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KSC LUBRICANT TESTING PROGRAM

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16. Abstract

A program was conducted to evaluate the performance of various lubricants in use and considered for use at Kennedy Space Center (KSC). The overall objectives of the program were to: (1) determine the lubrication characteristics and relative corrosion resistance of lubricants in use and proposed for use at KSC, (2) identify materials which may be equivalent to or better than KEL F-90 and Krytox 240 AC greases, and (3) identify or develop an improved lubricating oil suitable for use in liquid oxygen (LOX) pumps at KSC.

It was concluded that: (1) earth gel thickened greases are very poor corrosion preventive materials in the KSC environment, (2) Halocarbon 25-5S and Braycote 656 were suitable substitutes for KEL F-90 and Krytox 240 AC respectively, and (3) none of the oils evaluated possessed the necessary inertness, lubricity, and corrosion prevention characteristics for the KSC LOX pumping systems in their present configuration.

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KSC FORM 16-272 (5/72)

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LUBRICANT TESTING PROGRAM

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INTRODUCTION

This report summarizes the work performed from March 1970 through December 1972 on a program to evaluate various lubricants in use and considered for use at Kennedy Space Center (KSC).

The overall objectives of the program were:

a. To determine the lubrication characteristics and relative corrosion protection provided by lubricants in use or considered for use at KSC.

b. To identify materials which may be interchangeable with KEL-F-90 and Krytox 240 AC greases.

c. To identify or develop an improved lubricating oil suitable for use in liquid oxygen (LOX) pumps.

MATERIALS AND EQUIPMENT

The majority of the lubricants in this testing program were procured by Military Specification Number. Other lubricants were ordered by brand name where a specific material has been used at KSC in a very limited number of applications. The lubricants evaluated are listed in the following paragraph.

Materials

Greases

KEL-F-90; 3M Company

Fluorolube GR362; Lot 11-6-69, Hooker Chemical Corporation

Halocarbon 25-5S; Batch 31869, Halocarbon Products Corporation

Halocarbon 25-20M; NASA 105457, Halocarbon Products Corporation

Halocarbon 25-20M-5A; Batch 10268, Halocarbon Products Corporation

Dag Disperson 1730; Lot 50, Acheson Colloids Company

Nu-Lub All Purpose Grease; Batch 115, Nu-Chem Industries

Braycote Micronic 631A; Batch B8LN1, Bray Oil Company

Drilube 822; Lot 4931, Drilube Corporation

FS-1281; Lot 104, Dow Corning Corporation

Electromoly 30; Batch 3886, Electrofilm, Incorporated

Versilube G-341L; MIS 13014, General Electric Company

DC33M; Lot M648, Dow Corning Corporation

Bison 88, American Lubricants Company

Krytox 250 AC; Lot 2, E.I. du Pont de Nemours & Company

Krytox 260 AC, Lot 5, E.I. du Pont de Nemours & Company

Krytox 280 AC; Lot 1, E.I. du Pont de Nemours & Company

Atlantic 54, Atlantic Refining Company

MIL-G-3545C; High Temperature Aircraft Grease; Batch 77607, Southwest Grease and Oil Company, Incorporated (Kansas City Division)

MIL-G-4343B, Pneumatic System Grease; DC 55M, Dow Corning Corporation

MIL-G-4343B, Lot 31, Pneumatic System Grease; Royal Lubricants Company

MIL-G-7711A, General Purpose Aircraft Grease; GB 382, Batch 1, International Lubricant Corporation

MIL-G-10924B, Automotive and Artillery Grease; G403, Batch 3, International Lubricant Corporation

MIL-C-11796(1), Class 2, Braycote 165, Bray Oil Company

MIL-L-15719A, Lubricating Grease (High-Temperature) Electric Motor, Ball and Roller Bearings; DC 44, Lot BA181, Dow Corning Corporation

Greases (Continued)

MIL-G-18458A, Wire Rope-Exposed Gear Grease; Open Gear No. 4, Allube Corporation

MIL-G-18709A, Ball and Roller Bearing Grease; B53528, unknown

MIL-G-18709A, Ball and Roller Bearing Grease; Alvania Grease No. 2, Shell Oil Company

MIL-G-21164B, Molybdenum Disulfide Grease; Lot 33, Royal Lubricants Company

MIL-G-23549A, General Purpose Grease; Batch 34, American Oil Company

MIL-G-23549A, General Purpose Grease; Code 16710, Southwest Grease and Oil Company (Kansas City Division)

MIL-G-23549A, General Purpose Grease; Grease Catapult Foot Pad, Royal Lubricants Company

MIL-G-23549A, General Purpose Grease; Hulmoly NCG 10301, Hulburt Oil and Grease Company

MIL-G-23827A, Aircraft and Instruments Gear and Actuator Screw Grease; G354, Lot 19, Royal Lubricants Company

MIL-G-25013D, Aircraft Ball and Roller Bearing Grease; BRH, Batch BRB 7355, Standard Oil Company of California

MIL-L-25681C, Molybdenum Disulfide Silicone Lubricant; Oil with Molybdenum Disulfide, Batch P0046, Dow Corning Corporation

MIL-G-27617A, Fuel and Oil Resistant Aircraft Grease; FS-1292, Lot BA201, Dow Corning Corporation

MIL-G-27617A, Fuel and Oil Resistant Aircraft Grease; Krytox 240 AC, Lot 54, E.I. du Pont de Nemours & Company

MIL-G-27617A, Fuel and Oil Resistant Aircraft Grease; Braycote 656, Batch COLA2, Bray Oil Company

MIL-G-81322A, General Purpose Wide Temperature Range Aircraft Grease; Batch WB 3002, Mobil Oil Corporation

Oils

Nu-Trol Mark II, Nu-Chem Industries

Halocarbon 10-25; Batch P.O. CC 72955, Halocarbon Products Corporation

Halocarbon 11-21E; Batch 10868, Halocarbon Products Corporation

Halocarbon 13-21E; Batch 6969, Halocarbon Products Corporation

Krytox 143 AC; Lot 26, E.I. du Pont de Nemours & Company

Krytox 143 AY; Lot 7, E.I. du Pont de Nemours & Company

Solid Lubricants

MIL-M-7866B, Lubrication Grade Molybdenum Disulfide; Molykote Z, Dow Corning Corporation

MIL-L-81329A, Extreme Environment Solid Film Lubricant; Everlube 811, Batch 335-1, Everlube Corporation

MIL-L-46010A, Heat-Cured Inhibiting Solid Film Lubricant; DC 3400, Dow Corning Corporation

Equipment

The following test equipment was used in this testing program.

Universal Penetrometer with Automatic Timer and Test Cones, Precision Scientific No. 73513

Motor-Matic Grease Working Machine, Precision Scientific No. 73501

One Quarter Size Grease Worker, Precision Scientific No. 73534

Water Washout Grease Tester, Precision Scientific No. 73602

Dropping Point Apparatus, Precision Scientific No. 73455

Mechanical Bearing Packer, Custom Scientific per ASTM D-1743

Bearing Thrust Loading Device, Custom Scientific per ASTM D-1743

Low Temperature Torque Tester, Custom Scientific per ASTM D-1478

Precision-Shell 4-Ball Extreme Pressure Lubricant Tester, Precision Scientific No. 75015

Equipment (Continued)

Precision-Shell 4-Ball Wear Tester, Precision Scientific No. 73603

Dow Corning High Speed LFW-1 Friction and Wear Tester

Constant Temperature Bath, Precision Scientific No. 66648

Cloud and Pour Point Apparatus, Precision Scientific No. 74521

Evaporation Test Cells, Precision Scientific Nos. 74905 and 74929

Oxidation Stability Bombs, Precision Scientific No. 73414

Salt Spray Test Chamber, Associated Testing Laboratories, Incorporated, Model MX 9204

Temperature and Humidity Chamber, Tenney Engineering, Incorporated, Model T27UFR-100350

TEST PROCEDURES

When possible, all test procedures were taken from ASTM (American Society for Testing and Materials) standards, and Federal Test Method Standard 791B. A brief summary of each test method used during this testing program is as follows:

ASTM D-217, "Test for Cone Penetration of Lubricating Greases." - This test encompasses five procedures for measuring the consistency of lubricating greases by penetration of a standard cone. Two of these procedures were used: worked and unworked. Worked penetration is a measure of the consistency of a lubricating grease after it has been brought to 25°C (77°F) and then subjected to 60 double strokes in a standard grease worker. Unworked penetration is the consistency at 25°C (77°F) of a sample of lubricating grease which has received only minimum disturbance in transfer from the sample can to a grease-worker cup or a dimensionally equivalent container. In instances where insufficient sample quantity was a factor, alternate Method D-217 was utilized. This method utilizes a hand-operated grease worker for the worked penetration. Also a smaller, standard-size penetrometer cup was used for the worked and unworked penetration tests for these instances.

ASTM D-566, "Test for Dropping Point of Lubricating Greases." - The dropping point is the temperature at which grease passes from a semi-solid to a liquid state under the conditions of the test. The test procedure consists of applying a very thin film coating of the grease to a standard-size, chromium-plated brass cup, inserting the cup into a test tube, placing a thermometer into the cup, then inserting the assembled apparatus into an oil bath which is also equipped with a thermometer. The oil bath is then heated at a specified rate until a drop of the grease protrudes through the orifice in the grease cup. At this time, the temperatures of the two thermometers are noted and the average temperature recorded as the dropping point.

ASTM D-942, "Oxidation Stability of Lubricating Greases by the Oxygen Bomb Method." - This method of testing determines the resistance of lubricating greases to oxidation when stored under static conditions. In this test method, the sample of grease is oxidized in a bomb heated to 99°C (210°F) filled with oxygen at 758, 428 N/m^2 (110 psi). Pressure is observed and recorded and the degree of oxidation after 168 hours is determined by the corresponding decrease in oxygen pressure.

ASTM D-972, "Test for Evaporation Loss of Lubricating Greases and Oils." - This test determines the evaporation loss of lubricating greases and oils for applications where evaporation loss is a factor. A sample of the lubricant is placed in a bath at 99°C (210°F) for 22 hours. Heated air is passed over the surface and evaporation loss is calculated from the loss in weight of the sample.

ASTM D-1264, "Water Washout Characteristics of Lubricating Greases." - This method of testing is intended to evaluate the resistance of a lubricating grease to be washed from a bearing by water when tested at 38°C (100°F) and 79°C (175°F) under prescribed conditions. The grease is packed in a ball bearing, weighed, and then inserted in a housing with specified clearances and rotated at 62.8 rad./sec. (600 rpm). Water, controlled at the specified test temperature, impinges on the bearing housing at 5 ml per second for 1 hour. The bearing is then dried for 16 hours at 77°C (170°F) and reweighed; then weight loss is determined. The test procedure calls for 4 grams of grease to be packed into the bearings. However, in this testing program, due to varying densities of the greases, the bearings were packed with 4 to 8 grams of grease.

ASTM D-1402, "Effect of Copper on Oxidation Rate of Grease." - The resistance of lubricating greases to oxidation when stored in contact with copper is determined by partially immersing a copper strip in the lubricant in a bomb at 99°C (210°F) and filled with oxygen to 758,428 N/m^2 (110 psi). Pressure is observed, recorded, and the degree of oxidation is determined after 168 hours by the corresponding decrease in oxygen pressure.

ASTM D-1478, "Low-Temperature Torque of Ball Bearing Greases." - This method determines the extent to which a low-temperature grease retards the rotation of a slow-speed ball bearing when subjected to sub-zero temperature. The force, in gram-centimeters, required to restrain the outer ring of a No. 204, ABEC-1, open ball bearing lubricated with the test grease is measured at -54°C (-65°F). Starting torque is determined after 2 hours of equilibration time and running torques after 10 minutes of rotation. Several lubricants of particular interest were tested at temperatures other than -54°C to determine the minimum use temperature, reported in the tables as the minimum temperature.

ASTM D-1743, "Test for Rust Preventive Properties of Lubricating Greases (bearing in the bottle)." - This is a test to determine the corrosion-preventive properties of greases, using grease-lubricated, tapered roller bearings stored under wet conditions. In this test procedure, clean new bearings are packed with the test lubricant, run under a light-thrust load for 60 seconds at 183.2 rad./sec. (1,750 rpm), and stored for 2 weeks at 25°C (77°F) and 100-percent relative humidity. After 2 weeks, the bearings are examined for evidence of corrosion, and rated accordingly. The tests are run in triplicate.

ASTM D-1748, "Test for Rust Protection by Metal Preservatives in the Humidity Cabinet." - This test is used to evaluate the rust-preventive characteristics of metal preservatives under conditions of high humidity. This method was adapted to the Lubricant Testing Program by applying a 0.25 mm (10-mil) grease film to the test panels instead of dipping the panels in the preservative as the method prescribed. The steel test panels, fabricated from low-carbon, cold-rolled sheet or strip steel, were prepared to a prescribed surface finish, coated with the test lubricant, and suspended in a humidity cabinet at 49°C (120°F) and 100-percent relative humidity for 2,541.7 hours. At the end of the test period, the test panels were rated on a scale of 1 to 7, where 1 is excellent and 7 is significantly worse than an untreated control specimen.

ASTM D-2266, "Wear Preventive Characteristics of Lubricating Grease (Four-Ball Method)." - This test determines the wear preventive characteristics of lubricants in sliding steel-on-steel and is not intended to predict wear characteristics of other metal pairs or to evaluate the extreme pressure characteristics of lubricants. In this method, a steel ball is rotated at 125.6 rad./sec. (1200 rpm) against three stationary balls, AISI-C 52100 steel, for 2 hours at 10, 30, and 50 kg loads while immersed in the test lubricant at 75°C (167°F). The tests are run in duplicate and the diameters of the wear scars on the stationary balls are measured. It should be emphasized that no correlation has been established between the four-ball wear test and field service.

ASTM D-2596, "Method for Measurement of Extreme-Pressure Properties of Lubricating Grease (Four-Ball Method)." - This method determines the load-carrying properties of lubricants. Two determinations are normally made: (1) the Load-Wear Index (Mean Hertz Load), and (2) the Weld Point. However, a third determination can be made in which the Last Non-seizure Load is reported. In this method, a steel ball is rotated under load at 185.3 rad./sec. (1,770 rpm) against three stationary balls, AISI-C 52100, for 10 seconds. The applied load is gradually increased until welding occurs. It should be emphasized that no correlation has been established between the four-ball extreme-pressure results and field service. Also, this method is not considered applicable to lubricants containing silicones, halogenated silicones, or mixtures of silicone and petroleum fluids.

ASTM D-2714, "Method for Calibration and Operation of the Alpha Model LFW-1 Friction and Wear Testing Machine." - A steel test ring, SAE 4620, is rotated against a stationary steel block, SAE 01, at a spindle speed of 7.5 rad./sec. (72 rpm) under a 68 kg applied load for 5,000 revolutions. Oils were tested using an oil cup thermostatically controlled at 43.3°C (110°F). Greases were tested initially by applying a thin coat of lubricant to the test ring. However, the results were very erratic and a grease feeding system using a syringe and syringe pump was developed and is shown in Figure 1. The results from this system were highly reproducible. Two determinations were made: (1) the average width of the wear scar on the block, and (2) the weight loss of the block at the end of the test. In the event that the travel range of the loading system was exceeded during the test, the number of revolutions to that point was recorded. In addition, the wear block scar was examined microscopically with a scanning electron microscope (SEM), Cambridge Stereoscan, Mark 2A, in order to elucidate any characteristics wear problems which might be associated with individual lubricants.

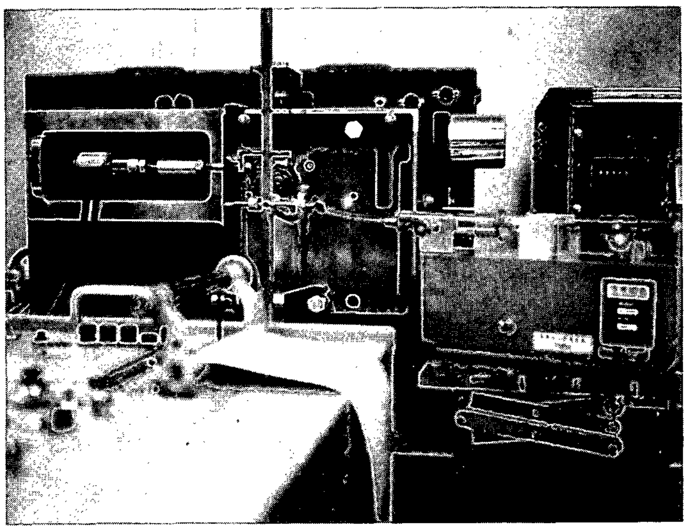


Figure 1. Automatic Grease Feeding System for Dow Corning LFW-1

Aluminum Shear (Nonreactivity with aluminum alloys). - This method is included in NAR Specification MBO 140-005. It is used for determining if any sparking, flame, or explosive sound is produced when subjecting lubricants to high-shear loads when in contact with aluminum. The test method consists of placing between 1 and 3 grams of lubricant in a 12.7 mm (1/2-inch) diameter, 12.7 mm (1/2-inch) deep recess in an aluminum block (6061-T6), inserting a 6.4 mm (1/4-inch) flat-ended and surface-finished to 813×10^{-6} to 1600×10^{-6} mm (32 to 63 microinches) aluminum dowel (6061-T6) into the recess, and rotating it at 62.8 rad./sec. (600 rpm) for 5 minutes under a 13,789,600 N/m^2 (2,000 psi) load. Any reactions are then noted and recorded. The tests are run in triplicate.

Federal Test Method Standard 791B; Lubricants, Liquid Fuels, and Related Products; Methods of Testing, Method 4001.2, "Corrosion Protection by Coating: Salt-Spray (Fog) Test." - This method is used to determine the corrosion protection provided by fluid, semi-solid, and solid coatings. The test panels, procured and prepared as specified in ASTM D-1748 and coated with a 0.25 mm (10-mil) grease film, were exposed to a 5-percent salt fog for 1,003 hours. After removal from the salt-spray chamber, the test panels were rated on a scale of 1 to 6, where 1 is excellent and 6 is equivalent to an uncoated control specimen. The ratings were determined after the removal of the test coating.

Exposed Beach Corrosion Test. - This test was used to determine corrosion protection provided by the test lubricants under exposed, beachside conditions. The test panels, procured and prepared as specified in ASTM D-1748 and coated with a 0.25 mm (10-mil) grease film, were placed on a wood-framed rack facing south, with the panels mounted at a 45-degree angle from the vertical for 1 year, December 1, 1971 to December 1, 1972.

Chemical Analysis. - All grease samples were sent to the Microchemical Analysis Laboratory for chemical analysis. Analyses performed included x-ray fluorescense, emission spectrography, infra spectroscopy, and electron microscopy of the thickeners and extreme pressure additives.

TEST RESULTS AND DISCUSSION

Since the majority of lubricants in this testing program are bought to military specifications, the test results are summarized in Tables 1 through 18 under the applicable military specification. In the cases of non-specification lubricants, the test results are reported in Tables 19 through 26, based on the type of fluid of the liquid base.

The majority of the military specifications have many different products on the qualified products list (QPL). In most cases, only the single product supplied in accordance with the procurement request to that particular specification was evaluated. It is realized that in many cases this may not be the best lubricant available under the specification; but, due to the large number of different specifications in use at KSC, it was felt that this was the only way to accomplish this testing program in a reasonable amount of time.

In theory, all materials available on a QPL for a particular specification should be equivalent in composition and performance. However, since the specifications, in general, do not specify or limit the components of the lubricants, this is not the case. For instance, MIL-G-18709 has both soap and earth gel thickened greases available. It is felt that for any particular specification, the composition should be specified for all materials on each QPL.

Another example of the wide selection of materials available under one specification is MIL-G-4343B. Two lubricants were obtained and tested from this specification: Royal Aircraft Grease, a silicate ester fluid based grease; and Dow Corning 55M, a silicone fluid based grease. This ready availability of different fluid based greases could not only result in inadvertent mixing or contamination, but also in the use of a silicone where it may ultimately result in galling if used in steel-on-steel couples under boundary lubricating conditions.

Some of the more interesting results of this testing program came from the corrosion tests. As expected, the outdoor, beach-side exposure test was very severe. The solvent cut-back corrosion preventive compound, MIL-C-11796, Braycote 165 was found to be very effective in protecting the exposed test panel. Although the coating darkened and appeared to thicken with age, the only corrosion noted on the test panel was around the outer rim. A few other materials were found to afford adequate protection for up to six months exposure. These include the AMOCO and Royal products available under MIL-G-23549, Halocarbon 25-20M and Halocarbon 25-20M-5A, and Allube Open Gear #4 available under MIL-G-18458.

In general, it was noted during the corrosion tests that the earth gel thickened greases did not afford as much corrosion protection as did greases thickened with other materials. This was shown most dramatically in the Halocarbon series of greases and in the four greases tested from MIL-G-23549 in which the earth gel thickened greases were significantly worse in performance than the other greases.

It is theorized that since the earth gels are generally hygroscopic in nature, they act as a transfer medium for moisture to the metal surface. This process, therefore, maintains a more than adequate moisture supply to promote corrosion of the substrate which presently used inhibitors are unable to prevent. Therefore, earth gel thickened greases should be carefully evaluated as to use environment before implementing usage at KSC.

Figure 2 shows the layout of the test panels on one of the two specimen holders used in the beach site exposure tests. An aerial photograph of the beach corrosion test site is shown in Figure 3. The condition of the test specimens after 1 year of exposure and with the loose scale removed is shown in Figure 4, sheets 1 through 8.

Figure 5 shows the layout of the test panels for the 2542-hour humidity cabinet corrosion test and Figure 6, sheets 1 through 8, shows the condition of the panels at the end of the test after the loose scale had been removed.

The general layout of the test panels in the 1003-hour salt-spray chamber test is shown in Figure 7, sheets 1 and 2. Figure 8, sheets 1 through 6, shows the condition of the panels at the completion of the test after the loose scale had been removed.

The results of the corrosion tests revealed that, as a class, the silicone fluid-based greases are better, in general, than the other lubricants tested. This is probably because of the tenacious manner in which silicone fluids adhere to metal surfaces. This is exemplified by the well-known difficulties encountered in removing silicone films, generally formed by processing aids, from metal surfaces before painting.

Several deviations were noted in the water washout test between the test results and the specification requirements. The ASTM method is quite vague concerning test material that is washed off the bearing, but which remains in the housing. For this testing program, the lubricant remaining in the housing was treated as water-removed material. This may account for some of the variations noted.

No reactions were observed in the aluminum shear tests with the perfluoroalkyl ether materials. However, reactions were observed, as expected, with the chlorotrifluoroethylene lubricants, and these materials should not be used in contact with aluminum where shearing actions may occur.

Testing of one lubricant, Krytox 260 AC, was discontinued during early phases of the program. This grease is basically Krytox 240 AC with MoS_2 and a rust inhibitor added. However, it was noted that the material developed an irritating odor and was found to be quite active during corrosion tests. Chemical analysis revealed a substantial number of compounds which were not originally present and were obviously chemical reaction products of the MoS_2 and the inhibitor. The manufacturer was contacted, the results confirmed, and the product was removed from the market.

Several photomicrographs from an electron microscope are shown depicting the thickener used in five of the greases in this testing program. Figure 9 shows the mixed sodium and calcium thickeners used in the MIL-G-18709 from an unknown vendor. The "donuts" are quite typical of sodium soap thickened greases. Figure 10 depicts the rod shaped thickener, a urea type, from MIL-G-27617, Dow Corning 1292. Figure 11 is typical of a silica thickened grease. Figure 12 shows the platelet structure of the polychlorotrifluroethylene thickener used in Halocarbon 25-20M. The Vydax thickener used in Krytox 280 AC is shown in Figure 13. This type of analysis has proven to be of great value at KSC in failure analysis where the degree of chain fragmentation may be determined and small amounts of contaminants, wear, and corrosion products may be identified.

Photomicrographs taken with the Scanning Electron Microscope (SEM) of the wear scars on test blocks from the Dow Corning LFW-1 are shown in Figures 14 through 26. Figure 14 shows galling which occurred on the block when a test was performed without a lubricant. Figure 15 was run as a control with a compressor oil, Texaco Capella B, as the lubricant. Dow Corning FS 1292, a urea thickened fluorosilicone, was one of the better wearing silicone greases, but even it showed some welding as shown by the pits in Figure 16. Figure 17 shows the wear scar from an earth gel thickened grease. Figure 18 depicts the wear scar from a lithium soap thickened grease and Figure 19 shows the wear scar from a lithium soap thickened grease containing MoS_2 as an extreme pressure additive. Figure 20 shows the wear scar from a polychlorotrifluoroethylene thickened grease exhibiting corrosion products which formed almost immediately upon removal from the test apparatus while Figure 21 depicts the wear scar from the same grease, but containing a rust inhibitor. The last series of photomicrographs, Figures 22 through 26, depict the following wear scars: (1) Krytox 143 AC, a perfluoroalkyl ether oil; (2) Krytox 240 AC, Vydax thickened Krytox 143 AC; (3) Krytox 250 AC, MoS_2 added to Krytox 240 AC; (4) Krytox 280 AC, a rust inhibitor added to Krytox 240 AC; and (5) Braycote 656, a polytetrafluoroethylene thickened grease based on the perfluoroalkyl ether Fomblin oil manufactured by the Italian firm, Montecantini Edison, S.P.A.

