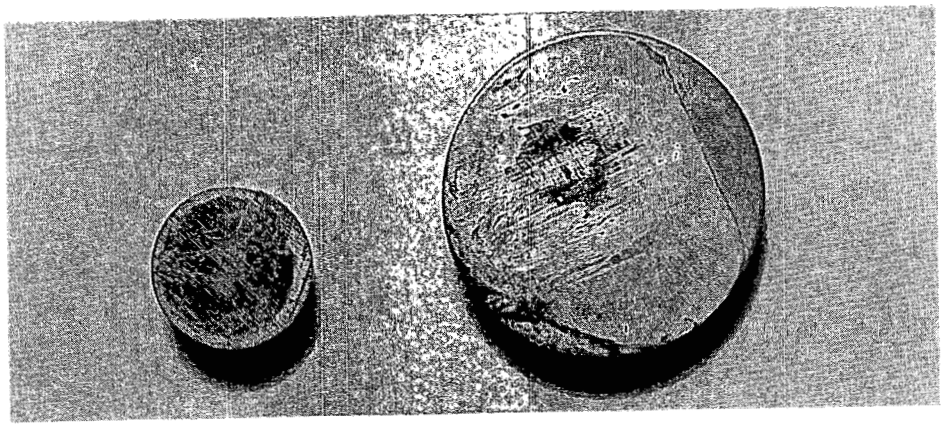
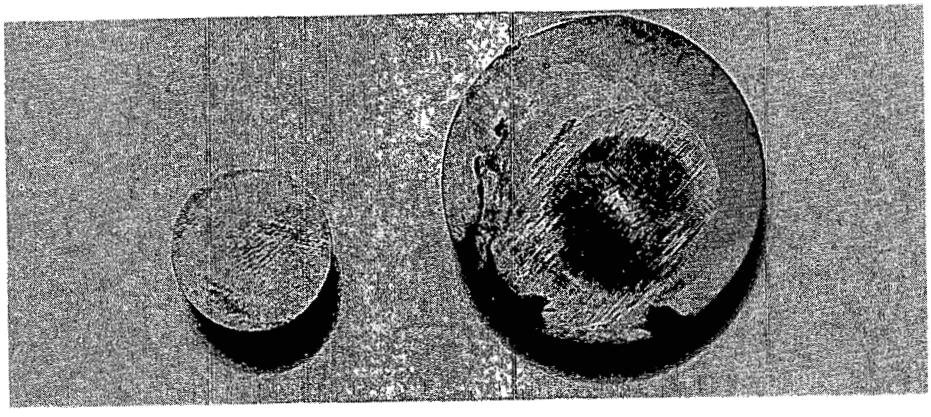
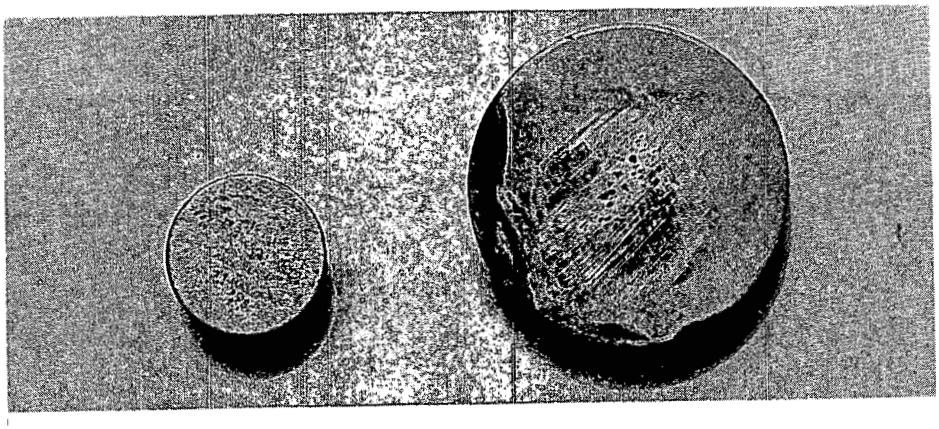
Figure 5. Friction Matrix No. 9 — Friction Coefficients vs Wear Cycles (Sheet 3 of 3)



TRIBALOY 700 (WD) INCONEL 718
COUPLE 17 6507-51318



TRIBALOY 400 (WD) INCONEL 718
COUPLE 5 6507-51316



TRIBALOY 800 (PC) INCONEL 718
COUPLE 6 6507-51314

6507-51399

Figure 6. Friction Matrix No. 9

TABLE 6

SUMMARY TABLE OF FRICTION IN SODIUM
MATRIX 9
(HEDL Format)
(Sheet 1 of 6)

Test			Test Conditions						Friction Results							
Number	Materials		Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in./sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Static Friction			Dynamic Friction			Comments
	Pin	Plate								Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
9-1	Tribaloy 400 (WD) B316	Tribaloy 400 (WD) B316	450	157.1/ 800	0.07	d/2	35/17.5	20	0.16	0.15	0.20	0.19	0.21	0.25	0.25	Previous experience includes 10/5 at 450°F prior to cold trapping.
							260/130	64	0.33	0.29	0.34	0.33	0.43	0.46	0.46	Rubbing experience includes prior 35/17.5 at 450°F plus 200/100 at higher temperature levels.
			800				110/55	20	0.34	0.29	0.36	0.33	0.37	0.38	0.38	Rubbing experience includes 85/42.5 at lower temperature levels
			1160				210/105	20	0.73	0.38	0.43	0.38	0.43	0.43	0.43	Rubbing experience includes 185/92.5 at lower temperature levels.
							235/117.5	64	1.01	0.43	0.48	0.45	0.48	0.48	0.47	Rubbing experience includes 185,92.5 at lower temperature levels plus 25/12.5 at prior 1160°F.
9-2	Tribaloy 800 (PC) B316	Tribaloy 800 (PC) B316	450				35/17.5	20	0.17	0.20	0.23	0.22	0.29	0.29	0.29	
							260/130	64	1.01	0.28	0.31	0.29	0.31	0.38	0.38	
			800				110/55	20	0.29	0.20	0.22	0.20	0.25	0.25	0.25	Same as 9-1
			1160				210/105	20	0.65	0.21	0.26	0.25	0.30	0.33	0.33	
							235/117.5	64	0.68	0.25	0.30	0.28	0.28	0.31	0.31	
9-3	Tribaloy 700 (PC) B316	Tribaloy 700 (PC) B316	450				35/17.5	20	0.14	0.13	0.14	0.14	0.20	0.23	0.23	
							260/130	64	0.94	0.43	0.47	0.47	0.50	0.55	0.53	
			800				110/55	20	0.36	0.28	0.32	0.32	0.33	0.35	0.35	Same as 9-1
			1160				210/105	20	1.07	0.39	0.51	0.51	0.51	0.55	0.55	
							235/117.5	64	0.97	0.41	0.44	0.44	0.45	0.52	0.51	

TABLE 6

SUMMARY TABLE OF FRICTION IN SODIUM
MATRIX 9
(HEDL Format)
(Sheet 2 of 6)

Test			Test Conditions						Friction Results							Comments
Number	Materials		Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in. /sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Static Friction			Dynamic Friction			
	Pin	Plate								Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
9-4	Tribaloy 700 (PC) B316	Tribaloy 700 (PC) B316	450	58.9/300	0.07	d/2	35/17.5	16	0.18	0.17	0.20	0.20	0.27	0.31	0.31	
							260/130	64	0.47	0.28	0.45	0.45	0.57	0.60	0.60	
			800				110/55	16	0.25	0.22	0.26	0.21	0.34	0.34	0.31	Same as 9-1
			1160				210/105	16	0.25	0.27	0.30	0.30	0.31	0.38	0.38	
							235/117.5	64	0.39	0.27	0.31	0.25	0.34	0.43	0.43	
9-5	Tribaloy 400 (WD) B316	Inconel 718	450	157.1/800			35/17.5	16	0.35	0.31	0.31	0.19	0.40	0.40	0.40	
							260/130	64	0.39	0.40	0.52	0.52	0.53	0.62	0.62	
			800				110/55	16	0.33	0.43	0.49	0.49	0.47	0.53	0.53	Same as 9-1
			1160				210/105	16	0.57	0.28	0.38	0.27	0.41	0.49	0.49	
							235/117.5	64	0.88	0.29	0.43	0.38	0.43	0.51	0.51	
9-6	Tribaloy 800 (PC) B316	Inconel 718	450				35/17.5	16	0.21	0.22	0.27	0.27	0.29	0.34	0.34	
							260/130	64	0.66	0.49	0.51	0.51	0.56	0.60	0.60	
			800				110/55	16	0.25	0.29	0.31	0.31	0.33	0.34	0.34	Same as 9-1
			1160				210/105	16	0.62	0.39	0.41	0.41	0.43	0.47	0.47	
							235/117.5	64	0.86	0.45	0.52	0.52	0.49	0.52	0.52	

TABLE 6

SUMMARY TABLE OF FRICTION IN SODIUM
MATRIX 9
(HEDL Format)
(Sheet 3 of 6)

Test			Test Conditions						Friction Results							
	Materials									Static Friction			Dynamic Friction			
Number	Pin	Plate	Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in. /sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Break-away Friction	Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	Comments
9-7	Tribaloy 800 (PC) B316	Aluminized Inconel 718	450	157.1/800	0.07	d/2	35/17.5	16	0.18	0.25	0.30	0.30	0.27	0.34	0.34	
							260/130	64	0.51	0.39	0.41	0.41	0.51	0.55	0.55	
			800				110/55	16	0.31	0.28	0.29	0.28	0.32	0.34	0.34	Same as 9-1
			1160				210/105	16	0.26	0.24	0.31	0.31	0.35	0.42	0.42	
							235/117.5	64	0.88	0.29	0.39	0.38	0.43	0.55	0.55	
9-8	Tribaloy 800 (PC) B316	Stellite 6B	450				35/17.5	16	0.20	0.14	0.18	0.13	0.25	0.28	0.28	
							260/130	64	0.48	0.33	0.35	0.35	0.38	0.41	0.41	
			800				110/55	16	0.26	0.23	0.26	0.25	0.30	0.32	0.32	Same as 9-1
			1160				210/105	16	0.59	0.15	0.29	0.19	0.22	0.24	0.24	
							235/117.5	64	0.72	0.23	0.34	0.27	0.26	0.27	0.27	
9-9	Aluminized Inconel 718	Tribaloy 400 (WD) B316	450				35/17.5	16	0.18	0.19	0.27	0.26	0.32	0.37	0.37	
							260/130	64	0.76	0.43	0.48	0.48	0.55	0.55	0.55	
			800				110/55	16	0.31	0.30	0.35	0.35	0.34	0.38	0.38	Same as 9-1
			1160				210/105	16	0.82	0.43	0.53	0.49	0.49	0.55	0.55	
							235/117.5	64	1.09	0.39	0.42	0.42	0.54	0.55	0.53	

TABLE 6

SUMMARY TABLE OF FRICTION IN SODIUM
MATRIX 9
(HEDL Format)
(Sheet 4 of 6)

Test			Test Conditions						Friction Results							Comments
Number	Materials		Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in./sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Static Friction			Dynamic Friction			
	Pin	Plate								Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
9-10	Chromized-Carburized 304SS	Aluminized Inconel 718	450	58.9/300	0.07	d/2	35/17.5	16	0.25	0.29	0.30	0.30	0.40	0.45	0.45	
							260/130	64	0.66	0.32	0.43	0.29	0.54	0.59	0.54	
			800				110/55	16	0.34	0.37	0.41	0.41	0.41	0.45	0.45	Same as 9-1
			1600				210/105	16	0.54	0.09	0.25	0.06	0.19	0.20	0.10	
							235/117.5	64	0.70	0.11	0.32	0.09	0.29	0.31	0.29	
9-11	Stellite 6B	Aluminized Inconel 718	450	157.1/800			35/17.5	16	0.23	0.20	0.20	0.18	0.35	0.35	0.34	
							260/130	64	0.51	0.29	0.41	0.38	0.55	0.57	0.57	
			800				110/55	16	0.25	0.21	0.25	0.22	0.31	0.33	0.33	Same as 9-1
			1600				210/105	16	0.58	0.25	0.34	0.27	0.29	0.33	0.33	
							235/117.5	64	0.80	0.25	0.36	0.26	0.37	0.41	0.41	
9-12	Borided A-286	Borided A-286	450	58.9/300			35/17.5	16	0.14	0.19	0.23	0.23	0.29	0.32	0.32	
							260/130	64	0.82	0.32	0.35	0.32	0.59	0.59	0.59	
			800				110/55	16	0.23	0.13	0.19	0.14	0.22	0.25	0.25	Same as 9-1
			1160				210/105	16	0.55	0.18	0.35	0.18	0.31	0.31	0.31	
							235/117.5	64	0.82	0.20	0.43	0.20	0.35	0.36	0.36	

TABLE 6

SUMMARY TABLE OF FRICTION IN SODIUM
MATRIX 9
(HEDL Format)
(Sheet 5 of 6)

Test			Test Conditions						Friction Results							Comments
Number	Materials		Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in./sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Break-away Friction	Static Friction			Dynamic Friction			
	Pin	Plate								Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
9-13	Chromized-Carburized 304 SS	Chromized-Carburized 304 SS	450	58.9/300	0.07	d/2	35/17.5	16	0.14	0.12	0.19	0.16	0.24	0.23	0.23	
							260/130	64	0.43	0.37	0.63	0.39	0.62	0.62	0.62	
			800				110/55	16	0.29	0.30	0.31	0.30	0.36	0.40	0.40	Same as 9-1
			1160				210/105	16	1.02	0.38	0.49	0.36	0.40	0.41	0.41	
							235/117.5	64	1.21	0.39	0.41	0.41	0.49	0.55	0.55	
9-14	Borided A-286	Aluminized Inconel 718	450				35/17.5	16	0.08	0.07	0.14	0.04	0.18	0.20	0.20	
							260/130	64	0.44	0.32	0.39	0.32	0.45	0.50	0.50	
			800				110/55	16	0.19	0.12	0.22	0.22	0.22	0.25	0.25	Same as 9-1
			1160				210/105	16	0.55	0.23	0.42	0.15	0.30	0.29	0.29	
							235/117.5	64	0.88	0.16	0.28	0.17	0.25	0.27	0.27	
9-15	Aluminized Hastelloy C	Aluminized Hastelloy C	450				35/17.5	16	0.14	0.09	0.11	0.09	0.21	0.22	0.21	
							260/130	64	1.09	0.35	0.39	0.39	0.56	0.62	0.62	
			800				110/55	16	0.27	0.29	0.38	0.31	0.41	0.45	0.45	Same as 9-1
			1160				210/105	16	0.68	0.34	0.43	0.41	0.47	0.49	0.49	
							235/117.5	64	1.25	0.36	0.49	0.39	0.51	0.59	0.59	

TABLE 6

SUMMARY TABLE OF FRICTION IN SODIUM
MATRIX 9
(HEDL Format)
(Sheet 6 of 6)

Test			Test Conditions						Friction Results							
Number	Materials		Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in./sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Static Friction			Dynamic Friction			Comments
	Pin	Plate								Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
9-16	Tribaloy 700 (WD) B316	Tribaloy 700 (WD) B316	450	157.1/800	0.07	d/2	35/17.5	16	0.13	0.17	0.21	0.21	0.22	0.29	0.29	
							260/130	64	0.50	0.52	0.60	0.60	0.56	0.61	0.61	
			800				110/55	16	0.34	0.31	0.36	0.35	0.38	0.40	0.40	Same as 9-1
			1160				210/105	16	0.90	0.29	0.31	0.31	0.35	0.37	0.37	
							235/117.5	64	1.32	0.34	0.38	0.38	0.43	0.47	0.47	
9-17	Tribaloy 700 (WD) B316	Inconel 718	450				35/17.5	16	0.23	0.29	0.38	0.38	0.32	0.45	0.45	
							260/130	64	0.53	0.39	0.57	0.57	0.47	0.62	0.62	
			800				110/55	16	0.35	0.38	0.43	0.43	0.38	0.45	0.45	Same as 9-1
			1160				210/105	16	0.68	0.29	0.41	0.29	0.35	0.39	0.39	
							235/117.5	64	0.86	0.39	0.52	0.37	0.43	0.51	0.51	
9-18	Tribaloy 700 (WD) B316	Aluminized Inconel 718	450				35/17.5	16	0.19	0.20	0.25	0.25	0.28	0.33	0.33	
							260/130	64	0.48	0.35	0.39	0.39	0.40	0.46	0.46	
			800				110/55	16	0.27	0.28	0.30	0.29	0.35	0.35	0.35	Same as 9-1
			1160				210/105	16	0.70	0.24	0.28	0.28	0.30	0.32	0.32	
							235/117.5	64	1.17	0.34	0.43	0.37	0.36	0.41	0.41	

Inconel 718 experienced severe wear when matched against Tribaloy 700 (Couple 17). Moderate wear occurred when tested against Tribaloy 400 (Couple 5) or Tribaloy 800 (Couple 6).

