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SHIPBOARD EXPOSURE TESTING - USS AMERICA

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Results of corrosion tests of various inorganic coatings on 17-4 PH and 4130 steel specimens exposed on the flight deck of an aircraft carrier are given in the report. Also described are the results of exposure on EMI seals, water displacing paint, cadmium and aluminum coated steel fasteners in aluminum alloy plate, and boron/aluminum composite material.

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INTRODUCTION

Corrosion tests aboard aircraft carriers are being conducted under the authorization of reference (a). A variety of aircraft materials and finishes are being exposed to the environment on the flight decks to provide background information for the development of a realistic accelerated corrosion test. Additionally, the corrosion behavior of materials projected for naval aircraft use is being determined.

This report covers the results of eleven months of exposure testing on the USS AMERICA.

Tests of various coatings on 17-4 PH stainless steel and some of the 4130 steel specimens were conducted at the request of the Naval Weapons Center, China Lake, in connection with a corrosion problem on the Sidewinder missile. Tests of EMI seals were undertaken as part of an avionics corrosion prevention program to determine whether elastomeric seals with metallic powder fillers would accelerate corrosion when in contact with aluminum surfaces.

DESCRIPTION OF TESTS

Exposure Rack

The rack was made of steel, cadmium plated, chromated, and painted with MIL-P-23377 epoxy primer and MIL-C-81773 polyurethane topcoat. The rack was designed to expose the specimens at a 45° angle. Specimens were attached to the rack with nylon bolts. MIL-A-46146 silicone sealant was applied in the bolt holes and under the heads to prevent crevice corrosion. The rack was welded to the radar tower aft of the island about 1.5 meters (5') above the deck. The rack was 2.4 meters long by 0.3 meter wide (8' x 1'). The rack is shown in figure (1).

Deployment

The rack was placed aboard the carrier on 18 December 1980. Until early April 1980, the carrier was operating out of Norfolk, Virginia. It was then deployed to the Indian Ocean. It returned to Norfolk on 19 November 1981 and the specimens were removed on 23 November 1981.

An interim inspection was made at the end of March, but no further inspections were made during the cruise. However, ship personnel furnished photographs of the specimens periodically which allowed a periodic assessment of corrosion damage to be made.

Exposure Conditions

Exposure conditions during the first four months were relatively mild. The exposure that followed was very severe.

Reports from the Indian Ocean indicate that during the months of May through August there is a continuous monsoon flow producing extremely high humidity.

The weather has been described as unchanging: low overcast, 1-3 nautical miles visibility, winds from the southwest 10-20 knots, seas 10-20 feet, temperature 27-32 C (80-90 F), relative humidity 70-80 percent rising to 95 to 100 percent at night with a continuous salt/sand mist in the air.

Test Materials

17-4 PH Stainless Steel Specimens

Both cast and wrought samples about 5.1 x 12.7 cm (2" x 5") were exposed uncoated as received, uncoated grit blasted, and coated with chromium (5-10 μm (0.0002"-0.0004")), chromium (5-10 μm) over nickel (10-15 μm (0.0004"-0.0006")), and SermeTel 725 (62.5 μm (0.0025") nominal).

SermeTel W is a coating consisting of an aluminum powder in an inorganic binder. The coating meets the requirements of MIL-C-81751. SermeTel 725 is a SermeTel W coating with an overcoating of a chromate containing sealing material.

4130 Steel Specimens

Steel panels, 5.1 x 12.7 cm (2" x 5"), were coated with chromium (5-10 μm), chromium (5-10 μm) over nickel (10-15 μm), ion vapor deposited (IVD) aluminum (25 μm (0.001")), and cadmium (13 μm (0.0005")). These specimens were furnished by the Naval Weapons Center, China Lake.

IVD aluminum was applied to two 7.6 x 15.2 cm (3" x 6") panels to a thickness of 13 μm (.0005") by the McDonnell Aircraft Company. Six bare panels were also furnished by McDonnell. Two panels for each coating were plated with bright cyanide cadmium (13 μm), dull "low hydrogen embrittlement" cadmium (13 μm), and aluminum-manganese alloy (13 μm). The "low hydrogen embrittlement" bath was prepared in accordance with a McDonnell-Douglas process specification. Aluminum-manganese was plated from an experimental molten salt bath. Composition of the coating is approximately 75% aluminum, 25% manganese. All the coatings in this group were given a supplementary chromate conversion coating treatment.

Coated Steel Screws

Six steel screws coated with 7.6 μm (.0003") of IVD aluminum and six coated with 7.6 μm of cadmium were installed in 7075-T6 aluminum alloy plate material 1.3 cm thick x 2.5 cm wide (0.5" x 1"). The aluminum alloy was sulfuric acid anodized and dichromate sealed prior to drilling and countersinking the screw holes. These assemblies were furnished by the McDonnell Aircraft Company.

Similar assemblies were prepared by this command with coatings of aluminum-manganese (7.6 μm) and cadmium (7.6 μm).

All screws were given a supplementary chromate conversion coating treatment.

EM1 Seal Assemblies

EM1 seal assemblies consisted of drawn 3003-0 aluminum alloy boxes, 6.4 cm deep x 9.5 cm wide x 11.4 cm long (2½" x 3-3/4" x 4½") with a 1.6 cm 6061-T6 flange dip brazed to the box. The box covers were 6061-T6 aluminum alloy. All surfaces were chromate conversion coated in accordance with MIL-C-5541. The outer surfaces of the boxes and covers were painted with one coat of MIL-P-23377 primer and one coat of MIL-C-22750 epoxy topcoat. The inside surfaces were not painted except for about 4.7 mm (3/16") over the outer edges of the flanges and the outer edges of the covers. Conductive EM1 gaskets made of 0.157 cm (.062") thick silver filled silicone rubber and silver plated copper filled silicone rubber were placed between the flange and the cover. The cover was held in place by stainless steel bolts insulated from the aluminum by mylar washers. Unfilled silicone gaskets were also tested as controls. Three of the boxes, one for each type of gasket, had holes drilled in each corner of the bottom. Three were completely closed. The purpose of these tests was to determine whether corrosion of the aluminum would be accelerated by contact with the filler metals in the gaskets. No electrical measurements were made.

Composite Materials

A 17.8 x 26.7 cm (7" x 10½") sample of boron/aluminum composite material and a 4.4 x 11.4 cm (1-3/4" x 4½") sample of aluminum oxide/aluminum were exposed. The boron/aluminum, manufactured by AVCO, was 10 ply $0/\pm 45^{o}$ with the zero direction longitudinal. The fiber type was .020 cm (.008"). Fiber spacing was 103/2.54 cm (103/in.). Matrix material was 6061 aluminum alloy in the F temper. The material was identified as M506 and was 0.25 cm (0.1") thick.

The aluminum oxide/aluminum material had a 6061 aluminum alloy matrix and was manufactured by the liquid infiltration process.

AMLGUARD and Water Displacing Paint

AMLGUARD, a clear water displacing preservative covered by specification MIL-C-85054, was applied to MIL-C-5541 chromate conversion coated, 7.6 x 15.2 cm (3" x 6") 2024-T3 aluminum alloy panels by spraying.

