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TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 400

ADVANTAGES OF OXIDE FILMS AS BASES FOR ALUMINUM PIGMENTED SURFACE COATINGS FOR ALUMINUM ALLOYS

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Bureau of Standards

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Introduction

The advent of metals into aircraft construction has caused a demand for light-weight, high-strength alloys. It is highly desirable that such structures, especially when in the form of sheet material, be resistant to corrosion. Alloys of aluminum and of magnesium, which conform to the weight and strength requirements, are susceptible to corrosion and are especially sensitive to salt (sea-water) atmospheres. The problem of producing a satisfactory corrosion-resistant (under severe conditions) alloy having the requisite physical properties has not yet been completely solved. The alternative then is to use the alloys now known to have best physical properties and to obtain improved corrosion resistance by the application of "protective" coatings or "films", either chemically or mechanically, which will tend to retard corrosion. The investigation of this problem was carried out at the Bureau of Standards in cooperation with the National Advisory Committee for Aeronautics, the Bureau of Aeronautics of the Navy Department, and the Army Air Corps.

The protective coatings utilized on aluminum alloys may be roughly classified into three groups. One group may be considered as including all coatings in which the active protective agent is an oxide film formed directly upon and from the surface of the material by suitable chemical or electrochemical processes. A second group may be taken to include coatings primarily nonmetallic, such as paints, varnishes, oils, greases, etc., mechanically applied directly to a cleansed or slightly roughened surface, and themselves functioning as the protective agents. Metallic coatings, superimposed on the surface by electrochemical or mechanical processes, constitute a third group of protective coatings.

A large number of coatings are available (in all three groups) which will afford excellent protection to the under-

lying metal under ordinary conditions of service exposure, for example, in a temperate climate and inland. Aircraft, however, is not infrequently used under saline service conditions, either coming into contact with salt water or salt spray, and the difficulties in finding a suitable protective coating become numerous. Oxide films and coatings of the second type, although they retard the onset of corrosion to a greater or less extent, have not been found to render very satisfactory service over long periods under such circumstances.

Oxide coatings may be produced by a variety of methods. They exhibit considerable variations in color, ability to absorb dyes, corrosion resistance, etc., depending on the composition of the alloy coated and the conditions under which the coating is formed. Those formed electrochemically show, as a rule, better corrosion resistance, than those applied by purely chemical means. Oxide coatings produced by electrochemical processes are usually termed anodic coatings, since, regardless of the electrolyte employed, the aluminum or aluminum-rich alloy to be coated is made the anode. The process itself is frequently referred to as anodization. Numerous electrolytes have been employed, the following brief list serving to illustrate their diversity: sodium-hydrogen phosphate (reference 1), ammonium hydroxide (reference 2), ammonium sulphide (reference 2), oxalic acid (reference 3), sulphuric acid (reference 4), and chromic acid (reference 5). Films formed by chromic acid anodization have been among the most corrosion-resistant produced to date and are widely used.

Paints, varnishes, greases and oils have been used so extensively for protection of metals against corrosion on metals other than light alloys that they need be treated in little detail here. Paints and varnishes possess a number of obvious advantages over greases and oils for most practical purposes, provided that coatings of relatively the same "protective" merit are compared, and are probably used to a greater extent than the latter. When paints and varnishes are used on aluminum alloys, preliminary roughening of the surface is almost requisite for good adherence. Coatings requiring a "baking" process are not suitable for use where corrosion-resistance is paramount, since such baking frequently renders the metal susceptible to corrosion and, once coating "break down" has commenced, the attack on the metal may be expected to be rapid. The protective qualities of paints and varnishes may frequently be enhanced by ad-

ditions of aluminum powder.

Both experiments and theoretical considerations indicate that zinc, cadmium, aluminum, manganese, and magnesium are the metallic coatings which may be expected to afford maximum protection against corrosion of aluminum alloys. (Reference 6.) Zinc, aluminum and cadmium offer the most promise from a practical point of view. The electrodeposition of these metals on aluminum alloys has not been attended with much success. However, the most corrosion-resistant light alloy developed to date is of the metallic coating type. The product, commercially known as "Alclad", has been described in detail by Dix. (Reference 7.) It consists, essentially, of an alloy base (17S alloy of the Aluminum Company of America) to which is integrally alloyed a uniform, nonporous layer of high purity aluminum. The thickness of the layer, on either side of the sheet, is approximately 5 per cent of the total thickness. In its heat-treated condition the tensile strength and yield point of Alclad sheet, calculated on the basis of total thickness, are approximately 10 per cent lower than those of 17S sheet of like gauge. The elongation values remain unchanged. Owing, perhaps, to the slight decrease in mechanical properties and its somewhat higher cost, Alclad has not attained such widespread use as its markedly superior corrosion resistance undoubtedly warrants under severe service conditions.

Since there may be valid reasons, under certain circumstances, for not employing Alclad, even though the corrosive conditions be severe, it becomes almost imperative to attempt to develop coatings of the remaining two types to a point where adequate protection is assured over relatively long periods of service. Up to the present neither oxide coatings nor paints, oils, etc., when used independently, have afforded such protection. It has been known for some time that judicious combinations of coatings of the second type with those of the oxide film type make for improvement in corrosion resistance.

It is the purpose of this paper to present the results obtained in a number of corrosion tests, carried out by various methods, on a combination oxide-varnish coating which was found to possess a degree of corrosion resistance superior to that of a number of other coatings investigated. The tests in question represent only a relatively small number of those performed in connection with a current research, begun in 1925, being conducted at the Bureau of Standards,

on the corrosion of light metal alloys used in aircraft. (Reference 8.)

Material.- With the exception of a few of the earlier tests all the work was carried out upon a duralumin type alloy commercially available under the name "17ST". The material was supplied by the Aluminum Company of America.

The average composition of this material was,

Copper	4.1 per cent
Iron	0.34 per cent
Silicon	0.32 per cent
Manganese	0.51 per cent
Magnesium	0.61 per cent
Aluminum	remainder

The average tensile properties of this material in the form of 14 gauge sheet were determined to be,

Ultimate tensile strength	59,000 to 61,000 lb./sq.in.
Yield point (stress for 0.006 in./in.) (extension under load)	40,000 to 42,000 lb./sq.in.
Elongation (2 inches)	19 to 22 per cent

Preliminary preparation of specimens.- For these tests a standard test bar was selected. The bars were cut from a 1-inch strip, to a 2-inch gauge length, 3/4-inch test width and to a reduction in thickness of one thousandth of an inch on each side at the center of the test portion. (Fig. 1.)

Experiments at the Bureau of Standards have shown that the heat treatment has a very definite bearing on the susceptibility of duralumin to corrosion. (Reference 8,c.) Quenching duralumin from 510°C. in boiling water encourages intercrystalline attack. A portion of the specimens reported herein was purposely heat treated in this manner in order that corrosive attack would occur immediately following coating "breakdowns".

Prior to the application of any protective coatings all the specimens were given a preliminary cleansing by washing with benzol, alcohol and water, in the order named, and then dried with either alcohol or ether.

Methods of applying coatings.- The anodic process on which the findings of these experiments were based is patented. The process was reported in full in 1926 by Bengough (reference 5) who holds the present patent which was issued in this country in July 1930.

