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SUMMARY

This report describes an investigation to determine the effect of spot-weld quality on the corrosion behavior of panels fabricated from alclad 24S-T3, 24S-T3, R-301-T6, alclad XB75S-T6, and XB75S-T6, all of 0.040-inch thickness; and R-301-T6 of 0.020-inch thickness. The panels were welded at the Rensselaer Polytechnic Institute at Troy, New York. The exposure tests and visual observations of corrosion were conducted by the National Bureau of Standards, Washington, D. C. After exposure the panels were returned to the Rensselaer Polytechnic Institute for mechanical tests of the welds and metallographic examination of typical weld sections.

This investigation disclosed that exposures of 1 year to tidewater and 3 years to weather had practically no effect on the shear strength of sound spot welds in 0.040-inch alclad 24S-T3. Similarly, exposures of 3 years in tidewater and 3 years in weather had practically no effect on the shear strength of sound spot welds in 0.020-inch R-301-T6, 0.040-inch R-301-T6, and 0.040-inch alclad XB75S-T6. When spot welds in chemically prepared 0.040-inch alclad 24S-T3 sheet exhibited such defects as internal cracks, surface cracks, expelled metal, and dirty surfaces, exposure to tidewater and weather still had little effect on the shear strength of the welds. Observation of corrosion product distribution and metallographic examination, however, indicated that such defects as surface cracks and contamination of the cladding render spot welds in the clad materials susceptible to localized corrosion. In the present investigation the conditions of exposure and the protective effect of adjacent cladding were such that the localized corrosion did not proceed to a point where it could affect the shear strength of the welds. The alloys 24S-T3 and XB75S-T6 were found to be extremely susceptible to corrosion without adequate protection in the form of anodizing and painting. The alclad 24S-T3 sheet which was prepared for spot-welding by wire brushing appeared to be somewhat susceptible to general corrosion. Furthermore, exposure to tidewater and weather was found to reduce the shear strength of spot welds in alclad 24S-T3 sheet which had been wire-brushed. Caution was found necessary in spot-welding

alclad 24S-T3 sheet in which any appreciable diffusion of alloying elements from the core into the cladding has occurred as a consequence of improper heat treatment. In such sheet even spot-welding under optimum conditions tends to accentuate the diffusion which may in time reduce the corrosion resistance of the cladding and eventually lead to localized corrosion of the weld area and loss of weld strength. Exposure to tidewater and weather definitely reduced the shear strength of spot welds in 0.020-inch R-301-T6 sheet made with dirty electrodes and exhibiting surface cracks. The corrosion resistance of defective welds in 0.040-inch R-301-T6 and 0.040-inch alclad XB75S-T6 was not fully revealed in this investigation but the results were generally favorable.

INTRODUCTION

The primary objective of this investigation was to determine the corrosion behavior of spot-welded aluminum-alloy panels which were prepared to exhibit different degrees of weld quality. Tidewater and weather exposure tests had been made on such panels before but with practically no attention to the effect of spot-weld quality on the results. In the latter work the emphasis had been on comparing alloys and methods of assembly (reference 1).

In this investigation it was desired to compare sound spot welds made under optimum conditions with spot welds exhibiting the following defects:

(1) Internal cracks

(2) External cracks

(3) Expelled metal between faying surfaces

(4) Dirty surfaces due to dirty electrodes

It was also desired to compare the corrosion behavior of sound spot welds in sheet whose surfaces were prepared by wire brushing with sound spot welds in sheet which had been chemically surface-treated. The effects of anodizing and painting on the corrosion behavior of certain panels were also to be observed. Originally, it was also desired to compare sound spot welds made with the usual capacitor-discharge equipment with welds subjected to an alternating-current preheat prior to the capacitor discharge, and with welds subjected to an alternating-current postheat following the capacitor discharge. Unfortunately, lack of knowledge of the effects of preheating and postheating and limitations in equipment prevented the satisfactory welding of the latter types of panels at the time the other panels were prepared.

The original investigation was limited in scope to two materials: 24S-T3 and alclad 24S-T3, both in the 0.040-inch gage. All of the 24S-T3 panels and half of the alclad panels exhibiting welds with surface cracks and dirty surfaces were anodized. Two series of 24S-T3 panels were painted after anodizing. At a later date the investigation was extended to include the newer high-strength aluminum alloys, R-301-T6 in the 0.020- and 0.040-inch gages, alclad XB75S-T6 in the 0.040-inch gage and XB75S-T6 in the 0.040-inch gage. Panels were exposed to both tidewater and weather, and the results have been evaluated largely in terms of distribution of corrosion products and effects on weld strength.

This investigation was conducted by the Rensselaer Polytechnic Institute and the National Bureau of Standards with the suggestions and the financial assistance of the Materials Laboratory, Air Materiel Command, Wright-Patterson Air Force Base; the Bureau of Aeronautics of the Navy Department; and the National Advisory Committee for Aeronautics.

PREPARATION OF TEST PANELS

Design.- The test panels were designed as shown in figure 1. The over-all dimensions and location of mounting holes were determined by the exposure racks on which the panels were to be mounted. It was intended that welds 1 to 4 were to be individually tested in shear, and that welds 9 and 10 were to be tested in normal tension. Welds 5 to 8 were intended for radiographic and metallographic examination.

Panel schedule.- The original plans called for the preparation of eight panels for each of the nine conditions shown in table I. Out of each group of eight panels three were to be subjected to tidewater exposure, three to weather exposure, and two were to be safely preserved in the unexposed condition for comparison. The panels of series 2 and series 8 never did materialize because, at the time the rest of the panels were welded, there was no information or experience to serve as a basis for the intelligent selection of conditions for welding panels with preheat or panels which had been assembled prior to their surface treatment. As it turned out, the welding of the panels with postheat in series 3 should not have been attempted for the same reason. At a later date the plan was extended, as shown in table I, to include panels of the high-strength aluminum alloys, R-301-T6 and XB75S-T6.

Surface preparation.- All panels were first degreased in trichloroethylene vapor. After the precleaning operation the panels were subjected to the surface treatment recorded in table II. The panels of series 6 were left with untreated faying surfaces to promote expulsion of metal from the welds. Following the chemical surface treatment the panels were rinsed in clean cold water. The 24S-T3 panels were dried by wiping, whereas the R-301-T6 and XB75S-T6 panels were dried in clean air. In preparing the R-301-T6 and XB75S-T6 panels the vapor degreasing was preceded by an acetone wash.

Spot-welding.- The panels were spot-welded on a machine of the capacitor-discharge type (Federal Spot Welder Type P2-30-RA, Serial No. 8707). The welding current was controlled by means of a special unit which made possible the passage of an alternating-current preheat or postheat in conjunction with the capacitor discharge. The welding conditions are summarized in table III(a). Additional data on actual machine settings are recorded in table III(b). The welding conditions were varied from one series of panels to another in order to obtain the desired weld quality. In all series the magnitude of the welding current was adjusted to give a weld of desired size as determined by the quick section technique. Clean electrode tips and a forging force were always employed when spot welds of the best quality were to be obtained. Cracking of the desired degree was secured by strategic omission of the forging force in combination with a reduction in the welding force, and sometimes with an increase in current. Dirty weld surfaces were obtained by welding with dirty electrodes which had been purposely fouled by welding a few pieces of untreated material at frequent intervals. Strange as it may seem, considerable difficulty was experienced in maintaining the electrode tips in a dirty condition in welding the 24S-T3 panels. At the start of each run the tips were fouled by welding a few pieces of untreated alclad 24S-T3 sheet. The tips invariably cleaned themselves very rapidly as the welding of the 24S-T3 sheet progressed. This is quite the opposite of tip behavior in welding alclad 24S-T3. The difference is believed to be due to the difference in surface hardness of the two materials. A special current wave form consisting of a capacitor discharge followed by an alternating-current postheat was used only in series 3 and P3. A rapidly rising current wave form was employed in series 1, P1, 3, and P3, whereas a slowly rising wave form was employed in all other series. All of the alclad and 24S-T3 panels were welded in the spring of 1943. The R-301-T6 and XB75S-T6 panels were welded in the spring of 1944.

Radiography.- Following the welding, all panels were radiographed to determine which welds were cracked and which were crack-free. With the exception of a few welds the desired results were obtained.

Anodizing.- All of the 24S-T3 panels and two series of the alclad 24S-T3 panels (7 and 10) were anodized at the New Kensington Plant of the Aluminum Company of America. The following procedure was followed:

(1) The panels were first cleaned by immersing for 1 minute in a 6-ounce-per-gallon Oakite Aviation cleaner at 180° F. The panels were then racked and treated in batches of 14 pieces per rack. They were anodically coated in a solution containing approximately 35 grams per liter of chromic acid operated at 95° F with a pH of 0.75. The voltage was increased at the rate of about 8 volts per minute to 40 volts, and the anodic treatment then continued for 30 minutes at that voltage.

(2) The panels were rinsed, more thoroughly perhaps then usual, in order to remove the chromic acid which bled from the lapped joints. This was done by immersing in water and draining in air five times in succession. The panels were then unracked and dried.

Unfortunately, in the anodizing operation it was not realized that both 24S-T3 and alclad 24S-T3 panels were being treated. When one group failed to produce any coating, the ends were lightly filed to insure contact and the panels recoated as before. The panels so treated are believed to have been the alclad 24S-T3 panels in series 7'.

Painting.- After being anodized, two series of the 24S-T3 panels (P1' and P9') were painted at the Naval Research Laboratory in accordance with the specifications of the Bureau of Aeronautics of the Navy Department. The painting consisted of two coats of a P-27 primer, and two coats of a nonspecular lacquer, gray, M-485-C.

EXPOSURE TESTS

The panels were exposed, both in the marine atmosphere and in the tidewater at the U. S. Naval Air Station, Hampton Roads, Virginia. The distribution of panels with respect to type and duration of exposure is shown in table IV. The tidewater panels were suspended vertically with their 14-inch length along the horizontal axis at mean tide level so that they were completely immersed at high tide and completely exposed to the atmosphere at low tide. The panels exposed in the atmosphere were inclined at an angle of 45° from the horizontal and faced east-southeast. The A sides (fig. 1) were exposed toward the sky and welds numbered from 1 to 4 were in the upper half of the panels.

The results of the visual examinations of the corroded alloys after various periods of exposure are given in tables V to IX, inclusive. The capital letters and numerals in the tables signify the following types and degrees of corrosive attack:

A	no corrosion products
B	ring of corrosion products just inside circumference of weld as illustrated in figure 2

C	area of corrosion products in center of weld as illustrated in figure 3
D	corrosion products on circumference (rim of depressed area) of weld, a typical example of which is shown in figure 4
E	rough discolored ring inside circumference of weld, darker than main portion of panel as shown in figure 5
F	dark gray colored area in center of weld as shown in figure 6
G	corrosion products general, that is, about equally distributed on the welds and the rest of the panel (This is illustrated in fig. 7, which is the earthward surface of a panel after 36 months of exposure in marine atmosphere. Skyward surfaces of panels, panels exposed in tidewater, and panels exposed for shorter periods of time (less than 36 months) were not necessarily as severely corroded as that shown in fig. 7, but uniformity of corrosive attack was about the same in each case.)
H	brown stains or corrosion products with yellow color, indicating seepage of chromic acid
I	corrosion products 1/16 to 1/8 inch in diameter, mostly on top third of panel and equally distributed on welds and main part of panel
J	general severe corrosion on spot welds as illustrated in figure 8
K	corrosive attack in form of patterned ring on spot weld as shown in figure 9
L	welds separated at faying surfaces as shown in figure 10
M	general pitting type of corrosive attack
N	cracks visible on surface of welds as illustrated in figure 11
P	deep pitting, corrosive attack penetrated weld spot to interface between the two sheets; entire weld consisted of corrosion products (Illustrations of these two conditions are shown in figs. 12 and 13.)
R	deeply pitted dark ring on circumference of weld as illustrated in figure 14
S	corrosive attack penetrated sheet from faying surface to outer surface

1 corrosion products between faying surfaces forced sheets apart a maximum distance of 1/16 inch (Illustrations of separations of faying surfaces are shown in figs. 15 and 16.)

2 corrosion products between faying surfaces forced sheets apart a distance of 2/16 inch

3 corrosion products between faying surfaces forced sheets apart a distance of 3/16 inch

Discussion of Results

24S-T3 and alclad 24S-T3.- After 2 days of exposure in the tidewater all of the unpainted, anodized 24S-T3 panels were covered with white corrosion products. On the panels in which the spot welds were cracked to the surface and expelled (series P5-6)[1], a ring of white corrosion products formed a concentric circle within the circumference of each weld, only on one side of the panels. A typical example of this formation is shown in figure 2. Such rings were also present on some of the sound spot welds having 50-percent or less penetration (series 9), on unanodized alclad 24S-T3 panels with sound welds having 50-percent or less penetration (series 1), and on "poor" welds made with dirty electrode tips resulting in surface burning or blackening (series 7).

This early rapid attack on the anodized 24S-T3 panels resulted because their treatment was not in accordance with the best recommended practice. These panels were anodized in a bath containing 3.5 percent chromic acid, operated at 40 volts, for approximately 30 minutes. More corrosion-resistant coatings are obtained when the chromic acid concentration is about 9.5 percent and when the period of treatment is prolonged to 1 hour. Panels of 24S-T3 alloy treated in accordance with this practice showed little evidence of corrosive attack after exposure for 1 month under similar conditions at the same location.

The alclad 24S-T3 panels were uncorroded after 2 days of exposure in the tidewater, except for the welds. Sound welds having 50-percent or less penetration (series 3) and welds made with dirty electrode tips (series 7) were unattacked. Corrosion products were found at the centers of some welds on panels welded so as to leave high residual stresses (series 4); panels with cracks visible on the surface of the welds (series 5); and panels with fins of weld metal expelled between the sheets (series 6), a typical example of which is shown in figure 3.

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[1] Numbers in parentheses refer to panel numbers given in table IV.

On anodized panels welded so that cracks were visible on the surface of the welds (series 10), white corrosion products sharply outlined these cracks.

The appearance of the panels after 1 month was essentially the same as after 2 days of exposure in the tidewater.

In general, with the exceptions noted later, there were no significant changes in the surface appearance of the panels between the second and twelfth month of exposure in the tidewater. Most of the corrosive attack on the anodized 24S-T3 panels occurred at the faying surfaces after the first month of exposure. The reason for this was that the panels were anodized after they were spot-welded, hence the faying surfaces were not anodically coated. Corrosion products approximately 1/8 inch thick accumulated between the faying surfaces of the anodized 24S-T3 panels after 6 months of exposure (fig. 15), and they were about 3/16 inch thick after 12 months of exposure (fig. 16). Such corrosion products were present, but to a lesser degree, on the anodized and painted 24S-T3 panels but were not present on the alclad 24S-T3 panels.

The 24S-T3 panels on which corrosion products were present in greatest quantity at the 1- by 4-inch areas of overlap were: One with sound welds having 50-percent or less penetration (series P1), one with sound welds having 50-percent or less penetration using a hot postheat (series P3), one with welds cracked to the surface and expelled (series P5-6) (6 months of exposure in the tidewater), and one with welds cracked to the surface and expelled (series P5-6) (12 months of exposure in the tidewater). After 12 months of exposure in the tidewater, the 24S-T3 panel, which was welded so as to leave high residual stresses so that any given weld may or may not contain fine internal cracks (series P4), was completely separated at the 1- by 4-inch overlap. On the areas of overlap, which were 4 by 5 inches, corrosive attack starting at the faying surfaces penetrated the sheet in some areas. Holes so formed were present on the following 24S-T3 panels after 12 months of exposure in the tidewater: One with sound welds having 50-percent or less penetration (series P1), one with sound welds having 50-percent or less penetration using a hot postheat (series P3), one with welds cracked to the surface and expelled (series P5-6) (6 months of exposure), one in which the welds were made with dirty electrode tips (series P7), and one with sound welds having 50-percent or less penetration (series P9).

After 24 months of exposure in the marine atmosphere, the quantity of corrosion products on the panels was somewhat greater than on those removed after 12 months of exposure. The products were confined chiefly to the earthward surfaces, and were more or less uniformly distributed on the welded and unwelded areas with the following exceptions: The corrosion products were considerably thicker on the earthward surfaces (side B) of welds numbered 5 through 10 than on the unwelded areas of the following alclad 24S-T3 panels: One with sound welds having 50-percent or less penetration (series 1), one with cracked welds having cracks visible on the surface (series 5), one on which fins of weld metal were expelled between the sheets (series 6), and one on which the welds were made with dirty electrode tips (series 7). On the panel with sound welds having 50-percent or less penetration (series 1), the corrosion products were also heavier on the welds numbered 1 through 4 on the earthward surface (side B, fig. 1).

After 24 months of exposure in the marine atmosphere, the welds on all the anodized 24S-T3 panels, irrespective of the technique used in their preparation, exhibited no evidence of severe corrosion. Products of corrosion were present to about the same extent on these welds as on the remainder of the sheet. All of the welds on the alclad 24S-T3 panels were in good condition except welds numbered 5 through 10 on the panel with cracked welds with cracks visible at the surface (series 5), on one which had fins of weld metal expelled between the sheets (series 6), and on one on which the welds were made with dirty electrode tips (series 7).

There was no evidence of paint failures or of corrosion products on the painted panels after 24 months of exposure in the marine atmosphere.

At the end of 36 months of exposure in the marine atmosphere the quantity of corrosion products on the earthward surfaces of the panels was greater than on those removed from exposure at the end of 24 months. On the alclad 24S-T3 panels fabricated with cracked welds (series 5) and with dirty electrode tips (series 7), the corrosion products on the earthward surfaces were considerably thicker on the welds numbered 5 through 10 than on the remaining portions of the panels. The anodized alclad 24S-T3 panels fabricated with dirty electrode tips (series 7) and with cracked welds (series 10) were light gray on their skyward surfaces and mottled with dark gray spots. On the earthward surfaces the corroded areas were fewer than on the anodized 24S-T3 panels but were larger in diameter.

XB75S-T6, alclad XB75S-T6, and R-301-T6.- The spot welds on the XB75S-T6 panels were selectively attacked when exposed both in the tidewater and in the marine atmosphere irrespective of whether the welding technique was "good" or "poor." These welds were considerably corroded after 2 days of exposure in the tidewater and were severely corroded at the end of 2 weeks, as is illustrated in figure 17. After 12 months it was evident that the attack was most severe in a ring of pits on the circumference of the welds (fig. 14) and that the depth of these pits increased with time. Ultimately the centers of some of the welds were also severely attacked (fig. 8) and after 24 months of exposure in the tidewater complete penetration of the weld metal was effected in some cases (figs. 12 and 13).

During spot-welding the high temperatures attained and the rapid rates of heating and cooling may have caused some grain-boundary fusion, which possibly was accompanied by local precipitation of some constituent out of solid solution. The corrosion resistance in areas of grain-boundary fusion or in those containing local precipitates of either cathodic or anodic constituents would be impaired under most conditions of exposure.

The XB75S-T6 panel fabricated with poor welds had separated into its three component parts when it was removed from the tidewater after 36 months of exposure. The faying surfaces after cleaning to remove the corrosion products are shown in figure 10. The corrosive attack on these surfaces was severe, with pits of considerable depth, approximately one-third the thickness of the sheet, in the area adjacent to weld 7.

The welds in the XB75S-T6 panels were also severely attacked after 7 months of exposure in the marine atmosphere, this attack being more severe on the panels welded with the poor technique.

The welds made with the poor technique on the alclad XB75S-T6 and R-301-T6 panels were attacked more than those made with the good technique after 7 months of exposure in the tidewater. The attack on the poor welds frequently was characterized by a pattern suggesting an origin associated with the dirty welding electrode tip, an example of which is illustrated in figure 9. This pattern invariably occurred only on one side of a panel. It was also present on panels with poor welds after 12, 24, and 36 months of exposure. In no case was it present on the good welds on these materials exposed in the tidewater for periods up to 36 months.

Poor welds numbered 5 and 6 on the 0.020-inch-thick R-301-T6 panel had split apart at the faying surfaces and the latter were somewhat more corroded than the outer surfaces of the sheets after 12 months of exposure in the tidewater.

The good welds on the alclad XB75S-T6 and R-301-T6 panels were corroded to about the same extent as the main portion of the panels after 7 months of exposure in the marine atmosphere while the poor welds were corroded more than the main portion of the panels. These same conditions were obtained for exposures as long as 36 months.

There was no evidence of electrolytic corrosion of the "core" materials of the alclad XB75S-T6 and R-301-T6 alloys along the cut edges of the panels after 36 months of exposure in the tidewater and in the marine atmosphere.

There were no indications of the accumulation of corrosion products at the faying surfaces of the XB75S-T6, alclad XB75S-T6, and R-301-T6 panels after 36 months of exposure in the marine atmosphere.

Some corrosion products had accumulated at the faying surfaces of the XB75S-T6 panels after 12 months of exposure in the tidewater. Two poor spot welds on the 0.020-inch-thick R-301-T6 panel had parted at the faying surfaces, and these surfaces were more corroded than the outer surfaces. There were corrosion products at the faying surfaces on all except the alclad XB75S-T6 panels at the end of 24 months of exposure in the tidewater. These products were at least twice as thick on the XB75S-T6 panels as on the R-301-T6 panels. At the end of 36 months of exposure in the tidewater, there were corrosion products at the faying surfaces of all the panels. They were much thicker on the XB75S-T6 than on the alclad XB75S-T6 and the R-301-T6 panels. The poor welds on the XB75S-T6 panel had parted at the faying surfaces which were considerably more corroded than the outer surfaces. Deep wide pits were found in the centers of the surfaces of the 4- by 5-inch overlap.

The surfaces of the XB75S-T6, alclad XB75S-T6, and R-301-T6 panels were unattacked for the first 7 months of exposure in the tidewater but shallow pitting developed in scattered areas during the next 5 months. The pitting became more general during the succeeding 12 months and increased in depth up to 36 months of exposure. The pits in the R-301-T6 panels were larger in diameter but appeared to be no deeper than those in the XB75S-T6 and the alclad XB75S-T6 panels.

The skyward surfaces of the panels exposed in the marine atmosphere turned a dirty gray color and were mottled with occasional areas of thin white corrosion products during the first 12 months of exposure. In the succeeding 24 months the panels darkened in color and the mottling became general.

The earthward surfaces became more or less uniformly covered with white corrosion products during the first 12 months of exposure in the marine atmosphere. These products were thicker on the XB75S-T6 and the alclad XB75S-T6 than on the R-301-T6 panels. They increased in thickness and turned gray during the next 24 months, but after 36 months they were thinner and more uniformly distributed on the XB75S-T6 and alclad XB75S-T6 than on the R-301-T6 panels. The corrosion products were also thicker on the XB75S-T6 than on the alclad XB75S-T6 panels.

Summary of Corrosion Observations

From exposure tests and visual examination of the corrosion of spot-welded panels fabricated from alclad 24S-T3, 24S-T3, R-301-T6, alclad XB75S-T6, and XB75S-T6, the following observations were made:

(1) In general, irrespective of the welding techniques employed, most of the spot welds on the 24S-T3 and alclad 24S-T3 alloys were as resistant to corrosion as were unwelded alloys after exposure periods of 12 months in the tidewater and 36 months in the marine atmosphere. There were a few panels on which the spot welds were less resistant to corrosion than the sheet material but the corrosion damage was not considered to be serious: (a) Some of the spot welds on the alclad 24S-T3 panels made with dirty electrode tips and in such a manner so as to produce cracks extending to the surface; (b) the spot welds on the anodized alclad 24S-T3 panel initially made with cracks extending to the surface.

(2) The anodic films on the 24S-T3 panels afforded negligible protection because they were formed in a 3.5 percent chromic acid solution operated for only 30 minutes. More protective anodic films are obtained if the concentration of the bath is maintained at 9.5 percent chromic acid and the time of anodization is prolonged to 1 hour. All the anodized 24S-T3 panels were covered with corrosion products after 2 days of exposure in the tidewater. In previous tests, at the same location, of 24S-T3 material anodized in a 9.5 percent chromic acid solution, corrosion products did not form until after 30 days of exposure in the tidewater.

(3) The most severe corrosive attack occurred at the faying surfaces of the sheets of anodized 24S-T3 panels exposed in the tidewater. Because these surfaces were not anodized, the retention of sea water between the sheets resulted in crevice or concentration cell corrosion causing complete penetration in some cases.

There was negligible attack at the faying surfaces of the alclad 24S-T3 panels after 12 months of exposure in the tidewater, irrespective of whether or not they were anodized.

No severe attack occurred at the faying surfaces of the 24S-T3 and alclad 24S-T3 panels exposed as long as 36 months in the marine atmosphere.

