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MATER AI - STEEL, ALUMINUM, BRONZE -
COMBINED GALVANIC, STRESS CORROSION OF

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REPORT FGT-2939

DATE 4-3-62

MODEL B-58

TEST No. 50-1833

TITLE

MATERIAL - STEEL, ALUMINUM, BRONZE - COMBINED
GALVANIC, STRESS CORROSION OF

SUBMITTED UNDER
CONTRACT NUMBER
AF33(600)-41891

Tests described in this report were conducted between November 7, 1961 and February 1, 1962.

PREPARED BY: E. W. Turns
E. W. Turns

GROUP: Chemistry Section
Engineering Test Lab.

REFERENCE: FSG-529

CHECKED BY: J. E. Halkias
J. E. Halkias

APPROVED BY: K E Dorcas
K.E. Dorcas

D C Wilson
D. C. Wilson

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MATERIAL - STEEL, ALUMINUM, BRONZE - COMBINED GALVANIC, STRESS CORROSION OF

PURPOSE:

The purpose of this test was to determine what galvanic effect dissimilar metals have on stress corrosion in critical areas on the landing gears. The dissimilar materials in this area are S.A.E. 4340 electric furnace steel (heat treated to 260-292 KSI F_{tu}) axle, hard anodized (Alumilite 226) unclad 7075-T6 aluminum spacer ring, manganese (Mn) bronze scissor bushing and possibly several landing gear greases.

SUMMARY:

Tests were conducted to determine what effects the various dissimilar materials in the landing gear have on accelerated stress corrosion of the landing gear axle material, 4340 steel. Based on test results the following conclusions were made:

1. Water absorption by the various landing gear greases was virtually equal with a 200 to 300% increase over the amount present in the grease.

2. The combined galvanic effect of the dissimilar metals in the landing gear fail area does not increase stress corrosion of 260-292 KSI Ftu 4340 steel when tested in a 20% salt spray accelerated stress corrosion environment.

MATERIAL - STEEL, ALUMINUM, BRONZE - COMBINED
GALVANIC, STRESS CORROSION OF

OBJECT:

To conduct tests to determine the following:

1. Absorption of water by landing gear greases.
2. Relative electromotive potentials of landing gear materials.
3. Accuracy of deflection specimen loading method.
4. Effects of various materials on wear life and galling of X-38 solid film lubricant.
5. Galvanic effects of materials on accelerated stress corrosion of 4340 steel bent beam specimens.

SPECIMEN, MATERIALS AND EQUIPMENT:

SPECIMENS

Item	Use	Source
A. Test Greases		
1. MIL-G-21164 Grease	Test I	Standard Oil of Indiana Whiting, Indiana
2. FMS-0169 (Royco 60 AMS) Grease	Test I and IV	Royal Lubricants Inc. Hanover, N. J.
3. MIL-G-25760 (Amber) Grease	Test I and IV	Standard Oil of Indiana Whiting, Indiana
4. MIL-G-25760 A Grease	Test I and IV	Standard Oil of Indiana Whiting, Indiana
5. 4L210 (1 part by wt. MIL-M-7866 Molybdenumdisulfide + 32 parts by wt. MIL-G-7118)	Test I, IV and VI	The Almasol Corporation 316 North Sylvania Fort Worth, Texas

Item	Use	Source
6. Used B-58 Landing Gear Grease	Test I	GD/FW Flight Line

B. Test Metals

Item	Use	Source
1. 37 pieces of 4340 Steel, MIL-S-5000, .040" x 1"x3" heat treated to 285 KSI FTU	Test II, III, and VI	United States Steel Corp. 525 William Penn Place Pittsburgh 30. Penn.
2. 12 pieces of .040"x1"x1" Hard Anodized unclad 7075-T6 Aluminum	Test II and VI	Aluminum Company of America 1200 Alcoa Building Pittsburgh 19, Pa.
3. 12 pieces of .040"x1"x1" unclad 7075-T6 Aluminum	Test II and VI	Aluminum Company of America 1200 Alcoa Building Pittsburgh 19, Pa.
4. 16 standard Timken races	Test IV and V	The Alpha Molykote Corp. 64 Harvard Avenue Stamford, Conn.
5. 21 pieces of .040"x1"x1" manganese bronze QQ-B-726 Class C	Test II and VI	American Brass Company Waterbury 20, Conn.