The process calls for a 3 per cent chromic acid solution (this percentage is not critical and may be varied slightly either way with equally good results. The general practice being to make up a solution of about 2.8 per cent and, as the solution is used, build it up to 3 per cent or better). The article to be coated is made the anode of an electrolytic cell. Although the patented process calls for a carbon cathode; the cathode may be of almost any conductor. The general practice in this country is to use a steel tank which serves both as cathode and container. In the experiments to be described a low carbon steel tank was used. The cell was maintained at a temperature of 40°C. ±2°C. The voltage was gradually raised from ~~zero~~ 0 to 40 volts through a period of 15 minutes. It was maintained at 40 volts for 35 minutes, after which it was gradually raised to 50 volts over a period of 5 minutes and maintained at this voltage for 5 minutes, thus completing the cycle. The specimen was immediately removed from the bath and washed in warm water to remove the chromic acid.

Other investigators have found that the anodic treatment of aluminum alloys in 3 per cent chromic acid usually results in a slight loss in weight and that the effect of the treatment upon the tensile properties, is, for all practical purposes, negligible.

The aluminum-pigmented spar varnish used throughout this investigation was prepared by adding two pounds of aluminum bronze powder (reference 9) per gallon of spar varnish vehicle, the latter complying with Navy Department Specifications. (Reference 10.) Three coats were applied, by brushing, to each specimen painted. Specimens were air-dried at room temperatures for 48 hours between each coating, this also being the minimum drying period for the final coat before corrosion tests were begun.

Corrosion test methods.- With the exception of a relatively few specimens corroded by weather-exposure, the corro-

sion tests reported herein were conducted in the laboratory. Essentially, two types of laboratory corrosion methods were employed, namely, the intermittent immersion and salt spray methods. Modifications of the former method permitted the performance of tests in which specimens were stressed by repeated flexure or in static tension while being simultaneously subjected to the action of the corroding medium. The various kinds of apparatus used have already been described in some detail by H. S. Rawdon (reference 8,b) and therefore are only briefly discussed here.

The intermittent immersion method was intended to simulate conditions more comparable to the conditions obtaining in aircraft service (as an occasional wetting followed by a period of drying) than do the more usual continuous immersion laboratory methods. Tensile specimens, supported horizontally on edge in a frame constructed from glass rod, were lowered at 14-minute intervals into enameled cast iron tanks containing the corroding medium. In all the intermittent immersion tests reported herein the corroding medium consisted of nine parts (by volume) normal sodium chloride and one part hydrogen peroxide. The specimens remained in the corroding medium for a period of approximately one minute, and were suspended in the air for the remainder of the time to permit drying. The apparatus used is shown in Figure 2.

No fundamental changes in the intermittent immersion method were necessary in order to corrode specimens under static tension, except that the apparatus sustaining the static load was substituted for the glass racks which ordinarily supported the specimens. The static tension apparatus was constructed of steel and was heavily coated with paraffin prior to corroding the specimen which it held. Reference to the photograph, (fig. 3), will serve to illustrate its operation. The load was applied to the specimen in an Amsler testing machine through the end blocks B-B' and the grips G-G', the four nuts N not being in contact with the end blocks. When the desired load was recorded on the Amsler machine the nuts N were tightened until the load on the Amsler registered zero, the rods R-R' then sustaining the load.

For corrosion of specimens by the intermittent immersion method while being simultaneously subjected to repeated flexural stresses it was necessary to design and construct

a special apparatus,* the appearance of which is shown in Figure 4. At intervals of 14 minutes, the tank (T) was automatically raised sufficiently high to immerse the specimens under test. The specimens remained in the solution for approximately a minute. For the purpose of comparison, a second specimen was suspended freely by the side of the stressed one and corroded under the same conditions but without being stressed.

The mechanism of that portion of the apparatus which applied flexural stresses to the specimens has been described in detail in a previous Technical Note (reference 8,c) along with the method by which the stresses on the specimen were determined. It is only necessary to point out here that the magnitude of the stresses could be varied by varying the angle of bend and that specimens were flexed at a rate of approximately 75 cycles (one cycle = one forward and one backward bend) per minute.

The salt spray box used in these experiments was a duplicate of the standard Navy box except that it had 5 per cent less capacity. The box, (fig. 5), made of alberene stone, was 29.5 inches long, 14 inches wide and 11.5 inches deep. A piece of heavy plate glass was used as a cover for the top. This glass rested on a seal of rubber tubing which had a soft iron core. The box was encircled with angle iron, the edge of which was made flush with the top of the box. The purpose of this angle iron was to afford a grip for clamps which secured the glass to the top. The back of the box was vented to insure the filling of the box with the spray by means of circulation. The specimens to be tested were suspended in glass racks as illustrated.

The spray was produced by a Monel metal atomizer. Directly in front of the atomizer was a plate glass baffle, which the spray struck. The larger drops of the spray were thus removed, the spray that reached the specimens being a very finely divided mist. Part of this mist condensed in

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*The machine was constructed by J. Ludwig, mechanician; the essential features, especially the suspension of the uprights being suggested by Dr. L. B. Tuckerman, Engineer Physicist, both of the Bureau of Standards.

the specimen chamber and, since the box was sloped to the front, (where the atomizer was), the condensed mist ran toward the front of the box. To prevent this condensate from being used over again a plate glass dam divided the specimen chamber from the atomizer chamber. The collected liquid was siphoned off at intervals to prevent it from overflowing into the atomizer chamber. Between the dam and the baffle there was a small opening to increase the circulation and insure a better distribution of the mist.

The air used to operate the atomizer was maintained at 15 lb./sq.in. pressure and was passed through a 20-inch water column before passing into the atomizer.

Specimens, corroded by one or more of the methods described above, were removed at predetermined intervals, photographed, and tested in tension. It has previously been shown (reference 8,b) that elongation values, in particular, serve as a rough criterion of the extent of corrosive attack. Samples for microscopic examination were removed from the reduced sections of each specimen after the tensile tests had been completed.

Intermittent Immersion

(a) Without accompanying stress.- Specimens of both hot and cold water-quenched materials were treated variously, prior to corrosion tests, by the intermittent immersion method, as follows: (1) surfaces cleaned free from grease and no protective coating applied; (2) surfaces cleaned free from grease and coated with three coats of aluminum-pigmented spar varnish; (3) surfaces anodized, in a 3 per cent solution of chromic acid using the recommended procedure; (4) surfaces anodized as in (3) and coated with three coats of aluminum-pigmented spar varnish.

Within a week after the tests were begun small "blisters" were in evidence on the pigmented varnish coatings which had been applied to unanodized surfaces. The blisters increased in size and number as the tests progressed and at the conclusion of an 80-day test period the coating had peeled off almost completely over large areas. Coatings which had been applied to previously anodized surfaces, however, showed no visible evidence of "breakdown" during the first 45 days of the tests. Shortly thereafter, small blis-

ters made their appearance along the edges of the specimens but remained relatively few in number at the conclusion of an 80-day test period. That prior anodization resulted in better adherence of the paint coatings was therefore apparent. The uncoated specimens began to show visible evidence of corrosive attack within a few hours after the tests were commenced, while the anodically treated but unvarnished specimens began to show first evidences of "breakdown" after approximately 15 days. The surface appearance of the specimens at various periods in the tests, is shown in Figure 6. Should show initial appearance at 0 time

The fact that aluminum-pigmented spar varnish adhered much better when applied to an anodized surface was also demonstrated during the tensile testing. Coatings applied to unanodized surfaces, after about 30-days' corrosion, flaked or peeled off almost entirely while the load was being applied. Those applied to anodized surfaces, on the other hand, still adhered very well after 80-days' corrosion, seldom peeled off over an area extending more than an eighth of an inch on either side of the fracture.