(4) There was slight evidence of corrosive attack on the anodized and painted 24S-T3 panels after 12 months of exposure in the tidewater and none after 36 months of exposure in the marine atmosphere.

(5) Spot-welded alclad 24S-T3 material is considered to be satisfactory for use in marine atmospheres and for use where it is subject to wetting by sea water at frequent intervals for at least 12 months.

(6) Spot-welded and anodized 24S-T3 material should have additional protection, especially at the faying surfaces, if it is to be subjected to frequent wetting by sea water or sea spray.

(7) The spot welds on the XB75S-T6 panels were very susceptible to corrosion both in the tidewater and in the marine atmosphere. They were severely corroded after 15 days of exposure in the tidewater and 7 months of exposure in the marine atmosphere.

(8) There were no indications of the accumulation of corrosion products at the faying surfaces of the XB75S-T6, alclad XB75S-T6, and R-301-T6 panels after 36 months of exposure in the marine atmosphere. There was no severe attack at the faying surfaces of the alclad XB75S-T6 and R-301-T6 panels after 36 months of exposure in the tidewater. The most severe attack occurred at the faying surfaces of the XB75S-T6 panels welded with a "poor" technique and exposed in the tidewater.

(9) Spot-welded alclad XB75S-T6 and R-301-T6 materials are considered to be satisfactory for use in marine atmospheres and for periods of time up to 36 months where they are subject to wetting by sea water or sea spray.

(10) Unprotected spot-welded XB75S-T6 is not recommended for use under marine conditions.

MECHANICAL TESTS

Following the return of the exposed panels to Rensselaer Polytechnic Institute, each panel was shear-cut into its component specimens for mechanical testing and metallographic examination. The shear and tensile specimens were both tested in a hydraulic testing machine operated at a head speed of the order of 0.2 inch per minute. Templin self-alining grips were used for the shear specimens. The tensile specimens were of the U type which required drilling and forming to fit test blocks (reference 2). This was unfortunate because a number of specimens broke in the sheet while being bent to fit the test blocks. This occurred most often in those specimens where there was bad general corrosion of the sheet along the bend line. In the case of the XB75S-T6 all the tensile specimens broke in this manner while being bent. The U-type tensile specimen has been largely superseded by the "cross" type which requires no bending (reference 2). It should be pointed out, however, that the latter type of specimen cannot be obtained from the standard corrosion test panel. All of the alclad 24S-T3 and 24S-T3 panels with the exception of those exposed to weather for 24 and 36 months were tested in the fall of 1944. The R-301-T6 and XB75S-T6 panels and the remaining 24S-T3 panels were tested in the spring of 1948.

The average results of the mechanical tests are presented in tables X and XI. These results are summarized in a more useful form, in terms of percent change in strength due to exposure, in tables XII through XVII. It was evident that the welds of series 7 and 7' were very inconsistent for some unknown reason. The coefficients of variation of the control welds for these series were 67 and 59 percent, respectively, whereas the corresponding coefficients never exceeded 12 percent in the other series. The results of these two series have not been included in the summary tables since it is felt that they should be disregarded.

Effect of Exposure on Weld Shear Strength

The effects of exposure on the shear strength of spot welds in alclad 24S-T panels are summarized in table XII. Exposure had practically no effect on the sound welds of series 1. Actually a gain in strength was indicated but this is not attributed to the exposure. A significant loss in strength of the welds of series 3 is indicated for exposure to both tidewater and weather. In interpreting this result, account must be taken not only of the fact that these welds were subjected to postheating in the welding machine but also of the fact that the welds were small in comparison to the other welds in these tests. The loss in strength upon exposure cannot be attributed to either postheating or weld size until further evidence is available. The internally cracked welds in series 4 showed a definite loss in shear strength after exposure to tidewater for 1 month but this was not substantiated by the results obtained after longer exposures to tidewater and weather. This indicates that internal cracks have little or no influence on the effects of exposure with respect to weld shear strength in alclad 24S-T3. The welds which were cracked to the surface in series 5 showed a loss in shear strength of 10.6 percent after 7 months' exposure in tidewater but this was not substantiated by results obtained with longer exposures to tidewater and weather. Furthermore, the above loss is not very significant when the strength consistency of the control welds is considered. It should be pointed out that the cracks were visible on only one surface of the welds in these panels. The effect of exposure might have been greater if the cracking had been still more severe. It may be said that, under some conditions, surface cracks do not influence the effect of exposure on weld shear strength.

Welds from which metal was expelled in series 6 exhibited a general loss in strength ranging from 1.2 percent after an exposure of 4 weeks to tidewater to 13.5 percent after an exposure of 2 years to weather. It should be noted that these panels were prepared for welding by wire brushing the outer surfaces and leaving the faying surfaces untreated in order to promote expulsion. This was probably a mistake since the loss in strength may have been due more to the wire brushing than to the presence of particles of expelled metal between the faying surfaces. At any rate the expulsion was very severe, yet the general loss in strength was a little less than that exhibited by the sound welds in fully wire-brushed panels of series 9. In the latter series the average loss in weld strength was 9 percent for all periods of exposure. This is believed to be significant, especially since the loss ranged between 10.3 and 13.3 percent for four of the six periods of exposure. It appears that the effect of exposure on weld shear strength was much more severe on sound welds in wire-brushed sheet than on sound welds in chemically treated sheet. It should be recalled that for welds of equal size higher shear strength can be obtained with wire-brushed material than with chemically treated material (reference 3). This is due to the fact that in wire-brushed material the cladding is bonded for a short distance beyond the zone of fusion. It may be that the strength of this bond is weakened by exposure. The panels of series 10 were prepared for the purpose of determining the extent to which anodizing protects spot welds that are cracked to the surface. In this series the changes in weld strength were scattered between a gain of 8.4 percent after exposure of 4 weeks to tidewater to a loss of 12.2 percent after exposure of 2 years to weather. It does not appear that any change in weld strength can be attributed to exposure, but the same might be said about the welds of series 5 which were also cracked to the surface and left without the protection of anodizing. Anodizing probably provides protection which was not greatly needed under the conditions of this investigation. Therefore, no conclusions pertaining to the benefits of anodizing can be drawn. The above observations can be summarized by the statement that, under the conditions of this investigation, surface preparation of alclad 24S-T3 sheet by wire brushing appears to be somewhat more detrimental with respect to effect of exposure on weld shear strength than such defects as internal cracks, surface cracks, and particles of expelled metal between the faying surfaces.

The effects of exposure on the shear strength of spot welds in 24S-T3 panels are summarized in table XIII. It should be pointed out that all these panels were anodized after welding, yet areas of general corrosion developed at many points on the surfaces of nearly all panels. This is taken as an indication that there was something wrong with the anodizing. The more serious losses in weld strength seem to have occurred where a weld happened to be located within an area of general corrosion. As a result, the more serious losses in weld strength occurred rather erratically. The sound welds of series P1 exhibited a loss in strength of 35 percent after exposure of 7 months to tidewater but this loss was not substantiated by the results obtained after other periods of exposure. This erratic behavior was typical of nearly all the anodized 24S-T3 panels and is probably indicative of the conditions referred to above. It should be pointed out that all the welds in this series exhibited evidence of particles of expelled metal between the faying surfaces without serious consequences. The panels of series P1' were so well-protected by the anodizing and the paint that there was no significant change in shear strength due to exposure either in tidewater or in weather. As in the previous series, all the welds exhibited evidence of particles of expelled metal between the faying surfaces with no serious consequences. The welds of series P3 exhibited a very serious loss in shear strength of 81 percent after an exposure of 7 months to tidewater. At the opposite end of the same panel two tension specimens showed a loss of only 13 percent in strength. Exposure at other periods in both tidewater and weather seemed to have no effect whatever upon weld shear strength. This is further evidence of the erratic behavior of the 24S-T3 panels which is attributed to some defect in the anodizing. It does not appear that the postheating of these welds in the welding machine was detrimental with respect to the effects of exposure on weld shear strength. It should be pointed out that within the knowledge of the investigators nothing was accomplished by the postheating. In the internally cracked welds of series P4 serious losses in shear strength of 19 and 100 percent occurred upon exposures to tidewater of 7 and 12 months, respectively. In the latter cases the welds were entirely corroded away, whereas at the opposite end of the same panel the two tensile specimens lost only 13 percent in strength. As in the three previous series, these losses are attributed more to inferior anodizing than to the presence of internal cracks. There seems to be a slight tendency toward loss of strength with exposure to weather. The welds made with cracks extending to the surface and with particles of expelled metal between the faying surfaces in series P5/6 show serious losses of 27 and 44 percent after exposures of 7 and 12 months, respectively, in tidewater. Here there is a question whether the inferior anodizing or the surface cracks were responsible for the severe losses. Judging from the results in series P1, the losses probably cannot be attributed to the particles of expelled metal between the faying surfaces. Exposure to weather for 12 months had no effect on weld strength but losses of the order of 9 percent appeared after exposures of 2 and 3 years to weather. Exposure to tidewater or weather had no effect on the shear strength of the welds made with dirty electrodes in series P7. In fact a gain in shear strength is indicated by the results for all but one exposure. At the opposite end of the same panel similar welds exhibited a serious loss in normal tensile strength at all but one exposure. If the above discrepancy can be explained in terms of erratic conditions associated with the anodizing, one might conclude that welding of 24S-T3 with dirty electrode tips is not particularly harmful when a good job of anodizing is done. One must bear in mind, however, the difficulty in maintaining the electrode tips in a dirty condition while welding this series of panels. It is possible that the tips were somewhat cleaner for welding the shear specimens in this particular panel. Sound welds in wire-brushed panels, series P9, showed a serious loss in shear strength for four out of six periods of exposure. It is impossible to say whether this was due to wire brushing or to inferior anodizing. The panels of series P9' were similar to those of series P9 except for the fact that they were painted after anodizing. While the loss in shear strength ranged from 7 to 9 percent for all exposures, it was definitely less than in series P9. It is evident that while the painting was beneficial, it did not make up for the inferior anodizing, the effects of wire brushing, or possibly both. There is not much point in attempting to summarize the above observations in view of the erratic conditions encountered.

The effect of exposure on the shear strength of spot welds in the high-strength aluminum alloys, R-301-T6 and XB75S-T6, are summarized in table XIV. In series 2R it is evident that the shear strength of sound welds in 0.020-inch R-301-T6 was unaffected by exposures up to 3 years in tidewater and in weather. Welds made in the same material with dirty electrode tips and with surface cracks, series 2R', exhibited very serious losses in shear strength for all periods of exposure. In the 0.040-inch R-301-T6 sheet the shear strength of sound welds was also unaffected by exposures up to 3 years in tidewater and in weather as shown in series 4R. Welds made in the same material with dirty electrode tips and with internal cracks, series 4R', exhibited a distinct gain in shear strength for all exposures. This is in spite of the fact that all of the electrode impressions showed evidence of the dirty condition of the electrode tips. The only explanation for this gain in shear strength seems to be that the welds may have undergone further age-hardening during exposure, which more than offset any losses due to corrosion. This is difficult to accept in view of the fact that the sound welds exhibited no such effect. If this is true, it would seem that it must have been the effect of elevated temperature due to exposure to the sun which was responsible for the aging, rather than time alone. Otherwise, the control welds would have experienced the same gain in strength and no increase would have been detected in the strength of the exposed welds. It should be remembered that in this series of panels the cracks did not extend to the surface of the sheet. Otherwise, the results might have been quite different. The change in shear strength of sound welds in 0.040-inch alclad XB75S-T6, series XC, was insignificant for exposures up to 3 years in tidewater and in weather. Welds made in the same material with dirty electrode tips and with cracks extending to the surface of the sheet, series XC', exhibited losses of the order of 7 percent for exposures of 12 and 36 months to tidewater. On the other hand, a gain in strength of the order of 11 percent was obtained for exposures of 7 months to tidewater and for exposures of 1 and 2 years to weather. The shear strength was unchanged for an exposure of 2 years to tidewater. These results suggest that in this material the welds may have undergone a further age-hardening which more than offset losses due to exposure to weather, but this explanation is subject to the same criticism as in the case of series 4R'. It is difficult to draw any general conclusions from these results. In series X it is evident that sound welds in XB75S-T6 sheet suffered rather severely in all but one period of exposure. Welds made in the same material with dirty electrode tips and with cracks extending to the surface of the sheet, series X', exhibited still greater losses in shear strength for all exposures. It should be noted that in this material a distinct loss in shear strength occurred in only 12 days' exposure to tidewater, regardless of the quality of the welds. It is very evident that spot welds in XB75S-T6 should not be exposed to corrosive conditions without effective protection. The above observations can be summarized rather briefly. The shear strength of sound welds in 0.020-inch R-301-T6 and 0.040-inch alclad XB75S-T6 is unaffected by exposures up to 3 years in tidewater and in weather. Defective welds are definitely to be avoided in 0.020-inch R-301-T6 when corrosive conditions are present. The corrosion resistance of defective welds in 0.040-inch R-301-T6 and alclad XB75S-T6 has not been fully revealed by this investigation but the general picture is favorable. Spot welds are definitely to be avoided in XB75S-T6 under corrosive conditions unless the welds can be given adequate protection.

Effect of Exposure on Normal Tensile Strength of Welds

The effects of exposure on the normal tensile strength of the spot welds are summarized in tables XV to XVII. These tables are not discussed in as great detail as the corresponding tables for shear strength since the normal tensile strength is not ordinarily as important as the shear strength of spot welds. What is probably more important is the ratio of average normal tensile strength to average shear strength for any given panel. This ratio has been calculated for all the panels and the results are presented in table XVIII.

The ratio of normal tensile strength has been taken in previous investigations as an approximate indication of the ductility of spot welds in the material in question; the higher the ratio, the higher the ductility. It has been shown that, within certain limits, the ratio tends to vary inversely with weld size; the larger the weld, the smaller the ratio (reference 4). In the present investigation the ratio gives an indication of the relative effects of exposure on the normal tensile and shear strengths. A reduction in the ratio below that obtained from the unexposed control welds indicates that the normal tensile strength was more adversely affected by exposure than the shear strength.

Conversely, the exposure affected the shear strength more adversely than the normal tensile strength when the ratio exceeds that obtained from the unexposed control welds. The ratio for the unexposed control welds can be taken as a basis for comparison for the panels of any given series, but the above relation between the ratio and weld size must be taken into account in comparing ratios for panels in different series.

In many instances the effects of exposure were approximately of the same order of magnitude for the normal tensile strength as for the shear strength. In alclad 24S-T3 the greatest discrepancy between changes in shear and normal tensile strength occurred in the chemically treated panels after exposures of 2 and 3 years to weather. Examination of tables XII and XV reveals that all the chemically treated panels in series 1 and 3 to 5 exhibited relatively more severe losses in normal tensile strength than in shear strength as a consequence of the above exposures. The panels of series 6 whose faying surfaces were untreated behaved like the chemically prepared panels, whereas the wire-brushed panels of series 9 and the anodized panels of series 10 did not exhibit this discrepancy. The above discrepancies are reflected in the relatively low values of the ratio of normal tensile strength to shear strength for series 1 and 3 to 6 at exposures of 24 and 36 months to weather as shown in table XVIII. No explanation is offered for this phenomenon at the present time. It is believed to be significant of something, however, since it occurred so persistently at the same exposures in five different series of panels. In 24S-T3 the greatest discrepancy between changes in shear and normal tensile strength occurred in the exposed panels of series P7 which were welded with dirty electrodes. This is revealed by examination of the pertinent data in tables XIII, XVI, and XVIII. In the R-301-T6 and XB75S-T6 alloys a definite discrepancy occurred in all but the 12-month-tidewater panel of series 4R' which were welded with dirty electrodes and which contained internal cracks. This is revealed by examination of the pertinent data in tables XIV, XVII, and XVIII. It is difficult to understand how these discrepancies can be explained in the rather isolated cases in the 24S-T3, R-301-T6, and XB75S-T6 series of panels. No attention is given those cases where the shear strength was more adversely affected by exposure than the normal tensile strength, since those cases were scattered and did not occur in any particular pattern.

METALLOGRAPHIC EXAMINATION OF SPOT WELDS

The specific purpose of the metallographic examination was to study microscopically and to record the extent and type of corrosion attack associated with various welding and exposure conditions.

Discussion of Observations

A discussion of the observations made during the examination and a presentation of photographs of typical structures will be made by grouping the samples in the manner listed in table XIX.

Samples from panel series 1.- Welding conditions for this series of alclad 24S-T3 panels were chosen so as to produce sound welds. A macrograph of a representative weld, 1C, is shown in figure 18 and indicates the sound nature of the nugget centrally located between the outer surfaces of the sheets.

There was no significant extent of corrosion attack on sample 1C after a tidewater exposure of 1 year. This is shown in figures 18 and 19.

There was no detectible corrosion attack on the laboratory exposed sample, 1G, after 3 years. The conditions found at the outer surface of the sheet and at the faying surface are shown in figures 20 and 21, respectively. The structure at the faying surface in figure 21 was representative of all the alclad 24S-T3 samples examined. The penetration of the 2S cladding into the nugget provided continuous cathodic protection at the faying surfaces.

After 3 years in a sea coast atmosphere a pitting type of attack was observed on the outer surfaces of sample 1E. As illustrated in figure 22, the attack did not penetrate the protective coating. It was observed that the attack was more concentrated in the vicinity of the weld than on the normal surfaces of the sheet.

Samples from panel series 5.- Two samples, 5C and 5F, of this series (figs. 23 to 26) exhibited severe weld cracks, extension of the fused zone to one surface, and localized corrosion attack in the region where the cladding was reduced in thickness. Macrostructures of these samples are shown in figures 23 and 25. In sample 5C tiny fragments of the cladding remained to provide protection as shown in figure 24. On the sheet surface to which the fused zone did not extend there was no evidence of corrosion attack in 3 years in a sea coast atmosphere, as shown in figure 26. There was no evidence of corrosion attack along the faying surfaces. From these observations it was concluded that the poor welding conditions accelerated corrosion attack in the immediate locality where the fused zone approached the surface.

Samples from panel series 6.- Welding conditions were chosen for this series of panels so as to cause expulsion of metal between the faying surfaces in order that the effect of the expulsion on the corrosion resistance of the spot welds might be determined. Evidence of the expulsion in sample 6C is shown in figures 27 and 28 after an exposure of 1 year in tidewater. There was no evidence of corrosion attack associated with expulsion along the faying surfaces, and the outer surfaces showed no significant extent of attack. The tongue or sliver of expelled metal was surrounded completely by cladding which prevented any possibility of attack.

In addition to causing expulsion the welding conditions produced small nugget cracks that did not reach the surface, as shown in figure 29. After 3 years in a sea coast atmosphere the most severe degree of attack did not penetrate the surface coating as shown in figure 30. This attack was principally in the weld vicinity and on the outer surfaces of the sheet.

Welding conditions causing expulsion resulted in unsoundness in nugget centers but caused no lowering of the resistance to corrosion of alclad 24S-T3 in tidewater for 1 year and only a moderate tendency to produce localized attack in the weld zone on the outer surfaces after 3 years in a sea coast atmosphere. No evidence was observed to indicate that expulsion had an adverse effect on the resistance to corrosion at the faying surfaces.

Samples from panel series 9.- These panels (figs. 31 to 36) were wire-brushed for surface treatment prior to welding under conditions to produce a sound structure. The zone of fusion approached one clad surface in samples 9C and 9F, however, as indicated in figures 31 and 34.

A significant feature common to these two samples was the noticeable extent of diffusion of copper into the 2S cladding. This was not an effect of welding but a condition resulting from some deviation from standard practice in the production of the sheet. The typical appearance of the sheet some distance from the weld zone is shown in figure 33.

In sample 9C the effect of welding was to cause an acceleration of the copper diffusion into the cladding and to promote a localized corrosion attack on the outer surfaces of the weld zone, as shown in figures 31 and 32. In several areas the diffusion appeared to penetrate the grain boundaries of the cladding and in these areas the corrosion attack was most severe. This would be expected since the cladding had become less anodic and less protective in those areas. The highly localized nature of this condition may be observed by comparing figures 32 and 33.

The same general effects were found in sample 9F after 3 years in a sea coast atmosphere. The approach of the fused zone to the surface cladding was less than in sample 9C (compare figs. 31 and 34 and figs. 32 and 35) and the severity of the diffusion was less. On the side of the weld where the fused zone was not near the surface, the corrosion attack in sample 9F was a general pitting condition as noted in figure 36.

Examination of samples 9C and 5F indicated that for alclad 24S-T3 sheet, exhibiting a significant extent of a core-to-cladding diffusion zone, there was no good possibility of accentuating the diffusion zone and decreasing the local resistance to corrosion by spot welding. The closer the approach of the fused zone to the cladding, the more pronounced was this tendency.

Samples from panel series 2R.- Samples 2R4, 2R5, and 2R7 were intended to be sound welds and the examination indicated that this was true. The structures of samples 2R4 and 2R7 were similar and there was no evidence of corrosion attack on the inner or outer surfaces. An example of this condition is shown in figures 37 and 38.

There was a general condition of corrosion attack on the inner and outer surfaces of the sheet of sample 2R6 (figs. 39 to 42) but none on the inner surfaces near the weld. The attack appeared to be more extensive in the weld vicinity on the outer surfaces. As is shown in figures 41 and 42, exposure to a sea coast atmosphere for 3 years produced an intergranular type of attack that did not penetrate completely the anodic cladding.

A condition which was characteristic of the R-301-T6 spot welds, and which was also observed in the XB75S-T6 welds but not in the alclad 24S-T3 welds, is shown in figure 40. This envelope of secondary constituents along the periphery of the fused zone of the weld was particularly prominent in weld zones in the R-301-T6 sheet. The identity of the undissolved constituents was not established conclusively but from etching characteristics it was believed that the particles were of the aluminum-copper-iron-manganese phase. No evidence was found to indicate that the envelope surrounding the nugget had an adverse effect on resistance to corrosion. The effect of this condition on the propagation of a fracture is illustrated in figure 40.

The structures of samples 2R15, 2R16, 2R12, and 2R14, which were welded with dirty electrodes, were similar in detail to those shown for 2R7, 2R4, and 2R6.

Samples from panel series X.- The samples of XB75S-T6 sheet welded with dirty electrodes were characterized by severe weld cracks and unsound nuggets.

The appearance of sample X-15 after 3 years in the laboratory atmosphere is shown in figures 43 and 44. There was no evidence of corrosion attack on inner or outer surfaces of this sample.

Extremely severe intergranular corrosion attack was developed in 12 days' exposure to tidewater by sample X-9. As shown in figures 45 and 46, the attack was most concentrated at the periphery of the electrode indentation. The attack was observed on both the outer and inner surfaces of the sheet. The intergranular nature of the attack is illustrated in figures 47 and 48. A small envelope of undissolved constituent particles is shown in figure 47, which had no apparent connection with corrosion attack.

After 1 year in a sea coast atmosphere sample X-13 exhibited the same type of attack but less severe than sample X-9. The evidence is presented in figures 49 to 52. In this sample, as well as in X-9, most of the intergranular attack was associated with the weld zone and the area immediately adjacent to this region.

Examination of samples of XB75S-T6 sheet spot-welded with dirty electrodes indicated that the resistance to corrosion was severely lowered for salt water exposures. Considered from the standpoint of the mechanism of intergranular corrosion, it is doubtful if the resistance to intergranular attack would be increased by any method other than the use of an anodic coating or by solution-treating and rapidly quenching the welded structures.

Summary of Metallographic Observations

From metallographic examinations of spot-welded samples of alclad 24S-T3, R-301-T6, and XB75S-T6, the following observations were made concerning the extent and type of corrosion attack associated with various welding and exposure conditions:

(1) The beneficial cathodic protection of the cladding in preventing severe corrosion attack was clearly illustrated for alclad 24S-T3 and R-301-T6 samples in comparison with the severe intergranular corrosion attack suffered by the XB75S-T6.

(2) Where corrosion attack was found, the welding conditions intended to produce unsatisfactory welds accelerated the rate of attack in the weld zone. In all samples, the extent of corrosion attack did not reach the core of the sheet.

(3) There was no distinct evidence of corrosion attack along the faying surfaces of the clad sheet. In all samples of alclad 24S-T3

and R-301-T6 examined, the higher-melting cladding material extended into the nugget zone and afforded continuous protection at the inner surfaces of the sheet.

(4) The expulsion of molten metal between the faying surfaces of alclad 24S-T3 sheet did not produce corrosion attack in this region. In the sample examined, the expelled metal was surrounded completely by the cladding material, which provided cathodic protection.

(5) The cathodic protection provided by even tiny fragments of the cladding was demonstrated in two samples of alclad 24S-T3, 5C and 5F, where the nugget absorbed most of the cladding.