C. Test Metal Finishes

Item	Use	Source
1. 1 pint of FMS-0003 Epoxy Primer	Test V	Andrew Brown Company Irving, Texas #TA 862
2. 1 pint Dry Galv (zinc dust plus dibutyltitanate)	Test V	American Solder Flux Co. 19th and Willard Street Philadelphia, Pa.
3. X-38 solid film lubricant	Test IV, and V	Prepared in Engineering Chemistry Laboratory

Item	Use	Source
D. Test Fluids		
1. MIL-H-8446B. Amend.1 (Oronite 8515) Hydraulic Fluid	Test IV	Oronite Chemical Company 200 Bush Street San Francisco 20, Calif.
2. MIL-H-5606 Hydraulic Fluid	Test IV	Bray Oil Company 344 Medford Street Los Angeles, Calif.

MATERIALS:

Item	Use	Source
1. 1 gallon of Karl Fisher Reagent	Test I	The W. H. Curtin Company 1800 Sidney Houston 1, Texas
2. 1 liter of 5% sodium chloride	Test II Electrolyte	The W. H. Curtin Company 1800 Sidney Houston 1, Texas
3. 4 strain gauges C6121 (Budd Metal film gage)	Test III	The Budd Company P. O. Box 245 Phoenixville, Pa.
4. One gallon of Parco Lubrite Number 2	Test IV and V	Parker Rust Proofing Company 2169 East Milwaukee Detroit 11, Michigan
5. 6 manganese bronze rub shoes QQ-B-726 Class C	Test IV	Fabricated by GD/FW in Department 37
6. Zero to six inch scale graduated in 0.01" divisions.	Test III and VI	The L. S. Starrett Company 101 Crescent Street Athol, Mass.
7. SR 4 Strain Indicator SN 562964	Test III	The Baldwin Lima Hamilton Corp. Philadelphia National Bank Bldg. Philadelphia 7, Pa.
8. Modified Mac Millan Wear Tester	Test IV and V	Hartmann Tool Company 6626 San Fernando Road Glendale 1, California

	Item	Use	
9.	Salt Spray Chamber, Model No. C. A. 1	Test VI	Universal Filter & Pump Mfg. Co. Chicago, Ill.
10.	Heat Treat Furnace	Heat Treating 4340 Steel Specimen	Heavi Duty Furnace Company Milwaukee, Wisconsin
11.	V Block Specimen Holders, Cadmium Plated, and painted	Application Bending Load to specimens	Manufactured in GD/FW by Dept. 81, per FTJ-1345-2

TEST PROCEDURES:

I. Water in landing gear greases before and after humidity exposure.

Test greases shown in the materials section were identified, spread out separately on glass slides and placed in a cyclic R. T. to 160°F, 95% relative humidity chamber operated as described in MIL-E-5272B. After 72 hours they were removed from the chamber and immediately weighed on a tared piece of aluminum foil. The foil and grease were immersed in Karl Fisher reagent for analysis on the aquameter. Standard Karl Fisher aquameter procedures (per FZM-1776) were used to determine water content. Control specimens of the various greases, not exposed to humidity, were analyzed along with test specimens. The used grease was obtained from a B-58 on the flight line.

II. Potential measurements of landing gear materials in 5% sodium chloride.

Small specimens cut from 260-292 KSI Ftu 4340 steel bar stock, Hardas anodized unclad 7075-T6 aluminum, and unclad 7075-T6 aluminum without anodize were grouped in different pairs and immersed by pairs (but each separated physically) in 5% by weight sodium chloride. Prior to test the 4340 steel specimens were vapor honed to remove heat treat scale. Bare 7075T6 aluminum specimens were washed in methyl ethyl ketone and vapor degreased in trichloroethylene. Finished surfaces of all specimens were then protected from contamination until test.

Each pair of specimens was joined electrically through a vacuum tube voltmeter, allowed to stabilize about 5 minutes, and the resultant voltage was determined and recorded. The stressed specimen (see Table II) was mounted in a loading device and stressed to 180,000 psi (tensile) as illustrated in Figure 1. No potential between unstressed specimens was detectable.

III. Comparison of bent beam specimen loads calculated by deflection and measured with a strain gauge.

Heat treated 4340 steel specimens were placed in a loading device shown in Figure 1 and stressed by screwing in the bolt, thus bending the specimen. Deflection was measured with a linear scale (having 0.01" subdivisions) from a point on a line between the two specimen ends to a point of maximum deflection (center) of the specimen. Prior to bending, a strain gauge (C6121) had been applied to the area of most tension deflection. Read out was accomplished on a SR-4 strain indicator type N. The set-up was single gauge with compensator. See procedure, section VI, for procedure used to calculate load by deflection method.