The results of the tensile tests are shown in Figures 7 and 8, where the four upper curves represent ultimate tensile strengths and the four lower ones elongations. should show on figure. The general form of the curves for the uncoated specimens should be noted, inasmuch as it is more or less characteristic. It may be seen that the elongation values decreased quite rapidly in the earlier stages of the tests and subsequently dropped off very slowly.

The application of protective coatings, such as aluminum-pigmented spar varnish or an anodic oxide film, appreciably retarded the rate of loss of elongation, otherwise, the form of the curves was, in general, but little changed. When a combination of these two coatings was used, however, the added degree of protection afforded was enough to change appreciably the form of the curve. No significant loss in tensile properties was revealed over a period of 30 days, and thereafter loss occurred at a relatively slow rate.

It is apparent from the curves that the combination oxide-pigmented varnish coatings were markedly superior, in the degree of protection afforded, to that of either coating used separately. On the cold-water quenched material, the aluminum-pigmented spar varnish coating applied to an unanodized surface offered somewhat better protection than did the anodic coating alone. On the hot-water quenched material, however, the pigmented varnish coating was more

effective only in the earlier stages of the tests.

(b) With accompanying static stress.- Hot-water quenched specimens coated with spar varnish were corroded under a static tension stress of approximately 10,000 pounds per square inch. The two right-hand columns of Figure 10 compare the results obtained with the two coatings: aluminum-pigmented spar varnish and aluminum-pigmented spar varnish on the anodic film. After 80 days in the static grip, the specimen coated with aluminum-pigmented spar varnish was found broken in the grips due to stress-corrosion. On account of the fact that the specimen was coated, visual examination of the specimen in the grips during corrosion had not disclosed when the specimen broke. The specimen coated with aluminum-pigmented spar varnish on the anodic oxide film was still intact at the end of 80-days' corrosion under these severe conditions. This specimen still retained almost two-thirds its initial strength, but only 10 per cent of its original elongation.

From the intermittent immersion test it was found that the spar varnish and the anodic film that had been applied separately broke down after about the same periods. This test then shows the great superiority of the combination of these coatings over either one used separately. (Figure 7.)

(c) With accompanying flexural stress.- This is probably one of the most searching tests that has as yet been used on protective coatings. It simulates the vibrating effect that is necessarily to be dealt with in aircraft structures. Coatings that stand up under this severe test must have both good protection against corrosion and be tough.

Figure 9 is a diagram giving the comparative values of uncoated hot-water quenched and cold-water quenched duralumin when corroded in the flexural stress machine. This diagram is divided in two halves. The upper half shows the hot-water quenched material and the lower half the cold-water quenched material. The tensile strength and elongation are plotted in columns. The number under the columns indicates the days for which the specimen represented by the column was corroded. The solid lines represent the stressed specimens. The broken lines represent the control specimens which were corroded at the same time in the same tank but unstressed. The broken or solid

cross-hatched lines represent elongation. The difference in width between the solid line columns and the broken line columns has no significance. The numbers in the colums represent the number of cycles the specimen was run before testing in tension. The jagged line across the top of the columns indicates that the specimen broke in the flexural-stress apparatus and that no tensile test was made.

In this test a hot-water quenched specimen failed in the machine in 4.8 days and micro-examination showed the specimen to be almost entirely corroded through. The comparison or unstressed specimen lost about 50 per cent of its ductility in this same length of time and approximately 33 per cent of its tensile strength. (Figure 9.)

Figure 10, another figure of the same type as Figure 9, shows the added protection afforded duralumin when coated. It is apparently a characteristic of this apparatus that the specimen first deteriorates rapidly and if there are any flaws in the coating continues to do so. If the specimen is capable of withstanding the test over this first period, the constant working of the specimen gives it a new lease of life and seems to strengthen it. This is shown in both Figures 9 and 10. The cold-water quenched material, coated and uncoated, showed this strengthening effect, while the hot-water quenched material was attacked so rapidly that it broke in the first stage. The addition of a coating to the hot-water quenched duralumin, helped it through this first stage as shown in Figure 10. If the coating is of poor quality, the test is so searching that this is soon apparent, as the specimen has a tendency to break in the machine long before its allotted time. As can be seen, the specimens merely coated with spar varnish and aluminum show this effect. The five-day specimen was attacked almost immediately and broke in the machine on the first rapid attack, while another specimen broke at 17 days. Comparing these results with the specimen coated first anodically and then with aluminum-pigmented spar varnish, it is seen that in general, the latter specimens gave much better results and that none of these specimens broke early in the test due to poor protective films as did the aluminum-pigmented spar varnish coated specimens. From Figure 10, it is then readily seen that although the coating of aluminum-pigmented spar varnish afforded good protection against corrosion by itself, that the use of an anodic film base greatly improved these properties.

Salt spray.- Results from the 20 per cent NaCl spray test showed the aluminum-pigmented spar varnish on an anodized surface to be a superior type of coating. After 240 days' corrosion by this method, aluminum-pigmented spar varnish on an anodized surface coated specimen showed very little surface attack. This attack took the form of small blisters along the edges of the specimen. An anodically coated specimen corroded with this specimen plainly showed surface breakdown. The appearance of the surface of these two specimens after 240 days' corrosion is shown in Figure 11.

After 150 days' corrosion the plain anodic film showed small loss in tensile strength but 66 per cent drop in elongation, whereas the specimen first anodically treated and then coated with aluminum-pigmented spar varnish showed no drop in tensile strength and only 28 per cent drop in elongation, less than half that of the anodic film.

After 240 days' corrosion the anodic specimen showed 15 per cent drop in tensile strength and 80 per cent drop in the elongation. The aluminum-pigmented spar varnish on an anodized surface coated specimen stood up much better. The loss in tensile strength was much less, being in the neighborhood of 5 per cent, while the specimen retained 38 per cent of its original elongation or nearly twice that of the plain anodic specimen.

These results are further evidence of the value of a combination coating as herein described.

Weather-exposure tests.- It should be borne in mind that the ultimate criterion by which the efficiency of protective paint coatings must be judged is their behavior in service under actual conditions of weather-exposure. Laboratory corrosion tests of the types reported herein cannot always be expected to serve as a reliable criterion and should be correlated with the results of weather-exposure tests.

A series of weather-exposure tests is now being conducted by the Bureau of Standards with the purpose, in part, of obtaining data relative to the efficiency of various protective coatings. (Reference 8,c.) These tests were begun in 1927 and have not yet been concluded. The specimens are being exposed at the Bureau of Standards (temperate inland conditions), at Hampton Roads, Va.,

(temperate sea-coastal conditions), and at Coco Solo, C.Z., (tropic sea-coastal conditions).

Included among the specimens placed outdoors for weather-exposure were specimens of aluminum alloys in the uncoated condition, in the anodized condition, and others painted with aluminum-pigmented spar varnish with and without prior anodization. The results of the exposure tests to date have uniformly confirmed those of the laboratory corrosion tests with regard to these particular surface treatments. This may best be shown by briefly reviewing the results obtained on specimens exposed at Hampton Roads, Va. The specimens at that locality were suspended in racks about three feet above salt water and were occasionally wetted by the water.

The appearance of a few of the specimens shortly after they were removed from the racks is shown in Figure 12. All the specimens shown in the figure were quenched in hot water with the exception of (a) which was quenched in cold water. The surface treatments were as follows: (a) none, (b) none, (c) Jirotka oxide film and greased with lanoline, (d) Bengough anodization and greased with lanoline, (e) three coats of aluminum-pigmented spar varnish applied to clean surface, (f) three coats of aluminum-pigmented spar varnish applied to surface anodized by the Bengough method, (g) Alclad material, with no additional coating. Specimens (a - f) were exposed to the weather for a period of three years; specimen (g) was exposed for a period of three and one-half years.