Water displacing paint was also applied over 2024-T3 aluminum alloy panels. A detailed description of the water displacing paint system is given in reference (b)

RESULTS AND DISCUSSION

GENERAL

As previously stated, exposure conditions on this cruise were very severe. In addition to the corrosion/deterioration damage, the specimens were covered with a thin dark grey film. There were also a few spots of paint on some of the specimens from inadvertent paint spattering during routine tower maintenance.

17-4 PH Specimens

The appearance of the 17-4 PH specimens following exposure is shown by figures 2 and 3. Table I gives ratings of the panels and evaluation of the appearance from the photographs furnished by ship personnel.

SermeTel 725 protected the basis metal better than any of the other coatings, showing only slight white surface corrosion. However, the coatings were quite thick (63 µm) compared to the chromium (5-10 µm), or even the chromium over nickel (total thickness 15-25 µm). Both chromium and chromium over nickel were considered poor. It should be noted that SermeTel 725 is a dark brown coating with much the same appearance as rust in the photographs.

The difference between the uncoated as-received, and grit blasted panels was striking, especially for the wrought material. Apparently, any passivity the surface had as-received was destroyed by grit blasting. It also roughened the surface and may have embedded impurities in it. In any case, the grit blasted panels rusted considerably more than the as-received panels.

4130 Specimens

As shown in figures 4 to 6 and Table II, the most protective coating for 4130 steel was SermeTel 725, which again showed only light white corrosion. Cadmium, both bright and dull (13 µm) was next best with general white corrosion and some slight rust staining at the end of the cruise. IVD aluminum, 25 µm thick, had general white corrosion and a few rust spots through the coating; the 13 µm coating was completely replaced by rust. The aluminum-manganese coated panels were 90% rusted. Both chromium and chromium over nickel plated panels were badly rusted - chromium 100% and chromium over nickel only slightly less.

Some further rating of the coatings was possible from the photographs taken periodically. By the end of February, two months after exposure began, chromium showed superficial rust over the whole surface, and chromium over nickel had many isolated rust spots. The thin (13 µm) IVD aluminum coating had only white corrosion at the end of April, but by July the panels were 75% rusted. Aluminum-manganese began to show rust spots by the end of two months, but corroded more slowly than IVD aluminum.

Coated Steel Screws

The coated steel screws installed in 7075-T6 plate are shown in figure 7. There were two sets of cadmium plated screws, one for controls for the IVD aluminum coatings and one for controls for the aluminum-manganese. The cadmium screws were generally in fairly good condition on the heads. A few had small rust spots, but otherwise had only white corrosion. The IVD coatings had largely given way to rust. Aluminum-manganese showed rust spots, but most of the coating was intact.

The appearance of the countersinks, shown in figure 8, was not what was expected. The countersink areas in which IVD fasteners were installed were more corroded than those in which contact had been made with cadmium. Metallographic examination of cross sections of the countersink areas confirmed the conclusions reached by visual examination. Photomicrographs of the cross sections are shown in figure 9. Apparently, the oxide coating that forms on aluminum polarized the IVD coating and prevented it from acting as a sacrifical anode to the extent anticipated. Cadmium does not polarize as readily.

A direct comparison could not be made between IVD aluminum and aluminum-manganese because the screws used for plating and the 7075-T6 aluminum alloy blocks were from different batches of material. (McDonnell furnished IVD aluminum and cadmium plated fasteners already installed in aluminum blocks. The Naval Air Development Center prepared similar blocks with aluminum-manganese and cadmium plated fasteners.) The aluminum-manganese coated fasteners did not protect the countersinks as well as cadmium coated fasteners, so in that respect they were similar to the IVD coated fasteners. Corrosion was slightly deeper in the 7075 aluminum countersinks in contact with IVD coating than it was in countersinks in contact with aluminum-manganese. The differences may have been due to differences in the heat treatment or composition of the aluminum alloy blocks, however.

EMI Seal Assemblies

The EMI seal assemblies were opened up at the interim inspection, 109 days after they had been placed on the rack. At that time, they were in perfect condition, showing no signs of corrosion in the seal area or elsewhere on the boxes, and no deterioration of the gaskets. They were then resealed. The pictures taken in April showed what appeared to be the beginning of very slight corrosion at the bottom edge of the seal area on the boxes with silver plated copper filled seals. By July, the corrosion had advanced very slightly and there was some very slight corrosion beginning at the seal area of the boxes with silver filled gaskets. Figure 10 shows three of the assemblies at the end of the exposure period. Covers and seals from these assemblies are shown in figure 11. The assemblies not shown were similar in appearance. The silver plated copper filled gaskets resulted in the most galvanic corrosion with silver filled gaskets next and no corrosion on the aluminum in contact with the unfilled silicone gaskets. Some of the apparent deterioration was in the form of slight swelling of the exposed edges of the filled gaskets.

Figure 12 shows all six boxes with the covers and seals removed. The only difference between the boxes with holes drilled in the bottoms and those completely closed was slight corrosion in the bottoms of the "open" boxes. Otherwise, corrosion was confined to the outer edges of the seal areas and was not nearly as severe as it appeared to be from the outside. The unpainted contact areas, where the EMI seals have to maintain good electrical contact, were in excellent condition. A temporary preservative such as AMLGUARD (MIL-C-85054) might have prevented corrosion from appearing at all, if it had been applied periodically to the outer edges.

AMLGUARD and Water Displacing Paint

AMLGUARD protected the underlying aluminum very well for the first two months of exposure. At the end of the third month, at the interim inspection, slight corrosion began to appear, and by July, there was considerable corrosion under the coating. The appearance of the panels after eleven months is shown in figure 13.

AMLGUARD is considered a temporary preservative that should be replaced every four to six weeks under severe conditions. The protection it offered was therefore as expected.

The water displacing paint samples stood the carrier exposure very well. There was no blistering of the coating and no evidence of corrosion under the coating. The only corrosion was in the scribe marks where the scribe had cut through the paint. The material tested was developed at this command and is fully described in reference (b).

Composite Materials

The boron/aluminum and aluminum oxide/aluminum composite materials are shown in figure 14. Both were generally pitted, but the pitting did not appear to be deep.

Aluminum Alloy Control Specimens

Both the 2124 and 7075 control specimens were severely exfoliated, as shown in figure 15. In that respect, they were very similar to the controls used in previous exposure tests and served only to show that exposure on this carrier cruise was just as severe as previous exposures in the Indian Ocean. References (c) and (d) describe results of previous carrier tests of these materials.

CONCLUSIONS

1. The environment in the Indian Ocean is extremely corrosive.

2. SermeTel 725 coatings provide excellent protection to 17-4 PH stainless steel and 4130 steel.

3. Grit blasting is detrimental to the corrosion resistance of 17-4 PH stainless steel - especially wrought material.

4. Cadmium plating, both bright and dull (unbrightened), provides better protection to 4130 steel than an equal thickness of IVD aluminum.

5. Cadmium plating, both bright and dull, 13 μm thick, and IVD aluminum coatings, 25 μm thick, provide satisfactory protection to 4130 steel for at least eleven months under severe exposure conditions.

6. Thin deposits of chromium (5-10 μm) and chromium (5-10 μm) over nickel (10-15 μm) do not protect 17-4 PH stainless steel or 4130 under severe exposure conditions. They are especially poor on 4130 steel.

7. The countersink areas in 7075-T6 plate corrode more severely in contact with IVD aluminum coated fasteners than they do in contact with either cadmium plated or aluminum-manganese plated fasteners.