Aluminized Inconel 718 showed much better wear characteristics than the base metal. When tested against Stellite 6B (Couple 11) and Tribaloy 700 (Couple 18), wear was light to moderate. Little or no wear was evident when aluminized Inconel 718 was against Chromized-Carburized Type 304 stainless steel (Couple 10), Borided A-286 (Couple 14), Tribaloy 800 (Couple 7), or Tribaloy 400 (Couple 9).

Aluminized Hastelloy C vs itself (Couple 15), and Borided A-286 vs itself (Couple 12) showed little or no surface wear. Chromized-Carburized Type 304 stainless steel vs itself (Couple 13) had light to moderate wear.

Except for moderate breakaway values, most of the material combinations demonstrated low to moderate static and dynamic friction coefficients over the entire temperature range. Generally, the corrected friction coefficients (static and dynamic) ranged from ~0.2 to ~0.6. There were very few instances where couples exceeded 0.6, anywhere in the temperature sequence. Five couples (1, 2, 8, 14, and 18) never exceeded 0.5. There was no obvious correlation that could be made between the friction traces and the observed surface wear on the specimens. Observations of wear were based on visual inspection and evaluation. No metallurgical examinations were made of the coating condition or depth, or of the type and extent of wear.

As noted in Table 4, five of the test couples in the ninth matrix (10, 12, 13, 14, 15) were repeats from the eighth matrix, but in the ninth matrix these test couples were at contact loads of 300 psi. During the prior Matrix 8 testing at 800 psi, none had sustained significant surface wear. For comparative purposes, data from these five are presented in Figure 7. In addition, data from Matrix 7, Couple 11, (Tribaloy 400 vs itself) are included on the figure, for comparison with Couple 1 of Matrix 9. A study of the corresponding curves shows, in general, very good agreement. When significant differences do occur, the friction values for the ninth matrix are lower than those from previous matrices (Couple 13 lower at high temperature, Couple 15 lower at low temperatures, and Couple 14 lower throughout). A possible reason for

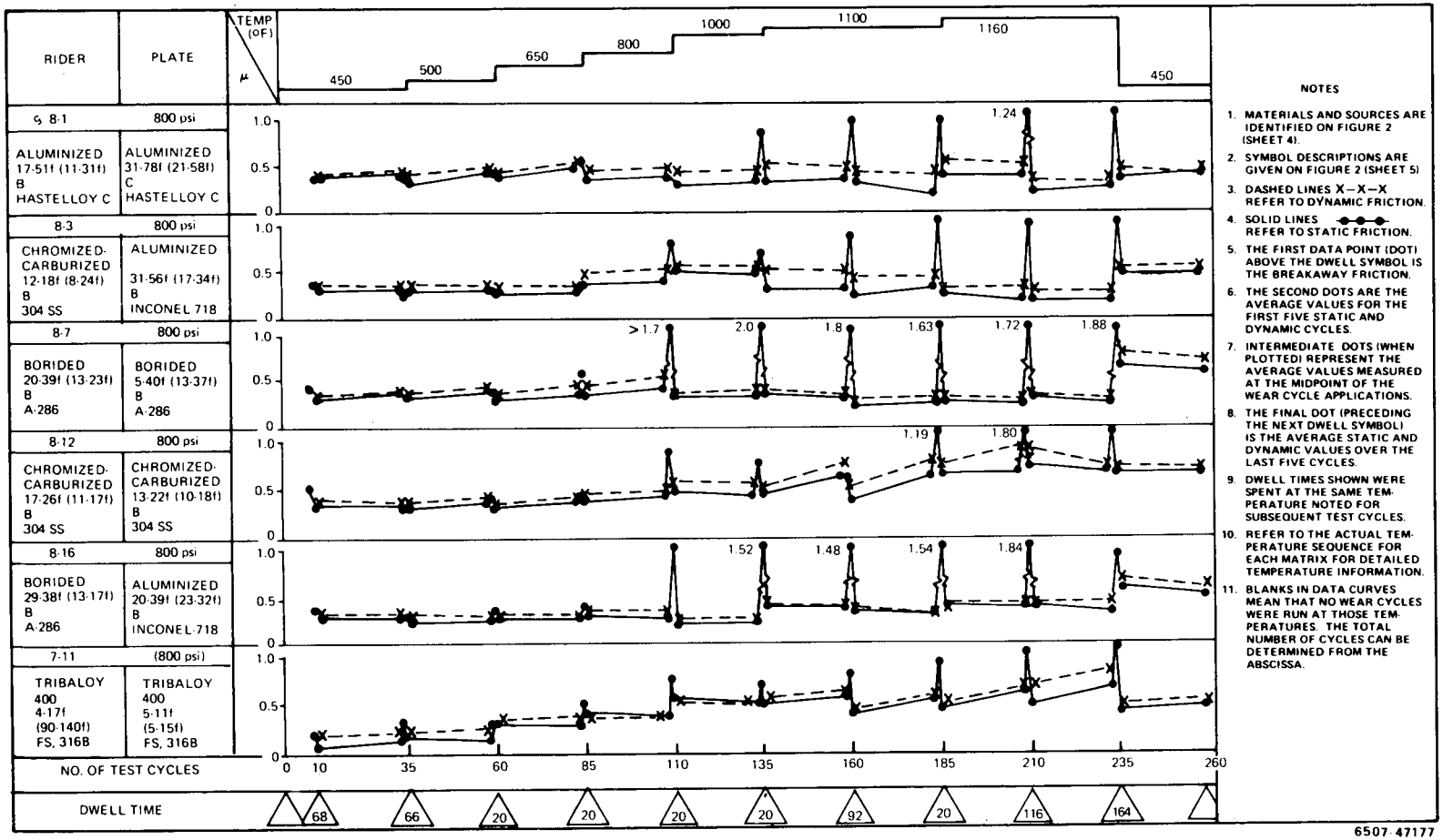


Figure 7. Friction Coefficients vs Wear Cycles for Selected Couples from Matrices 7 and 8

these differences may be the surface preparations prior to test. When those specimens noted on Figure 7 were initially tested, each was placed in the test rig with the test surfaces in the "as-received" conditions. Prior to retesting in the ninth matrix, each was lapped or polished to remove surface blemishes and to break the edges, so the surface condition in Matrix 9 may have been more conducive to lower friction forces.

C. FRICTION MATRIX 9A

Friction Matrix 9A was a special matrix introduced into the program by joint AI and HEDL agreement to (1) generate sufficient information to establish a correction factor for Matrix 9 data (see preceding section), and (2) provide the first bit of friction test statistical information in the program. Accordingly, HEDL specified the 9A matrix composition, as noted in Table 7. Twelve of the couples (1, 2, 3, 5, 6, 7, 8, 9, 10, 13, 17, and 18) were taken from the ninth matrix. Two couples were made up of Matrix 6 and 7 specimens. The remainder were new and/or previously untested parts. All previously tested parts were used "as is" when surface wear was minimal, or were polished or refaced as necessary when pronounced surface irregularities were evident.

Testing of Matrix 9A followed the same temperature sequence, Figure 4, which was used for Matrix 9. The test sequence was concluded on April 12, 1974 and was performed without deviation from the noted operational procedures. Sodium samples, taken periodically during the test and analyzed for oxygen content per ANL/ST-6, showed that the oxygen level remained below the 5-ppm maximum allowable content.

Friction coefficients (breakaway, static, and dynamic) obtained from the twelve common 9 and 9A couples were averaged at each temperature level as a group for each matrix. These averaged values for the eleven temperatures are shown in Table 8, with the resulting matrix-to-matrix ratios.

When the eleven 9/9A ratios were averaged, a value of 2.42 was obtained. This agrees extremely well (within 5.5%) with the 2.56 step change noted in the pre- to post-calibration values. Since no pronounced inconsistencies were evident at any of the temperature levels, it became apparent that the Matrix 9A

TABLE 7

FRICTION MATRIX NO. 9A

Couple	Rider	Plate	Load (psi)	Rework	Previous Matrix	
					Rider	Plate
1	Tribaloy 400(WD)	Tribaloy 400(WD)	800	No	9-1	9-1
2	Tribaloy 800(PC)	Tribaloy 800(PC)	800	No	9-2	9-2
3	Tribaloy 700(PC)	Tribaloy 700(PC)	800	No	9-3	9-3
4	Haynes 90(WD)	Aluminized I 718	800	No	6-17	6-13
5	Tribaloy 400(WD)	Inconel 718	800	Reface Plate	9-5	9-5
6	Tribaloy 800(PC)	Inconel 718	800	Reface Plate	9-6	9-6
7	Tribaloy 800(PC)	Aluminized I 718	800	No	9-7	9-7
8	Tribaloy 800(PC)	Stellite 6B	800	No	9-8	9-8
9	Tribaloy 700(WD)	Inconel 718	800	Reface Plate	9-17	9-17
10	Tribaloy 700(WD)	Tribaloy 400(WD)	800	No	9-18	9-9
11	CI-D	Aluminized 718	800	No	7-6	6-8
12	Borided Hastelloy C	Borided Hastelloy C	800	No	—	—
13	Tribaloy 700(WD)	Tribaloy 700(WD)	800	No	9-16	9-16
14	$Cr_{23}C_6$ (ion coat)	$Cr_{23}C_6$ (ion coat)	300	No	—	—
15	TiC (ion coat)	TiC (ion coat)	300	No	—	—
16	TiC TiN (ion coat)	TiC TiN (ion coat)	300	No	—	—
17	Tribaloy 700(PC)	Tribaloy 700(PC)	300	Polish Rider	9-4	9-4
18	Aluminized Hastelloy C	Aluminized Hastelloy C	300	No	9-15	9-15

(WD) Weld Deposited on Type 316 Stainless Steel
(PC) Plasma Coated on Type 316 Stainless Steel

TABLE 8

MATRIX 9/MATRIX 9A FRICTION COEFFICIENT RATIOS

Temperature (°F)	Friction Coefficient Averages		Ratios
	Matrix 9	Matrix 9A	Matrix 9/ Matrix 9A
450	0.96	0.36	2.70
450	0.61	0.27	2.26
500	0.70	0.29	2.41
650	0.76 q	0,32	2.38
800	0.87	0.35	2.50
1000	1.00	0.38	2.63
1100	1.17	0.39	3.00
1100	1.05	0.51	2.06
1160	1.01	0.56	1.80
1160	1.21	0.59	2.05
450	1.30	0.46	2.83
Averages			2.42

data were affected by a step change in the instrumentation sensitivity after the pretest calibration, but before start of the actual test program. It was on the basis of this information that all of the original Matrix 9 data were changed by the 2.56 correction factor to the values reported in the previous section.

Test data from Matrix 9A are tabulated in Table 9. Plots of the friction coefficients vs temperature levels appear in Figure 8. Photographs taken of the most severely worn couples are shown in Figure 9. Test data are also presented in the summary table format (specified by HEDL) in Table 10.

The Tribaloy materials demonstrated excellent wear characteristics. Generally the only evidence of any surface deformation was that which might be described as a surface "polishing," wherein high spots were smoothed out. No metallurgical examinations were made of the coating condition or depth, or of the type and extent of wear. All of the Tribaloy specimens which appeared in Matrix 9 were repeated in Matrix 9A (see Table 7), and all were rerun

TABLE 9

DATA SUMMARY – FRICTION TEST 9A
(Sheet 1 of 2)