It may be seen in Figure 12 that there was no marked difference in the surface appearance of specimens (a), (b), (c) and (d). Specimen (e) showed somewhat less evidence of attack than the former mentioned specimens but it will be noted that the paint coating had weathered off completely. The coating on the anodized specimen (f) had just commenced to show first evidence of "breakdown". The surface of the Alclad specimen (g) indicated the presence of corrosive attack. The surface appearance of Alclad material does not, however, serve as a very reliable criterion of the extent or depth of penetration of corrosive attack because the pure aluminum layer itself might be severely attacked while the duralumin base remains unattacked.

The appearance of the specimens as seen under the microscope in transverse section revealed the comparative efficiency of the various surface treatments rather strik-

ingly. The most severe areas of corrosive attack on each specimen are shown in Figure 13. The absence of intercrystalline attack on specimen (a), which was cold-water quenched, illustrates the importance of proper heat treatment as a factor in protection from corrosion. Severe intercrystalline attack may be seen on the uncoated hot-water quenched specimen (b). The grease coatings applied to the oxide-film surfaces of specimens (c) and (d) and the aluminum-pigmented varnish applied to the untreated surface of specimen (e) afforded approximately the same degree of protection. A comparison of these with (b) will serve to illustrate that the coatings appreciably retarded the initial corrosive attack. The protection afforded by the paint applied to the anodized surface of specimen (f) was vastly superior; corrosion had just begun after three years' exposure. The corrosive attack on the Alclad specimen (g) was entirely confined to the aluminum coating, which had not yet been penetrated through.

Conclusions

Both laboratory and weather-exposure corrosion tests showed conclusively that the protection afforded by aluminum-pigmented spar varnish coatings applied to previously anodized surfaces was greatly superior to that afforded by the same coatings applied to surfaces which had simply been cleaned free from grease and not anodized.

Bureau of Standards,
Washington, D. C., October 30, 1931.

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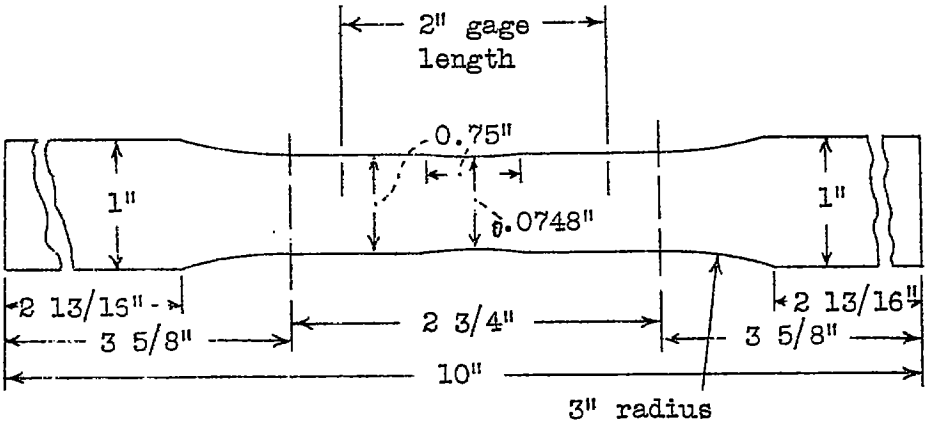
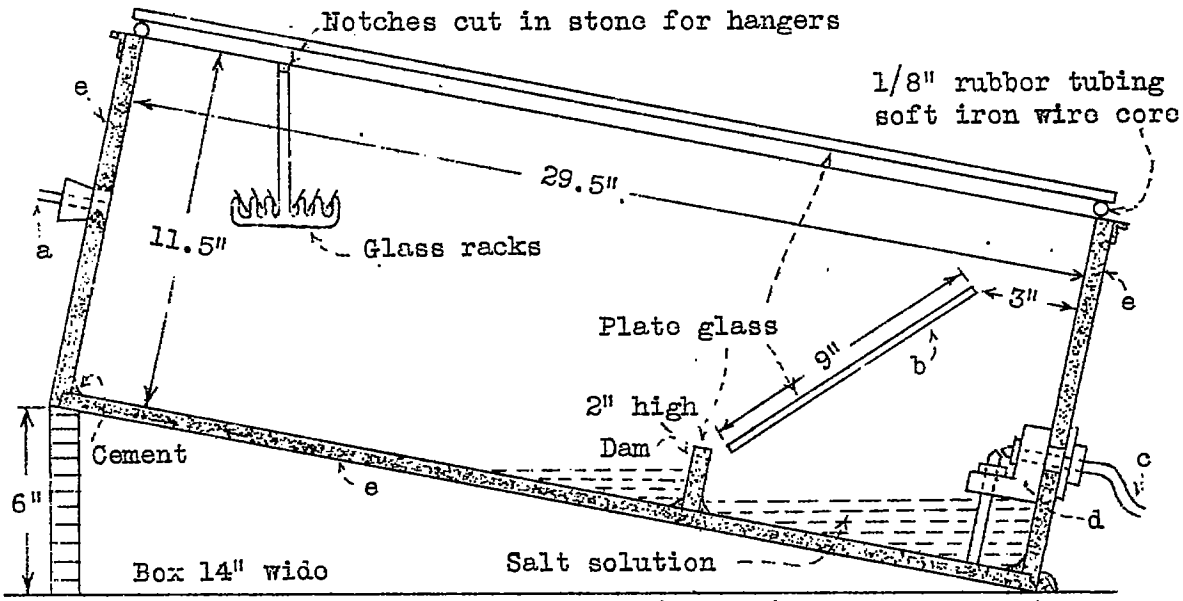


Fig. 1 Diagram showing the dimensions of the sheet aluminum alloy tensile specimens.



a, Vent 1/2" rubber tubing. b, Rabbet 3/8" x 3/8" baffle support.
c, Air intake to atomizer. e, Each side of box Alberene stone, 1/4" thick.
d, Atomizer and bracket of Monel metal.

