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DAVID W. TAYLOR
NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER
Bethesda, Md. 20084



SEAWATER CORROSION OF FASTENERS IN
VARIOUS STRUCTURAL MATERIALS

by
Harvey P. Hack

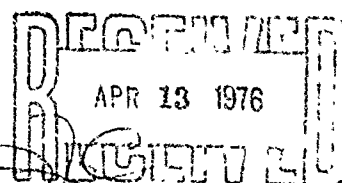
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MATERIALS DEPARTMENT
Annapolis
RESEARCH AND DEVELOPMENT REPORT

April 1976

Report 76-0034

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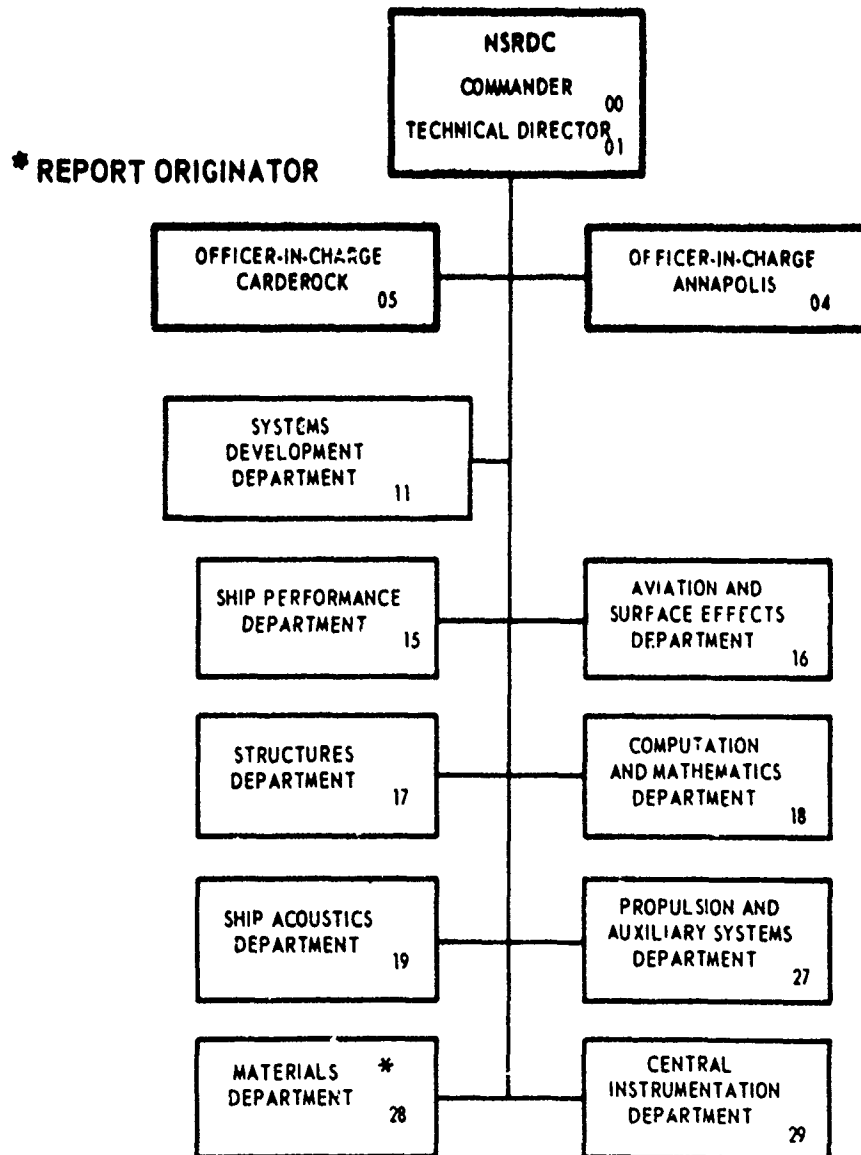


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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER DTNSRDC-76-0034	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER A-11
4. TITLE (and Subtitle) SEAWATER CORROSION OF FASTENERS IN VARIOUS STRUCTURAL MATERIALS,		5. TYPE OF REPORT & PERIOD COVERED Research & Development Rept.
6. AUTHOR(s) Harvey P. Hack		7. PERFORMING ORG. REPORT NUMBER
8. CONTRACT OR GRANT NUMBER(s)		9. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Task Area-54606 Task-01724 Work Unit 1153-524
10. CONTROLLING OFFICE NAME AND ADDRESS David W. Taylor Naval Ship R&D Center Bethesda, Maryland 20084		11. REPORT DATE Apr 76
12. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		13. NUMBER OF PAGES 35
14. SECURITY CLASS. (of this report) Unclassified		15. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Seawater corrosion Bolt materials Structural materials Sealant material Constant-immersion exposures Panel materials		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Constant-immersion seawater exposures were conducted on panels with 1/4-inch bolts inserted with and without bolt sealant. Five panel materials were tested: fiber glass, 5456-H117 aluminum, HY-130 steel, titanium-6AL-4V, and 17-4PH stainless steel. The seven bolt materials were: 2024 aluminum, anodized ASTM grade 5 steel, 304 and 316 stainless steels, A286 stainless steel, MP35N multiphase, and titanium-6AL-4V. The (over)		

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20. Abstract (Cont)

sealant material was Coast Pro-Seal 800/B-2. Results of the study are presented. For fiber glass structures in constant saltwater immersion, titanium, MP35N, A286, and 316 stainless steel fasteners with sealant performed well in these tests. For 5456 aluminum structures in similar environments, use of a sealant and additional corrosion protection would have been necessary to minimize corrosion regardless of the bolt material. HY-130 steel structures in constant immersion performed adequately with properly sealed titanium, MP35N, A286, 304, or 316 stainless steel fasteners. Only titanium and MP35N fasteners performed well in titanium structures. Use of MP35N, A286, and 304 stainless steel fasteners for constantly immersed 17-4PH stainless steel structures would have been satisfactory only if sealant was not used and if protection had been provided to the 17-4PH to minimize crevice corrosion. Additional tests should be performed if different materials are to be joined or if the service environment is different from that of these exposures.

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ADMINISTRATIVE INFORMATION

This work was performed under Task Area 54606, Task 01724, Work Unit 1153-524, covering hydrofoil materials. The program manager for this work is Mr. W. O'Neill, DTNSRDC (Code 1153), and the project managers are Mr. J. J. Kelly and Mr. A. G. S. Morton, DTNSRDC (Code 2803).

LIST OF ABBREVIATIONS

corr - corrosion
crev - crevice
galv - galvanic
int - intense
 μ m - micrometers
m - meters
mm - millimeters
prob - probable
SS - stainless steel

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TABLE OF CONTENTS

	<u>Page</u>
ADMINISTRATIVE INFORMATION	i
LIST OF ABBREVIATIONS	i
INTRODUCTION	1
Fasteners	1
Panels	2
Sealant	3
EXPERIMENTAL PROCEDURE	3
RESULTS AND DISCUSSION	3
Fiber Glass Titanium and HY-130 Steel Panels	6
Aluminum Panels	6
17-4PH Stainless Steel Panels	6
Bolts in Fiber Glass Panels	7
Bolts in Aluminum Panels	7
Bolts in HY-130 Panels	8
Bolts in Titanium Panels	8
Bolts in 17-4PH Panels	8
Small 304 Sample Fasteners from PHM	9
Joints with Mixed Materials	9
CONCLUSIONS AND RECOMMENDATIONS	10
Fiber Glass	10
5456 Aluminum	10
HY-130 Steel	10
Titanium	11
17-4PH Stainless Steel	11
Mixed Materials	11
TECHNICAL REFERENCES	11
LIST OF FIGURES	
Figure 1 - Photograph; Bolt Assembly with Sealant, Before Exposure	
Figure 2 - Photographs; Corrosion Attack on HY-130 Steel Panels	
Figure 3 - Photographs; Localized Corrosion Attack on Aluminum Panels (Bolt Materials as Indicated)	
Figure 4 - Photograph; Corrosion Attack on 17-4PH Panels with Aluminum Bolts	
Figure 5 - Photograph; Corrosion Attack on 17-4PH Panels with Steel Bolts	
Figure 6 - Photograph; Corrosion Attack on 17-4PH Panels with 304 Stainless Bolts	
Figure 7 - Photograph; Corrosion Attack on 17-4PH Panels with 316 Stainless Bolts	
Figure 8 - Photograph; Corrosion Attack on 17-4PH Panels with A286 Bolts	
Figure 9 - Photograph; Corrosion Attack on 17-4PH Panels with MP35N Bolts	
Figure 10 - Photograph; Corrosion Attack on 17-4PH Panels with Titanium Bolts	
Figure 11 - Photograph; Corrosion Attack on 17-4PH Panel with Small 304 Stainless Bolts	

TABLE OF CONTENTS (Cont)

Figure 12 -	Photograph; Corrosion Attack on Bolts in Fiber Glass Panels
Figure 13 -	Photograph; Corrosion Attack on Bolts in Aluminum Panels
Figure 14 -	Photograph; Corrosion Attack on Bolts in HY-130 Panels
Figure 15 -	Photograph; Corrosion Attack on Bolts in Titanium Panels
Figure 16 -	Photograph; Corrosion Attack on Bolts in 17-4PH Panels
Figure 17 -	Photograph; Corrosion Attack on Small 304 Stainless Bolts in 17-4PH Panel

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INTRODUCTION

Due to the weight-critical nature of hydrofoil craft, the hulls are generally constructed of aluminum. Several materials have been used or are being considered for strut-foil systems. These include 17-4PH stainless steel, HY-130 steel, aluminum, mild steel, and titanium alloys. In addition, fiber glass is frequently used for nonstructural fairings.

