TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 284

CORROSION EMBRITTLEMENT OF DURALUMIN

III. EFFECT OF THE PREVIOUS TREATMENT OF SHEET MATERIAL ON THE SUSCEPTIBILITY TO THIS TYPE OF CORROSION

By Henry S. Rawdon
Bureau of Standards

Washington
April, 1928

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL NOTE NO. 284.

CORROSION EMBRITTLEMENT OF DURALUMIN.

III. EFFECT OF THE PREVIOUS TREATMENT OF SHEET MATERIAL ON THE SUSCEPTIBILITY TO THIS TYPE OF CORROSION.

By Henry S. Rawdon.

Light aluminum alloys of the duralumin type, that is, high-strength wrought alloys whose properties can be improved decidedly by heat treatment are of very great importance, especially in the form of sheet and tubes, for aircraft construction. The permanence of such materials when exposed to corrosive conditions such as may obtain in aircraft service should be known, however, with a high degree of certainty and precautionary measures taken to guard against any possible serious deterioration in service. To obtain reliable information along this line an investigation, the results of which form the basis of this series of reports (Reference 1), has been carried out at the Bureau of Standards in cooperation with the National Advisory Committee for Aeronautics, Bureau of Aeronautics of the Navy Department, and Army Air Corps. The leading manufacturers have also participated in the investigation by furnishing practically all of the materials needed. The investigation, which was started in the latter part of 1925, is still in progress and final and complete answers have not been reached on all points concerning the permanence of duralumin in service. The information which has been obtained, however, is of very considerable value to both manufacturers and users of aircraft and its publication at this time would seem to be warranted although possibly some of the statements made may be modified slightly in the light of future results.

I. Introduction

In the preceding report of this series, the deteriorating effect of intercrystalline corrosion upon the tensile properties of sheet duralumin was described and it was shown by means of accelerated corrosion tests that the duralumin type of alloy is, in general, subject to this form of deterioration. Although some of the different heat-treatable aluminum alloys are much more susceptible to the intercrystalline form of corrosion than others, the composition of the alloy does not appear to be the single controlling factor. Brief reference was also made to the fact that duralumin obtained from different sources frequently varied very considerably in susceptibility to intercrystalline corrosion. Mention was also made to the effect that, with the same material, the corrosion resistance appeared to vary according to its previous treatment, particularly its heat treatment. The outstanding characteristic of duralumin and the one which underlies its usefulness as a high-strength light alloy, is the fact that its mechanical properties can be very materially improved by heat treatment. It is of decided importance, therefore, to know whether or not the unsatisfactory behavior of duralumin under corrosive conditions is, in any way, related to or determined by the heat treatment methods used for developing the high-strength properties of the material.

In this report, the dependence of the susceptibility of sheet duralumin to intercrystalline corrosion upon the treatment which the material has received is discussed. The materials used and the methods are similar to those described in the previous report, to which reference should be made for details.

II. Principles of Heat Treatment of Aluminum Alloys

The term "heat treatment" is used here in a slightly limited sense to refer only to the series of thermal operations by which the hardness and strength properties of the material are increased. Essentially this treatment consists in two parts: first, heating the material at a sufficiently high temperature and for a sufficiently long period to permit the structural constituents resulting from the presence of the alloying elements (Cu, Si, Mg) to be absorbed in solid solution by the aluminum-rich matrix, followed by rapid cooling in order to maintain this structural condition at room temperature; second, an aging of the quenched material whereby the hardness and strength are very materially increased. A precipitation of the alloying constituents from the solid-solution form into discrete particles still of submicroscopic dimensions, however, is quite generally believed by metallurgists to constitute the "mechanism" of aging. In duralumin, aging takes place at room temperature and begins soon after the material has been quenched. In some of the related high-strength light aluminum alloys, however, heating is necessary in order to bring about the full strengthening effect of aging. This is termed "accelerated aging."