Couple	Rider	Plate	Contact Pressure (psi)	Breakaway B) Static(S)* Dynamic(D)*	Friction Coefficient										
					450°F†	450°F ⚠	500°F ⚠	650°F ⚠	800°F ⚠	1000°F ⚠	1100°F ⚠	1100°F ⚠	1160°F ⚠	1160°F ⚠	450°F ⚠
					0-10 Cycles	11-35 Cycles	36-60 Cycles	61-85 Cycles	86-110 Cycles	111-135 Cycles	136-160 Cycles	161-185 Cycles	186-210 Cycles	211-235 Cycles	235-260 Cycles
1	Tribaloy 400 (WD)	Tribaloy 400 (WD)	800	B	0.20	0.25	0.27	0.28	0.32	0.43	0.55	0.72	0.84	1.07	0.31
				S	0.12	0.13	0.18	0.21	0.33	0.30	0.39	0.37	0.47	0.55	0.26
	9-1§	9-1§		D	0.21	0.24	0.26	0.34	0.35	0.35	0.45	0.43	0.64	0.59	0.35
2	Tribaloy 800 (PC)	Tribaloy 800 (PC)	800	B	0.40	0.33	0.33	0.28	0.21	0.44	0.66	0.82	0.75	1.05	0.90
				S	0.29	0.32	0.25	0.18	0.24	0.26	0.32	0.24	0.44	0.50	0.52
	9-2	9-2		D	0.43	0.32	0.29	0.26	0.31	0.31	0.34	0.30	0.52	0.54	0.62
3	Tribaloy 700 (PC)	Tribaloy 700 (PC)	800	B	0.35	0.37	0.45	0.36	0.30	0.54	0.75	1.03	0.93	1.18	0.95
				S	0.34	0.35	0.34	0.27	0.42	0.41	0.43	0.58	0.53	0.52	0.54
	9-3	9-3		D	0.35	0.36	0.36	0.33	0.43	0.41	0.43	0.58	0.55	0.58	0.57
4	Haynes 90 (WD)	Aluminized Inconel 718	800	B	0.20	0.16	0.28	0.40	0.34	0.42	0.57	0.63	0.62	0.65	0.65
				S	0.20	0.31	0.43	0.34	0.24	0.22	0.17	0.23	0.26	0.24	0.33
	6-17	6-13		D	0.24	0.40	0.44	0.37	0.29	0.25	0.22	0.31	0.30	0.31	0.41
5	Tribaloy 400 (WD)	Inconel 718	800	B	0.66	0.30	0.40	0.40	0.27	0.57	0.59	0.77	0.97	1.16	0.53
				S	0.73	0.40	0.30	0.43	0.38	0.38	0.35	0.45	0.53	0.54	0.51
	9-5	9-5		D	1.02	0.42	0.41	0.44	0.47	0.44	0.38	0.55	0.66	0.66	0.53
6	Tribaloy 800 (PC)	Inconel 718	800	B	0.35	0.23	0.20	0.26	0.30	0.40	0.60	0.77	0.79	0.85	0.77
				S	0.26	0.20	0.23	0.27	0.27	0.33	0.33	0.45	0.48	0.48	0.48
	9-6	9-6		D	0.48	0.27	0.24	0.31	0.30	0.38	0.40	0.57	0.61	0.61	0.54
7	Tribaloy 800 (PC)	Aluminized Inconel 718	800	B	0.38	0.25	0.43	0.46	0.37	0.56	0.82	1.16	1.20	1.48	0.65
				S	0.41	0.39	0.39	0.38	0.39	0.39	0.33	0.48	0.51	0.34	0.30
	9-7	9-7		D	0.43	0.38	0.37	0.39	0.38	0.40	0.39	0.59	0.60	0.53	0.37
8	Tribaloy 800 (WD)	Stellite 6B	800	B	0.29	0.30	0.25	0.36	0.38	0.46	0.48	0.57	0.62	0.67	0.60
				S	0.37	0.17	0.16	0.28	0.33	0.29	0.16	0.19	0.19	0.24	0.29
	9-8	9-8		D	0.42	0.20	0.20	0.29	0.33	0.32	0.17	0.22	0.26	0.25	0.30
9	Tribaloy 700 (WD)	Inconel 718	800	B	0.22	0.23	0.32	0.38	0.43	0.66	0.72	1.16	1.26	1.65	0.45
				S	0.22	0.23	0.28	0.33	0.31	0.32	0.32	0.53	0.61	0.65	0.50
	9-18	9-17		D	0.38	0.24	0.31	0.37	0.39	0.37	0.39	0.65	0.55	0.68	0.54
10	Tribaloy 700 (WD)	Tribaloy 400 (WD)	800	B	0.18	0.21	0.30	0.34	0.38	0.65	0.64	1.10	1.05	1.35	0.41
				S	0.20	0.22	0.26	0.33	0.34	0.41	0.42	0.56	0.72	0.65	0.42
	9-18	9-9		D	0.30	0.24	0.27	0.34	0.38	0.44	0.47	0.68	0.73	0.75	0.43
11	CI-D	Aluminized Inconel 718	800	B	0.75	0.16	0.12	0.16	0.23	0.35	0.35	0.43	0.43	0.54	0.36
				S	0.52	0.07	0.12	0.22	0.35	0.13	0.10	0.15	0.20	0.17	0.43
	7-6	6-8		D	0.58	0.14	0.18	0.25	0.36	0.18	0.15	0.26	0.24	0.25	0.44
12	Borided Hastelloy C	Borided Hastelloy C	800	B	0.50	0.33	0.37	0.38	0.32	0.69	0.73	0.80	0.74	0.98	1.05
				S	0.46	0.23	0.22	0.27	0.27	0.19	0.18	0.28	0.27	0.43	0.45
	–	–		D	0.53	0.26	0.25	0.28	0.29	0.23	0.26	0.37	0.35	0.53	0.47

TABLE 9

DATA SUMMARY – FRICTION TEST 9A
(Sheet 2 of 2)

Couple	Rider	Plate	Contact Pressure (psi)	Breakaway(B) Static(S)* Dynamic(D)*	Friction Coefficient										
					450°F†	450°F ⚠	500°F ⚠	650°F ⚠	800°F ⚠	1000°F ⚠	1100°F ⚠	1100°F ⚠⚠	1160°F ⚠	1160°F ⚠⚠	450°F ⚠⚠
					0-10 Cycles	11-35 Cycles	36-60 Cycles	61-85 Cycles	86-110 Cycles	111-135 Cycles	136-160 Cycles	161-185 Cycles	186-210 Cycles	211-235 Cycles	235-260 Cycles
13	Tribaloy 700 (WD)	Tribaloy 700 (WD)	800	B	0.15	0.14	0.12	0.18	0.33	0.56	0.55	0.90	1.00	1.48	0.32
				S	0.13	0.06	0.07	0.26	0.38	0.34	0.29	0.41	0.40	0.48	0.36
	9-16	9-16		D	0.19	0.11	0.13	0.28	0.39	0.37	0.31	0.49	0.49	0.48	0.38
14	$Cr_{23}C_6$ (Ion Coat)	$Cr_{23}C_6$ (Ion Coat)	300	B	0.25	0.27	0.50	0.60	0.45	0.57	0.77	0.88	0.71	0.90	0.53
				S	0.28	0.25	0.32	0.36	0.32	0.18	0.16	0.36	0.46	0.17	0.31
	–	–		D	0.36	0.39	0.40	0.43	0.35	0.33	0.32	0.55	0.67	0.37	0.46
15	TiC (Ion Coat)	TiC (Ion Coat)	300	B	0.40	0.32	0.40	0.46	0.37	0.48	0.60	0.55	0.81	0.88	0.98
				S	0.77	0.33	0.36	0.43	0.39	0.28	0.25	0.41	0.68	0.59	0.19
	–	–		D	0.96	0.52	0.49	0.49	0.51	0.53	0.44	0.73	1.00	0.64	0.35
16	TiC-TiN (Ion Coat)	TiC-TiN (Ion Coat)	300	B	0.65	0.37	0.50	0.55	0.40	0.47	0.26	0.52	0.72	0.95	1.00
				S	0.85	0.43	0.46	0.41	0.36	0.26	0.21	0.36	0.71	0.44	0.21
	–	–		D	0.98	0.52	0.52	0.50	0.44	0.32	0.32	0.55	0.90	0.67	0.36
17	Tribaloy 700 (PC)	Tribaloy 700 (PC)	300	B	0.33	0.25	0.25	0.30	0.27	0.57	0.75	0.90	1.02	1.80	1.52
				S	0.35	0.24	0.18	0.21	0.20	0.28	0.24	0.36	0.30	0.36	0.32
	9-4	9-4		D	0.45	0.32	0.30	0.30	0.29	0.33	0.32	0.41	0.45	0.39	0.42
18	Aluminized Hastelloy C	Aluminized Hastelloy C	300	B	0.16	0.16	0.25	0.39	0.41	0.58	0.80	0.90	1.30	1.32	1.33
				S	0.09	0.17	0.25	0.30	0.27	0.27	0.30	0.42	0.51	0.39	0.28
	9-15	9-15		D	0.18	0.21	0.32	0.37	0.37	0.31	0.35	0.57	0.55	0.58	0.43

*Average observed during Cycles 1 to 5 and 19 to 25
†Prior to cold trapping
§Previous test usage of coupon: (9-1) = Matrix 9, Couple 1

⚠ Measurements made after overnight dwell (16-hr minimum)
⚠⚠ Measurements made after 3-day dwell (minimum)

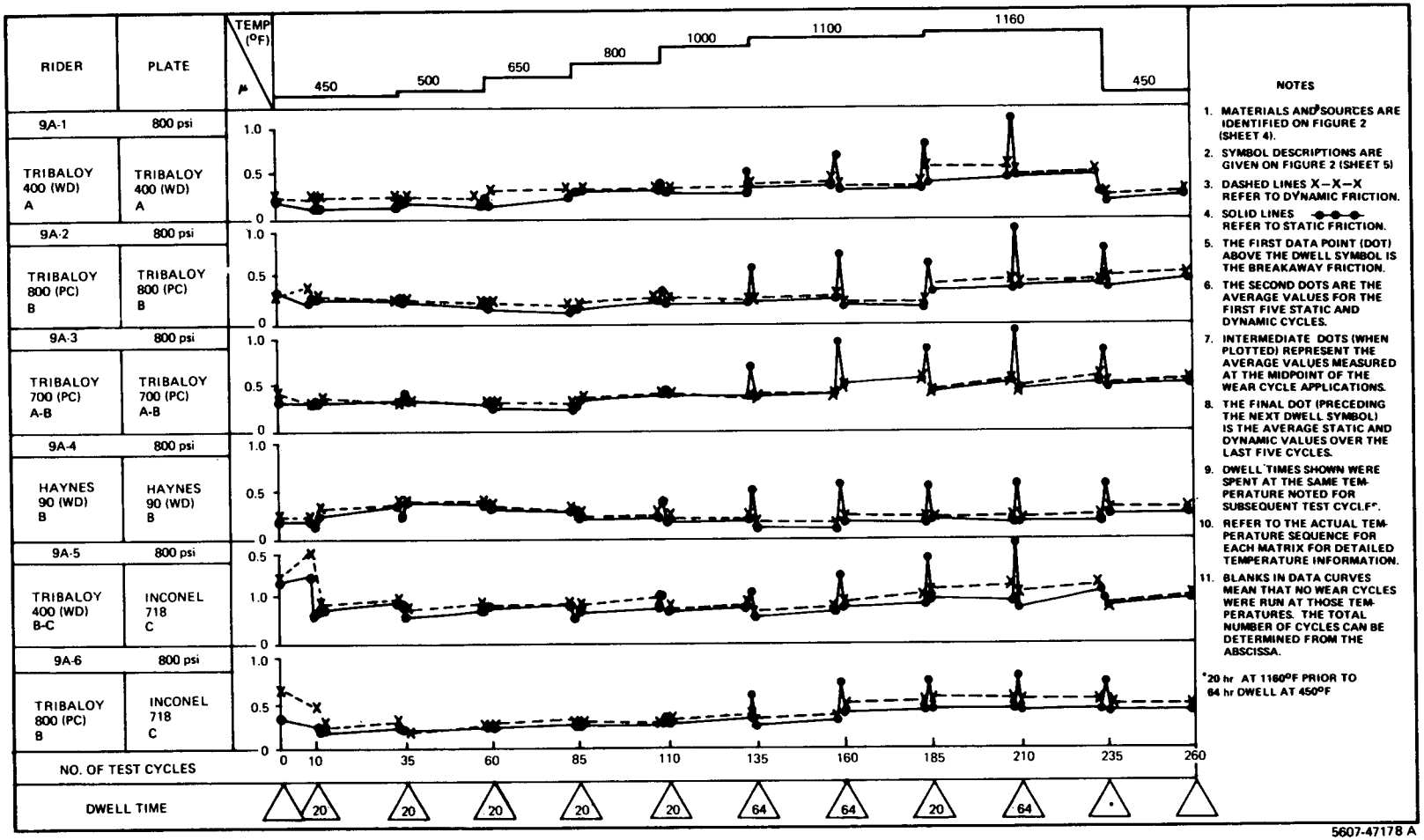


Figure 8. Friction Matrix 9A – Friction Coefficients vs Wear Cycles
(Sheet 1 of 3)

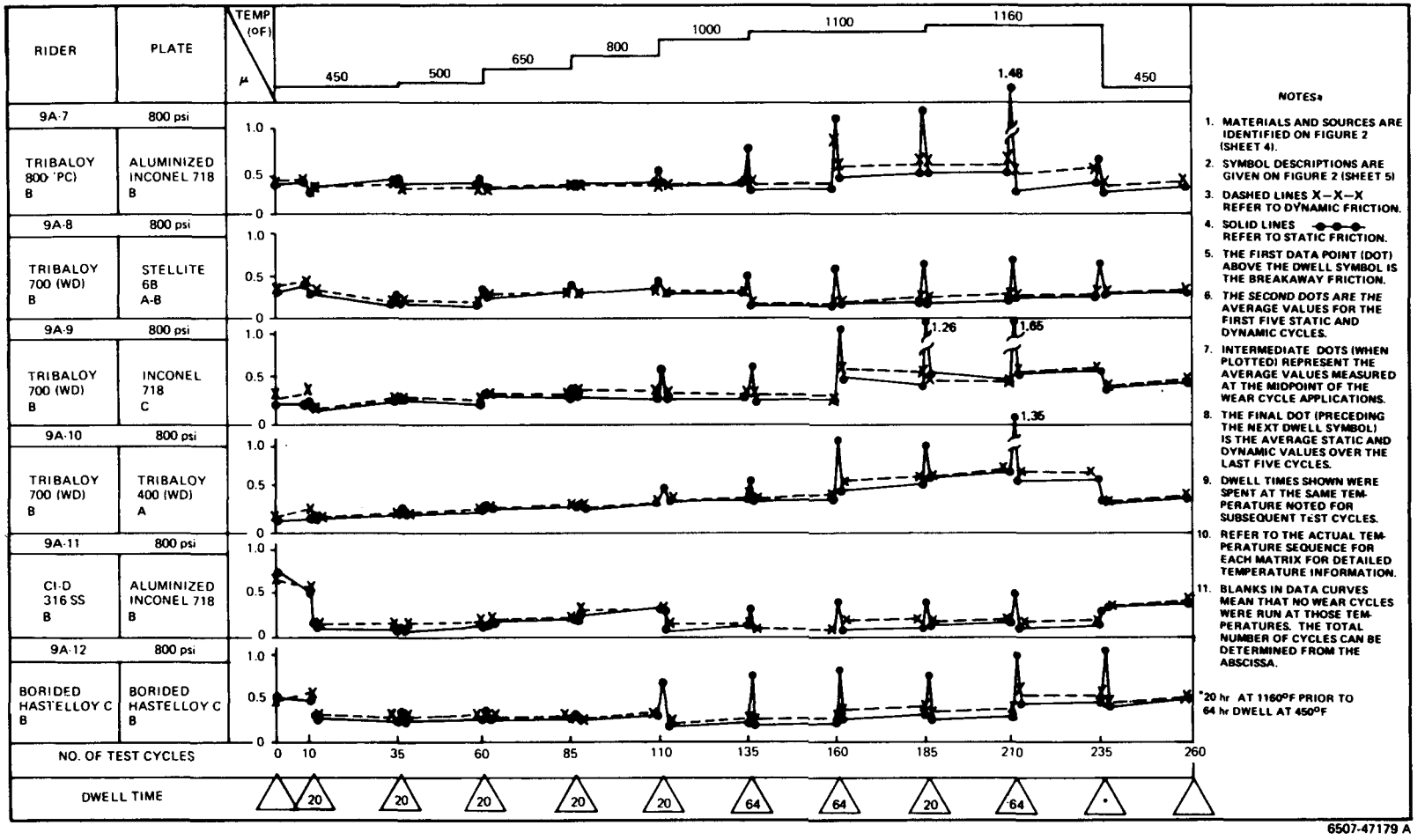


Figure 8. Friction Matrix 9A — Friction Coefficients vs Wear Cycles
(Sheet 2 of 3)