8. Silver plated copper filled silicone EMI gaskets and silver filled silicone EMI gaskets do not cause severe galvanic corrosion of 6061 aluminum alloy surfaces in the type of assembly tested - only slight edge corrosion was noted.

9. Silver plated copper filled gaskets cause more galvanic corrosion than silver filled gaskets.

10. Both the boron/aluminum and aluminum oxide/aluminum composites tested are resistant to exfoliation and deep pitting.

11. AMLGUARD protects the underlying aluminum well for at least two months under severe exposure conditions.

12. Water displacing paint shows promise as a protective system for naval aircraft.

FUTURE PLANS

Two more corrosion racks have been placed aboard carriers, one on the USS CONSTELLATION and one on the USS JOHN F. KENNEDY. The CONSTELLATION rack is largely devoted to testing finishing and sealing methods used in construction of the F-18 aircraft. Specimens for this rack were furnished by McDonnell-Douglas. The KENNEDY rack has adhesively bonded titanium specimens, 7091 aluminum alloy, 7075-T6 with and without an RRA (retrogression and reaging) heat treatment, countermeasure paint systems, flexible primers, panels to test systems for field repair of ion vapor aluminum coatings, and graphite/epoxy material proposed for use in electrical connectors.

Both carriers are currently deployed. Specimens will be removed when the carriers return, damage will be assessed, and reports will be written on the results.

Work on an accelerated laboratory test will continue.

ACKNOWLEDGEMENTS

The cooperation and assistance of Mr. Garrett T. Browne of COMNAVAIRLANT, and of personnel of the USS AMERICA is gratefully acknowledged. The special effort put forth in supplying photographs of the rack was especially helpful.

Appreciation is also expressed to Mr. Peter Sabatini for his work in preparing the rack and mounting the specimens, and Mr. Lee Biggs for his metallographic work on the specimens following exposure.

REFERENCES

(a) AIRTASK No. WF61-542-001, Work Unit No. ZM501.

(b) C. R. Hegedus, Development of a Water Displacing Touch-Up Paint, NAVAIRDEVCEN Report No. NADC-80207-60 of 24 Feb 1981.

(c) E. J. Jankowsky, S. J. Ketcham, and V. S. Agarwala, Aircraft Carrier Exposure Tests of Aluminum Alloys, NAVAIRDEVCEN Report No. NADC-79251-60 of 1 Nov 1979.

(d) E. J. Jankowsky and S. J. Ketcham, Shipboard Exposure Testing, NAVAIRDEVCEN Report No. NADC-81075-60 of 9 Sep 1981.

TABLE I. RESULTS OF EXPOSURE TESTS OF VARIOUS COATINGS ON 17-4 PH STAINLESS STEEL

Basis Metal	Coating/ Treatment	Photographs 2/23/81	Predeployment Inspection 3/31/81	Photographs 4/23/81	Photographs 7/23/81	Photographs 8/31/81	Photographs 9/23/81	Final Inspection 11/23/81	Order of Merit *
17-4 PH Cast	Sermetal 725	Good-No corrosion	Good	No change	Good	Not shown	Same as 8/31	Very good-Slight white corrosion	1 (17-4 Cast)
17-4 PH Cast	Bare, as received	Very light rusting	Slight rusting	No change	General light rusting	Not shown	Same as 8/31	General light rusting	4 (17-4 Cast)
17-4 PH Cast	Bare, grit blasted	General light rusting	Slight rusting	No change	General rusting	General rusting	Same as 8/31	General corrosion & shallow pitting	5 (17-4 Cast)
17-4 PH Cast	Chromium, no underplate	A few rust spots	Slight rusting	No change	Many rust spots	Rust spots	Same as 8/31	Rust spots	2 (17-4 Cast)
17-4 PH Cast	Chromium over nickel	Many rust spots	Slight rusting	No change	Many rust spots	Rust spots	Same as 8/31	Very much like chromium alone	3 (17-4 Cast)
17-4 PH Wrought	Bare, as received	Light general rusting	Very slight rusting	No change	Slight rusting in many spots	Light rust in many spots	Same as 8/31	Light rusting	3 (17-4 Wrought)
17-4 PH Wrought	Bare, grit blasted	General rusting	Rusting	No change	General rusting	General rusting	Same as 8/31	General rusting	5 (17-4 Wrought)
17-4 PH Wrought	Chromium, no underplate	Some rust spots	Slight rusting	No change	Many rust spots	Rust spots	Same as 8/31	Rust spots	4 (17-4 Wrought)
17-4 PH Wrought	Chromium over nickel	Many rust spots	Slight rusting	No change	Many rust spots	Rust spots	Same as 8/31	Slightly better than chromium alone	2 (17-4 Wrought)
17-4 PH Wrought	Sermetel 725	Good-Very slight white corrosion	Good	No change	Good	Good-White corrosion spots only	Same as 8/31	Very good-Slight white corrosion	1 (17-4 Wrought)

* 1 Best

5 Worst

TABLE II. RESULTS OF EXPOSURE TESTS OF VARIOUS COATINGS ON 4130 STEEL

Coating/ Treatment	Photographs 2/23/81	Predeployment Inspection 3/31/81	Photographs 4/23/81	Photographs 7/23/81	Photographs 8/31/81	Photographs 9/23/81	Final Inspection 11/23/81	Order of Merit *
Chromium, no under-plate	Entire face rust stained	Rusting	No change	General heavy rusting	General rusting	Same as 8/31	Completely rusted	8
Chromium over nickel	Many rust spots	Slight rusting	No change	General heavy rusting	General rusting	Same as 8/31	Badly rusted, but some coating left	7
Sermetel 725	Good-No corrosion	Good	No change	Good	Good-Some white corrosion	Same as 8/31	Very good-Slight white corrosion	1
IVD Al (25 μm)	Good	Very slight white corrosion	No change	Much white corrosion	White corrosion and rust stains	Same as 8/31	White corrosion and rust spots	4
IVD Al (13 μm)	Good	Slight white corrosion	No chagne	60-75% Rusted	100% Rusted	No change	All rusted	5
Bright cadmium	Good	Very slight white corrosion	No change	Slight white corrosion	White corrosion	No change	General white corrosion with slight rust stains	2
Dull cadmium	Darkening - no corrosion	Very slight white corrosion	No change	Slight white corrosion	White corrosion	No change	General white corrosion with slight rust stains	3
Aluminum-manganese	Isolated rust spots	Rust mainly at panel holes	No change	80% Rusted	90% Rusted	No change	Some coating left Remainder rusted	6