The fabrication of any "built-up" structure of any of the high-strength aluminum alloys must of necessity be done on the relatively soft material if any forming operations are required. Whenever possible, it is preferable to carry out the heat treatment on the assembled structure. Often this is not practicable, in which case, the forming operations must be done after the material has been quenched but before the hardening (aging) process has advanced to any pronounced extent. Any forming operation of the heat-treated material would constitute a cold working of the alloy and, reasoning by analogy from our knowledge of the effect of cold working on the corrodibility of iron and steel, such a condition would be regarded as undesirable as judged by its effects upon the corrosion of the material.

In this investigation the effect of the cold working of the material on its behavior when corroded was observed by corroding tension specimens which had been permanently stretched an arbitrarily determined amount, the stretching being carried out at progressively longer intervals of time following the quenching of the material. Some additional tests were carried out on specimens which had been deformed either by cold rolling, bending, or crimping. In the study of the effect of the heat-treatment factors upon the susceptibility of duralumin to corrosion, particular attention was paid to the following: (1) The effect of temperature and duration of heating prior to quenching; (2) The effect of the quenching medium; (3) The effect of accelerated aging and heating after aging.

III. Effect of Cold Working

In considering the possible interrelation of the deformation of sheet duralumin by cold working and the rate of corrosion, one is interested, first of all, in determining whether the susceptibility to intercrystalline corrosive attack of cold-worked heat-treated sheet duralumin is greater than that of plain heat-treated material and, if so, how the cold forming of such material should be carried out with respect to the heat treatment operations.

In Figure 1 are summarized the results of corrosion tests carried out by the intermittent repeated-immersion method on tension bars of commercially heat-treated sheet duralumin which had been cold-worked by permanently stretching the bars before subjecting them to corrosion. (The composition of the material is the same as that given in the previous report, Table II.) In determining the magnitude of the effect of cold working upon corrodibility, comparison should, of course, always be made with the material as cold-worked, but before corrosion, instead of with the material in its initial state, since cold deformation results in a raising of the ultimate tensile strength and a lowering of the unit elongation. In numerous cases, the tensile strength of the stretched bars after corrosion was greater than that of the initial unstretched material. Likewise, if allowance is made for the drop in the elongation which resulted from cold working, it will be seen that the change in this property, which resulted from corrosion, is much less than might be assumed from casual inspection. The results obtained with specimens which were deformed in the cold by bending them either transversely or longitudinally along the central axis (followed by straightening in both cases) are in general accord with those for the stretched bars. However, since the change in the properties of the material locally, that is, along the line of the bend, is unknown, a close comparison cannot be made. It might be expected in these cases that, as a result of microscopic fissures formed along the line of bending, the corrosive attack would be most severe in such portions. No distinct evidence of this was noted, however.

On the whole, the results obtained by corroding specimens which had been deformed (cold) by stretching them a known amount, measured in each case on the 2-inch gauge length (Fig. 1) indicate that heat-treated sheet duralumin which has been deformed cold corrodes at a somewhat faster rate than similar material which has not been strained in this manner. The difference in the behavior, however, is not great enough to justify the conclusion that cold working is the fundamental cause of the intercrystalline corrosion of duralumin and this condition should therefore, be regarded as a contributory factor, only.

The results obtained with tension bars which were stretched a definite amount within a known period after being quenched serve to confirm this conclusion. The aging process by which duralumin becomes stronger and harder begins very shortly after the material has been quenched and continues at a slowly diminishing rate for several days. Approximately full strength is attained after 72 hours' aging. This is shown by Figure 2, which gives the stress required in order to stretch a specimen 2 per cent in length. Such a diagram demonstrates more strikingly the advantage of carrying out all forming operations immediately after quenching than does the one usually given which shows the change in hardness occurring during aging. As will be seen from the results of Figure 3, permanent stretching of sheet duralumin by an amount of 2 per cent (measured on a central 2-inch gauge length), does not appreciably affect the corrosion behavior of the material, provided that the stretching is done within 24 hours after the material has been quenched. Bars stretched 72 hours after being quenched gave indications of a somewhat greater susceptibility to corrosion. Even in these cases, however, the results, for the corrosive condition used, were not at all suggestive that the corrosive attack had been very greatly accelerated by deforming the sheet in this manner.