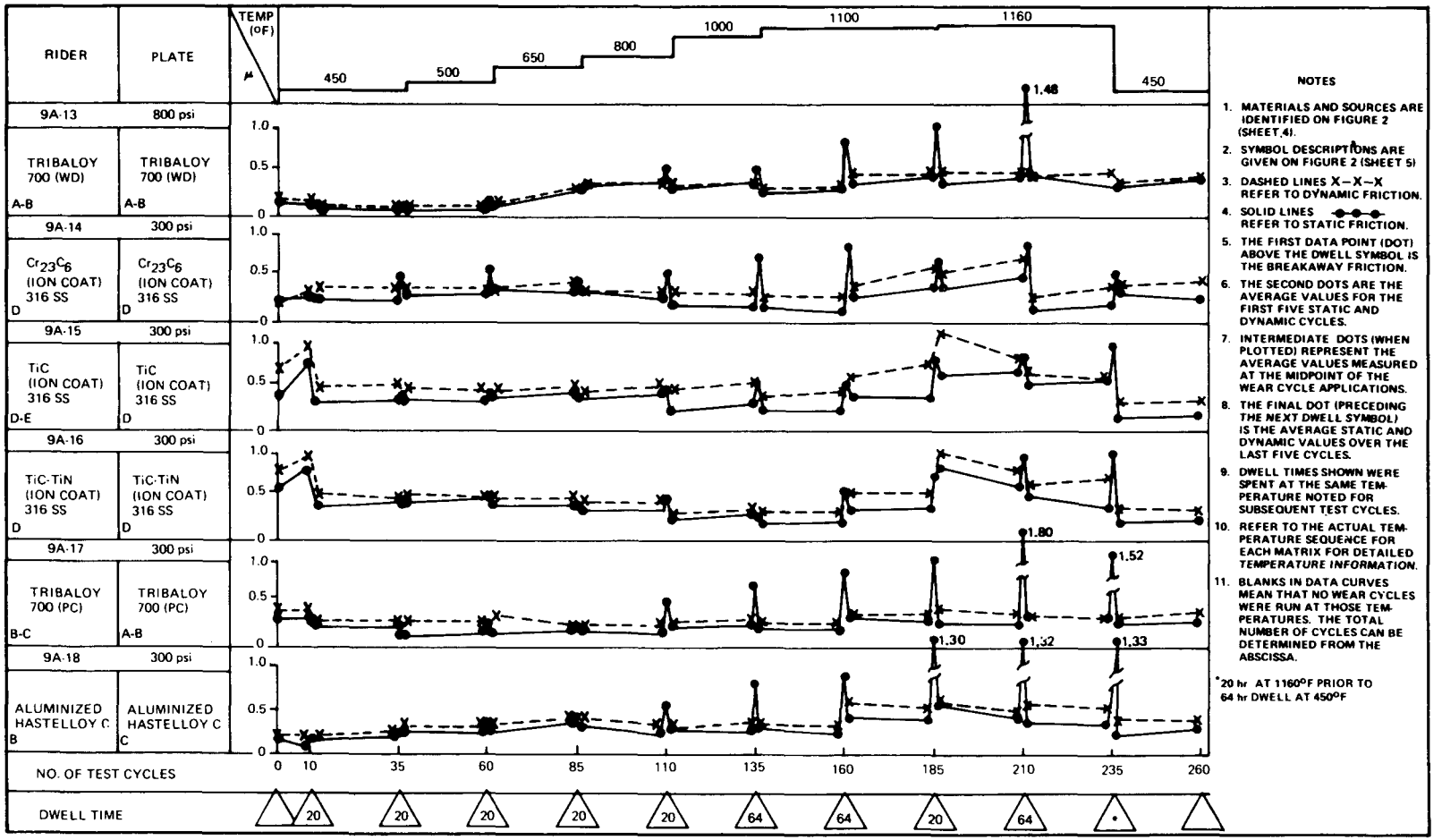
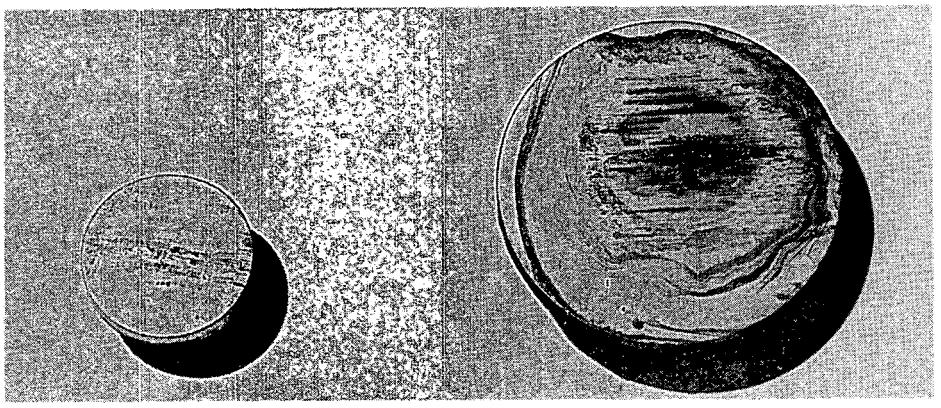
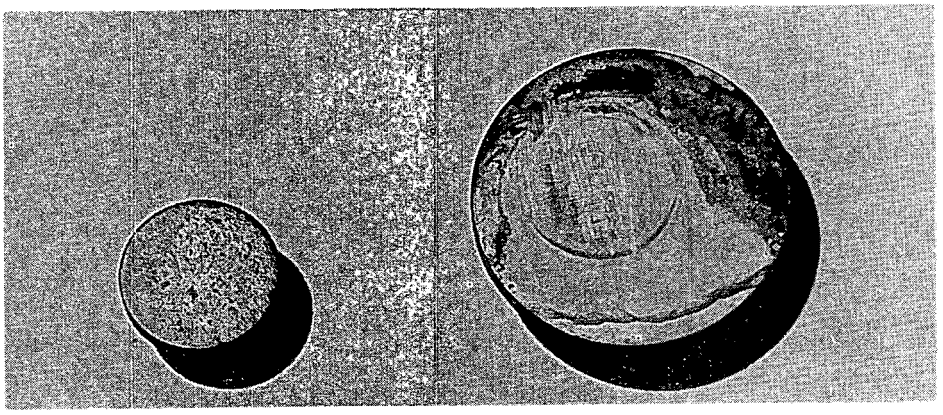


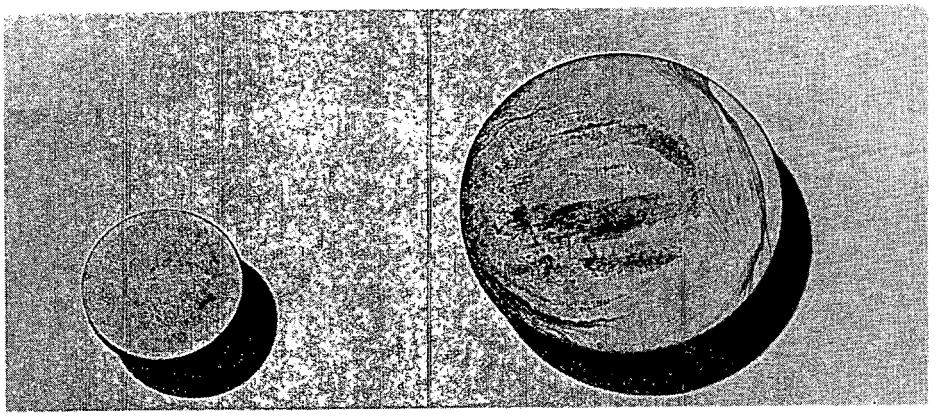
Figure 8. Friction Matrix 9A – Friction Coefficients vs Wear Cycles
(Sheet 3 of 3)



TRIBALOY 400 (WD) COUPLE 5 INCONEL 718 6507-51354



TRIBALOY 800 (PC) COUPLE 6 INCONEL 718 6507-51350



TRIBALOY 700 (WD) COUPLE 9 INCONEL 718 6507-51364

6507-51400

Figure 9. Friction Matrix No. 9A Test Couples
(Sheet 1 of 2)

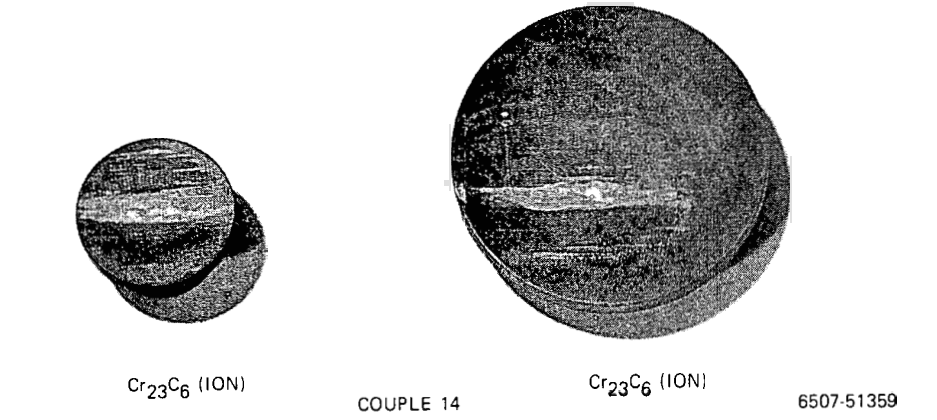


Figure 9. Friction Matrix No. 9A Test Couples
(Sheet 2 of 2)

TABLE 10

SUMMARY TABLE OF FRICTION IN SODIUM
MATRIX 9A
(HEDL Format)
(Sheet 1 of 6)

Test			Test Conditions						Friction Results							Comments
Number	Materials		Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in./sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Static Friction			Dynamic Friction			
	Pin	Plate								Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
9A-1	Tribaloy 400 WD B 316	Tribaloy 400 WD B 316	450	157.1/800	0.07	d/2	35/17.5	20	0.25	0.13	0.20	0.13	0.23	0.25	0.25	Previous experience includes 10/5 at 450°F prior to cold trapping.
							260/130	64*	0.31	0.23	0.28	0.28	0.33	0.37	0.37	Rubbing experience includes prior 35/17.5 at 450°F plus 200/100 at higher temp levels
			800	157.1/800	0.07	d/2	110/55	20	0.32	0.33	0.33	0.33	0.34	0.35	0.35	Rubbing experience includes 85/42.5 at lower temperature levels
			1160	157.1/800	0.07	d/2	210/105	20	0.84	0.44	0.67	0.50	0.63	0.64	0.64	Rubbing experience includes 185/92.5 at lower temperature levels
							237/117.5	64	1.07	0.52	0.65	0.57	0.57	0.60	0.60	Rubbing experience includes 185/92.5 at lower temp. levels + 25/12.5 at prior 1160°F
9A-2	Tribaloy 800 PC B 316	Tribaloy 800 PC B 316	450	157.1/800	0.07	d/2	35/17.5	20	0.33	0.32	0.34	0.32	0.33	0.36	0.30	Same as 9A-1
							260/130	64*	0.90	0.48	0.57	0.57	0.60	0.64	0.64	Same as 9A-1
			800	157.1/800	0.07	d/2	110/55	20	0.21	0.20	0.28	0.28	0.28	0.34	0.34	Same as 9A-1
			1160	157.1/800	0.07	d/2	210/105	20	0.75	0.42	0.45	0.45	0.51	0.53	0.53	Same as 9A-1
							235/117.5	64	1.05	0.48	0.51	0.51	0.53	0.54	0.54	Same as 9A-1
9A-3	Tribaloy 700 PC B 316	Tribaloy 700 PC B 316	450	157.1/800	0.07	d/2	35/17.5	20	0.37	0.36	0.36	0.34	0.38	0.38	0.34	Same as 9A-1
							260/130	64*	0.95	0.53	0.54	0.54	0.56	0.58	0.58	Same as 9A-1
			800	157.1/800	0.07	d/2	110/55	20	0.30	0.39	0.45	0.45	0.40	0.45	0.45	Same as 9A-1
			1160	157.1/800	0.07	d/2	210/105	20	0.93	0.47	0.58	0.58	0.49	0.60	0.60	Same as 9A-1
							235/117.5	64	1.18	0.48	0.55	0.55	0.52	0.63	0.63	Same as 9A-1

*Plus 20 hr dwell at 1160°F

TABLE 10

SUMMARY TABLE OF FRICTION IN SODIUM
MATRIX 9A
(HEDL Format)
(Sheet 2 of 6)

Test			Test Conditions						Friction Results							Comments
	Materials									Static Friction			Dynamic Friction			
Number	Pin	Plate	Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in./sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
9A-4	Haynes 90 WD B316	Alumi-nized 718	450	157.1/800	0.07	d/2	35/17.5	20	0.16	0.25	0.38	0.38	0.36	0.43	0.43	Same as 9A-1
							260/130	64*	0.65	0.32	0.34	0.34	0.41	0.41	0.40	
			800	157.1/800	0.07	d/2	110/55	20	0.34	0.23	0.25	0.25	0.28	0.30	0.30	Same as 9A-1
			1160	157.1/800	0.07	d/2	210/105	20	0.62	0.27	0.39	0.24	0.28	0.31	0.31	Same as 9A-1
							237/117.5	64	0.65	0.23	0.42	0.25	0.30	0.33	0.32	
9A-5	Tribaloy 400 WD B316	Inconel 718	450	157.1/800	0.07	d/2	35/17.5	20	0.30	0.35	0.44	0.44	0.39	0.45	0.45	Same as 9A-1
							260/130	64*	0.53	0.48	0.54	0.54	0.48	0.58	0.58	
			800	157.1/800	0.07	d/2	110/55	20	0.27	0.35	0.40	0.40	0.43	0.50	0.50	Same as 9A-1
			1160	157.1/800	0.07	d/2	210/105	20	0.97	0.54	0.54	0.52	0.63	0.69	0.69	Same as 9A-1
							235/117.5	64	1.16	0.45	0.63	0.63	0.60	0.71	0.71	
9A-6	Tribaloy 800 PC B316	Inconel 718	450	157.1/800	0.07	d/2	35/17.5	20	0.23	0.18	0.22	0.22	0.25	0.29	0.29	Same as 9A-1
							260/130	64*	0.77	0.48	0.48	0.48	0.54	0.54	0.54	
			800	157.1/800	0.07	d/2	110/55	20	0.30	0.28	0.28	0.26	0.30	0.30	0.30	Same as 9A-1
			1600	157.1/800	0.07	d/2	210/105	20	0.79	0.48	0.49	0.48	0.62	0.62	0.60	Same as 9A-1
							235/117.5	64	0.85	0.46	0.50	0.50	0.60	0.68	0.61	

*Plus 20 hr dwell at 1160°F

TABLE 10

SUMMARY TABLE OF FRICTION IN SODIUM
MATRIX 9A
(HEDL Format)
(Sheet 3 of 6)