(6) The R-301-T6 welds were characterized by a band of concentrated secondary constituents surrounding the fused zone in the form of an envelope. This condition was not found in the alclad 24S-T3 samples but was observed to a lesser extent in the XB75S-T6 welds. The constituents were believed to be of the insoluble aluminum-copper-iron-manganese phase. While the envelope apparently had no adverse effect on the resistance to corrosion, it did provide a convenient path for cracking.

(7) Caution should be exercised when spot-welding alclad 24S-T3 sheet exhibiting a significant extent of diffusion from the core into the cladding. Even sound welding conditions accentuate the diffusion of copper into the 2S cladding; the closer the approach of the fused zone to the cladding, the greater the extent of the diffusion. In sample 9C, this condition was observed to increase the rate of local corrosion attack in the vicinity of the diffusion into the cladding.

GENERAL OBSERVATIONS

Small Spark Craters at Weld Surfaces

Occasionally welding conditions are such that a small spark occurs between the work and the electrode tip at the instant the two are separated after a spot weld is made. This usually leaves a small crater on the surface of the weld. There has been some speculation as to how these craters may affect the corrosion behavior of spot welds. In fact, it is believed that many spot-welded assemblies have been rejected by inspectors on account of these craters. In the present investigation sparking occurred in a number of instances, thus providing an opportunity for observation of the effects of spark craters. Visual examination of the weld surfaces revealed no evidence of any local corrosion at the craters. There was no evidence that the strength of the welds was affected in any way by the presence of the craters. This should not be interpreted as meaning that all spark craters are harmless from the viewpoint of corrosion. Craters undoubtedly vary in size and depth. There may be conditions under which the presence of spark craters may aggravate corrosion.

Discoloration of Weld Surfaces

The surfaces of spot welds in the aluminum alloys frequently appear discolored in some fashion. It is difficult to describe this discoloration since it occurs in a variety of forms and since it seems to change according to the angles at which the weld surface is illuminated and viewed. For example, a weld surface which appears to have a dark area in the center under one set of conditions may appear to have a light area in the center under other conditions. The discolored area may occur centrally on the surface of the weld or it may occur in a pattern of circular, concentric bands. The area may be faintly or distinctly colored, or it may simply appear lighter or darker than the surrounding surface. Discoloration of the surface of spot welds in the aluminum alloys is a complex subject. The significance of the different types of discoloration has never been investigated within the knowledge of the authors. This makes it difficult, if not impossible, to draw any general conclusions from exposure tests where discolored welds are involved. A number of spot welds in the present investigation exhibited discolored surfaces but, unfortunately, the discoloration frequently coincided with other defects such as surface cracks and, therefore, it was difficult to distinguish between the effects of each type of defect.

CONCLUSIONS

In considering the conclusions drawn from this work the limitations of the investigation must be kept in mind. Except for the R-301-T6 material, the work was limited to sheet 0.040 inch in thickness. While the effects of exposure would probably have been less pronounced for thicker sheet, the effects would certainly have been more severe for thinner sheet as was evident in the R-301-T6 material. There was often a considerable variation from weld to weld in the magnitude of the weld defects whose effects on the corrosion behavior of the spot welds were to be studied. It was sometimes impossible to produce the desired weld defect in a series of panels without simultaneously producing some other defect. In such cases it was difficult or impossible to learn the relative effects of the different defects in determining the corrosion of the spot welds. In spite of such limitations and difficulties the work yielded a few facts which are recorded in the following conclusions:

1. Exposures of 1 year to tidewater and 3 years to weather had practically no effect on the shear strength of sound spot welds in 0.040-inch alclad 24S-T3.

2. Exposures of 3 years to tidewater and 3 years to weather had practically no effect on the shear strength of sound spot welds in 0.020-inch R-301-T6, 0.040-inch R-301-T6, and 0.040-inch alclad XB75S-T6.

3. Under the conditions of this investigation, exposure to tidewater and weather had little effect on the shear strength of spot welds in chemically prepared 0.040-inch sheet, even when the welds exhibited such defects as internal cracks, surface cracks, expelled metal between the faying surfaces, and dirty surfaces.

4. Observation of corrosion product distribution and metallographic examination of weld sections indicate that such defects as surface cracks and contamination of the cladding render spot welds in 0.040-inch alclad 24S-T3 sheet susceptible to localized corrosion. In the present investigation, the conditions of exposure and the protective effect of adjacent cladding were such that the localized corrosion did not proceed to a point where it could affect the shear strength of the welds. Furthermore, the distribution of stress in a shear test of a spot weld is such that the corrosion would have to be quite severe before the test results would be affected.

5. The alclad 24S-T3 sheet which was prepared for spot-welding by wire brushing appeared to be somewhat susceptible to general corrosion. There was practically no evidence of general corrosion of sheet which had been chemically surface-treated in the fluosilicic acid H_2SiF_6 solution.

6. Exposure to tidewater and weather appeared to reduce the shear strength of spot welds in 0.040-inch alclad 24S-T3 sheet which had been prepared for spot-welding by wire brushing.

7. Caution is advised in spot-welding alclad 24S-T3 sheet in which any appreciable diffusion of alloying elements from the core into the cladding has occurred as a consequence of improper heat treatment. In such sheet even optimum spot-welding conditions tend to accentuate the diffusion which may in time reduce the corrosion resistance of the cladding and eventually lead to localized corrosion of the weld area and loss of weld strength.

8. Exposure to tidewater and weather definitely reduced the shear strength of spot welds in 0.020-inch R-301-T6 made with dirty electrodes and exhibiting surface cracks.

9. The corrosion resistance of defective welds in 0.040-inch R-301-T6 and alclad XB75S-T6 was not fully revealed in this investigation but the results were generally favorable.

10. Spot welds in XB75S-T6 were extremely susceptible to localized corrosion and loss of shear strength upon exposure to tidewater and weather.

11. Aluminum-alloy 24S-T3 sheet, even without the presence of spot welds, is extremely susceptible to general corrosion unless adequate protection is provided in the form of effective anodizing and painting.

12. Severe general corrosion occurred over large surface areas located at random on the 24S-T3 panels which had been anodized by a competent firm. These panels had been prepared for spot-welding by a chemical surface treatment which is excellent from the spot-welding point of view but which is not commonly employed prior to anodizing. These facts suggest that the surface treatment may have had an adverse effect on the subsequent anodizing operation.

13. In many instances the effects of exposure were of approximately the same order of magnitude in percent for the normal tensile strength as for the shear strength of the spot welds concerned. However, a number of panels exhibited a relatively more severe loss in normal tensile strength than in shear strength as a consequence of exposure, for which no explanation is offered.

14. Under the conditions of this investigation small spark craters on the weld surfaces had no effect on the corrosion behavior of spot welds in 0.040-inch alclad 24S-T3 sheet.

15. From the viewpoint of corrosion a solution of fluosilicic acid H_2SiF_6 appears to be perfectly satisfactory for preparing the surfaces of such aluminum alloys as alclad 24S-T3, R-301-T6, and alclad XB75S-T6 for spot-welding.

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4. Hess, W. F., Wyant, R. A., and Winsor, F. J.: The Spot Welding of Ten Aluminum Alloys in the 0.040-Inch Gage - Including XB75S-T (Bare & Alclad), R-301-T, Alclad 24S-T81, 24S-T (Bare & Alclad), 3S-1/2H, 14S-T, 52S-1/2H, and 61S-T. The Welding Jour., vol. 25, no. 8, Aug. 1946, pp. 467s-484s.

TABLE I

PLAN OF INVESTIGATION

Condition of welds	Material	Panel series	Final surface condition		
			As-welded	Anodized	Anodized and painted
Original plan[a]					
Sound welds having 50-percent penetration or less, welded with capacitor-discharge equipment using steep wave front; chemical surface preparation	Alclad 24S-T3	1	X		
	24S-T3	P1		X	
	24S-T3	P1'			X
Sound welds having 50-percent penetration or less, welded with capacitor-discharge equipment using hot preheat preceding capacitor discharge; chemical surface preparation	Alclad 24S-T3	2	X		
	24S-T3	P2		X	
Sound welds having 50-percent penetration or less, welded with capacitor-discharge equipment using hot postheat following capacitor discharge; chemical surface preparation	Alclad 24S-T3	3	X		
	24S-T3	P3		X	
Welds made under conditions such as to leave high residual stresses so that any one weld may or may not contain fine internal cracks; chemical surface preparation	Alclad 24S-T3	4	X		
	24S-T3	P4		X	
Cracked welds with cracks visible at surface; chemical surface preparation	Alclad 24S-T3	5	X		
	Alclad 24S-T3	[b]5'		X	
	24S-T3	P5		X	
Welds from which metal was expelled leaving fins of expelled metal between faying surfaces; chemical surface preparation	Alclad 24S-T3	6	X		
	24S-T3	P6		X	
Welds with surface burning or blackening as result of advanced stage of electrode "pick-up" (dirty tips); chemical surface preparation	Alclad 24S-T3	7	X		
	Alclad 24S-T3	7'		X	
	24S-T3	P7		X	
Welds made after panels were chemically cleaned as an assembly with small clearance between parts so that treating solution would leave deposit on faying surfaces	Alclad 24S-T3	8	X		
	24S-T3	P8		X	
Sound welds having 50-percent penetration or less, welded with capacitor-discharge equipment using steep wave front; wire-brushed surfaces	Alclad 24S-T3	9	X		
	24S-T3	P9		X	
	24S-T3	P9'			X
Extended plan					
Sound welds in chemically prepared sheet	0.020-in. R-301-T6	2R	X		
	.040-in. R-301-T6	4R	X		
	.040-in. alclad XB75S-T6	XC	X		
	.040-in. XB75S-T6	X	X		
Welds in chemically prepared sheet with cracks visible at surface and with dirty surfaces due to dirty electrodes	0.020-in. R-301-T6	2R'	X		
	.040-in. R-301-T6	4R'	X		
	.040-in. alclad XB75S-T6	XC'	X		
	.040-in. XB75S-T6	X'	X		

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[a] All material 0.040-in. in thickness.

[b] Finally designated as series 10.

TABLE II

SURFACE PREPARATION OF PANELS FOR SPOT-WELDING

Material	Panel	Treatment[1]
24S-T3	P1-P7	8 min at 180° F in 2 percent HNO_3
	P9	Wire-brushed
Alclad 24S-T3	1-5, 7, and 10	8 min at 75° F in 3 percent H_2SiF_6
	6	Faying surfaces - untreated Outer surfaces - wire-brushed
	9	Wire-brushed
0.020-in. R-301-T6	All	10 min at 75° F in 3 percent H_2SiF_6
0.040-in. R-301-T6	All	$7\frac{1}{2}$ min at 75° F in 3 percent H_2SiF_6
Alclad XB75S-T6	All	$7\frac{1}{2}$ min at 75° F in 3 percent H_2SiF_6
XB75S-T6	All	4 min at 75° F in 3 percent H_2SiF_6

[1] Concentrations of treating solutions are expressed in percent by volume of the concentrated acids (70 percent nitric acid HNO_3 and 28 percent fluosilicic acid H_2SiF_6). Each solution also contained a small amount of the wetting agent, Nacconol NR (0.2 percent by weight in HNO_3 and 0.1 percent by weight in H_2SiF_6). Wire brushing was done by means of a motor-driven brush, 3-in. diam. by 1/2-in. face, having mild steel bristles 0.003-in. in diam., and turning at 2700 rpm.

TABLE III

CONDITIONS AND MACHINE SETTINGS FOR SPOT-WELDING CORROSION PANELS

(a) Welding conditions[1]

Panel series	Peak current (amperes)	Time to current peak (sec)	Electrode force		Time from weld to forge (sec)	Electrode dome-tip radius (in.)	Electrode tip condition
			Weld (lb)	Forge (lb)			
1	44,800	-----	800	2400	-----	$2\frac{1}{2}$	Clean
3	47,600	-----	1400	----	-----		Do.
4	36,800	-----	1000	----	-----		Do.
5	33,000	-----	800	----	-----		Do.
6	30,500	0.016	800	2400	-----		Do.
7	33,000	-----	800	2400	-----		Dirty
7'	33,000	.014	1400	----	-----		Do.
9	30,500	.016	800	2400	-----		Clean
10	33,000	-----	800	----	-----		Do.
P1	39,200	-----	800	2400	-----		Do.
P3	44,200	-----	1400	----	-----		Do.
P4	30,800	-----	1000	----	-----		Do.
P5/6	33,000	.015	800	----	-----		Do.
P7	33,000	.015	1400	----	-----		Dirty
P9	33,000	.015	1200	----	-----		Clean
2R	38,800	0.005	500	1200	0.015	4	Clean
2R'	38,800	.005	500	----	-----		Dirty
4R	29,500	.012	800	2000	.051		Clean
4R'	29,500	.012	800	----	-----		Dirty
XC	31,200	.012	800	2000	.051		Clean
XC'	31,200	.012	800	----	-----		Dirty
X	29,500	.012	800	2000	.051		Clean
X'	29,500	.012	800	----	-----		Dirty

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[1] Measurements were not complete for all series.

TABLE III

CONDITIONS AND MACHINE SETTINGS FOR SPOT-WELDING CORROSION PANELS - Concluded

(b) Machine settings

[Federal Spot Welder, Type P2-30-RA, Serial No. 8707]

Panel series	Transformer-turns ratio	Capacitor (microfarads)	Capacitor (volts)
1	103	720	2300
3	144 [a]48	720 ---	2400 ----
4	398	720	2350
5	398	720	2100
6	398	720	2200
7	398	720	2200
7'	398	720	2100
9	398	720	2200
10	398	720	2000
P1	144	720	2300
P3	144 [b]48	720 ---	---- ----
P4	398	720	2050
P5/6	398	720	2200
P7	398	720	2250
P9	398	720	2200
2R	150	480	----
2R'	150	480	----
4R	300	720	----
4R'	300	720	----
XC	300	720	----
XC'	300	720	----
X	300	720	----
X'	300	720	----

[a] Capacitor discharge followed by alternating-current postheat of 19,100 amperes for 1/2 sec.

[b] Capacitor discharge followed by alternating-current postheat of 19,500 amperes for 1/2 sec.

TABLE IV

DISTRIBUTION OF PANELS

Panel series	Unexposed	Tidewater exposure						Weather exposure		
		12 days	4 weeks	7 months	12 months	24 months	36 months	12 months	24 months	36 months
1	1G 1H	--	1A	1B	1C	----	----	1D	1E	1F
3	3G 3H	--	3A	3B	3C	----	----	3D	3E	3F
4	4G 4H	--	4A	4B	4C	----	----	4D	4E	4F
5	5G 5H	--	5A	5B	5C	----	----	5D	5E	5F
6	6G 6H	--	6A	6B	6C	----	----	6D	6E	6F
7	7G 7H	--	7A	7B	7C	----	----	7D	7E	7F
7'	7O 7P	--	7I	-----	7J 7K	----	----	7L	7M	7N
9	9G 9H	--	9A	9B	9C	----	----	9D	9E	9F
10	10G 10H	--	10A	10B	10C	----	----	10D	10E	10F
P1	P1G P1H	--	P1A	P1B	P1C	----	----	P1D	P1E	P1F
P1'	P1O P1P	--	-----	P1J	P1I P1K	----	----	P1L	P1M	P1N
P3	P3G P3H	--	P3A	P3B	P3C	----	----	P3D	P3E	P3F
P4	P4G P4H	--	P4A	P4B	P4C	----	----	P4D	P4E	P4F
P5/6	P5/6G P5/6H	--	P5/6A	P5/6B	P5/6C	----	----	P5/6D	P5/6E	P5/6F
P7	P7G P7H	--	P7A	P7B	P7C	----	----	P7D	P7E	P7F
P9	P9G P9H	--	P9A	P9B	P9C	----	----	P9D	P9E	P9F
P9'	P9O P9P	--	-----	P9J	P9I P9K	----	----	P9L	P9M	P9N
2R	2R7 2R8	--	-----	2R1	2R2	2R3	2R4	2R5	-----	2R6
2R'	2R15 2R16	--	-----	2R9	2R10	2R11	2R12	2R13	-----	2R14
4R	4R7 4R8	--	-----	4R1	4R2	4R3	4R4	4R5	-----	4R6
4R'	4R15 4R16	--	-----	4R9	4R10	4R11	4R12	4R13	-----	4R14
XC	XC7 XC8	--	-----	XC1	XC2	XC3	XC4	XC5	-----	XC6
XC'	XC15 XC16	--	-----	XC9	XC10	XC11	XC12	XC13	-----	XC14
X	X7 X8	X1	-----	-----	X2	X3	X4	X5	-----	X6
X'	X15 X16	X9	-----	-----	X10	X11	X12	X13	-----	X14

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TABLE V

DISTRIBUTION OF CORROSION PRODUCTS ON SPOT-WELDED PANELS EXPOSED AT HAMPTON ROADS, VIRGINIA, FOR EITHER 12 DAYS OR 1 MONTH

Material	Panel	Side of panel (a)	Tidewater exposure											Faying surface	Weather exposure											Faying surface
			Identification number of spot weld										Panel		Identification number of spot weld										Panel	
			1	2	3	4	5	6	7	8	9	10			1	2	3	4	5	6	7	8	9	10		
Alclad 24S-T3	1A,D,E,F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
		B	A	A	A	A	B	B	B	A	B	A	A	A	I	I	I	I	A	A	A	A	A	A	I	A
24S-T3	P1A,D,E,F	A	G	G	G	G	G	G	G	G	G	G	G	A	A	A	A	A	A	A	A	A	A	A	A	A
		B	G	G	G	G	G	G	G	G	G	G	G	A	A	A	A	A	A	A	A	A	A	A	A	A
24S-T3	P1L,M,N	A	-----	-----	-----	---	---	---	---	---	---	---	-----	-	A	A	A	A	A	A	A	A	A	A	A	A
		B	-----	-----	-----	---	---	---	---	---	---	---	-----	-	A	A	A	A	A	A	A	A	A	A	A	A
Alclad 24S-T3	3A,D,E,F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
		B	A	A	A	A	A	A	A	A	A	A	A	A	I	I	I	I	A	A	A	A	A	A	I	A
24S-T3	P3A,D,E,F	A	G	G	G	G	G	G	G	G	G	G	G	A	A	A	A	A	A	A	A	A	A	A	A	A
		B	G	G	G	G	G	G	G	G	G	G	G	A	A	A	A	A	A	A	A	A	A	A	A	A
Alclad 24S-T3	4A,D,E,F	A	A	A	A	A	C	C	C	C	C	C	A	A	A	A	A	A	A	A	A	A	A	A	A	A
		B	C	C	C	C	D	D	D	A	A	A	A	A	I	I	I	I	A	A	A	A	A	A	I	A
24S-T3	P4A,D,E,F	A	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G	A	A	A	A	A	A	A	A	A	A	A	A	A
		B	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G	A	A	A	A	A	A	A	A	A	A	A	A	A
Alclad 24S-T3	5A,D,E,F	A	C,H	C,H	A,H	C,H	C	C	C	C	C	C	A	A	A	A	A	A	A	A	A	A	A	A	A	A
		B	A	A	A	A	A,H	A,H	A,H	A,H	A,H	A,H	A	A	I	I	I	I	A	A	A	A	A	A	I	A
Alclad 24S-T3	6A,D,E,F	A	C	C	A	C	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
		B	A	A	A	A	A	A	A	A	A	A	A	A	I	I	I	I	C	C	C	A	A	A	I	A
24S-T3	P5-6A,D,E,F	A	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G	A	H	A	H	A	H	H	H	H	H	H	A	A
		B	G	G	G,D	G	G,D	G,D	G	G	G	G	G	A	H	H	H	H	H	A	A	A	A	A	A	A
Alclad 24S-T3	7A,D,E,F	A	B	B	B	B	B	B	B	B	B	B	A	A	E	E	E	E	A	A	A	A	A	A	A	A
		B	B	B	B	B	B	B	B	B	B	B	A	A	I	I	I	I	I,E	I,E	I,E	I,E	I,E	I,E	I	A
Alclad 24S-T3	7I,L,M,N	A	A,F	A,F	A,F	A,F	A,E	A,E	A,E	A,E	A,E	A,E	A	A	E	E	E	E	A	A	A	A	A	A	A	A
		B	A,E	A,E	A,E	A,E	A,F	A,F	A,F	A,F	A,F	A,F	A	A	A	A	A	A	E	E	E	E	E	E	A	A
24S-T3	P7A,D,E,F	A	G,D,F	G,D,F	G,D,F	G	G	G	G	G	G	G	G	A	H,E	H,E	H,E	H,E	A	A	A	A	A	A	A	A
		B	G	G	G	G	G	G	G	G	G	G	G	A	A	A	A	A	E	E	E	E	E	E	A	A
Alclad 24S-T3	9A,D,E,F	A	C	C	C	C	C	C	C	C	C	C	A	A	A	A	A	A	A	A	A	A	A	A	A	A
		B	C	C	C	C	C	C	C	C	C	C	A	A	I	I	I	I	C	C	C	A	A	A	I	A
24S-T3	P9A,D,E,F	A	G	G,D	G,D	G	G	G,D	G,D	G,D	G	G	G	A	A	A	A	A	A	A	A	A	A	A	A	A
		B	D	D	D	G,D	G	G	G	G	G	G	G	A	A	A	A	A	A	A	A	A	A	A	A	A
24S-T3	P9L,M,N	A	-----	-----	-----	---	---	---	---	---	---	---	-----	-	A	A	A	A	A	A	A	A	A	A	A	A
		B	-----	-----	-----	---	---	---	---	---	---	---	-----	-	A	A	A	A	A	A	A	A	A	A	A	A
Alclad 24S-T3	10A,D,E,F	A	C,H	C,H	C,H	C,H	A	A	A	A	A	A	A	A	H	H	H	H	A	A	A	A	A	A	A	A
		B	A	A	A	A	C,H	C,H	C,H	C,H	C,H	C,H	A	A	A	A	A	A	H	H	H	H	H	H	A	A
R-301-T6	2R1	A	A	A	A	A	A	A	A	A	A	A	A	A	---	---	---	---	---	---	---	---	---	---	-	-
		B	A	A	A	A	A	A	A	A	A	A	A	A	---	---	---	---	---	---	---	---	---	---	-	-
R-301-T6	2R9	A	A	A	A	A	A	A	A	A	A	A	A	A	---	---	---	---	---	---	---	---	---	---	-	-
		B	A	A	A	A	A	A	A	A	A	A	A	A	---	---	---	---	---	---	---	---	---	---	-	-
R-301-T6	4R1	A	A	A	A	A	A	A	A	A	A	A	A	A	---	---	---	---	---	---	---	---	---	---	-	-
		B	A	A	A	A	A	A	A	A	A	A	A	A	---	---	---	---	---	---	---	---	---	---	-	-
R-301-T6	4R9	A	A	A	A	A	A	A	A	A	A	A	A	A	---	---	---	---	---	---	---	---	---	---	-	-
		B	A	A	A	A	A	A	A	A	A	A	A	A	---	---	---	---	---	---	---	---	---	---	-	-
Alclad XB75S-T6	XC1	A	A	A	A	A	A	A	A	A	A	A	A	A	---	---	---	---	---	---	---	---	---	---	-	-
		B	A	A	A	A	A	A	A	A	A	A	A	A	---	---	---	---	---	---	---	---	---	---	-	-
Alclad XB75S-T6	XC9	A	A	A	A	A	A	A	A	A	A	A	A	A	---	---	---	---	---	---	---	---	---	---	-	-
		B	A	A	A	A	A	A	A	A	A	A	A	A	---	---	---	---	---	---	---	---	---	---	-	-
[b]XB75S-T6	X1	A	J	J	J	J	J	J	J	J	J	J	G	A	---	---	---	---	---	---	---	---	---	---	-	-
		B	J	J	J	J	J	J	J	J	J	J	G	A	---	---	---	---	---	---	---	---	---	---	-	-
[b]XB75S-T6	X9	A	J	J	J	J	J	J	J	J	J	J	G	A	---	---	---	---	---	---	---	---	---	---	-	-
		B	J	J	J	J	J	J	J	J	J	J	G	A	---	---	---	---	---	---	---	---	---	---	-	-

[a] Besides designating panel sides as shown in fig. 1, letters also designate faying surfaces: A designates 1- by 4-in. overlap containing welds 1 to 4 and B designates 4- by 5-in. overlap containing welds 5 to 10.

[b] Panels were removed after 12 days of exposure because of excessive corrosion.