This unique combination of materials leads to complex problems of fastener selection. Two somewhat interrelated factors affecting the selection of fastener materials from a corrosion standpoint are galvanic compatibility and susceptibility to crevice corrosion.^{1,2} Most papers written on the subject of fastener corrosion emphasize corrosion in marine or industrial atmospheres.^{3,4} These environments are quite different from constant seawater immersion environments. The intensities of galvanic and crevice corrosion are greater in constant-immersion environments than in atmospheric environments. Sacrificial coatings which can be of great value in limiting corrosion attack in atmospheric exposures^{3,4} are depleted too rapidly to be of value in constant-immersion exposures. Thus, evaluation of the interrelationship between galvanic and crevice corrosion in fastened assemblies and of the overall compatibility between various base materials and various fastener materials in marine environments is best accomplished by means of constant-immersion seawater corrosion exposures. This report presents the results of such a set of exposures and makes recommendations regarding the selection of fastener materials from a corrosion standpoint for specific structure/material combinations.

MATERIALS

FASTENERS

Aluminum alloy 2024-T4 hex head fasteners, 1/4 - 20 x 1 1/2 inches (40 mm),* were supplied by ITT Harper Company, Inc. These were subsequently cut to 1-inch (25-mm) length and threaded up to the head to obtain the standard size 1/4 - 20 x 1 inch (25 mm) used for the test.

Anodized ASTM grade 5 steel hex head fasteners, 1/4 - 20 x 1 inch (25 mm), were obtained from GSA (stock No. 5305-225-3840). Passivated stainless steel hex head bolts of types 304 and 316 in this size were also furnished by ITT Harper Company, Inc., and A286 stainless steel fasteners in this size were obtained from Standard Pressed Steel Company.

¹Superscripts refer to similarly numbered entries in the Technical References at the end of the text.

*Definitions of abbreviations used are given in page i.

Also supplied by Standard Pressed Steel Company were fasteners of MP35N multiphase and Titanium-6Al-4V. The MP35N fasteners had 12-point hi-torque heads and were 1/4 - 28 x 2 1/4 inches (60 mm) with a 1 3/4-inch (45-mm) unthreaded shank. The titanium fasteners were hex head, 1/4 - 28 x 1 1/2 inches (40 mm) with 1 1/8-inch (30-mm) unthreaded shank. Fasteners of both materials were cut to the standard length and rethreaded to standard test size of 1/4 - 20 x 1 inch (25 mm).

Smaller Phillips-drive fasteners of 304 stainless steel of the type used on the PHM hydrofoil were also obtained for tests. Two sizes were tested, 10 - 32 x 1/2-inch (10-mm) pan head and 4 - 40 x 7/16-inch (10-mm) flat head.

Nominal compositions of all fastener materials are shown in table 1.

TABLE 1
NOMINAL COMPOSITIONS OF ALLOYS

<u>Alloys</u>	<u>Nominal Compositions</u>
	<u>Fasteners</u>
Aluminum	
Al2024	4.5Cu, 1.5Mg, 0.5Mn
Stainless steels	
Type 304	18Ni, 8Cr
Type 316	18Ni, 12Cr, 2.5Mo
A286	26Ni, 15Cr, 1.75Mo, 2.0Ti
Titanium	
Ti6-4	6Al, 4V
Multiphase	
MP35N	35Ni, 35Co, 20Cr, 10Mo
Steel	Medium-carbon anodized steel
	<u>Panels</u>
Aluminum	
Al5456	5Mg, 0.8Mn, 0.1Cr
Low alloy steel	
HY-130	5Ni, 0.6Cr, 0.4Mo
Stainless steel	
17-4PH	17Cr, 4Ni, 4Cu, 0.3(Nb+Ta)
Titanium	
Ti6-4	6Al, 4V

PANELS

The test panels were made from 1/4-inch (6-mm) thick fiber glass type G-10, aluminum alloy 5456-H117, HY-130 steel, titanium-6Al-4V, and 17-4PH-H950 stainless steel. The 17-4PH

material was obtained from strut fairings taken from USS TUCUMCARI (PGH 2), while the rest of the materials were obtained from normal commercial sources. Nominal compositions of the metallic plate materials are presented in table 1.

SEALANT

The fastener sealant used in this investigation was a two-part, room-temperature-curing, flexible, synthetic rubber sealant (polysulfide base) without corrosion inhibitors, which has been used on fasteners in service on hydrofoils.

EXPERIMENTAL PROCEDURE

Fourteen panels of each material were cut to 4 x 12 inches (0.1 x 0.3 m), and a 1/4 - 20 hole was drilled and tapped in the center of each. To enable the bolt heads to seat flat against the panel, a 45° taper was added to the hole on the side of the panel which would contain the bolt head. This was necessary to provide clearance for the short section of shank under the bolt head which was not fully threaded.

Duplicate specimens were prepared for each bolt-material/panel-material combination. The threads of one of the bolts in each pair were dipped in sealant immediately before assembly. All bolts were tightened after assembly of the test panels. A completed bolt assembly, with sealant, is shown in figure 1. An additional panel of 17-4PH stainless steel was prepared with threaded holes for six of each of the two smaller-sized 304 stainless steel bolts. Half of these were installed with sealant and half without.

On 17 June 1974, all test panels were exposed in quiet seawater at the Francis L. LaQue Corrosion Laboratory in Wrightsville Beach, North Carolina. All panels were fully immersed for a total test period of 6 months. At the end of this time, all panels except those made of HY-130 and all bolts except those made of steel were cleaned in a 30% nitric acid solution. The steel panels and fasteners were cleaned in an ammonium citrate solution.

RESULTS AND DISCUSSION

A summary of the results of the corrosion exposures is presented as table 2. This table has four triangles for each bolt-panel combination. In each triangle is a description of the type of corrosion attack which took place on the item to which that triangle refers. The upper two triangles in each set refer to the bolt-panel combination without sealant, while the lower two refer to the combination assembled with sealant. The left-hand triangle in each pair refers to the corrosion behavior of the bolt, whereas the right-hand triangle refers to the corrosion behavior on the panel. There are 7 bolt materials, one in each row, and 5 panel materials, one in each column, for a total of 35 bolt-panel combinations.

TABLE 2
SUMMARY OF MARINE EXPOSURE RESULTS

Bolt	Panel				
	Fiberglass Type G-10	Aluminum 5456	Hy-130 Steel	Titanium 6Al-4V	17-4PH Stainless
Aluminum 2024-T4	no attack	mild pits & edge corr; very int galv corr	very mild galv corr; general corr	no attack	very int crev corr & tunneling; mild pits & tunneling
	pits in crev; pits in bolt end	no attack	mild galv corr head	very int galv corr	very int galv corr
	no attack	very mild pits & edge corr; very int galv corr	general corr	no attack	very int tunneling
Anodized Steel	pits on entire bolt	corr exposed threads	galv corr exposed surfaces	very int galv corr	galv corr head & end
	no attack	no attack	general corr	no attack	int tunneling
	mild corr exposed threads	no attack	int galv corr; exposed surfaces	missing; prob very int galv corr	missing; prob very int galv corr
304 SS	mild corr exposed threads	no attack	general corr	no attack	int galv corr under sealant; mild pits & very int tunneling
	no attack	mild pits & edge corr; galv corr	very mild galv corr; general corr	missing; prob very int galv corr	missing; prob very int galv corr
	mild crev corr	no attack	no attack	no attack	very int crev corr & tunneling; mild crev corr
With sealant	no attack	very mild edge corr; galv corr	general corr	no attack	very int crev corr & tunneling; mild pits
	mild crev corr	no attack	no attack	int crev corr; very int pits on threads	very int crev corr
	mild crev corr	no attack	no attack	no attack	very int crev corr