Test			Test Conditions						Friction Results							
	Materials									Static Friction			Dynamic Friction			
Number	Pin	Plate	Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in./sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	Comments
9A-7	Tribaloy 800 PC B 316	Aluminized Inconel 718	450	157.1/800	0.07	d/2	35/17.5	20	0.25	0.35	0.42	0.40	0.36	0.40	0.40	Same as 9A-1
							260/130	64*	0.65	0.28	0.32	0.32	0.35	0.38	0.38	Same as 9A-1
			800	157.1/800	0.07	d/2	110/55	20	0.37	0.38	0.39	0.39	0.38	0.38	0.38	Same as 9A-1
			1160	157.1/800	0.07	d/2	210/105	20	1.20	0.51	0.51	0.51	0.60	0.60	0.60	Same as 9A-1
							237/117.5	64	1.48	0.30	0.38	0.38	0.50	0.56	0.56	Same as 9A-1
9A-8	Tribaloy 800 PC B 316	Stellite 6B	450	157.1/800	0.07	d/2	35/17.5	20	0.30	0.19	0.20	0.15	0.21	0.21	0.18	Same as 9A-1
							260/130	64*	0.60	0.30	0.32	0.28	0.30	0.30	0.30	Same as 9A-1
			800	157.1/800	0.07	d/2	110/55	20	0.38	0.30	0.35	0.35	0.30	0.35	0.35	Same as 9A-1
			1160	157.1/800	0.07	d/2	210/105	20	0.62	0.18	0.40	0.20	0.23	0.28	0.28	Same as 9A-1
							235/117.5	64	0.67	0.23	0.35	0.25	0.24	0.26	0.26	Same as 9A-1
9A-9	Tribaloy 700 WD B 316	Inconel 718	450	157.1/800	0.07	d/2	35/17.5	20	0.23	0.16	0.29	0.29	0.18	0.31	0.31	Same as 9A-1
							260/130	64*	0.45	0.47	0.53	0.53	0.50	0.57	0.57	Same as 9A-1
			800	157.1/800	0.07	d/2	110/55	20	0.43	0.32	0.35	0.30	0.40	0.40	0.38	Same as 9A-1
			1160	157.1/800	0.07	d/2	210/105	20	1.26	0.63	0.73	0.58	0.55	0.66	0.54	Same as 9A-1
							235/117.5	64	1.65	0.62	0.76	0.67	0.65	0.70	0.70	Same as 9A-1

*Plus 20 hr dwell at 1160°F

TABLE 10

SUMMARY TABLE OF FRICTION IN SODIUM
MATRIX 9A
(HEDL Format)
(Sheet 4 of 6)

Test			Test Conditions						Friction Results							Comments
	Materials									Static Friction			Dynamic Friction			
Number	Pin	Plate	Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in./sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
9A-10	Tribaloy 700 WD B 316	Tribaloy 400 WD B 316	450	157.1/800	0.07	d/2	35/17.5	20	0.21	0.19	0.24	0.24	0.21	0.26	0.26	Same as 9A-1
							260/130	64*	0.41	0.40	0.44	0.44	0.40	0.45	0.45	Same as 9A-1
			800	157.1/800	0.07	d/2	110/55	20	0.38	0.30	0.37	0.37	0.35	0.40	0.40	Same as 9A-1
			1160	157.1/800	0.07	d/2	210/105	20	1.05	0.68	0.76	0.76	0.68	0.78	0.78	Same as 9A-1
							237/117.5	64	1.35	0.65	0.65	0.65	0.74	0.75	0.75	Same as 9A-1
9A-11	CI-D B 316	Aluminized Inconel 718	450	157.1/800	0.07	d/2	35/17.5	20	0.16	0.04	0.10	0.09	0.12	0.17	0.17	Same as 9A-1
							260/130	64*	0.36	0.43	0.43	0.43	0.43	0.45	0.45	Same as 9A-1
			800	157.1/800	0.07	d/2	110/55	20	0.23	0.29	0.40	0.40	0.35	0.36	0.36	Same as 9A-1
			1160	157.1/800	0.07	d/2	210/105	20	0.43	0.18	0.30	0.21	0.22	0.25	0.25	Same as 9A-1
							235/117.5	64	0.54	0.15	0.37	0.19	0.22	0.27	0.27	Same as 9A-1
9A-12	Borided Hastelloy C	Borided Hastelloy C	450	157.1/800	0.07	d/2	35/17.5	20	0.33	0.23	0.28	0.22	0.27	0.27	0.25	Same as 9A-1
							260/130	64*	1.05	0.40	0.49	0.49	0.45	0.49	0.49	Same as 9A-1
			800	157.1/800	0.07	d/2	110/55	20	0.32	0.24	0.30	0.30	0.25	0.32	0.32	Same as 9A-1
			1160	157.1/800	0.07	d/2	210/105	20	0.74	0.25	0.36	0.28	0.34	0.36	0.36	Same as 9A-1
							235/117.5	64	0.98	0.43	0.47	0.43	0.53	0.53	0.52	Same as 9A-1

*Plus 20 hr dwell at 1160°F

TABLE 10

SUMMARY TABLE OF FRICTION IN SODIUM
MATRIX 9A
(HEDL Format)
(Sheet 5 of 6)

Test			Test Conditions						Friction Results							Comments
Number	Materials		Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in. /sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Static Friction			Dynamic Friction			
	Pin	Plate								Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
9A-13	Tribaloy 700 WD B 316	Tribaloy 700 WD B 316	450	157.1/800	0.07	d/2	35/17.5	20	0.14	0.07	0.11	0.05	0.12	0.13	0.10	Same as 9A-1
							260/130	64*	0.32	0.32	0.40	0.40	0.35	0.41	0.41	Same as 9A-1
			800	157.1/800	0.07	d/2	110/55	20	0.33	0.35	0.40	0.40	0.37	0.40	0.40	Same as 9A-1
			1160	157.1/800	0.07	d/2	210/105	20	1.00	0.37	0.42	0.42	0.48	0.54	0.50	Same as 9A-1
							237/117.5	64	1.48	0.47	0.49	0.49	0.46	0.49	0.49	Same as 9A-1
9A-14	$Cr_{23}C_6$ Ion Coat B 316	$Cr_{23}C_6$ Ion Coat B 316	450	58.9/300	0.07	d/2	35/17.5	20	0.27	0.25	0.38	0.25	0.39	0.45	0.38	Same as 9A-1
							260/130	64*	0.53	0.35	0.35	0.27	0.44	0.48	0.48	Same as 9A-1
			800	58.9/300	0.07	d/2	110/55	20	0.45	0.35	0.37	0.28	0.35	0.39	0.35	Same as 9A-1
			1160	58.9/300	0.07	d/2	210/105	20	0.71	0.40	0.53	0.52	0.60	0.74	0.74	Same as 9A-1
							235/117.5	64	0.90	0.13	0.38	0.21	0.30	0.43	0.43	Same as 9A-1
9A-15	TiC Ion Coat B 316	TiC Ion Coat B 316	450	58.9/300	0.07	d/2	35/17.5	20	0.32	0.31	0.37	0.35	0.50	0.54	0.54	Same as 9A-1
							260/130	64*	0.98	0.17	0.27	0.20	0.34	0.36	0.36	Same as 9A-1
			800	58.9/300	0.07	d/2	110/55	20	0.37	0.36	0.44	0.42	0.46	0.55	0.55	Same as 9A-1
			1160	58.9/300	0.07	d/2	210/105	20	0.81	0.65	0.72	0.70	1.14	1.14	0.85	Same as 9A-1
							235/117.5	64	0.88	0.57	0.62	0.60	0.67	0.67	0.60	Same as 9A-1

*Plus 20 hr dwell at 1160°F

TABLE 10

SUMMARY TABLE OF FRICTION IN SODIUM
MATRIX 9A
(HEDL Format)
(Sheet 6 of 6)

Test			Test Conditions						Friction Results							Comments
Number	Materials		Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in. /sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Static Friction			Dynamic Friction			
	Pin	Plate								Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
9A-16	TiC TiN ion coat B316	TiC TiN ion coat B316	450	58.9/300	0.07	d/2	35/17.5	20	0.37	0.40	0.45	0.45	0.54	0.54	0.50	Same as 9A-1
							260/130	64*	1.00	0.20	0.32	0.21	0.37	0.37	0.35	
			800	58.9/300	0.07	d/2	110/55	20	0.40	0.35	0.36	0.36	0.45	0.45	0.43	Same as 9A-1
			1160	58.9/300	0.07	d/2	210/105	20	0.72	0.82	0.82	0.60	1.00	1.10	0.80	Same as 9A-1
							237/117.5	64	0.95	0.50	0.50	0.37	0.64	0.70	0.70	
9A-17	Tribaloy 700 PC B316	Tribaloy 700 PC B316	450	58.9/300	0.07	d/2	35/17.5	20	0.25	0.23	0.27	0.26	0.31	0.32	0.32	Same as 9A-1
							260/130	64*	1.52	0.30	0.38	0.33	0.40	0.43	0.43	
			800	58.9/300	0.07	d/2	110/55	20	0.27	0.20	0.25	0.20	0.29	0.29	0.29	Same as 9A-1
			1160	58.9/300	0.07	d/2	210/105	20	1.02	0.30	0.40	0.30	0.48	0.48	0.42	Same as 9A-1
							235/117.5	64	1.80	0.38	0.53	0.34	0.40	0.40	0.38	
9A-18	Alumi-nized Hastelloy C	Alumi-nized Hastelloy C	450	58.9/300	0.07	d/2	35/17.5	20	0.16	0.14	0.19	0.19	0.20	0.22	0.22	Same as 9A-1
							260/130	64*	1.33	0.25	0.30	0.30	0.42	0.44	0.44	
			800	58.9/300	0.07	d/2	110/55	20	0.41	0.31	0.33	0.23	0.40	0.40	0.34	Same as 9A-1
			1600	58.9/300	0.07	d/2	210/105	20	1.30	0.58	0.58	0.43	0.60	0.60	0.50	Same as 9A-1
							235/117.5	64	1.32	0.40	0.57	0.38	0.60	0.60	0.55	

*Plus 20 hr dwell at 1160°F

without surface refinishing (with the exception of the Couple 17 rider) because of the lack of previous surface wear. Any significant increase in wear as a result of the Matrix 9A tests was not obvious.

Moderate wear occurred on all three Inconel 718 parts when tested against Tribaloy (Couples 5, 6, 9). This is consistent with the wear characteristics observed in the previous test matrix. Aluminized Inconel 718 continued to show wear resistance superior to the bare Inconel 718 as evidenced in Couples 7 (vs Tribaloy) and 11 (vs CI-D).

Stellite 6B again showed excellent wear resistance when matched against Tribaloy (Couple 8).

Borided Hastelloy C vs itself (Couple 12), which was one of the few "new" couples in Matrix 9A, displayed little or no wear as a result of the test. Aluminized Hastelloy C vs itself (Couple 18) continued to show good wear resistance.

Three new material entries performed badly from the wear standpoint. Each of the ion-coated specimens, $Cr_{23}C_6$ (Couple 14), TiC (Couple 15), and TiCTiN (Couple 16) experienced considerable surface wear.

The friction coefficients measured on the twelve couples which were common to Matrices 9 and 9A showed exceptionally good agreement. As a group, the Tribaloy materials continue to show fairly uniform static and dynamic friction coefficients over the entire temperature range ($\sim$0.1 to 0.4 at lower temperatures to 0.4 to 0.7 at higher temperatures). However, this material is characterized by breakaway peaks at temperatures above 1000°F. The maximum peak observed on the Tribaloys was 1.8 on Couple 17. Most peaks were considerably lower, however.

Two couples showed excellent all-around performance. Couple 8 matched a Tribaloy rider against a Stellite 6B plate, and the static and dynamic friction coefficients did not exceed 0.35 at any temperature; breakaway friction did not exceed 0.68. Similar performance was observed on this couple during Matrix 9 testing, and the accumulated wear from both tests was insignificant. Couple 11 which evaluated a CI-D rider (from Matrix 7) with an aluminized Inconel 718 plate (from Matrix 6) also showed excellent friction results. Static and dynamic

friction coefficients (after the initial 10 wear-in cycles at 450°F) did not exceed 0.4 at any temperature; breakaway peaks did not exceed 0.55. Surface wear appeared insignificant.

Of the three ion-coated specimens, Couple 14 was the best performer, from the standpoint of friction. However, its performance in this regard did not exceed that of many other materials and it, like the other two ion couples, experienced extensive surface wear and/or deformation.

Matrix 9A provided the first bit of data on a group of predominantly "repeat" test specimens. The results showed excellent repeatability of material performance using the AI test rig and showed a definite consistency of test techniques and data acquisition and evaluation.

D. FRICTION MATRIX 10

Friction Matrix 10, Table 11, was tested to the temperature time-wear cycle profile shown in Figure 10. The test environment was argon gas saturated with high purity sodium vapor. At no time were the coupons washed by, or immersed in, liquid sodium. To maximize the sodium vapor content, a highest possible sodium temperature – lowest sodium surface level relationship was maintained, consistent with the required specimen temperature (Figure 10). Specimen temperatures were measured by thermocouples embedded in the test fixture, adjacent to the test articles. Testing to the required temperature sequence was performed without incident; however, some additional testing was performed to obtain friction vs load, and breakaway vs dwell time data, as noted in subsequent paragraphs.

The breakaway, static and dynamic friction coefficients, which were measured as required at each of the specified temperature levels, are summarized in Table 12, while Figure 11 shows plots of the friction coefficients vs wear cycles and temperature. Photos of several specimens which incurred significant surface wear are displayed in Figure 12. A presentation of the data in the HEDL Summary Table Format is made in Table 13.

A study of the data plots (Figure 11) shows consistently low friction values (0.3 or less) for four specimens, No. 7 (Ni-Resist vs Vitrolube Type 304 stainless steel), No. 9 (Triboloy 700 vs Inconel 718), No. 10 (Triboloy 700 vs

TABLE 11

FRICTION MATRIX No. 10
(SODIUM VAPOR TESTS)

Couple	Rider	Plate	Temperature (° F)	Pressure (psi)
1	Aluminum Bronze	Colmonoy 5	400	200
2	Aluminized I 718	Aluminized I 718	900	800
3	Aluminized I 718	Aluminized I 718	900	200
4	Inconel X-750	Nitrided Type 304 SS	500	200
5	Stellite 6B	I 718	500	200
6	Stellite 6B	Aluminized I 718	500	200
7	Ni-Resist	Type 304 SS + Vitrolube	400	200
8	Tribaloy 400*	I 718	900	200
9	Tribaloy 700*	I 718	900	200
10	Tribaloy 700*	Aluminized I 718	900	200
11	K-Ramic*	I 718	900	200
12	CN-1B*	CN-1B*	900	200
13	CN-1B*	Aluminized I 718	900	200
14	AmCerMet 701-65	I 718	900	200
15	AmCoMo 68-31	AmCoMo 68-31	900	200
16	Stellite 6	Stellite 6	900	200
17	Electrolyzed Chromium Plate*	Electrolyzed Chromium Plate*	900	300
18	Chromium Plate*	Chromium Plate*	900	300

