NATIONAL BUREAU OF STANDARDS REPORT

9513

The Stress Corrosion and Galvanic Behavior of 17-4 PH Fasteners in Marine Environments

by

W. F. Gerhold
Engineering Metallurgy Section

To

Materials Division
Air Systems Command
Department of the Navy

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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NBS PROJECT **NBS REPORT**

3120410 APR 25 1967 9513

(NASC) RRMA-2055

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Reference: (a) Bureau of Naval Weapons (NASC) letter RRMA-43: SG/125, dated March 23, 1962.

Introduction: It has been proposed that 17-4 PH stainless steel alloy fasteners be used in Model T-56 engines. In this application the fasteners may affect or be affected by the corrosion of dissimilar metals with which they would be coupled, specifically cadmium plated carbon steel alloys and types 410, 302 and 321 stainless steel alloys. In addition, mismatch conditions between the fasteners and other components, due to fabrication and / or application, could precipitate stress corrosion. Reference (a) requested that the dissimilar metal and stress corrosion behavior of the fasteners be determined in marine environments for possible material limitations.

Material: Bolts representative of the types of 17-4 PH stainless steel alloy fasteners to be used in the fabrication of the engines were submitted under Reference (a). The number of pieces, part number and fastener size of the parts submitted are given in Table 1.

Stress Corrosion Tests.

Specimen Preparation: For these tests two sections of 17-4 PH stainless steel alloy forged stock approximately 1 3/8 inches wide by 1 inch thick by 8 1/2 inches long were ground flat on parallel sides, across the width of the stock. Holes, 1/2 inch apart were drilled and tapped in each section to accept 3 bolts of each size of fastener. In order to establish mismatch conditions, the sections were further machined so that there were offsets of 0.005 inches and 0.003 inches at the center lines of the holes for two of each size of fastener. One area on each section was left as ground, with no offset, for control purposes. Fasteners of the appropriate size were threaded into the holes, finger tight, and then torqued down to 85 lb-in. and 190 lb-in., respectively, for the 1/4 in.-28 and 5/16 in.-24 fasteners. The torque values used were in accordance with standard manufacturing procedures. Figure 1 is a sketch of a typical assembly. As noted in Figure 1, parallelism between the spot face of the bolt head and mating surface of the part resulting from this arrangement may deviate up to 0.003 inch maximum. This deviation is governed by the squareness of the head surface to the shank and is a function of the tooling operations.

Exposure: All of the stress corrosion tests were conducted at the marine corrosion test facilities of the International Nickel Co. One of the assemblies was exposed in the seawater in the tidal zone at Harbor Island, N.C. and the other was exposed in the marine atmosphere in the 80 ft. lot at Kure Beach, N.C.

Results: There were no stress corrosion failures of the 17-4 PH stainless steel alloy bolts after 39 1/2 months exposure in either test environment. Localized corrosion, attributed to the formation of oxygen concentration cells, at the bolt and block interface areas and at areas where marine organisms had attached themselves, was observed on the seawater exposure assembly. Similar effects from oxygen concentration cells, but to a lesser degree, were also observed at the bolt and block interface areas on the marine atmosphere exposure assembly. The effects on both assemblies and fasteners are shown in Figures 2, 3 and 4.

Dissimilar Metal Corrosion Tests.

Specimen Preparation: Panels for these tests were prepared by fastening together 2 pieces of sheet material in the combinations given in Table 2. Each member of the couple was machined to size, 4 inches by 5 inches. Bolt holes (1/4 inch in diameter), 1 inch apart and 1/2 inch from the edges, were drilled in one end of each member. The members were then fastened together by alternately inserting into the drilled holes one bolt from the top surface of one member and one bolt from the bottom surface of the other member of the couple. The bolts were held in place by a finger tight 18-8 stainless steel alloy hex nut. A torque of 85 lb-in. was then applied to draw the nut up tight on each bolt. The finished panels were 4 inches by 9 inches with a 1 inch overlap at the faying surfaces. Figure 5 shows a sketch of a typical assembly.

Exposure: All of the dissimilar metal couples were exposed in the marine atmosphere in the 80 ft. lot of the International Nickel Company's test facility at Kure Beach, N.C. for 39 1/2 months.

Examination: The dissimilar metal couples were examined after removal from exposure, then disassembled and cleaned, using the procedures given in Table 3, and then reexamined. The extent of the corrosion based on visual examination after disassembly and cleaning is given in Table 4.

Figures 6, 7 and 8 show before disassembly, the cadmium plated steel members that were coupled respectively with the types 410, 302 and 321 stainless steel alloy members. The most severe corrosion on the cadmium plated steel was indicated

by adherent rust colored corrosion products (darker areas) at the fastener areas and at areas immediately adjacent to the faying surface. When these couples were disassembled, it was noted that the corrosion products beneath the bolt heads and at the faying surfaces were gray to grayish white indicating the presence of sufficient cadmium at these areas to provide protection for the fasteners and coupled members. No corrosion was observed at the contact areas of any of the fasteners coupled with the cadmium plated steel members.

Figures 9, 10 and 11 show, respectively, after cleaning, the surfaces of the types 410, 302 and 321 stainless steel members that had been coupled to the cadmium plated steel members. There was no corrosion at the fastener contact areas of any of the stainless steel members or at the faying surfaces of the types 302 or 321 steel specimens. The type 410 steel was slightly etched at the faying surface. No corrosion was found at the washer face contact areas on any of the fasteners coupled with the type 410 steel member or on the type 18-8 stainless steel nuts that were coupled with the types 302 and 321 steel members. However, shallow pits were found on the washer face of the 17-4 PH steel fasteners that were coupled with the types 302 and 321 steel members.

Figure 12 shows the extent of corrosion on the types 321 and 410 steels that were coupled together. There was no corrosion at the fastener contact areas on the type 321 steel member, but there was some slight pin hole attack at the faying surface. There was pitting corrosion at the fastener contact areas on the type 410 steel specimen which was more severe where the type 18-8 stainless steel nuts made contact than where contact was made with the 17-4 PH steel bolts. Pitting was more severe at the faying surface on this member than at the exposed surfaces.

Shallow pitting was noted on the contact surfaces of the 17-4 PH steel fasteners coupled with the type 321 steel member. The 17-4 PH steel fasteners coupled with the type 410 steel were stained at the washer face contact areas. No corrosion was observed at the contact areas of the type 18-8 stainless steel alloy nuts.

Figure 13 shows the surface appearance of the types 302 and 410 steel specimens that were coupled together. There was no corrosion at the fastener contact areas on either member. However, there was some local pitting at the faying surface of the type 302 steel member and severe attack at the faying surface of the type 410 steel member. The attack at the faying surface on the type 410 steel

member was more severe than at exposed areas.

Shallow pitting at the washer face contact areas was noted on the 17-4 PH steel fasteners that were coupled with both the types 302 and 410 steel members. The pitting was of a more general nature than that observed on the other fasteners previously cited. There was no corrosion damage on any of the type 18-8 steel nuts coupled with either member.

The surface appearance of the types 321 and 302 steel members that were coupled together is shown in Figure 14. There was no corrosion at the fastener contact areas on either member. Evidence of concentration cell corrosion was noted at the bolt hole areas on the faying surfaces of both specimens. The attack was more severe on the type 321 steel specimen in that surface cracking was noted in these areas. One of these areas is shown in Figure 15. The path of the cracking at the surface was in a direction that was predominantly concentric with the bolt holes and 1/8 to 3/16 inches from the bolt hole base.

Other areas on the type 321 steel specimen, one of which is shown at arrow a in Figure 15, showed evidence of the metal surface erupting from corrosion below the surface.

Metallographic examination of a section cut from one of the bolt hole areas, that included both modes of cracking, revealed that the concentric cracking propogated from a pitted area on the surface, arrow a, Figure 16, to a depth of approximately 0.02 inches at which point it branched. One branch progressed in a direction nearly parallel with the surface, and then curved back toward the surface, emerging at the area designated by arrow a in Figure 15 and by arrow b in Figure 16. The propagation of the other branch was in a direction toward the opposite surface (exposed surface) to a point which was nearly coincidental with the periphery of the type 18-8 stainless steel nut washer face (arrow c in Figure 16). However, this crack did not penetrate to the surface. Additional surface cracks were noted at the area designated by arrow d in Figure 16. These faying surface cracks were directly opposite the periphery of the type 18-8 stainless steel nut washer face on the exposed surface.

Metallographic examination of the section after repolishing and etching showed that the cracks were predominantly transgranular, Figure 17.