* 1 Best

8 Worst

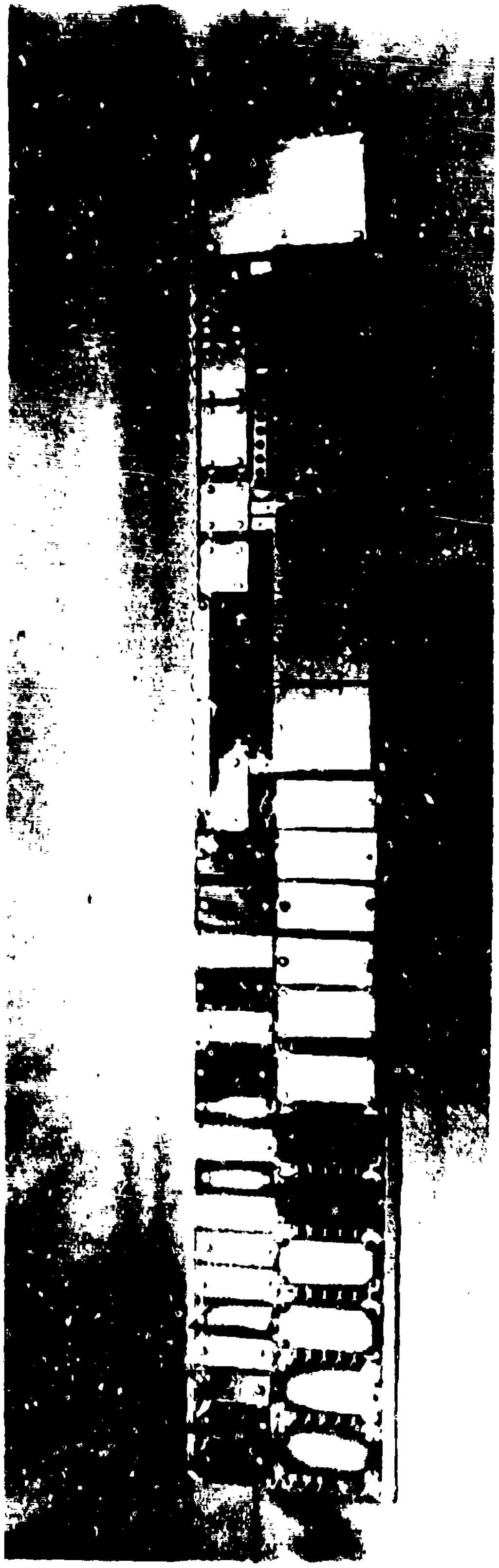


FIGURE 1. CORROSION RACK PRIOR TO EXPOSURE

FIGURE 2. CAST 17-4 PH STAINLESS STEEL SPECIMENS AFTER EXPOSURE