IV. Variables in Heat Treatment

1. Effect of Temperature and Duration of Heating Prior to Quenching

In the heat treatment of duralumin, the alloy is usually heated at a temperature slightly above 500°C (930°F) and quenched from this temperature. In the latest recommendations for the heat treatment of aluminum alloys (Reference 2), a temperature range of 495-515°C (925-960°F) with a preferred temperature of 510°C (950°F) is given for the duralumin composition. In order to show what effect the temperature at which duralumin is heated and the duration of heating at that temperature prior to quenching may have upon the susceptibility of the heat-treated alloy to intercrystalline corrosion, specimens were heated at a temperature well above that at which complete solubility of the copper constituent is attained, and a similar set at a temperature somewhat below this point. At the time this investigation was started, the most reliable information as to the temperature at which solubility of the copper constituent is complete was that given by Archer and Jeffries (Reference 3), who showed that complete solubility of the copper constituent in an alloy containing 4 per cent copper may be expected to occur at approximately 460°C. Accordingly, a temperature of 505°C (500-510°) was chosen as representative of one well above the solubility point, also incidentally as representative of current heat treatment practice, and a temperature of 425°C as being well below the point of complete solubility.

In a very carefully conducted investigation on very pure materials, Dix (Reference 4) has recently shown, however, that complete solubility of the copper constituent in a 4 per cent Cu-Al alloy is not attained until a temperature only slightly below 500°C is reached.

The specimens of the 14-gauge sheet used were of the same composition as given in the previous report (Table I) and were considered to be representative of the product of the two cooperating manufacturers (A and B). The heating periods for the higher temperature ranged from 15 minutes to 8 hours; for the lower temperature, 1 to 8 hours. The tensile properties of the heat-treated material (quenched in cold water and aged at room temperature) before corrosion and after 40 days' attack by a calcium chloride solution are summarized in Figure 4.

These results show definitely that 425°C is too low a quenching temperature to develop fully the properties of duralumin by aging. For the sheet material heat-treated at the higher temperature, no practical advantage would appear to be gained by prolonging the heating period much beyond 15 minutes. Specimens heated for a very long time (5 to 8 hours) showed a somewhat lower tensile strength than those heated for a very much shorter time, presumably because of the increased grain size occurring during the long heating periods. In addition to uniformly lower tensile properties shown by the material quenched at 425°C, these specimens also showed a lower corrosion resistance which in the case of the A material was decidedly lower. In general, the results obtained for the corroded specimens indicated no pronounced or significant differences which could be attributed to the different heating periods used, aside from a slightly greater corrosion-resistance shown by the material heated for the longest periods. This difference, however, was not great enough to warrant consideration of it as a practicable means for increasing the corrosion resistance of duralumin. It may be concluded from these tests, therefore, that provided the material is "fully heat-treated" by being quenched from a temperature well above that at which solution of the alloy constituents is attained, the corrosion resistance is not materially improved by holding the material for a relatively long time at this temperature prior to quenching.

2. Effect of Quenching Medium

It is very generally recognized that the mechanical properties of heat-treated sheet duralumin are quite uniform, regardless of the quenching medium used in carrying out the heat treatment. The results summarized in Figure 5 are in good agreement with previously published data by other investigators, and show no wide variations in the tensile properties of 14-gauge sheet duralumin aged after being quenched in various media, ranging from boiling water at one extreme to ice water at the other. The properties, in each case, are of the same order of magnitude and are well above the minimum values often specified for such material (55,000-60,000 lb./sq.in. ultimate tensile strength, 18% elongation in 2 in.). The difference in the susceptibility of this material to intercrystalline corrosion after being heat-treated in the different ways indicated is not nearly so well known, however. At the time this investigation was started almost no information on the point was available. Knerr (Reference 5) had previously mentioned "that there was some evidence that the resistance to corrosion is improved by quenching in cold water" and had cited in support of this, a few observations made on heat-treated sheet specimens which had been exposed for 30 days in the salt (NaCl) spray test. The materials which had been quenched in boiling water and in oil (70°F) were graded as showing only "slight corrosion" but more than that of similar material quenched in cold water (60°F) which showed "very slight corrosion." That this observation was considered of academic interest rather than as having any practical significance is evidenced by the fact that in describing the various high-strength aluminum alloys and the methods for treating them, Archer and Jeffries (Reference 3) stated, three years later, that "it is common to quench them in hot water." Hot-water quenching has been followed rather extensively as a commercial practice and its advantage strongly emphasized (Reference 6), especially when fused salt baths (nitrates) are used as the means for heating the alloy prior to quenching, since the adhering salt film is much more readily removed by the hot water than by any other of the common quenching media.