IV. Effects of various materials on wear life of X-38 solid film lubricant.

Standard Timken races were phosphate pretreated in 12.5 point Parco Lubrite No. 2 for 20 minutes at 205°F. The race was then coated with X-38 solid film lubricant prepared from Type Z MoS_2 which had been ball milled 8 hours.

The race was then tested on a modified Mac Millan test machine operating in oscillating motion in a 22 1/2° arc with a speed of 240 cycles per minute. Loading was 630 pounds (approximately 63,000 psi) on the race. Prior to running test specimens, two controls without grease or fluid were tested. Test greases were then applied individually to separate areas of the race contacting the rub shoe during oscillation. Automatic shut off occurred when coefficient of friction exceeded 0.1.

V. Galling effects of various coatings applied to standard races.

Standard Timken races which had been phosphate pretreated in Parco Lubrite No. 2, coated with the various test primers, and then coated with X-38 solid film lubricant, were furnished by the Materials and Processes group. Rub shoes for this test were manganese-bronze alloy. The test machine was a modified Mac Millan operating in a 22 1/2° oscillating motion at 240 cycles per minute.

Two separate 22 1/2° areas on each race were tested. One test was at 69.5 pounds load (approximately 6950 psi) while the second run on a new area was made using a 99 pound load (approximately 9900 psi). New manganese bronze rub shoes were used for each run. Time to failure shown in Table V was based on visual observations of a stop watch.

VI. Effects of 20% salt spray on combined galvanic-stress corrosion of landing gear materials.

Various combinations of landing gear materials, shown in Table VI were assembled in triplicate and stressed as illustrated in Figure 1. Special effort and consideration was made to isolate and/or combine each material that might have galvanic effects on the prime test material, 4340 steel.

The 4340 steel specimens used for this test were 1" x 3" x .040" machined from mill run 1 1/4" 4340 steel bar stock. Specimens were ground to the .040" thickness and held to a tolerance of ±.001". After grinding, specimens were solution heat treated at 1550°F for 1/2 hour, oil quenched, then subjected to a 1 hour draw at 400°F. Rockwell C hardness test indicated a tensile ultimate strength of 285,000 psi. Heat treat scale was removed by vapor honing using 320 grit aluminum oxide in an aqueous suspension at 100 psi air pressure. The ends of steel specimens were covered with a polyester film (Mylar) tape to insulate the specimen galvanically from the painted, cadmium plated mild steel V block. Attachment clamps to hold the dissimilar materials were made of teflon. Calculation of the required deflection to obtain a bending stress of 180 KSI was accomplished as follows:

$$Y = \frac{Pl^3}{48EI} \qquad S = \frac{MC}{I} \qquad M = \frac{Pl}{4}$$

When

M = Bending moment in inch pounds
Y = Deflection (applied) in inches
P = Force in pounds
l = Beam length in inches
E = Test material modulus of elasticity in psi
I = Moment of inertia (inches^4)
C = $\frac{\text{Thickness}}{2}$ (t) in inches
S = Stress in psi of outer fiber of specimen

Therefore by substitution and rearrangement

$$Y = \frac{Sl^2}{6Et}$$

The necessary deflection of the specimen, Y, can be obtained by substituting in the equation known thickness, beam length, material modulus and bending stress desired.

Specimens of unclad 7075-T6 aluminum requiring hard anodize received 2 mils of Hardas anodize at Anadite, Inc; Hurst, Texas. Later it was learned the hard anodize coating on the spacer ring was actually Alumilite 226; however, the properties are virtually identical and this erroneous substitution should not affect the test results.

After assembly test greases were applied with a spatula. The area of maximum tensile stress on the required steel specimens was covered with grease.

RESULTS:

Water adsorption properties of all the test greases are shown in Table I. Table II reveals the various electromotive potentials generated between 4340 steel, manganese bronze, unclad 7075-T6 and Hardas anodized unclad 7075-T6 aluminum. Similarity between calculated deflection and strain gage measured stress levels on bent beam stress corrosion test specimen is shown in Table III. Effects of various test materials on wear life and galling are illustrated in Tables IV and V. Finally, in Table VI the effects of 20% salt spray on various isolated and/or combined landing gear materials may be observed.

DISCUSSION:

The critical area of the main landing gear axle beam is a specific area bounded by an Alumilite 226 hard anodized unclad 7075-T6 aluminum spacer ring and a manganese bronze scissor bushing insert. It became desirable to determine what effect these dissimilar materials, plus possibly moisture in 4-L-210 grease, have on the combined galvanic and stress corrosion of the axle beam. A test was conducted to determine the actual galvanic potentials between these materials. By examining Table II it is apparent that manganese bronze is cathodic to 4340 steel. However, the bare 7075-T6 aluminum is anodic to the steel by a larger extent so that the overall effects of all of the dissimilar metals should be slight anodic protection for the steel.