CONCLUSIONS

The results of this program reinforce the idea that the best lubricant for a given application can be determined only by careful analysis of the requirements which are placed on that lubricant. This obviously involves knowledge of design requirements of the equipment, method of lubricant application, and cost. Hopefully, the data presented in the tables accompanying this report will aid in selection of the proper lubricant for a given application.

Considerable care must be exercised in highly corrosive environments. It may be necessary to adopt a more frequent lubrication schedule if the proper lubricant does not offer the best corrosion protection. In more extreme cases, a redesign of the system may be necessary to achieve a useful life expectancy from the equipment. This may be the most economical method where down time can result in many lost man-hours or an extremely high degree of reliability is required.

Special care should be exercised to avoid mixing lubricants. If a change in lubricant type is required, the old lubricant should be removed entirely to avoid compatibility problems which may result in equipment failure.

It is essential that the polychlorotrifluoroethylene type of lubricant not be used in contact with aluminum under shear conditions. The perfluoroalkyl ether lubricants were found to be unreactive under the aluminum shear test conditions previously described. However, it is still recommended that care be exercised when utilizing the perfluoroalkyl lubricants with aluminum.

Halocarbon 25-5S appears to be a suitable replacement for KEL-F-90, which is no longer commercially available.

Braycote 656 has been added to the QPL for MIL-G-27617 and was found to be essentially equivalent to Krytox 240 AC. However, in keeping with past NASA policy, this material should be maintained as a batch test item in terms of oxygen compatibility until suitable confidence is gained that an inert material is being consistently produced.

Considering the design of the liquid oxygen pumping systems at KSC, a suitable oil possessing the required lubricity, inertness, and corrosion resistance has not been found which will allow long term operation.

TABLE 1. MILITARY SPECIFICATION: MIL-G-3545C(MR) GREASE, AIRCRAFT, HIGH-TEMPERATURE

Properties	Specification Requirement	SOWESCO
Composition:		
Oil Type	---	Hydrocarbon
Thickener	---	Soap
Dropping Point, °C	> 177	184
Penetration:		
Unworked	---	264
Worked, 60 cycles	250 - 300	286
Evaporation, Weight % Loss	---	0.42
Oxidation Stability, N/m^2 Loss	68,940 (100 hrs)	106,857 (168 hrs)
Effect of Copper on Oxidation Stability, N/m^2 Loss	---	108,925 (168 hrs)
Low Temperature Torque, gm-cm:		
Starting Torque (Min. Temp. °C)	15,000 (-18°)	> 44,250 (-54°)
Running Torque (Min. Temp. °C)	5,000 (-18°)	> 44,250 (-54°)
Aluminum Shear Test	---	0/3
Water Washout, % Weight Loss		
38°C (100°F)	< 20 (41°C)	6.7
79°C (175°F)	---	49.6
Wear and Load Carrying Capacity:		
Mean Hertz Load, Kgs	---	20.08
Last Non-Seizure Load, Kgs	---	40
Weld Point, Kgs	---	126
4-Ball Wear Tests, Scar (mm):		
10 Kgs	---	0.331
30 Kgs	---	0.606
50 Kgs	---	0.816
LFW-1 Wear Tests:		
Block Weight Loss, mgms	---	7.5
Block Wear Scar, mm	---	3.38
Performance in Corrosion Tests:		
Bearing in Bottle (ASTM D-1743)	2*	1*
Humidity Cabinet, 2541 hrs	---	2**
Salt Spray Chamber, 1003 hrs	---	5**
Beach Exposure, 1 year	---	6**

*Numerical Rating:
- 1 - No visible corrosion
- 2 - No more than 3 small spots
- 3 - Anything more severe

**Rating Code:
- 1 - Excellent
- 2 - Very good
- 3 - Good
- 4 - Poor
- 5 - Bad
- 6 - Equivalent to control
- 7 - Significantly worse than control

TABLE 2. MILITARY SPECIFICATION: MIL-G-4343B GREASE, PNEUMATIC SYSTEM

Properties	Specification Requirement	Royal Aircraft Grease	Dow-Corning 55M
Composition:			
Oil Type	---	Silicate Ester	Methyl Phenyl Silicone
Thickener	---	Soap	Soap
Dropping Point, (°C)	>162	163	199
Penetration:			
Unworked	---	299	317
Worked 60 cycles	260-300	302	304
Evaporation, Weight % Loss	<2.5	2.7	0.74
Oxidation Stability, N/m^2 Loss	34,470 (100 hrs)	6,894 (168 hrs)	6,894 (168 hrs)
Effect of Copper on Oxidation Stability, N/m^2 Loss	---	94,447	6,894
Low Temperature Torque, gm-cm:			
Starting Torque (Min. Temp. °C)	---	1,475 (-54°)	1,014 (-54°)
Running Torque (Min. Temp. °C)	---	369 (-54°)	184 (-54°)
Aluminum Shear Test	---	0/3	0/3
Water Washout, % Weight Loss:			
38°C (100°F)	---	15.8	4.5
79°C (175°F)	---	31.1	13.8
Wear and Load Carrying Capacity:			
Mean Hertz Load, Kgs	---	39.79	14.39
Last Non-Seizure Load, Kgs	---	100	< 10
Weld Point, Kgs	---	160	126
4-Ball Wear Test, Scar (mm):			
10 Kg	---	0.489	Inadequate lubrication
30 Kg	---	0.722	"
50 Kg	---	0.884	"
LFW-1 Wear Test:			
Block Weight Loss, mgms	---	2.1	137.7*
Block wear scar, mm	---	2.18	8.5*
Performance in Corrosion Tests:			
Bearing in Bottle (ASTM D 1743)	2**	2**	1**
Humidity Cabinet, 2541 hrs	---	2***	2***
Salt Spray Chamber, 1003 hrs	---	3***	2***
Beach Exposure, 1 year	---	6***	6***

NOTE: 4-Ball test methods are not truly applicable to silicone based lubricants.

*Failed after 1800 revolutions

**Numerical Rating:
1 - No visible corrosion
2 - No more than 3 small spots
3 - Anything more severe

***Rating Code:
1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

TABLE 3. MILITARY SPECIFICATION: MIL-G-7711A GREASE, AIRCRAFT, GENERAL PURPOSE

Properties	Specification Requirement	Int. Lub Co. GB G382
Composition:		
Oil Type	Mineral or Synthetic	Hydrocarbon
Thickener	---	Bentone Type
Dropping Point, °C	>149	156
Penetration:		
Unworked	---	280
Worked 60 cycles	265 - 340	300
Evaporation, Weight % Loss	---	0.43
Oxidation Stability, N/m^2 Loss	<68,940 (100 hrs)	77,902 (168 hrs)
Effect of Copper on Oxidation Stability, N/m^2 Loss	---	122,713
Low Temperature Torque, gm-cms:		
Starting Torque (Min. Temp. °C)	<10,000 (-40°)	>44,250 (-54°)
Running Torque (Min. Temp. °C)	<1,000 (-40°)	>44,250 (-54°)
Aluminum Shear Test	---	0/3
Water Washout, % Weight Loss:		
38°C (100°F)	<15.0	19.8
79°C (175°F)	---	18.9
Wear and Load Carrying Capacity:		
Mean Hertz Load, Kgs	---	40.35
Last Non-Seizure Load, Kgs	---	80
Weld Point, Kgs	---	160
4-Ball Wear Tests, Scar (mm)		
10 Kgs	---	0.395
30 Kgs	---	0.620
50 Kgs	---	0.885
LFW-1 Wear Test:		
Block Weight Loss, mgms	---	98.5
Block Wear Scar, mm	---	6.50
Performance in Corrosion Tests:		
Bearing in Bottle (ASTM D 1743)	2*	1*
Humidity Cabinet, 2541 hours	---	4**
Salt Spray Chamber, 1003 hours	---	2**
Beach Exposure, 1 year	---	6**

*Numerical Rating:

1 - No visible corrosion
2 - No more than 3 small spots
3 - Anything more severe

**Rating Code:

1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

TABLE 4. MILITARY SPECIFICATION: MIL-M-7866B
MOLYBDENUM DISULFIDE, TECHNICAL, LUBRICATION GRADE

Properties	Specification Requirement	Molykote Z
Composition:		
Solids	98.5% MoS_2	MoS_2
Performance in Corrosion Tests:		
Humidity Cabinet, 2541 hours	---	7*
Salt Spray Chamber, 1003 hours	---	6*
Beach Exposure, 1 year	---	6*
Aluminum Shear Tests	---	0/3
LFW-1 Wear Tests:		
Block Weight Loss, mgms	---	0.1
Block Wear Scar, mm	---	0.68

NOTE: Powder was applied to test panels as a slurry in methyl ethyl keytone.

*Rating Code:

1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

TABLE 5. MILITARY SPECIFICATION: MIL-G-10924B GREASE, AUTOMOTIVE AND ARTILLERY

Properties	Specification Requirement	Int. Lub. Co. G403
Composition:		
Oil	Mineral or Synthetic	Hydrocarbon
Thickener	>10% by weight	Calcium Soap
Dropping Point, °C	---	140
Penetration:		
Unworked	265 - 295	268
Worked 60 cycles	265 - 295	284
Evaporation, Weight % Loss	<10.0	6.0
Oxidation Stability, N/m^2 Loss	<137,880 (400 hrs)	34,470 (168 hrs)
Effect of Copper on Oxidation Stability, N/m^2 Loss	---	467,413 (168 hrs)
Low Temperature Torque, gm-cms:		
Starting Torque (Min. Temp. °C)	---	8,753 (-54°)
Running Torque (Min. Temp. °C)	---	2,213 (-54°)
Aluminum Shear Test	---	0/3
Water Washout, % Weight Loss:		
38°C (100°F)	---	24.5
79°C (175°F)	---	30.6
Wear and Load Carrying Capacity:		
Mean Hertz Load, Kgs	---	21.67
Last Non-Seizure Load, Kgs	---	40
Weld Point, Kgs	---	126
4-Ball Wear Tests, Scar (mm):		
10 Kgs	---	0.460
30 Kgs	---	0.565
50 Kgs	---	0.615
LFW-1 Wear Tests:		
Block Weight Loss, mgms	---	0.9
Block Wear Scar, mm	---	1.45
Performance in Corrosion Tests:		
Bearing in Bottle (ASTM D 1743)	2*	1*
Humidity Cabinet, 2541 hours	---	3**
Salt Spray Chamber, 1003 hours	---	3**
Beach Exposure, 1 year	---	6**

*Numerical Rating:

1 - No visible corrosion
2 - No more than 3 small spots
3 - Anything more severe

**Rating Code:

1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

TABLE 6. MILITARY SPECIFICATION: MIL-C-11796, CLASS 2
CORROSION PREVENTIVE COMPOUND, PETROLATUM, HOT APPLICATION

Properties	Braycote 165*
Performance in Corrosion Tests:	
Humidity Cabinet, 2541 hours	2**
Salt Spray Chamber, 1003 hours	3**
Beach Exposure, 1 year	1**

*Braycote 265 with 30% by weight of PD 680 solvent added.

**Rating Code:
- 1 - Excellent
- 2 - Very good
- 3 - Good
- 4 - Poor
- 5 - Bad
- 6 - Equivalent to control
- 7 - Significantly worse than control

NOTE: Only the corrosion resistance of this material was evaluated.

TABLE 7. MILITARY SPECIFICATION: MIL-L-15719A LUBRICATING GREASE (HIGH-TEMPERATURE, ELECTRIC MOTOR, BALL AND ROLLER BEARINGS)

Properties	Specification Requirement	Dow-Corning 44M
Composition:		
Oil Type	Methylphenyl silicone	Methylphenyl silicone
Thickeners	Lithium Soap	Lithium Soap
Additives	Inhibitors and Wear Additives Permitted	
Dropping Point, °C	> 190	> 202
Penetration:		
Unworked	---	335
Worked 60 cycles	< 375	313
Evaporation, Weight % Loss	2.0 (149°C, 50 hrs)	0.31
Oxidation Stability, N/m^2 Loss	34,470 (149°C, 50 hrs)	0.0
Effect of Copper on Oxidation Stability, N/m^2 Loss	---	4826
Low Temperature Torque, gm-cms		
Starting Torque (Min. Temp. °C)	---	> 44,250 (-54°)
Running Torque (Min. Temp. °C)	---	> 44,250 (-54°)
Aluminum Shear Tests	---	0/3
Water Washout, % Weight Loss		
38°C (100°F)	< 20.0 (49°C)	4.7
79°C (175°F)	---	6.2
Wear and Load Carrying Capacity:		
Mean Hertz Load, Kgs	---	10.05
Last Non-Seizure Load, Kgs	---	< 10
Weld Point, Kgs	---	126
4-Ball Wear Tests, Scar (mm)		
10 Kg	---	*
30 Kg	---	*
50 Kg	---	*
LFW-1 Wear Test		
Block Weight Loss, mgm	---	0.7
Block Wear Scar, mm	---	1.33
Performance in Corrosion Tests:		
Bearing in Bottle (ASTM D-1743)	---	3**
Humidity Cabinet, 2541 hours	---	1***
Salt Spray Chamber, 1003 hours	---	1***
Beach Exposure, 1 year	---	6***

*Inadequate Lubrication

**Numerical Rating:
1 - No visible corrosion
2 - No more than 3 small spots
3 - Anything more severe

***Rating Code:
1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

TABLE 8. MILITARY SPECIFICATION: MIL-G-18458(SHIPS) GREASE, WIRE ROPE - EXPOSED GEAR

Properties	Specification Requirement	Allube Open Gear #4
Composition:		
Oil Type	Petroleum	Hydrocarbon
Thickener	---	Soap
Additives	---	MoS_2
Dropping Point, °C	>66	99
Penetration:		
Unworked	---	248
Worked 60 cycles	200 - 300	292
Evaporation, Weight % Loss	---	3.66
Oxidation Stability, N/m^2 Loss	---	582,543
Effect of Copper on Oxidation Stability, N/m^2 Loss	---	634,248
Low-Temperature Torque, gm-cms:		
Starting Torque (Min. Temp. °C)	---	>44,250 (-54°)
Running Torque (Min. Temp °C)	---	> 44,250 (-54°)
Aluminum Shear Tests	---	0/3
Water Washout, % Weight Loss		
38°C (100°F)	---	8.1
79°C (175°F)	---	9.6
Wear and Load Carrying Capacity:		
Mean Hertz Load, Kgs	---	38.97
Last Non-Seizure Load, Kgs	---	50
Weld Point, Kgs	---	200
4-Ball Wear Tests, Scar (mm)		
10 Kg	---	0.434
30 Kg	---	0.621
50 Kg	---	0.843
LFW-1 Wear Test:		
Block Weight Loss, mgm	---	0.6
Block Wear Scar, mm	---	0.75
Performance in Corrosion Tests:		
Bearing in Bottle (ASTM D-1743)	---	3*
Humidity Cabinet, 2541 hours	---	3**
Salt Spray Chamber, 1003 hours	---	3**
Beach Exposure, 1 year	---	5**

*Numerical Rating:

1 - No visible corrosion
2 - No more than 3 small spots
3 - Anything more severe

**Rating Code:

1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

TABLE 9. MILITARY SPECIFICATION: MIL-G-18709A(NAVY) GREASE, BALL AND ROLLER BEARING

Properties	Specification Requirements	Unknown B53528	Shell Alvania #2
Composition:			
Oil Type	---	Hydrocarbon	Hydrocarbon
Thickener	---	Sodium/Calcium Soap	Lithium Soap
Dropping Point, (°C)	>149	156	187
Penetration:			
Unworked	---	261	286
Worked 60 cycles	---	299	260
Evaporation, % Weight Loss	---	0.88	1.37
Oxidation Stability, N/m^2 Loss	---	361,935	134,433
Effect of Copper on Oxidation Stability, N/m^2 Loss	---	582,543	365,382
Low Temperature Torque, gm-cms:			
Starting Torque (Min. Temp. °C)	---	>44,250 (-54°)	>44,250 (-54°)
Running Torque (Min. Temp. °C)	---	>44,250 (-54°)	>44,250 (-54°)
Aluminum Shear Test	---	0/3	0/3
Water Washout, % Weight Loss:			
38°C (100°F)	---	21.5	6.2
79°C (175°F)	---	56.0	45.0
Wear and Load Carrying Capacity:			
Mean Hertz Load, Kgs	---	25.81	19.53
Last Non-Seizure Load, Kgs	---	50	32
Weld Point, Kgs	---	160	160
4-Ball Wear Tests, Scar (mm):			
10 Kg	---	0.31	0.35
30 Kg	---	0.60	0.71
50 Kg	---	0.82	0.83
LFW-1 Wear Tests:			
Block Weight Loss, mgms	---	4.2	5.7
Block Wear Scar, mm	---	2.67	3.04
Performance in Corrosion Tests:			
Bearing in Bottle (ASTM D 1743)	---	2*	1*
Humidity Cabinet, 2541 hrs	---	4**	5**
Salt Spray Chamber, 1003 hrs	---	4**	4**
Beach Exposure, 1 year	---	6**	6**

*Numerical Rating:

1-No visible corrosion
2-No more than 3 small spots
3-Anything more severe

**Rating Code:

1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

TABLE 10. MILITARY SPECIFICATION: MIL-G-21164C
GREASE, MOLYBDENUM DISULFIDE, FOR LOW AND HIGH TEMPERATURES

Properties	Specification Requirement	Royal
Composition:		
Oil Type	---	Adipate Ester
Thickener	---	Lithium Soap
Additives	MoS_2 (4.5-5.5% by wt)	MoS_2
Dropping Point, °C	>163	178
Penetration:		
Unworked	>200	279
Worked 60 cycles	260 - 310	282
Evaporation, Weight % Loss	<2.0	0.89
Oxidation Stability, N/m^2 Loss	<68,940 (100 hrs)	20,682 (168 hrs)
Effect of Copper on Oxidation Stability, N/m^2 Loss	---	62,046
Low Temperature Towque, gm-cms		
Starting Torque (Min. Temp. °C)	10,000 (-73°)	2,766 (-54°)
Running Torque (Min. Temp. °C)	1,000 (-73°)	738 (-54°)
Aluminum Shear Test	---	0/3
Water Washout, % Weight Loss		
38°C (100°F)	<20	18.1
79°C (175°F)	---	46.1
Wear and Load Carrying Capacity:		
Mean Hertz Load, Kgs	>50	49.30
Last Non-Seizure Load, Kgs	---	100
Weld Point, Kgs	---	315
4-Ball Wear Tests, Scar (mm)		
10 Kgs	---	0.567
30 Kgs	---	0.700
50 Kgs	---	0.794
LFW-1 Wear Tests:		
Block Weight Loss, mgms	---	2.8
Block Wear Scar, mm	---	2.60
Performance in Corrosion Tests:		
Bearing in Bottle (ASTM D 1743)	2*	1*
Humidity Cabinet, 2541 hours	---	2**
Salt Spray Chamber, 1003 hours	---	4**
Beach Exposure, 1 year	---	7**

*Numerical Rating:

1 - No visible corrosion
2 - No more than 3 small spots
3 - Anything more severe

**Rating Code:

1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

TABLE 11. MILITARY SPECIFICATION: MIL-G-23549A(ASG) GREASE, GENERAL PURPOSE

Properties	Specification Requirement	AMOCO 94532	Hulburt NCG 10301	Royal Catapult Grease	SOWESCO 16710
Composition:					
Oil Type	Mineral	Hydrocarbon	Hydrocarbon	Hydrocarbon	Hydrocarbon
Thickener	Non-Soap	Urea	Silica Type	Urea	Bentone Type
Solid Lubricant	MoS_2	MoS_2	MoS_2	MoS_2	MoS_2
Dropping Point, (°C)	>232	>244	>244	>244	>244
Penetration:					
Unworked	---	263	294	234	294
Worked 60 cycles	270 - 315	275	320	249	343
Evaporation, % Weight Loss	---	0.36	0.61	0.25	0.15
Oxidation Stability, N/m^2 Loss	---	62,046	3,447	57,220	319,882
Effect of Copper on Oxidation Stability, N/m^2 Loss	---	113,062	6,205	119,266	503,262
Low Temperature Torque, gm-cms:					
Starting Torque (Min. Temp. °C)	---	5,163 (-6°)	2,213 (-28°)	3,872 (-1°)	3,042 (-1°)
Running Torque (Min. Temp. °C)	---	2,028 (-6°)	830 (-28°)	922 (-1°)	1,936 (-6°)
Aluminum Shear Test	---	0/3	0/3	0/3	0/3
Water Washout, % Weight Loss:					
38°C (100°F)	---	17.9	3.9	6.9	19.5
79°C (175°F)	---	13.5	3.7	19.3	18.1
Wear and Load Carrying Capacity:					
Mean Hertz Load, Kgs	>50	57.22	62.51	62.43	41.38
Last Non-Seizure Load, Kgs	---	126	160	126	100
Weld Point, Kgs	---	400	250	400	200
4-Ball Wear Tests, Scar (mm):					
10 Kg	---	0.429	0.462	0.408	0.425
30 Kg	---	0.489	0.500	0.448	0.512
50 Kg	---	0.595	0.666	0.504	0.543
LFW-1 Wear Tests:					
Block Weight Loss, mgms	---	1.1	6.8	0.9	2.1
Block Wear Scar, mm	---	1.40	3.30	1.33	2.25
Performance in Corrosion Tests:					
Bearing in Bottle (ASTM D 1743)	---	1*	1*	1*	3*
Humidity Cabinet, 2541 hrs	---	2**	Not run	Not run	Not run
Salt Spray Chamber, 1003 hrs	---	8**	Not run	Not run	Not run
Beach Exposure, 1 year	---	4**	6**	3**	6**

*Numerical Rating:

1 - No visible corrosion
2 - No more than 3 small spots
3 - Anything more severe

**Rating Code:

1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

TABLE 12. MILITARY SPECIFICATION: MIL-G-23827A GREASE, AIRCRAFT AND INSTRUMENT, GEAR AND ACTUATOR SCREW

Properties	Specification Requirement	Royal G354
Composition:		
Oil Type	---	Adipate Ester
Thickener	---	Lithium Soap
Additive	Extreme Pressure	
Dropping Point, °C	>163	179
Penetration:		
Unworked	> 200	314
Worked 60 cycles	270 - 310	299
Evaporation, Weight % Loss	< 2.0	1.52
Oxidation Stability, N/m^2 Loss	<68,940 (100 hrs)	34,470 (168 hrs)
Effect of Copper on Oxidation Stability, N/m^2 Loss	< 6,894 (20 hrs)	38,606 (168 hrs)
Low Temperature Torque, gm-cms:		
Starting Torque (Min. Temp. °C)	< 10,000 (-73°)	1,936 (-54°)
Running Torque (Min. Temp. °C)	< 1,000 (-73°)	645 (-54°)
Aluminum Shear Tests	---	0/3
Water Washout, % Weight Loss:		
38°C (100°F)	< 20.0	27.0
79°C (175°F)	---	46.1
Wear and Load Carrying Capacity:		
Mean Hertz Load, Kgs	> 30	44.68
Last Non-Seizure Load, Kgs	---	63
Weld Point, Kgs	---	400
4-Ball Wear Tests, Scar (mm):		
10 Kg	---	*
30 Kg	---	1.15
50 Kg	---	1.31
LFW-1 Wear Tests:		
Block weight Loss, mgms	---	2.3
Block Wear Scar, mm	---	2.19
Performance in Corrosion Tests:		
Bearing in Bottle (ASTM D 1743)	2**	3**
Humidity Cabinet, 2541 hrs	---	5***
Salt Spray Chamber, 1003 hrs	---	2***
Beach Exposure, 1 year	---	6***