316 SS	Without sealant	no attack	mild pits & edge corr; galv corr	very mild galv corr; general corr	no attack	no attack	very int crev corr & tunneling; tunneling & mild pits
	With sealant	very mild crev corr	mild pits & edge corr; very int galv corr	no attack	very mild galv corr; general corr	crev corr	no attack
		no attack	no attack	no attack	no attack	crev corr; pits on threads	very int crev corr & tunneling; mild pits
A286	Without sealant	no attack	galv corr; mild edge corr	general corr	no attack	no attack	very int crev corr & tunneling
	With sealant	very mild crev corr	mild pits; mild edge corr	no attack	general corr	int crev corr; pits on exposed surfaces	no attack
		no attack	no attack	no attack	no attack	int crev corr; int pits on exposed threads	very int crev corr & tunneling
MP35N	Without sealant	no attack	pits & edge corr; int galv corr	very mild galv corr; general corr	no attack	no attack	very int crev corr & tunneling; mild tunneling
	With sealant	no attack	very mild pits & edge corr	no attack	very mild galv corr; general corr	no attack	very int crev corr & tunneling; mild tunneling
		no attack	no attack	no attack	no attack	no attack	missing; prob no attack
Titanium	Without sealant	no attack	very mild pits & edge corr; int galv corr	general corr	no attack	no attack	very int crev corr & tunneling; mild tunneling
	With sealant	no attack	very mild pits & edge corr; int galv corr	very mild galv corr; general corr	no attack	no attack	very int crev corr & tunneling; mild tunneling
		no attack	no attack	no attack	no attack	no attack	no attack

FIBER GLASS TITANIUM AND HY-130 STEEL PANELS

No attack occurred on any of the fiber glass or titanium panels. Corrosion of the HY-130 steel panels consisted primarily of a general, uniform attack, as shown in item (2) of figure 2. In some instances, especially on panels which had housed the more noble bolt materials, a very mild form of galvanic attack was present, as shown in items (b) and (c) of figure 2. This electrochemical attack was, in most cases, barely visible and fairly broad, with a maximum depth of 2-5 mils (50-125 μ m). On the panels where sealant was used, it occurred outside of the area covered by sealant (which oozed out from the threads as the bolt was tightened). On the panels where sealant was not used, it occurred outside of the area of bolt-head contact. Unexpectedly, this corrosion was present on one panel containing an aluminum bolt.

ALUMINUM PANELS

The corrosion attack on the aluminum panels was usually in the form of mild pitting and local attack at the plate edges. Also present was a mild-to-intense form of localized inter-granular attack, up to 3/16 inches (5 mm) deep at the bolt hole. This attack is shown for both front and back of each panel in figure 3.

It is not surprising that most of the aluminum panels which had bolts of the materials more noble than aluminum (steel, the stainless steels, A286, MP35N and titanium) experienced galvanic attack. However, the panel with aluminum bolts also experienced very intense galvanic attack at the bolt holes. It should be noted that 2024 aluminum is slightly more noble than 5456 aluminum. The intensity of the attack on the panels did not appear to be related to the relative position of the bolt material in the electromotive series, as the most intense attack took place on the panels with aluminum bolts and the least attack took place on the panels with A286 bolts. Use of the sealant tended to reduce galvanic attack near the bolt head but had no systematic effect on the attack on the opposite side of the panels near the threaded shank, where sealant had not accumulated.

17-4PH STAINLESS STEEL PANELS

Attack of the 17-4PH panels was very erratic. In every case some major localized attack was present, but this attack was not always in the bolt area; rather it sometimes occurred several inches from the bolt, leaving the bolt area unaffected. Attack was always of an intense, localized, tunneling nature, with a great deal of material removal taking place beneath the metal surface where it was not visible. Generally,

each panel had only one major area of attack, although in several cases areas of minor crevice attack or pitting were present on the same plate.

The relative position of the bolt material in the electro-motive series did not appear to have any significant effect on the intensity, location, or probability of attack. In one instance the corrosion appeared to initiate at the crevice formed by an aluminum bolt. The use of the sealant seemed to have the effect of establishing a better crevice, thereby increasing the extent of the attack under the sealant.

Photographs of the side of the panels which contained the bolt head are presented as figures 4 through 10. The upper photographs are the panels where no sealant was used, and the lower photographs are the panels where sealant was used. In several instances the attack at the bolt hole clearly delineates the areas where the sealant was in contact with the plate. Also present in some panels were areas of localized attack which were not associated with the fasteners.

Figure 11 is a photograph of the 17-4PH panel with the small 304 stainless steel sample fasteners from PHM. The attack on this panel was confined to only two bolt holes (marked with arrows) and a small area near the edge, in spite of the number of crevices present. In addition, the intensity of attack did not appear as great as the panels with the large 304 stainless steel bolts (figure 6).

BOLTS IN FIBER GLASS PANELS

Figure 12 shows the corrosion attack on the bolts from the fiber glass panels. The aluminum bolts experienced pitting in the threads, especially at the cut end of the bolt, and intense pitting of the head of the bolt applied with sealant. Both steel bolts experienced a mild general attack, with some protection afforded under the sealant. The 304 stainless steel bolts suffered mild crevice attack which was somewhat reduced near the bolt head where sealant had been used. The 316 and A286 bolts suffered a mild crevice attack which amounted to only a slight etching. Use of the sealant completely eliminated this attack, however MP35N and titanium bolts were unaffected by the exposure.

BOLTS IN ALUMINUM PANELS

Bolts in the aluminum panels, illustrated in figure 13, all received adequate galvanic protection to eliminate all corrosion attack with one exception. The aluminum bolt applied with sealant experienced intense pitting on the exposed threads. This was not expected, as 2024 aluminum is slightly cathodic to 5456 aluminum in seawater.

BOLTS IN HY-130 PANELS

As can be seen in figure 14, all bolts, except those of aluminum and steel, received adequate galvanic protection from HY-130 panels to reduce their corrosion attack. The entire surface of the aluminum bolts, except that under the sealant, was uniformly pitted. The end of one of these bolts was broken off during the test. Although some galvanic corrosion of the steel bolts was expected, as they should have been slightly anodic to the 5Ni steel in seawater, the actual attack was much more intense than would be predicted. Although almost complete protection was afforded in the crevices, extensive corrosion attack occurred on the exposed surfaces.

BOLTS IN TITANIUM PANELS

The titanium panels generally caused very extensive galvanic attack on the bolts, as seen in figure 15. The entire aluminum bolts, except for the areas in the crevices, were completely corroded away. The steel bolts were missing, and it can be deduced, since the threads in the panels were intact, that these bolts either corroded away completely or suffered sufficiently extensive attack to allow them to fall out of the panels. The 316 stainless steel bolts were riddled with holes, and the attack on the 304 stainless steel bolts, although limited to the threads in or near the crevice, was still quite intense. The only time in the entire test series where A286 experienced major attack was in these panels. This attack was most intense in the crevice area but was also very significant in the head of the bolt without sealant and under the sealant in the head and threads of the bolt with sealant. Generally, the sealant afforded no protection against the galvanic attack on any of the bolts. In contrast to the others, the MP35N and titanium bolts experienced no corrosive attack whatsoever.

BOLTS IN 17-4PH PANELS

The attack on the standard-sized bolts in the 17-4PH stainless steel panels, as pictured in figure 16, appeared to be considerably less than the bolts in the titanium panels. Galvanic corrosion of the aluminum bolts was quite variable. One bolt was almost completely corroded away, except for the portion inside the crevice, while the other bolt experienced some pitting on the head and the cut end of its threads which was minor by comparison (although still considered significant). The steel bolts were both missing. Since the threads in both panels were still intact and since the areas around these bolts holes were stained with rust, these bolts probably either corroded completely or fell out after extensive attack had occurred. Extensive crevice attack was apparent on the 304 stainless steel bolt with sealant, while some attack was present but not as obvious in the threads and under the head of the bolt applied without sealant. None of the other bolts in this panel experienced

significant attack. The A286 bolt applied without sealant was broken during the test, however. In addition, one of the MP35N bolts was missing. Examination of the panel housing this bolt shows extensive corrosion, with complete destruction of the threaded hole. This evidence, along with the appearance of the other bolt, leads to the conclusion that the MP35N bolt fell out of the plate as the plate corroded away.