Fig. 5 Diagrammatic sketch of salt spray box

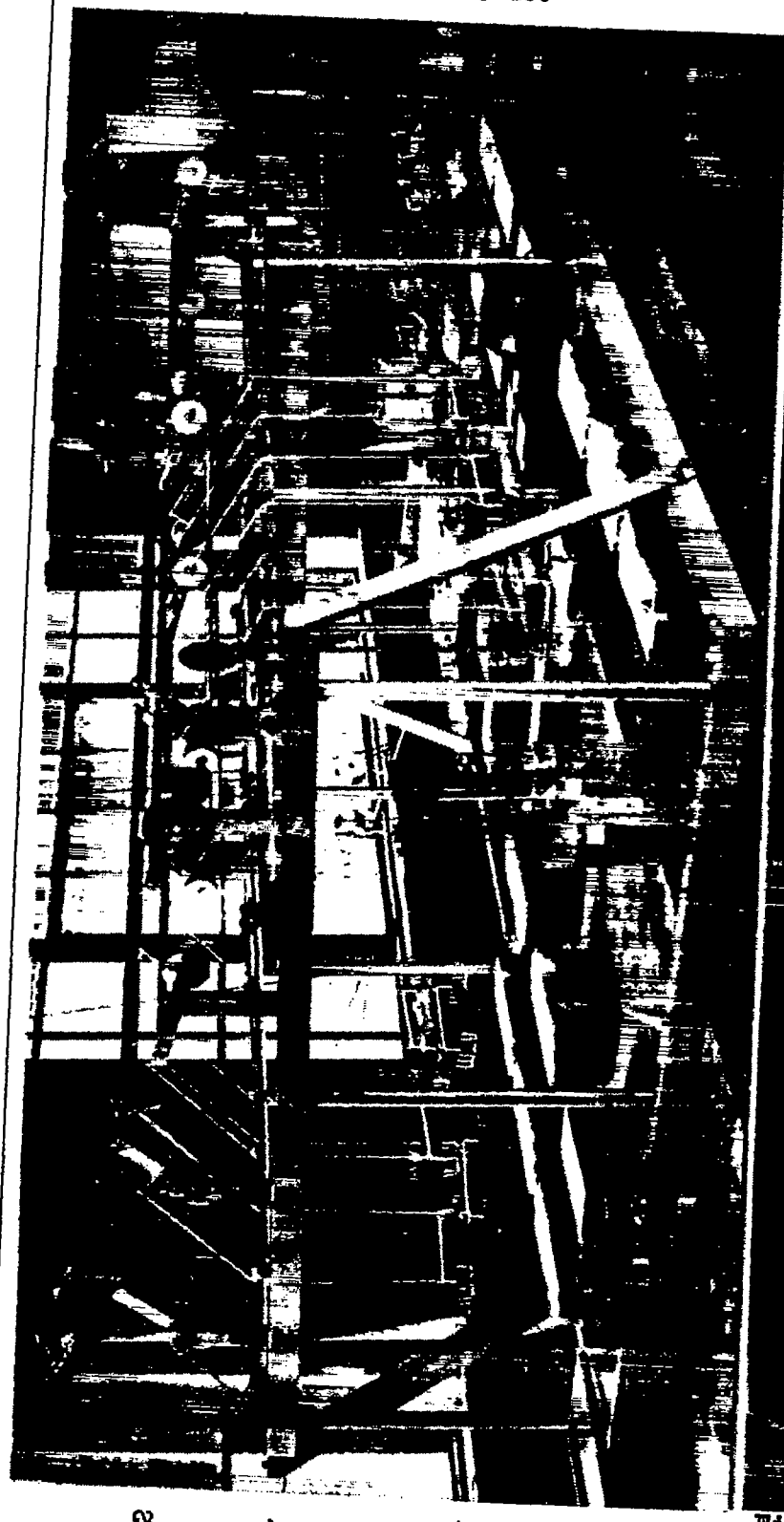


Fig. 2 View of intermittent immersion apparatus used in the corrosion tests.

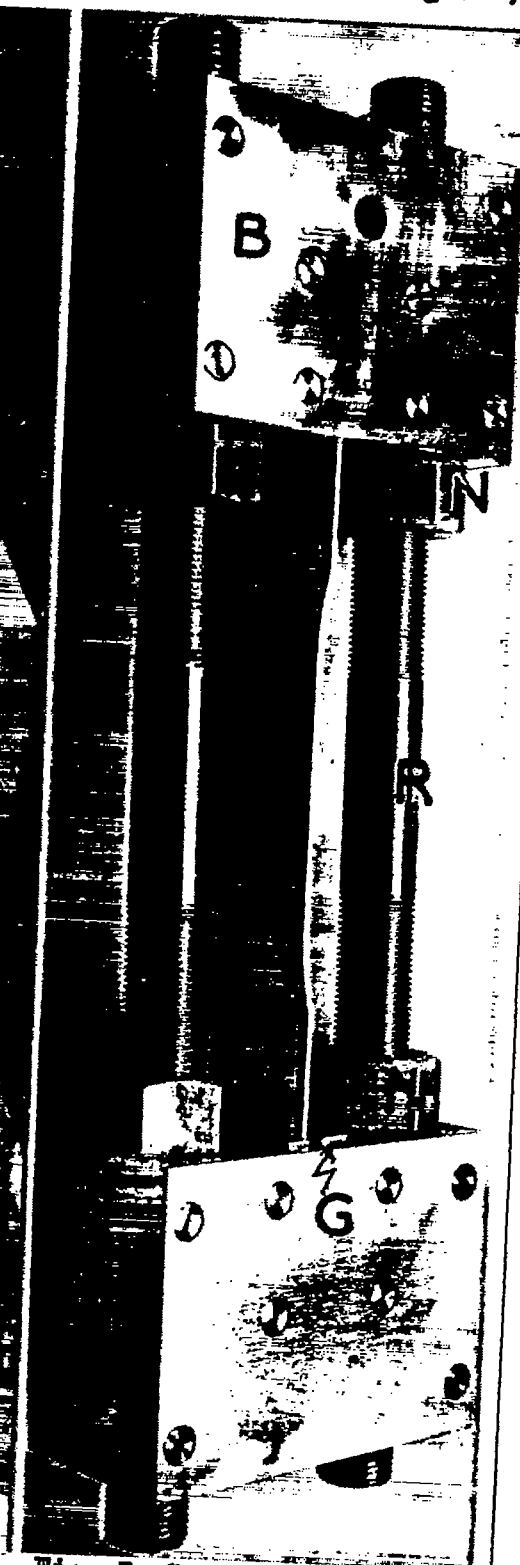


Fig. 3 Specially designed grips for securing static stress on specimens during corrosion tests.