*Inadequate lubrication

**Numerical Rating:

1 - No visible corrosion
2 - No more than 3 small spots
3 - Anything more severe

***Rating Code:

1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

TABLE 13. MILITARY SPECIFICATION: MIL-G-25013D
GREASE, AIRCRAFT, BALL AND ROLLER BEARING

Properties	Specification Requirement	Standard Oil California
Composition:		
Oil Type	---	Phenyl Methyl Silicone
Thickener	---	Blue Aromatic Dye
Dropping Point, °C	> 232	238
Penetration:		
Unworked	---	290
Worked 60 cycles	260 - 330	287
Evaporation, Weight % Loss	< 4.0 (204°)	0.07 (99°)
Oxidation Stability, N/m^2 Loss	34,470 (100 hrs, 121°)	68,940 (168 hrs)
Effect of Copper on Oxidation Stability, N/m^2 Loss	---	24,129 (168 hrs)
Low Temperature Torque, gm-cms:		
Starting Torque (Min. Temp. °C)	2,000 (-73°)	645 (-54°)
Running Torque (Min. Temp. °C)	500 (-73°)	92 (-54°)
Aluminum Shear Test	---	0/3
Water Washout, % Weight Loss:		
38°C (100°F)	< 20.0	0.77
79°C (175°F)	---	1.2
Wear and Load Carrying Capacity:		
Mean Hertz Load, Kgs	---	13.12
Last Non-Seizure Load, Kgs	---	< 10
Weld Point, Kgs	---	200
4-Ball Wear Tests, Scar (mm):		
10 Kg	---	*
30 Kg	---	*
50 Kg	---	*
LFW-1 Wear Tests:		
Block Weight Loss, mgms	---	128.7
Block Wear Scar, mm	---	8.50
Performance in Corrosion Tests:		
Bearing in Bottle (ASTM D 1743)	2**	1**
Humidity Cabinet, 2541 hrs	---	1***
Salt Spray Chamber, 1003 hrs	---	3***
Beach Exposure, 1 year	---	6***

*Inadequate lubrication

**Numerical Rating:

1 - No visible corrosion
2 - No more than 3 small spots
3 - Anything more severe

***Rating Code:

1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

TABLE 14. MILITARY SPECIFICATION: MIL-L-25681C LUBRICANT, MOLYBDENUM DISULFIDE, SILICONE

Properties	Specification Requirement	Dow-Corning
Composition:		
Oil Type	Methyl Phenyl Polysiloxane, 50 ± 1%	Methyl Phenyl Polysiloxane
Additives	Molybdenum Disulfide, 50 ± 1%	MoS_2
	Corrosion Inhibitor	
Evaporation, Weight % Loss	---	0.22
Load Carrying Capacity:		
Mean Hertz Load, Kgs	---	26.19
Last Non-Seizure Load, Kgs	---	< 10
Weld Point, Kgs	---	400
LFW-1 Wear Test:		
Block Weight Loss, mgms	---	129.1*
Block Wear Scar, mm	---	8.50*
Performance in Corrosion Tests:		
Humidity Cabinet, 2541 hours	---	7**
Salt Spray Chamber, 1003 hours	---	6**
Beach Exposure, 1 year	---	6**
Aluminum Shear Tests	---	0/3

*Failed at 1230 revolutions

**Rating Code:

1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

TABLE 15. MILITARY SPECIFICATION: MIL-G-27617 (USAF)
GREASE, AIRCRAFT, FUEL AND OIL RESISTANT

Properties	Specification Requirement	Dow-Corning FS 1292	duPont Krytox 240 AC	Bray Oil Braycote 656
Composition:				
Oil Type	---	Fluorosilicone	Perfluoro alkyl ether	Perfluoro alkyl ether
Thickener	---	Urea	Polytetrafluoro-ethylene	Polytetrafluoro-ethylene
Dropping Point, Min. (°C)	---	252	174	140
Penetration (1/4 Scale):				
Unworked	200 (minimum)	305	268	331
Worked 60 cycles	---	272	275	320
Evaporation, % Weight Loss	---	0.07	0.93	0.012
Oxidation Stability, N/m^2 Loss	---	0	0	3,447
Effect of Copper Oxidation Stability, N/m^2 Loss	---	33,091	6894	6205
Low Temperature Torque, gm-cms:				
Starting Torque (Min. Temp. °C)	7000 (-35°)	> 44,250 (-54°)	35,031 (-28°)	2,213 (-28°)
Running Torque (Min. Temp. °C)	2000 (-35°)	> 44,250 (-54°)	1,383 (-28°)	830 (-28°)
Aluminum Shear Test	---	0/3	0/3	0/3
Water Washout, % Weight Loss:				
38°C (100°F)	---	9.2	12.4	18.0
79°C (175°F)	---	10.5	11.4	15.8
Wear and Load Carrying Capacity:				
Mean Hertz Load, Kgs	---	87.1	97.2	89.7
Last Non-Seizure Load, Kgs	---	50	32	40
Weld Point, Kgs	---	440	480	400
4-Ball Wear Tests, Scar (mm):				
10 Kg	---	*	0.35	0.42
30 Kg	---	*	0.92	0.53
50 Kg	---	*	1.44	0.99
LFW-1 Wear Test (SAE 01 Blocks, 4620 rings, 72 rpm, 5000 cycles, 150 lb load)				
Block Weight Loss, mgms	---	2.0	1.2	6.5
Block Wear Scar, mm	---	1.95	1.68	3.26
Liquid Oxygen Compatibility	No Reaction	Fails	Passes	Passes**
Performance in Corrosion Tests:				
Bearing in Bottle (ASTM D1743)	---	1***	3***	1***
Humidity Cabinet, 100% RH, 120°F, 2541 hrs	---	1****	3****	Not run
Salt Spray Chamber, 5% solution, 1003 hrs	---	3****	3****	Not run
Beach Exposure, 1 year	---	7****	6****	6****

*Inadequate lubrication
**Batch Test
***Numerical Rating:
1 - No visible corrosion
2 - No more than 3 small spots
3 - Anything more severe

****Rating Code:
1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

TABLE 16. MILITARY SPECIFICATION: MIL-L-46010(MR) LUBRICANT, SOLID-FILM: HEAT-CURED, CORROSION INHIBITING

Properties	Specification Requirement	Dow-Corning 3400
Composition:		
Binder	Thermosetting Resin	Epoxy Resin
Additives	Lubricating Pigment	MoS_2
Performance in Corrosion Tests:		
Humidity Cabinet, 2541 hours	---	3*
Salt Spray Chamber, 1003 hours	---	5*
Beach Exposure, 1 year	---	6*
Aluminum Shear Test	---	0/3
LFW-1 Wear Test:		
Block Weight Loss, mgms	---	0.6**
Block Wear Scar, mm	---	Approx. 1.75**

*Rating Code:
- 1 - Excellent
- 2 - Very good
- 3 - Good
- 4 - Poor
- 5 - Bad
- 6 - Equivalent to control
- 7 - Significantly worse than control

**Failed at 214 revolutions

TABLE 17. MILITARY SPECIFICATION: MIL-G-81322A GREASE, AIRCRAFT, GENERAL PURPOSE WIDE TEMPERATURE RANGE

Properties	Specification Requirement	Mobil Oil
Composition:		
Oil Type	---	Hydrocarbon
Thickener	---	Bentone Type
Dropping Point, °C	> 232	244
Penetration:		
Unworked	---	289
Worked 60 cycles	265 - 320	290
Evaporation, Weight % Loss	< 10.0% (177°C)	0.44
Oxidation Stability, N/m^2 Loss	172,350 (500 hrs)	124,092 (168 hrs)
Effect of Copper on Oxidation Stability, N/m^2 Loss	--	135,812 (168 hrs)
Low Temperature Torque, gm-cms:		
Starting Torque (Min. Temp. °C)	10,000 (-54°)	7,559 (-54°)
Running Torque (Min. Temp. °C)	1,000 (-54°)	2,120 (-54°)
Aluminum Shear Test	---	0/3
Water Washout, % Weight Loss:		
38°C (100°F)	< 20.0 (41°)	1.7
79°C (175°F)	---	2.8
Wear and Load Carrying Capacity:		
Mean Hertz Load, Kgs	> 30	50.60
Last Non-Seizure Load, Kgs	---	126
Weld Point, Kgs	---	200
4-Ball Wear Tests, Scar (mm):		
10 Kg	---	0.450
30 Kg	---	0.560
50 Kg	---	1.012
LFW-1 Wear Tests:		
Block Weight Loss, mgms	---	1.5
Block Wear Scar, mm	---	1.70
Performance in Corrosion Tests:		
Bearing in Bottle (ASTM D 1743)	2*	2*
Humidity Cabinet, 2541 hrs	---	5**
Salt Spray Chamber, 1003 hrs	---	3**
Beach Exposure, 1 year	---	6**

*Numerical Rating:
1 - No visible corrosion
2 - No more than 3 small spots
3 - Anything more severe

**Rating Code:
1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

TABLE 18. MILITARY SPECIFICATION: MIL-L-81329A(ASG) LUBRICANT, SOLID FILM, EXTREME ENVIRONMENT

Properties	Specification Requirement	Everlube 811
Composition:		
Binder	Inorganic	Silicate
Additive	Solid Lubricant	MoS_2
Performance in Corrosion Tests:		
Humidity Cabinet, 2541 hours	---	5*
Salt Spray Chamber, 1003 hours	---	5*
Beach Exposure, 1 year	---	6*
Aluminum Shear Test	---	0/3
LFW-1 Wear Test:		
Block Weight Loss, mgms	---	4.8**
Block Wear Scar, mm	---	*Approx.* 4.0**

*Rating Code:
1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

**Failed at 2000 revolutions

TABLE 19. NONSPECIFICATION PERFLUOROALKYLPOLYETHER FLUIDS (E. I. duPont deNemours and Company)

Properties	Krytox ® 143 AY	Krytox ® 143 AC
Cloud Point, °C	---	< -65
Pour Point, °C	-43	-25
Evaporation, Weight % Loss	2.03	6 mgm gain
Aluminum Shear Tests	0/3	0/3
Wear and Load Carrying Capacity:		
Mean Hertz Load, Kgs	---	117.72
Last Non-Seizure Load, Kgs	---	80
Weld Point, Kgs	---	450
4-Ball Wear Tests, Scar (mm):		
10 Kgs	---	0.28
30 Kgs	---	0.54
50 Kgs	---	1.33*
LFW-1 Wear Tests:		
Block Weight Loss, mgms	2.6	2.1
Block Wear Scar, mm	2.25	2.70
Oxygen Compatibility (MSFC-SPEC-106B)	Passes	Passes
Performance in Corrosion Tests:		
Humidity Cabinet, 2541 hours	---	6**
Salt Spray Chamber, 1003 hours	---	6**
Beach Exposure, 1 year	---	6**

NOTE: Tests on Krytox ® 143 AY were run for a particular use at KSC and was not fully evaluated.

*Ran hot, 90° to 95°C
**Rating Code:
1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

TABLE 20. NONSPECIFICATION PERFLUOROALKYLPOLYETHER FLUID-BASED GREASES

Properties	Braycote ® Micronic 631A	Krytox ® 250 AC	Krytox ® 280 AC
Composition:			
Thickener	Polytetrafluoro-ethylene solids	Polytetrafluoro-ethylene solids	Polytetrafluoro-ethylene solids
Additives	None	MoS^2	Rust Inhibitor
Dropping Point, °C	135	138	138
Penetration (1/4 Scale):			
Unworked	343	275	268
Worked 60 cycles (Max.)	314	290	275
Evaporation, Weight % Loss	0.25	0.08	0.12
Oxidation Stability, N/m^2 Loss	0.0	10,341	6894
Effect of Copper on Oxidation Stability, N/m^2 Loss	0.0	12,409	8273
Low Temperature Torque, gm-cms:			
Starting Torque (Min. Temp. °C)	3,964 (-28°)	21,388 (-35°)	12,353 (-28°)
Running Torque (Min. Temp. °C)	1,291 (-28°)	1,844 (-35°)	2,950 (-28°)
Aluminum Shear Tests	0/3	0/3	0/3
Water Washout, % Weight Loss:			
38°C (100°F)	24.2	7.7	8.3
79°C (175°F)	21.1	13.5	10.2
Wear and Load Carrying Capacity:			
Mean Hertz Load, Kgs	89.49	107.22	110.48
Last Non-Seizure Load, Kgs	50	50	63
Weld Point, Kgs	360	> 800	> 800
4-Ball Wear Tests, Scar (mm):			
10 Kg	0.385	0.437	0.370
30 Kg	0.520	0.848	0.535
50 Kg	Erratic	0.986	0.690
LFW-1 Wear Test:			
Block Weight Loss, mgms	3.3	1.0	1.7
Block Wear Scar, mm	2.55	1.75	2.21
Oxygen Compatibility (MSFC-SPEC-106B)	Passes	Passed*	Passed*
Performance in Corrosion Tests:			
Bearing in Bottle (ASTM D-1743)	3**	2**	1**
Humidity Cabinet, 2541 hours	3***	2***	2***
Salt Spray Chamber, 1003 hours	4***	4***	5***
Beach Exposure, 1 year	6***	6***	6***

*Batch Test

**Numerical Rating:
1 - No visible corrosion
2 - No more than 3 small spots
3 - Anything more severe

***Rating Code:
1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

TABLE 21. NONSPECIFICATION POLYCHLOROTRIFLUOROETHYLENE FLUIDS

Properties	Nutrol Oil	Halocarbon Oils 10-25	11-21E	13-21E
Composition:				
Additives	Polytetra-fluoroethylene solids	---	Rust Inhibitor	Rust Inhibitor
Pour Point, °C	-29	---	-26	-18
Cloud Point, °C	---	---	-22	-15
Evaporation, Weight % Loss	20.9	---	26.4	22.8
Aluminum Shear Tests	3/3	---	3/3	3/3
Wear and Load Carrying Capacity:				
Mean Hertz Load, Kgs	99.97	---	110.78	107.38
Last Non-Seizure Load, Kgs	40	---	40	30
Weld Point, Kgs	700	---	>800	>800
4-Ball Wear Tests, Scar (mm):				
10 Kgs	0.56	---	0.40	0.49
30 Kgs	1.10	---	1.09	0.91
50 Kgs	Failed	---	Failed	Failed
LFW-1 Wear Test:				
Block Weight Loss, mgms	12.7	17.7	6.9	6.4
Block Wear Scar, mm	3.96	4.46	3.44	3.15
Oxygen Compatibility (MSFC-SPEC-106B)	Passes	---	Passes	Passes
Performance in Corrosion Tests:				
Humidity Cabinet, 2541 hours	7*	---	7*	7*
Salt Spray Chamber, 1003 hrs	6*	---	6*	6*
Beach Exposure, 1 year	6*	---	7*	6*

NOTE: Halocarbon 10-25 was tested only in the LFW-1 Tests.

*Rating Code:

1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

TABLE 22. NONSPECIFICATION POLYCHLOROTRIFLUOROETHYLENE FLUID-BASED GREASES

Properties	Nulube Grease	Fluorolube GR 362	KEL-F 90	Halocarbon Greases 25-20M	25-5S	25-20M-5A
Composition:						
Thickener	Silica	Silica	Silica	Polychloro-trifluoroethylene solids	Silica	Polychloro-trifluoroethylene solids
Additives	---	---	---	---	---	Rust inhibitor
Dropping Point, (°C)	141	187	199	155	186	156
Penetration (1/4 scale):						
Unworked	320	273	---	200	223	228
Worked 60 cycles	332	304	---	287	238	281
Evaporation, Weight % Loss	22.8	13.00	2.3	0.57	2.62	0.63
Oxidation Stability, N/m^2 Loss	13,788	6,894	---	17,235	13,788	24,129
Effect of Copper on Oxidation Stability, N/m^2 Loss	93,758	11,719	---	8,273	3,447	13,788
Low Temperature Torque, gm-cm:						
Starting Torque (Min. Temp. °C)	17,700 (-43°)	>44,250 (-54°)	---	> 44,250 (-54°)	18,530 (-7°)	11,984 (-7°)
Running Torque (Min. Temp. °C)	4,241 (-43°)	>44,250 (-54°)	---	> 44,250 (-54°)	3,227 (-7°)	5,808 (-7°)
Aluminum Shear Tests	2/3	2/3	0/3	2/3	1/3	1/3
Water Washout, % Weight Loss:						
38°C (100°F)	21.1	20.3	---	8.5	84.1	12.6
79°C (175°F)	31.8	29.8	---	25.6	96.7	23.7
Wear and Load Carrying Capacity:						
Mean Hertz Load, Kgs	79.75	67.46	---	109.49	94.30	124.85
Last Non-Seizure Load, Kgs	20	< 10	---	40	32	50
Weld Point, Kgs	>800	> 800	---	>800	>800	>800
4-Ball Wear Test, Scar (mm)						
10 Kg	0.800	Erratic	---	0.484	0.467	0.293
30 Kg	1.17	0.918	---	0.559	0.730	0.731
50 Kg	1.45	>1.5	---	0.759	Erratic	0.918
LFW-1 Wear Test:						
Block Weight Loss, mgms	10.8	5.1	1.5	0.7	1.4	0.6
Block Wear Scar, mm	3.90	3.00	1.80	1.20	2.00	0.82
Oxygen Compatibility (MSFC-SPEC-106B)	Passed	Passed	Passed	Passed	Passed	Passed
Performance in Corrosion Tests:						
Bearing in Bottle (ASTM D 1743)	3*	3*	---	3*	3*	3*
Humidity Cabinet, 2541 hrs	7**	6**	6**	7**	7**	3**
Salt Spray Chamber, 1003 hrs	5**	7**	6**	3**	6**	2**
Beach Exposure, 1 year	7**	7**	6**	3**	7**	2**

*Numerical Rating:

1 - No visible corrosion
2 - No more than 3 small spots
3 - Anything more severe

**Rating Code:

1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

NOTE:

KEL-F 90 is no longer available and amounts were sufficient only for those tests reported.

TABLE 23. NONSPECIFICATION SILICONE FLUID-BASED GREASES

Properties	General Electric Versilube G-341-L	Drilube 822	Dow-Corning DC 33M	Dow-Corning FS1281
Composition:				
Oil Base	Methylphenyl Silicone	Fluoro-silicone	Phenyl-methyl silicone	Fluoro-silicone
Thickener	Soap	Polytetra-fluoro-ethylene solids	Soap	Silica
Dropping Point, °C	225	198	220	> 238
Penetration:				
Unworked	313	388	257	245
Worked 60 cycles	324	358	253	276
Evaporation, Weight % Loss	0.35	1.19	1.72	0.10
Oxidation Stability, N/m^2 Loss	0.0	4826	1379	10,341
Effect of Copper on Oxidation Stability, N/m^2 Loss	4136	2758	7583	3447
Low Temperature Torque, gm-cms:				
Starting Torque (Min. Temp. °C)	1,844 (-54°)	>44,250 (-54°)	1,752 (-54°)	> 44,250 (-54°)
Running Torque (Min. Temp. °C)	277 (-54°)	>44,250 (-54°)	369 (-54°)	> 44,250 (-54°)
Aluminum Shear Test	0/3	0/3	0/3	0/3
Water Washout, % Weight Loss:				
38°C (100°F)	3.9	9.8	6.2	13.4
79°C (175°F)	10.6	16.6	7.9	11.4
Wear and Load Carrying Capacity:				
Mean Hertz Load, Kgs	13.50	96.88	14.69	45.69
Last Non-Seizure Load, Kgs	< 10	50	< 10	13
Weld Point, Kgs	160	800	160	400
4-Ball Wear Tests, Scar (mm):				
10 Kg	*	0.316	*	0.953
30 Kg	*	0.557	*	1.08
50 Kg	*	1.04	*	1.16
LFW-1 Wear Test:				
Block Weight Loss, mgms	121.4[1]	4.8	123.0[2]	5.6
Block Wear Scar, mm	8.00	2.40	8.30	3.15
Oxygen Compatibility (MSFC-SPEC-106B)	Fails	Fails	Fails	Fails
Performance in Corrosion Tests:				
Bearing in Bottle (ASTM D 1743)	3**	3**	1**	3*
Humidity Cabinet, 2541 hours	2***	3***	1***	2***
Salt Spray Chamber, 1003 hours	2***	3***	2***	6***
Beach Exposure, 1 year	6***	7***	6***	5***

*Inadequate Lubrication

**Numerical Rating:

1 - No visible corrosion
2 - No more than 3 small spots
3 - Anything more severe

***Rating Code:

1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

NOTE:

1 - Failed at 2600 revolutions
2 - Failed at 2250 revolutions

TABLE 24. NONSPECIFICATION MOLYBDENUM DISULFIDE IN OIL

Properties	Electromoly 30
Composition:	
Oil Type	Adipate Ester
Solid Lubricant	MoS_2
Aluminum Shear Test	0/3
Evaporation Loss, Weight % Loss	2.40
Wear and Load Carrying Capacity:	
Mean Hertz Load, Kgs	71.27
Last Non-Seizure Load, Kgs	32 & 160*
Weld Point, Kgs	400
4-Ball Wear Test, Scar (mm):	
10 Kgs	0.547
30 Kgs	0.873
50 Kgs	0.950
LFW-1 Wear Tests:	
Block Weight Loss, mgms	0.6
Block Wear Scar, mm	0.70
Performance in Corrosion Tests:	
Humidity Cabinet, 2541 hours	7**
Salt Spray Chamber, 1003 hours	3**
Beach Exposure, 1 year	6**

*Material was slightly above limits at 40, 50, and 63 Kgs.

**Rating Code:

1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

TABLE 25. NONSPECIFICATION CHLORINATED BIPHENYL FLUID-BASED GREASE

Properties	DAG Dispersion EC1730
Composition:	
Thickener	Graphite
Dropping Point, °C	249
Penetration:	
Unworked	197
Worked 60 cycles	242
Evaporation, Weight % Loss	0.79
Oxidation Stability, N/m^2 Loss	3102
Effect of Copper on Oxidation Stability, N/m^2 Loss	1930
Low Temperature Torque, gm-cms	
Starting Torque (Min. Temp. °C)	>44,250 (-54°)
Running Torque (Min. Temp. °C)	> 44,250 (-54°)
Aluminum Shear Test	0/3
Water Washout, % Weight Loss:	
38°C (100°F)	24.4
79°C (175°F)	23.2
Wear and Load Carrying Capacity:	
Mean Hertz Load, Kgs	63.79
Last Non-Seizure Load, Kgs	<10
Weld Point, Kgs	620
4-Ball Wear Tests, Scar (mm)	
10 Kg	0.513
30 Kg	0.944
50 Kg	1.44
LFW-1 Wear Tests:	
Block Weight Loss, mgms	1.2
Block Wear Scar, mm	1.48
Oxygen Compatibility (MSFC-SPEC-106B)	Passes
Performance in Corrosion Tests:	
Bearing in Bottle (ASTM D 1743)	3*
Humidity Cabinet, 2541 hours	5**
Salt Spray Chamber, 1003 hours	4**
Beach Exposure, 1 year	6**

*Numerical Rating:

1 - No visible corrosion
2 - No more than 3 small spots
3 - Anything more severe

**Rating Code:

1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

TABLE 26. NONSPECIFICATION GREASES, MISCELLANEOUS

Properties	Bison 88	Atlantic 54
Composition:		
Oil Type	Hydrocarbon	Hydrocarbon
Thickener	---	Soap
Additives	Aluminum Powder, MoS_2	
Dropping Point, °C	108	199
Penetration:		
Unworked	350	294
Worked 60 cycles	355	249
Evaporation, Weight % Loss	0.56	0.90
Oxidation Stability, N/m^2 Loss	> 413,640	> 24,129
Effect of Copper on Oxidation Stability, N/m^2 Loss	> 472,239	> 248,184
Low Temperature Torque, gm-cms:		
Starting Torque (Min. Temp. °C)	44,250 (-54°)	44,250 (-54°)
Running Torque (Min. Temp. °C)	44,250 (-54°)	44,250 (-54°)
Aluminum Shear Test	0/3	0/3
Water Washout, % Weight Loss:		
38°C (100°F)	---	7.2
79°C (175°F)	---	24.2
Wear and Load Carrying Capacity:		
Mean Hertz Load, Kgs	59.27	26.14
Last Non-Seizure Load, Kgs	32	63
Weld Point, Kgs	620	160
4-Ball Wear Tests, Scar (mm)		
10 Kg	0.496	0.495
30 Kg	0.648	0.640
50 Kg	1.08	0.797
LFW-1 Wear Tests:		
Block Weight Loss, mgms	1.1	13.7
Block Wear Scar, mm	1.00	4.14
Performance in Corrosion Tests:		
Bearing in Bottle (ASTM D 1743)	3*	3*
Humidity Cabinet, 2541 hours	7**	1**
Salt Spray Chamber, 1003 hours	5**	4**
Beach Exposure, 1 year	4**	6**

*Numerical Rating:

1 - No visible corrosion
2 - No more than 3 small spots
3 - Anything more severe

**Rating Code:

1 - Excellent
2 - Very good
3 - Good
4 - Poor
5 - Bad
6 - Equivalent to control
7 - Significantly worse than control