Duralumin tension specimens which had been heat-treated by being permitted to age 6 days at room temperature after being quenched in various ways were corroded by the intermittent immersion method previously described. The following quenching methods were used: boiling water; oil (Houghton's No. 2) at 29°C (84°F); water, 25°C (77°F); 15 per cent sodium chloride brine, 27°C (80°F); ice water, 2°C (35°F); and a water "pressure spray" (50 lb. pressure from a series of orifices surrounding the specimen). (The sodium-chloride brine was used only for experimental purposes, because of its high "quenching properties" as shown with steel, and is not recommended as a commercial method for aluminum alloys.) The properties of the specimens after corrosion are summarized in Figure 5. The greater susceptibility to corrosion of the material quenched in hot water or in oil is very evident, in the change in both the tensile strength and in the elongation. The differences in properties, after corrosion, of the specimens quenched in water at room temperature as compared with those quenched more drastically are, on the whole, not pronounced enough to warrant a recommendation for the exclusive use of the one in preference to the other. The microstructure of the corroded specimens clearly shows, even more strikingly than do the tension tests, the difference in the nature of the corrosive attack following the different quenching treatments. This is shown in Figure 6.

The "B" duralumin received in the oil-quenched and aged condition and quite susceptible to intercrystalline corrosion as received, due to the slow cooling rate in quenching, was made equally resistant with the cold-water quenched "A" material by retreatment and cold-water quenching. The more pronounced susceptibility of hot-water-quenched duralumin sheet to intercrystalline corrosive attack by chloride solutions, as compared with that of cold-water-quenched material, would appear to be established beyond all question and as such, has been recognized in the most recent recommendations for the heat treatment of this class of material (Reference 2). Material which has been quenched in cold water is not to be considered, however, as being completely resistant to all corrosive attack. The familiar pitting type of attack still occurred to some extent for such material when it was corroded by the accelerated corrosion test method.

Very thin sheet duralumin (for example, .008 inch) which has been quenched in cold water frequently, shows a corrosion resistance which is no better than that of the same material quenched in hot water. This is especially true when the treatment is carried out on rather small pieces. Even when the material is transferred from the fused nitrate heating bath to the cold water with as little delay as possible, the heat-treated sheet is not very different in its corrosion resistance from the hot-water-quenched sheet. Both are quite susceptible to intercrystalline corrosion. The shielding of the surface by the adhering nitrate film as the material enters the cold water, is probably responsible for much of the effect.

Even with some of the alloys, the full aging of which can only be accomplished at an elevated temperature, such as the alloy of copper and aluminum (25S), the rate of quenching may have a very decided effect upon the susceptibility of the quenched material to corrosion as may be seen by the results in Figure 7. The specimens of the material, 25S, which were quenched at a slower rate, by using oil and hot water, showed lower resistance to corrosion than those quenched more rapidly by the use of cold water. It will be seen from the discussion in the next section, that the use of a medium having a relatively slow quenching rate approximates accelerated aging to some extent in its results. Hence, the alloy 25S quenched in hot water, when corroded behaves in a somewhat similar manner to the alloy aged at an elevated temperature, although the hot-water treatment is not sufficient to develop fully the strength properties of the material. On the other hand the alloy 51S (Mg-Si-Al alloy), when quenched in hot water, did not show the marked difference in its corrosion-resistance from that quenched in cold water, as did the Cu-Al alloy. In this case, hot-water quenching resulted in practically no aging of the material since a higher temperature and a much longer period is required for the alloy, 51S.