*316 SS substrate

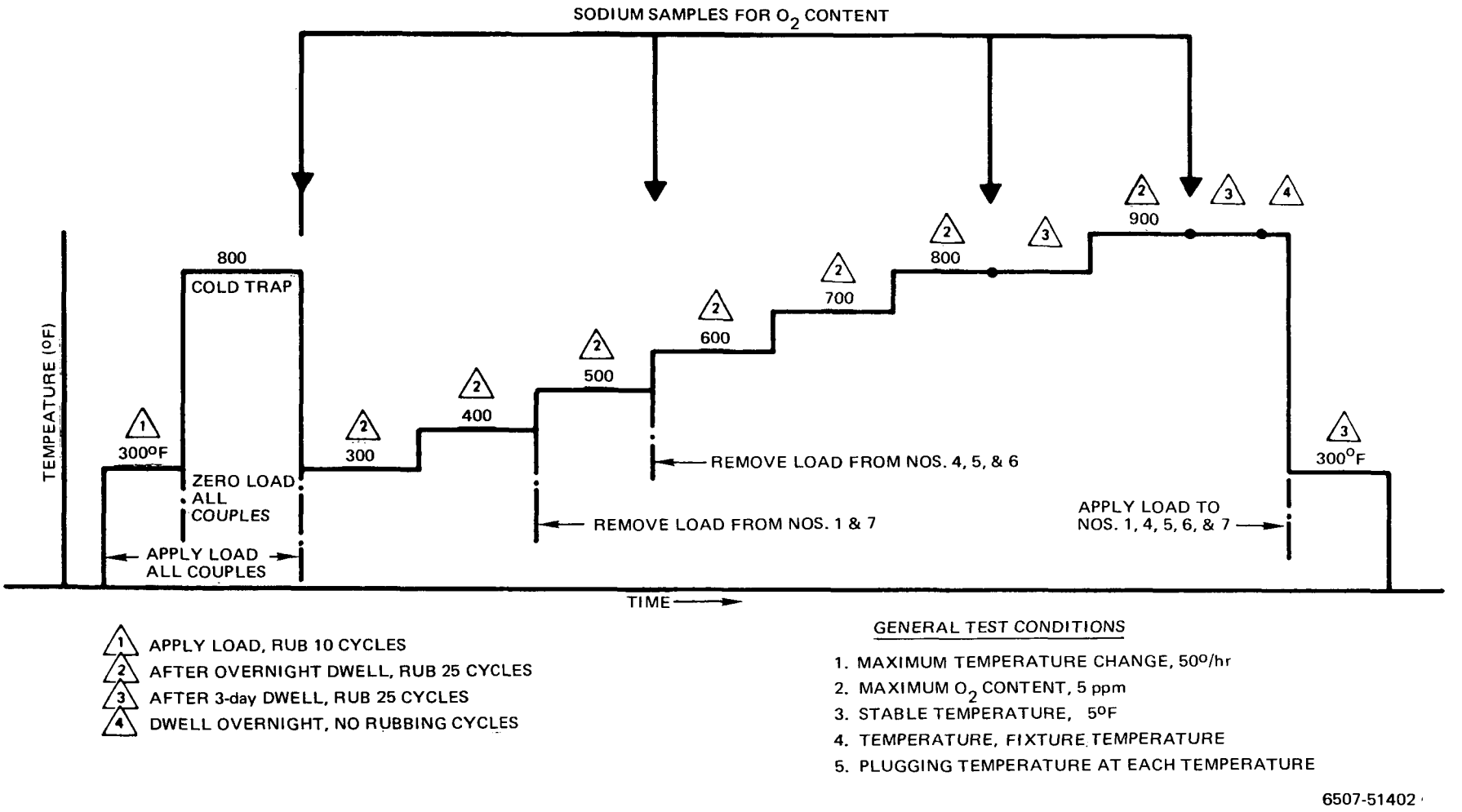


Figure 10. Friction Matrix 10 Temperature-Time-Wear Cycle Profile

TABLE 12

DATA SUMMARY – FRICTION TEST 10
(Sheet 1 of 2)

Couple	Rider	Plate	Contact Pressure (psi)	Breakaway(B) Static(S)* Dynamic(D)*	Friction Coefficient										
					300°F†	300°F △1	400°F △1	500°F △1	600°F △1	700°F △1	800°F △1	800°F △2	900°F △1	900°F △2	300°F △2
					0-10 Cycles	11-35 Cycles	36-60 Cycles	61-85 Cycles	86-110 Cycles	110-135 Cycles	136-160 Cycles	161-185 Cycles	185-210 Cycles	211-235 Cycles	235-260 Cycles
1	Aluminum Bronze	Colmonoy	200	B	-	0.28	0.27								0.50
				S	0.25	0.23	0.39	No data taken above 400°F							0.34
				D	0.28	0.39	0.44								0.41
2	Aluminized Inconel 718	Aluminized Inconel 718	800	B	-	0.32	0.18	0.35	0.36	0.80	0.30	0.32	0.32	0.35	0.35
				S	0.21	0.32	0.20	0.32	0.44	0.34	0.33	0.18	0.29	0.33	0.37
				D	0.31	0.41	0.31	0.43	0.51	0.39	0.39	0.34	0.34	0.36	0.41
3	Aluminized Inconel 718	Aluminized Inconel 718	200	B	-	0.15	0.12	0.34	-	0.43	0.40	0.42	0.34	0.33	0.37
				S	0.22	0.23	0.14	0.36	0.29	0.29	0.27	0.31	0.30	0.34	0.33
				D	0.30	0.33	0.23	0.39	0.41	0.39	0.30	0.40	0.36	0.40	0.42
4	Inconel X-750	Nitrided Type 304 SS	200	B	-	0.35	0.15	0.23							0.40
				S	0.40	0.33	0.31	0.23	No data taken above 500°F						0.24
				D	0.52	0.45	0.55	0.38							0.40
5	Stellite 6B	Inconel 718	200	B	-	0.15	0.15	0.20							0.23
				S	0.40	0.15	0.19	0.13	No data taken above 500°F						0.21
				D	0.58	0.25	0.34	0.26							0.29
6	Stellite 6B	Aluminized Inconel 718	200	B	-	0.16	0.15	0.16							0.30
				S	0.30	0.14	0.15	0.15	No data taken above 500°F						0.29
				D	0.35	0.29	0.25	0.27							0.45
7	Ni-Resist	Type 304 SS + Vitrolube	200	B	-	0.40	0.57								0.13
				S	0.13	0.21	0.22	No data taken above 400°F							0.03
				D	0.16	0.29	0.24								0.13
8	Triboloy 400	Inconel 718	200	B	-	0.25	0.35	0.27	0.27	0.40	0.36	0.42	0.31	0.40	0.46
				S	0.06	0.19	0.24	0.11	0.06	0.07	0.22	0.31	0.40	0.49	0.17
				D	0.11	0.29	0.30	0.22	0.15	0.13	0.25	0.37	0.46	0.52	0.14
9	Triboloy 700	Inconel 718	200	B	-	0.32	0.38	0.30	0.28	0.35	0.36	0.55	0.56	0.36	0.28
				S	0.15	0.20	0.19	0.17	0.16	0.07	0.24	0.22	0.20	0.17	0.21
				D	0.20	0.27	0.27	0.26	0.22	0.14	0.27	0.29	0.30	0.26	0.22

*Average observed during cycles
†Prior to cold trapping

△1 Measurements made after overnight dwell (16-hr minimum)
△2 Measurements made after 3-day dwell (minimum)

TABLE 12

DATA SUMMARY – FRICTION TEST 10
(Sheet 2 of 2)

Couple	Rider	Plate	Contact Pressure (psi)	Breakaway(B) Static(S)* Dynamic(D)*	Friction Coefficient										
					300°F†	300°F △1	400°F △1	500°F △1	600°F △1	700°F △1	800°F △1	800°F △2	900°F △1	900°F △2	300°F △2
					0-10 Cycles	11-35 Cycles	36-60 Cycles	61-85 Cycles	86-110 Cycles	110-135 Cycles	136-160 Cycles	161-185 Cycles	185-210 Cycles	211-235 Cycles	235-260 Cycles
10	Tribaloy 700	Aluminized Inconel 718	200	B	-	0.13	0.10	0.12	0.20	0.23	0.15	0.20	0.25	0.06	0.24
				S	0.13	0.05	0.10	0.11	0.09	0.04	0.13	0.09	0.12	0.16	0.18
				D	0.20	0.17	0.20	0.21	0.20	0.09	0.16	0.19	0.18	0.22	0.32
11	K-Ramic	Inconel 718	200	B	-	0.20	0.12	0.30	0.36	0.30	0.50	0.41	0.36	0.28	0.40
				S	0.14	0.10	0.47	0.20	0.10	0.21	0.34	0.32	0.26	0.20	0.49
				D	0.22	0.21	0.72	0.37	0.24	0.27	0.37	0.38	0.31	0.38	0.64
12	CN-1B	CN-1B	200	B	-	0.07	0.08	0.18	0.10	0.22	0.28	0.40	0.33	0.50	0.36
				S	0.09	0.06	0.08	0.04	0.05	0.05	0.28	0.21	0.31	0.32	0.16
				D	0.15	0.13	0.12	0.12	0.15	0.18	0.31	0.25	0.38	0.42	0.24
13	CN-1B	Aluminized Inconel 718	200	B	-	0.17	0.10	0.32	0.28	0.33	0.37	0.48	0.42	0.30	0.36
				S	0.18	0.18	0.08	0.22	0.29	0.26	0.29	0.29	0.29	0.27	0.33
				D	0.23	0.32	0.19	0.34	0.37	0.33	0.35	0.37	0.37	0.38	0.46
14	Am Cer Met 701-N65	Inconel 718	200	B	-	0.20	0.22	0.30	0.40	0.52	0.60	0.61	0.50	0.84	0.88
				S	0.16	0.17	0.17	0.12	0.16	0.17	0.19	0.30	0.41	0.37	0.35
				D	0.19	0.22	0.33	0.21	0.29	0.27	0.27	0.37	0.52	0.43	0.42
15	Ni-Resist	Tribaloy 700 PC	200	B	-	0.13	0.10	0.15	0.08	0.17	0.04	0.19	0.20	0.26	0.36
				S	0.23	0.07	0.07	0.07	0.02	0.05	0.04	0.07	0.09	0.09	0.18
				D	0.26	0.18	0.19	0.19	0.13	0.11	0.14	0.14	0.18	0.19	0.29
16	Stellite 6	Stellite 6	200	B	-	0.20	0.18	0.37	0.20	0.15	0.15	0.23	0.30	0.32	0.25
				S	0.18	0.20	0.21	0.17	0.11	0.17	0.12	0.18	0.22	0.24	0.29
				D	0.24	0.25	0.24	0.22	0.17	0.18	0.25	0.27	0.36	0.31	0.32
17	Electrolyzed Chrome Plate on Type 316 SS	Electrolyzed Chrome Plate on Type 316 SS	300	B	-	0.37	0.33	0.57	0.47	0.33	0.35	0.35	0.40	0.44	0.63
				S	0.29	0.29	0.22	0.38	0.44	0.33	0.25	0.28	0.29	0.31	0.47
				D	0.46	0.46	0.44	0.52	0.51	0.44	0.39	0.37	0.36	0.39	0.68
18	Chrome Plate on Type 316 SS	Chrome Plate on Type 316 SS	300	B	-	0.38	0.28	0.28	0.32	0.71	0.68	0.75	0.85	0.82	0.65
				S	0.08	0.21	0.20	0.24	0.42	0.43	0.52	0.45	0.44	0.51	0.51
				D	0.12	0.30	0.26	0.26	0.50	0.54	0.55	0.57	0.51	0.54	0.57

*Average observed during cycles
†Prior to cold trapping

△1 Measurements made after overnight dwell (16-hr minimum)
△2 Measurements made after 3-day dwell (minimum)

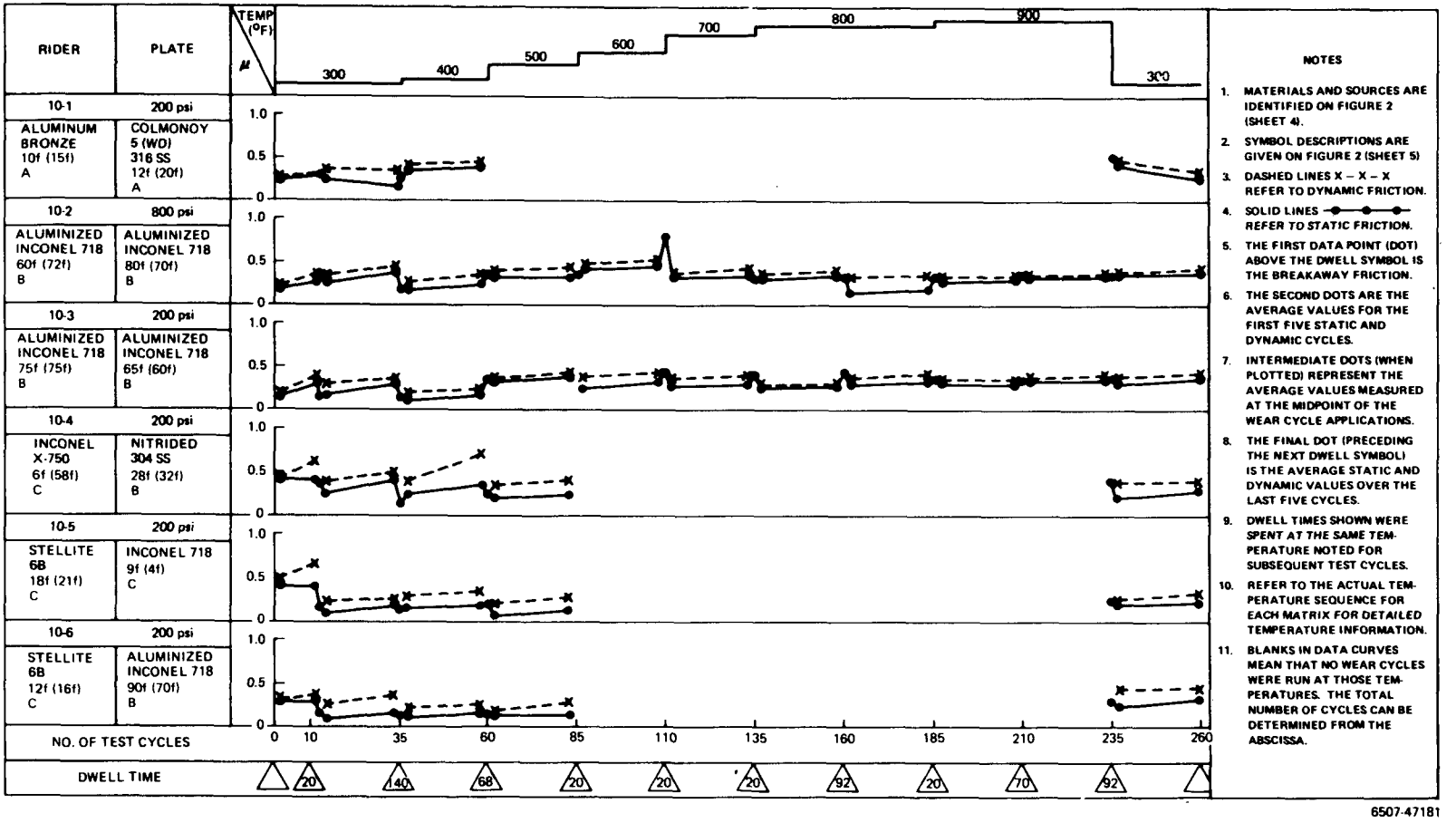


Figure 11. Friction Matrix No. 10 – Friction Coefficients vs Wear Cycles
(Sheet 1 of 3)