The nature and paths of the cracks observed indicate the presence of high tensile stresses at areas on the faying surface adjacent to similar areas at the periphy of the fastener washer faces on the exposed surface. The stresses were most likely induced by the pressure exerted from the exposed surface when the fasteners were tightened prior to exposure. The entrapment of salt laden moisture from the atmospheres at the faying surface and the apparent cathodic nature of the type 302 steel member of the couple resulted in the formation of a galvanic cell which initiated local pitting corrosion. The combination of high surface tensile stresses and the corrosive effects at the faying area resulted in the surface cracking or stress corrosion failure observed.

No cracking was observed on any of the other couple members examined.

The corrosion damage on the fasteners in contact with both the types 321 and 302 steel members of this couple was similar to that observed on the type 321 vs. type 302 dissimilar metal couple.

Conclusions: The results of stress corrosion tests conducted on 17-4 PH stainless steel fasteners in the tidewater and in the marine atmosphere indicate that the fasteners have good resistance to stress corrosion cracking. There were no failure of any of the specimens after 39 1/2 months exposure.

The results of the visual examination after 39 1/2 months exposure in the marine atmosphere of the various components used in the dissimilar metal couples indicated:

(1) Cadmium plated SAE 4130 alloy steel is anodic to type 410, 302 and 321 stainless steel alloys.

(2) Type 321 stainless steel is anodic to type 302 stainless steel alloy.

(3) Type 410 is anodic to both the type 302 and 321 stainless steel alloys.

(4) There was no apparent galvanic reaction between the type 410 stainless steel alloy members and the 17-4 PH steel fasteners.

(5) The 17-4 PH steel fasteners were anodic to the type 302 and 321 stainless steel alloys.

(6) Cadmium plated SAE 4130 steel is anodic to the 17-4 PH stainless steel fasteners.

(7) The type 18-8 fasteners were cathodic to all of the dissimilar metal couple members except where no galvanic reaction could be determined, as in the case of those fasteners in contact with the types 302 and 321 steel members that were coupled with the cadmium plated SAE 4130 steel members; or when type 410 steel was coupled with type 302 steel.

Table 1

17-4 PH stainless steel alloy fasteners submitted for determination of the gavlanic and stress corrosion behavior in marine environments

Bolt Size	Part No.	No. of pieces
1/4 in.-28 by 0.750 inch	6808565	6
1/4 in.-28 by 0.812 inch	6820181-11	6
1/4 in.-28 by 0.469 inch[(a)]	6820217	24
5/16 in.-24 by 0.938 inch	6823447-11	6
5/16 in.-25 by 1.250 inches	6823447-16	6

(a) These bolts furnished for dissimilar metal corrosion tests only. Type 18-8 stainless steel alloy hex nuts furnished for fastening purposes.

Table 2

Combinations of materials fastened together with 17-4 PH stainless steel alloy bolts and type 18-8 stainless steel alloy nuts

Couple Combination
Type 410 stainless steel sheet and Cadmium plated SAE 4130 steel sheet
Type 302 stainless steel sheet and Cadmium plated SAE 4130 steel sheet
Type 321 stainless steel sheet and Cadmium plated SAE 4130 steel sheet
Type 410 stainless steel sheet and Type 321 stainless steel sheet
Type 302 stainless steel sheet and Type 410 stainless steel sheet
Type 321 stainless steel sheet and Type 302 stainless steel sheet

Table 3

Procedures employed to clean dissimilar metal couple components

Material	Procedure
17-4 PH stainless steel alloy bolts	Ultrasonically cleaned by immersion in an agueous solution of nitric acid (10% by volume) at 140°F.
18-8 stainless steel alloy nuts.	Same as above.
Stainless steel alloy sheet specimens	Inmersed at room temperature in an aqueous solution of nitric acid (50% by volume).
Cadmium plated SAE 4130 alloy steel	Scrubbed with a bristle brush in warm water, rinsed and dried.

Table 4

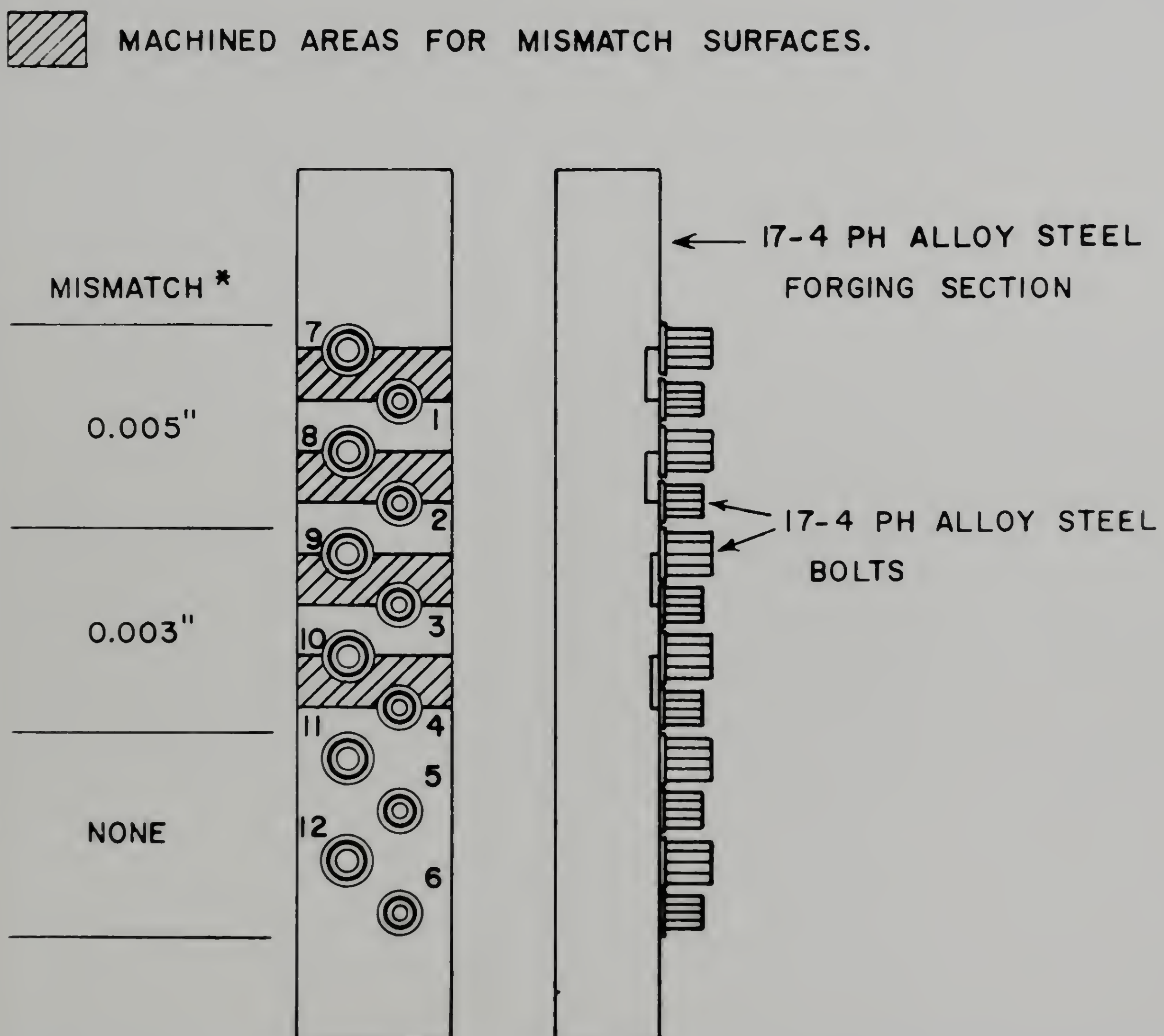
Results of Visual Examination of Specimens after Exposure. All specimens were examined after disassembly and cleaning, except cadmium plated steel specimens which were examined after disassembly only.