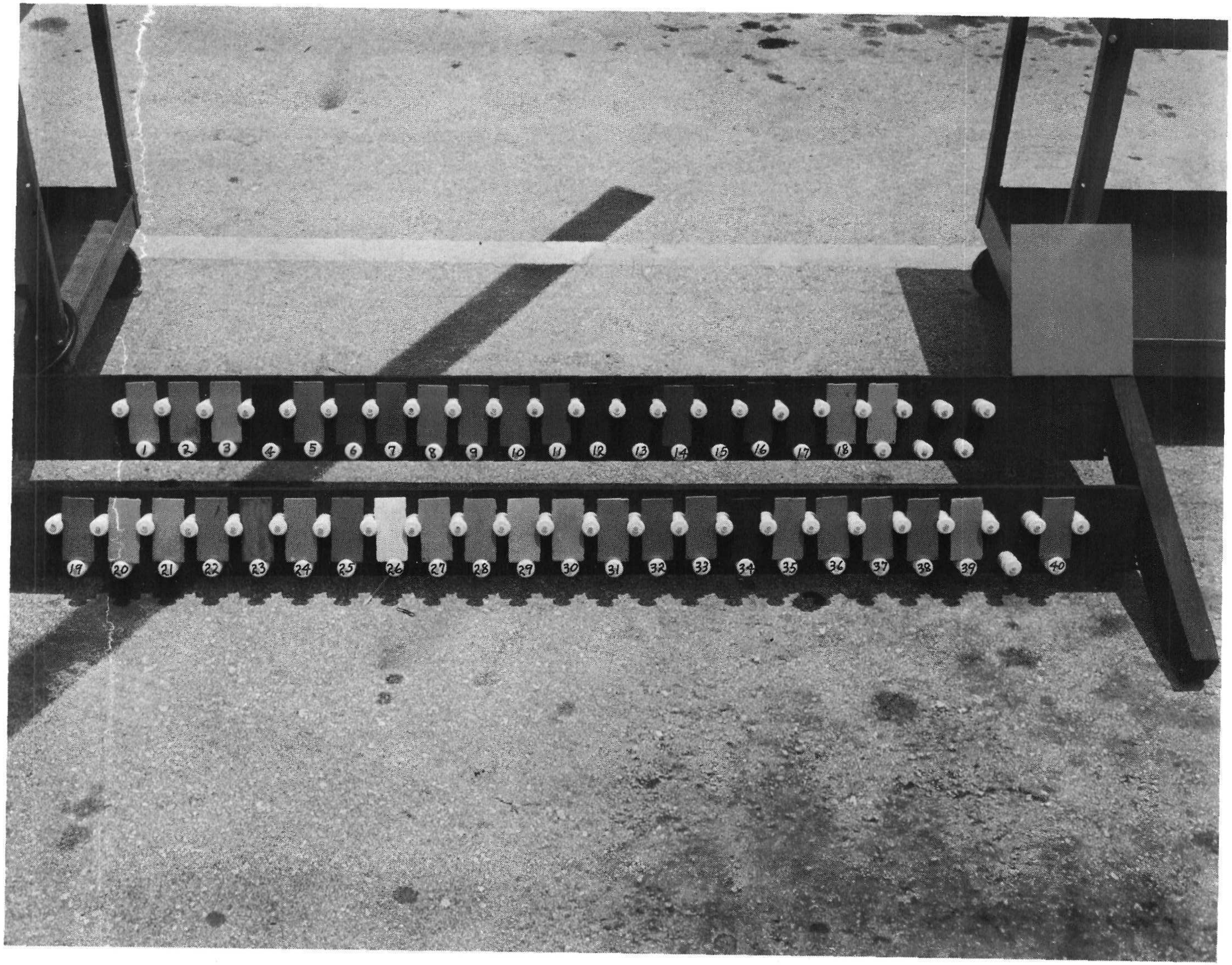
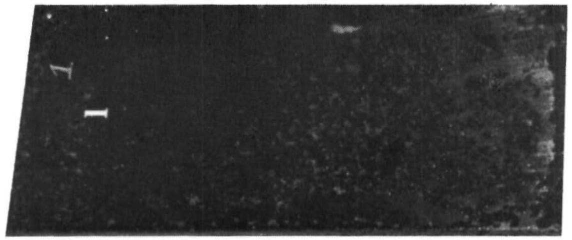
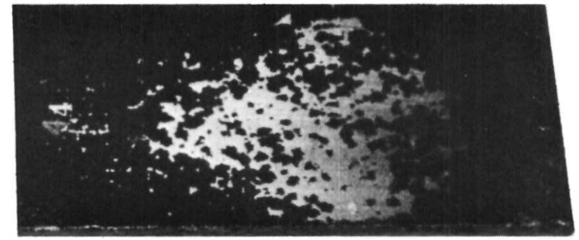


Figure 2. Beach Site Corrosion Test Panels on Exposure Rack before Placing the Rack on the Test Site

Figure 3. Aerial View of Corrosion Test Site, Facing Generally South.
Arrow Shows Position of Test Racks



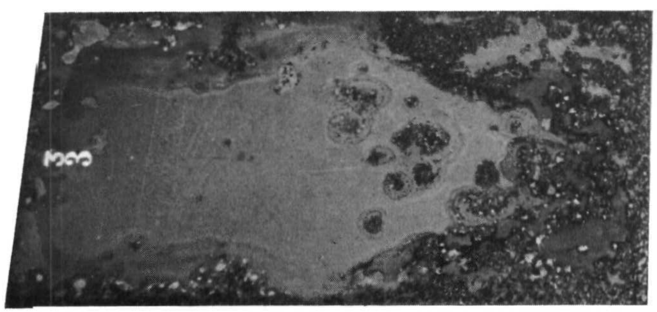
Halocarbon 25-20M; Halocarbon Products Corp.



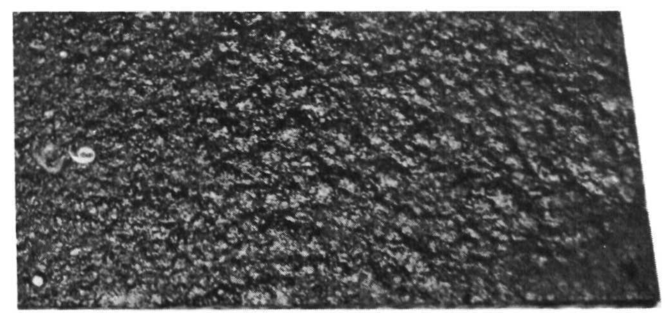
MIL-G-18458; Allube Corp.

Halocarbon 25-5S; Halocarbon Products Corp.

MIL-G-23827A; Royal Lubricants Co.

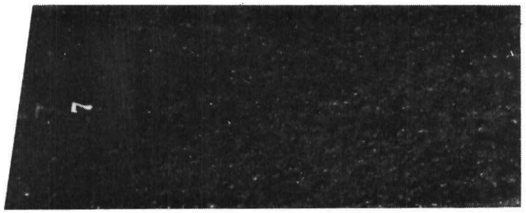


Halocarbon 25-20M-5A; Halocarbon Products Corp.

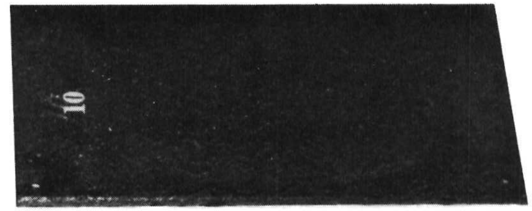


MIL-L-25681C; Dow Corning Corp.

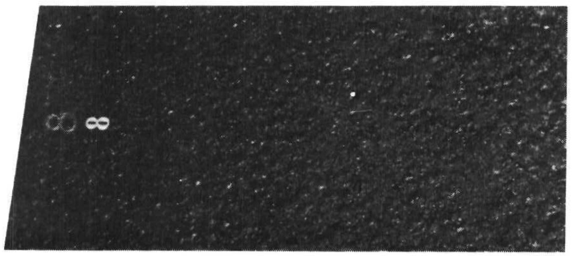
Figure 4. Test Specimens after 1 Year of Beach Exposure (Sheet 1 of 8)



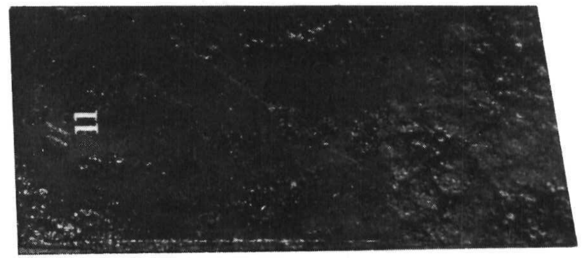
MIL-G-7711A; International Lubricant Corp.



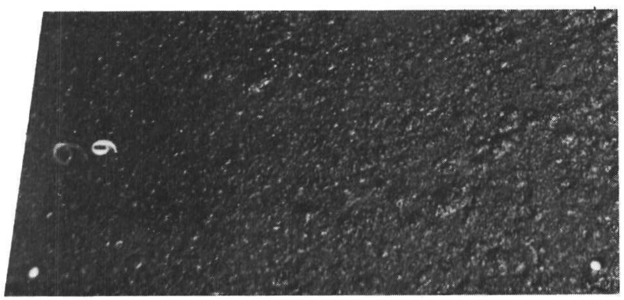
MIL-G-3545; SOWESCO (KCMO)



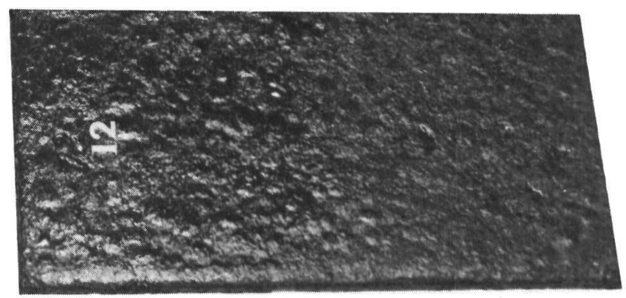
MIL-G-10924B; International Lubricant Corp.



MIL-L-46010A; Dow Corning Corp.



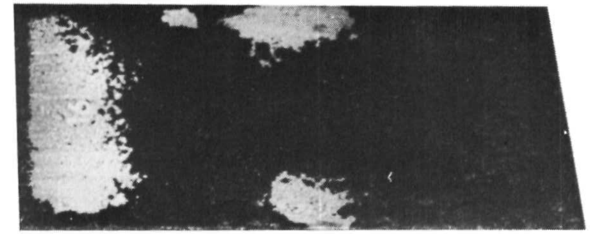
MIL-G-18709; Unknown



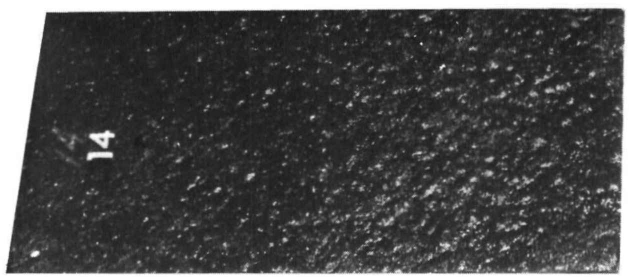
Dag Dispersion 1730; Acheson Colloids Co.

Figure 4. Test Specimens after 1 Year of Beach Exposure (Sheet 2 of 8)

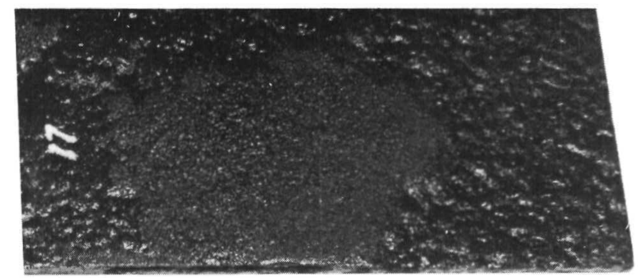
MIL-G-25013D; Standard Oil Co. of California



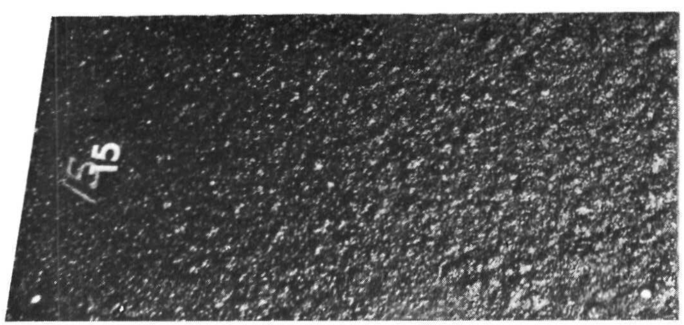
MIL-G-23549A; AMOCO



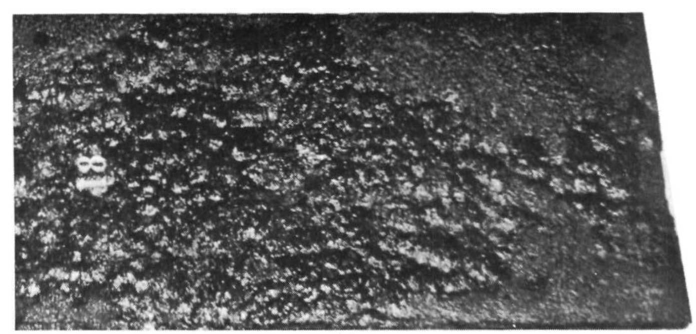
Electromoly 30; Electrofilm, Inc.



Fluorolube GR362; Hooker Chemical Corp.

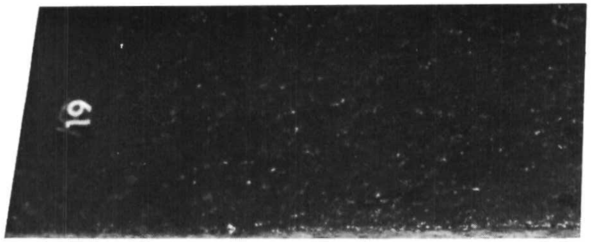


MIL-G-81322A; Mobil Oil Corp.

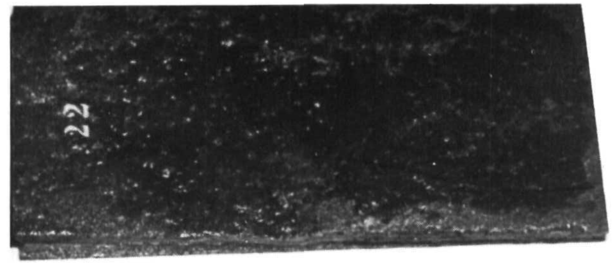


MIL-G-21164B; Royal Lubricants Co.

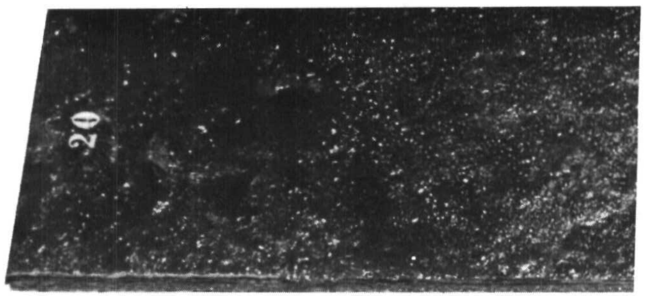
Figure 4. Test Specimens after 1 Year of Beach Exposure (Sheet 3 of 8)



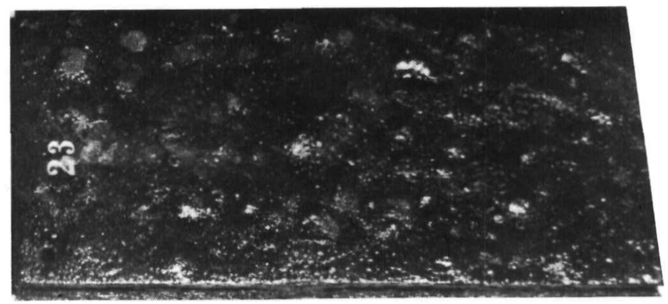
MIL-G-4343B; Royal Lubricants Co.



Nu-Lube All Purpose Grease; Nu-Chem Industries



MIL-G-27617A; E.I. duPont de Nemours & Co.

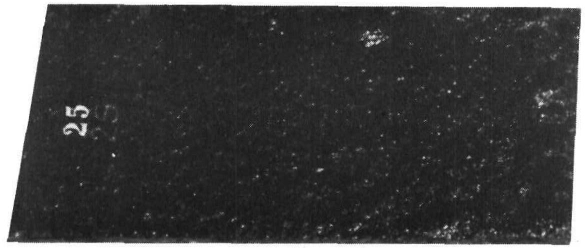


MIL-L-81329; Everlube Corp.

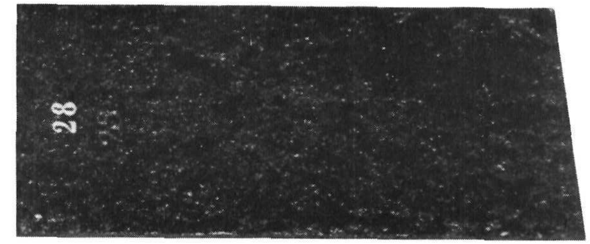
Braycote 631A; Bray Oil Co.

Drilube 822; Drilube Corp.

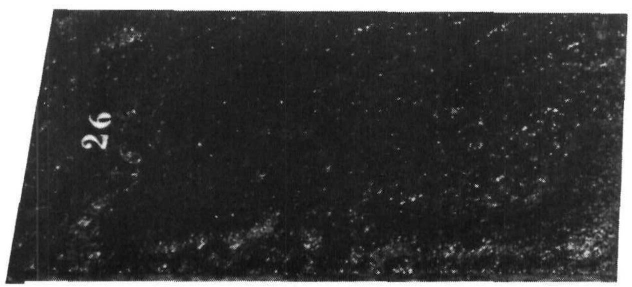
Figure 4. Test Specimens after 1 Year of Beach Exposure (Sheet 4 of 8)



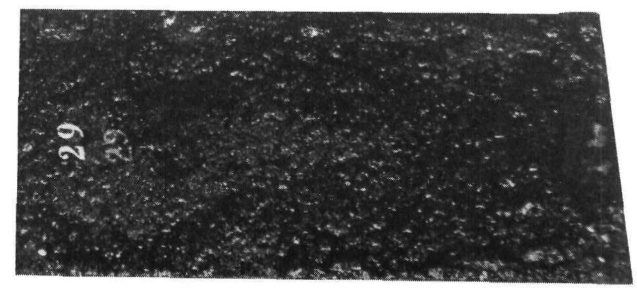
MIL-L-15719A; Dow Corning Corp.



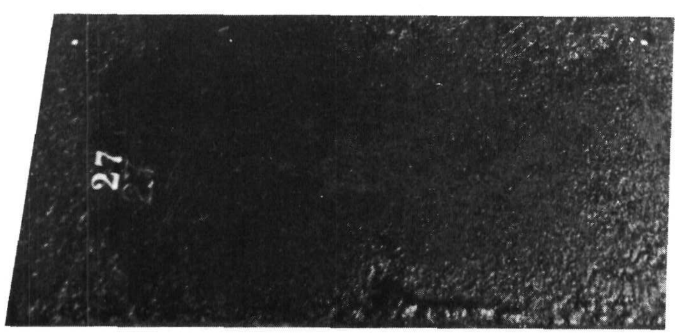
MIL-G-4343B; Dow Corning Corp.



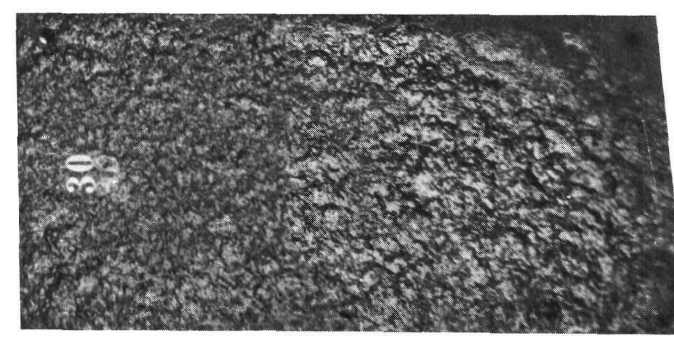
MIL-G-27617A; Dow Corning Corp.



Versilube G-341-L; General Electric Co.

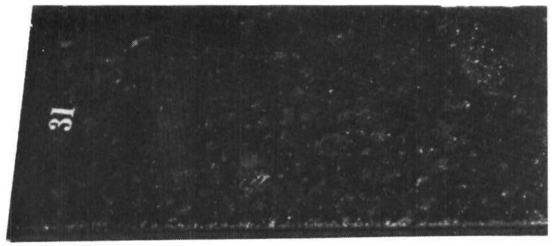


Dow Corning FS-1281; Dow Corning Corp.

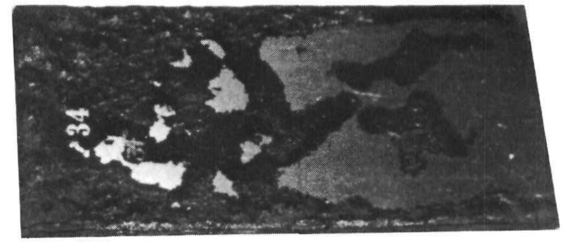


Dow Corning 33M; Dow Corning Corp.

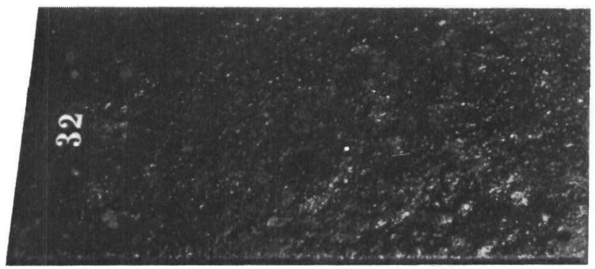
Figure 4. Test Specimens after 1 Year of Beach Exposure (Sheet 5 of 8)



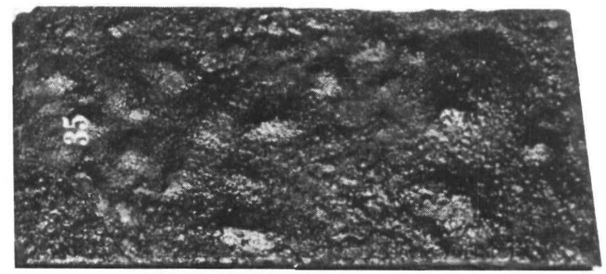
Krytox 143AC; E.I. duPont de Nemours & Co.



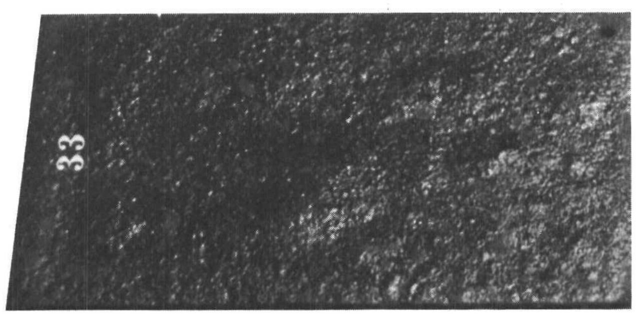
Bison 88; American Lubricants Co.



Halocarbon 13-21E Oil; Halocarbon Products Corp.



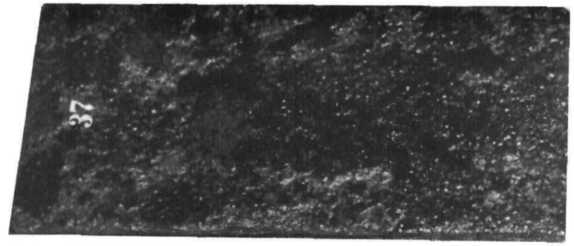
MIL-M-7866B; Dow Corning Corp.



Nu-Trol Mark II Oil; Nu-Chem Industries

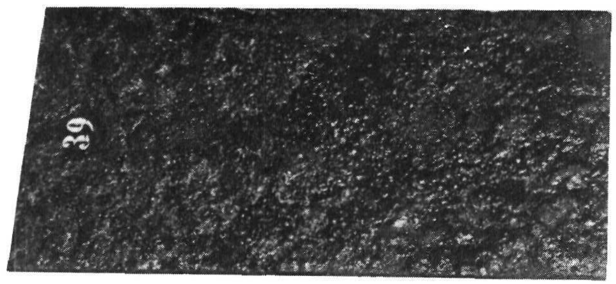
KEL-F-90; 3M Co.