SMALL 304 SAMPLE FASTENERS FROM PHM

The appearance of the small 304 stainless steel fasteners that were exposed in a 17-4PH panel is shown in figure 17. All of the small flat head fasteners, except the one shown, were destroyed for analysis. All were free of attack and similar in appearance to the one shown in figure 17. Likewise, the pan head fasteners were free of corrosion, except for slight etching of the threads in one fastener which is shown at the upper left in figure 17. One fastener had been put in a hole in the panel which subsequently had the threads completely corroded away. This fastener was missing after exposure and probably dropped out of the panel intact.

There is some inconsistency in the behavior of the 304 stainless steel fasteners in the 17-4PH stainless steel panels. The nominal 1/4-inch bolts suffered crevice attack, as previously mentioned and illustrated in figure 16, whereas the smaller flat head and pan head fasteners suffered essentially no attack under almost identical circumstances, as described above and illustrated in figure 17. The reason for this anomalous behavior is not known.

JOINTS WITH MIXED MATERIALS

The corrosion problems associated with bolted joints of several materials are complex. Galvanic compatibility between different structural materials must be considered as well as compatibility of the fasteners with the structure. Not only must the crevice around the fastener be considered, but also the crevice between the structural materials. As a result, prediction of the behavior of mixed-material joints is not possible from the results of this simple experiment. However, bolt materials which remain unaffected by seawater when used with each of the panel materials alone will probably still display good corrosion resistance in the mixed-material situation.

The two bolts which remained unattacked in all materials in this exposure were MP35N and titanium. These materials will therefore probably remain unaffected when used in mixed joints. The effect of these fasteners on the corrosion of the joint cannot, however, be easily determined.

CONCLUSIONS AND RECOMMENDATIONS

The conditions of this test are probably more severe than actual service conditions for fasteners. The panels were not painted, immersion was continuous, and no cathodic protection was employed. Other factors, such as area ratios, coatings, cathodic protection, and specific environmental conditions, can exert significant influence on the corrosion behavior of fastened assemblies. Therefore, the conclusions based on the results of this study should be considered as the worst case, applicable only to structures with exposure conditions similar to the test conditions.

FIBER GLASS

Generally, use of a good sealant is recommended for bolting of fiber glass structures as it reduces the extent of crevice corrosion on the bolts subject to this type of attack. Both titanium and MP35N are highly recommended fastener materials for this application. The A286 and 316 stainless steels are subject to mild crevice corrosion but would probably perform satisfactorily. Crevice corrosion on 304 stainless steel is of sufficient magnitude to make this material unsuitable for this application. Steel bolts are generally easy to obtain and may be suitable for short exposures; however, the general corrosion rate for steel makes it unsuitable for long exposures. Aluminum alloy 2024 is subject to considerable pitting and is not recommended for use in fiber glass structures.

5456 ALUMINUM

Use of a sealant material is highly recommended for aluminum alloy 5456 structures as this material appears to reduce the localized galvanic attack on the structure. Bolts of 2024 aluminum are not recommended as they will pit significantly. All of the other bolt materials in this study, although not suffering degradation themselves, could cause localized galvanic attack of the structure. They should be considered only if a form of corrosion protection, such as painting, liberal use of sealant to cover the entire bolt, or cathodic protection, is employed.

HY-130 STEEL

Bolt sealant is also recommended for HY-130 steel structures as it appears to prevent localized attack under the bolt heads. Aluminum and steel fasteners are not recommended due to their high rate of galvanic corrosion. All other materials in this study appear to be satisfactory, from a corrosion standpoint, for this application.

TITANIUM

Bolt sealant is not necessary to mitigate corrosion in bolted titanium structures. Its use appears to have no significant effect on the corrosion behavior of the fasteners. Titanium and MP35N are the only fasteners tested that are recommended for this application. The A286 and stainless steel fasteners would suffer serious pitting and crevice corrosion in this application, whereas the steel and aluminum fasteners would suffer serious galvanic attack.

17-4PH STAINLESS STEEL

Use of a sealant material on 17-4PH stainless steel structures is definitely contraindicated. The sealant tends to establish a tighter crevice, increasing the likelihood of crevice corrosion on the structure. Unless the entire structure is well painted, use of aluminum or steel bolts is not recommended due to their high rate of galvanic attack, and use of 304 stainless steel is undesirable due to extensive crevice corrosion of the fasteners. Use of A286, 316 stainless steel, MP35N, and titanium is favored from the viewpoint of fastener corrosion; however, some means of corrosion protection is necessary to prevent crevice attack of the structure.

MIXED MATERIALS

MP35N and titanium bolts did not experience any corrosion attack in any material tested and should therefore not corrode in a structure having a mixture of the panel materials tested. The effects of these bolt materials on the structural materials in a mixed joint are not known.

Listings of fastener material recommendations for mixed material joints are available.¹ These listings should be used only with caution, however, since many factors can exert significant influence on the corrosion behavior of fastened assemblies.

TECHNICAL REFERENCES

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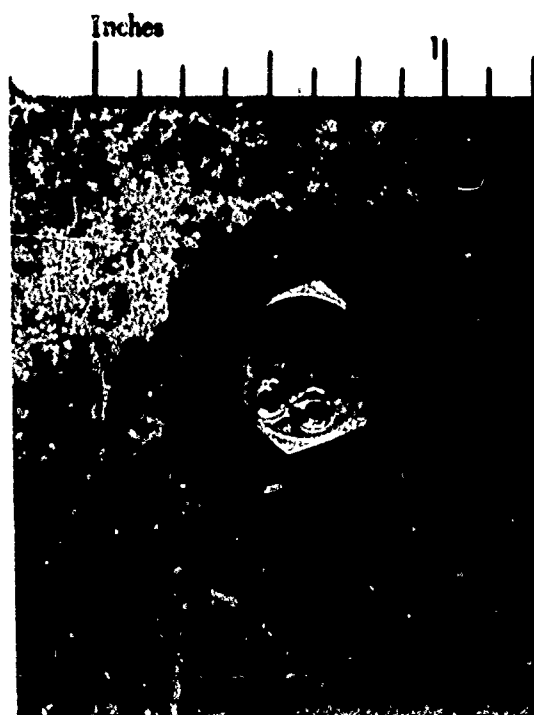