Material	Panel		Fastener Contact Areas			
	Exposed Surfaces	Faying Surfaces	17-4 PH Bolts		Type 18-8 Nuts	
			Panel	Bolts	Panel	Nut
Type 410	3	0	0	0	6	0
Cd plated SAE 4130	4(a), 6(b)	3(c)	3(c)	0	3(c)	0
Type 302	0	0	0	5	0	0
Cd plated SAE 4130	4(a), 6(b)	3(c)	3(c)	0	3(c)	0
Type 321	7(d)	0	0	5	0	0
Cd plated SAE 4130	4(a), 6(b)	3(c)	3(c)	0	3(c)	0
Type 321	7(d)	7(d),(e)	0	5	5	0
Type 410	4, 1	8, 6 (e)	1	1	6	0
Type 302	0	1, 8 (d)	0	6	0	0
Type 410	3	8, 6 (e)	5	6	5	0
Type 321	7(d)	2(g),9(f)	0	6	5	0
Type 302	7(d)	2(g),7(d)	0	6	5	0

0 - No corrosion
1 - Stained
2 - Etched
3 - Light general attack
4 - General attack
5 - Few shallow pits
6 - Shallow pits
7 - Pin-hole surface attack
8 - Medium pits
9 - Surface cracks

(a) - At edge of faying surface at fastener areas.
(b) - Scattered, had not penetrated to base metal.
(c) - Gray to grayish white corrosion products at these areas.
(d) - Scattered
(e) - At edge of faying surface.
(f) - At areas approximately 1/16 inch from bolt holes.
(g) - Around bolt holes

BOLT NO'S	SIZE	PART NO.	APPLIED TORQUE
1,3,5	1/4"-28 X 0.750"	6808565	85 LB-IN.
2,4,6	1/4"-28 X 0.812"	6820181-11	85 LB-IN.
7,9,11	5/16"-24 X 0.938"	6823447-11	190 LB-IN.
8,10,12	5/16"-24 X 1.250"	6823447-16	190 LB-IN.



*Parallelism between spot face surface of bolt head and mating surface of part may deviate up to 0.003 inches. This is governed by squareness of head surface to shank and is a function of tooling operations, according to D. F. Wright, General Motors, Allison Div. communication dated Feb. 2, 1962.

Figure 1. Typical Stress Corrosion Assembly.

Figure 2. Photograph of the 17-4 Ph threaded blocks after disassembly and cleaning; showing oxygen concentration cell effects at bolt-block interface areas on (a), specimen exposed in the marine atmosphere, and on (b), specimen exposed in the sea water in the tidal zone. Note also effects of marine organism attachment on (b). X1

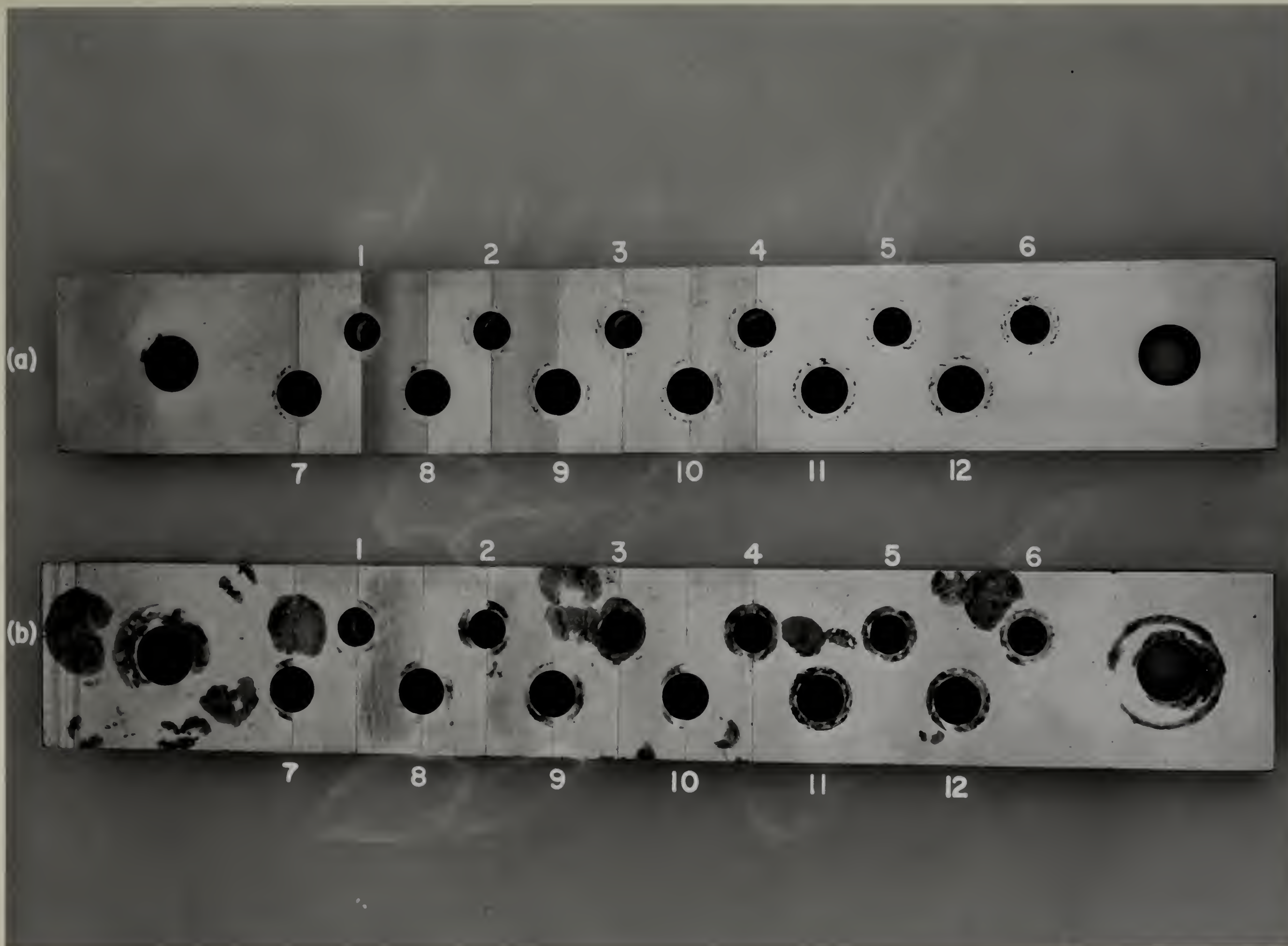

(a)
1 2 3 4 5 6
7 8 9 10 11 12
(b)
1 2 3 4 5 6
7 8 9 10 11 12

Figure 3. Appearance of 17-4 PH stainless steel alloy bolts removed from the marine atmosphere test assembly. Bolts are shown after cleaning. Note pitting effects from oxygen concentration cell corrosion at areas on the bolt washer faces. X1

Figure 4. Appearance of 17-4 PH stainless steel alloy bolts from seawater test assembly. Bolts are shown after cleaning. Note pitting corrosion on the washer face of the bolts and corrosive effects from marine organism attachment on the heads of bolts 1, 4 and 11. Corrosion on the shank areas of bolts 1 and 4 was due to marine organism attachment at areas within the threaded hole of the block. Corrosion is attributed to the formation of oxygen concentration cells. X1