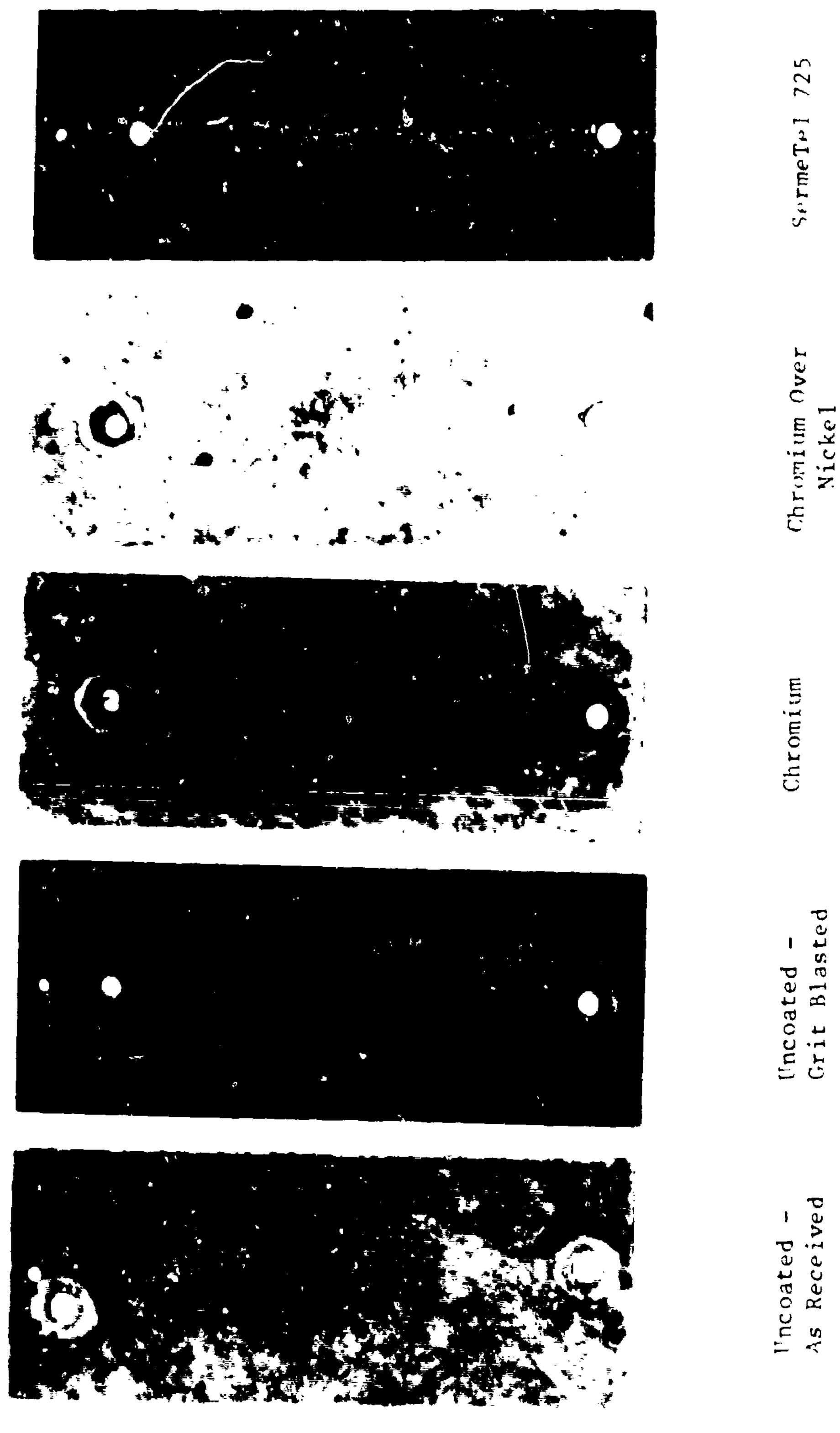


FIGURE 3. WROUGHT 17-4 PH STAINLESS STEEL SPECIMENS AFTER EXPOSURE

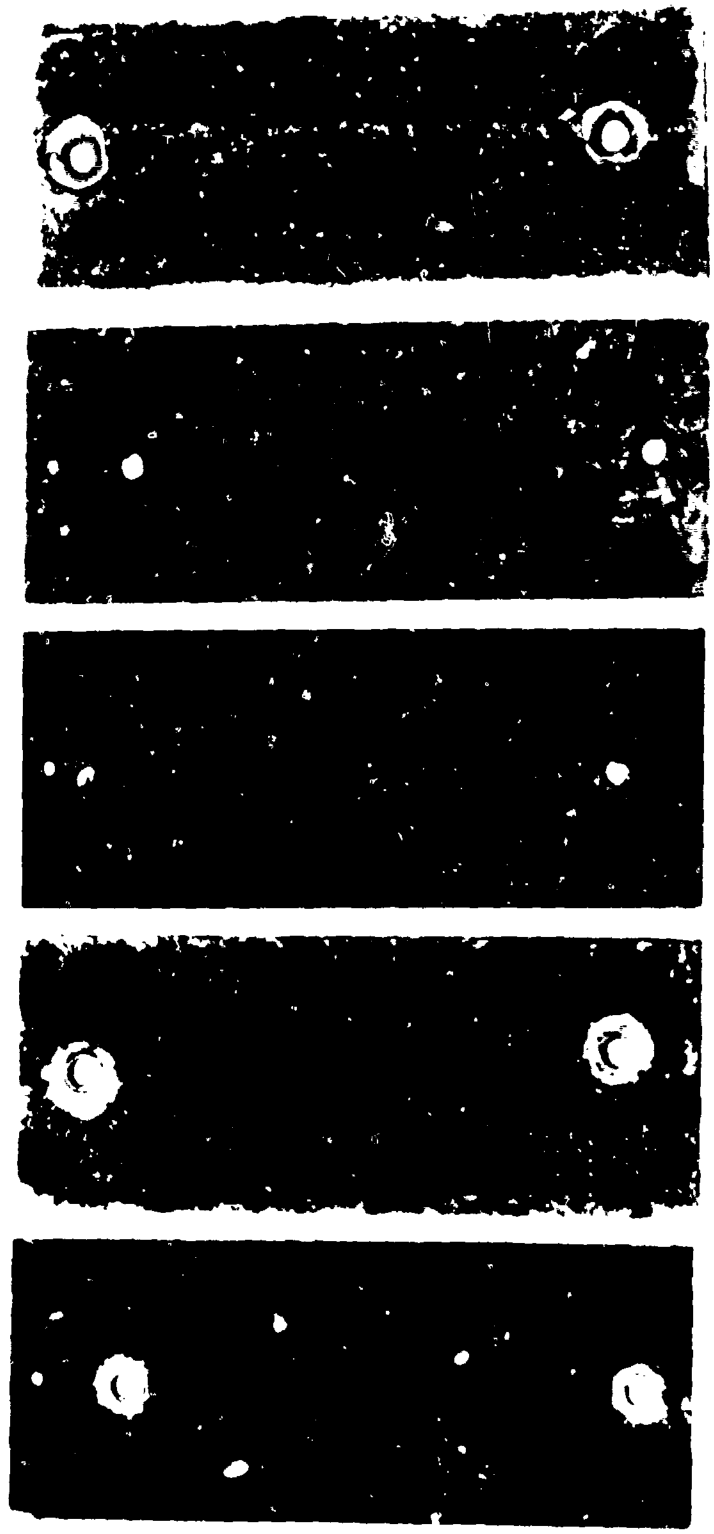
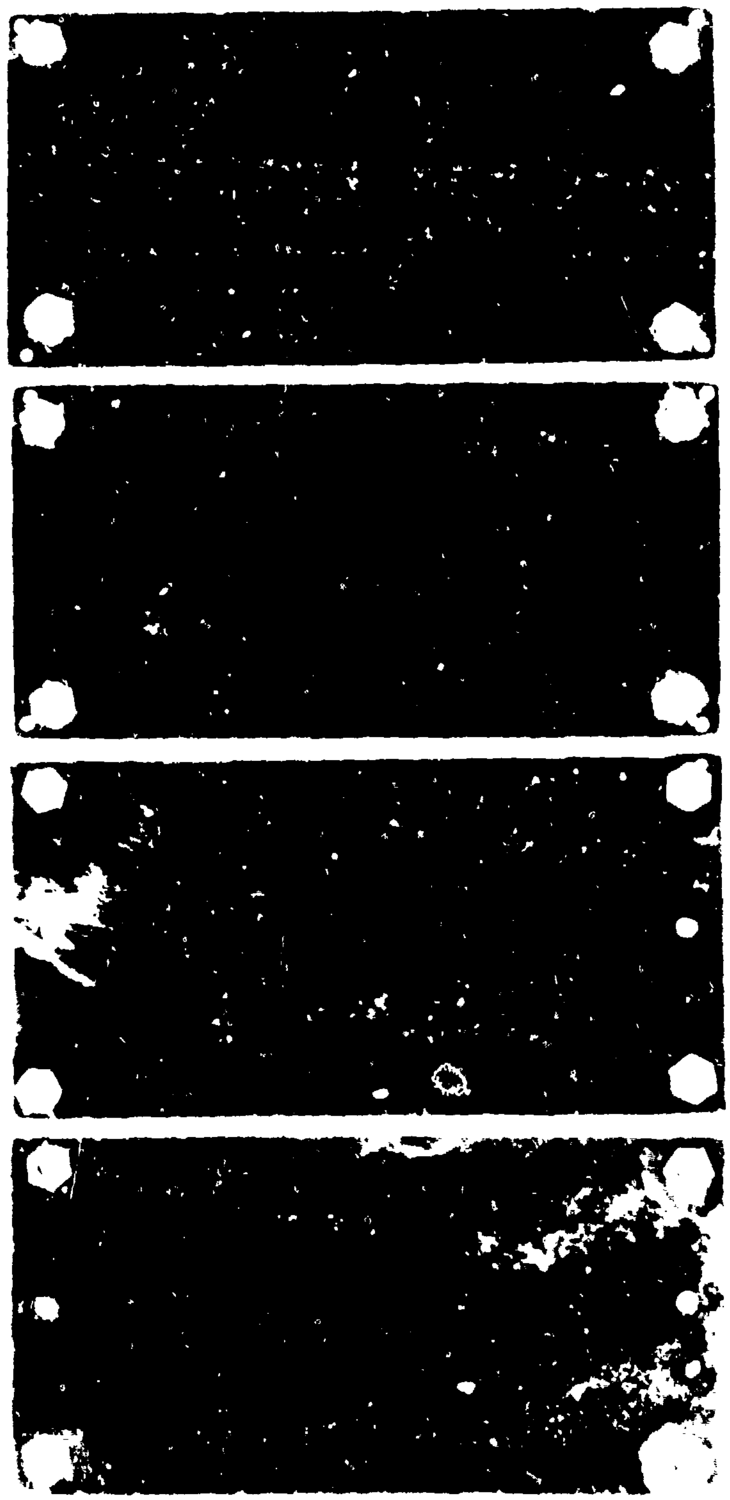