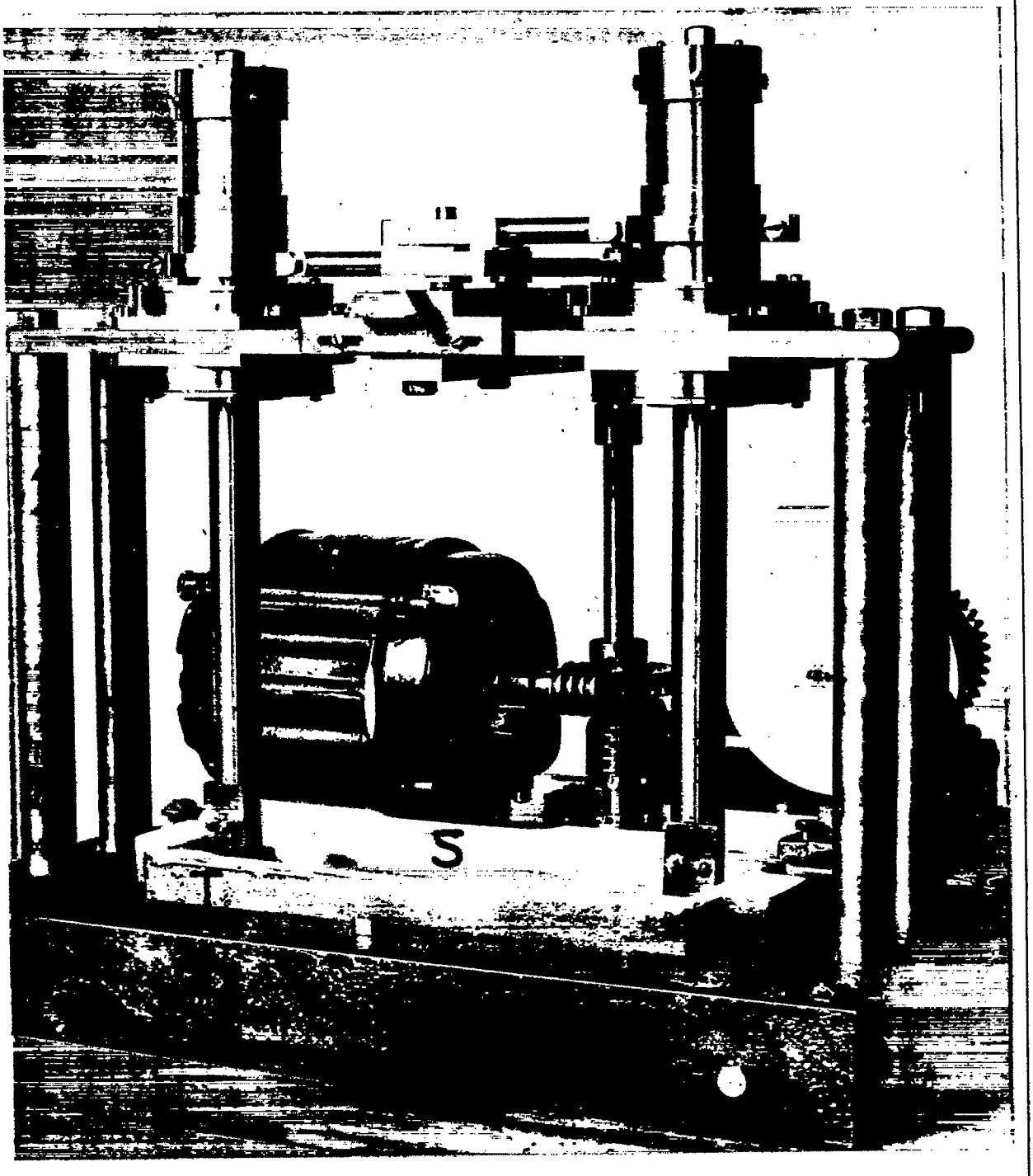


Fig. 4 View of apparatus which permitted the application of flexural stresses to specimens while simultaneously being corroded by the intermittent immersion method

Fig.6 U indicates the specimen was corroded bare, -A that the specimen was anodized, -S that the specimen was coated with aluminum pigmented spar varnish, -AS that the specimen was coated with aluminum pigmented spar varnish on an anodic film. The number after the letter indicates the days of corrosion, as: U15 means the specimen was corroded bare for 15 days. These specimens were corroded by the intermittent immersion apparatus in a solution of 9 parts N. NaCl to 1 part H_2O_2.

Effect of surface coating

on

hot water quenched duralumin,

Corroded in N-NACL + H_2O_2(9:1)

○ Clean - free of grease - not coated.
× Ditto-coated with three coats of Al-pigmented spar varnish.
+ Anodized in a 3% chromic acid solution by regular cycle.
△ Ditto-coated with three coats of Al-pigmented spar varnish.

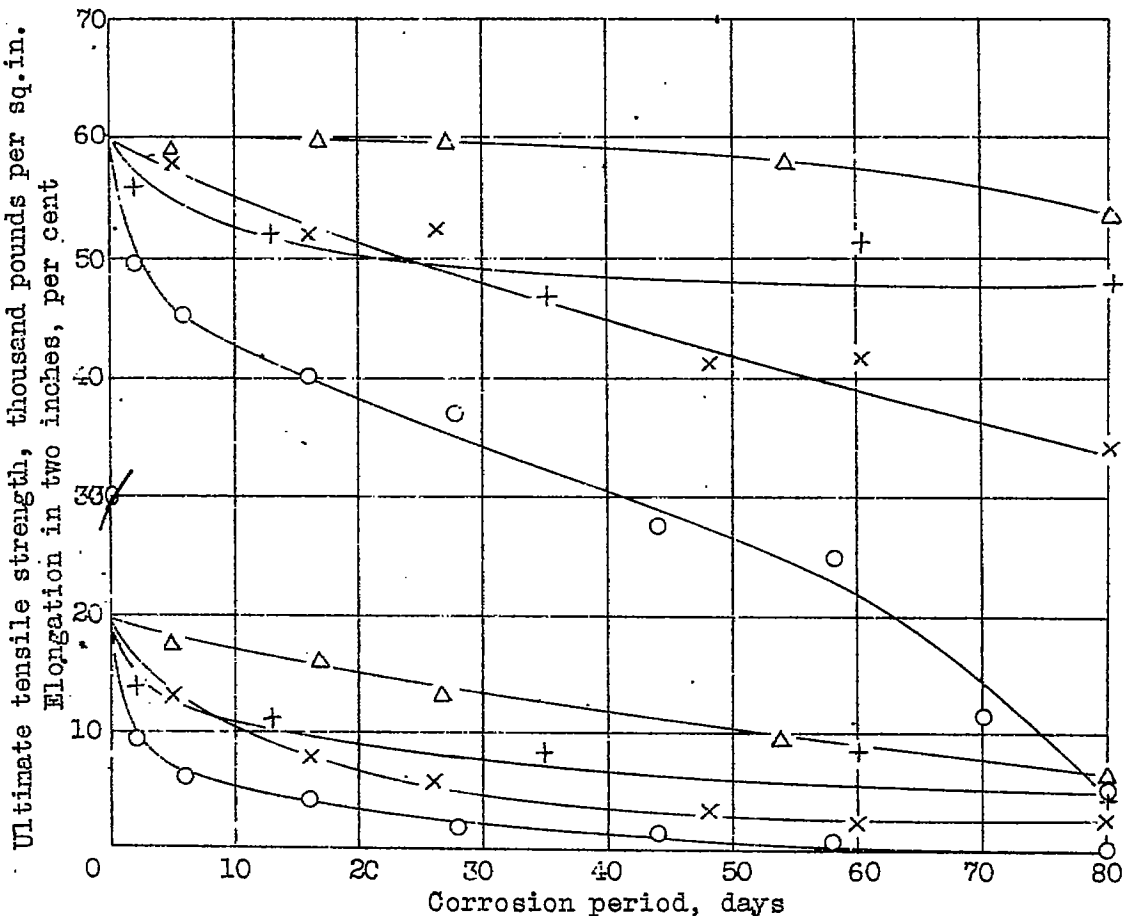


Fig. 7 Curves showing tensile results of specimens corroded by the intermittent immersion method in the unstressed condition.

Effect of surface coating

on

cold water quenched duralumin.

Corroded in N-NACL + H_2O_2 (9:1)