Figure 4. Test Specimens after 1 Year of Beach Exposure (Sheet 6 of 8)

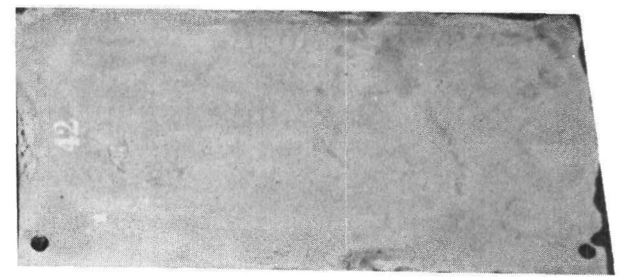


Krytox 250AC; E.I. duPont de Nemours & Co.

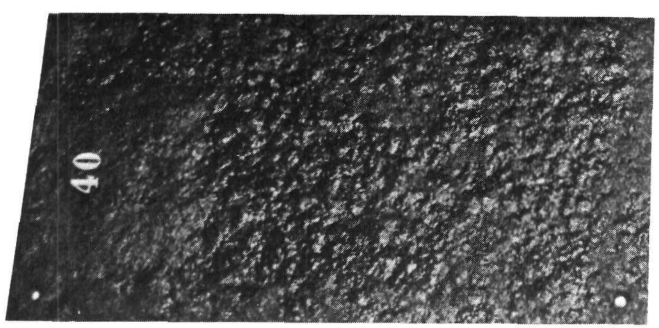
Atlantic 54; Atlantic Refining Co.



Krytox 280AC; E.I. duPont de Nemours & Co.



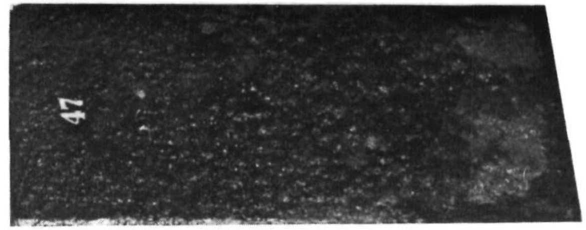
MIL-C-11796A(1); Bray Oil Co.



MIL-G-18709A; Shell Oil Co.

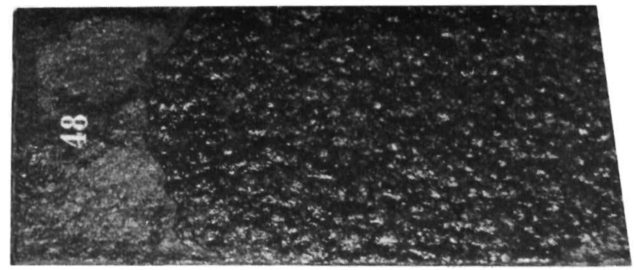
Figure 4. Test Specimens after 1 Year of Beach Exposure (Sheet 7 of 8)

Halocarbon 11-21E; Halocarbon Products Corp.

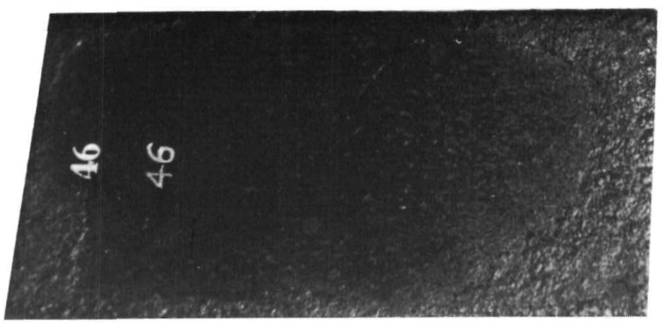


MIL-G-23549A; SOWESCO

Control (Uncoated) Panel



MIL-G-23549A; Hulburt Oil & Grease Co.



MIL-G-23549A; Royal Lubricants Co.

MIL-G-27617A; Bray Oil Co.

Figure 4. Test Specimens after 1 Year of Beach Exposure (Sheet 8 of 8)

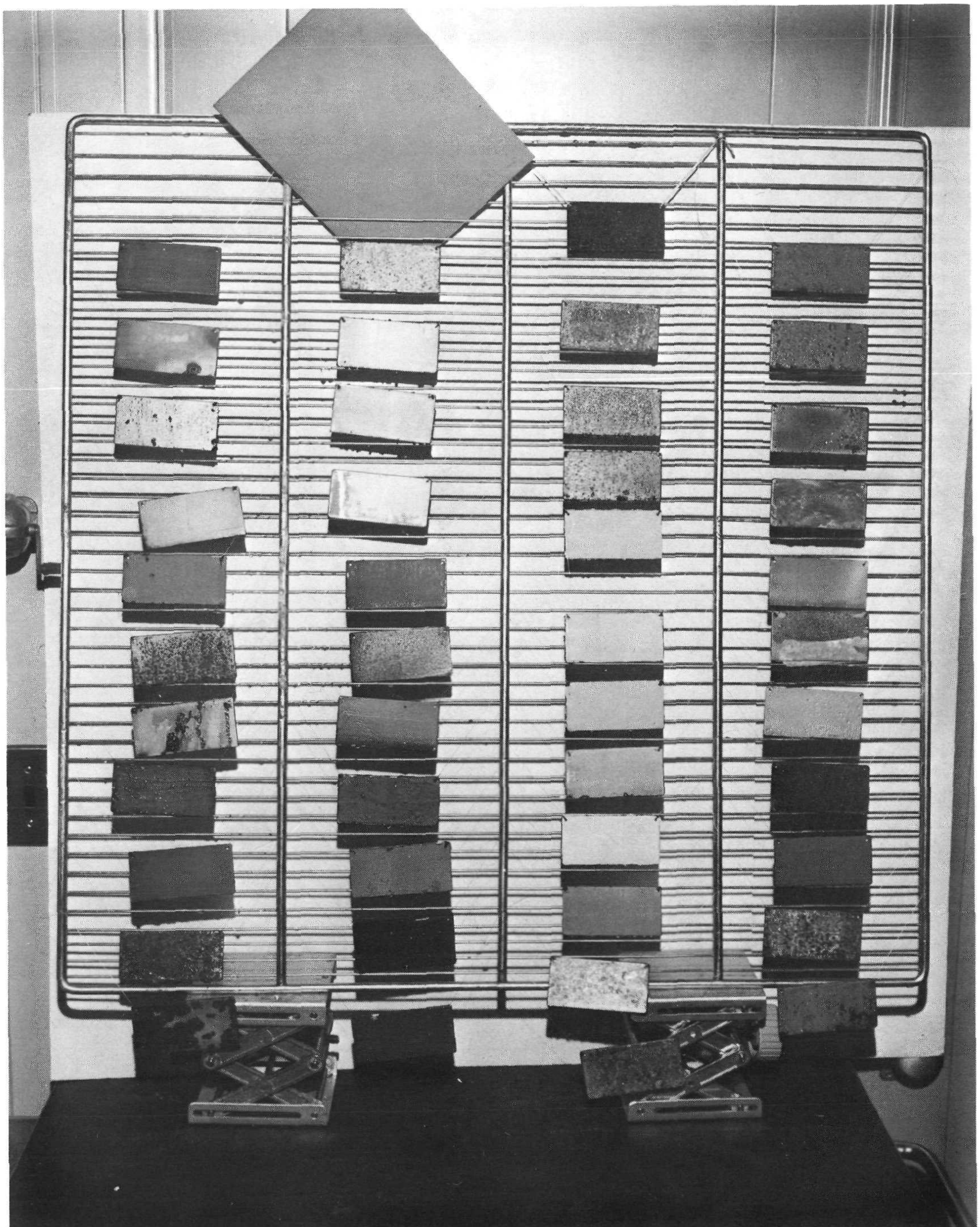
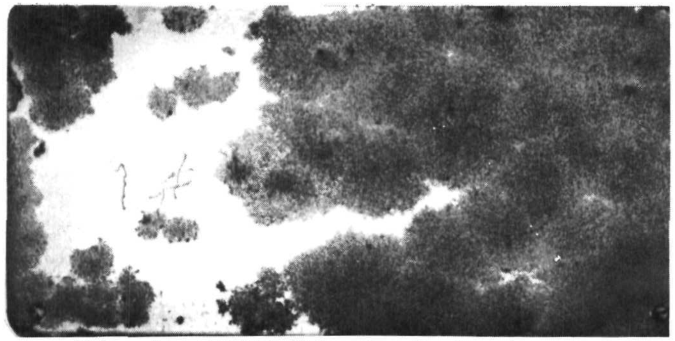
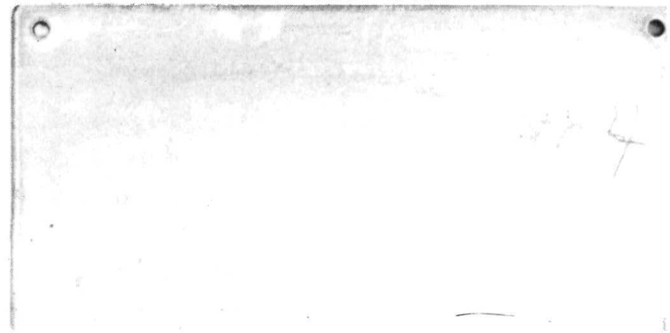


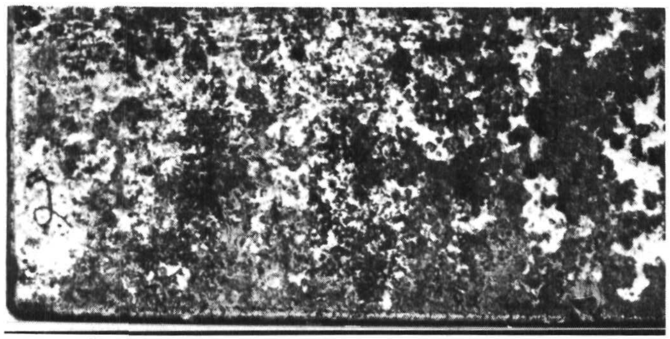
Figure 5. Layout of the Humidity Cabinet Corrosion Test Panels, Removed and Held Vertically for Photography (1,649 Hours Exposure)



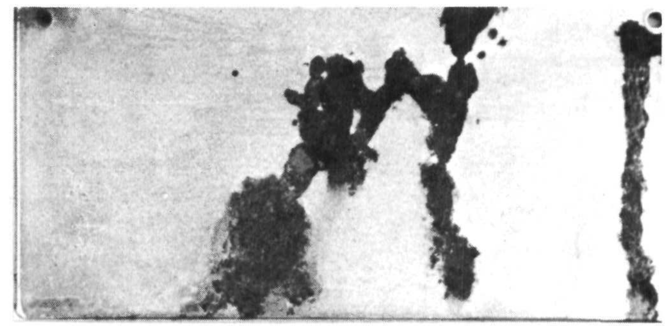
Halocarbon 25-20M; Halocarbon Products Corp.



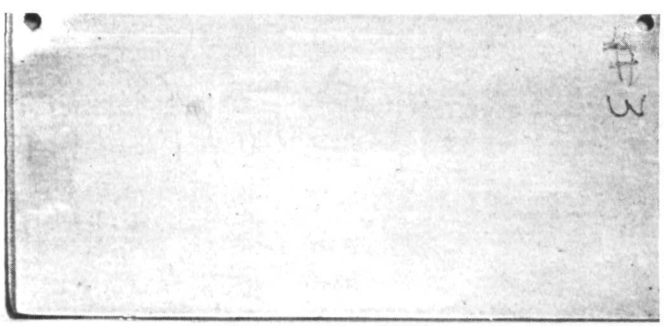
MIL-G-18458A; Allube Corp.



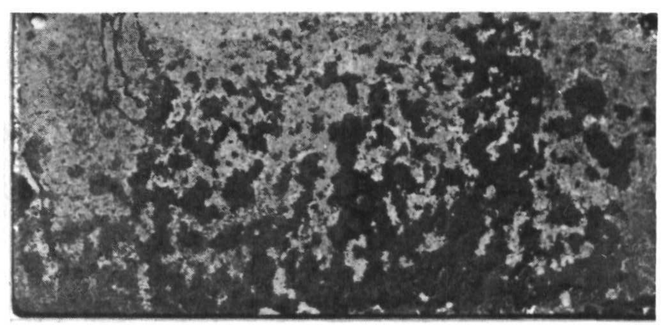
Halocarbon 25-5S; Halocarbon Products Corp.



MIL-G-23827A; Royal Lubricants Co.



Halocarbon 25-20M-5A; Halocarbon Products Corp.

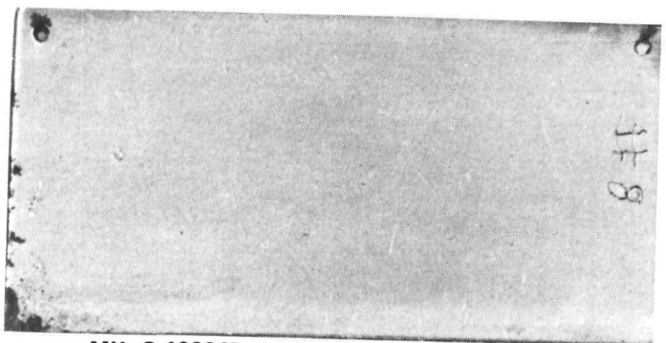


MIL-L-25681C; Dow Corning Corp.

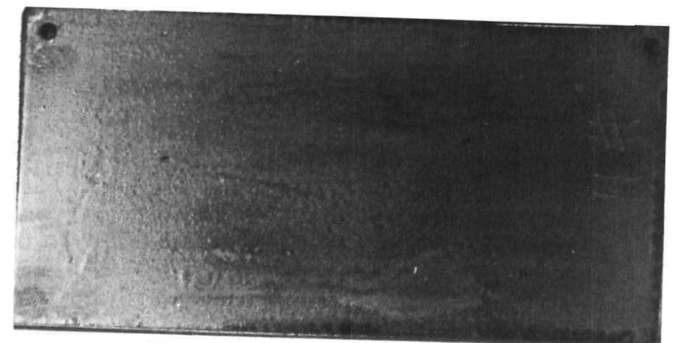
Figure 6. Humidity Cabinet Corrosion Test Panels after Cleaning (2,542 Hours Exposure) (Sheet 1 of 8)

MIL-G-7711A; International Lubricant Corp.

MIL-G-3545C; SOWESCO (KCMO)

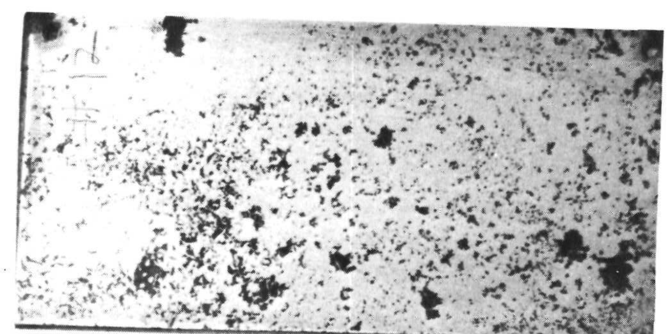


MIL-G-10924B; International Lubricant Corp.



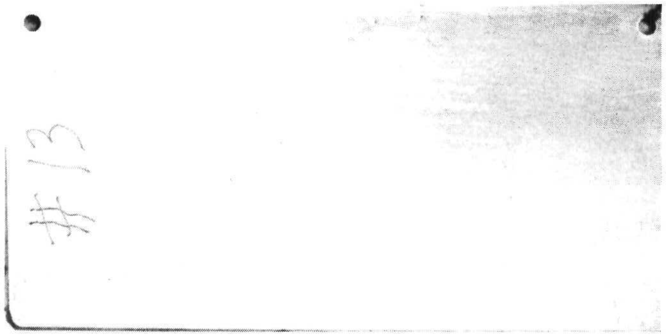
MIL-L-46010A; Dow Corning Corp.

MIL-G-18709A; Unknown

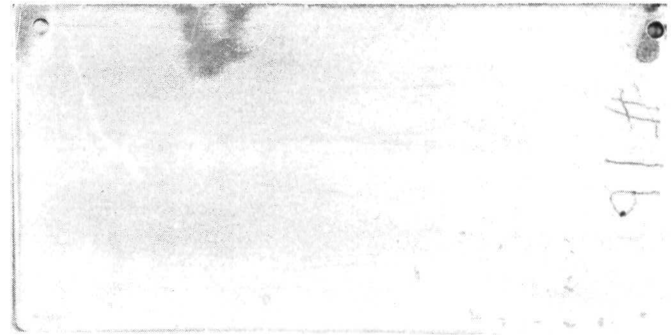


Dag Dispersion 1730; Acheson Colloids Co.

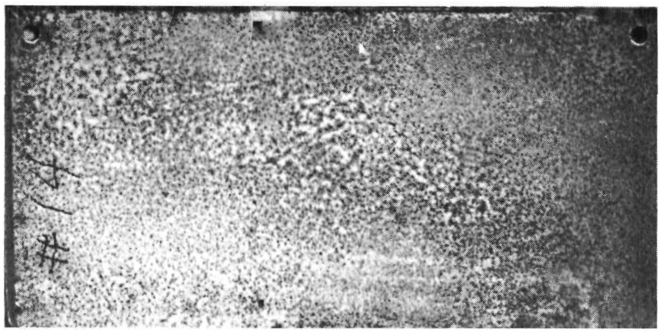
Figure 6. Humidity Cabinet Corrosion Test Panels after Cleaning (2,542 Hours Exposure) (Sheet 2 of 8)



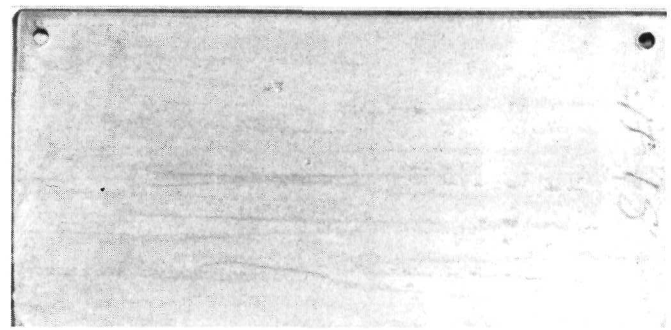
MIL-G-25013D; Standard Oil Co. of California



MIL-G-23549A; AMOCO

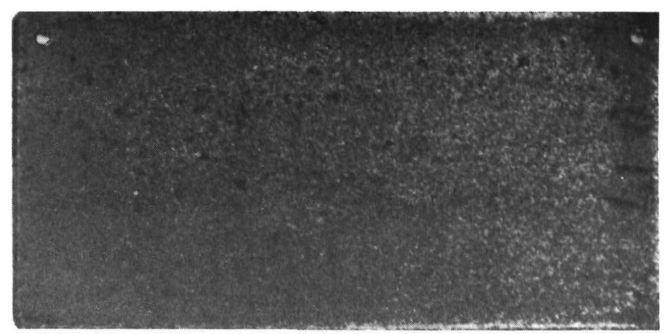


Electromoly 30; Electrofilm, Inc.



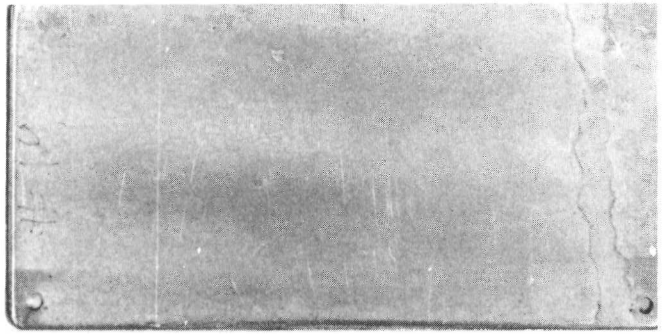
MIL-G-21164B; Royal Lubricants Co.

MIL-G-81322A; Mobil Oil Corp.

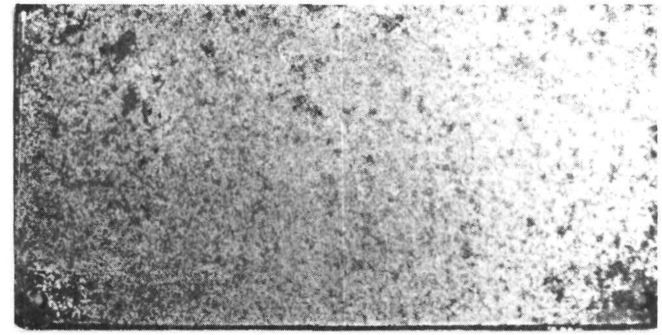


Fluorolube GR362; Hooker Chemical Corp.

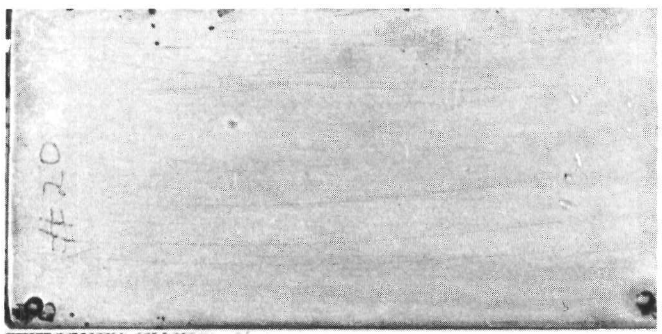
Figure 6. Humidity Cabinet Corrosion Test Panels after Cleaning (2,542 Hours Exposure) (Sheet 3 of 8)



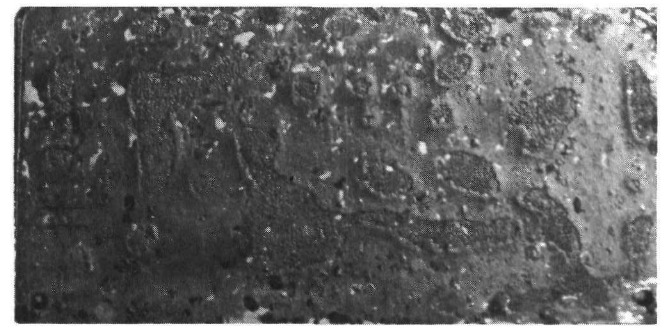
MIL-G-4343B; Royal Lubricants Co.



Nu-Lube All Purpose Grease; Nu-Chem Industries

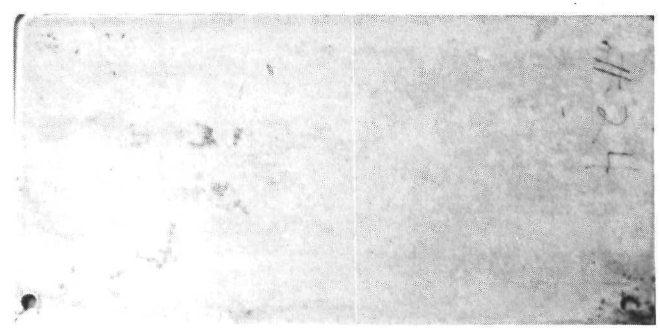


MIL-G-27617A; E.I. du Pont de Nemours & Co.



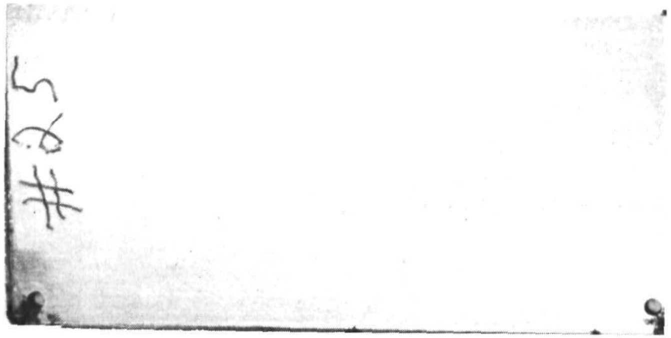
MIL-L-81329A; Everlube Corp.

Braycote Micronic 631A; Bray Oil Co.

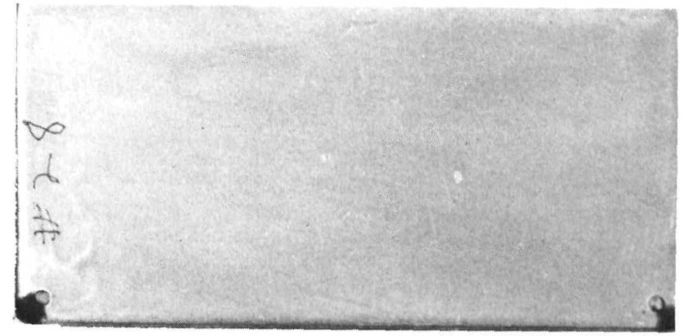


Drilube 822; Drilube Corp.