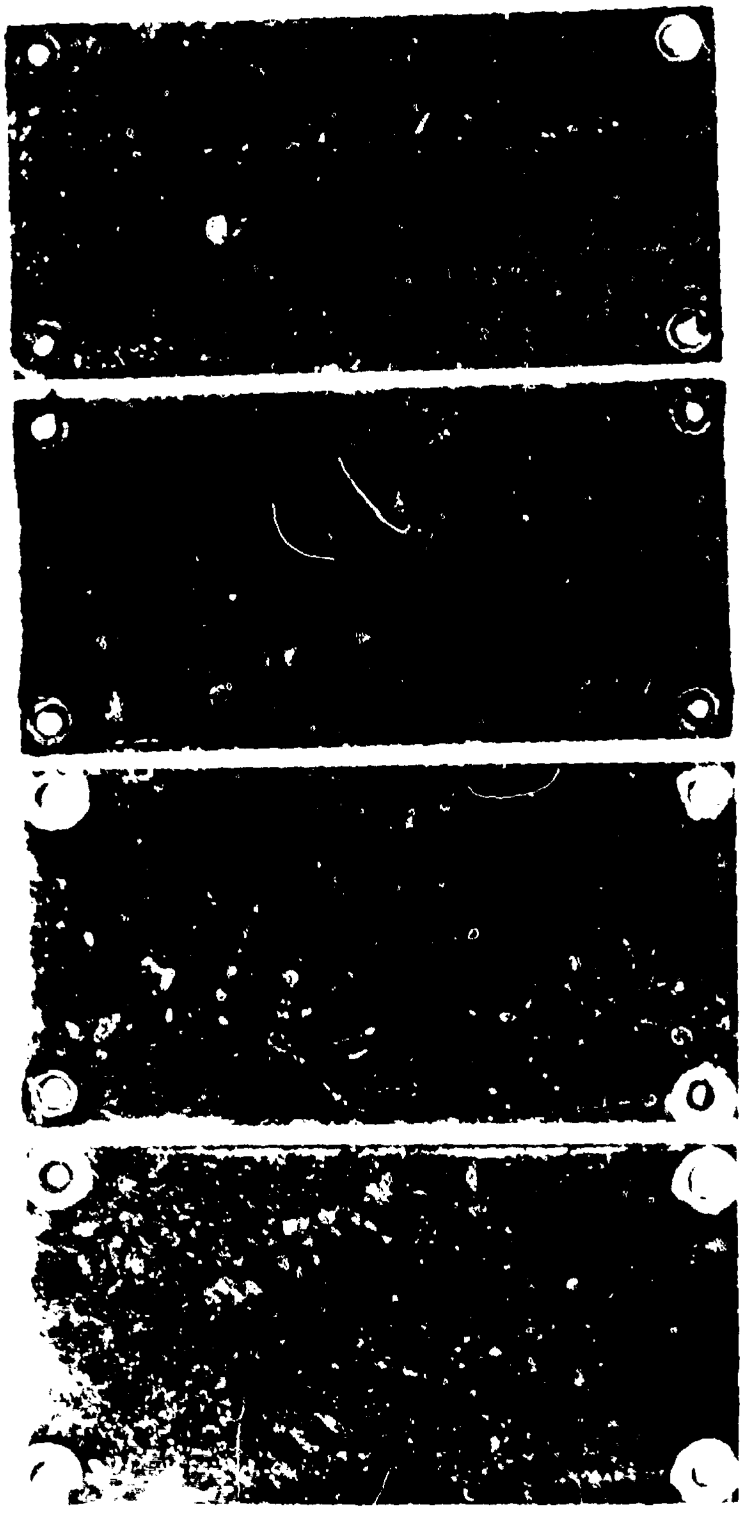
FIGURE 4. 4130 STEEL SPECIMENS AFTER EXPOSURE



IVD Aluminum
(13 μm)

Aluminum-Manganese
(13 μm)

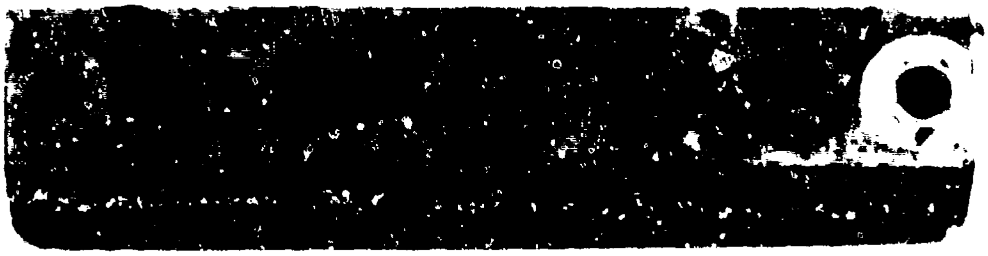
FIGURE 5. 4130 STEEL SPECIMENS AFTER EXPOSURE



Bright Cyanide Cadmium
(13 μm)

Dull "Low Hydrogen Embrittlement" Cadmium
(13 μm)