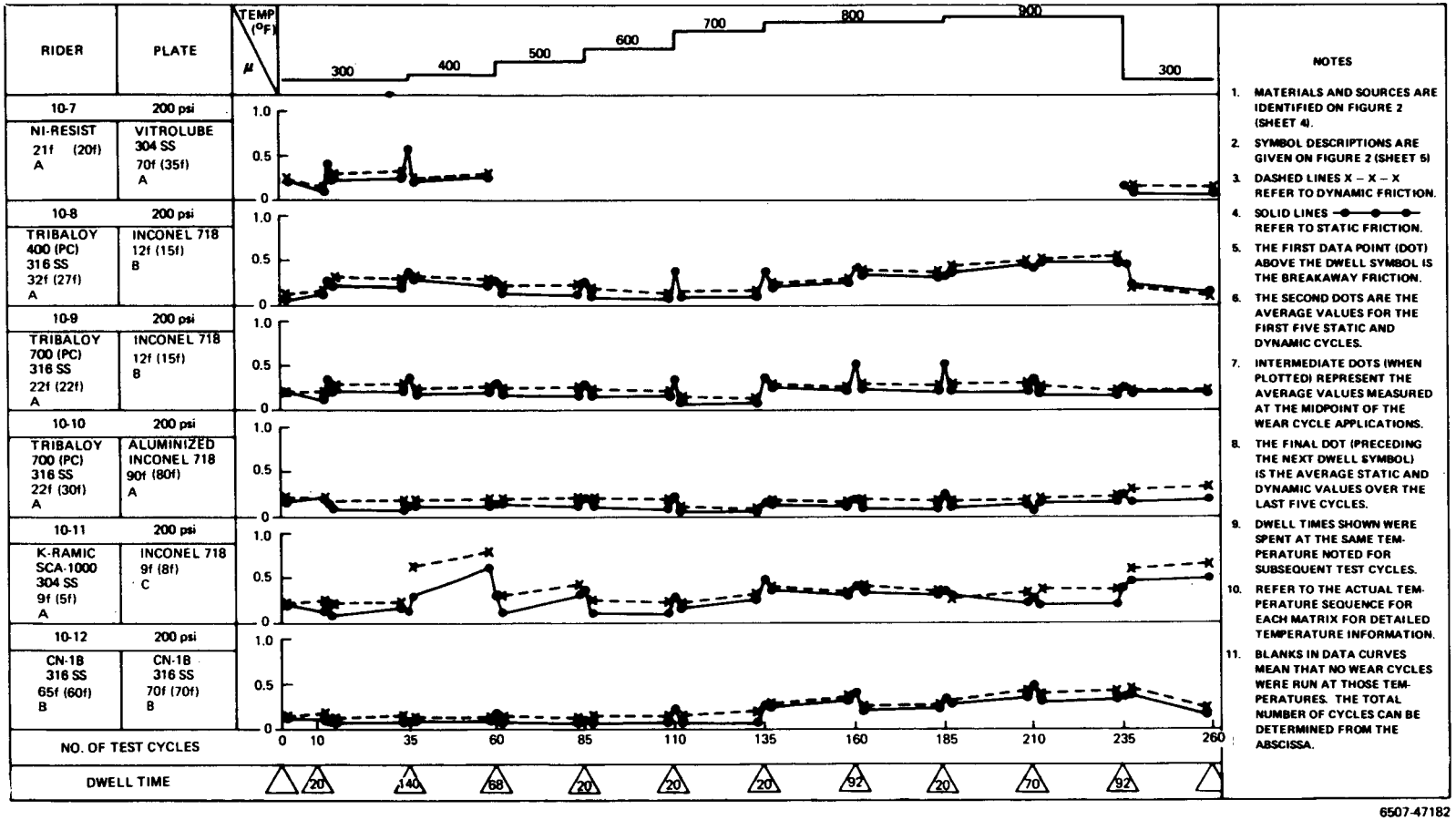


Figure 11. Friction Matrix No. 10 – Friction Coefficients vs Wear Cycles
(Sheet 2 of 3)

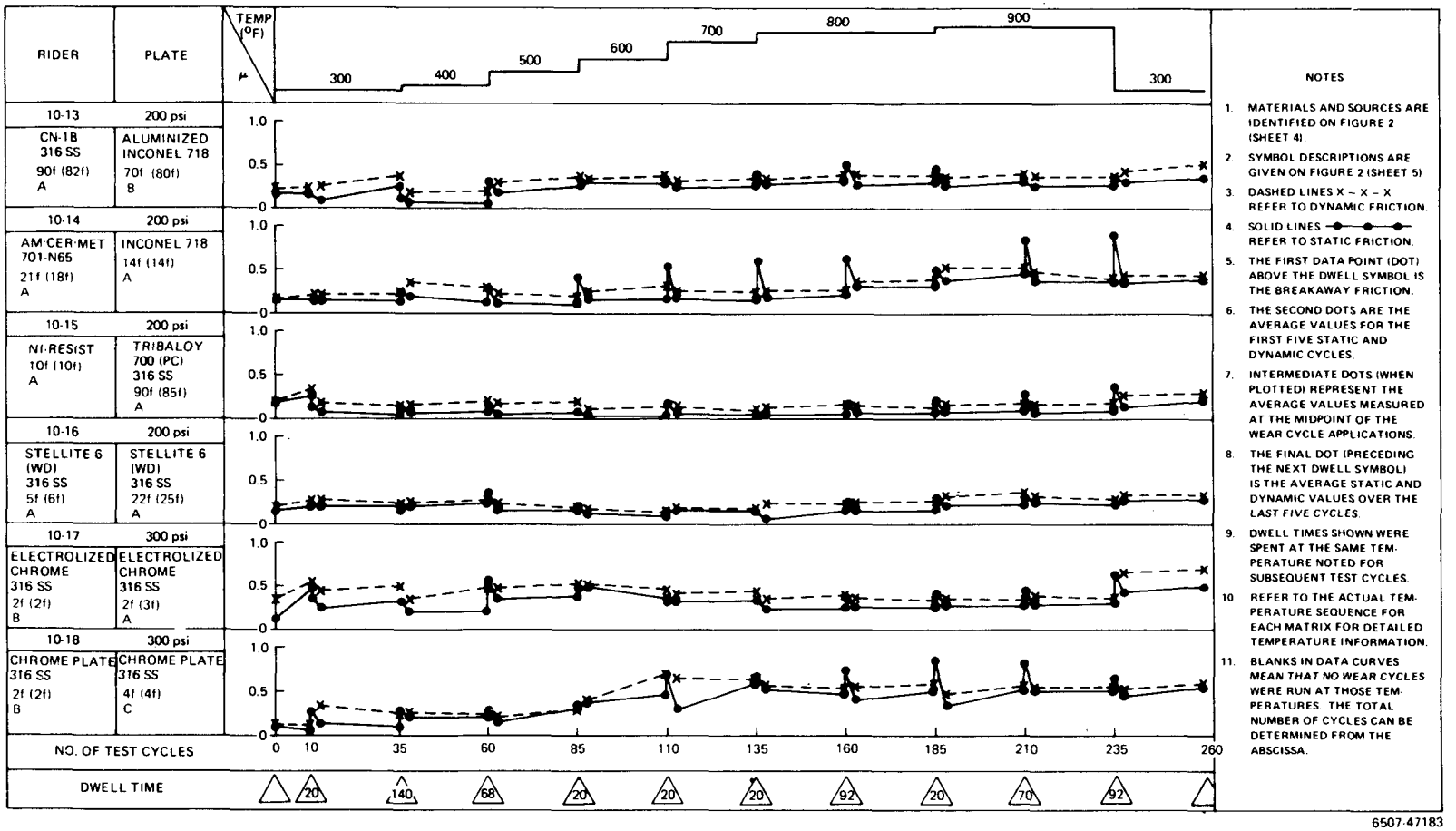
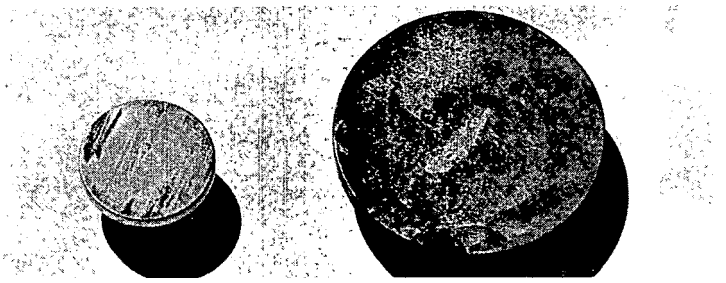
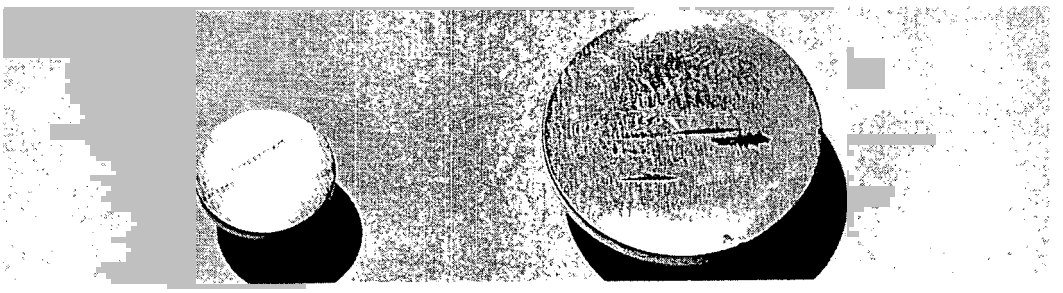


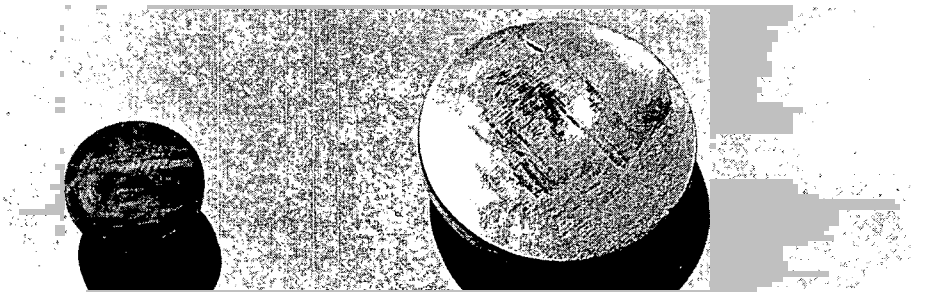
Figure 11. Friction Matrix No. 10 — Friction Coefficients vs Wear Cycles (Sheet 3 of 3)



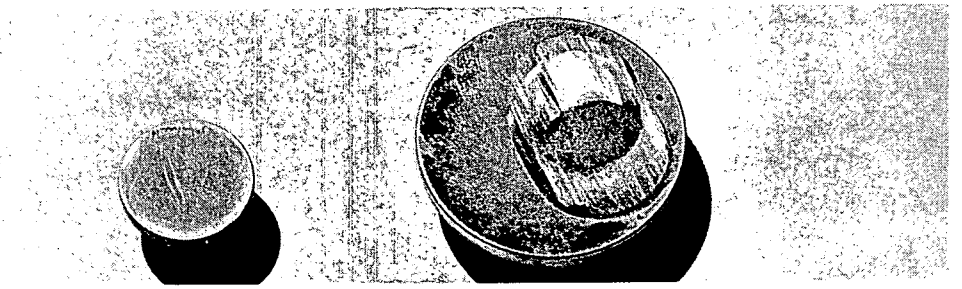
INCONEL X-750 NITRIDED TYPE 304 SS
COUPLE 4 6507-51380



STELLITE 6B INCONEL 718
COUPLE 5 6507-51383



K-RAMIC INCONEL 718
COUPLE 11 6507-51389



CHROME PLATE CHROME PLATE ON 316 SS
COUPLE 18 6507-51378

6507-51403

Figure 12. Friction Matrix No. 10 Test Couples

TABLE 13

SUMMARY TABLE OF FRICTION IN SODIUM VAPOR
MATRIX 10
(HEDL Format)
(Sheet 1 of 8)

Test			Test Conditions						Friction Results							Comments
	Materials									Static Friction			Dynamic Friction			
Number	Pin	Plate	Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in./sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
10-1	Aluminum Bronze	Colmonoy 5	400	39.3/200	0.07	d/2	60/30	140	0.27	0.37	0.40	0.40	0.42	0.45	0.45	Previous experience includes 10/5 at 300°F before cold trapping and 25/12.5 at 300°F after cold trapping.
			300	39.3/200			85/42.5	92	0.50	0.40	0.49	0.27	0.46	0.61	0.36	No wear cycles above 400°F. Load removed at 400°F and reapplied at 300°F at end of test. Previous wear cycles 60/30 as noted above.
10-2	Aluminized Inconel 718	Aluminized Inconel 718	400	157.1/ 800			60/30	140	0.18	0.17	0.23	0.23	0.27	0.35	0.35	Previous experience includes 10/5 at 300°F before cold trapping and 25/12.5 at 300°F after cold trapping.
			800				185/92.5	92	0.32	0.15	0.29	0.20	0.32	0.36	0.36	Rubbing experience includes 160/80 at previous temperature levels.
			900				235/ 117.5	70	0.35	0.32	0.34	0.34	0.34	0.37	0.37	Rubbing experience includes 210/105 at previous temperature levels.
			300				260/130	92	0.35	0.35	0.38	0.38	0.39	0.42	0.42	Rubbing experience includes 235/117.5 at previous temperature levels.
10-3	Aluminized Inconel 718	Aluminized Inconel 718	400	39.3/ 200			60/30	140	0.12	0.10	0.20	0.18	0.20	0.28	0.25	Same as 10-2
			800				185/92.5	92	0.42	0.30	0.32	0.32	0.38	0.50	0.42	
			900				235/ 117.5	70	0.33	0.33	0.34	0.34	0.38	0.50	0.42	
			300				260/ 130	92	0.37	0.30	0.38	0.36	0.40	0.55	0.43	

TABLE 13

SUMMARY TABLE OF FRICTION IN SODIUM VAPOR
MATRIX 10
(HEDL Format)
(Sheet 2 of 8)

Test			Test Conditions						Friction Results							Comments
Number	Materials		Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in./sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Static Friction			Dynamic Friction			
	Pin	Plate								Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
10-4	Inconel X-750	Nitrided Type 304 SS	400	39.3/ 200	0.07	d/2	60/30	140	0.15	0.25	0.40	0.36	0.40	0.70	0.70	Previous experience includes 10/5 at 300°F before cold trapping and 25/12.5 at 300°F after cold trapping.
			300				110/55	92	0.40	0.20	0.28	0.28	0.39	0.52	0.40	No wear cycles above 500°F. Load removed at 500°F and reapplied at 300°F at end of test. Previous rubbing experience includes 85/42.5 total at 300, 400, and 500°F.
10-5	Stellite 6B	Inconel 718	400				60/30	140	0.15	0.17	0.20	0.20	0.30	0.38	0.38	Same as 10-4
			300				110/55	92	0.23	0.20	0.22	0.22	0.25	0.36	0.32	
10-6	Stellite 6B	Aluminized Inconel 718	400				60/30	140	0.15	0.12	0.20	0.18	0.22	0.28	0.28	Same as 10-4
			300				110/55	92	0.30	0.25	0.32	0.32	0.44	0.55	0.46	
10-7	Niresist	Type 304 SS & Vitrolube	400				60/30	140	0.57	0.18	0.28	0.25	0.21	0.27	0.27	Same as 10-1
			300				85/ 42.5	92	0.13	0.04	0.13	0.02	0.13	0.18	0.12	

TABLE 13

SUMMARY TABLE OF FRICTION IN SODIUM VAPOR
MATRIX 10
(HEDL Format)
(Sheet 3 of 8)