Figure 1
Bolt Assembly with Sealant
Before Exposure

General Attack

Item (a)
Bolt Shank Side



Galvanic Attack

Item (b)
Bolt Head Side



Item (c)
Bolt Shank Side

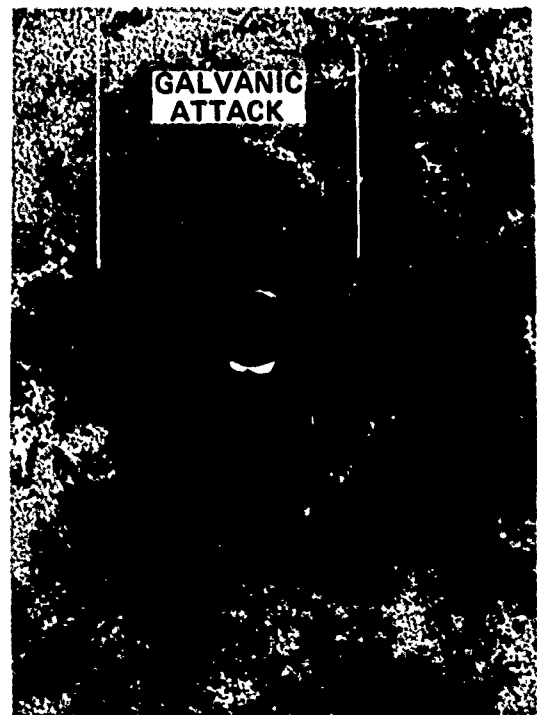
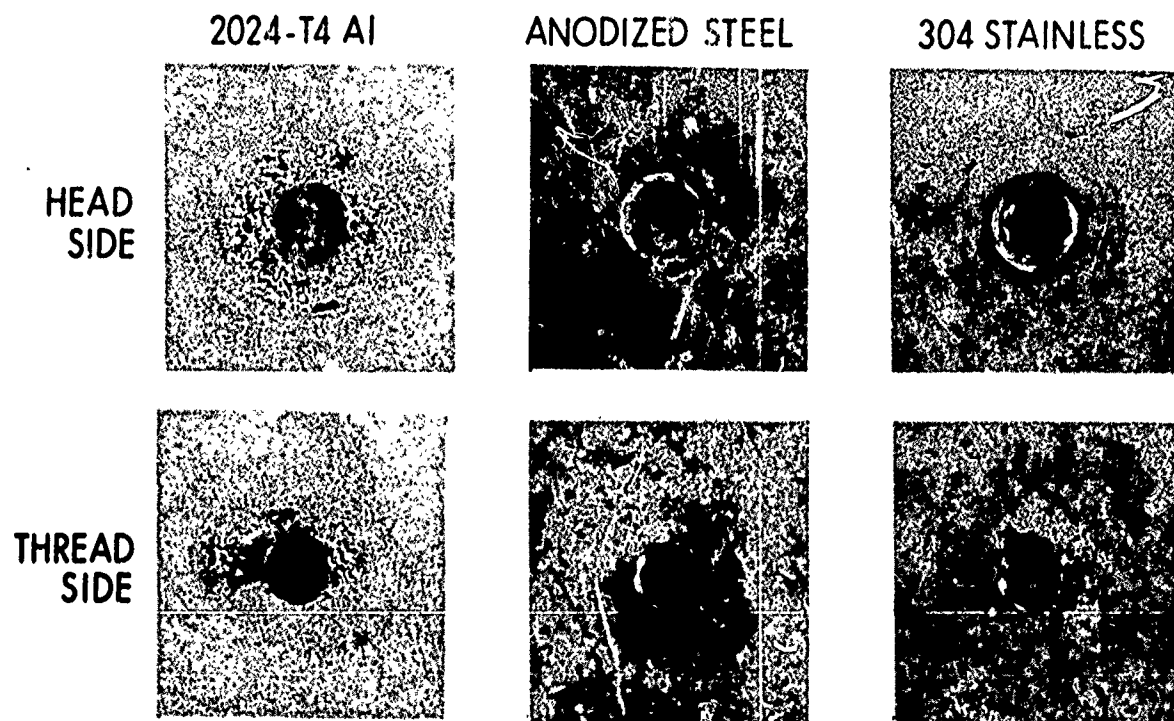
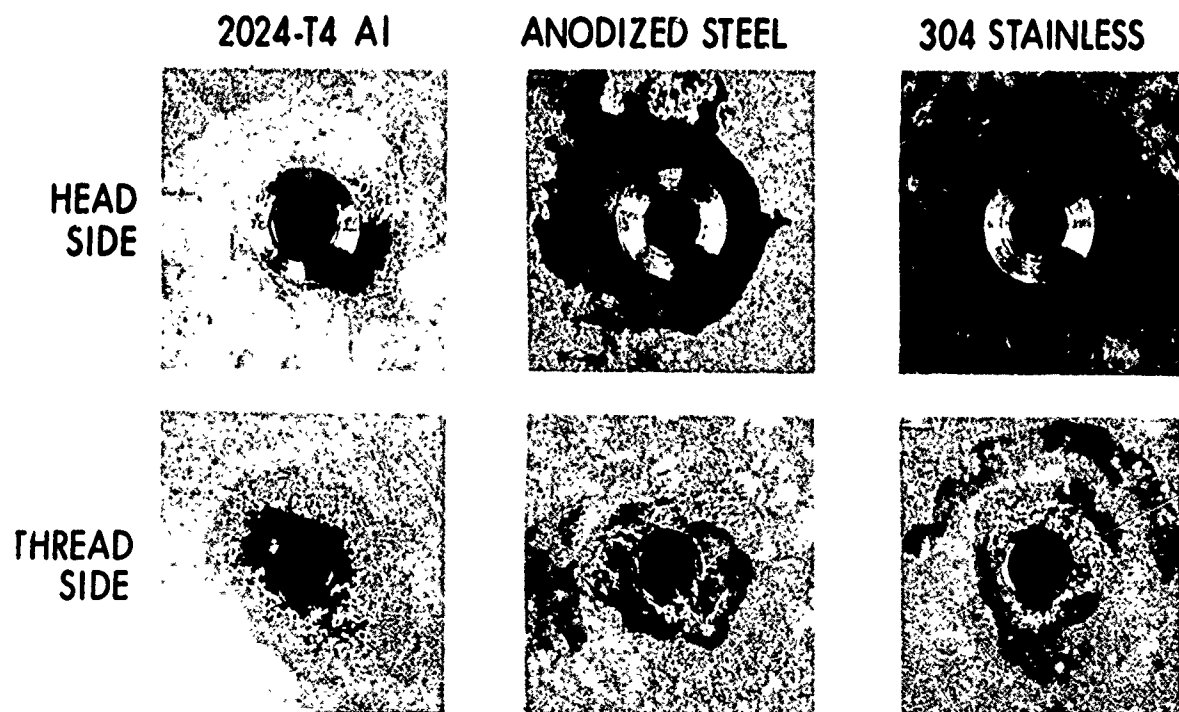


Figure 2
Corrosion Attack on HY-130 Steel Panels

WITH



WI



WITHOUT SEALANT

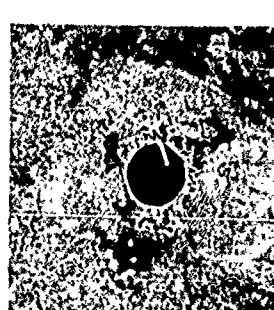
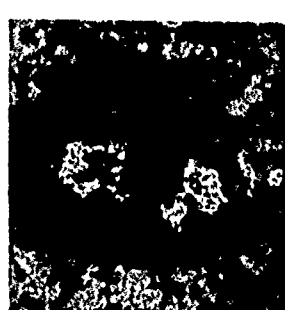
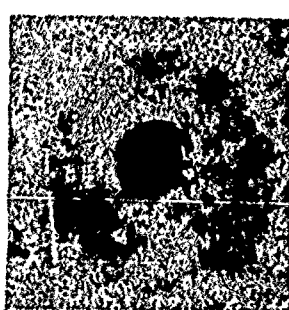
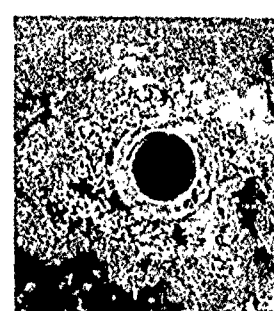
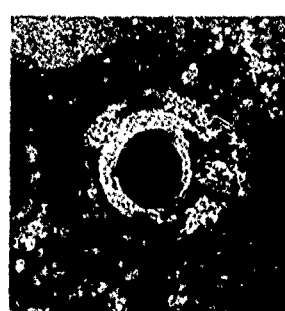
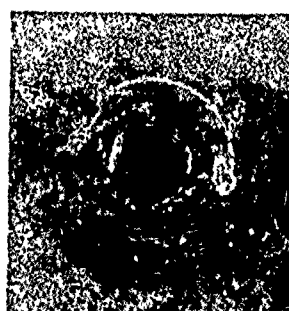
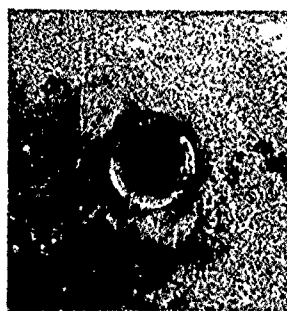
INLESS

316 STAINLESS

A286 IRON-BASE

MP35N MULTIPHASE

TITANIUM



WITH SEALANT

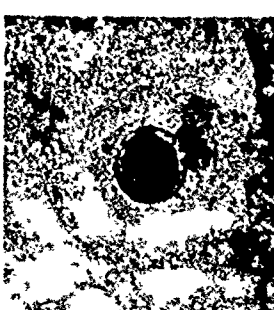
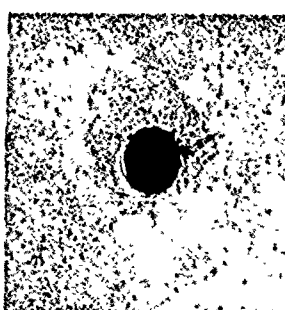
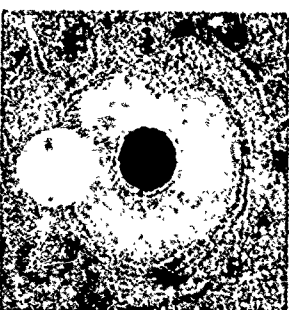
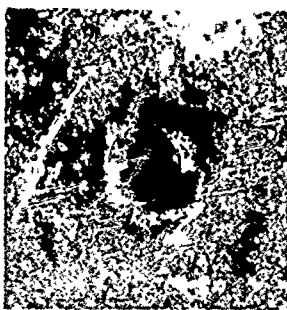
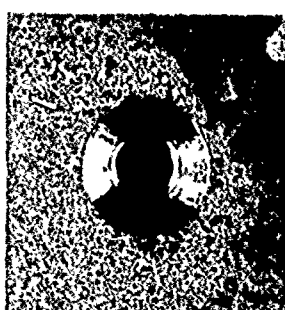
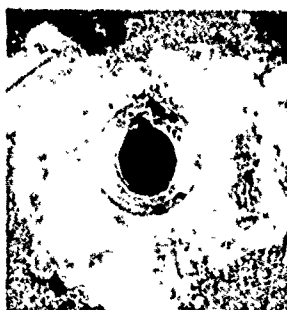
INLESS