Test results shown in Table VI do substantiate that anodic materials, unclad 7075-T6 aluminum, prolong the time to failure due to accelerated stress corrosion. However, the overall effects of the various materials in the fail area is inconsequential or minor.

At the beginning of the test there was no knowledge of water absorptive properties of the greases used in different areas and applications on the landing gear. Test data shown in Table I was collected to determine the extent water or electrolyte might be absorbed and contribute toward galvanic-stress corrosion. The water pick-up is 2 to 3 times the original water content value but not unusually great for any of the materials.

As a test to determine the effects of dissimilar metals, electrolyte and stress on corrosion of 4340, a bent beam specimen appeared best because it could be designed to simulate all of the landing gear materials and be used in an accelerated test environment. Since this was an unfamiliar specimen and loading device, a small scale test was conducted to determine the accuracy of the method for applying tensile load to the specimen. Data presented in Table III shows that reasonable accuracy can be expected in applying tensile loads by bending to calculated deflection.

A related landing gear problem has been lubrication of an area under a race that was occassionally subjected to sliding forces when the face sometimes turns, upon landing, on the axle beam. Solid film lubricant, X-38, has been applied for lubrication of the area. Another test was conducted to determine the effects of various landing gear greases and hydraulic fluids on the X-38 solid film lubricant. Data shown in Table IV shows that all of the materials tested are detrimental to the lubricating properties of X-38 solid film.

Soon after X-38 was applied, it was found that fatigue properties of the 4340 steel axle had apparently been lowered by the X-38 solid film phosphating pretreatment reported in FSG-529. Also, on axles without solid film, failures were being experienced and the cause appeared to be stress corrosion. Two treatments (1) FMS-0003 epoxy primer and (2) dry galv paint were being considered for pretreatment prior to X-38 solid film application. The detrimental effects of these materials on the lubricating properties of X-38 can be seen in Table V.

The last but probably most important test is reported in Table VI. In this test all of the materials from the landing gear failure area were isolated and then combined to various degrees to determine their galvanic effects on heat treated 4340 steel in 20% salt spray accelerated stress corrosion environment. Upon examining data for specimens 7, 8 and 9, it is apparent that manganese bronze does lower the stress corrosion resistance to below the control value. Data for specimens 4, 5 and 6 may be misleading because the anodic coating is a good insulator and the specimens did not make galvanic contact; therefore, they could not exert protective anodic influence. The protective effects of bare 7075T6 aluminum (without anodize) can be seen by examining data for specimens 13, 14, 15 and 28, 29, 30. Specimens 25, 26 and 27 represent all of the materials and conditions found in the fail areas after tests in 20% salt spray accelerated stress corrosion environment. This condition is obviously not conducive to accelerate stress corrosion failures. It is important to note, however, that this data is all from an accelerated environment and may not correlate with data obtained from actual service environment.

CONCLUSIONS:

1. Water adsorption of all B-58 landing gear greases are virtually equal with a 200 to 300% overall increase as compared to the original water content.

2. Bare 7075-T6 aluminum is anodic to 4340 steel while manganese bronze is cathodic. The overall effect is slightly anodic or protective to 4340 steel.

3. All materials listed in Table IV and V are detrimental to the lubricating properties of X-38 dry film.

4. The combined effect of the dissimilar metals in the landing gear fail area does not galvanically increase stress corrosion of 260-292 KSI Ftu 4340 steel when tested in a 20% salt spray accelerated stress corrosion environment.

TABLE I

WATER IN LANDING GEAR GREASES BEFORE AND AFTER HUMIDITY* EXPOSURE

Type Grease	Before Humidity **	After Humidity
MIL-G-21164	2.50 mg H_2O/gram	7.95 mg H_2O/gram
FMS-0169 (Royco 60 ams)	3.83 mg H_2O/gram	8.60 mg H_2O/gram
MIL-G-25760 (Amber)	3.54 mg H_2O/gram	9.69 mg H_2O/gram
MIL-G-25760 A	4.27 mg H_2O/gram	10.53 mg H_2O/gram
Landing Gear 4L210	4.06 mg H_2O/gram	10.18 mg H_2O/gram
Used Grease From A B-58 Landing Gear	4.20 mg H_2O/gram	Not applicable