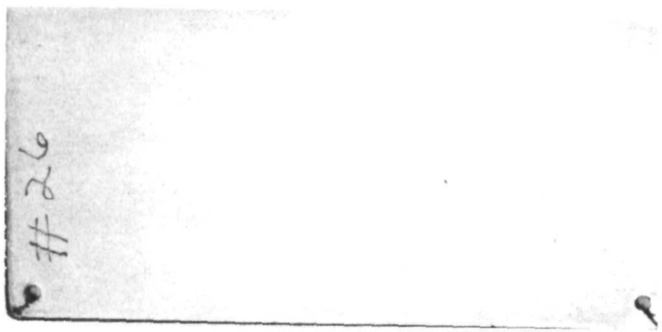
Figure 6. Humidity Cabinet Corrosion Test Panels after Cleaning (2,542 Hours Exposure) (Sheet 4 of 8)



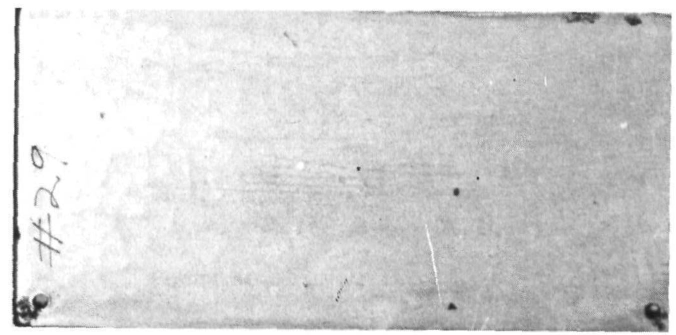
MIL-L-15719A; Dow Corning Corp.



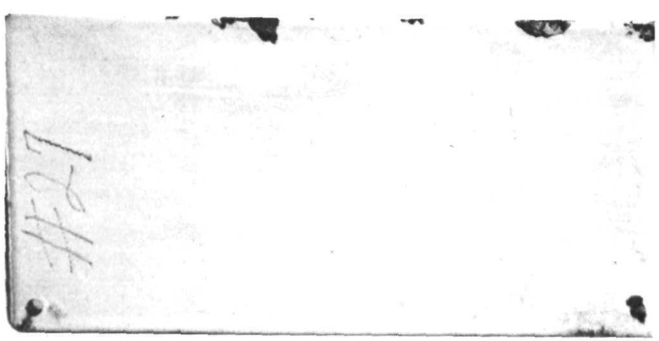
MIL-G-4343B; Dow Corning Corp.



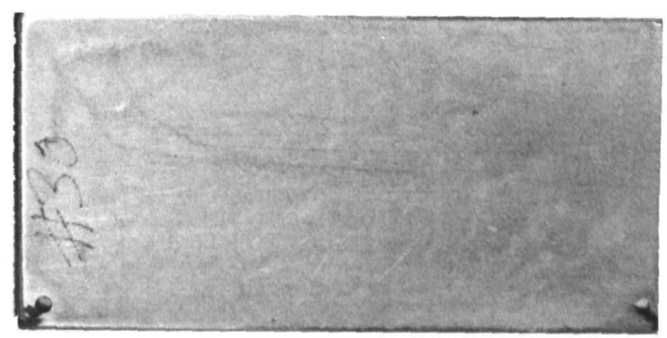
MIL-G-27617A; Dow Corning Corp.



Versilube G-341L; General Electric Co.

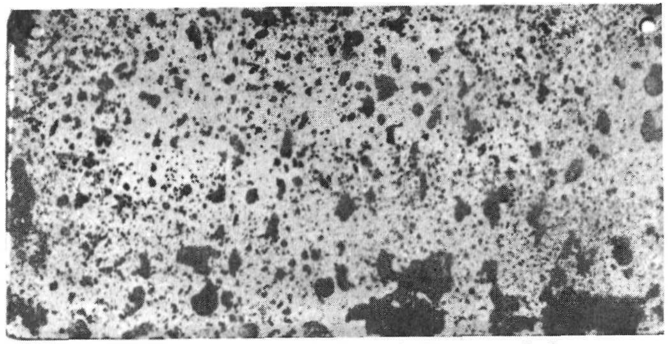


Dow Corning FS-1281; Dow Corning Corp.

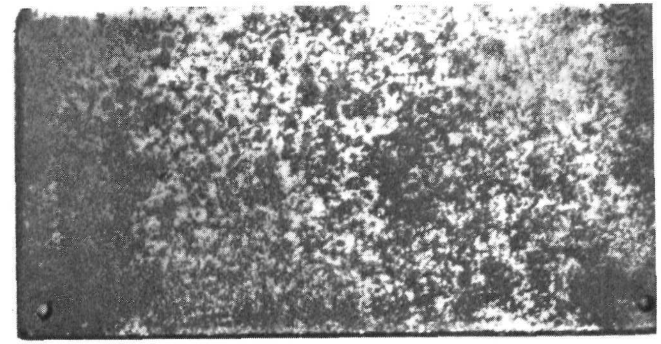


Dow Corning 33M; Dow Corning Corp.

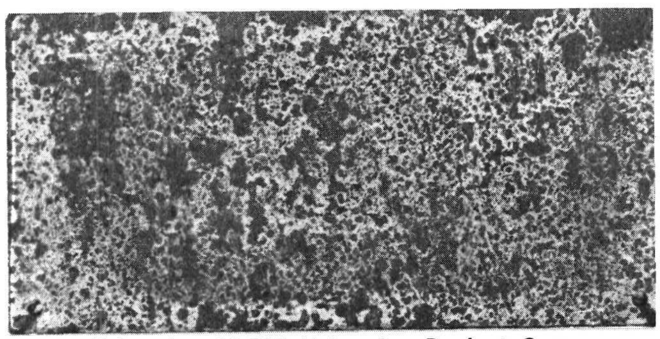
Figure 6. Humidity Cabinet Corrosion Test Panels after Cleaning (2,542 Hours Exposure) (Sheet 5 of 8)



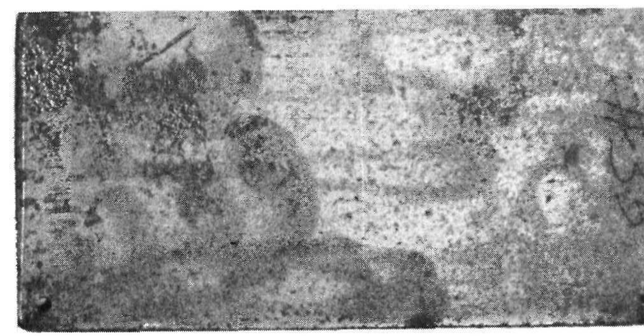
Krytox 143 AC; E.I. du Pont de Nemours & Co.



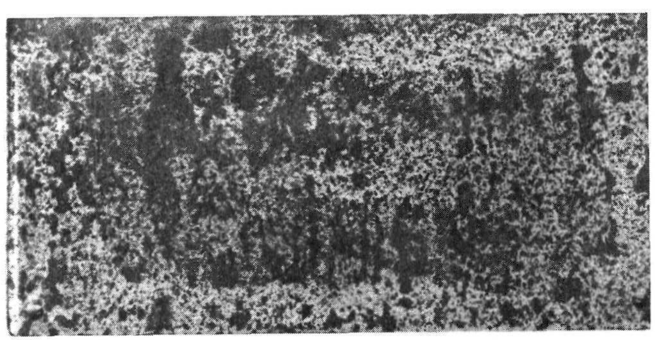
Bison 88; American Lubricants Co.



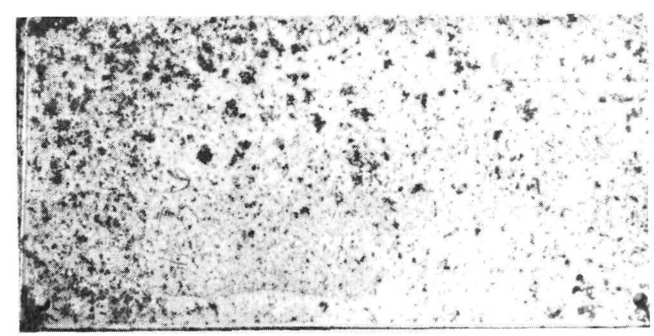
Halocarbon 13-21E; Halocarbon Products Corp.



MIL-M-7866B; Dow Corning Corp.



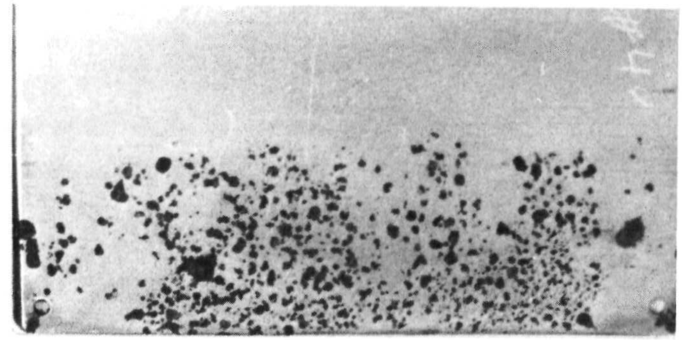
Nu-Trol Mark II; Nu-Chem Industries



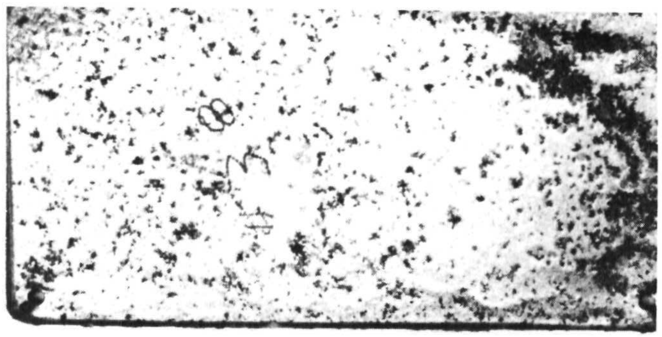
KEL-F-90; 3M Co.

Figure 6. Humidity Cabinet Corrosion Test Panels after Cleaning (2,542 Hours Exposure) (Sheet 6 of 8)

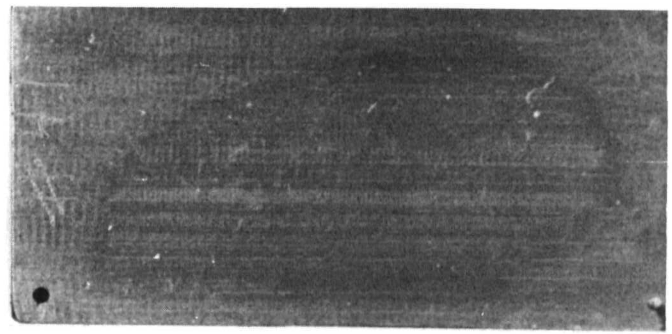
Krytox 250 AC; E.I. du Pont de Nemours & Co.



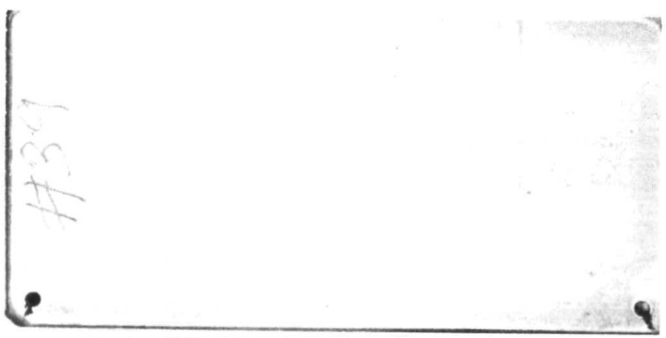
MIL-G-18709A; Shell Oil Co.



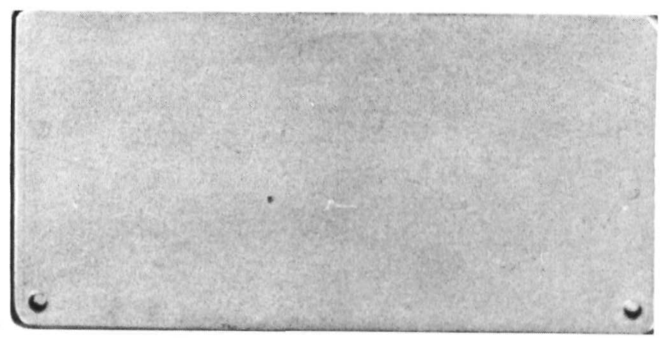
Krytox 260 AC; E.I. du Pont de Nemours & Co.



Atlantic 54, Atlantic Refining Co.

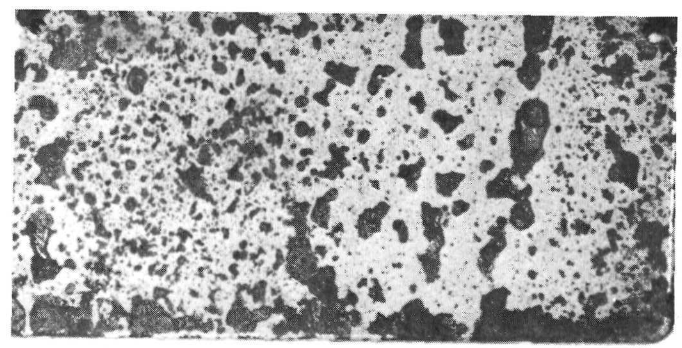


Krytox 280 AC; E.I. du Pont de Nemours & Co.

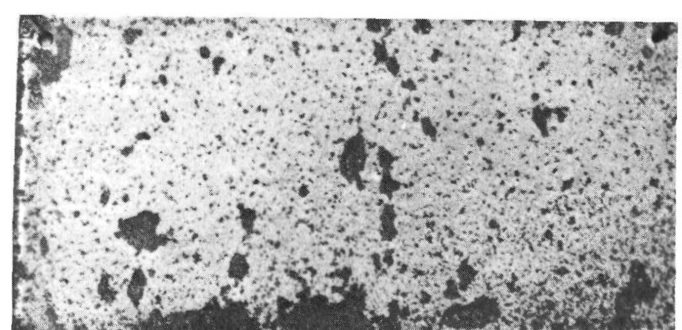


MIL-C-11796A (1); Bray Oil Co.

Figure 6. Humidity Cabinet Corrosion Test Panels after Cleaning (2,542 Hours Exposure) (Sheet 7 of 8)



Halocarbon 11-21E; Halocarbon Products Corp.

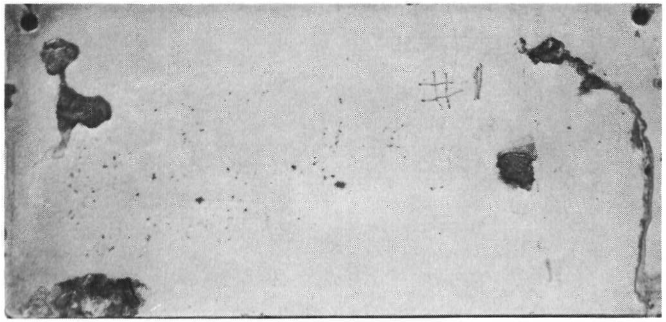


Control (uncoated) panel

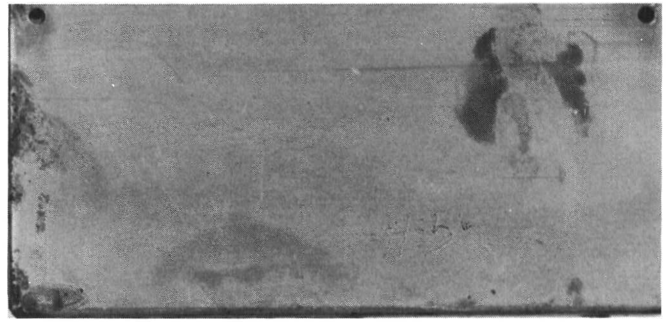
Figure 6. Humidity Cabinet Corrosion Test Panels after Cleaning (2,542 Hours Exposure) (Sheet 8 of 8)

Figure 7. Salt Spray Corrosion Test Panels in the Salt Spray Chamber (1,003 Hours Exposure) (Sheet 1 of 2)

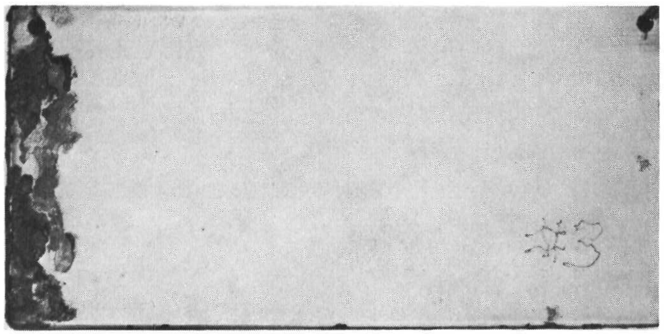
Figure 7. Salt Spray Corrosion Test Panels in the Salt Spray Chamber (1,003 Hours Exposure) (Sheet 2 of 2)



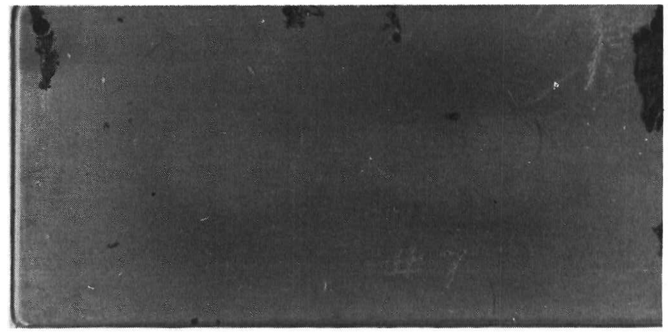
Halocarbon 25-20M; Halocarbon Products Corp.



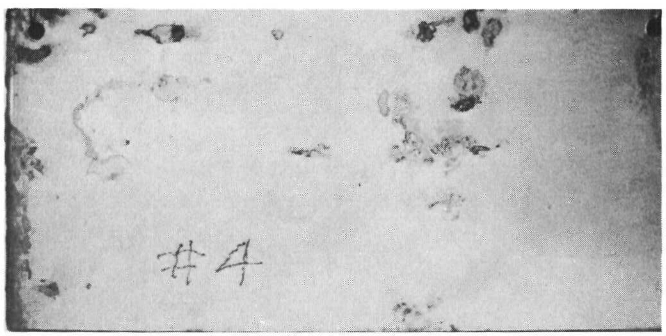
MIL-G-23827A; Royal Lubricants Co.



Halocarbon 25-20M-5A; Halocarbon Products Corp.



MIL-G-7711A; International Lubricant Corp.

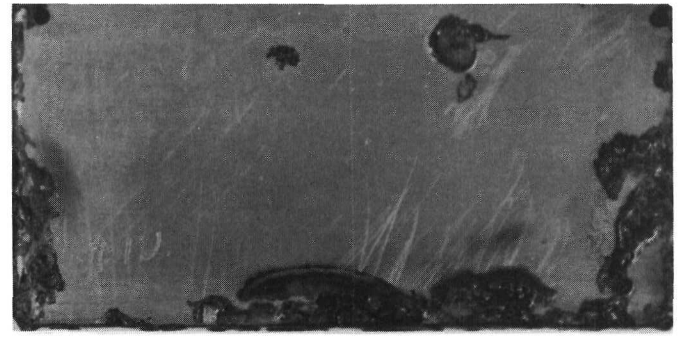


MIL-G-18458A; Allube Corp.

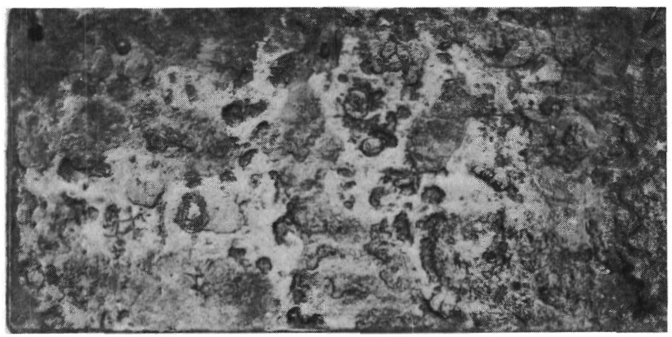
MIL-G-10924B; International Lubricant Corp.

Figure 8. Salt Spray Corrosion Test Panels after Cleaning (1,003 Hours Exposure) (Sheet 1 of 6)

MIL-G-18709A; Unknown

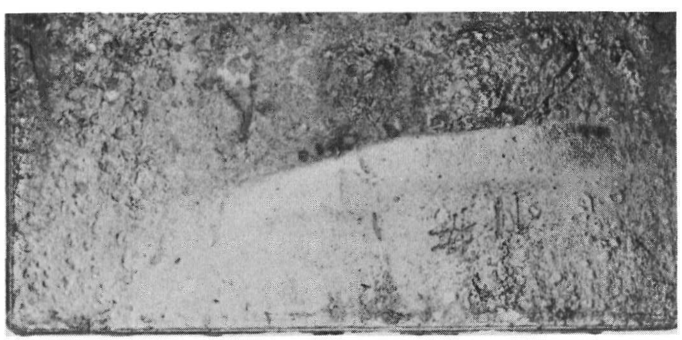


Dag Dispersion 1730; Acheson Colloids Co.

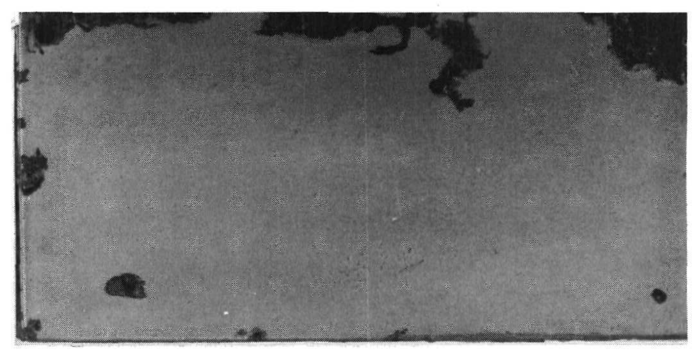


MIL-G-3545C; SOWESCO (KCMO)

MIL-G-25013D; Standard Oil Co. of California

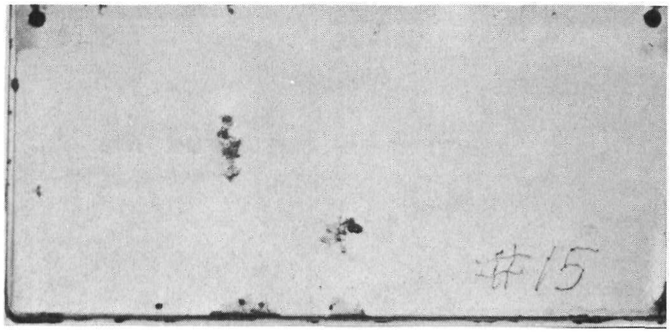


MIL-L-46010A; Dow Corning Corp.



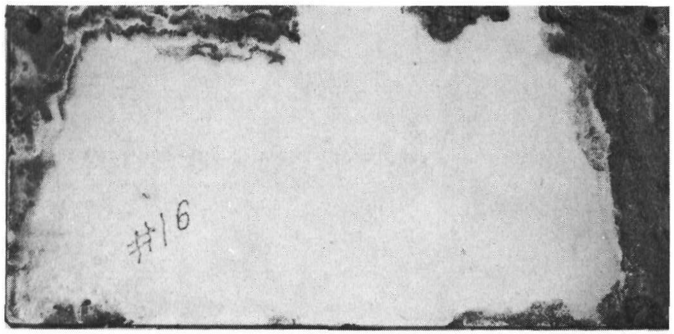
Electromoly 30; Electrofilm, Inc.

Figure 8. Salt Spray Corrosion Test Panels after Cleaning (1,003 Hours Exposure) (Sheet 2 of 6)



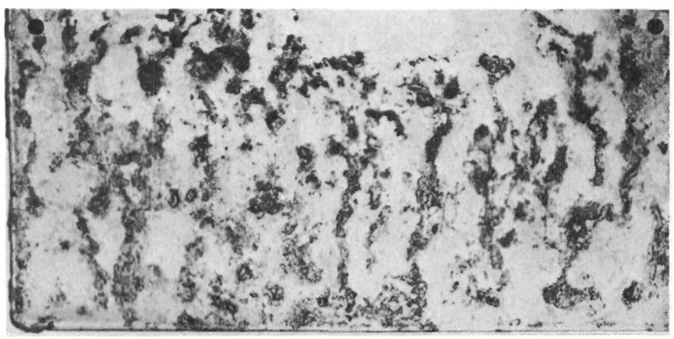
MIL-G-81322A; Mobil Oil Corp.

Fluorolube GR362; Hooker Chemical Corp.

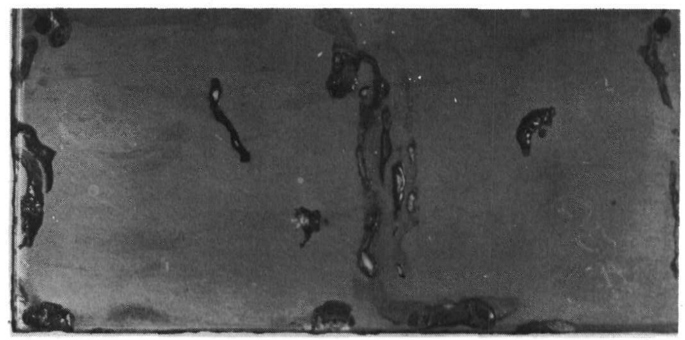


MIL-G-23549A; AMOCO

MIL-G-4343B; Royal Lubricants Co.