316 STAINLESS

A286 IRON-BASE

MP35N MULTIPHASE

TITANIUM



rosion Attack on Aluminum panels (Bolt Materials as Indicated)

Without Sealant

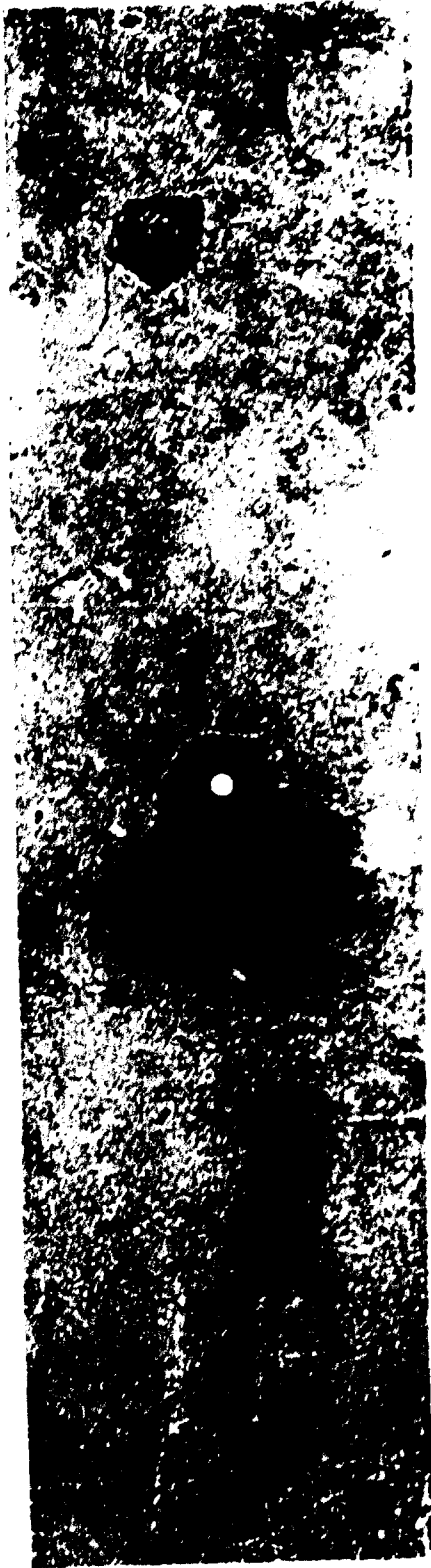


With Sealant



Figure 4
Corrosion Attack on 17-4PH Panels with Aluminum Bolts

Without Sealant



With Sealant



Figure 5
Corrosion Attack on 17-4PH Panels with Steel Bolts

Without Sealant



With Sealant



Figure 6
Corrosion Attack on 17-4PH Panels with 304 Stainless Bolts



With Sealant

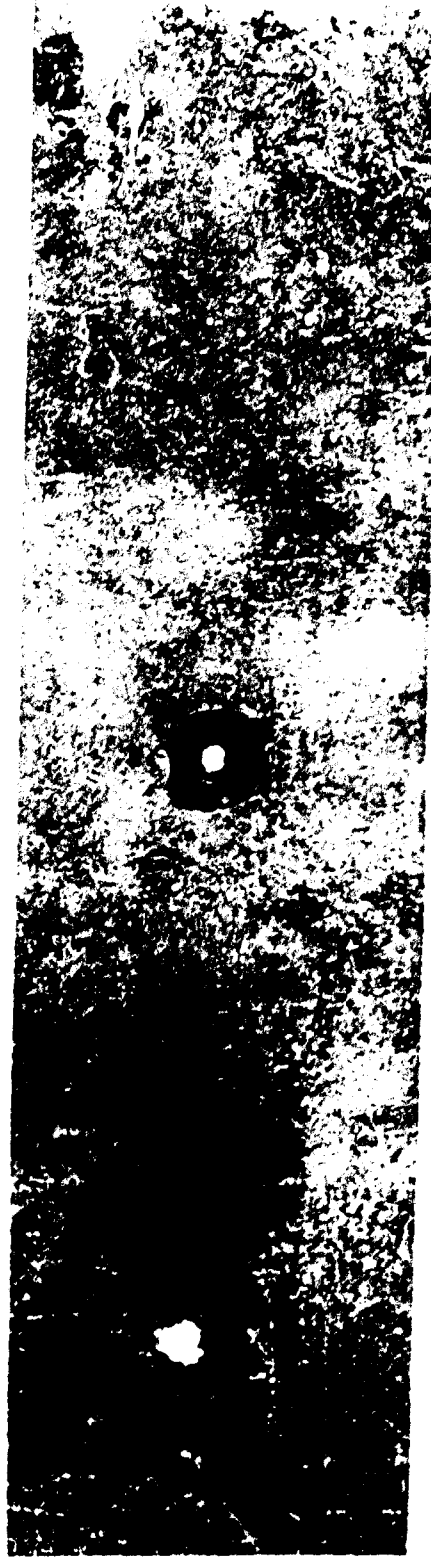
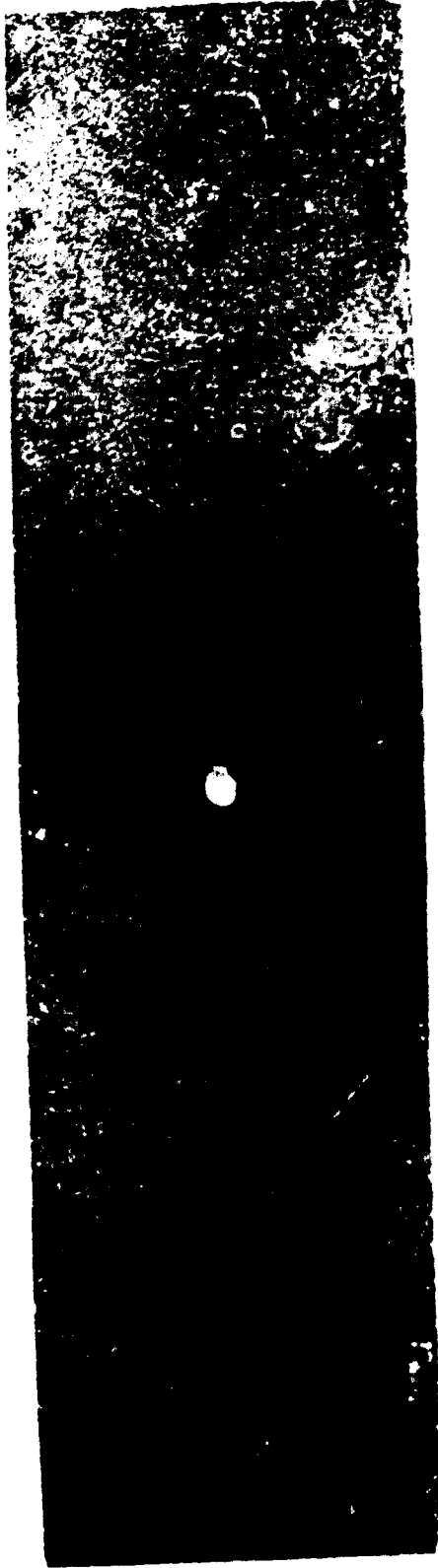