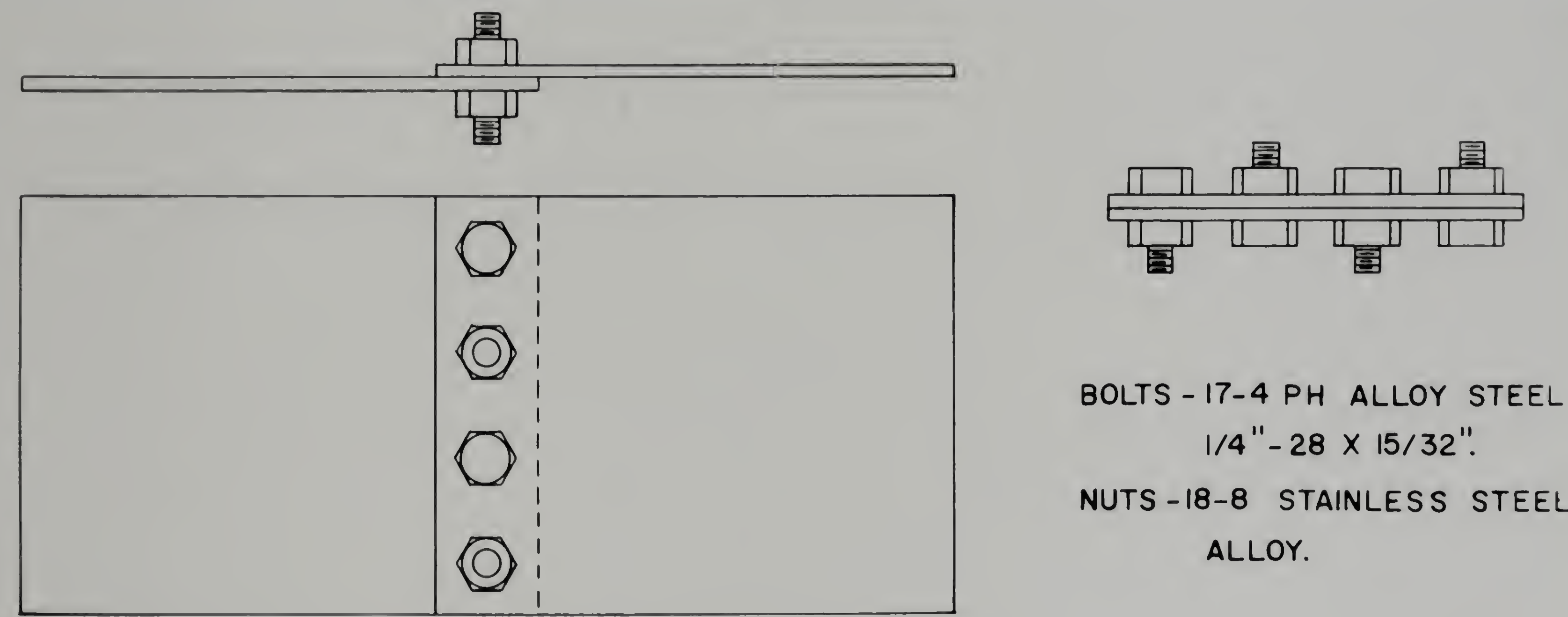
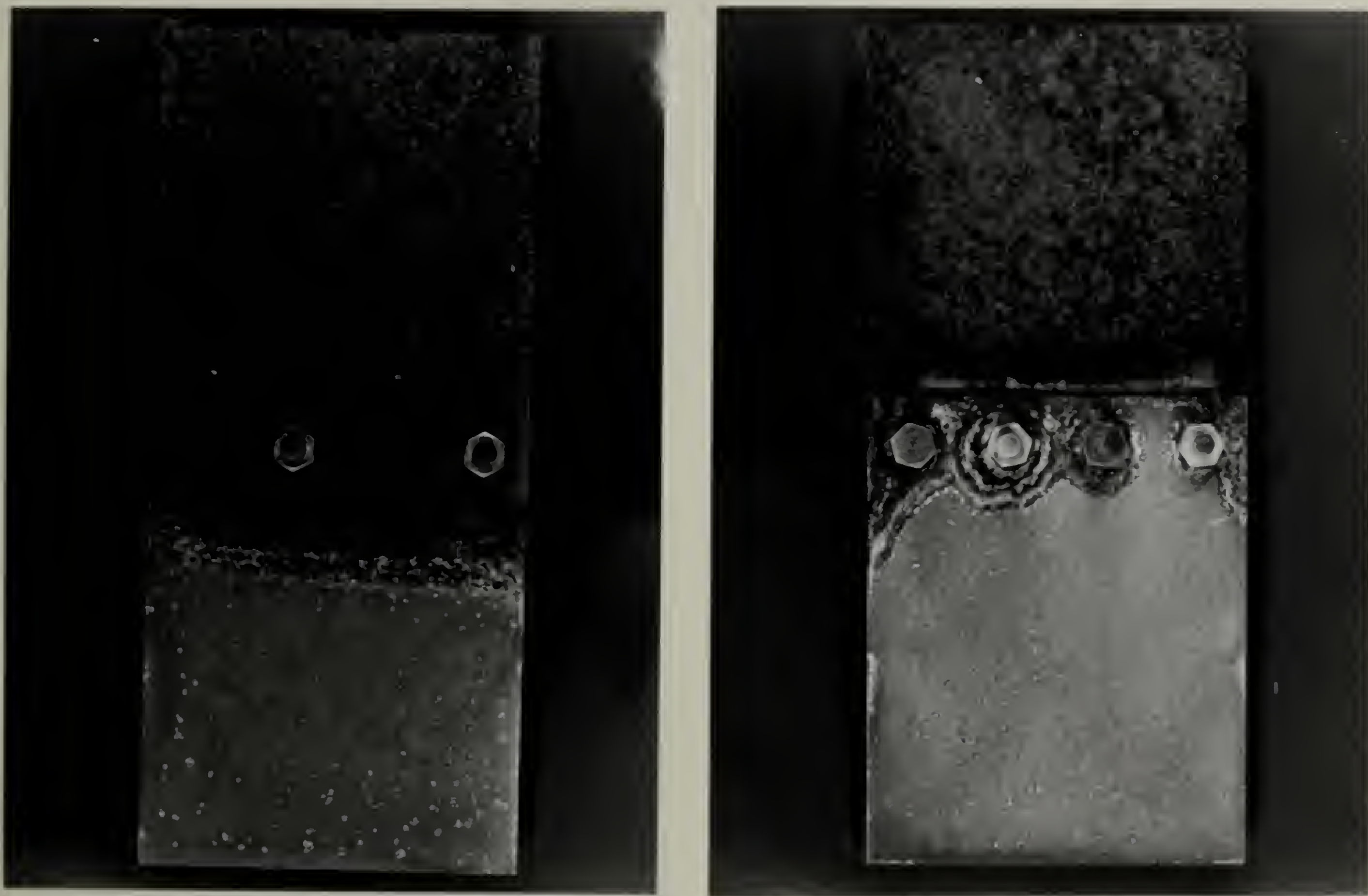


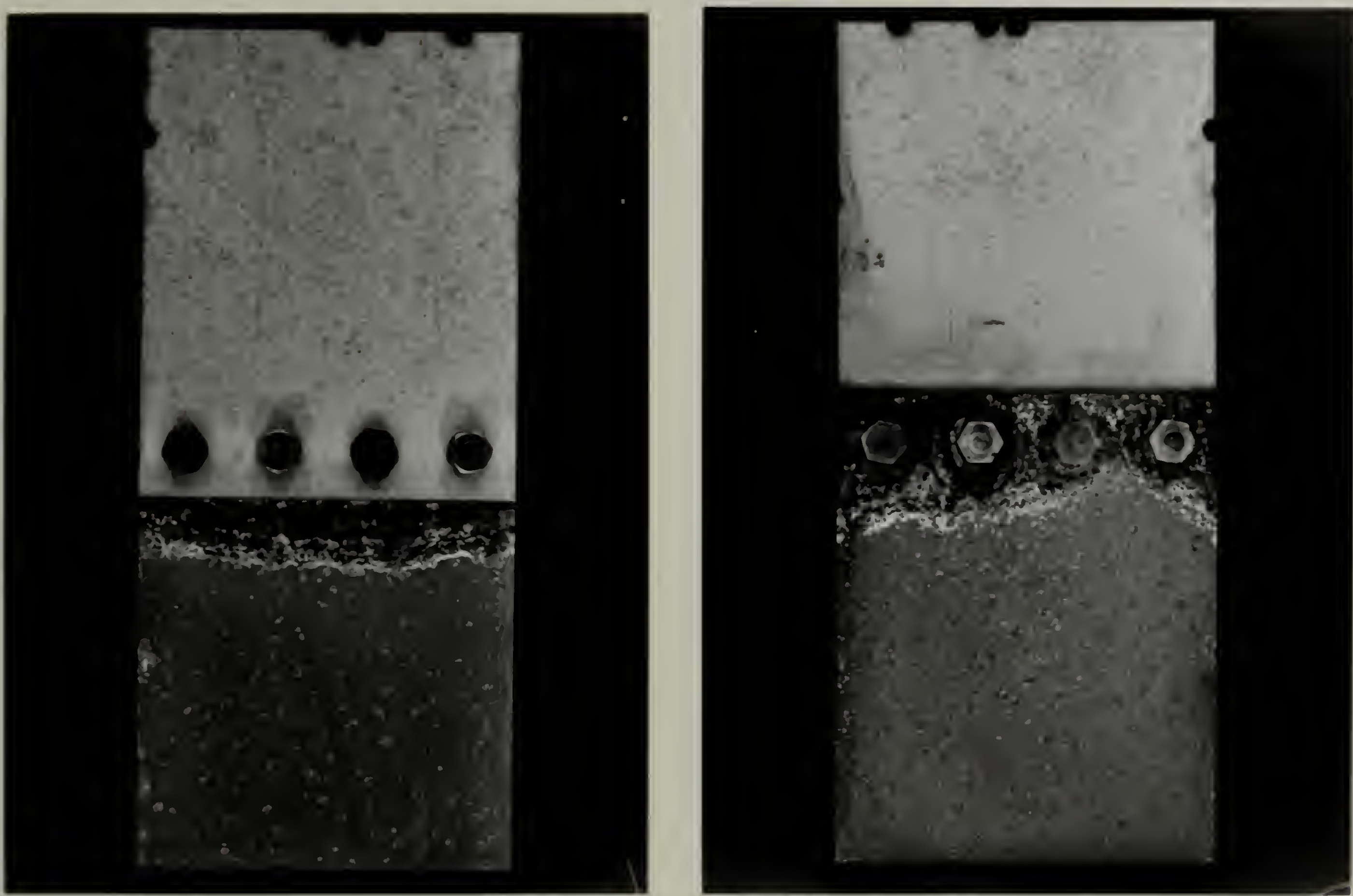
Figure 5. Typical dissimilar metal corrosion test assembly. 1/4" -28 bolts were positioned 1/2 inch from the edges and 1 inch apart. Applied torque to bolts was 85 lb-in. Sheet metal used is noted in Table 1.