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TABLE VI

DISTRIBUTION OF CORROSION PRODUCTS ON SPOT-WELDED PANELS EXPOSED AT HAMPTON ROADS, VIRGINIA, FOR 7 MONTHS

Material	Panel	Side of panel (1)	Tidewater exposure											Faying surface	Weather exposure											Faying surface
			Identification number of spot weld										Panel		Identification number of spot weld										Panel	
			1	2	3	4	5	6	7	8	9	10			1	2	3	4	5	6	7	8	9	10		
Alclad 24S-T3	1B,D,E,F	A	B	B	B	B	A	A	A	A	A	A	A	A	E	E	E	E	A	A	A	A	A	A	A	A
		B	A	A	B	A	B	B	B	B	B	A	A	A	I	I	I	I	I	I	I	I	I	I	I	A
24S-T3	P1B,D,E,F	A	G	G	G	G	G	G	G	G	G	G	G	2	A	A	A	A	A	A	A	A	A	A	A	A
		B	G	G	G	G	G	G	G	G	G	G	G	2	I	I	I	I	I	I	I	I	I	I	I	A
24S-T3	P1J,L,M,N	A	A	A	A	A	A	A	A	A	A	A	A	1	A	A	A	A	A	A	A	A	A	A	A	A
		B	A	A	A	A	A	A	A	A	A	A	A	1	A	A	A	A	A	A	A	A	A	A	A	A
Alclad 24S-T3	3B,D,E,F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
		B	A	A	A	A	A	A	A	A	A	A	A	A	I,C	I,C	I,C	I,C	I	I	I	I	I	I	I	A
24S-T3	P3B,D,E,F	A	G	G	G	G	G	G	G	G	G	G	G	2	A	A	A	A	A	A	A	A	A	A	A	A
		B	G	G	G	G	G	G	G	G	G	G	G	2	I	I	I	I	I	I	I	I	I	I	I	A
Alclad 24S-T3	4B,D,E,F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
		B	A	A	A	A	A	A	A	A	A	A	A	A	I,C	I,C	I,C	I,C	I	I	I	I	I	I	I	A
24S-T3	P4B,D,E,F	A	G	G	G	G	G,D	G,D	G,D	G,D	G	G	G	2	A	A	A	A	A	A	A	A	A	A	A	A
		B	G,D	G,D	G,D	G,D	G	G	G	G	G	G	G	2	I	I	I	I	I	I	I	I	I	I	I	A
Alclad 24S-T3	5B,D,E,F	A	C	C	C	C	C	C	C	C	C	C	A	A	C	C	A	A	C	C	C	C	C	C	A	A
		B	A	A	A	A	A	A	A	A	A	A	A	A	I,C	I,C	I,C	I,C	I	I	I	I	I	I	I	A
Alclad 24S-T3	6B,D,E,F	A	C	C	A	C	A	A	A	A	A	A	A	A	A	C	C	C	A	A	A	A	A	A	A	A
		B	A	A	A	A	A	A	C	C	A	A	A	A	I	I	I	I	I,C	I,C	I,C	I,C	I,C	I,C	I	A
24S-T3	P5-6B,D,E,F	A	G,D	G,C	G	G	G,D	G,D	G,D	G,D	G,D	G,D	G	2	H	A	H	A	H	H	H	H	H	H	A	A
		B	C	C	C	C	G	G	G	G	G	G	G	S	I,H	I,H	I,H	I,H	I,H	I,H	I,H	I,H	I,H	I,H	I	A
Alclad 24S-T3	7B,D,E,F	A	B	B	B	B	B	B	B	B	B	B	A	A	E	E	E	E	A	A	A	A	A	A	A	A
		B	B	B	B	B	B	B	B	B	B	B	A	A	I	I	I	I	I,E	I,E	I,E	I,E	I,E	I,E	I	A
Alclad 24S-T3	7L,M,N	A	A,F	A,F	A,F	A,F	A,E	A,E	A,E	A,E	A,E	A,E	A	A	F	F	F	F	F	F	F	F	F	F	A	A
		B	A,E	A,E	A,E	A,E	A,F	A,F	A,F	A,F	A,F	A,F	A	A	F	F	F	F	F	F	F	F	F	F	A	A
24S-T3	P7B,D,E,F	A	G,D,F	G,D,F	G,D,F	G,D,F	G,D	G,D	G,D	G,D	G,D	G,D	G	2	F,H	F,H	F,H	F,H	A	A	A	A	A	A	A	A
		B	G,D	G,D	G,D	G,D	G	G	G	G	G	G	G	2	I	I	I	I	F,I	F,I	F,I	F,I	F,I	F,I	I	A
Alclad 24S-T3	9B,D,E,F	A	C	C	C	C	C	C	C	C	C	C	A	A	A	A	A	A	C	C	C	C	A	A	A	A
		B	C	C	C	C	C	C	C	C	C	C	A	A	C,I	C,I	C,I	C,I	I	I	I	I	I	I	I	A
24S-T3	P9B,D,E,F	A	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G	2	A	A	A	A	A	A	A	A	A	A	A	A
		B	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G	2	I	I	C,I	I	I	I	I	I	I	I	I	A
24S-T3	P9J,L,M,N	A	A	A	A	A	A	A	A	A	A	A	A	1	A	A	A	A	A	A	A	A	A	A	A	A
		B	A	A	A	A	A	A	A	A	A	A	A	1	A	A	A	A	A	A	A	A	A	A	A	A
Alclad 24S-T3	10B,D,E,F	A	C	C	C	C	A	A	A	A	A	A	A	A	A	A	A	A	H	H	H	H	H	H	A	A
		B	A	A	A	A	C	C	C	C	C	C	A	A	H	H	H	H	A	A	A	A	A	A	A	A
R-301-T6	2R1,5,6	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
		B	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
R-301-T6	2R9,13,14	A	A	A	A	A	A	A	A	A	A	A	A	A	C	C	C	C	C	C	C	C	C	C	A	A
		B	A	A	K	K	A	A	A	K	A	K	A	A	C	C	C	C	C	C	C	C	C	C	A	A
R-301-T6	4R1,5,6	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
		B	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
R-301-T6	4R9,13,14	A	A	A	A	A	A	A	A	A	A	A	A	A	C	C	C	C	C	C	C	C	C	C	A	A
		B	K	K	K	K	K	K	K	K	K	K	A	A	C	C	C	C	C	C	C	C	C	C	A	A
Alclad XB75S-T6	XC1,5,6	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
		B	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Alclad XB75S-T6	XC9,13,14	A	K	K	K	K	K	K	K	K	K	K	A	A	C	C	C	C	C	C	C	C	C	C	A	A
		B	A	A	A	A	A	A	A	A	A	A	A	A	C	C	C	C	C	C	C	C	C	C	A	A
XB75S-T6	X5,6	A	-----	-----	-----	-----	---	---	---	---	---	---	-	-	J	J	J	J	J	J	J	J	J	J	G	A
		B	-----	-----	-----	-----	---	---	---	---	---	---	-	-	J	J	J	J	J	J	J	J	J	J	G	A
XB75S-T6	X13,14	A	-----	-----	-----	-----	---	---	---	---	---	---	-	-	J	J	J	J	J	J	J	J	J	J	G	A
		B	-----	-----	-----	-----	---	---	---	---	---	---	-	-	J	J	J	J	J	J	J	J	J	J	G	A

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[1] Besides designating panel sides as shown in fig. 1, letters also designate faying surfaces: A designates 1- by 4-in. overlap containing welds 1 to 4 and B designates 4- by 5-in. overlap containing welds 5 to 10.

TABLE VII

DISTRIBUTION OF CORROSION PRODUCTS ON SPOT-WELDED PANELS EXPOSED AT

HAMPTON ROADS, VIRGINIA, FOR 12 MONTHS

Material	Panel	Side of panel (1)	Tidewater exposure											Faying surface	Weather exposure											Faying surface
			Identification number of spot weld										Panel		Identification number of spot weld										Panel	
			1	2	3	4	5	6	7	8	9	10			1	2	3	4	5	6	7	8	9	10		
Alclad 24S-T3	1C,D	A	B	B	B	B	A	A	A	A	A	A	A	A	E	E	E	E	A	A	A	A	A	A	A	A
		B	A	A	B	A	B	B	B	B	B	A	A	A	I	I	I	I	I	I	I	I	I	I	I	A
24S-T3	P1C,D	A	G	G	G	G	G	G	G	G	G	G	G	3	A	A	A	A	A	A	A	A	A	A	A	A
		B	G	G	G	G	G	G	G	G	G	G	G	S	I	I	I	I	I	I	I	I	I	I	I	A
24S-T3	P1I,K,L	A	A	A	A	A	A	A	A	A	A	A	A	1	A	A	A	A	A	A	A	A	A	A	A	A
		B	A	A	A	A	A	A	A	A	A	A	A	1	A	A	A	A	A	A	A	A	A	A	A	A
Alclad 24S-T3	3C,D	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
		B	A	A	A	A	A	A	A	A	A	A	A	A	I,C	I,C	I,C	I,C	I	I	I	I	I	I	I	A
24S-T3	P3C,D	A	G	G	G	G	G	G	G	G	G	G	G	3	A	A	A	A	A	A	A	A	A	A	A	A
		B	G	G	G	G	G	G	G	G	G	G	G	S	I	I	I	I	I	I	I	I	I	I	I	A
Alclad 24S-T3	4C,D	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
		B	A	A	A	A	A	A	A	A	A	A	A	A	I,C	I,C	I,C	I,C	I	I	I	I	I	I	I	A
24S-T3	P4C,D	A	G	G	G	G	G,D	G,D	G,D	G,D	G	G	G	L	A	A	A	A	A	A	A	A	A	A	A	A
		B	G,D	G,D	G,D	G,D	G	G	G	G	G	G	G	L	I	I	I	I	I	I	I	I	I	I	I	A
Alclad 24S-T3	5C,D	A	C	C	C	C	C	C	C	C	C	C	A	A	C	C	A	A	C	C	C	C	C	C	A	A
		B	A	A	A	A	A	A	A	A	A	A	A	A	I,C	I,C	I,C	I,C	I	I	I	I	I	I	I	A
Alclad 24S-T3	6C,D	A	C	C	A	C	A	A	A	A	A	A	A	A	A	C	C	C	A	A	A	A	A	A	A	A
		B	A	A	A	A	A	A	C	C	A	A	A	A	I	I	I	I	I,C	I,C	I,C	I,C	I,C	I,C	I	A
24S-T3	P5-6C,D	A	G,D	G,C	G	G	G,D	G,D	G,D	G,D	G,D	G,D	G	3	H	A	H	H	H	H	H	H	H	H	A	A
		B	C	C	C	C	G	G	G	G	G	G	G	S	I,H	I,H	I,H	I,H	I,H	I,H	I,H	I,H	I,H	I,H	I	A
Alclad 24S-T3	7C,D	A	B	B	B	B	B	B	B	B	B	B	A	A	E	E	E	E	A	A	A	A	A	A	A	A
		B	B	B	B	B	B	B	B	B	B	B	A	A	I	I	I	I	I,E	I,E	I,E	I,E	I,E	I,E	I	A
Alclad 24S-T3	7J,K,L	A	A,F	A,F	A,F	A,F	A,E	A,E	A,E	A,E	A,E	A,E	A	A	F	F	F	F	F	F	F	F	F	F	A	A
		B	A,E	A,E	A,E	A,E	A,F	A,F	A,F	A,F	A,F	A,F	A	A	F	F	F	F	F	F	F	F	F	F	A	A
24S-T3	P7C,D	A	G,D,F	G,D,F	G,D,F	G,D,F	G,D	G,D	G,D	G,D	G,D	G,D	G	3	F,H	F,H	F,H	F,H	A	A	A	A	A	A	A	A
		B	G,D	G,D	G,D	G,D	G	G	G	G	G	G	G	S	I	I	I	I	F,I	F,I	F,I	F,I	F,I	F,I	I	A
Alclad 24S-T3	9C,D	A	C	C	C	C	C	C	C	C	C	C	A	A	A	A	A	A	C	C	C	C	A	A	A	A
		B	C	C	C	C	C	C	C	C	C	C	A	A	C,I	C,I	C,I	C,I	I	I	I	I	I	I	I	A
24S-T3	P9C,D	A	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G	3	A	A	A	A	A	A	A	A	A	A	A	A
		B	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G,D	G	S	I	I	C,I	I	I	I	I	I	I	I	I	A
24S-T3	P9I,K,L	A	A	A	A	A	A	A	A	A	A	A	A	1	A	A	A	A	A	A	A	A	A	A	A	A
		B	A	A	A	A	A	A	A	A	A	A	A	1	A	A	A	A	A	A	A	A	A	A	A	A
Alclad 24S-T3	10C,D	A	C	C	C	C	A	A	A	A	A	A	A	A	A	A	A	A	H	H	H	H	H	H	A	A
		B	A	A	A	A	C	C	C	C	C	C	A	A	H	H	H	H	A	A	A	A	A	A	A	A
R-301-T6	2R2,5	A	A	A	A	A	A	A	A	A	A	A	A	A	G	G	G	G	G	G	G	G	G	G	G	A
		B	A	A	A	A	A	A	A	A	A	A	A	A	G	G	G	G	G	G	G	G	G	G	G	A
R-301-T6	2R10,13	A	B	B	B	B	B,L	B,L	B	B	B	B	A	A	E	E	E	E	E	E	E	E	E	E	G	A
		B	A	A	A	A	A	A	A	A	A	A	A	L[2]	G	G	G	G	G	G	G	G	G	G	G	A
R-301-T6	4R2,5	A	A	A	A	A	A	A	A	A	A	A	A	A	G	G	G	G	G	G	G	G	G	G	G	A
		B	A	A	A	A	A	A	A	A	A	A	A	A	G	G	G	G	G	G	G	G	G	G	G	A
R-301-T6	4R10,13	A	A	A	A	A	A	A	A	A	A	A	A	A	G	G	G	G	G	G	G	G	G	G	G	A
		B	K	K	K	K	K	K	K	K	K	K	A	A	G	G	G	G	G	G	G	G	G	G	G	A
Alclad XB75S-T6	XC2,5	A	A	A	A	A	A	A	A	A	A	A	A	A	G	G	G	G	G	G	G	G	G	G	G	A
		B	A	A	A	A	A	A	A	A	A	A	A	A	G	G	G	G	G	G	G	G	G	G	G	A
Alclad XB75S-T6	XC10,13	A	K	K	K	K	K	K	K	K	K	K	A	A	K	K	K	K	K	K	K	K	K	K	G	A
		B	A	A	A	A	A	A	A	A	A	A	A	A	G	G	G	G	G	G	G	G	G	G	G	A
XB75S-T6	X2,5	A	J	J	J	J	J	J	J	J	J	J	G	1	E	E	E	E	E	E	E	E	E	E	G	A
		B	J	J	J	J	J	J	J	J	J	J	G	1	J	J	J	J	J	J	J	J	J	J	G	A
XB75S-T6	X10,13	A	J	J	J	J	J	J	J	J	J	J	G	1	G	G	G	G	K	K	K	K	K	K	G	A
		B	J	J	J	J	J	J	J	J	J	J	G	1	J	J	J	J	J	J	J	J	J	J	G	A

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[1] Besides designating panel sides as shown in fig. 1, letters also designate faying surfaces: A designates 1- by 4-in. overlap containing welds 1 to 4 and B designates 4- by 5-in. overlap containing welds 5 to 10.

[2] Only welds 5 and 6 were separated at faying surfaces.

TABLE VIII

DISTRIBUTION OF CORROSION PRODUCTS ON SPOT-WELDED PANELS EXPOSED AT HAMPTON ROADS, VIRGINIA, FOR 24 MONTHS

Material	Panel	Side of panel (1)	Tidewater exposure											Faying surface	Weather exposure											Faying surface
			Identification number of spot weld										Panel		Identification number of spot weld										Panel	
			1	2	3	4	5	6	7	8	9	10			1	2	3	4	5	6	7	8	9	10		
Alclad 24S-T3	1E	A	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	A,B	A,B	A,B	A,B	A,B	A,B	A,B	A,B	A,B	A,B	A	A
		B	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	I,B	I,B	I,B	I,B	I,B	I,B	I,B	I,B	I,B	I,B	I	A
24S-T3	P1E	A	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	A	A	A	A	A	A	A	A	A	A	A	A
		B	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	I	I	I	I	I	I	I	I	I	I	I	A
24S-T3	P1M	A	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	A	A	A	A	A	A	A	A	A	A	A	A
		B	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	A	A	A	A	A	A	A	A	A	A	A	A
Alclad 24S-T3	3E	A	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	A	A	A	A	A	A	A	A	A	A	A	A
		B	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	I,C	I,C	I,C	I,C	I,C	I,C	I,C	I,C	I,C	I,C	I	A
24S-T3	P3E	A	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	A	A	A	A	A	A	A	A	A	A	A	A
		B	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	I	I	I	I	I	I	I	I	I	I	I	A
Alclad 24S-T3	4E	A	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	A	A	A	A	A	A	A	A	A	A	A	A
		B	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	I,C	I,C	I,C	I,C	I,C	I,C	I,C	I,C	I,C	I,C	I	A
24S-T3	P4E	A	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	A	A	A	A	A	A	A	A	A	A	A	A
		B	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	I	I	I	I	I	I	I	I	I	I	I	A
Alclad 24S-T3	5E	A	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	A,C	A,E	A	A	A	A	A	A	A	A	A	A
		B	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	I	I	I	I	I,J	I,J	I,J	I,J	I,J	I,J	I	A
Alclad 24S-T3	6E	A	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	A,C	A	A	A	A	A	A	A	A	A	A	A
		B	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	I	I	I	I	I,C	I,C	I,C	I,C	I,C	I,C	I	A
24S-T3	P5-6E	A	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	A	A	A,H	A,H	A,H	A,H	A,H	A,H	A,H	A,H	A	A
		B	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	I,H	I,H	I,H	I,H	I	I	I	I	I	I	I	A
Alclad 24S-T3	7E	A	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	A,E	A,E	A,E	A,E	A,E	A,E	A,E	A,E	A,E	A,E	A	A
		B	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	I	I	I	I	I,B	I,B	I,B	I,B	I,B	I,B	I	A
Alclad 24S-T3	7M	A	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	A,F	A,F	A,F	A,F	A,F	A,F	A,F	A,F	A,F	A,F	A	A
		B	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	A,F	A,F	A,F	A,F	A,F	A,F	A,F	A,F	A,F	A,F	A	A
24S-T3	P7E	A	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	A,F	A,F	A,F,H	A,F	A	A	A	A	A	A	A	A
		B	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	I	I	I	I	I,F	I,F	I,F	I,F	I,F	I,F	I	A
Alclad 24S-T3	9E	A	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	A	A	A	A	A	A	A	A,C	A,C	A,C	A	A
		B	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	I	I	I,C	I,C	I	I	I	I	I	I	I	A
24S-T3	P9E	A	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	A	A	A	A	A	A	A	A	A	A	A	A
		B	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	I	I	I	I	I	I	I	I	I	I	I	A
24S-T3	P9M	A	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	A	A	A	A	A	A	A	A	A	A	A	A
		B	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	A	A	A	A	A	A	A	A	A	A	A	A
Alclad 24S-T3	10E	A	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	A,H	A,H	A,H	A,H	A	A	A	A	A	A	A	A
		B	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-------	A	A	A	A	A,H	A,H	A,H	A,H	A,H	A,H	A	A
R-301-T6	2R3	A	E,M	E,M	A,E	A,E	E,M	E,M	A,E	A,E	E,M	E,M	M	A	---	---	-----	---	---	---	---	---	---	---	-----	-------
		B	E,M	E,M	E,M	E,M	A,E	E,M	E,M	A,E	E,M	A,E	M	1	---	---	-----	---	---	---	---	---	---	---	-----	-------
R-301-T6	2R11	A	E,M	E,M,N	E,M,N	A,E	E,M,N	E,M	E,M,N	A,E,N	A,E,N	A,E,N	M	A	---	---	-----	---	---	---	---	---	---	---	-----	-------
		B	A,E,N	E,J,N	A,E,N	E,M,N	E,M	E,M	A,E	A,E	A,E	A,E	M	1	---	---	-----	---	---	---	---	---	---	---	-----	-------
R-301-T6	4R3	A	E,M	E,M	E,M	A,E	E,M	A,E	A,E	A,E	A,E	E,M	M	A	---	---	-----	---	---	---	---	---	---	---	-----	-------
		B	E,M	E,M	E,M	E,M	A,E	E,M	E,M	E,M	A,E	A,E	M	1	---	---	-----	---	---	---	---	---	---	---	-----	-------
R-301-T6	4R11	A	A,E	A,E	A,E	A,E	A,E	E,M	E,M,N	A,E	A,E	E,M,N	M	A	---	---	-----	---	---	---	---	---	---	---	-----	-------
		B	E,J,M	E,M	E,M	E,J	E,J,M	E,M	E,J	A,E	E,J,M	A,E	M	1	---	---	-----	---	---	---	---	---	---	---	-----	-------
Alclad XB75S-T6	XC3	A	E,M	A,E	A,E	A,E	A,E	A,E	E,M	A,E	A,E	A,E	M	A	---	---	-----	---	---	---	---	---	---	---	-----	-------
		B	A,E	A,E	A,E	A,E	E,M	E,M	A,E	E,M	E,M	A,E	M	A	---	---	-----	---	---	---	---	---	---	---	-----	-------
Alclad XB75S-T6	XC11	A	E,J,N	J	J	E,J,N	E,J,N	E,M,N	E,J,N	E,N	E,J,N	E,J,N	M	A	---	---	-----	---	---	---	---	---	---	---	-----	-------
		B	E,M	E,M	E,M	A,E,N	E,M	A,E	A,E	A,E,N	E,M	A,E	M	A	---	---	-----	---	---	---	---	---	---	---	-----	-------
XB75S-T6	X3	A	R	R	R	R	R	R	R	R	P	P	M	A	---	---	-----	---	---	---	---	---	---	---	-----	-------
		B	R	R	R	R	R	R	R	R	P	P	M	1	---	---	-----	---	---	---	---	---	---	---	-----	-------
XB75S-T6	X11	A	R	P	R	R	R	R	R	R	P	P	M	A	---	---	-----	---	---	---	---	---	---	---	-----	-------
		B	R	P	R	R	R	P	R	R	R	P	M	1	---	---	-----	---	---	---	---	---	---	---	-----	-------

[1] Besides designating panel sides as shown in fig. 1, letters also designate faying surfaces: A designates 1- by 4-in. overlap containing welds 1 to 4 and B designates 4- by 5-in. overlap containing welds 5 to 10.