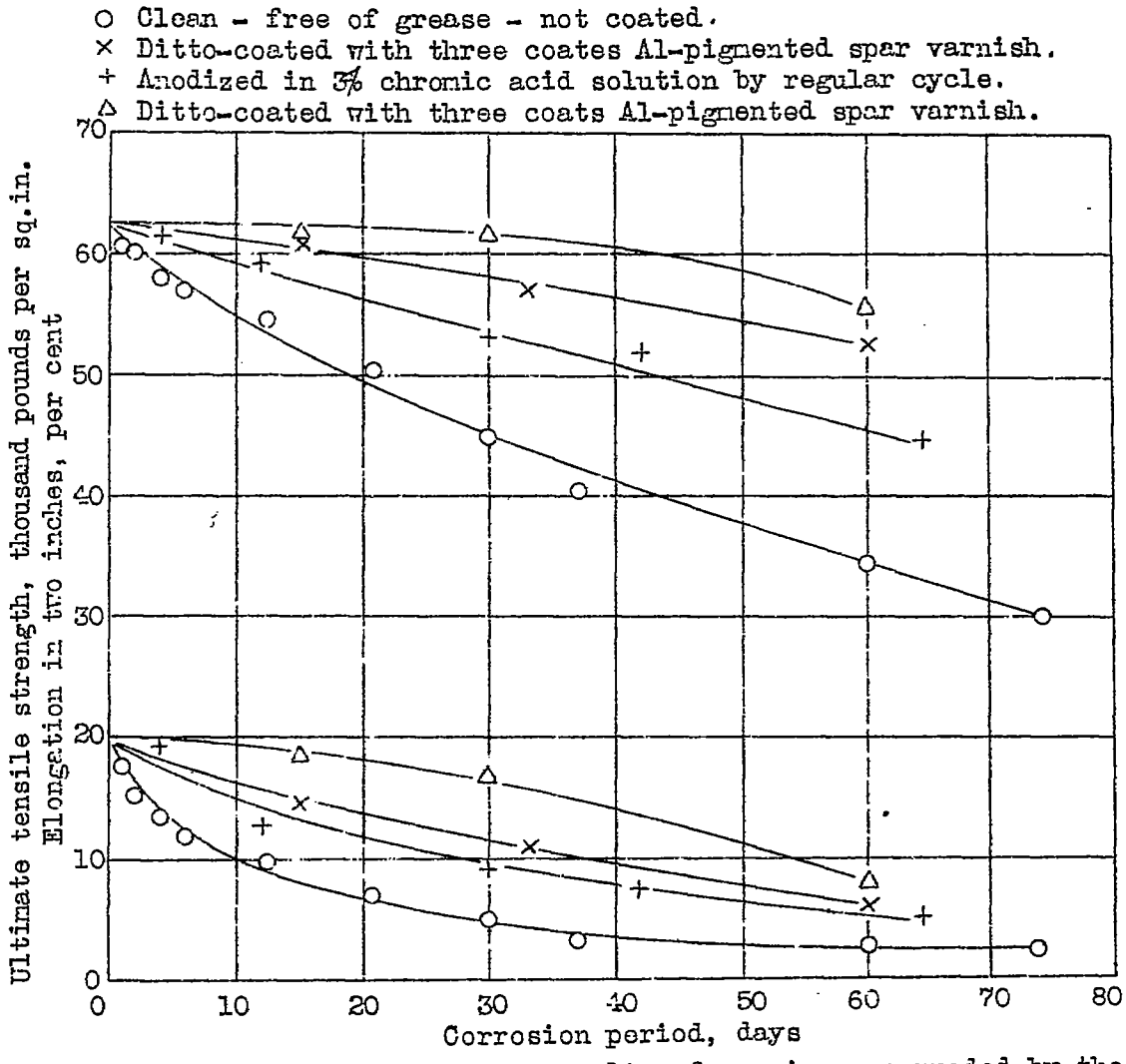


Fig. 8 Curves showing tensile results of specimens corroded by the intermittent immersion method in the unstressed condition.

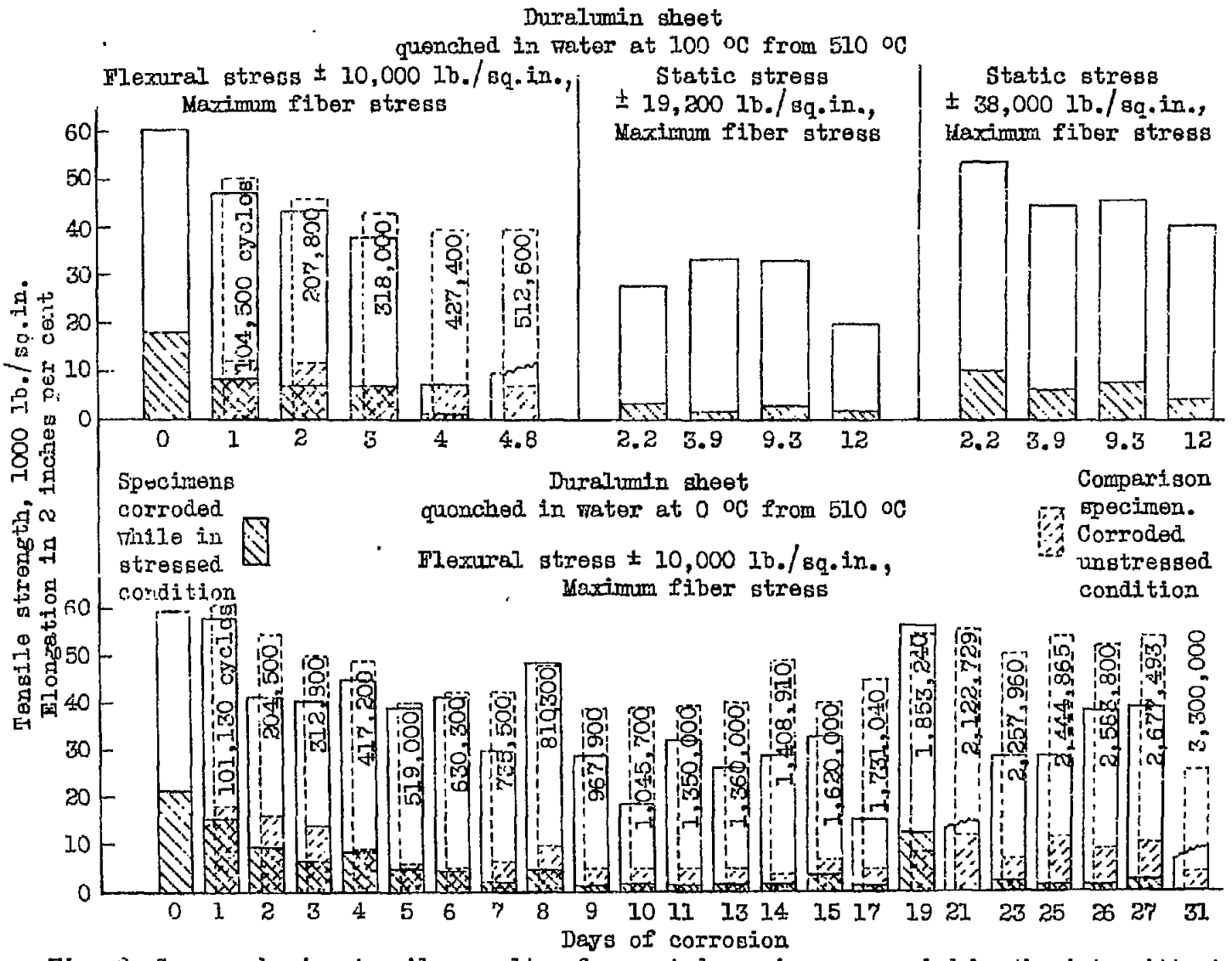


Fig. 9 Curves showing tensile results of uncoated specimens corroded by the intermittent immersion method while being subjected to flexural stress.