FIGURE 6. 4130 STEEL SPECIMENS AFTER EXPOSURE



Aluminum-Manganese

Cadmium

Cadmium

IVD Aluminum

FIGURE 7. COATED STEEL FASTENERS IN ANODIZED 7075-T6 ALUMINUM ALLOY PLATE AFTER EXPOSURE

COUNTERSINK IN CONTACT WITH IVD ALUMINUM - 7X

COUNTERSINK IN CONTACT WITH CADMIUM - 7X

FIGURE 8. COUNTERSINK AREAS IN 7075-T6 ALUMINUM ALLOY PLATE AFTER EXPOSURE

COUNTERSINK IN CONTACT WITH IVD ALUMINUM - 100X

COUNTERSINK IN CONTACT WITH CADMIUM - 100X

FIGURE 9. PHOTOMICROGRAPHS OF 7075-T6 ALUMINUM ALLOY COUNTERSINK AREAS

FIGURE 10. EMI SEAL ASSEMBLIES AFTER EXPOSURE

Inside Surfaces of Covers

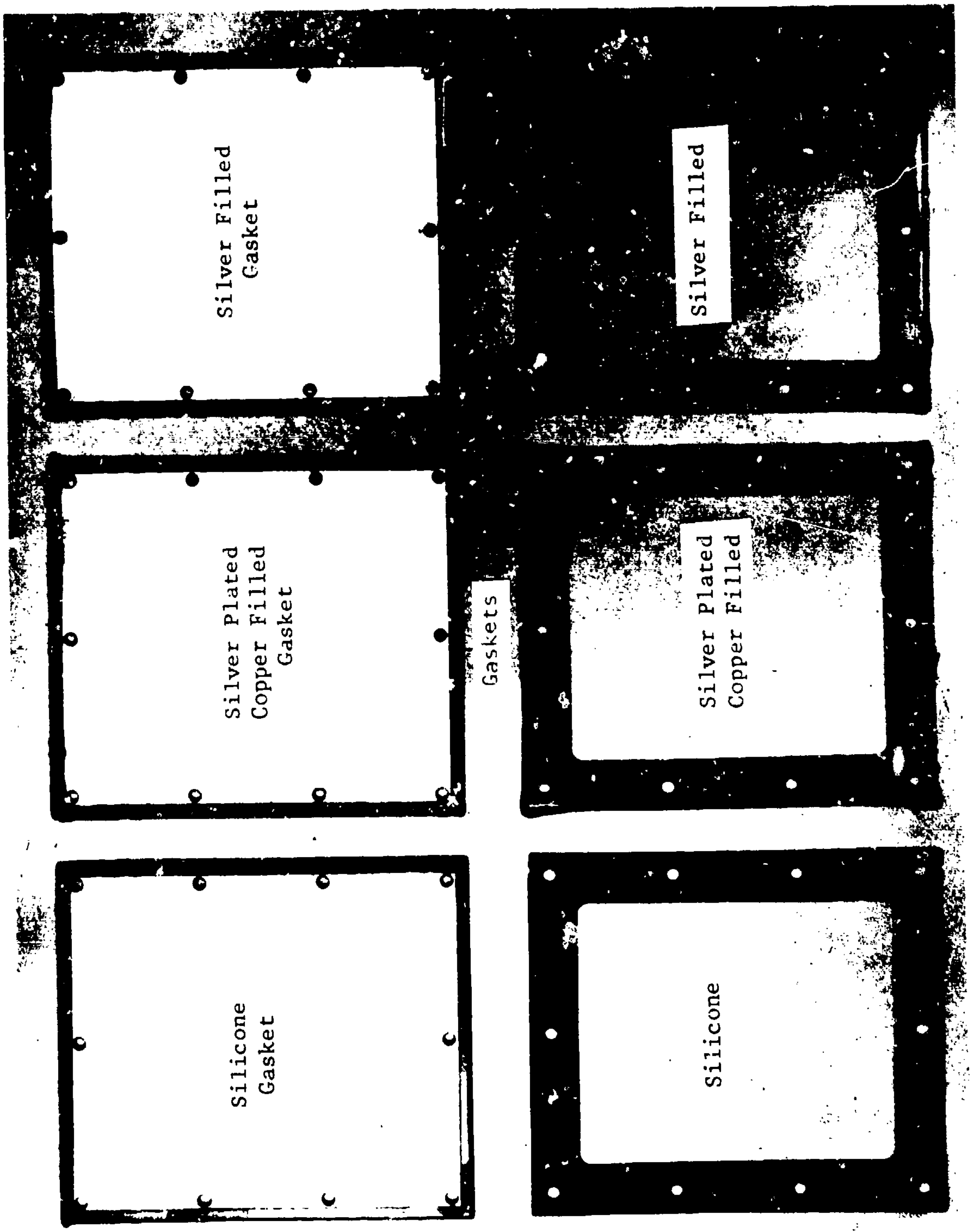


FIGURE 11. GASKETS AND COVERS OF EMI SEAL ASSEMBLIES AFTER EXPOSURE

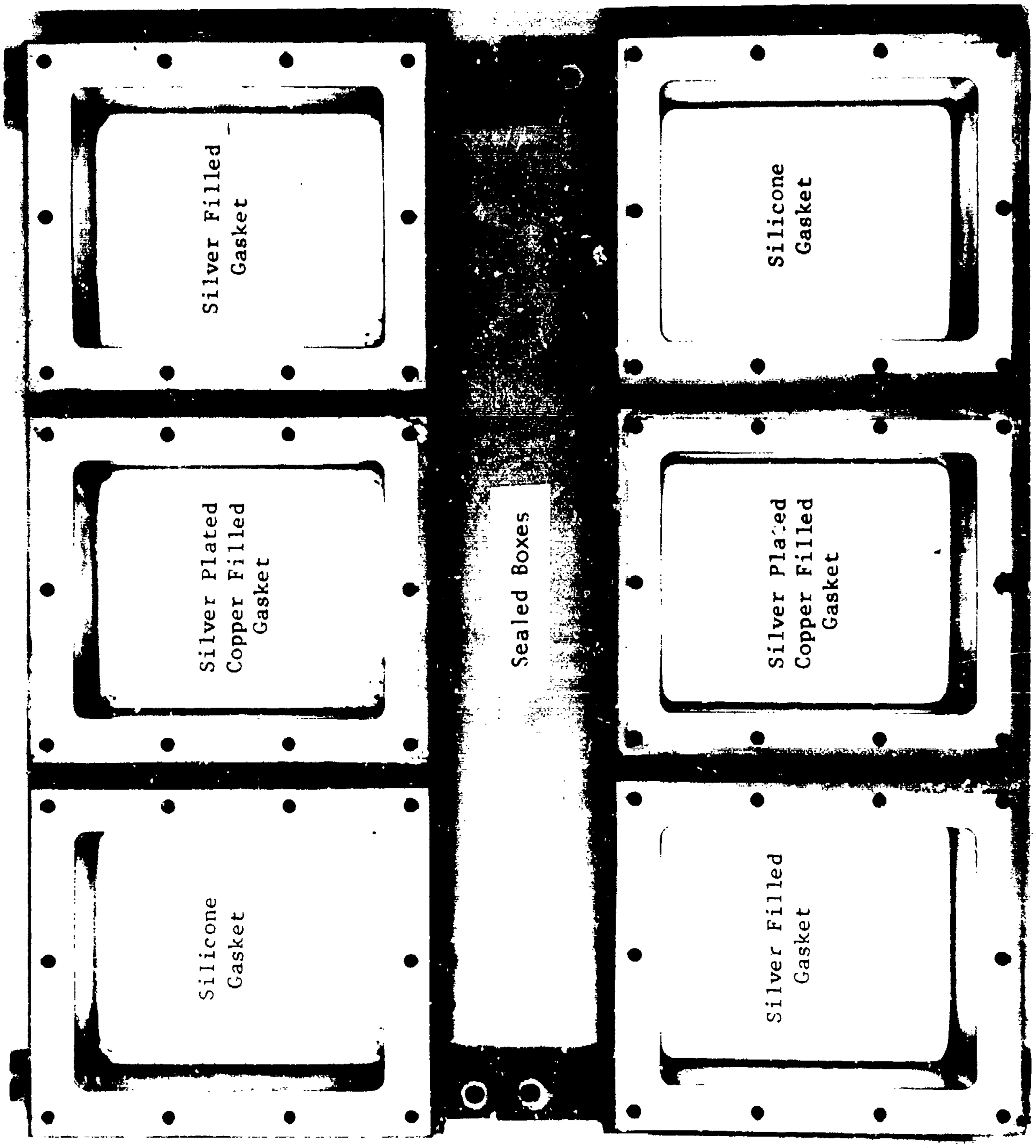
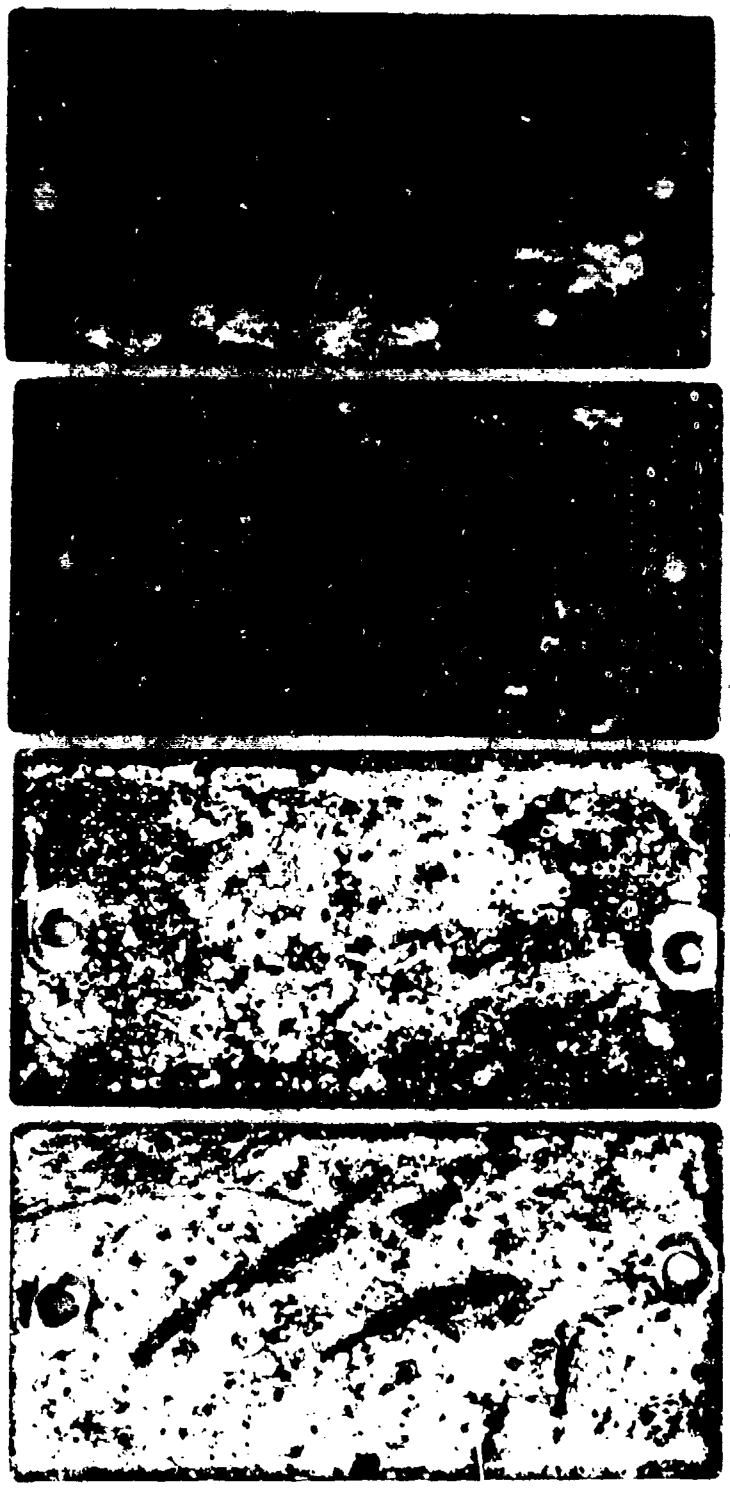