TABLE IX

DISTRIBUTION OF CORROSION PRODUCTS ON SPOT-WELDED PANELS EXPOSED AT HAMPTON ROADS, VIRGINIA, FOR 36 MONTHS

Material	Panel	Side of panel (1)	Tidewater exposure												Weather exposure											
			Identification number of spot weld										Panel	Faying surface	Identification number of spot weld										Panel	Faying surface
			1	2	3	4	5	6	7	8	9	10			1	2	3	4	5	6	7	8	9	10		
Alclad 24S-T3	1F	A	-	-	-	-	-	-	-	-	-	-	-	-	A,B	A,B	A,B	A,B	A,B	A,B	A,B	A,B	A,B	A,B	A	A
		B	-	-	-	-	-	-	-	-	-	-	-	-	I	I	I	I	I	I	I	I	I	I	I	A
24S-T3	P1F	A	-	-	-	-	-	-	-	-	-	-	-	-	A	A	A	A	A	A	A	A	A	A	A	A
		B	-	-	-	-	-	-	-	-	-	-	-	-	I	I	I	I	I	I	I	I	I	I	I	A
24S-T3	P1N	A	-	-	-	-	-	-	-	-	-	-	-	-	A	A	A	A	A	A	A	A	A	A	A	A
		B	-	-	-	-	-	-	-	-	-	-	-	-	A	A	A	A	A	A	A	A	A	A	A	A
Alclad 24S-T3	3F	A	-	-	-	-	-	-	-	-	-	-	-	-	A	A	A	A	A	A	A	A	A	A	A	A
		B	-	-	-	-	-	-	-	-	-	-	-	-	I,C	I,C	I,C	I,C	I,C	I,C	I,C	I,C	I,C	I,C	I	A
24S-T3	P3F	A	-	-	-	-	-	-	-	-	-	-	-	-	A	A	A	A	A	A	A	A	A	A	A	A
		B	-	-	-	-	-	-	-	-	-	-	-	-	I	I	I	I	I	I	I	I	I	I	I	A
Alclad 24S-T3	4F	A	-	-	-	-	-	-	-	-	-	-	-	-	A	A	A	A	A	A	A	A	A	A	A	A
		B	-	-	-	-	-	-	-	-	-	-	-	-	I	I	I	I	I	I	I	I	I	I	I	A
24S-T3	P4F	A	-	-	-	-	-	-	-	-	-	-	-	-	A	A	A	A	A	A	A	A	A	A	A	A
		B	-	-	-	-	-	-	-	-	-	-	-	-	I	I	I	I	I	I	I	I	I	I	I	A
Alclad 24S-T3	5F	A	-	-	-	-	-	-	-	-	-	-	-	-	A,C	A,C	A	A,C	A	A	A	A	A	A	A	A
		B	-	-	-	-	-	-	-	-	-	-	-	-	I	I	I	I	I,J	I,J	I,J	I,J	I,J	I,J	I	A
Alclad 24S-T3	6F	A	-	-	-	-	-	-	-	-	-	-	-	-	A	A	A	A	A	A	A	A	A	A	A	A
		B	-	-	-	-	-	-	-	-	-	-	-	-	I	I	I	I	I	I	I	I	I	I	I	A
24S-T3	P5-6F	A	-	-	-	-	-	-	-	-	-	-	-	-	A,H	A	A,H	A	A,H	A,H	A,H	A,H	A,H	A,H	A	A
		B	-	-	-	-	-	-	-	-	-	-	-	-	I,H	I,H	I,H	I,H	I,H	I,H	I,H	I	I	I	I	A
Alclad 24S-T3	7F	A	-	-	-	-	-	-	-	-	-	-	-	-	A,E	A,E	A,E	A,E	A	A	A	A	A	A	A	A
		B	-	-	-	-	-	-	-	-	-	-	-	-	I	I	I	I	I,D	I,D	I,D	I,D	I,D	I,D	I	A
Alclad 24S-T3	7N	A	-	-	-	-	-	-	-	-	-	-	-	-	A,F	A,F	A,F	A,F	A,F	A,F	A,F	A,F	A,F	A,F	A	A
		B	-	-	-	-	-	-	-	-	-	-	-	-	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I	A
24S-T3	P7F	A	-	-	-	-	-	-	-	-	-	-	-	-	A,F	A,F	A,F	A,F	A,F	A	A	A	A	A	A	A
		B	-	-	-	-	-	-	-	-	-	-	-	-	I	I	I	I	I,F	I,F	I,F	I,F	I,F	I,F	I	A
Alclad 24S-T3	9F	A	-	-	-	-	-	-	-	-	-	-	-	-	A	A	A	A	A,C	A,C	A,C	A,C	A,C	A,C	A	A
		B	-	-	-	-	-	-	-	-	-	-	-	-	I	I	I,C	I,C	I	I	I	I	I	I	I	A
24S-T3	P9F	A	-	-	-	-	-	-	-	-	-	-	-	-	A	A	A	A	A	A	A	A	A	A	A	A
		B	-	-	-	-	-	-	-	-	-	-	-	-	I,C	I,C	I,C	I,C	I,D	I,D	I,D	I,D	I,D	I,D	I	A
24S-T3	P9N	A	-	-	-	-	-	-	-	-	-	-	-	-	A	A	A	A	A	A	A	A	A	A	A	A
		B	-	-	-	-	-	-	-	-	-	-	-	-	A	A	A	A	A	A	A	A	A	A	A	A
Alclad 24S-T3	10F	A	-	-	-	-	-	-	-	-	-	-	-	-	A,H	A,H	A	A,H	A	A	A	A	A	A	A	A
		B	-	-	-	-	-	-	-	-	-	-	-	-	I	I	I	I	I,H	I,H	I,H	I,H	I,H	I,H	I	A
R-301-T6	2R4,6	A	M	M	M	M	M	M	M	M	M	M	M	1	G	G	G	G	G	E	E	E	G	G	G	A
		B	M	M	M	M	M	M	M	M	M	M	M	1	G	G	G	G	G	G	G	G	G	G	G	A
R-301-T6	2R12,14	A	M	M	M	M	M	M	M	M	M	M	M	1	G	G	G	E	E	E	E	E	G	E	G	A
		B	M	M	M	M	M	M	M	M	M	M	M	1	G	G	J	J	G	G	G	G	G	J	G	A
R-301-T6	4R4,6	A	M	M	M	M	M	M	M	M	M	M	M	1	G	G	G	G	G	G	G	G	G	G	G	A
		B	M	M	M	M	M	M	M	M	M	M	M	1	G	G	G	G	G	G	G	G	G	G	G	A
R-301-T6	4R12,14	A	M	M	M	M	M	M	M	M	M	M	M	1	G	G	G	G	G	G	E	E	G	G	G	A
		B	K	M	K	K	K	K	M	K	K	K	M	1	G	G	G	G	G	G	G	G	G	G	G	A
Alclad XB75S-T6	XC4,6	A	M	M	M	M	M	M	M	M	M	M	M	1	G	G	G	G	G	G	G	G	G	G	G	A
		B	M	M	M	M	M	M	M	M	M	M	M	1	G	G	G	G	G	G	G	G	G	G	G	A
Alclad XB75S-T6	XC12,14	A	M	M	M	M	M	M	M	M	M	M	M	1	K	G	K	K	K	G	K	K	K	G	G	A
		B	M	M	M	M	M	M	M	M	M	M	M	1	G	G	G	G	G	G	G	G	G	G	G	A
XB75S-T6	X4,6	A	R	J	R	R	R	J	P	R	R	P	M	2	E	E	E	E	E	E	E	E	E	E	G	A
		B	R	R	R	R	R	R	P	P	R	P	M	2	J	J	J	J	J	J	J	J	J	J	G	A
XB75S-T6	X12,14	A	J	J	J	J	J	P	P	J	J	J	M	L	E	E	E	E	E	E	E	E	E	E	G	A
		B	J	J	J	J	J	P	P	J	J	J	M	L	J	J	J	J	J	J	J	J	J	J	G	A

[1] Besides designating panel sides as shown in fig. 1, letters also designate faying surfaces: A designates 1- by 4-in. overlap containing welds 1 to 4 and B designate 4- and 5-in. overlap containing welds 5 to 10.

TABLE X

AVERAGE SHEAR STRENGTH OF SPOT WELDS

Panel series	Average shear strength (lb)									
	Unexposed	Tidewater exposure						Weather exposure		
		12 days	4 weeks	7 months	12 months	24 months	36 months	12 months	24 months	36 months
1	498	---	565	498	535	---	---	552	525	506
3	414	---	352	413	270	---	---	358	443	385
4	523	---	473	528	535	---	---	528	513	525
5	611	---	613	547	603	---	---	638	663	578
6	668	---	660	593	640	---	---	623	578	630
[a]7	369	---	417	463	360	---	---	380	220	605
[a]7'	158	---	203	---	335	---	---	325	155	83
9	667	---	598	578	667	---	---	618	580	598
10	558	---	605	595	602	---	---	570	[b]490	565
P1	548	---	528	355	558	---	---	602	530	553
P1'	572	---	---	575	559	---	---	573	570	563
P3	542	---	568	108	553	---	---	535	533	553
P4	602	---	610	488	0	---	---	595	565	558
P5/6	678	---	708	495	380	---	---	683	613	620
P7	569	---	610	608	595	---	---	605	555	588
P9	538	---	538	445	483	---	---	535	500	483
P9'	584	---	---	538	543	---	---	523	533	538
2R	220	---	---	210	210	213	215	223	---	210
2R'	[b]278	---	---	230	185	223	215	193	---	230
4R	449	---	---	450	443	(c)	463	440	---	450
4R'	489	---	---	---	---	578	603	608	---	533
XC	538	---	---	---	---	538	520	508	---	585
XC'	484	---	---	---	---	485	448	533	---	538
X	603	533	---	---	427	[b]500	[b]530	598	---	528
X'	612	498	---	---	275	303	0	508	---	493

[a] Welds in these series were very inconsistent before exposure.

[b] Value may not be very reliable.

[c] Specimens were improperly cut from panel.

TABLE XI

AVERAGE STRENGTH OF SPOT WELDS IN NORMAL TENSION

Panel series	Average strength in normal tension (lb)								
	Unexposed	Tidewater exposure					Weather exposure		
		4 weeks	7 months	12 months	24 months	36 months	12 months	24 months	36 months
1	160	165	165	175	---	---	165	120	145
3	255	220	225	270	---	---	215	180	220
4	235	255	228	218	---	---	255	185	170
5	240	250	255	230	---	---	225	195	190
6	210	205	235	225	---	---	260	175	155
[a]7	213	220	200	(b)	---	---	235	180	200
[a]7'	[c]40	170	---	193	---	---	220	120	200
9	222	185	185	190	---	---	220	205	200
10	215	200	295	250	---	---	225	195	185
P1	210	220	150	220	---	---	220	200	145
P1'	192	---	195	207	---	---	195	165	150
P3	195	185	170	160	---	---	200	160	155
P4	213	210	155	185	---	---	230	185	200
P5/6	213	235	120	130	---	---	205	180	200
P7	245	200	160	150	---	---	250	150	180
P9	223	200	180	170	75	85	210	175	200
P9'	213	---	210	207	---	---	205	180	180
2R	65	---	65	75	75	85	75	---	75
2R'	70	---	70	70	[c]80	75	0	---	65
4R	203	---	205	280	225	235	230	---	235
4R'	195	---	170	245	180	185	180	---	195
XC	80	---	85	(d)	100	85	95	---	105
XC'	73	---	75	105	[c]130	90	70	---	110
X	(d)	---	---	---	---	---	---	---	---
X'	(d)	---	---	---	---	---	---	---	---

[a] Welds in these series were very inconsistent before exposure.

[b] Specimens were missing.

[c] Value may not be very reliable.

[d] Specimens broke in being fitted to test blocks.

TABLE XII

SUMMARY OF EFFECTS OF EXPOSURE ON AVERAGE SHEAR STRENGTH OF SPOT WELDS IN 0.040-INCH ALCLAD 24S-T3

[Surfaces of all panels were chemically prepared for welding unless otherwise noted]

Panel series	Conditions	Control weld strength (lb)	Change in shear strength (percent)					
			Tidewater exposure			Weather exposure		
			4 weeks	7 months	12 months	12 months	24 months	36 months
1	Sound welds	498	13.4	0	7.4	10.8	5.4	1.4
3	Small but sound welds; postheated	414	-14.8	-0.3	-34.8	-13.5	7.0	-7.0
4	Welds internally cracked	523	-9.6	1.0	2.3	1.0	-1.9	0.4
5	Welds cracked to surface	611	0.2	-10.6	-1.3	4.4	8.5	-5.4
6	Faying surfaces untreated, outer surfaces wire-brushed; metal expelled from welds	668	-1.2	-11.2	-4.2	-6.9	-13.5	-5.7
9	Wire-brushed surfaces; sound welds	667	-10.3	-13.3	0	-7.3	-13.1	-10.3
10	Welds cracked to surface; panels anodized	558	8.4	6.6	-7.9	2.2	[a]-12.2	1.3

[a] Value may not be very reliable.

TABLE XIII

SUMMARY OF EFFECTS OF EXPOSURE ON AVERAGE SHEAR STRENGTH OF SPOT WELDS IN 0.040-INCH 24S-T3

[Surfaces of all panels were chemically prepared for welding unless otherwise noted; all panels were anodized after welding]

Panel series	Conditions	Control weld strength (lb)	Change in shear strength (percent)					
			Tidewater exposure			Weather exposure		
			4 weeks	7 months	12 months	12 months	24 months	34 months
P1	Sound welds	548	-4.0	-35.2	1.8	1.8	-3.3	0.9
P1'	Sound welds; panels painted after anodizing	572	----	0.5	-2.3	0.2	-0.4	-1.6
P3	Sound welds; postheated	542	4.8	-81.0	2.1	-1.3	-1.7	2.0
P4	Welds internally cracked	602	1.3	-18.9	-100.0	-1.2	-6.1	-7.3
P5/6	Welds cracked to surface; metal expelled from welds	678	4.4	-27.0	-43.9	0.1	-9.6	-8.6
P7	Welds made with dirty electrodes	569	7.2	7.0	4.7	6.3	-2.5	3.3
P9	Wire-brushed surfaces; sound welds	538	0	-17.3	-10.2	-0.6	-7.1	-10.0
P9'	Wire-brushed surfaces; sound welds; panels painted after anodizing	584	----	-7.9	-7.1	-10.7	-8.7	-7.9

TABLE XIV

SUMMARY OF EFFECTS OF EXPOSURE ON AVERAGE SHEAR STRENGTH

OF SPOT WELDS IN HIGH-STRENGTH ALUMINUM ALLOYS, R-301-T6 AND XB75S-T6

Panel series	Metal	Gage (in.)	Conditions	Control weld strength (lb)	Change in normal tensile strength (percent)						
					Tidewater exposure					Weather exposure	
					12 days	7 months	12 months	24 months	36 months	12 months	36 months
2R	R-301-T6	0.020	Sound welds	220	-----	-0.9	-4.5	-3.2	-2.3	1.4	-4.5
2R'	R-301-T6	0.020	Welds cracked to surface, made with dirty electrodes	[a]278	-----	-17.3	-33.5	-19.8	-22.7	-30.6	-17.3
4R	R-301-T6	0.040	Sound welds	449	-----	0.2	-1.3	(b)	3.1	-2.0	0.2
4R'	R-301-T6	0.040	Internally cracked welds made with dirty electrodes	489	-----	26.8	5.9	18.2	23.4	24.4	9.0
XC	Alclad XB75S-T6	0.040	Sound welds	538	-----	-2.4	-3.7	0	-3.4	-5.6	8.7
XC'	Alclad XB75S-T6	0.040	Welds cracked to surface, made with dirty electrodes	484	-----	13.2	-7.4	0.1	-7.4	10.1	11.2
X	XB75S-T6	0.040	Sound welds	603	-11.6	-----	-29.2	[a]-17.1	[a]-12.1	-0.8	-12.4
X'	XB75S-T6	0.040	Welds cracked to surface, made with dirty electrodes	612	-18.6	-----	[a]-55.0	-50.5	-100.0	-17.0	-19.5

[a] Value may not be very reliable.

[b] Specimens were improperly cut from panel.

TABLE XV

SUMMARY OF EFFECTS OF EXPOSURE ON NORMAL TENSILE STRENGTH OF SPOT WELDS IN 0.040-INCH ALCLAD 24S-T3

[Surfaces of all panels were chemically prepared for welding unless otherwise noted]

Panel series	Conditions	Control weld strength (lb)	Change in normal tensile strength (percent)					
			Tidewater exposure			Weather exposure		
			4 weeks	7 months	12 months	12 months	24 months	36 months
1	Sound welds	160	3.1	3.1	9.3	3.1	-25.0	-9.4
3	Small but sound welds; postheated	255	-13.7	-11.8	5.9	-15.7	-29.4	-13.7
4	Welds internally cracked	235	8.5	3.0	-7.2	8.5	-21.3	-27.6
5	Welds cracked to surface	240	4.2	-6.2	-4.2	-6.3	-18.8	-20.8
6	Faying surfaces untreated, outer surfaces wire-brushed; metal expelled from welds	210	-2.4	11.9	7.1	23.8	-16.7	-26.2
9	Wire-brushed surface; sound welds	222	-16.6	-16.6	-14.4	-0.9	-7.7	-9.9
10	Welds cracked to surface; panels anodized	215	-7.0	37.2	16.3	4.6	-9.3	-13.9

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TABLE XVI

SUMMARY OF EFFECTS OF EXPOSURE ON NORMAL TENSILE STRENGTH OF SPOT WELDS IN 0.040-INCH 24S-T3

[Surfaces of all panels were chemically prepared for welding unless otherwise noted; all panels were anodized after welding]

Panel series	Conditions	Control weld strength (lb)	Change in normal tensile strength (percent)					
			Tidewater exposure			Weather exposure		
			4 weeks	7 months	12 months	12 months	24 months	36 months
P1	Sound welds	210	4.8	-28.6	4.8	4.8	-4.8	-31.0
P1'	Sound welds; panels painted after anodizing	192	-----	1.6	7.8	1.6	-14.1	-21.9
P3	Sound welds; postheated	195	-5.1	-12.8	-18.0	2.6	-17.9	-20.5
P4	Welds internally cracked	213	-1.4	-27.2	-13.2	8.0	-13.1	-6.1
P5/6	Welds cracked to surface; metal expelled from welds	213	10.3	-43.7	-39.0	-3.8	-15.5	-6.1
P7	Welds made with dirty electrodes	245	-18.4	-34.7	[a]-38.8	2.0	-38.6	-26.6
P9	Wire-brushed surfaces; sound welds	223	-10.3	-19.3	-23.8	-5.8	-21.5	-10.3
P9'	Wire-brushed surfaces; sound welds; panels painted after anodizing	213	-----	-1.5	-2.8	-3.8	-15.5	-15.5

[a] Values may not be very reliable.

TABLE XVII

SUMMARY OF EFFECTS OF EXPOSURE ON NORMAL TENSILE STRENGTH OF SPOT WELDS IN HIGH-STRENGTH ALUMINUM ALLOYS, R-301-T6 AND XB75S-T6

[Surfaces of all panels were chemically prepared for welding]

Panel series	Metal	Gage (in.)	Conditions	Control weld strength (lb)	Change in normal tensile strength (percent)						
					Tidewater exposure					Weather exposure	
					12 days	7 months	12 months	24 months	36 months	12 months	36 months
2R	R-301-T6	0.020	Sound welds	75	---	-13.3	0	0	13.3	0	0
2R'	R-301-T6	0.020	Welds cracked to surface, made with dirty electrodes	70	---	0	0	[a]14.3	7.1	-100.0	-7.1
4R	R-301-T6	0.040	Sound welds	203	---	1.0	37.9	10.8	15.7	13.3	10.8
4R'	R-301-T6	0.040	Internally cracked welds made with dirty electrodes	195	---	-12.8	25.6	-7.7	-5.1	-7.7	0
XC	Alclad XB75S-T6	0.040	Sound welds	80	---	6.3	(b)	25.0	6.3	18.8	31.3
XC'	Alclad XB75S-T6	0.040	Welds cracked to surface, made with dirty electrodes	73	---	2.7	43.9	78.0	23.3	[a]-4.1	50.7
X	XB75S-T6	0.040	Sound welds	(b)	(b)	-----	(b)	(b)	(b)	(b)	(b)
X'	XB75S-T6	0.040	Welds cracked to surface, made with dirty electrodes	(b)	(b)	-----	(b)	(b)	(b)	(b)	(b)

[a] Value may not be very reliable.

[b] Specimens broke in being fitted to test fixture.

TABLE XVIII

RATIO OF AVERAGE NORMAL TENSILE STRENGTH TO AVERAGE SHEAR STRENGTH

Panel series	Unexposed	Tidewater exposure					Weather exposure		
		4 weeks	7 months	12 months	24 months	36 months	12 months	24 months	36 months
1	0.321	0.292	0.331	0.327	-----	-----	0.299	0.229	0.287
3	.616	.625	.545	-----	-----	-----	.601	.405	.572
4	.449	.539	.432	.408	-----	-----	.484	.361	.324
5	.393	.407	.467	.382	-----	-----	.353	.294	.329
6	.314	.311	.396	.352	-----	-----	.417	.303	.246
[a]7	.213	.528	.432	-----	-----	-----	.618	.819	.331
[a]7'	[b].252	.836	-----	.576	-----	-----	.677	.774	[b].361
9	.333	.310	.320	.285	-----	-----	.356	.354	.334
10	.386	.331	.496	.415	-----	-----	.395	[b].398	.327
P1	.383	.417	.422	.394	-----	-----	.365	.377	.262
P1'	.336	-----	.496	.371	-----	-----	-----	.289	.266
P3	.360	.325	-----	.289	-----	-----	.374	.300	.280
P4	.354	.344	.346	-----	-----	-----	.387	.328	.359
P5/6	.314	.332	.243	.342	-----	-----	.301	.293	.322
P7	.430	.328	.263	.252	-----	-----	.413	.270	.306
P9	.414	.372	.405	.352	-----	-----	.392	.350	.414
P9'	.365	-----	.391	.382	-----	-----	.392	.337	.334
2R	.295	-----	.298	.357	0.352	0.395	.336	-----	.357
2R'	[b].252	-----	.304	.378	[b].359	.348	-----	-----	.282
4R	.452	-----	.455	.632	-----	.507	.522	-----	.500
4R'	.399	-----	.274	.473	.312	.307	.296	-----	.366
XC	.149	-----	.162	-----	.186	.163	.187	-----	.179
XC'	.151	-----	.137	.234	.268	.404	[b].131	-----	.592

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[a] Welds in these series were very inconsistent before exposure.

[b] Value may not be very reliable.

TABLE XIX

SUMMARY OF WELDING CONDITIONS, EXPOSURE CONDITIONS, AND CHANGES IN WELD STRENGTH FOR PANELS FROM WHICH SPOT WELDS WERE TAKEN FOR METALLOGRAPHIC EXAMINATION

Panel series	Alloy	Surface treatment	Weld quality	Exposure conditions (1)	Average change in shear strength (percent)
1G	Alclad 24S-T3	Chemical	Sound	Laboratory	0
1C	Alclad 24S-T3	----do----	----do---	T.W., 1 year	7.4
1E	Alclad 24S-T3	----do----	----do---	W., 3 years	5.4
5C	Alclad 24S-T3	----do----	Cracks to surface	T.W., 1 year	-1.3
5F	Alclad 24S-T3	----do----	----do---	W., 3 years	-5.4
6C	Alclad 24S-T3	----do----	Expelled	T.W., 1 year	-4.2
6F	Alclad 24S-T3	----do----	----do---	W., 3 years	-5.7
9C	Alclad 24S-T3	Wire brush	Sound	T.W., 1 year	0
9F	Alclad 24S-T3	----do----	----do---	W., 3 years	-10.3
2R7	R-301-T6	Chemical	Good	Laboratory	0
2R4	R-301-T6	----do----	----do---	T.W., 3 years	-2.3
2R6	R-301-T6	----do----	----do---	W., 3 years	-3.2
2R15	R-301-T6	----do----	Poor[2]	Laboratory	0
2R16	R-301-T6	----do----	----do---	------do------	(3)
2R12	R-301-T6	----do----	----do---	T.W., 3 years	-22.7
2R14	R-301-T6	----do----	----do---	W., 3 years	-17.3
X-15	XB75S-T6	----do----	----do---	Laboratory	0
X-9	XB75S-T6	----do----	----do---	T.W., 12 days	-18.6
X-13	XB75S-T6	----do----	----do---	W., 1 year	-17.0

[1] Exposure conditions: Laboratory, indoors at Rensselaer Polytechnic Institue; T.W., tidewater; W., weather at sea coast.

[2] Poor weld quality intentionally produced with dirty electrodes.

[3] Not determined.

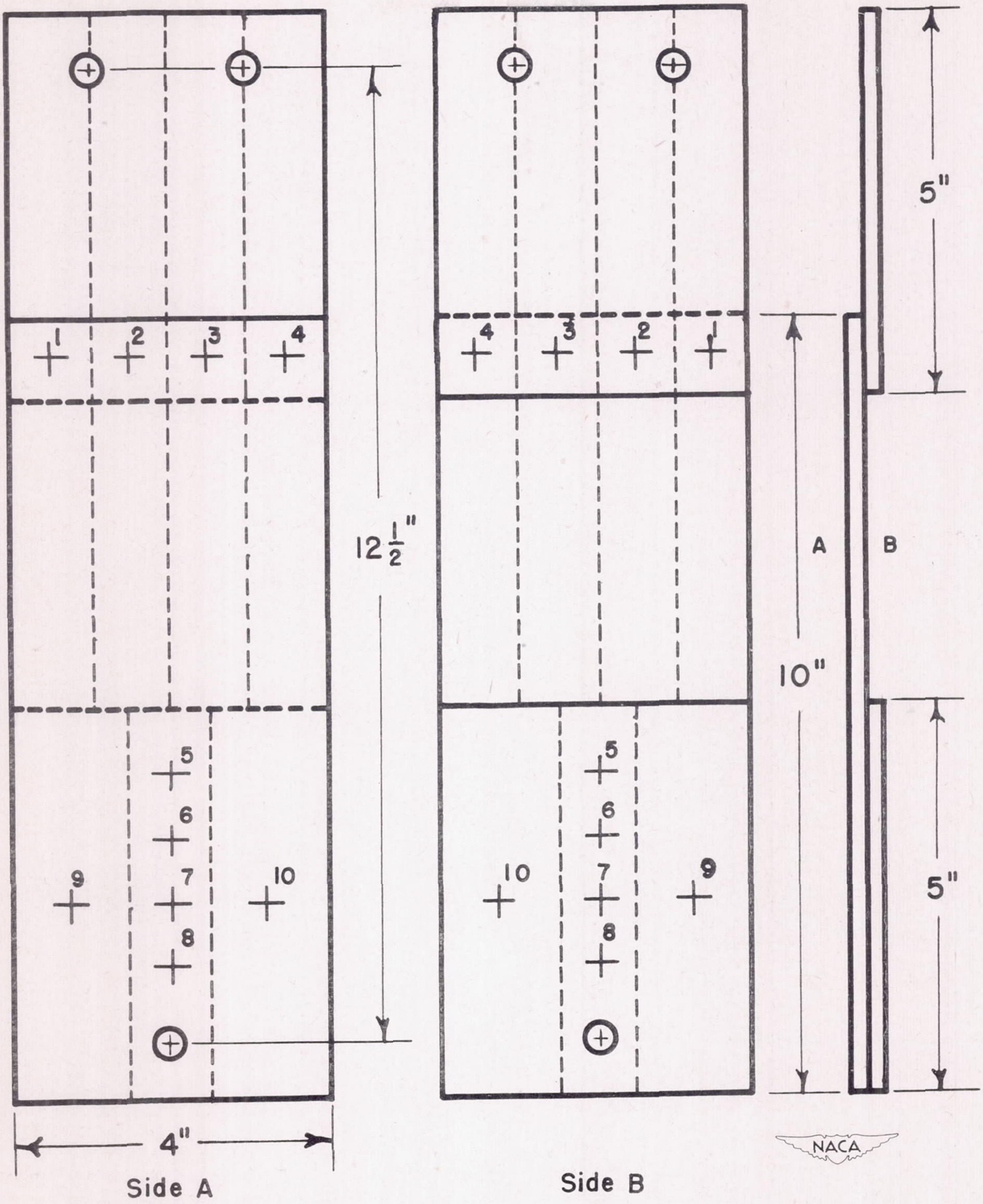

Figure 1.- Design for test panels of spot-welded aluminum alloys. Numbers indicate location of welds.