Test			Test Conditions						Friction Results							Comments
Number	Materials		Temperature (° F)	Load/ Pressure (lb)/(psi)	Average Velocity (in. /sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Break-away Friction	Static Friction			Dynamic Friction			
	Pin	Plate								Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
10-8	Triboloy 400	Inconel 718	400	39.3/ 200	0.07	d/2	60/30	140	0.35	0.28	0.38	0.20	0.31	0.48	0.28	
			800				185/ 92.5	92	0.42	0.31	0.36	0.30	0.38	0.43	0.36	Same as 10-2
			900				235/ 117.5	70	0.40	0.48	0.48	0.47	0.50	0.53	0.53	
			300				260/ 130	92	0.46	0.21	0.28	0.12	0.19	0.40	0.08	
10-9	Triboloy 700	Inconel 718	400				60/30	140	0.38	0.18	0.25	0.20	0.25	0.50	0.28	
			800				185/ 92.5	92	0.55	0.23	0.27	0.20	0.30	0.40	0.28	Same as 10-2
			900				235/ 117.5	70	0.36	0.17	0.28	0.16	0.29	0.29	0.22	
			300				260/ 130	92	0.28	0.22	0.38	0.20	0.22	0.34	0.21	

TABLE 13

SUMMARY TABLE OF FRICTION IN SODIUM VAPOR
MATRIX 10
(HEDL Format)
(Sheet 4 of 8)

Test			Test Conditions						Friction Results							Comments
Number	Materials		Temperature (° F)	Load/ Pressure (lb)/(psi)	Average Velocity (in. /sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Static Friction			Dynamic Friction			
	Pin	Plate								Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
10-10	Triboloy 700	Aluminized Inconel 718	400	39.3/ 200	0.07	d/2	60/30	140	0.10	0.10	0.12	0.10	0.19	0.30	0.20	
			800				185/ 92.5	92	0.20	0.09	0.16	0.09	0.20	0.30	0.18	Same as 10-2
			900				235/ 117.5	70	0.06	0.15	0.20	0.16	0.21	0.23	0.23	
			300				260/ 130	92	0.24	0.16	0.22	0.20	0.30	0.40	0.34	
10-11	K-ramic	Inconel 718	400				60/30	140	0.12	0.30	0.68	0.68	0.63	0.80	0.80	
			800				185/ 92.5	92	0.41	0.33	0.42	0.31	0.41	0.41	0.35	Same as 10-2
			900				235/ 117.5	70	0.28	0.20	0.39	0.20	0.38	0.39	0.38	
			300				260/ 130	92	0.40	0.48	0.51	0.50	0.61	0.67	0.67	

TABLE 13

SUMMARY TABLE OF FRICTION IN SODIUM VAPOR
MATRIX 10
(HEDL Format)
(Sheet 5 of 8)

Test			Test Conditions						Friction Results							Comments
	Materials									Static Friction			Dynamic Friction			
Number	Pin	Plate	Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in. /sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
10-12	CN-1B	CN-1B	400	39.3/ 200	0.07	d/2	60/30	140	0.08	0.08	0.09	0.08	0.12	0.21	0.12	
			800				185/ 92.5	92	0.40	0.20	0.22	0.22	0.23	0.36	0.26	Same as 10-2
			900				235/ 117.5	70	0.50	0.30	0.33	0.33	0.40	0.47	0.43	
			300				260/ 130	92	0.36	0.17	0.22	0.15	0.26	0.35	0.22	
10-13	CN-1B	Aluminized Inconel 718	400				60/30	140	0.10	0.08	0.12	0.08	0.18	0.22	0.20	
			800				185/ 92.5	92	0.48	0.27	0.32	0.30	0.36	0.40	0.38	Same as 10-2
			900				235/ 117.5	70	0.30	0.27	0.31	0.27	0.38	0.38	0.38	
			300				260/ 130	92	0.36	0.30	0.36	0.36	0.42	0.50	0.50	

TABLE 13

SUMMARY TABLE OF FRICTION IN SODIUM VAPOR
MATRIX 10
(HEDL Format)
(Sheet 6 of 8)

Test			Test Conditions						Friction Results							Comments
Number	Materials		Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in./sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Static Friction			Dynamic Friction			
	Pin	Plate								Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
10-14	AmCerMet 701-N65	Inconel 718	400	39.3/ 200	0.07	d/2	60/30	140	0.22	0.20	0.29	0.13	0.36	0.36	0.30	
			800				185/ 92.5	92	0.61	0.30	0.32	0.30	0.35	0.53	0.38	Same as 10-2
			900				235/ 117.5	70	0.84	0.37	0.39	0.37	0.47	0.50	0.39	
			300				260/ 130	92	0.88	0.32	0.40	0.38	0.42	0.52	0.41	
10-15	Ni-Resist	Triboloy 700 (PC)	400				120/ 60	140	0.10	0.05	0.09	0.09	0.17	0.28	0.20	Previous wear experience includes 10/5 at 300°F before cold trapping, 25/12.5 each at 300°F with 500 and 800 psi contact pressure, and 35/17.5 at 300°F and 200 psi contact pressure
			800				305/ 152.5	92	0.19	0.08	0.17	0.06	0.15	0.22	0.13	Previous rubbing experience includes 280/140 prior wear cycles at temperatures of 300 through 800°F with special contact loading tests at 300 and 500°F
			900				415/ 207.5	70	0.26	0.08	0.17	0.10	0.18	0.27	0.20	Previous rubbing experience includes 390/185 prior wear cycle at temperatures of 300 through 900°F with special contact loading tests at 300, 500, and 800°F
			300				500/ 250	92	0.36	0.16	0.20	0.20	0.28	0.33	0.30	Previous rubbing experience includes 475/237.5 prior wear cycles at temperatures of 300 through 900°F with special contact loading tests at 300, 500, 800, and 900°F

TABLE 13

SUMMARY TABLE OF FRICTION IN SODIUM VAPOR
MATRIX 10
(HEDL Format)
(Sheet 7 of 8)

Test			Test Conditions						Friction Results							Comments
Number	Materials		Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in. /sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Static Friction			Dynamic Friction			
	Pin	Plate								Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
10-16	Stellite (WD)	Stellite (WD)	400	39.3/ 200	0.07	d/2	60/30	140	0.18	0.20	0.22	0.22	0.2 3	0.25	0.25	
			800				185/ 92.5	92	0.23	0.17	0.22	0.18	0.26	0.34	0.28	Same as 10-2
			900				235/ 117.5	70	0.32	0.26	0.30	0.22	0.31	0.40	0.30	
			300				260/ 130	92	0.25	0.28	0.30	0.30	0.32	0.32	0.32	
10-17	Electrolyzed Chrome Plate on 316 SS		400	58.9/ 300			60/30	140	0.33	0.21	0.32	0.22	0.38	0.50	0.50	
			800				185/ 92.5	92	0.35	0.28	0.36	0.28	0.38	0.39	0.36	Same as 10-2
			900				235/ 117.5	70	0.44	0.30	0.38	0.31	0.40	0.40	0.38	
			300				260/ 130	92	0.63	0.43	0.50	0.50	0.65	0.70	0.70	

TABLE 13

SUMMARY TABLE OF FRICTION IN SODIUM VAPOR
MATRIX 10
(HEDL Format)
(Sheet 8 of 8)

Test			Test Conditions						Friction Results							Comments
Number	Materials		Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in. /sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Static Friction			Dynamic Friction			
	Pin	Plate								Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
10-18	Chrome Plate on 316SS	Chrome Plate on 316SS	400	58.9/ 300	0.07	d/2	60/30	140	0.28	0.20	0.30	0.20	0.27	0.40	0.25	
			800				185/ 92.5	92	0.75	0.40	0.50	0.50	0.53	0.60	0.60	Same as 10-2
			900				235/ 117.5	70	0.82	0.50	0.51	0.51	0.53	0.55	0.54	
			300				260/ 130	92	0.65	0.48	0.54	0.54	0.54	0.75	0.60	

Aluminized Inconel 718), and No. 15 (Ni-Resist vs Tribaloy 700). The first two of these, 7 and 9, showed some indication of metallurgical bonding as evidenced by the noted breakaway spikes. The latter two displayed excellent all-around performance. None of the four couples had any visual indication of surface wear other than very minor polishing of high spots.

Nine of the couples (1, 2, 3, 6, 8, 12, 13, 14, 16) demonstrated friction coefficients which touched as high as 0.4 to 0.5 somewhere in the temperature sequence. However, as noted in Figure 11, friction values were generally less than these values over most of the test range. The performance of Couple 14 (AmCerMet vs Inconel) was clouded by the presence of significant breakaway spikes which indicate some sort of metallurgical bonding for this material combination at relatively low service temperatures. None of the couples in this group experienced surface wear, other than slight polishing, with the exception of the rider (Stellite 6B) on Couple 6 which incurred some minor scratching.

The remaining five couples (4, 5, 11, 17, 18), by comparison, did not perform nearly so well as the other specimens. Dynamic friction coefficients on each reached as high as 0.7 at some temperatures, and the friction levels over the entire test were generally higher than those indicated for the other couples. The only significant wear observed on Matrix 10 couples occurred on four of these five, and consisted of slight scratching of one or both pieces of the couple. Figure 12 gives an indication of the nature of wear on Couple 4 (Inconel X-750 vs Nitrided Type 304 stainless steel), Couple 5 (Stellite 6B vs Inconel 718), Couple 15 (K-Ramic vs Inconel 718), and Couple 18 (Chrome-plated Type 316 stainless steel vs Chrome-plated Type 316 stainless steel).

After the specified 25 wear cycles were applied to each specimen at 800°F following the overnight (nominal 16 hours) dwell, Couple 15 (Ni-Resist vs Triboloy 700), which had displayed consistently low friction values, was selected for load tests to ascertain the effect, if any, of contact loading. In addition to the 25 wear-cycle run at 200 psi, 25 cycles were also run at 500- and 800-psi contact loading. Upon return to 200-psi loading, ten more wear cycles were applied. The tests showed that over this limited range of contact loadings there were no discernible changes in the measured static and dynamic friction coefficients.

At the conclusion of the scheduled 800° F friction measurements, eight couples were selected for a series of tests to study the effects of short-term dwells on the breakaway friction values. The eight were picked because after the overnight dwell at 800° F, each had shown a breakaway "spike" in excess of the average static friction value. Breakaways were then measured on each couple after an additional 4-hour dwell. Those still showing significant breakaway values were tested again after dwells of 30 min, 5 min, 1 min, 30 sec, and 1 sec. This same procedure was subsequently repeated on select specimens at 900, 300, and 500° F. Over these short dwell time durations, none of the test specimens gave positive indication that the dwell time had a significant effect on the magnitude of the breakaway friction.

E. FRICTION MATRICES 11 AND 12

The overall friction test program was reviewed at a general meeting at ARD on May 8 and 9, 1974, with representatives of AEC, HEDL, ARD, AI, LMEC, AMCO, GE, and General Atomics in attendance. The tentative content of the eleventh and twelfth matrices, which was formulated at this meeting, is shown on Table 14. Material procurement for the test couples is presently in progress.

III. IMPACT ON LMFBR PROGRAMS

The results of this program are needed for the selection of Material for the driver ducts for FFTF and FBR's, and will provide information to define the methods and forces required to clamp a core after refueling. This program will also support LMFBR technology, by providing friction (breakaway and sliding) data at various contact pressures for other reactor component materials and/or material combinations anticipated for use in a high-temperature (400 to 1600° F), high-purity (<5 ppm) sodium and/or sodium vapor environment.

TABLE 14

MATRIX 11 - SODIUM

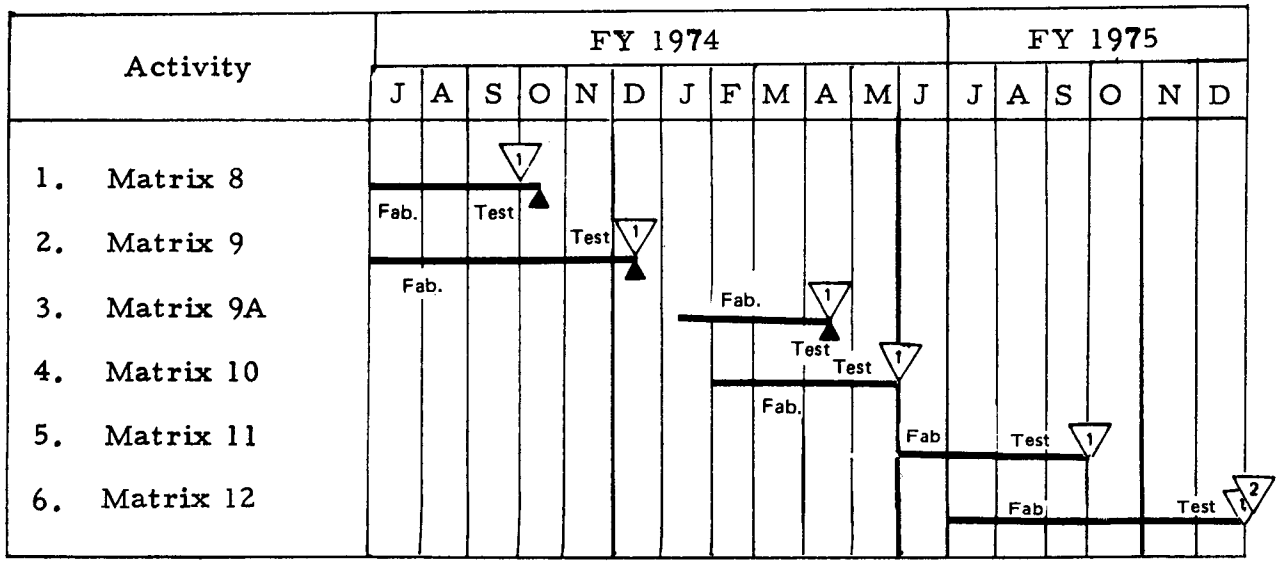
1.	Aluminized Inconel 718/self	(air heat treatment)
2.	Aluminized Inconel 718/self	(inert gas treatment)
3.	Aluminized Inconel 718/self	(air treat, hand polish)
4.	Aluminized Inconel 718/self	(inert treat, lap to <10 rms)
5.	Armco NP444/self	
6.	Inconel 903/self	
7.	Armco NP444/In 718	
8.	Armco NP444/Alum. In 718	
9.	Armco NP444/304SS	
10.	In 903/In 718	
11.	In 903/Armco NP444	
12.	In 903/Al. In 718	
13.	Al In 903/Al In 903	
14.	TiAl/self	
15.	304 SS/Incoloy 800	
16.	2 1/4 Cr - 1 Mo/self	
17.	AmCerMet 701 - N65/self	
18.	Trib. 700/self (D-Gun applied)	

MATRIX 12 - INERT GAS AND SODIUM VAPOR

1.	CN-16/self
2.	LC-1HD/self
3.	Armco NP444/self
4.	Inconel 903/self
5.	Tribaloy 700/self
6.	Tribaloy 400/self
7.	Stellite 21/self
8.	AmCerMet 701-N65/self
9.	CN-1B/Al In 718
10.	K-ramic/self
11.	Cr_2O_3/self (coating)
12.	Cr-Plate + K-ramic Treatment/self
13.	Cr-Plate + K-ramic Treatment/In 718
14.	Ni-Resist/NP444
15.	Ni-Resist/Trib. 700
16.	In 718/Lubricated In 718 (Lubricant TBD)
17.	In 718/Lubricated In 718 (Lubricant TBD)
18.	In 718/Lubricated In 718 (Lubricant TBD)
19.	In 718/Lubricated In 718 (Lubricant TBD)

IV. SCHEDULE

The program activities and milestones are shown in the following test schedule. The schedule has been updated to show inclusion of Matrices 11 and 12 in GFY '75.



1. Complete Test
2. Final Test Report

▲Denotes Completion

TASK 1 — Friction Test, Schedule and Milestones