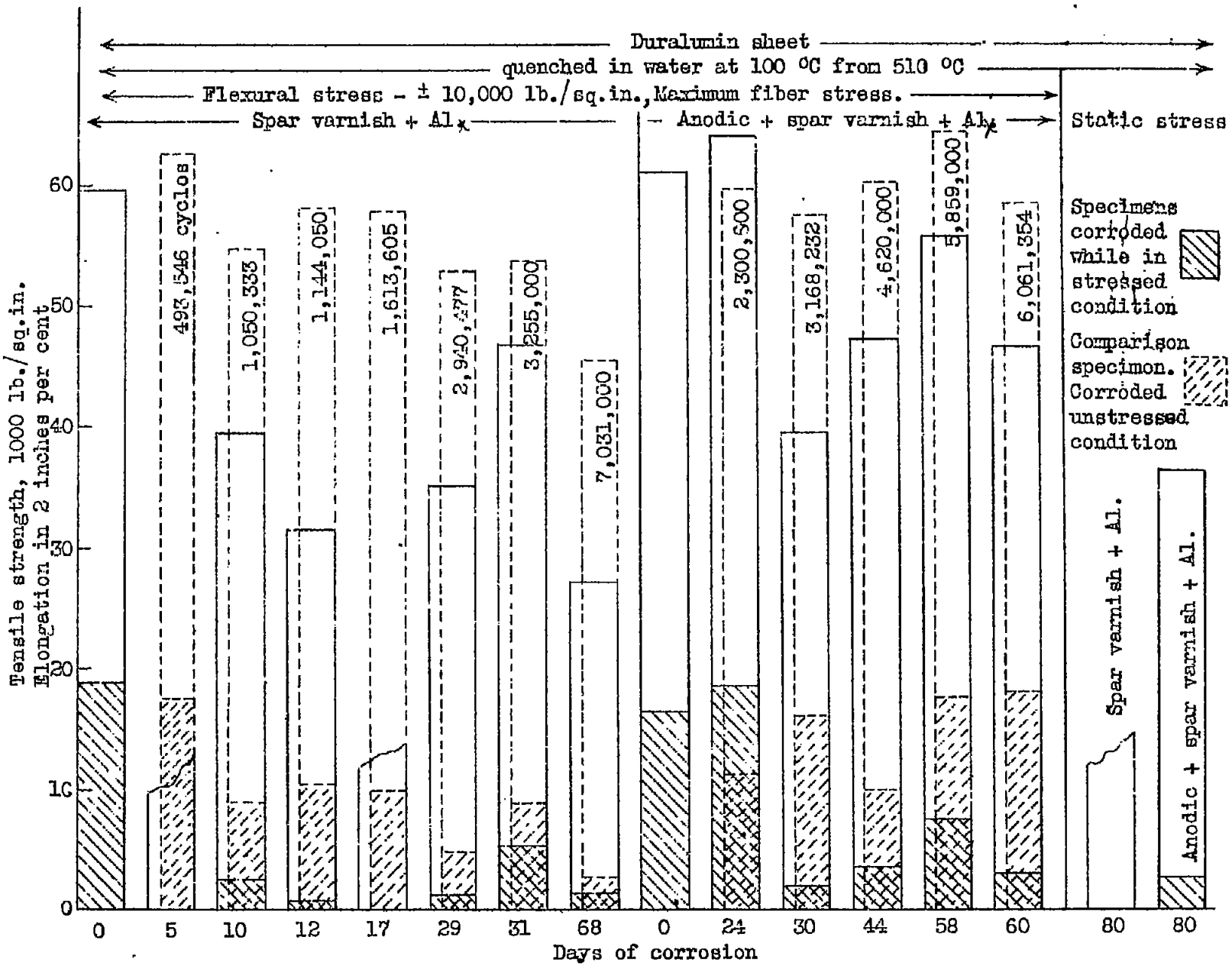


Fig. 10 Curves showing tensile results of coated specimens corroded by the intermittent immersion method while being subjected to flexural stress

Fig.11 Surface appearance of the anodic and of the anodic + Al-pigmented spar varnish specimens after 249 days' corrosion in a 20 per cent NaCl spray. A - anodic; B - anodic + Al-pigmented spar varnish.

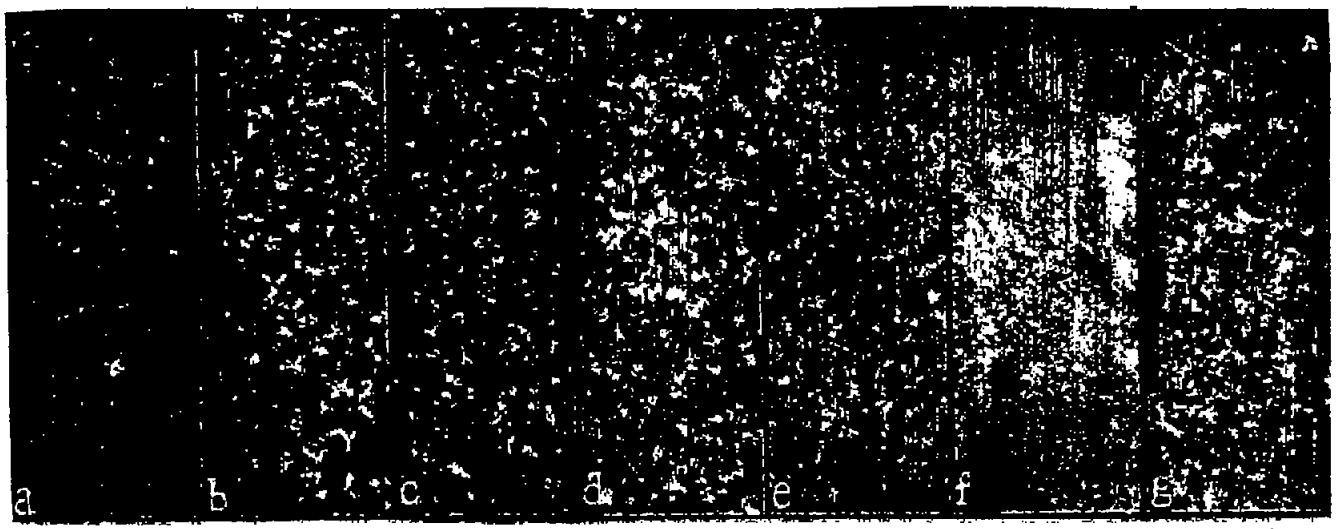


Fig.12 Surface appearance of specimens after approximately 3 years exposure to the weather at Hampton Roads Va. Specimens coated as follows: a and b, none - corroded bare; c - Jirotka oxide film + grease; d - anodic oxide film + grease; e - Al-pigmented spar varnish on untreated surface; f - same as e on an anodized surface; g - Alclad material.

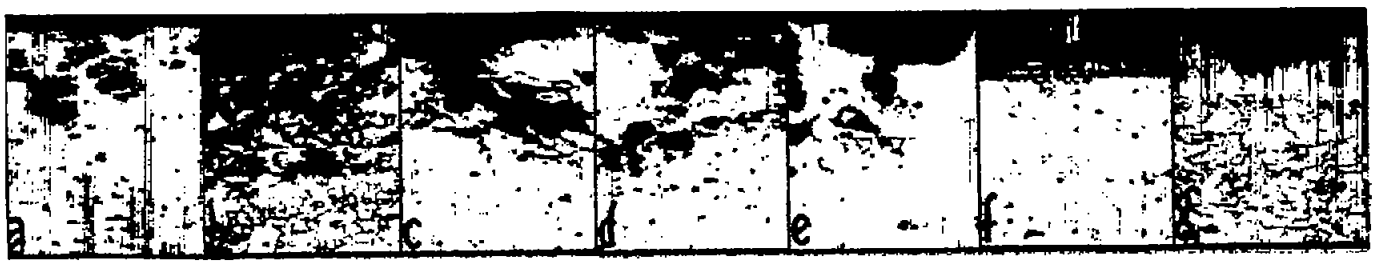


Fig.13 Microstructures of specimens shown in Fig.12. Originally photographed at x 250 and reduced to x 100. Specimens unetched except (g) which was etched to differentiate the aluminum coating from the base metal. The grain structure in (g) should not be confused with the intercrystalline type of corrosion as shown in the other specimens.