3. Accelerated Aging and Heating after Aging

In duralumin, the age-hardening process occurs normally at room temperatures and, although this change may be accelerated by using an elevated temperature, the need for accelerated aging of this material very seldom arises. For the other high-strength aluminum alloys, however, accelerated aging is ordinarily necessary in order to develop the highest mechanical properties. Some results included in the previous report indicated that these materials which had been aged at an elevated temperature showed more propensity toward intercrystalline corrosion than when aged at room temperature. In order to show this effect more definitely the tests, the results of which are summarized in Figure 8, were carried out.

Tension specimens of the duralumin composition were quenched in ice water from a temperature of 500°C. Some were aged immediately at 100°C (24 hours), others at 200°C (4 hours) and a third set allowed to age at room temperature. The tension tests of the bars after corrosion showed a very marked difference in the susceptibility toward corrosion of the material aged at 200°C as compared with that aged in the normal manner. According to the tension tests the material aged at 100°C, showed no marked difference in its corrosion behavior from that aged at room temperature. The microstructure of the corroded bars, however, showed definitely that the propensity to intercrystalline attack, for the aging treatments used, increased as the aging temperature was raised.

This effect of accelerated aging on the susceptibility to intercrystalline corrosion is much more strikingly shown by the results of tension tests of corroded specimens of the Cu-Al and Mg-Si-Al type of alloy (25S and 51S, respectively), full age-hardening of which cannot be accomplished at room temperature. It will be seen (Fig. 7) that not until the heating had been continued long enough to result in a considerable degree of age-hardening, as shown by the increase in tensile strength, was there any pronounced change in the behavior of the material when corroded. Both of these alloys aged at room temperature after quenching in cold water were highly resistant to intercrystalline attack but such a treatment does not confer upon the material the high-tensile properties which accelerated aging does. (It will be noticed that none of these materials was fully resistant in corrosion by the accelerated corrosion test used; corrosion of the ordinary type, pitting, often was quite severe and obscured to some extent the effect of the intercrystalline attack. Microscopic examination was necessary in order to make certain as to the character of the corrosive attack.)

Duralumin in the quenched-and-aged condition is very seldom heated intentionally. This may occur, however, incidental to some coating operations and in welding. The tests summarized in Figure 8 were for the purpose of throwing light on this point as well as for supplementing the tests on accelerated aging. The results show that the corrosion resistance of heat-treated duralumin is very much decreased by subsequent heating of the material. Microscopic examination of the corroded material showed that for the three temperatures used, 135°C, 200°C, and 285°C, the intercrystalline attack was most pronounced in the material heated at 135°C (Fig. 9). The intercrystalline attack decreased as the reheating temperature was raised above 135°C, the intercrystalline corrosive attack of the material heated at 285°C being relatively slight, although the pitting was quite pronounced.

4. Metallographic Aspects of Heat-Treated Sheet Duralumin

Microscopic examination failed to show, even at high magnifications, any structural features which could be considered as being characteristic of sheet duralumin which had been quenched in hot water as contrasted with the structure of the same material which had been quenched in cold water. Likewise, X-ray examinations, by the Laue method, of duralumin sheet heat-treated in these two ways showed only relatively slight differences between the two. Without doubt the difference in the corrosion behavior of sheet duralumin after these two forms of heat treatment is to be attributed to structural features of a submicroscopic character. The case of the increase in the solubility in acid of hardened steel upon tempering, a change ordinarily described as being a function of the size of the precipitated (submicroscopic) carbide particles, may be cited as an analogous one.