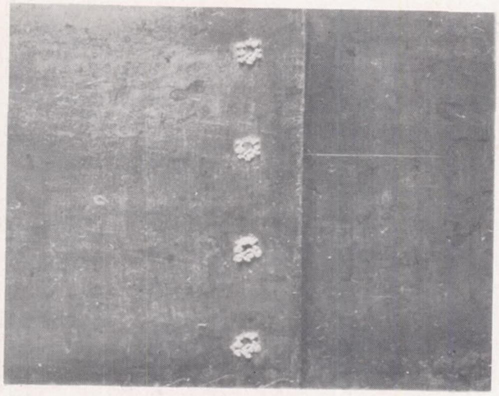

Figure 2.- Type B. Typical ring of corrosion products just inside circumference of welds, X$\frac{1}{2}$.

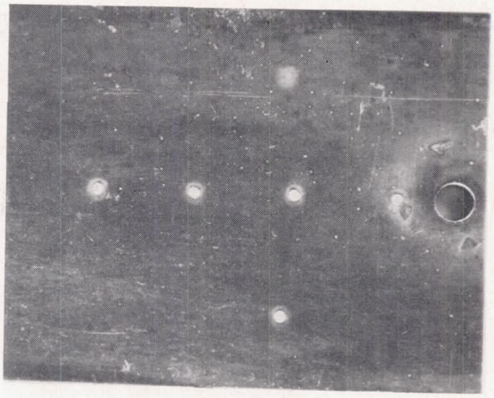

Figure 3.- Type C. Typical area of corrosion products in center of welds, X$\frac{1}{2}$.

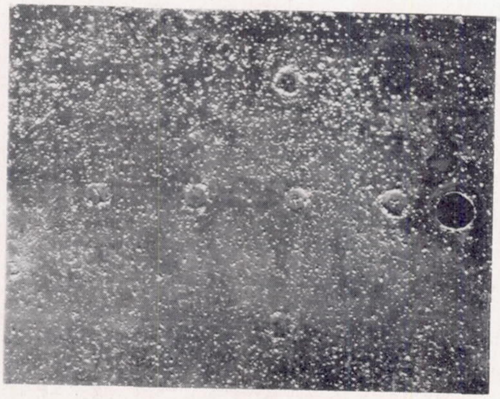

Figure 4.- Type D. Typical circumferential ring of corrosion products on rim of depressed area of weld, X$\frac{1}{2}$.

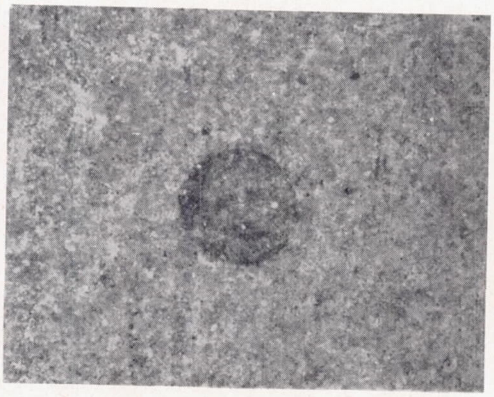

Figure 5.- Type E. Rough discolored ring inside weld, darker than main portion of panel, X3.

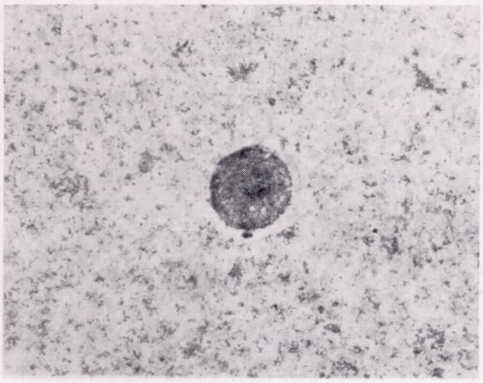

Figure 6.- Type F. Dark gray colored area in center of weld, darker than main portion of panel, X3.

Figure 7.- Type G. Corrosion products are approximately as heavy on panel as they are on weld, X3.

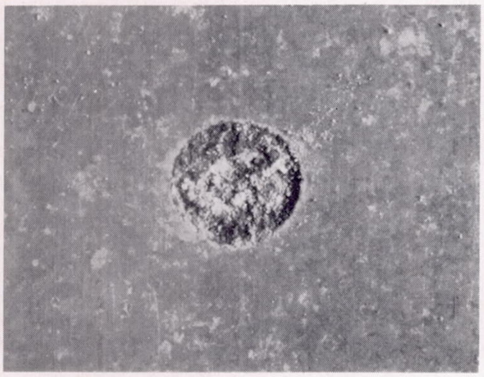

Figure 8.- Type J. General, severe corrosive attack on spot welds, X3.

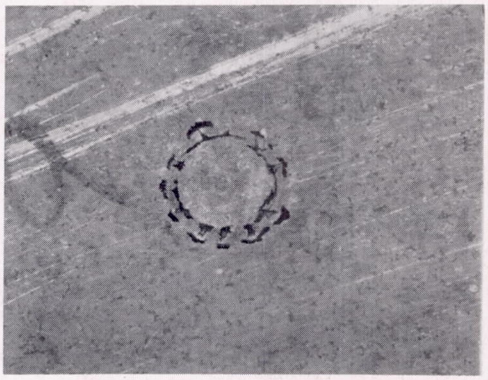

Figure 9.- Type K. "Pattern" corrosion on welds made with "poor" technique, X3.

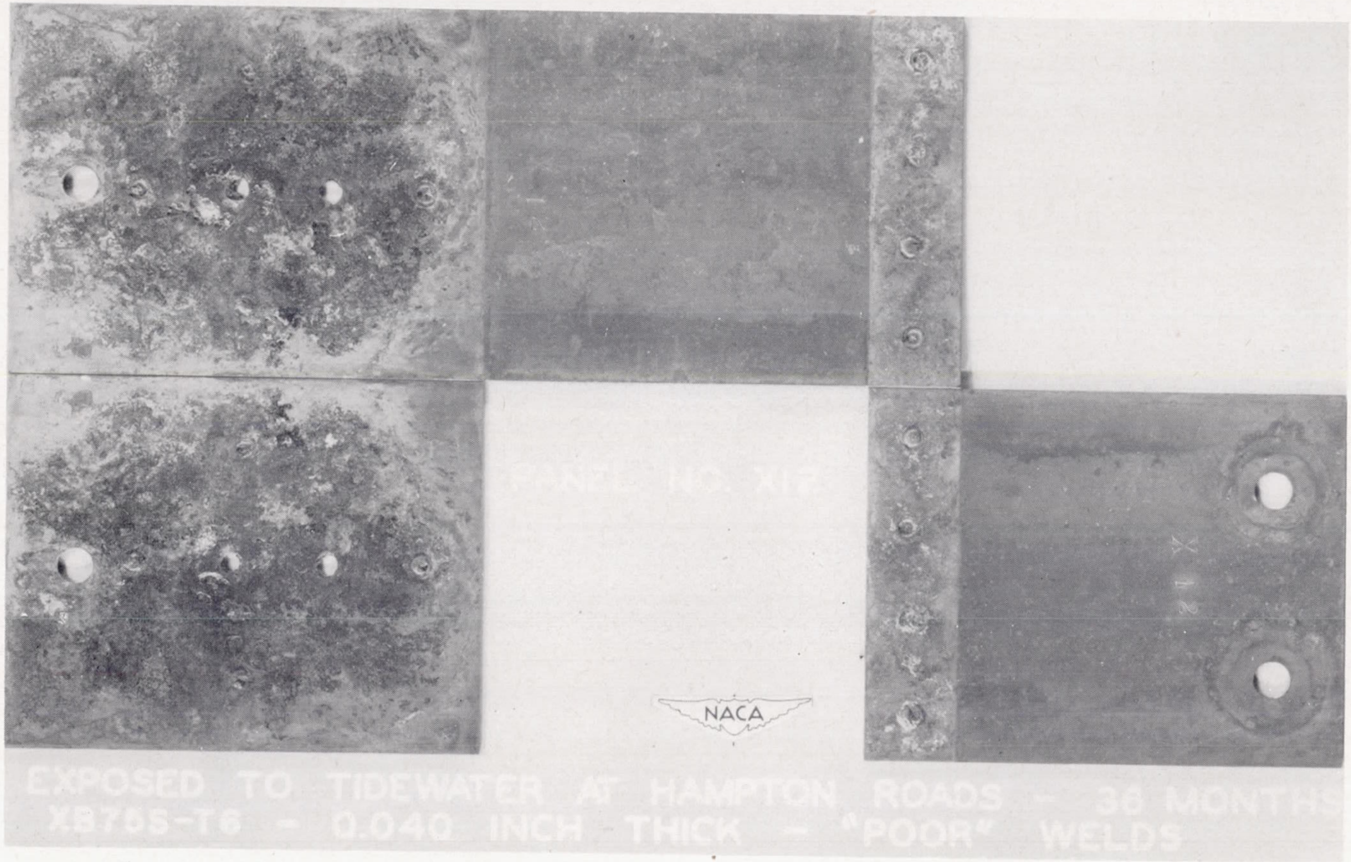

Figure 10.- Type L. Welds separated at faying surfaces by corrosive attack, $X\frac{1}{2}$.

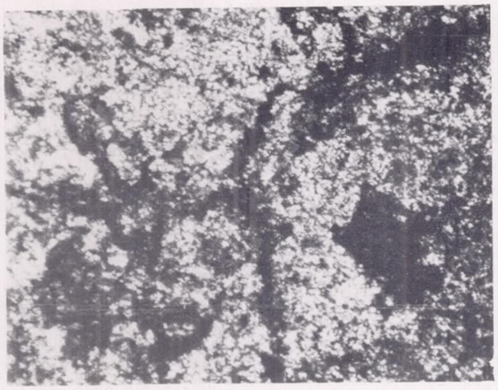

Figure 11.- Type N. Cracks representative of those found on surfaces of some welds, X50.

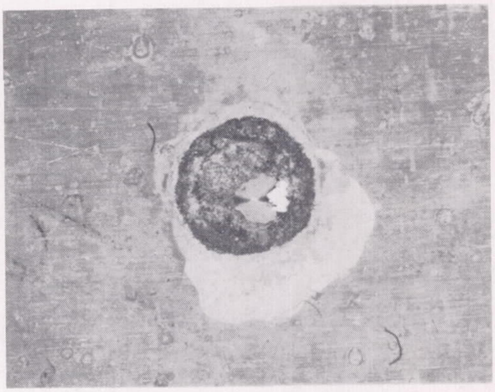

Figure 12.- Type P. Weld completely penetrated at one place and through one thickness of sheet in balance of weld, X3.

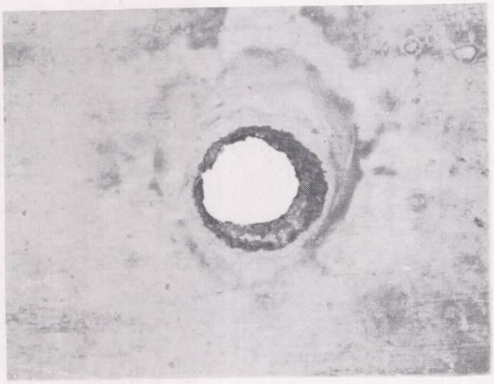

Figure 13.- Type P. Weld completely penetrated by corrosive attack, X3.

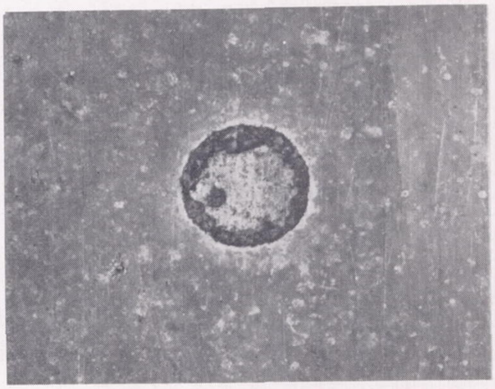

Figure 14.- Type R. Deeply pitted dark ring on circumference of weld, X3.

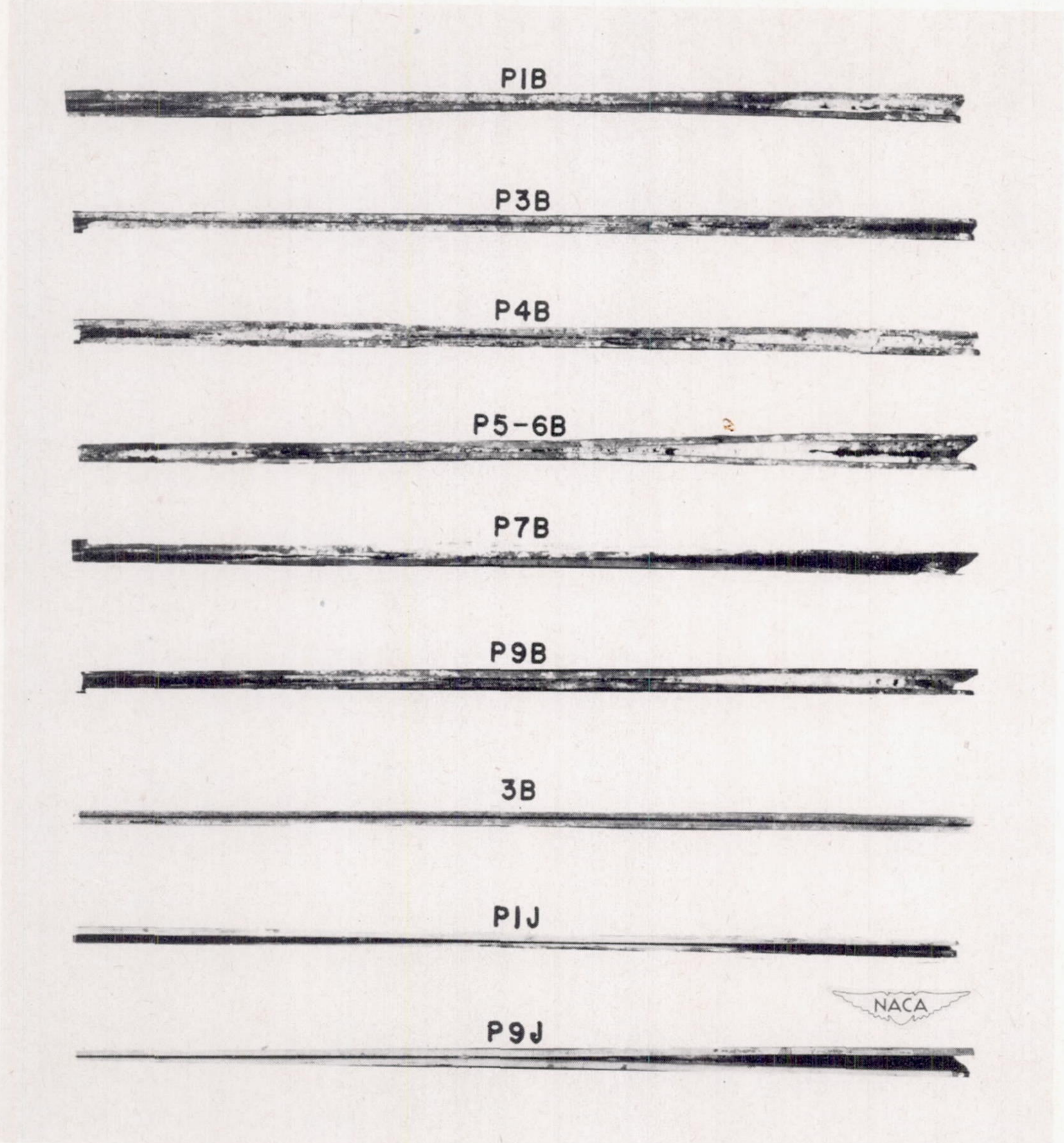

Figure 15.- Separation of sheets resulting from accumulation of corrosion products between faying surfaces, X1. Exposed in tidewater for 6 months. Panel 3B, alclad 24S-T3, was inserted for comparison purposes; no accumulation of corrosion products at faying surfaces.

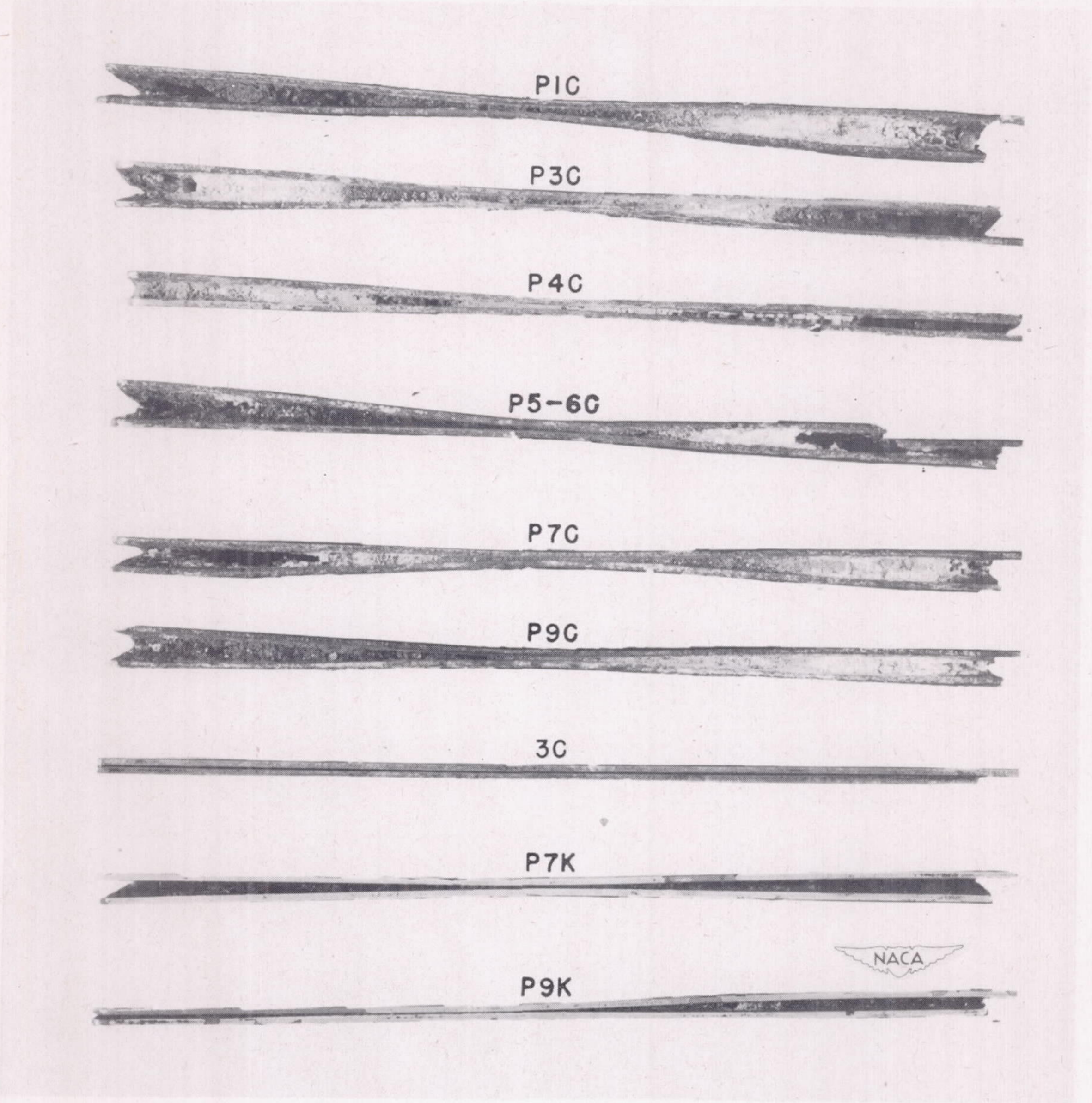

Figure 16.- Separation of sheets resulting from accumulation of corrosion products between faying surfaces, X1. Exposed in tidewater for 12 months. Panel 3C, alclad 24S-T3, was inserted for comparison purposes; no accumulation of corrosion products at faying surfaces.

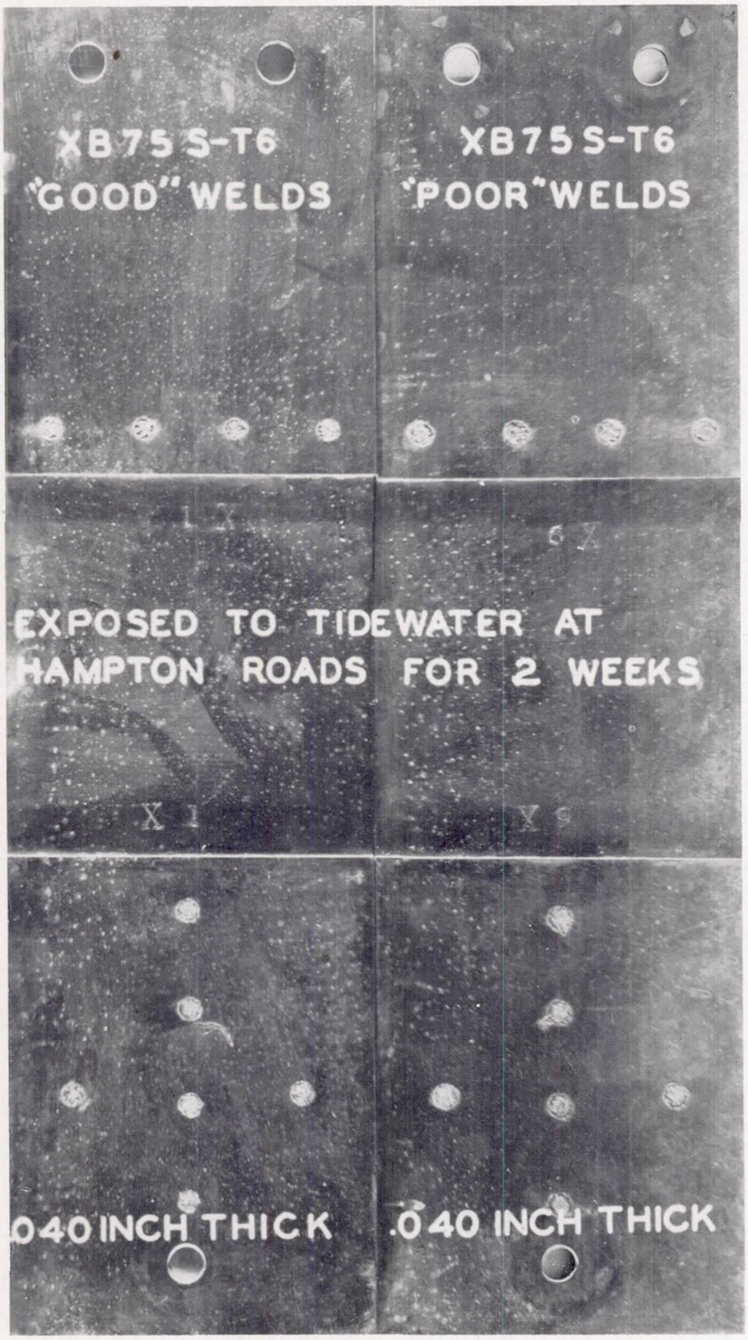

Figure 17.- Localized corrosion on spot welds made with both "good" and "poor" techniques, $X\frac{1}{2}$. Attack was almost as severe as shown here after 2 days of exposure to tidewater.