Figure 7
Corrosion Attack on 17-4PH Panels with 316 Stainless Bolts

Without Sealant



With Sealant

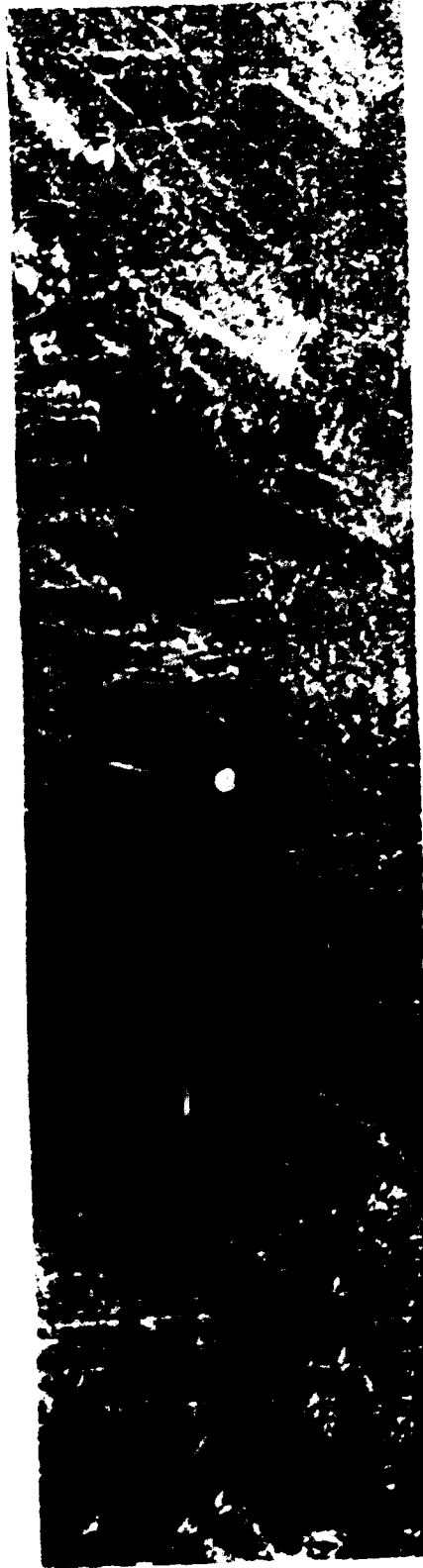


Figure 8
Corrosion Attack on 17-4PH Panels with A286 Bolts



With Sealant



Figure 3
Corrosion Attack on 17-4PH Panels with MP35N Bolts

Without Sealant



With Sealant



Figure 10
Corrosion Attack on 17-4PH Panels with Titanium Bolts

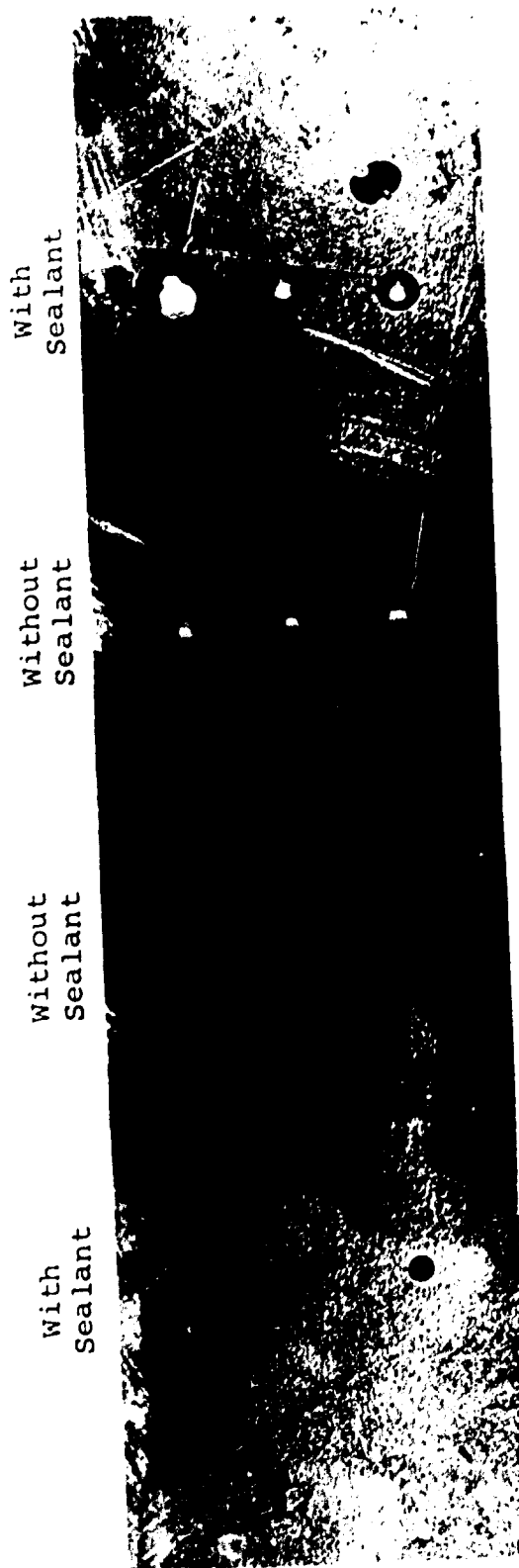
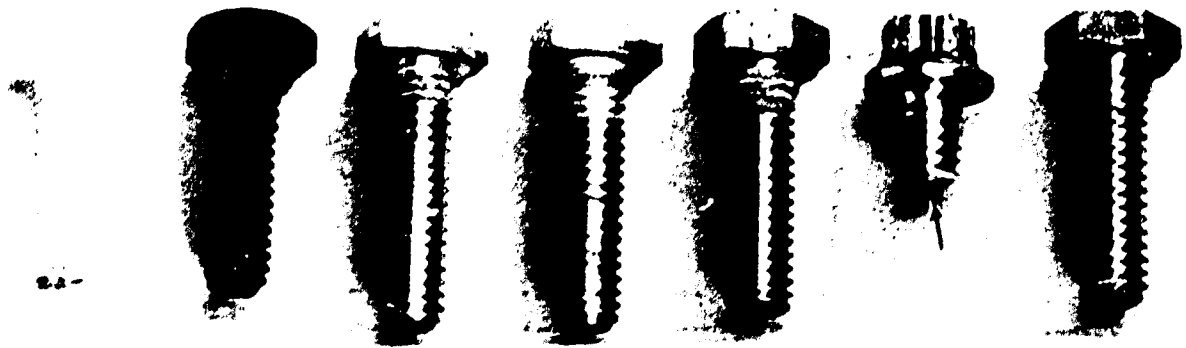
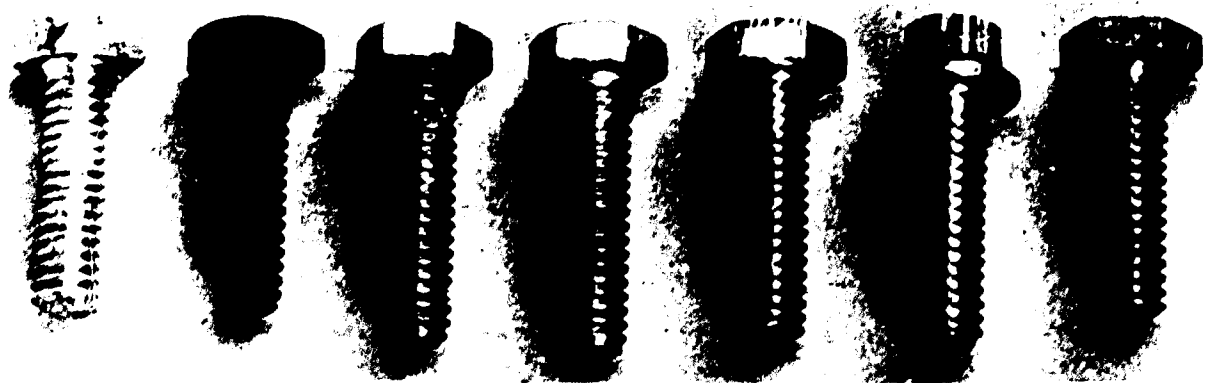


Figure 11
Corrosion Attack on 17-4PH Panel with Small 304 Stainless Bolts

Without Sealant



With Sealant



Al

Steel

304SS

316SS

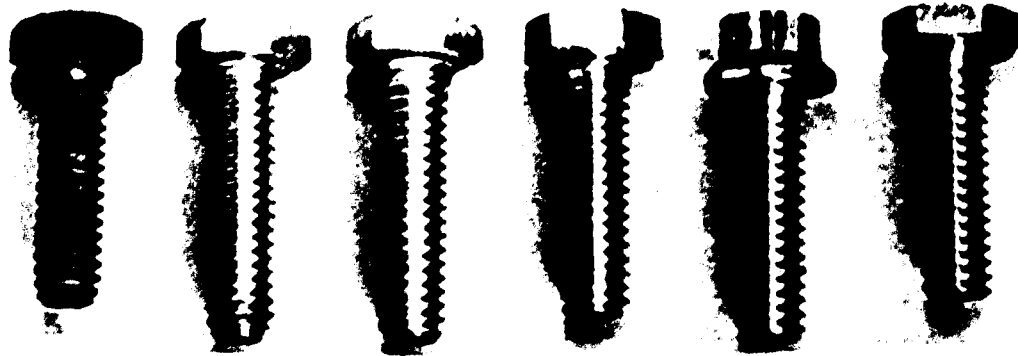
A286

MP35N

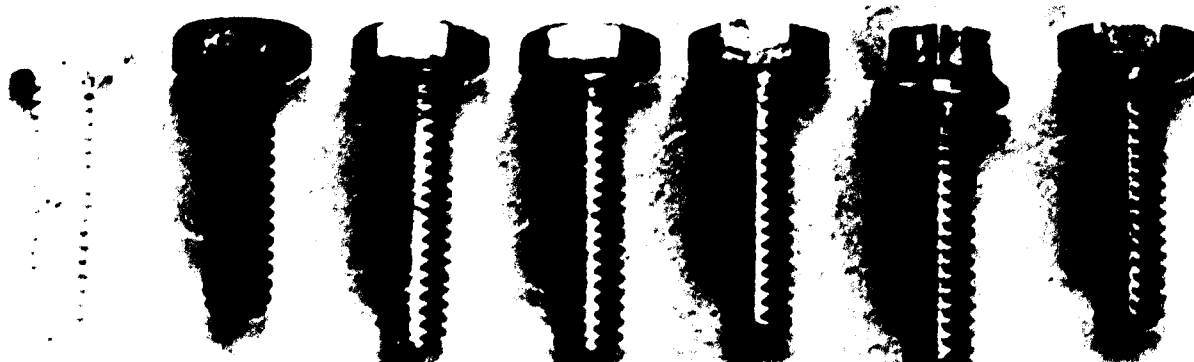
Ti

Figure 12
Corrosion Attack on Bolts in Fiber Glass Panels
(Arrow Indicates Mechanical Damage)