In order to show the nature of the structural change which is believed to underlie the aging of duralumin, it is necessary that the aging process be accentuated. Usually this is done by prolonging the accelerated aging treatment or by reheating the alloy after it has been aged at room temperature. By such a treatment the particles of the hardening constituents become large enough to be seen with the microscope. In Figure 10 are given thermal analysis curves (inverse-rate method) of a sample of commercial heat-treated duralumin sheet. It will be seen that two heat evolutions are shown by the heating curve, at 200°C and 270°C approximately, the exact nature of which is still in question but which are undoubtedly related to the age-hardening process. The cooling curve indicates nothing unusual in the behavior of the alloy. The micrographs of Figure 9 show the structural appearance of duralumin heated, after aging, at temperatures of 135, 200 and 285°C, respectively, these temperatures being chosen by reference to the heating curve, together with the structure of the material after accelerated corrosion in the laboratory. It will be seen from these micrographs that, as the material was heated, the aluminum-rich matrix changed in character by the appearance of small particles of the hardening constituents disseminated throughout it. This appearance became more pronounced as the heating was continued and the tendency toward localization of the particles on the grain boundaries became more marked. This preferential coalescence of the particles on the grain boundaries, is most probably to be associated with the intercrystalline form of corrosion which occurs in this material. However, it is evident that the relation between these two phenomena is not a simple one, since the tendency to intercrystalline corrosion was found to be most marked in specimens heated at 135°C in which material the grain boundary pattern was extremely slight whereas specimens (285°C) in which this pattern was most markedly developed showed a much less pronounced tendency toward an intercrystalline attack.

IV. Summary

1. The results summarized in this report show conclusively that the tendency of sheet duralumin and the related high-strength aluminum alloys to corrode in an intercrystalline manner is intimately related to the method of heat treatment used for the material.

2. The heat treatment of materials of this type for the production of high-strength properties is carried out in two stages which are more or less distinct, according to the alloy. The material is first heated at a temperature sufficiently high and for a sufficiently long period to permit the alloy constituents to be taken into solid solution by the aluminum-rich matrix and then quenched to maintain this condition at room temperature. The quenched alloy is then aged which, in the case of duralumin, takes place at room temperature. In some of the related high-strength aluminum alloys, however, the aging must be done at an elevated temperature. By aging, the material becomes harder and stronger, which result is believed to be brought about by the

precipitation of submicroscopic particles of the alloy constituents throughout the aluminum-rich matrix.

3. Cold deformation or forming operations on sheet duralumin, if not done upon the annealed material, should be carried out on the quenched material before aging has progressed very far. This is largely in order to facilitate the forming operations, however, and not primarily for increasing the corrosion resistance. The tendency toward intercrystalline corrosive attack of fully aged sheet duralumin, which has been cold-worked, is somewhat greater than that of the unworked heat-treated material. But this factor is of somewhat minor importance, as compared with others which influence the corrosion behavior of sheet duralumin, in this respect.

4. Provided the temperature at which duralumin is heated, prior to quenching, is well above that at which solution of the alloy constituents by the matrix is attained, no practical advantage is gained, so far as the corrosion resistance of the material is concerned, by the use of very long heating periods. For 14-gauge sheet, heated at 500°C, a heating period of 15 minutes in a fused nitrate bath gave essentially the same results as was obtained by using periods several times as long as this.

If the temperature is somewhat below that at which complete solubility of the alloy constituents is attained, the material will not be "fully heat-treated" and the corrosion resistance will be relatively low. By longer heating periods, this condition is improved somewhat but such material will not be the equal of that quenched from a higher temperature.

5. The rate at which sheet duralumin is quenched prior to aging, that is, the quenching medium used, has a pronounced influence on its susceptibility toward intercrystalline corrosion. Sheet material quenched in hot water shows a very much greater tendency toward intercrystalline attack than the same material after being quenched in cold water. Oil-quenched material lies intermediate between the other two in its corrosion behavior. The static strength properties of sheet duralumin quenched in different media do not differ materially, however. Hence, the tensile and related properties cannot be used as a criterion of the corrosion resistance of such material. However, with very thin sheet duralumin, the beneficial effect on corrosion resistance of cold water quenching is not ordinarily apparent.