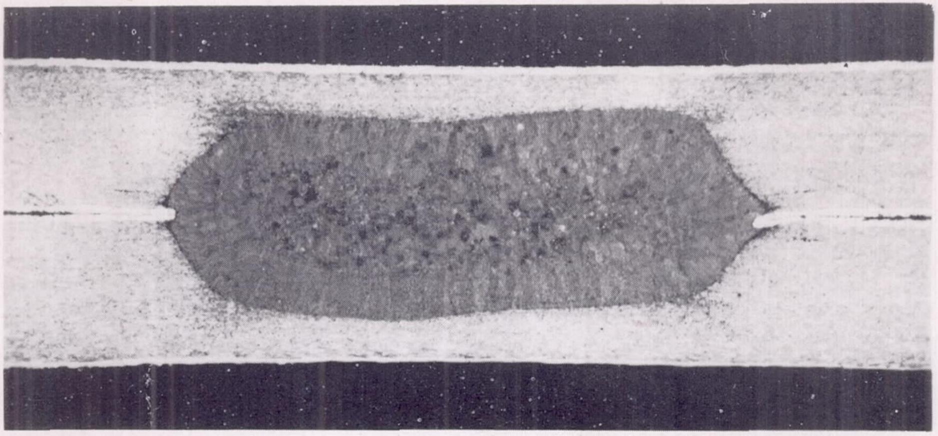

Figure 18.- Macrostructure of weld zone of sample 1C, alclad 24S-T3, exposed to tidewater for 1 year, X20. Keller's etch, 20 seconds. Weld structure was sound and uniformly distributed between two sheets. Structure was characteristic of group 1 samples which were welded under conditions to produce sound welds after chemical preparation of sheet surfaces.

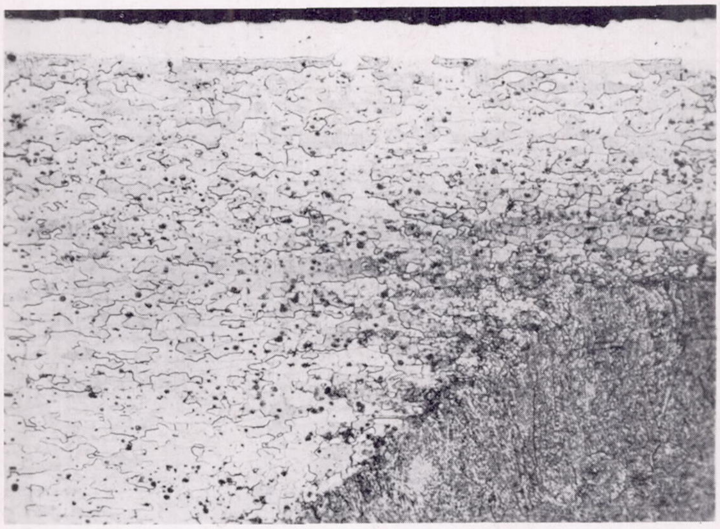

Figure 19.- Area from upper left corner of nugget shown in figure 18, X100. Keller's etch, 20 seconds. No significant extent of corrosion attack was observed on this sample.

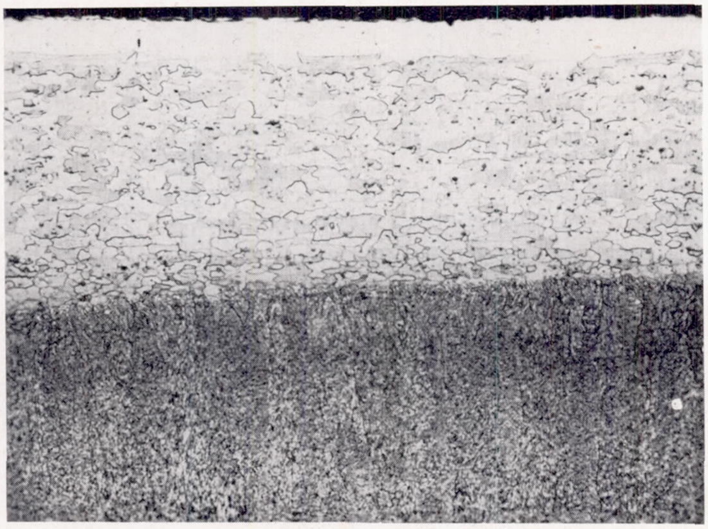

Figure 20.- Typical appearance of portion of nugget, core, and clad regions in sample 1G, alclad 24S-T3 sheet, exposed 3 years to laboratory atmosphere, X100. Keller's etch, 20 seconds. No evidence of corrosion attack on this sample.

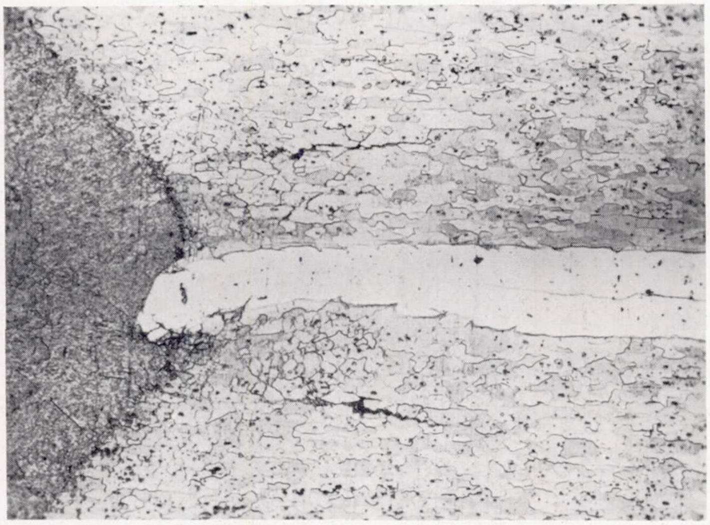

Figure 21.- Nugget-faying surface interface of sample shown in figure 20, X100. Keller's etch, 20 seconds. Structure was typical of appearance of alclad 24S-T3 samples examined in this study. Note continuation of higher-melting 2S clad into nugget zone and intrusion of eutectic into core structure above and below cladding.

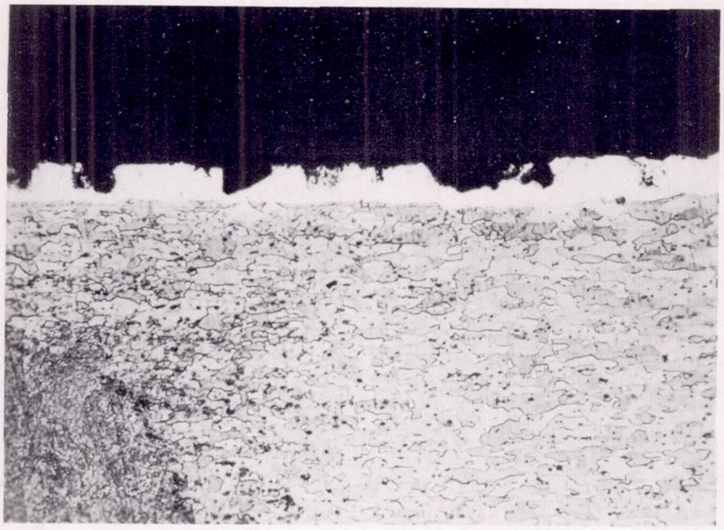

Figure 22.- Most severe degree of pitting type of corrosion attack on sample IE, alclad 24S-T3, exposed 3 years to a sea coast atmosphere, X100. Keller's etch, 20 seconds. Attack was concentrated near weld zone and did not penetrate cladding.

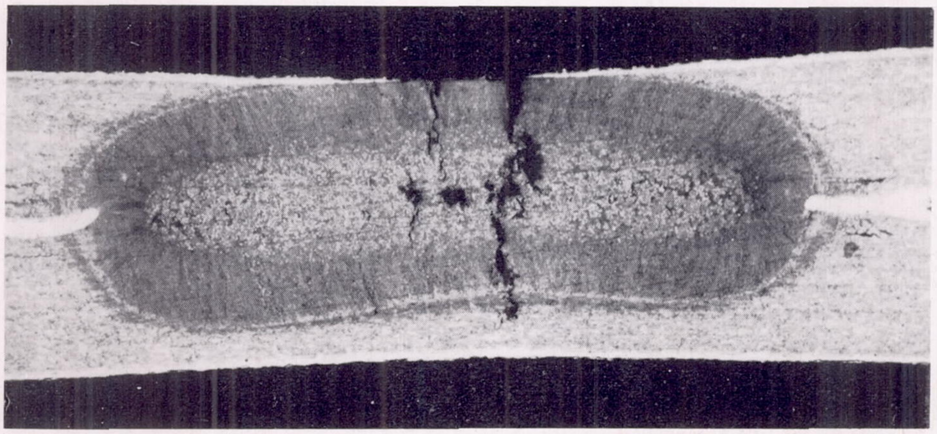

Figure 23.- Macrostructure of sample 5C, alclad 24S-T3, welded under conditions to produce cracking to surface and exposed 1 year to tidewater, X20. Keller's etch, 20 seconds. Nugget has absorbed portion of cladding on one surface. See figure 24.

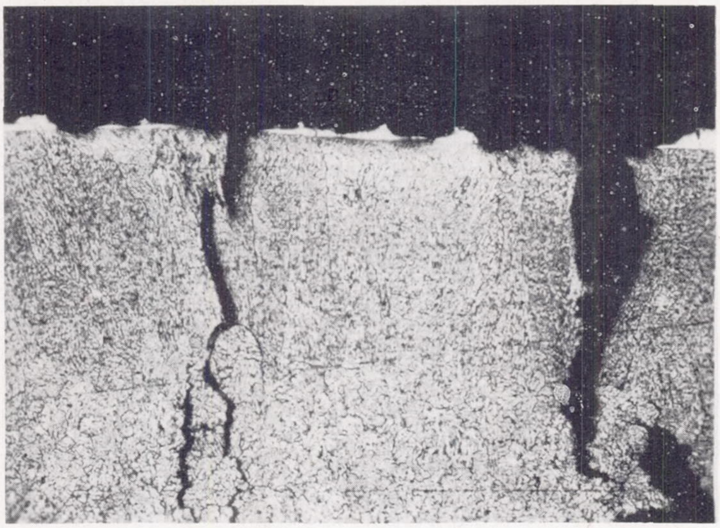

Figure 24.- Area from the top-center surface of weld shown in figure 23, X100. Keller's etch, 20 seconds. Note that tiny fragments of cladding have remained to provide effective cathodic protection for underlying core.

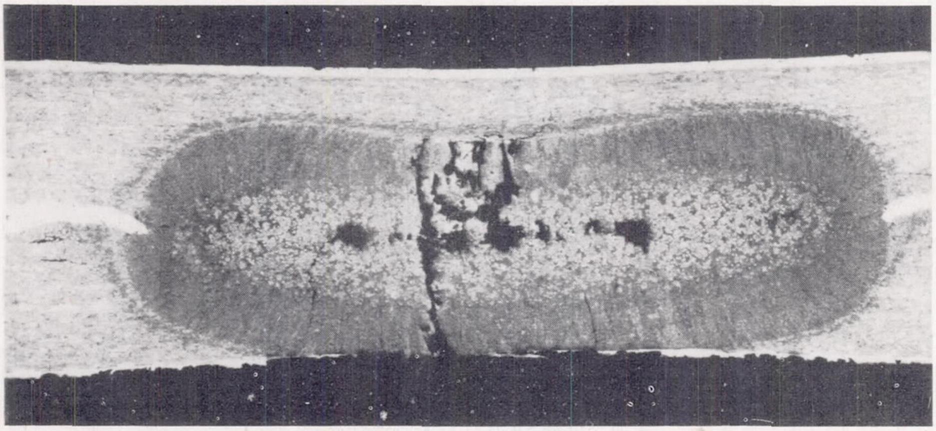

Figure 25.- Macrostructure of sample 5F, alclad 24S-T3, exposed 3 years to sea coast atmosphere after welding to produce cracks to surface, X20. Keller's etch, 20 seconds. Compare with figure 23. Note corrosion attack in cladding in vicinity of weld along bottom.

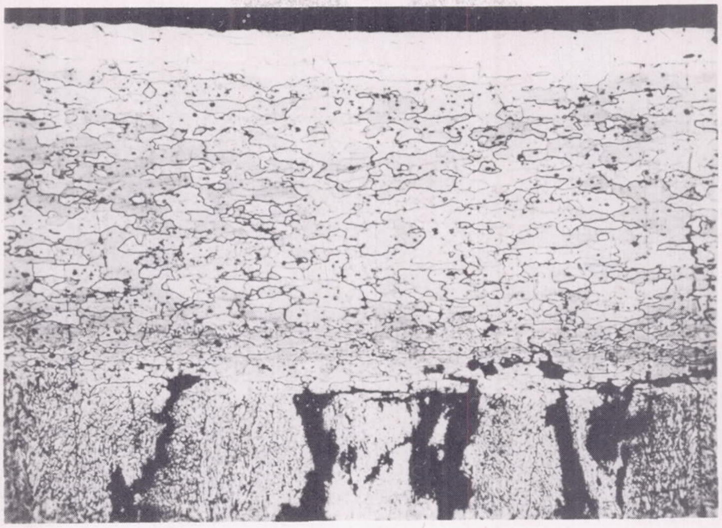

Figure 26.- Area from top center of figure 25 showing no significant extent of corrosion attack on surface, X100. Keller's etch, 20 seconds. Lower side of weld in figure 25 was similar in appearance to figure 24.

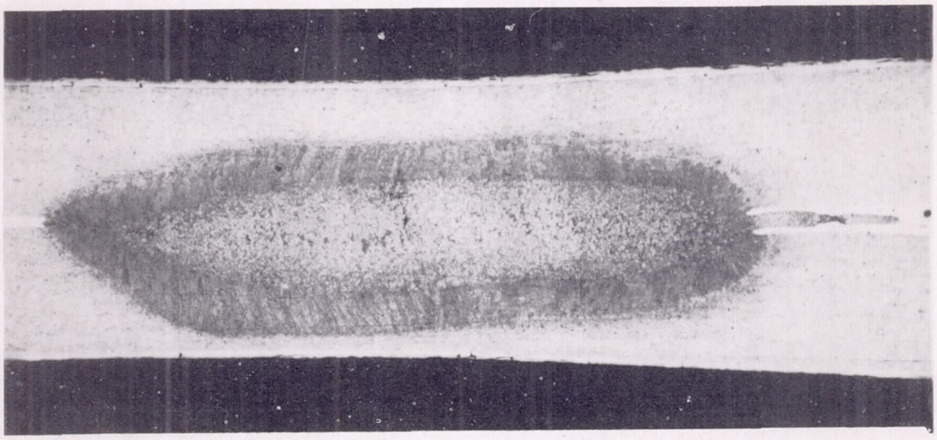

Figure 27.- Example of expulsion between faying surfaces of sample 6C, alclad 24S-T3, welded under conditions to induce expulsion and exposed 1 year to tidewater, X20. Keller's etch, 20 seconds.

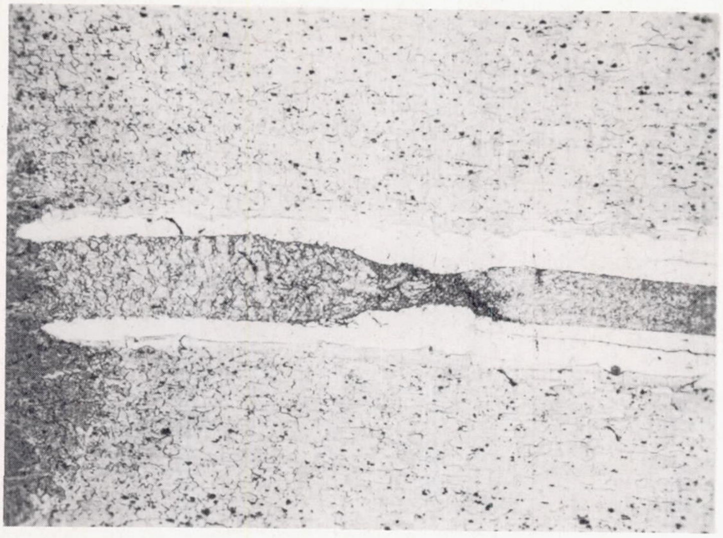

Figure 28.- Area of expelled metal showing retention of layer of cladding on either side, X100. Keller's etch, 20 seconds. No evidence of corrosion attack associated with this condition.

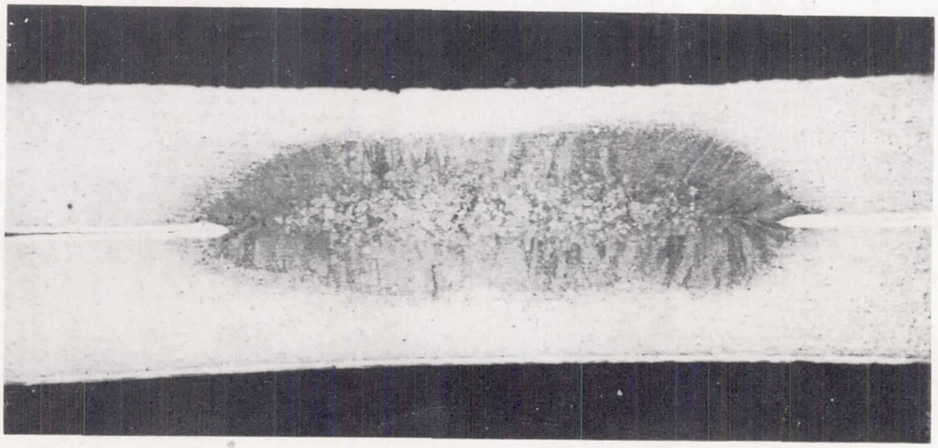

Figure 29.- Macrostructure of sample 6F, alclad 24S-T3, welded under conditions to produce expulsion and exposed 3 years in sea coast weather, X20. Keller's etch, 20 seconds.

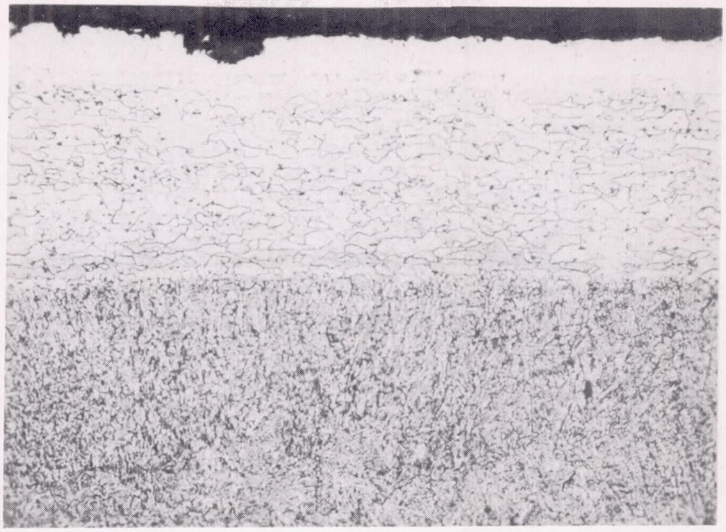

Figure 30.- Most severe degree of corrosion attack found in this specimen did not penetrate cladding. Area is from top center of figure 29, X100. Keller's etch, 20 seconds. No significant extent of attack on sheet away from weld zone. Note fine cracks in lower left corner in nugget structure.

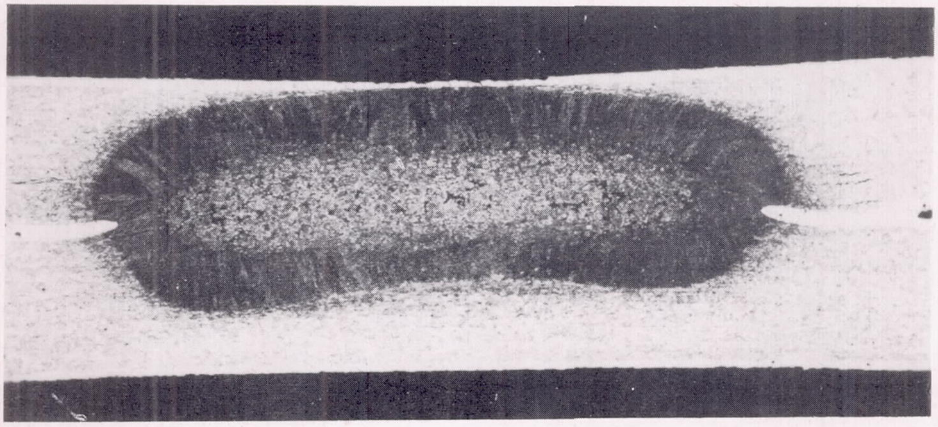

Figure 31.- Sample 9C, alclad 24S-T3, welded under conditions to produce a sound weld after wire-brush preparation. Nugget penetrated entirely to the cladding, X20. Keller's etch, 20 seconds.

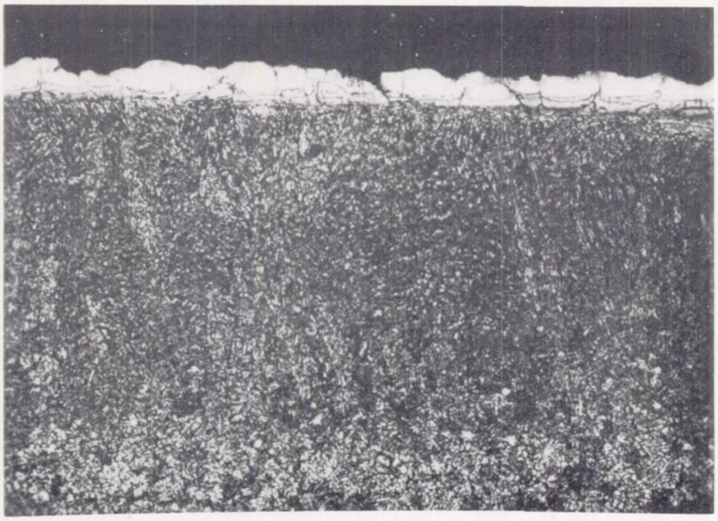

Figure 32.- Region from top center of figure 31 showing pronounced extent of diffusion of copper into cladding and evidence of corrosion attack, X100. Keller's etch, 20 seconds. As shown in figure 31, attack was confined to small area where nugget approached sheet surface.

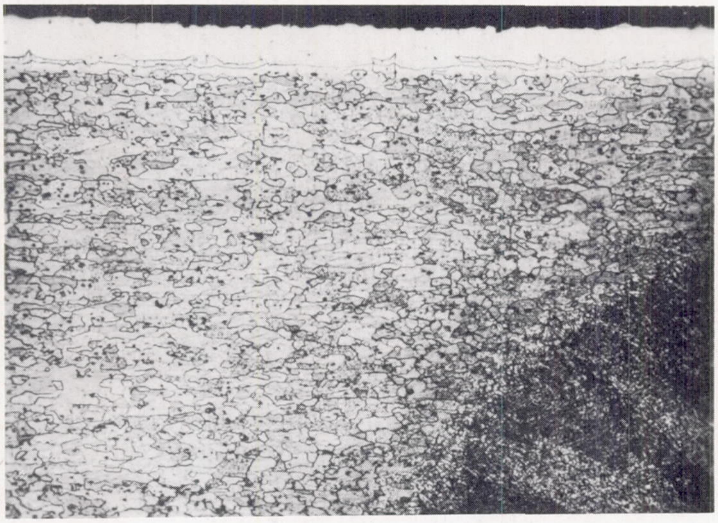

Figure 33.- General condition of diffusion of copper into cladding, typical of appearance in all parts of sheet. Area is from upper left corner of nugget in figure 31, X100. Keller's etch, 20 seconds. No significant extent of corrosion was observed.