a b

Figure 6. Appearance of dissimilar metal couple after 39 1/2 months exposure in the marine atmosphere at Kure Beach, N.C. In each photograph top panel component is type 410 stainless steel alloy and bottom panel component is cadmium plated SAE 4130 steel alloy. Corrosion products (dark areas) on cadmium plated steel at the faying surface and around the bolt holes were rust colored. After disassembly it was noted that the corrosion products on the faying surface and beneath the bolt heads were gray to grayish white in color. X 1/2

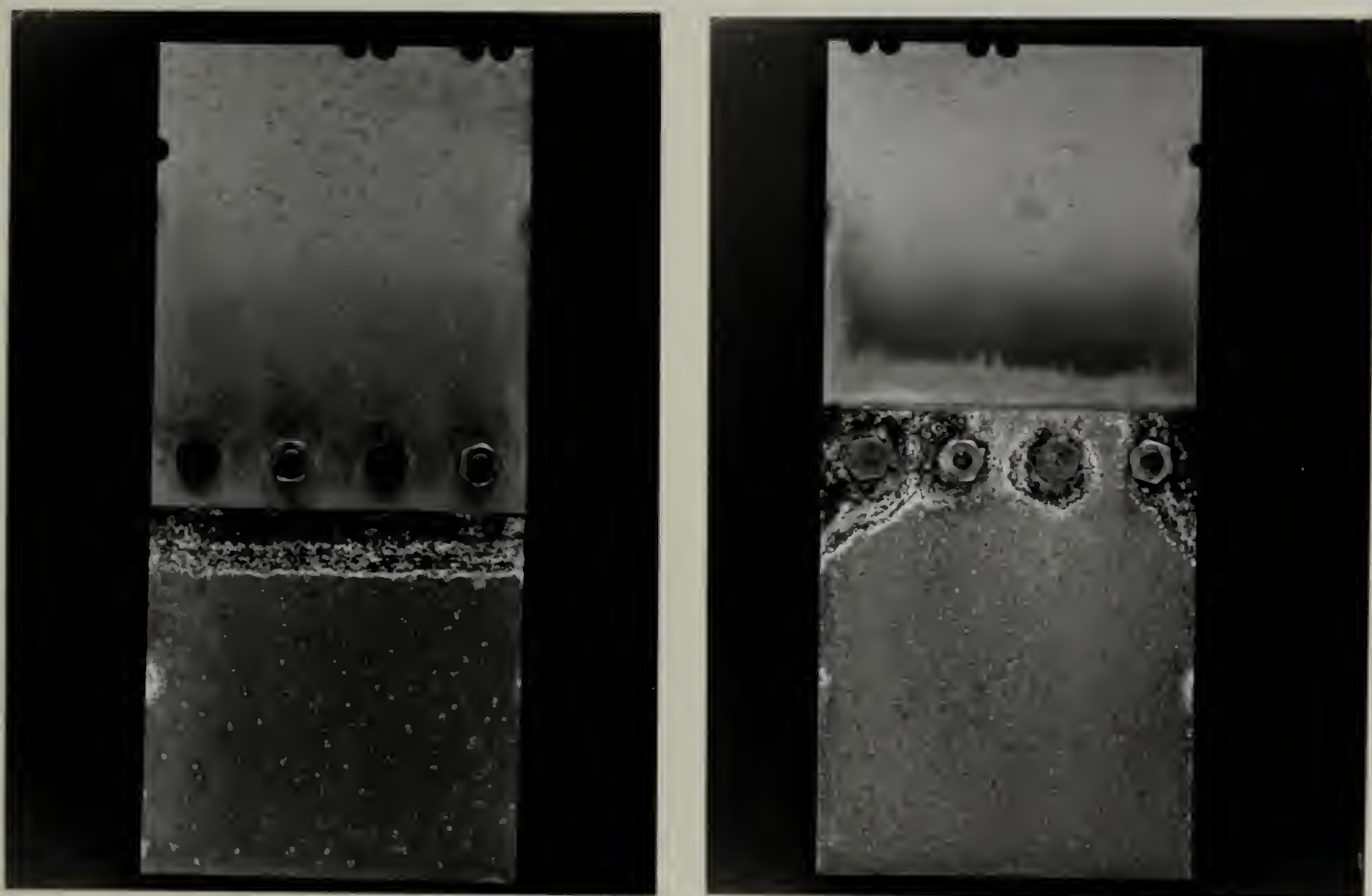
(a) skyward exposed surfaces
(b) earthward exposed surfaces



a b

Figure 7. Dissimilar metal couple after 39 1/2 months exposure in the marine atmosphere at Kure Beach, N.C. In each photograph top panel component is type 302 stainless steel alloy and bottom panel component is cadmium plated SAE 4130 steel alloy. Corrosion products (dark areas) on cadmium plated steel at the edge of the faying surface and around the bolt holes were rust colored. After disassembly it was noted that the corrosion products on the faying surface and beneath the bolt heads were gray to grayish-white in color. X1/2

(a) skyward exposed surfaces.
(b) earthward exposed surfaces.



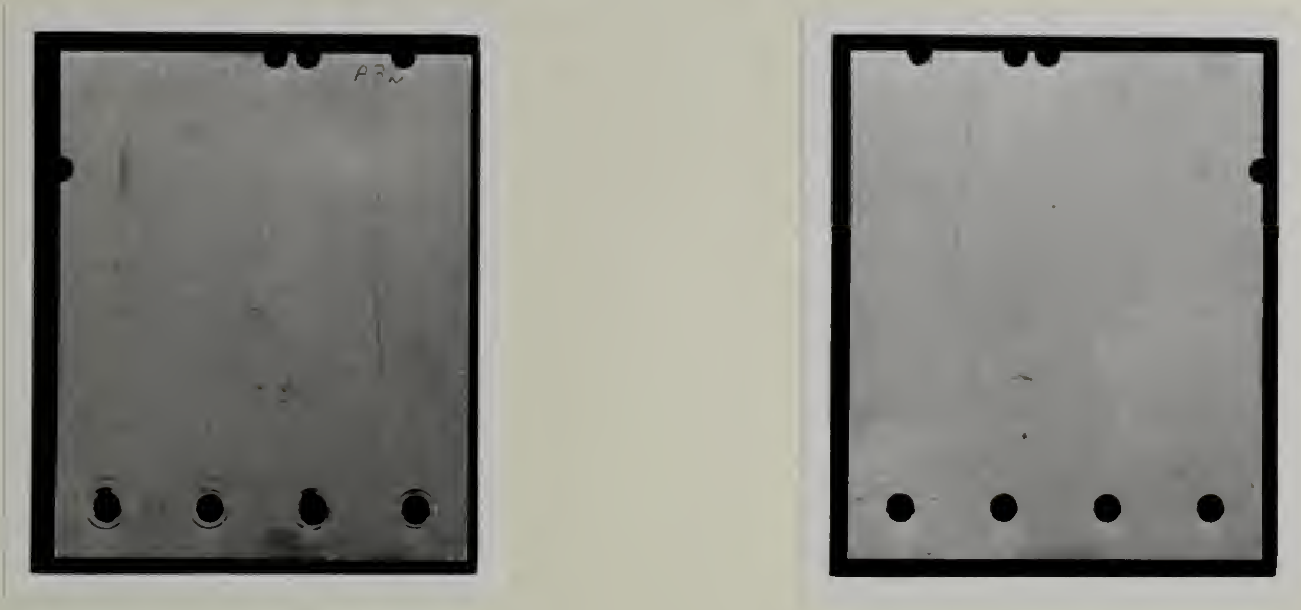
a b

Figure 8. Dissimilar metal couple assembly after 39 1/2 months exposure in the marine atmosphere at Kure Beach, N.C. In each photograph top panel component is type 321 stainless steel alloy and bottom panel component is cadmium plated SAE 4130 steel alloy. Corrosion products (dark areas) on cadmium plated steel member at the faying area and around the bolt holes were rust colored. After disassembly it was noted that the corrosion products on the faying surface and beneath the bolt heads were gray to grayish white in color. X 1/2.