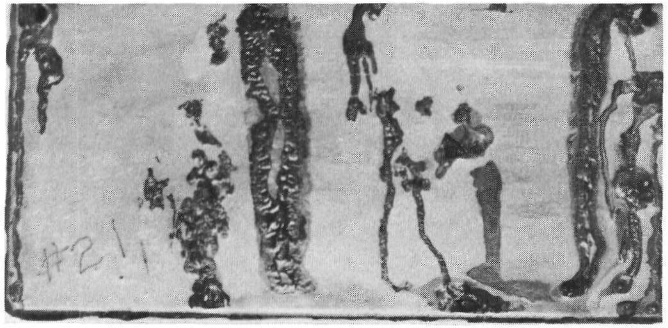


MIL-G-21164B; Royal Lubricants Co.

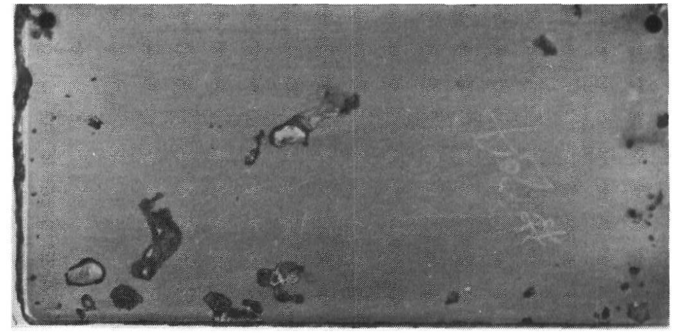


MIL-G-27617A; E.I. du Pont de Nemours & Co.

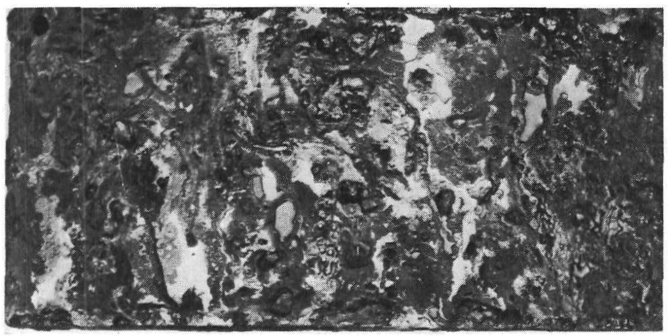
Figure 8. Salt Spray Corrosion Test Panels after Cleaning (1,003 Hours Exposure) (Sheet 3 of 6)



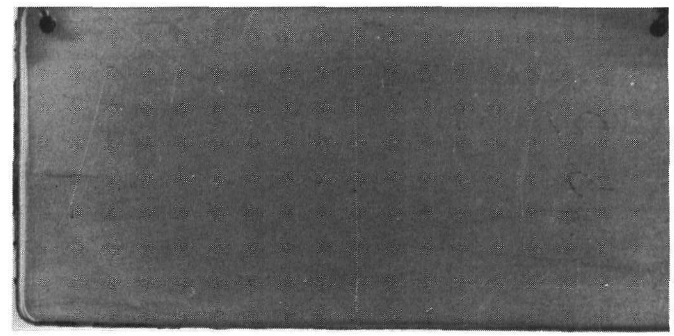
Braycote Micronic 631A; Bray Oil Co.



Drilube 822; Drilube Corp.

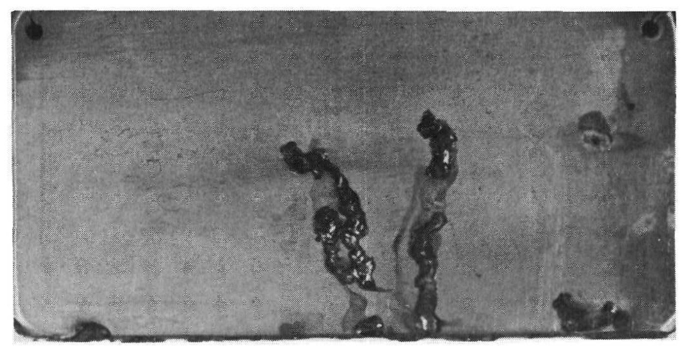


Nu-Lube All Purpose Grease; Nu-Chem Industries



MIL-L-15719A; Dow Corning Corp.

MIL-L-81329A; Everlube Corp.



MIL-G-27617A; Dow Corning Corp.

Figure 8. Salt Spray Corrosion Test Panels after Cleaning (1,003 Hours Exposure) (Sheet 4 of 6)

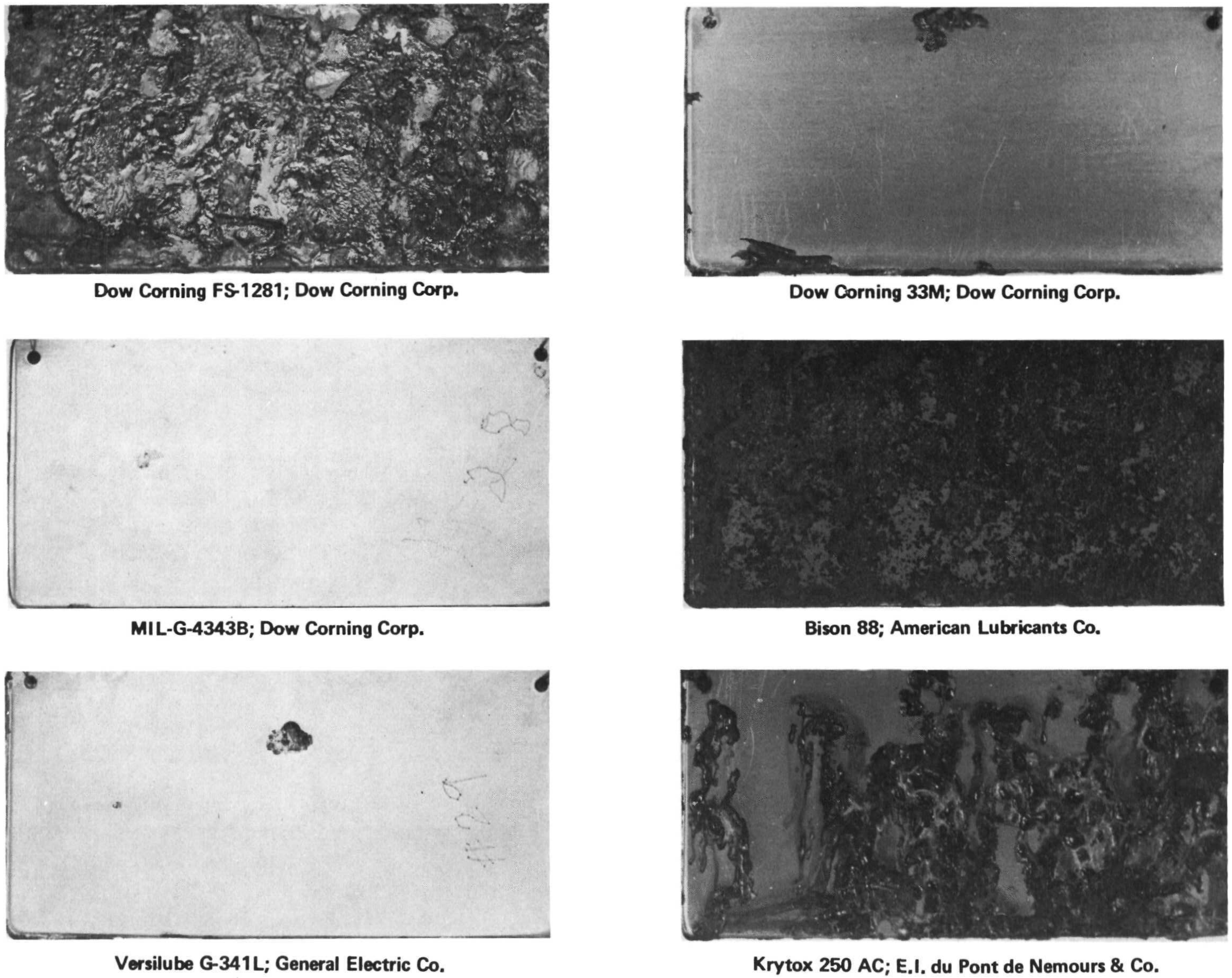
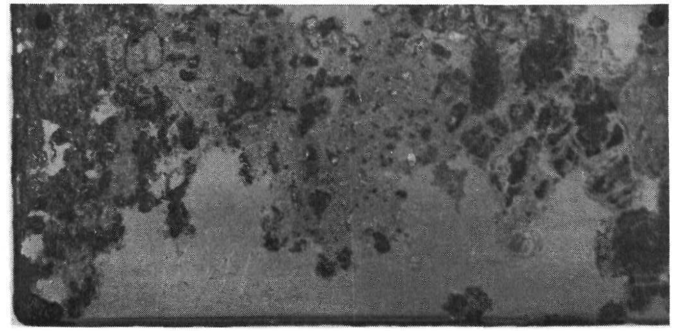
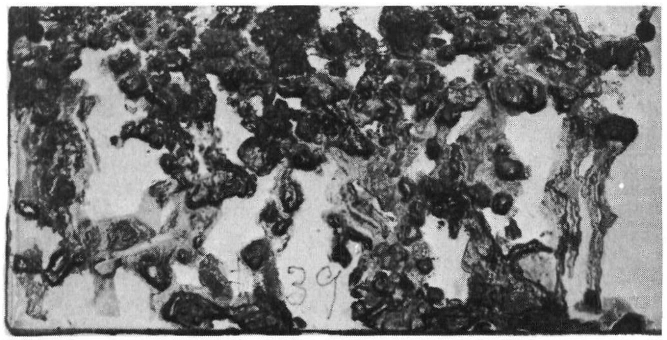


Figure 8. Salt Spray Corrosion Test Panels after Cleaning (1,003 Hours Exposure) (Sheet 5 of 6)

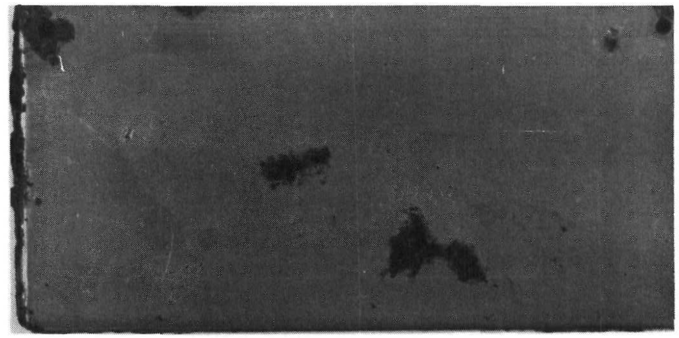
Krytox 260 AC; E.I. du Pont de Nemours & Co.



Atlantic 54; Atlantic Refining Co.



Krytox 280 AC; E.I. du Pont de Nemours & Co.



MIL-C-11796A (1); Bray Oil Co.

MIL-G-18709A; Shell Oil Co.

Control (uncoated) panel

Figure 8. Salt Spray Corrosion Test Panels after Cleaning (1,003 Hours Exposure) (Sheet 6 of 6)

Figure 9. MIL-G-18709, Unknown Manufacturer, Showing Mixed Sodium/Calcium Thickener