FIGURE 12. EM1 SEAL ASSEMBLIES AFTER EXPOSURE (BOTTOM HALF)



AMLGUARD over MIL-C-5541 Chemical Film

Water Displacing Paint

FIGURE 13. 2024-T3 ALUMINUM ALLOY SPECIMENS AFTER EXPOSURE

Boron/Aluminum

Aluminum oxide/
Aluminum

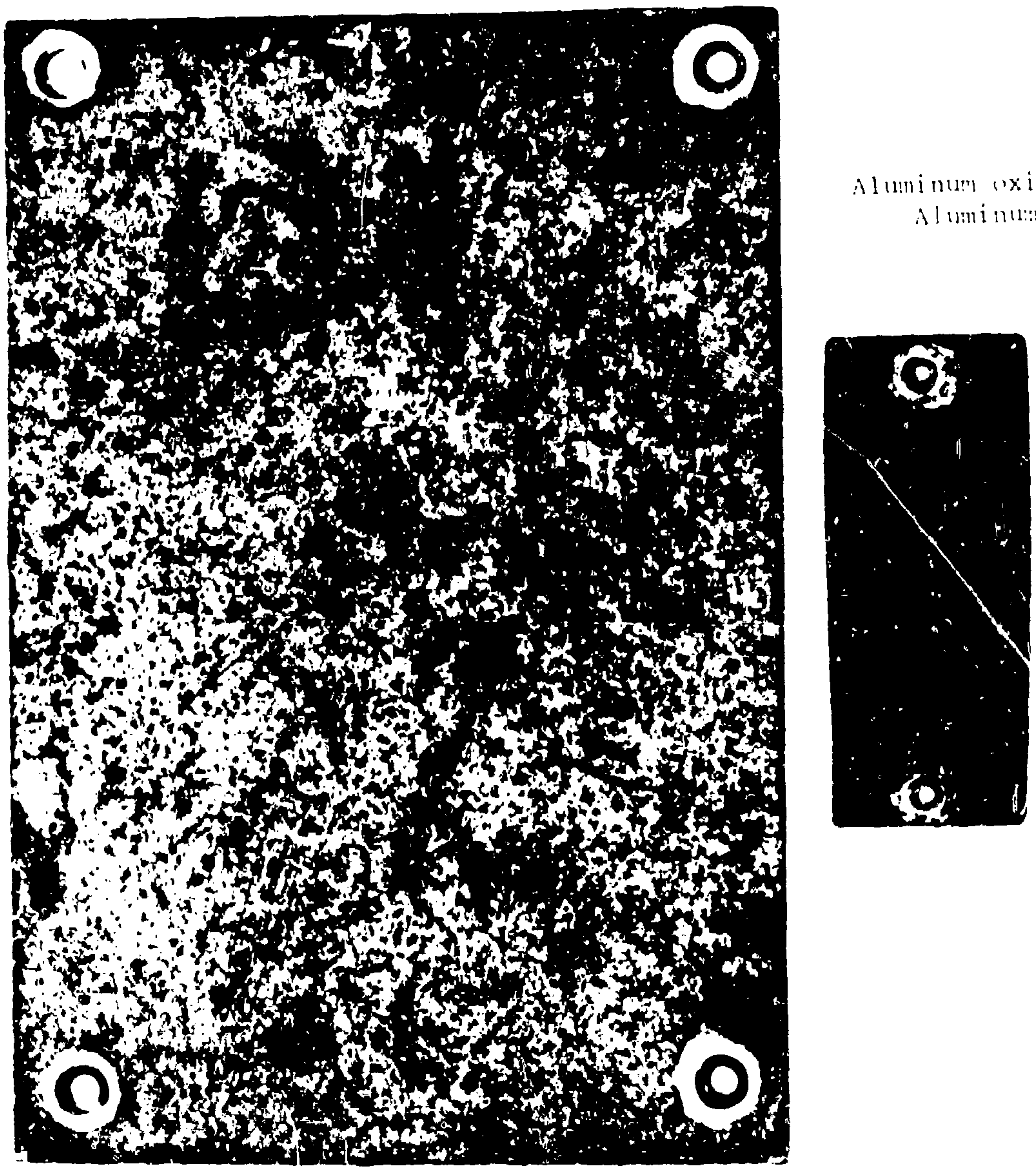


FIGURE 14. COMPOSITE SPECIMENS AFTER EXPOSURE

Low Resistance 2124

Low Resistance 7075

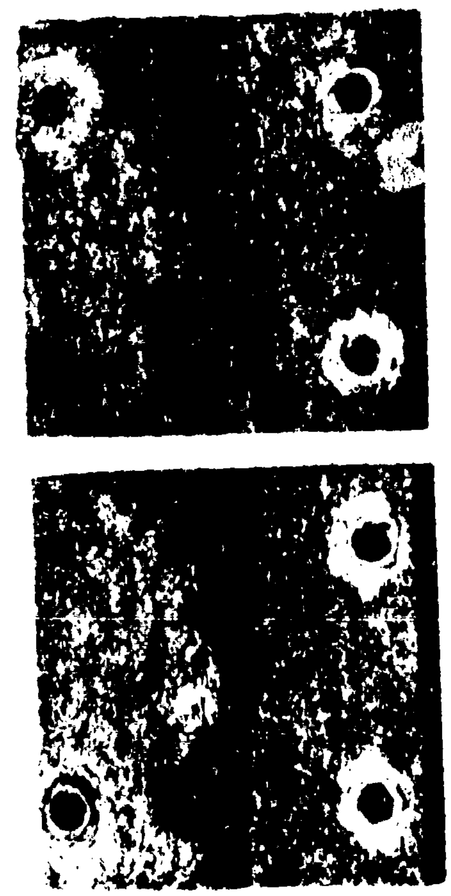


FIGURE 15. ALUMINUM ALLOY EXFOLIATION SPECIMENS AFTER EXPOSURE (CONTROLS)