(a) skyward exposure surfaces.
(b) earthward exposure surfaces.

a b

Figure 9. Photographs of the surfaces of the type 410 stainless steel alloy specimen that had been fastened to a cadmium plated SAE 4130 steel alloy member.. Specimen is shown after 39 1/2 months exposure and after disassembly and cleaning. Note that the corrosion is uniform on both surfaces except at fastener contact areas on the skyward exposed surface (a) and at the faying area of the earthward exposed surface (b). Faying surface area was slightly etched. Dark patches at bolt hole areas and in upper left corner of (a) are rusted areas that appeared after cleaning before the specimen could be photographed. X 1.2



a b

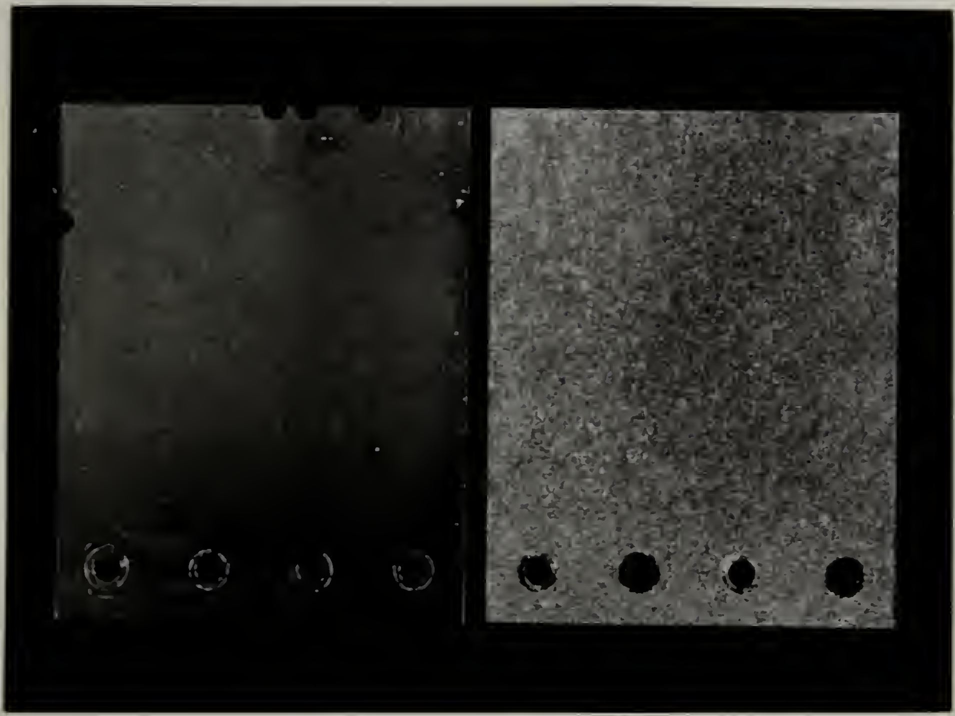
Figure 10. Photographs of the surfaces of the type 302 stainless alloy specimen that had been fastened to the cadmium plated SAE 4130 steel alloy member. Specimen is shown after 39 1/2 months exposure in the marine atmosphere and after disassembly and cleaning. There was no corrosive attack at the fastener contact areas on the skyward exposed surface (a) or the faying area on the earthward exposed surface(b).Rings around bolt holes are scoring marks introduced by the bolt and nut washer faces and by tools used to remove the fasteners. Darkened areas at bolt holes are from lighting used in photographing the specimen. X 1/2

a

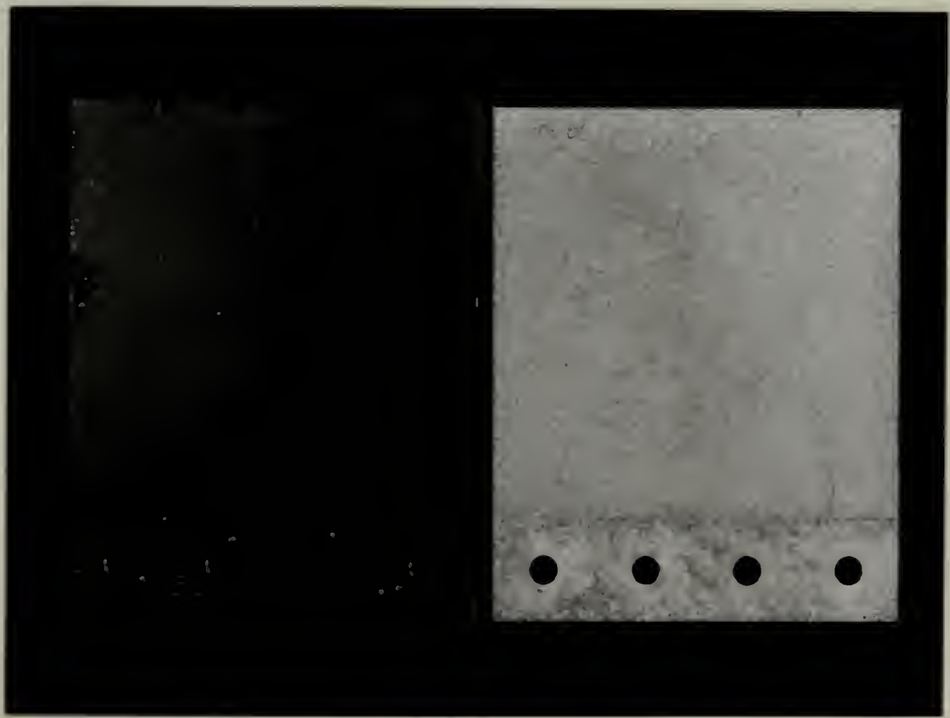
b

Figure 11. Photographs of the surfaces of the type 321 stainless steel alloy specimen that had been fastened to the cadmium plated SAE 4130 steel alloy member. Specimen is shown after 39 1/2 months exposure in the marine atmosphere and after disassembly and cleaning. There was no corrosive attack at the fastener contact areas on the skyward exposed surface (a) or at the faying area on the earthward exposed surface(b). There was scattered pin-point attack at other areas on the exposed surfaces. Rings at bolt hole areas are scoring marks introduced by the bolt and nut washer faces and by tools used to install and remove the fasteners. X 1/2

Figure 12. Surface appearance after 39 1/2 months exposure in the marine atmosphere and after disassembly and cleaning of types 321 and 410 stainless steel alloy specimens that had been coupled together. (a) and (b) are the skyward and earhtward exposure surfaces, respectively, of the type 321 steel specimen and (c) and (d) are the earthward and skyward exposure surfaces, respectively, of the type 410 steel specimen. There was no corrosion at the fastener areas on the exposed surface of the type 321 steel, but there was some slight pin hole surface attack at the faying areas. Rings at bolt hole areas are scoring marks introduced by the bolt and nut washer faces and by tools used to install and remove the fasteners. Corrosive effects were noted at the fastener contact areas on the type 410 steel specimen. This attack in the form of pitting was more severe at the 18-8 stainless steel nut contact areas than at the 17-4 PH steel bolt contact areas. Pitting occurred generally at the faying surface and was more severe here than on the exposed surfaces. X 1/2