* 72 hours of R.T. to 160°F Cyclic 95% Humidity per MIL-E-5272B

**Average of 2 specimens run on Karl-Fisher Aquameter.

TABLE II

POTENTIAL MEASUREMENTS* OF LANDING GEAR MATERIALS IN 5% SODIUM CHLORIDE

TEST MATERIALS		
Anode	Cathode	Volts
4340 Steel	Manganese Bronze	0.22
Hardas Anodized 7075 Aluminum	4340 Steel	0.18
Stressed 4340 Steel	Unstressed 4340 Steel	0.06
Bare 7075 Aluminum	4340 Steel	0.26

* Average of three consistent (± .02 volts) specimens measured with a vacuum tube voltmeter.

TABLE III

COMPARISON OF BENT BEAM SPECIMEN STRESS CALCULATIONS BY DEFLECTION AND MEASURED WITH STRAIN GAUGE*

Specimen Number	Calculated Stress By Deflection	Measured Stress By Strain Gauge
31	180,000 psi	213,000 psi
33	180,000 psi	180,000 psi
34	180,000 psi	199,000 psi
38	180,000 psi	172,000 psi
Average	180,000 psi	191,000 psi

* SR-4 Indicator USA 82581

TABLE IV

EFFECTS OF VARIOUS MATERIALS ON WEAR LIFE OF X-38 SOLID FILM LUBRICANT

Test Material	Wearlife, Hrs.*
None (Control)	12.8
FMS-0169 (Royco 60 AMS) Grease	2.2
MIL-H-8446 (Oronite 8515) Hyd. Fluid	0.6
MIL-H-5606 Hyd. Fluid	4.0
4 L 210 Grease, Consisting of: 1 part - MIL-M-7866 Molybdenum Disulfide, and 32 parts - MIL-G-7118 Grease	0.6

* At the average of two specimens - Run on modified Mac Millan Lubricant Test Machine

Rub shoes made of steel Rc 57-60, Races made of 4620 steel Rc 58-63, case hardened.

TABLE V

GALLING EFFECTS OF VARIOUS COATINGS APPLIED TO STANDARD RACES*

Test Material	Cycles to Failure @ 240 C.P.M.** 6950 PSI Load	9900 PSI Load
FMS-0003 Epoxy Primer	40	40
Dry Galv Paint (Zinc Dust Plus Dibutyltitinate)	12	12
X-38 Solid Film	Not Tested	2,664,000 and still running when discontinued.

* Standard races of 4620 steel, pretreated with Parco Lubrite No. 2. Rub shoes of manganese bronze, duplicate test.

**Failure was when coating had been rubbed off, exposing base coating, and a rumbling action began.

TABLE VI

EFFECTS OF 20% SALT SPRAY ON STRESS CORROSION OF LANDING GEAR MATERIALS

4340 Steel (Mill Run Bar) Specimens, Heat Treated to 285,000 PSI Tensile Ultimate, Bending Beam Load (Tensile) 180,000 PSI

Specimen Number	Test Material Combinations	Hours Exposure	Average Time of Exposure
1	4340 Steel (alone) Controls	250*	
2		136	212
3		250	
4	4340 Steel Plus Unclad 7075-T6,	211	
5	Hardas Anodized Aluminum	116	179
6		211	
7	4340 Steel Plus Manganese Bronze	197	
8		244	181
9		104.5	
10	4340 Steel Plus Hardas Anodized Aluminum	244	
11	Plus Manganese Bronze	250	248
12		250	
13	4340 Steel Plus Bare 7075 Aluminum (no anodize) Plus Manganese Bronze	250	
14		197	232
15		250	
16		250	
17	4340 Steel (alone) Plus Grease (4L210)	250	205
18		116	
19		250	
20	4340 Steel Plus Bare Hardas Anodized 7075	250	213
21	Aluminum Plus 4L210 Grease	140	
22	4340 Steel Plus Manganese Bronze Plus	250	
23	4L210 Grease	116	174
24		156	

TABLE VI (Continued)

Specimen Number	Test Material Combinations	Hours Exposure	Average Time of Exposure
25	4340 Steel Plus Hardas Anodized Bare 7075-T6,	167	
26	Aluminum Plus 4L210 Grease Plus Manganese Bronze.	250	212
27		220	
28	4340 Steel Plus Bare 7075 Aluminum (No	250	
29	Anodize) Plus Manganese Bronze Plus Grease	250	250
30	4L210	250	

* Test of assemblies was discontinued after 250 hours, specimens exposed to less than 250 hours actually failed at period indicated.