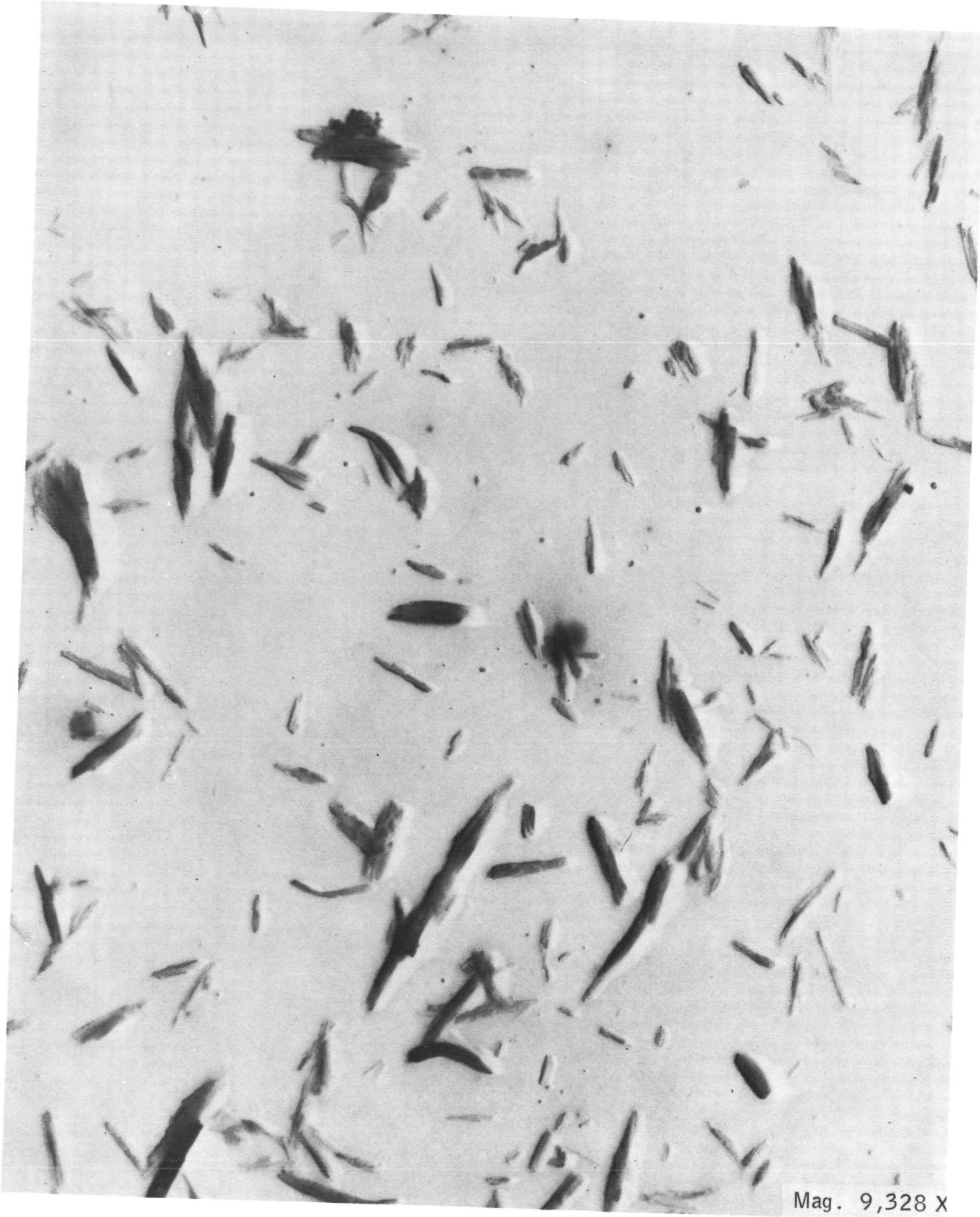


Figure 10. MIL-G-27617, Dow Corning FS 1292 Showing Urea Type Thickener

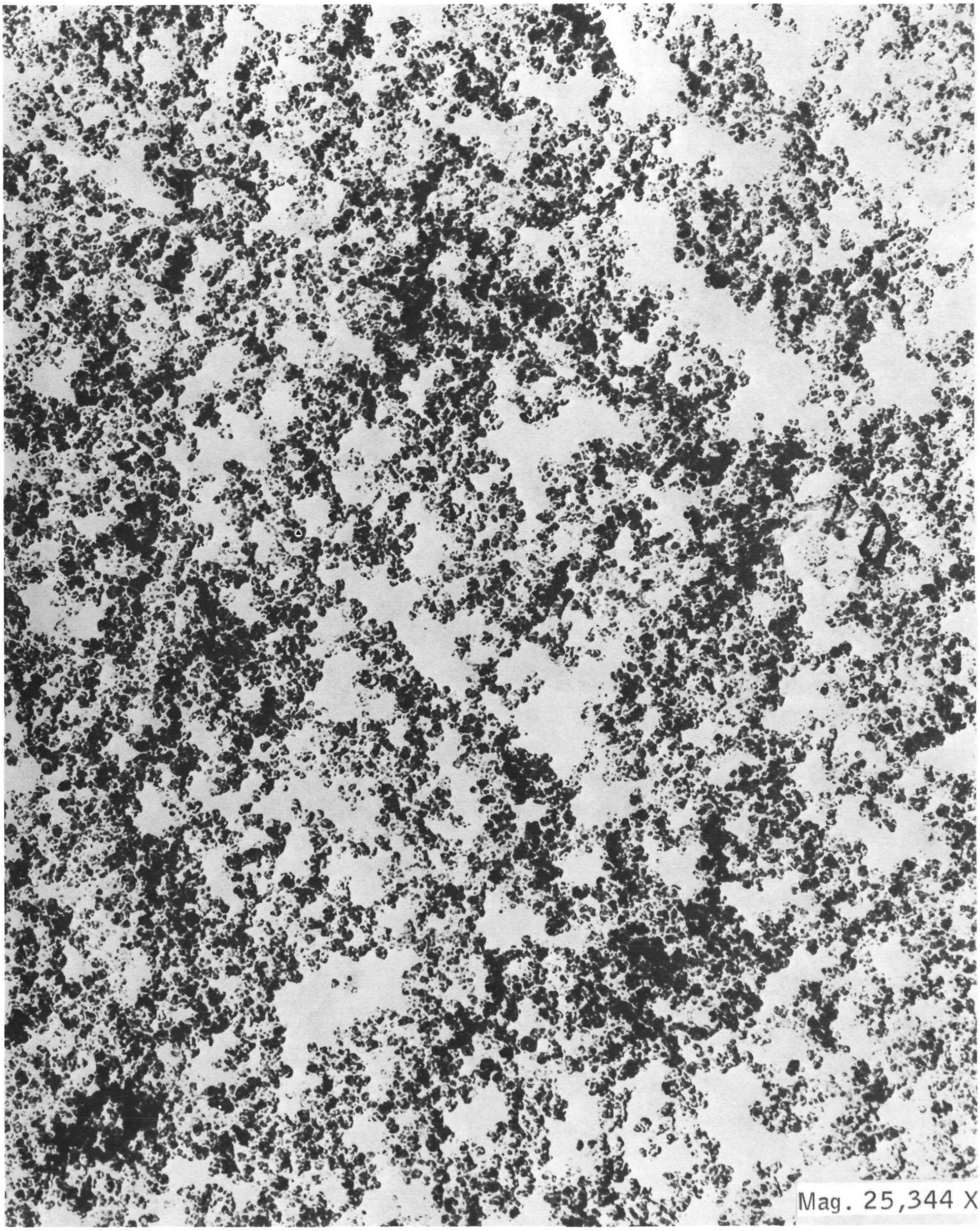


Figure 11. Nulube Grease - Silica Thickener

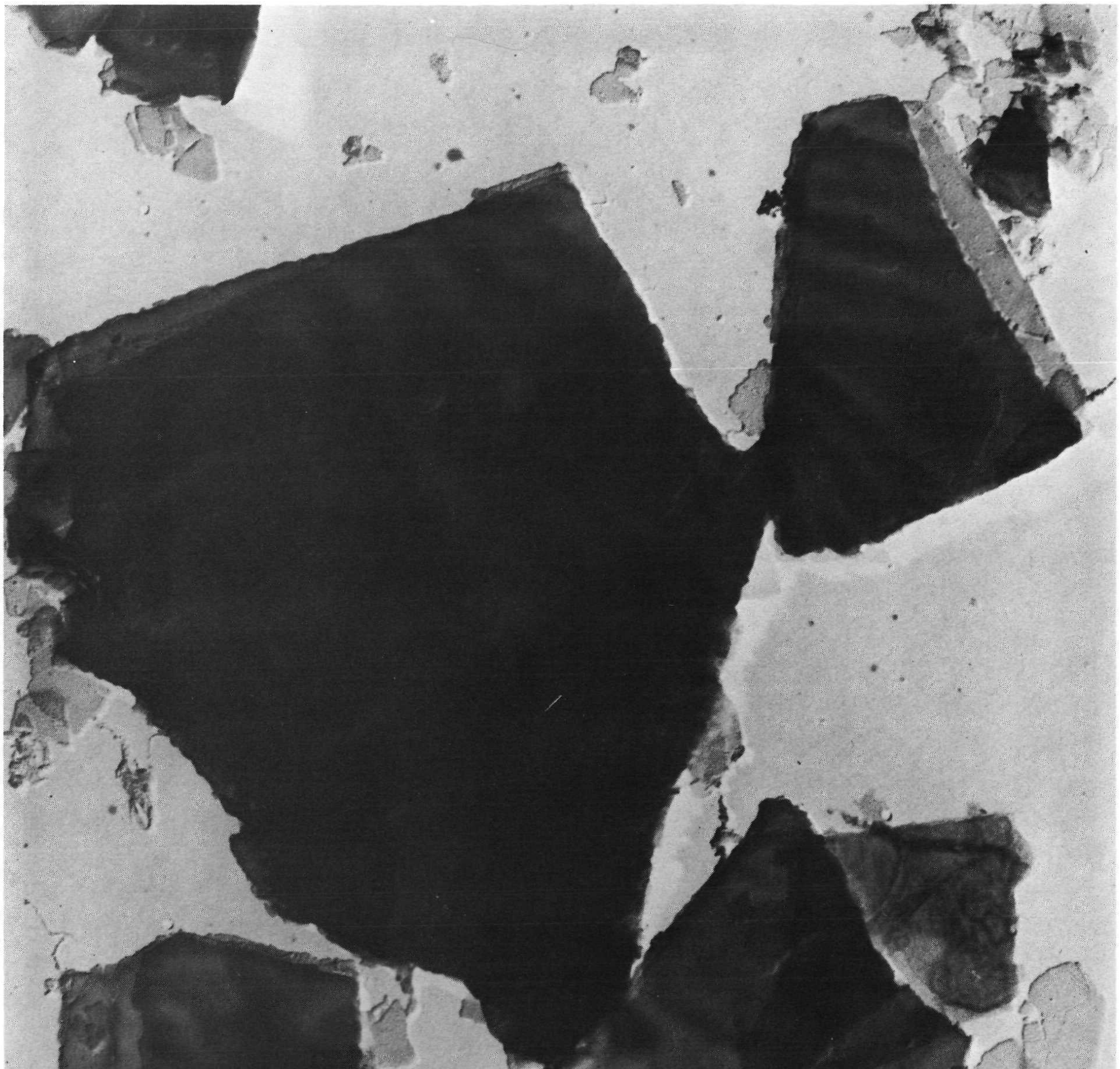


Figure 12. Halocarbon 25-20M Polychlorotrifluorethylene Thickener

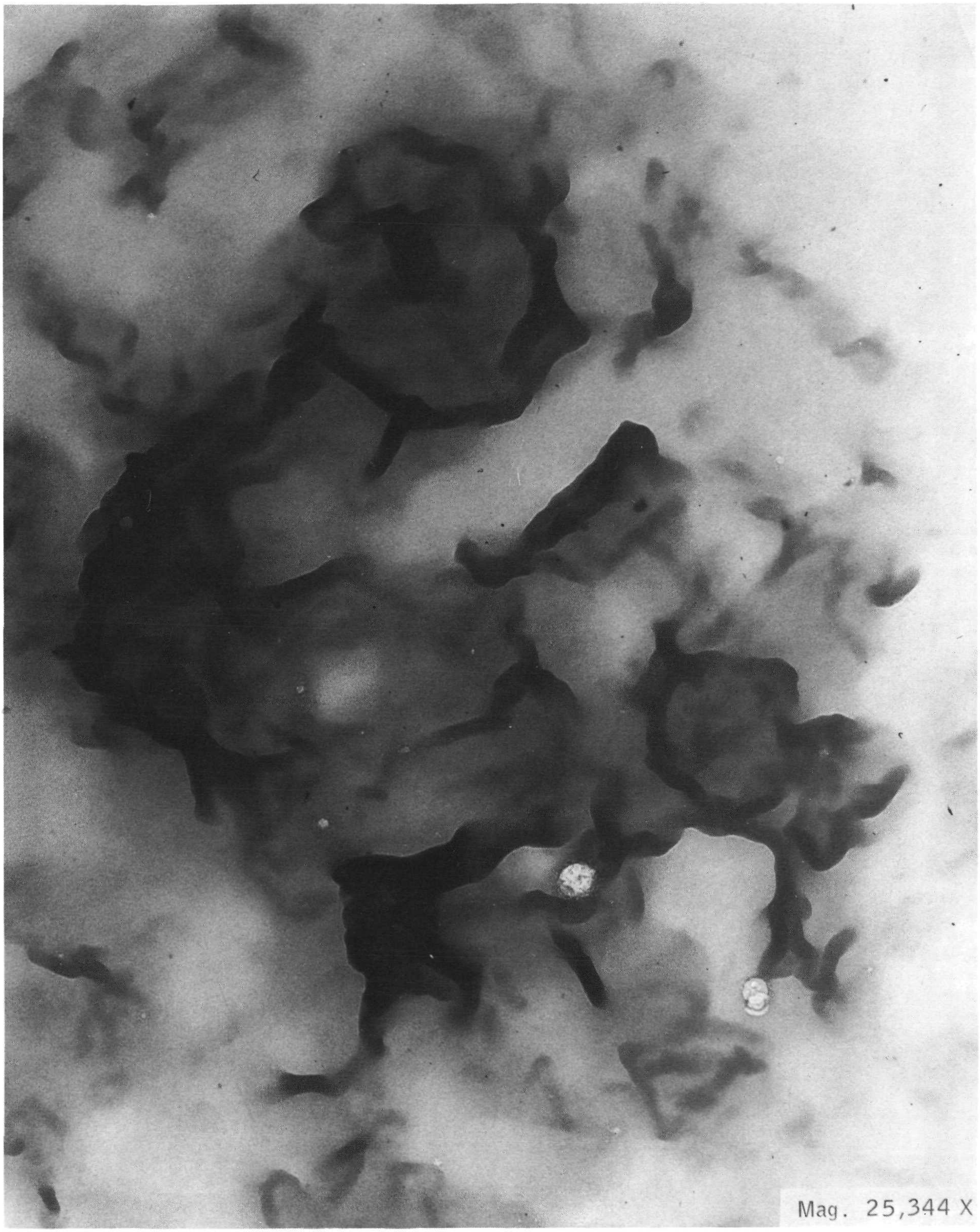
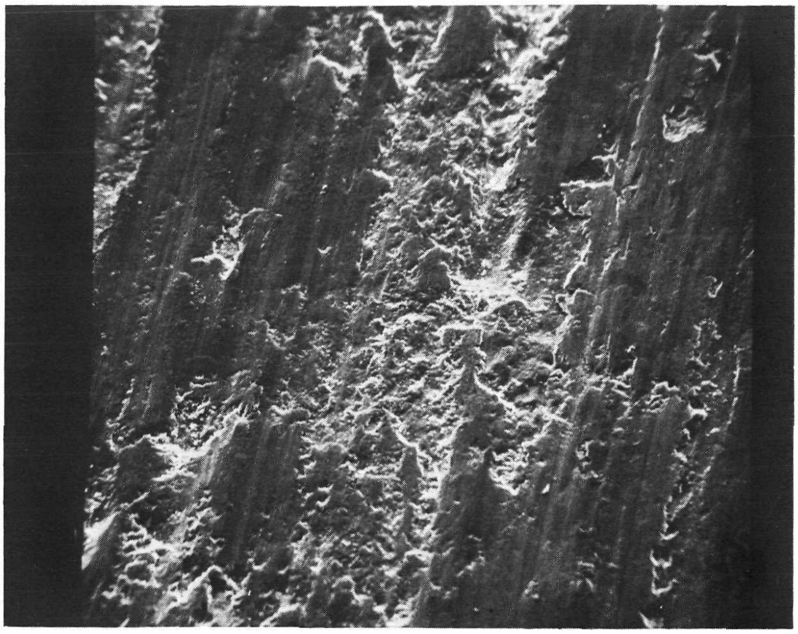
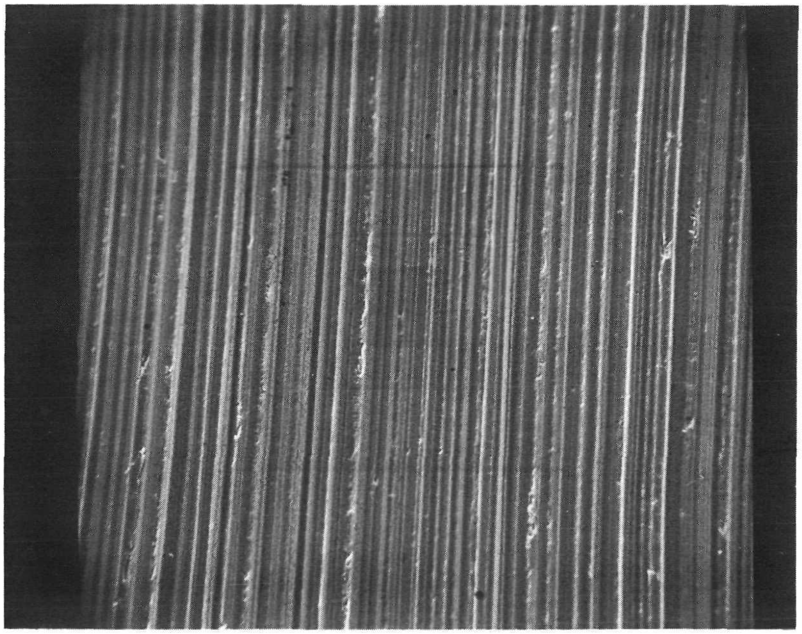


Figure 13. Krytox 280 AC Showing the Vydax Thickener



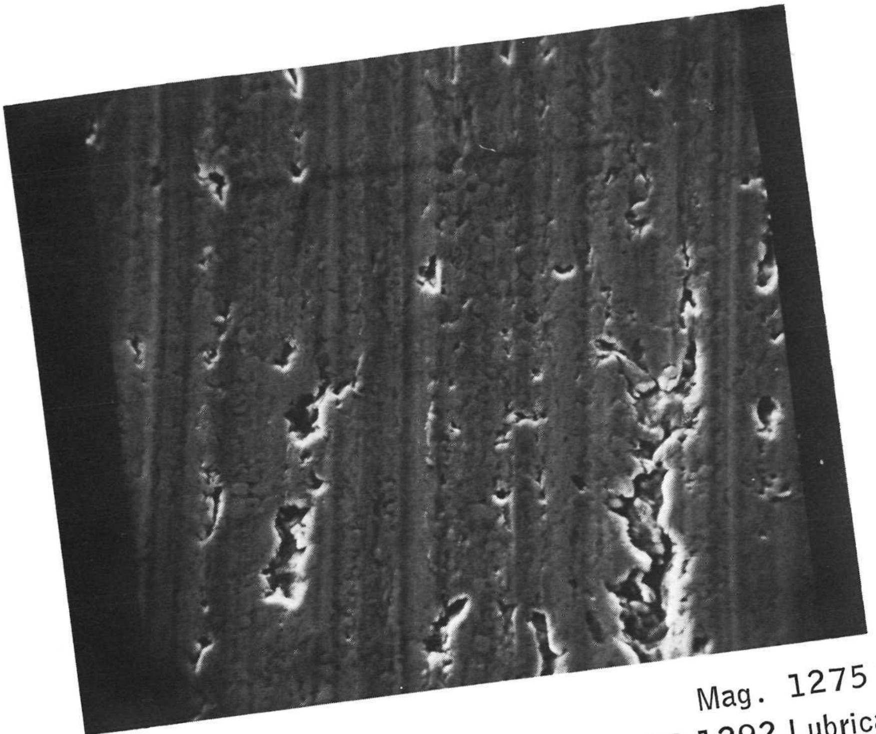
Mag. 234 X

Figure 14. Unlubricated Control Wear Scar from SAE 01 Steel Block on LFW-1



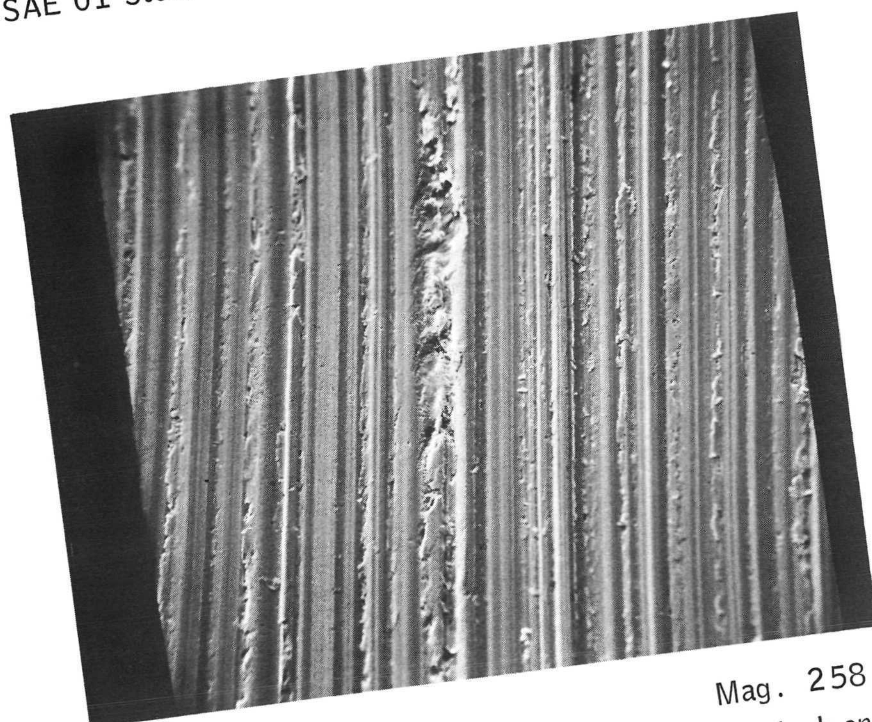
Mag. 264 X

Figure 15. Texaco Capella B Lubricated SAE 01 Steel Block on LFW-1 as an Example of Hydrocarbon Oil



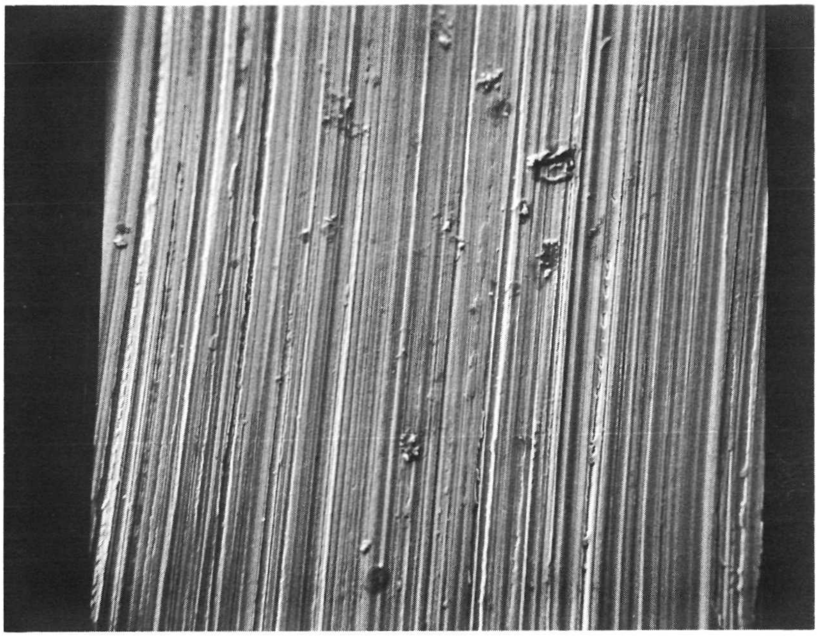
Mag. 1275 X

Figure 16. MIL-G-27617, Dow-Corning FS 1292 Lubricated SAE 01 Steel Block on LFW-1 Showing Incipient Welding



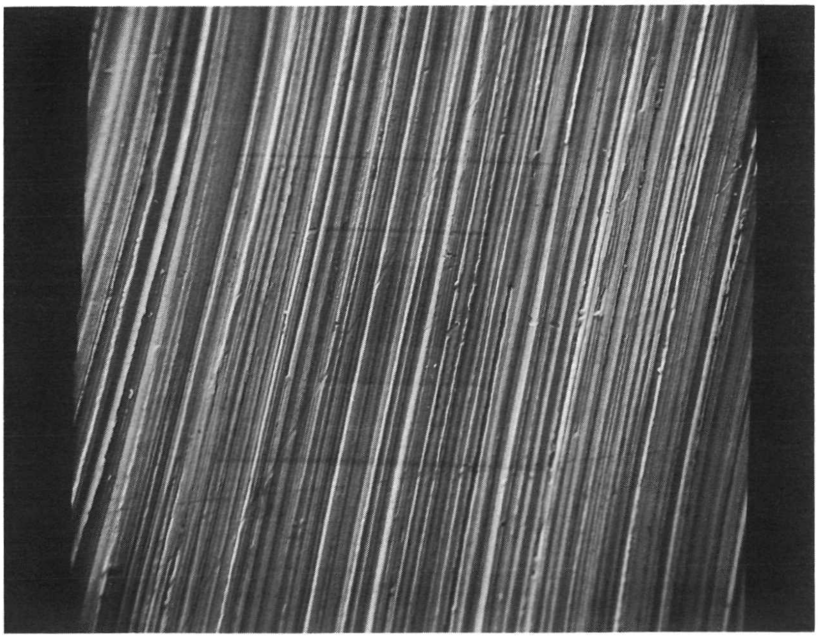
Mag. 258 X

Figure 17. MIL-G-7711 Lubricated SAE 01 Steel Block on LFW-1



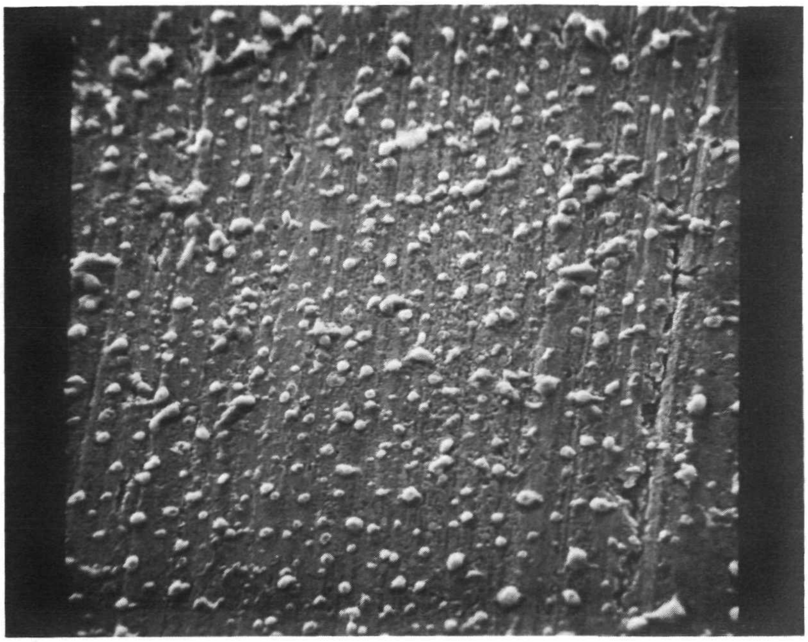
Mag. 268 X

Figure 18. MIL-G-18709, Shell Alvania #2 Lubricated SAE 01 Steel Block on LFW-1



Mag. 280 X

Figure 19. MIL-G-21164 Lubricated SAE 01 Steel Block on LFW-1

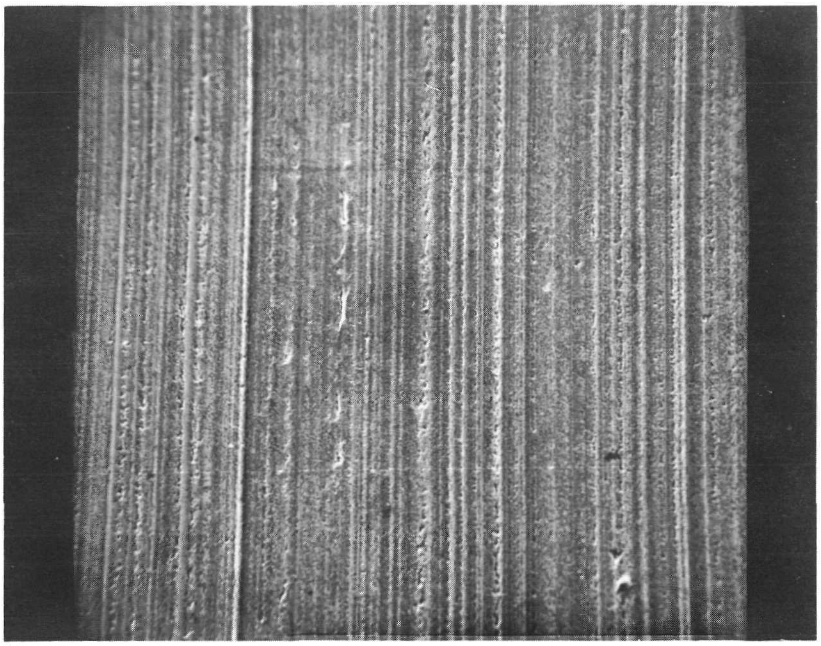


Mag. 620 X

Figure 20. Halocarbon 25-20M Lubricated SAE 01 Steel Block on LFW-1 Showing Corrosion Products

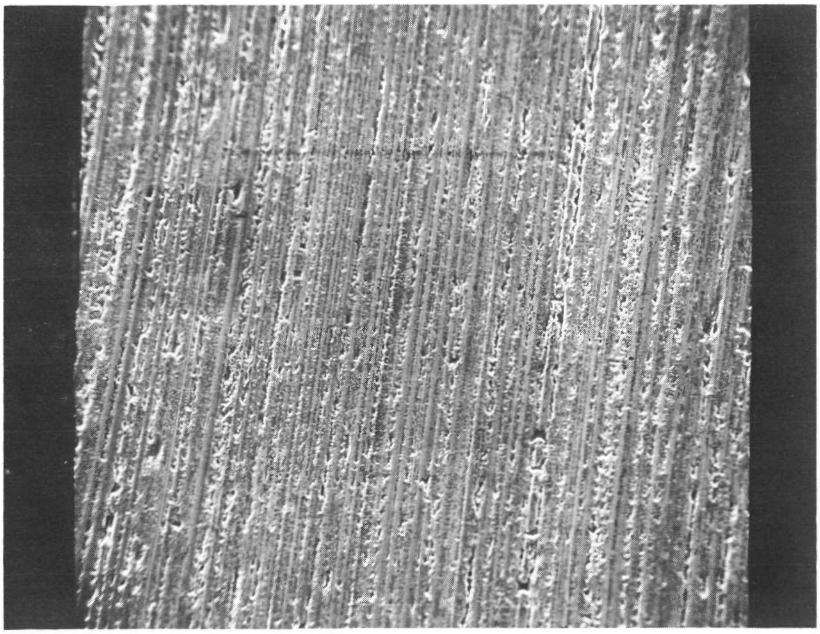
Mag. 612 X

Figure 21. Halocarbon 25-20M-5A Lubricated SAE 01 Steel Block on LFW-1 Showing Effectiveness of Corrosion Inhibitor



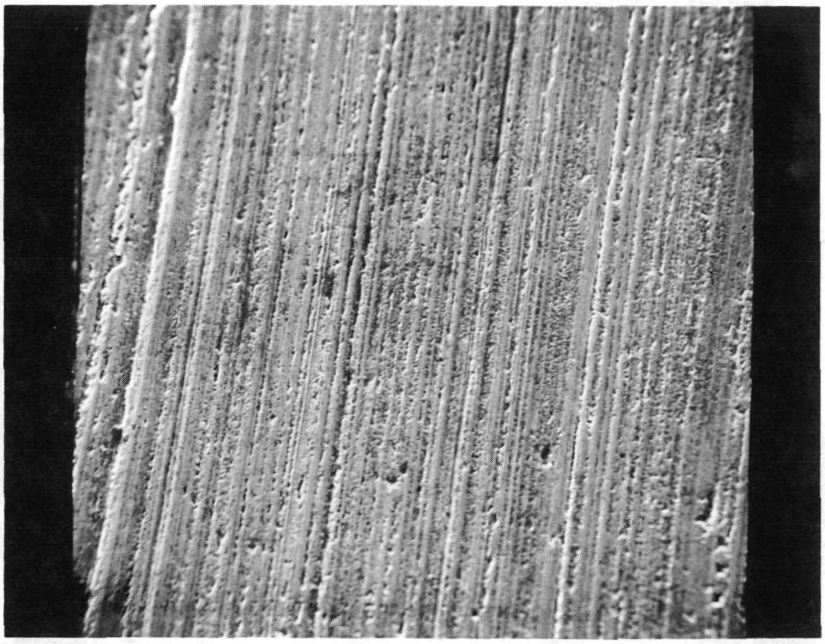
Mag. 260 X

Figure 22. Krytox 143 AC Oil Lubricated SAE 01 Steel Block on LFW-1



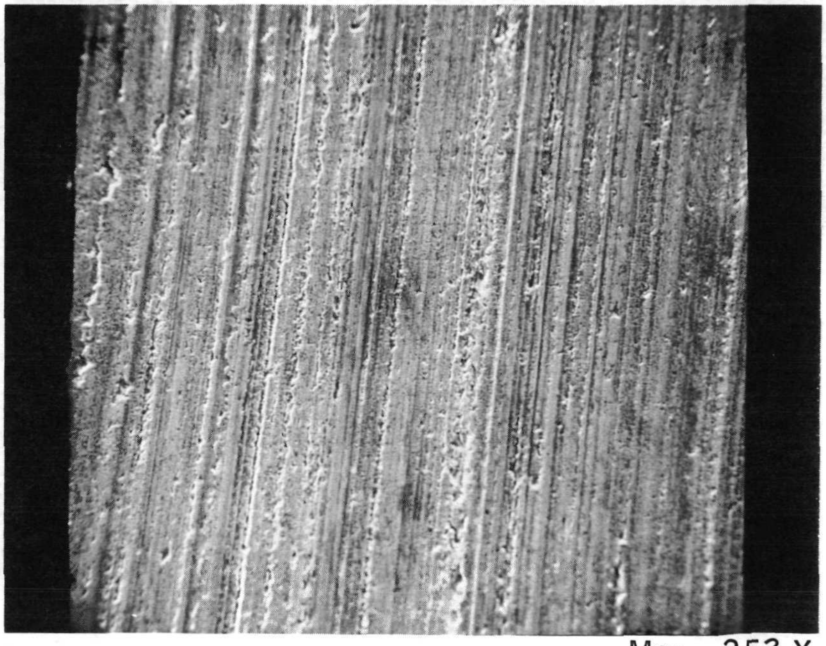
Mag. 252 X

Figure 23. Krytox 240 AC Lubricated SAE 01 Steel Block on LFW-1



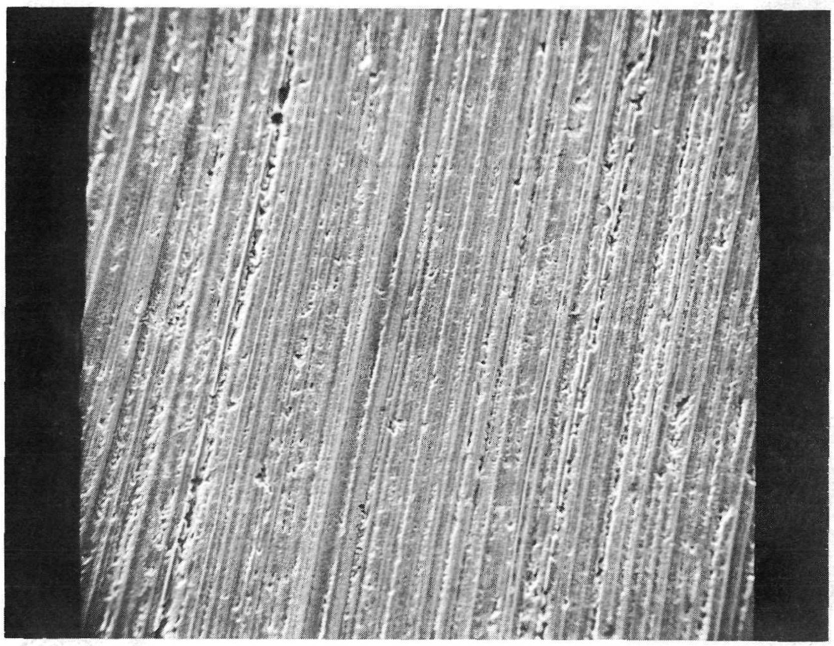
Mag. 265 X

Figure 24. Krytox 250 AC Lubricated SAE 01 Steel Block on LFW-1



Mag. 253 X

Figure 25. Krytox 280 AC Lubricated SAE 01 Steel Block on LFW-1



Mag. 246 X

Figure 26. Braycote 656 Lubricated SAE 01 Steel Block on LFW-1

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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