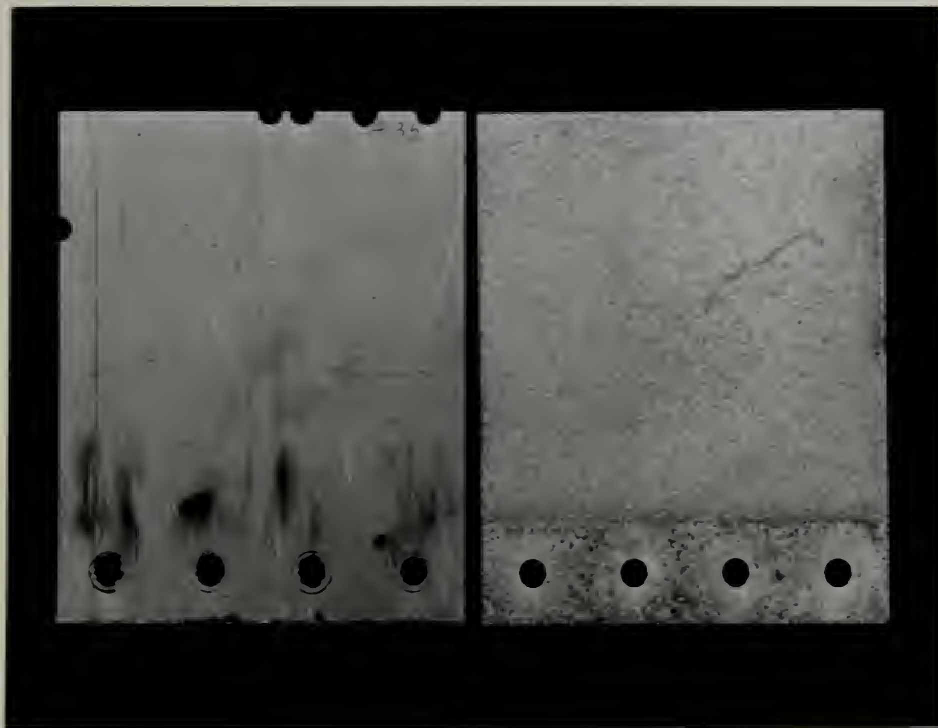


a c

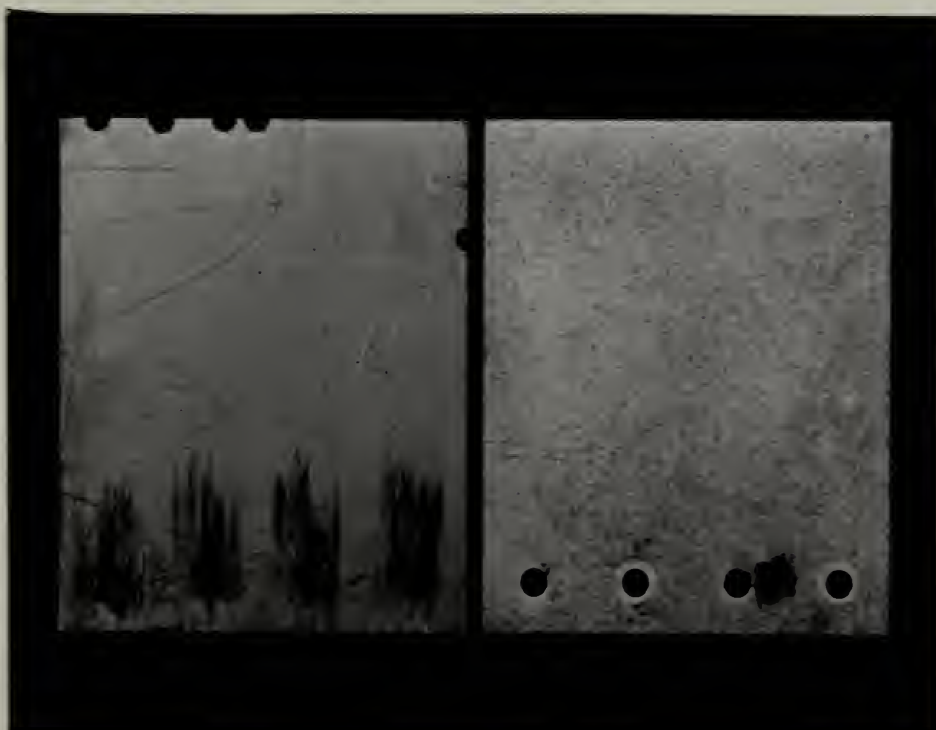


b d

Figure 13. Surface appearance, after 39 1/2 months exposure in the marine atmosphere and after disassembly and cleaning, of types 302 and 410 stainless steel specimens that had been coupled together. (a) and (b) are the skyward and earthward surfaces, respectively, of the type 302 steel and (c) and (d) are the skyward and earthward exposure surfaces respectively, of the type 410 steel member. There was no corrosion at the fastener contact areas on the exposed surface of the type 302 steel specimen, but there was some pitting attack at the faying area. Rings at fastener contact area are scoring marks introduced by the bolt and nut washer faces and by tools used to install or remove the fasteners. There was no pitting corrosion at the fastener contact areas on the type 410 steel. The faying surface of the type 410 steel was pitted more severely than the exposed surfaces. X 1/2

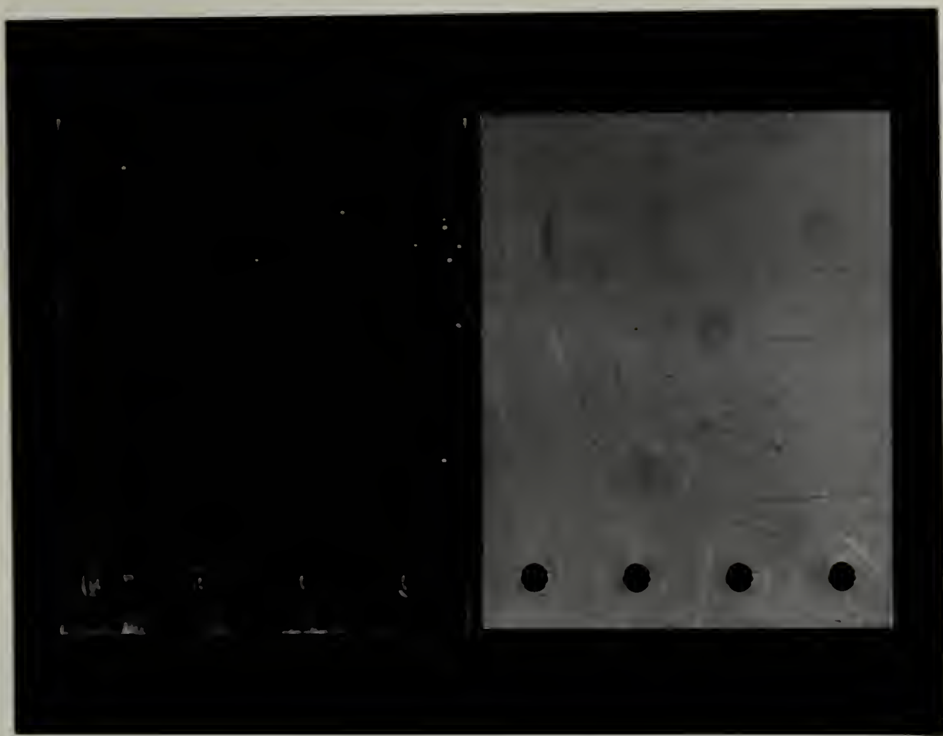


a c

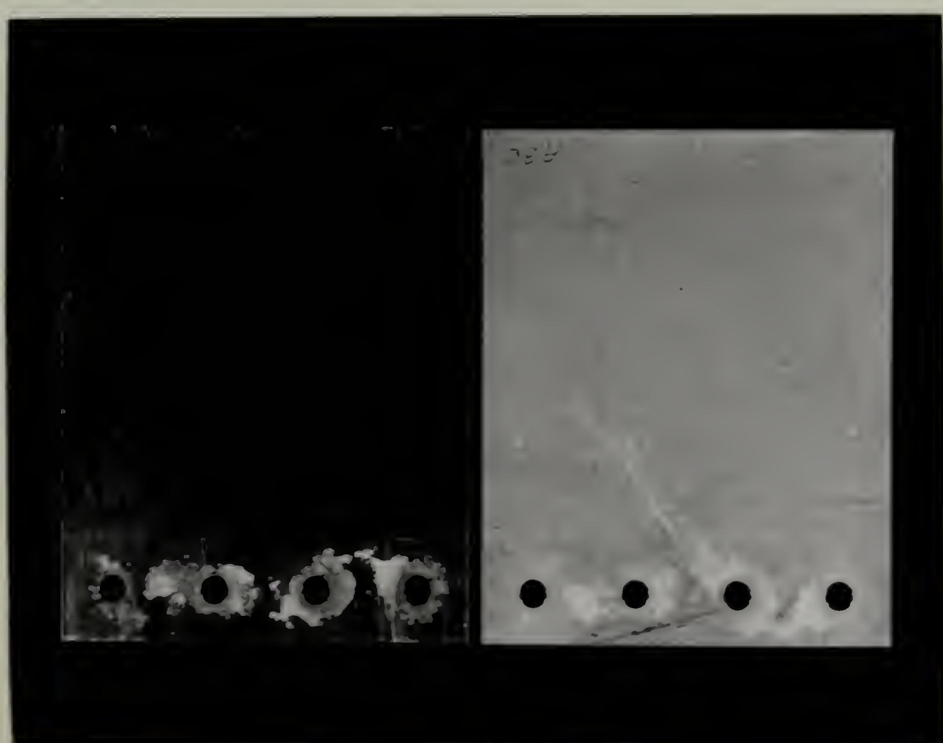


b d

Figure 14. Surface appearance, after 39 1/2 months exposure in the marine atmosphere and after disassembly and cleaning of types 321 and 302 stainless steel specimens that had been coupled together. (a) and (b) are the skyward and earthward exposure surfaces, respectively, of the type 321 steel and (c) and (d) are the earthward and skyward exposure surfaces, respectively, of the type 302 steel member. There was no corrosion at the fastener contact areas on either specimen. Rings at bolt hole areas are scoring marks introduced by the bolt and nut washer faces and by tools used to install or remove the specimens. Evidence of concentration cell corrosion was noted at the bolt hole areas at the faying surfaces of both specimens. The attack was more severe on the type 321 steel specimen in that surface cracking was noted in these areas. X 1/2