Without Sealant



With Sealant



Al

Steel

304SS

316SS

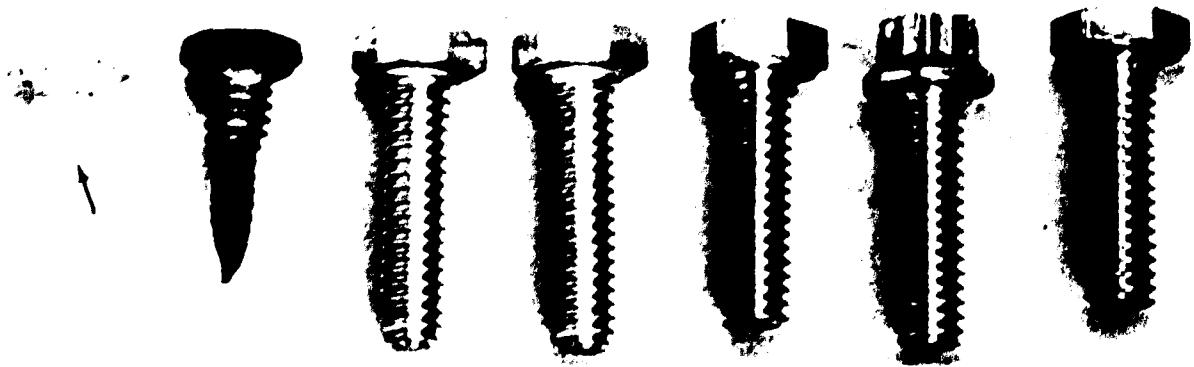
A286

MP35N

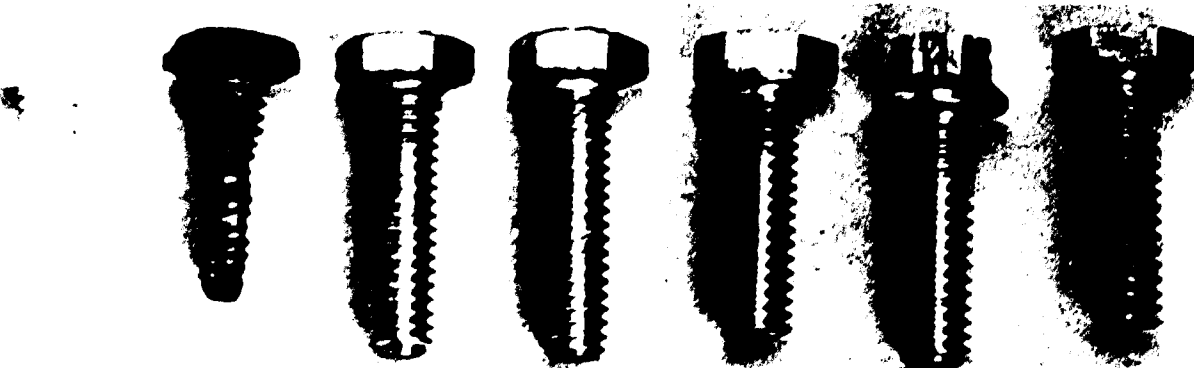
Ti

Figure 13
Corrosion Attack on Bolts in Aluminum Panels

Without Sealant



With Sealant



Al

Steel

304SS

316SS

A286

MP35N

Ti

Figure 14
Corrosion Attack on Bolts in HY-130 Panels
(Arrow Indicates Mechanical Damage)



Figure 15
Corrosion Attack on Bolts in Titanium Panels

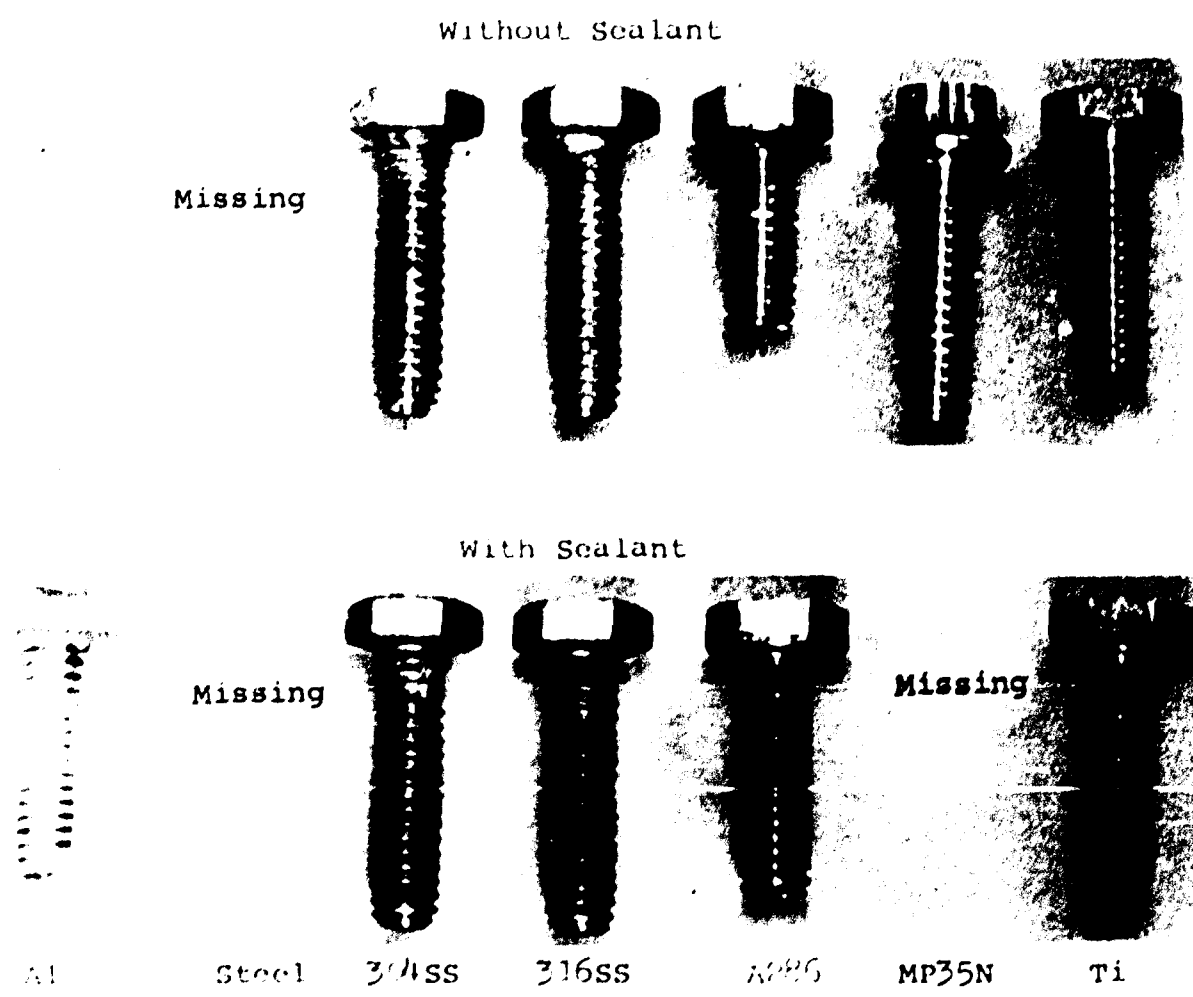


Figure 16
Corrosion Attack on Bolts in 17-4PH Panels

Without Sealant



With Sealant



Figure 17
Corrosion Attack on Small 304 Stainless
Bolts in 17-4PH Panel
(Arrow Indicates Mechanical Damage)

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