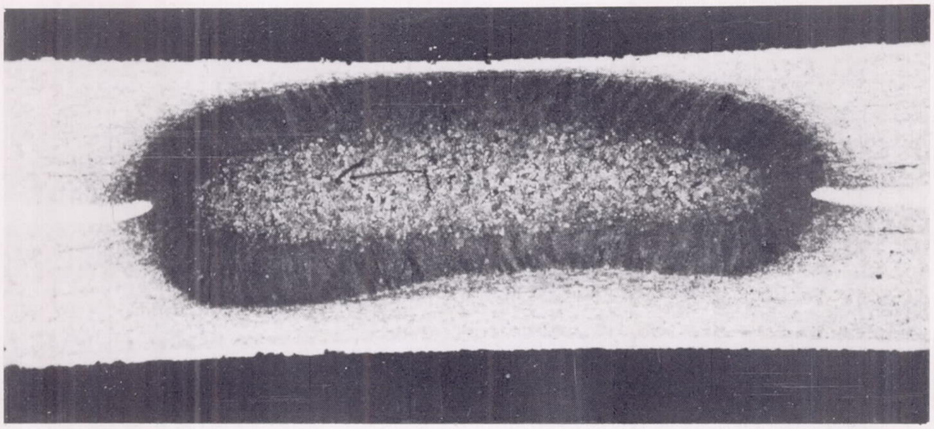

Figure 34.- Macrograph showing weld nugget slightly below clad surface in sample 9F, alclad 24S-T3, welded under conditions to produce a sound weld after wire-brush preparation and exposed 3 years to sea coast atmosphere, X20. Keller's etch, 20 seconds. Compare with figure 31.

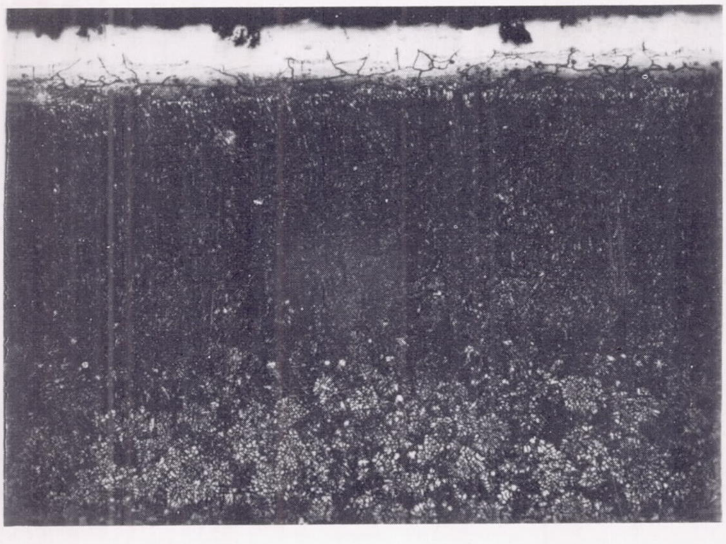

Figure 35.- Area from top center of figure 34 showing some evidence of diffusion of copper into cladding but less pronounced than in figure 32, X100. Keller's etch, 20 seconds. General condition of surface attack throughout sample, not accelerated in vicinity of weld.

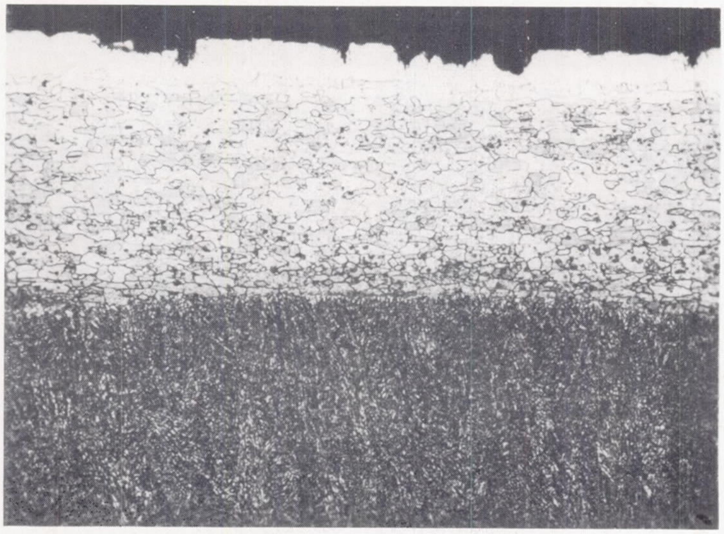

Figure 36.- Extent of surface attack on opposite side of sheet from region in figure 35, X100. Keller's etch, 20 seconds. Attack penetrated over half of cladding thickness, but was not greater in extent than in other parts of sheet surface away from weld.

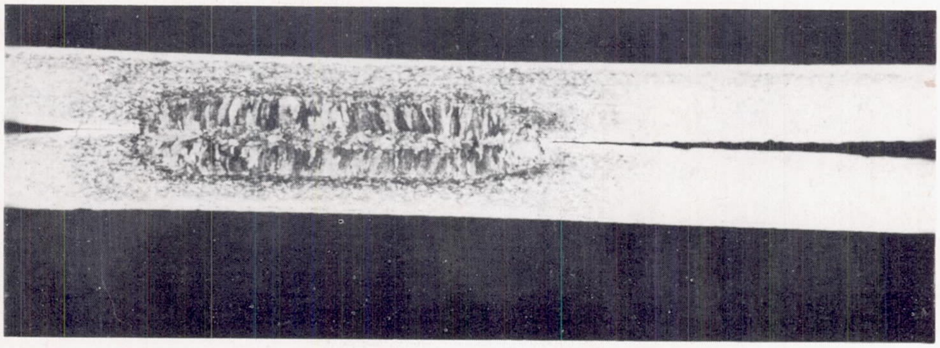

Figure 37.- Macrostructure of sample 2R4, R-301-T6, welded to produce a sound structure after chemical preparation of sheet and exposed 3 years in tidewater, X20. Keller's etch, 20 seconds.

Figure 38.- No significant extent of attack was observed on outer or faying surfaces of sample 2R4. Dark areas in cladding alloy are constituent particles, X100. Keller's etch, 20 seconds.

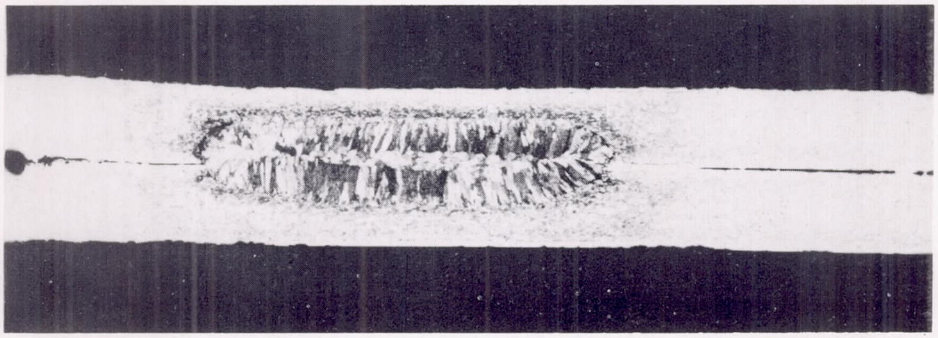

Figure 39.- Macrostructure of sample 2R6, R-301-T6, welded to produce a sound structure after chemical preparation and exposed 3 years to sea coast atmosphere, X20. Keller's etch, 30 seconds.

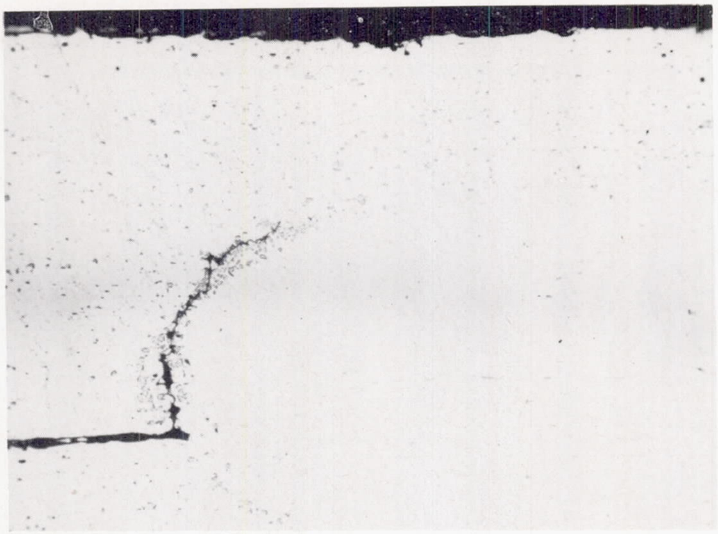

Figure 40.- Typical appearance of envelope of constituent particles segregated along periphery of weld nugget, X100. Unetched. This condition was characteristic of R-301-T6 sheet welds, was observed in XB75S-T6 welds, but not apparent in alclad 24S-T3 welds. Identity of constituents was not established completely but from etching characteristics it was believed that they were of the insoluble aluminum-copper-iron-manganese phase. The crack, possibly formed during specimen preparation, illustrated susceptibility of the condition to propagation of fracture.

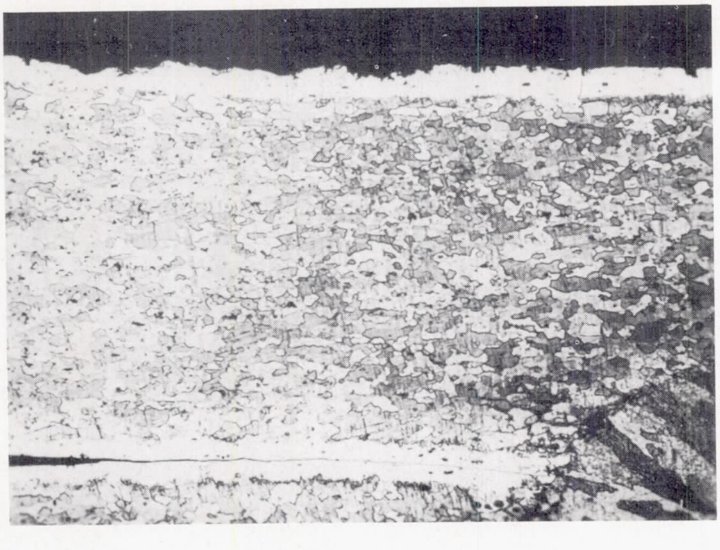

Figure 41.- Example of general type of corrosion observed on outer and inner surfaces of sample 2R6 in all parts of sample, X100. Keller's etch, 30 seconds.

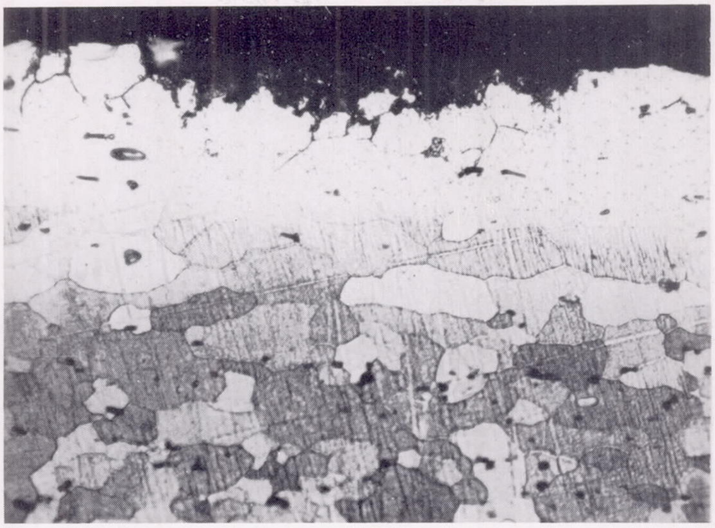

Figure 42.- Example of general type of corrosion observed on outer and inner surfaces of sample 2R6 in all parts of sample, X500. Keller's etch, 30 seconds. Attack appeared to be predominantly intergranular but had not penetrated coating.

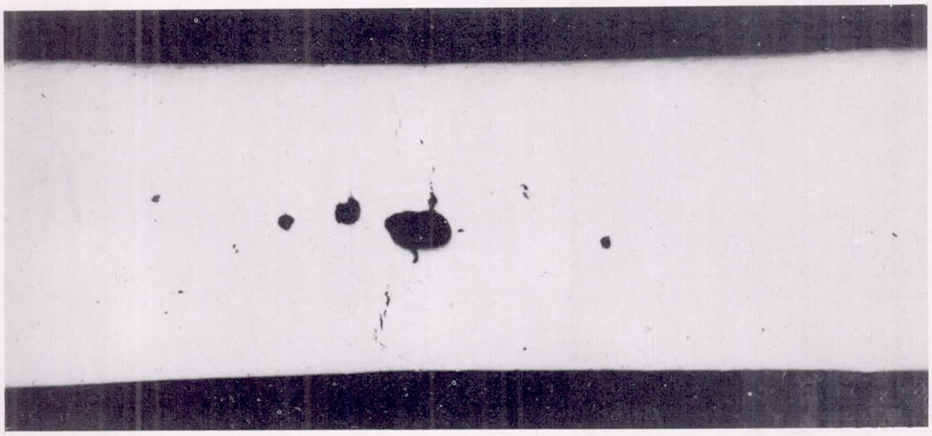

Figure 43.- Cracks to surface and general unsound weld structure of sample X-15, XB75S-T6, welded with dirty electrodes and exposed 3 years to laboratory atmosphere, X20. Unetched.

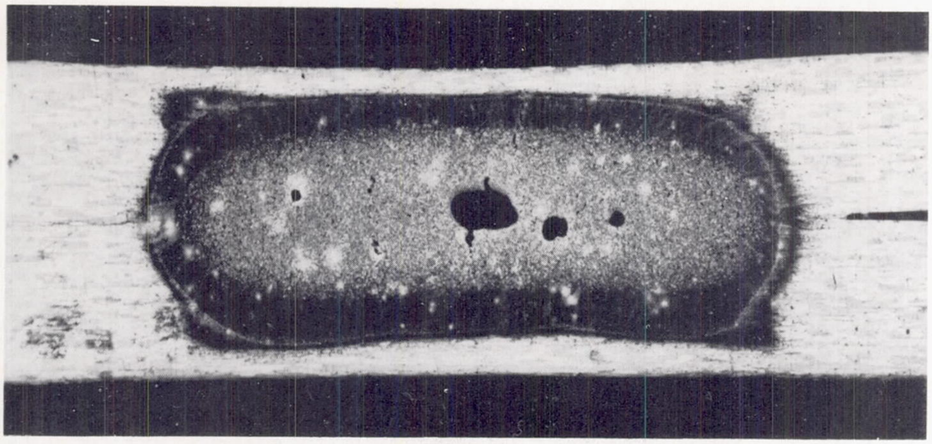

Figure 44.- Etched appearance of sample X-15, X20. Keller's etch, 30 seconds. No distinct evidence of corrosion attack was observed.

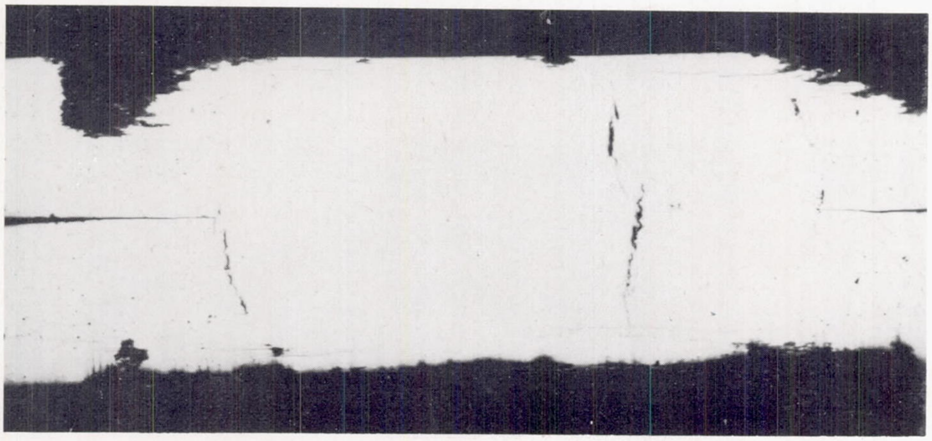

Figure 45.- Extremely severe intergranular corrosion attack accelerated at periphery of electrode indentation of sample X-9, XB75S-T6, welded with dirty electrodes after chemical preparation of surfaces and exposed 12 days in tidewater, X20. Unetched. Note thin envelope of constituent particles along periphery of nugget, shown more distinctly in figure 47.

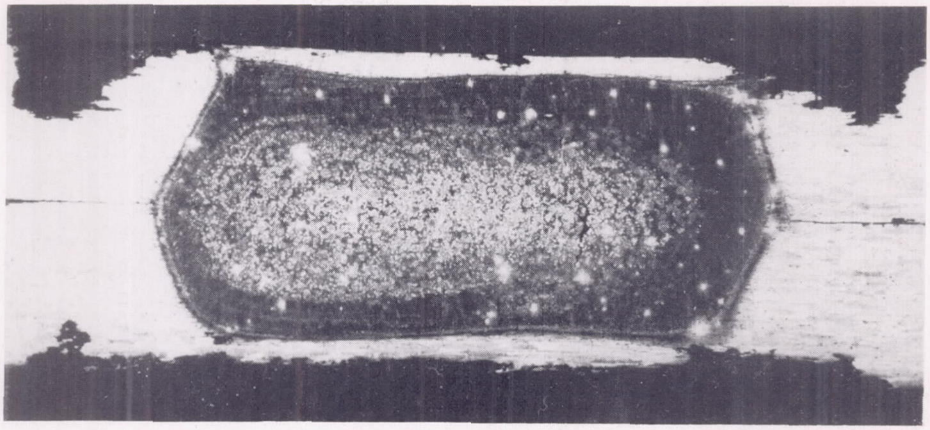

Figure 46.- Etched appearance of sample X-9, X20. Keller's etch, 20 seconds. Note intergranular attack along inner surface at extreme right.

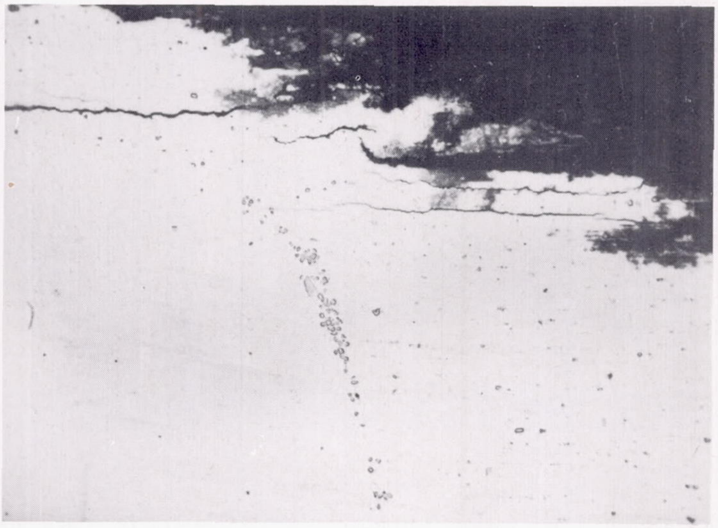

Figure 47.- Area from upper right corner of figure 45, X100. Unetched.

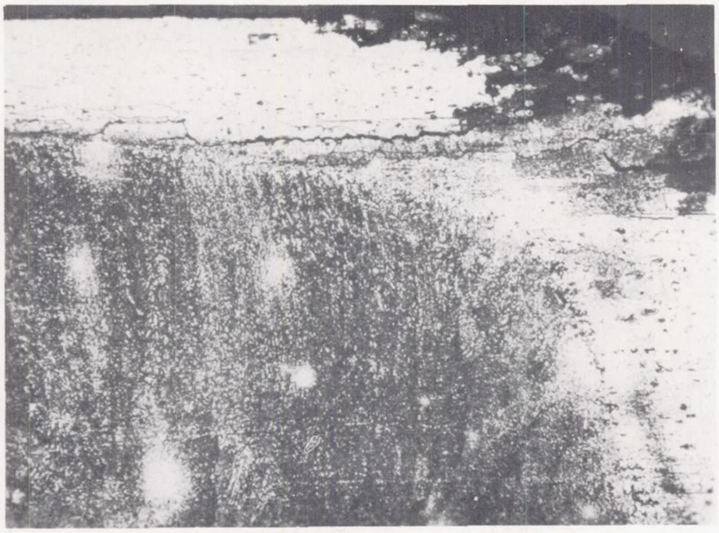

Figure 48.- Same area as in figure 47 showing intergranular corrosion attack, X100. Keller's etch, 30 seconds.

Figure 49.- Severe weld fracturing and intergranular corrosion attack on inner and outer surfaces of sample X-13, XB75S-T6, welded with dirty electrodes and exposed 1 year to sea coast atmosphere, X20. Unetched.

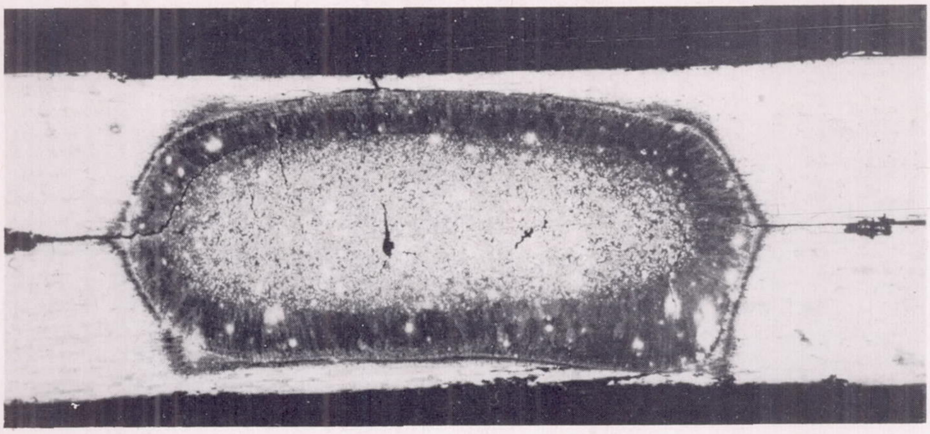

Figure 50.- Etched appearance of macrostructure shown in figure 49, X20. Keller's etch, 30 seconds.

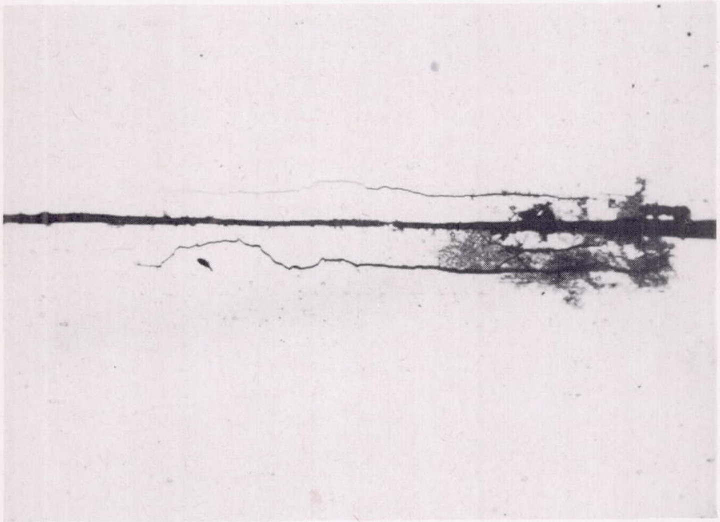

Figure 51.- Intergranular attack along faying surfaces in region at extreme right in figures 49 and 50, X100. Unetched.

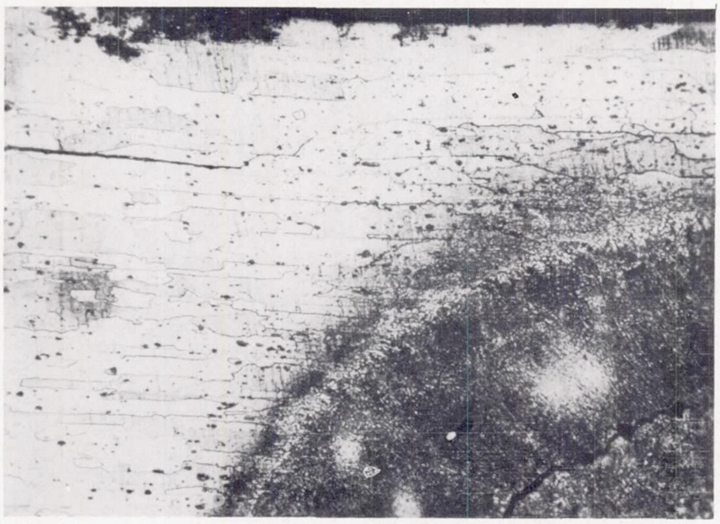

Figure 52.- Region from upper left corner of nugget (fig. 50) showing intergranular attack, X100. Keller's etch, 30 seconds. Note grain-boundary precipitate, visible at this low magnification, along which attack is proceeding from left to right.

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