a c



b d

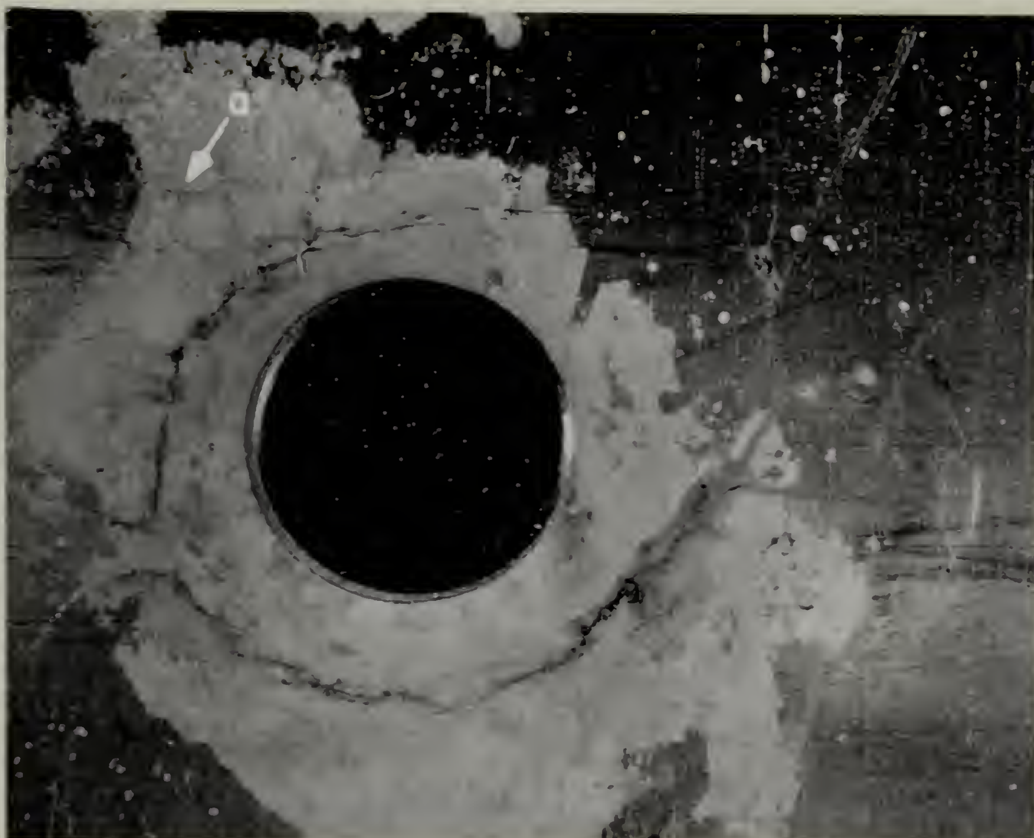


Figure 15. Example of surface cracking observed at the bolt holes on the faying surfaces on the type 321 steel specimen that was coupled with a type 302 steel specimen. Arrow a denotes area where an eruption at the surface was noted. X5

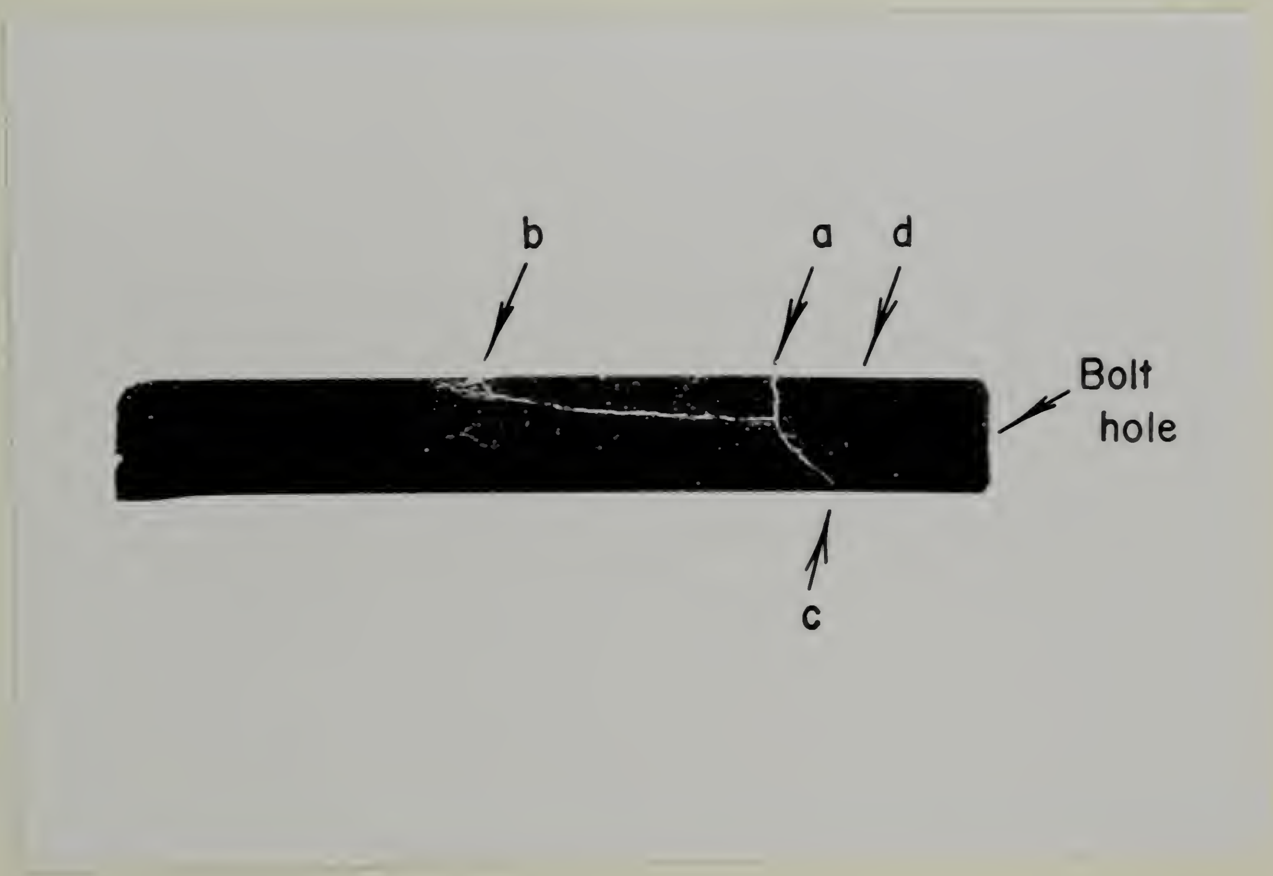


Figure 16. Photomacrograph of a section cut from the bolt hole area of a 321 stainless steel alloy specimen that had been coupled with a 302 stainless steel alloy specimen. Arrow a denotes the pitted area where circumferential cracking occurred adjacent to the bolt hole. Arrow b shows the area at arrow a in Figure 6 where eruption of the surface occurred and arrow c is at the periphery of the bolt or nut washer face. Arrow d denotes area where other cracks were observed. Unetched. X10

Figure 17. Photomicrograph of a portion of the section shown in Figure 16. Large cracks on right hand side are those whose origin were at arrow a in Figure 16. Tighter cracks toward center are those whose origin were at arrow d in Figure 16. Cracking is predominantly transgranular. Reversal of this photograph is due to the nature of the metallograph used. Etched with HCl and $FeCl_3$. X100

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