6. Sheet duralumin and related high-strength aluminum alloys which, after quenching, have been age-hardened at an elevated temperature show, in accelerated corrosion tests, a much more pronounced tendency toward intercrystalline corrosion than does the quenched material before heating. The strength properties after aging, of course, are superior to those before aging in certain alloys which do not age "spontaneously." The susceptibility of quenched-and-aged duralumin sheet to intercrystalline

corrosion is increased by heating the heat-treated material - a condition which may occur incidental to some coating operations.

7. Sheet duralumin which has been heat-treated so as to possess high resistance to intercrystalline corrosion is not necessarily "corrosion proof." In accelerated corrosion tests the more familiar or pitting type of corrosion often occurs in such material.

8. Microscopic and X-ray examinations have failed to show any marked and consistent differences in structure which can be considered as characteristic of the differences resulting from the quenching of sheet duralumin in hot water and in cold water, respectively. The difference in corrosion behavior of the material in these two conditions is most properly to be attributed to submicroscopic structural differences. As yet, no sure means for distinguishing between these two conditions, other than an accelerated corrosion test has been found.

9. The conclusions summarized above as to the effect of the variables of heat treatment of sheet duralumin upon its susceptibility toward intercrystalline corrosion have been based upon accelerated corrosion tests in the laboratory. Weather exposure tests of similar materials are now in progress for the purpose of obtaining definite information on the behavior under conditions more nearly comparable with those of service.

These exposure tests, so far as they have progressed, confirm the accelerated tests in the laboratory, in indicating that there is little hope of preventing intercrystalline attack of the high-strength aluminum alloy sheet material by control of composition or avoidance of the common impurities by using specially pure metals. However, all of these tests do indicate that much can be done by using a rapid coolant in quenching (that is, cold water) and avoiding the use of those alloys for which accelerated aging is necessary for devloping their high-strength properties in highest degree. While the differences in the rate of attack may not appear very great in the plotted results of the accelerated tests, in actual service, as simulated by weather exposure tests, the useful life of hot water quenched duralumin sheet may be measured in months whereas that of similar material quenched in cold water is a matter of years.

This control of the rate of quenching and the avoidance of accelerated aging by heating are the only means, so far found, of modifying the material itself so as to minimize the intercrystalline form of corrosive attack. It is so simple a means that it should be adopted even though it may not completely prevent, but only reduce, this form of corrosive attack. By so doing, the need for protection of the surface, which subject is discussed in the next of this series of notes, is thereby made less urgent; in brief, one should endeavor to depend as little as possible upon the surface coating applied, regardless of the kind used.

References

1. Rawdon, Henry S. : Corrosion Embrittlement of Duralumin. I. Practical Aspects of the Problem. N.A.C.A. Technical Note No. 282. (1928)

Corrosion Embrittlement of Duralumin. II. Accelerated Corrosion Tests and the Behavior of High-Strength Aluminum Alloys of Different Compositions. N.A.C.A. Technical Note No. 283. (1928)

Corrosion Embrittlement of Duralumin. IV. The Use of Protective Coatings. N.A.C.A. Technical Note No. 285. (1928)

2. American Society for Steel Treating Handbook, Data sheet Al-5601, Heat Treatment of Wrought Aluminum Alloys of High-Strength, September, 1927.

3. Archer, R. S. and Jeffries, Z. : New Developments in High-Strength Aluminum Alloys. Trans. Am. Inst. Min. Met. Eng. 71, 828, 1925.

4. Dix, E. H. and Richardson, H. H. : Equilibrium Relations in Aluminum-Copper Alloys of High Purity. Trans. Am. Inst. Min. Met. Eng. 73, 560, 1926.

5. Knerr, H. C. : Duralumin, A Digest of Information. Trans. American Society for Steel Treating 3, pp. 13-42, 1922.

6. Goldstrom, John : Replacing Wood in the Air. Iron Age, 118, 1753-9, 1926.

Bureau of Standards,

January 25, 1928.

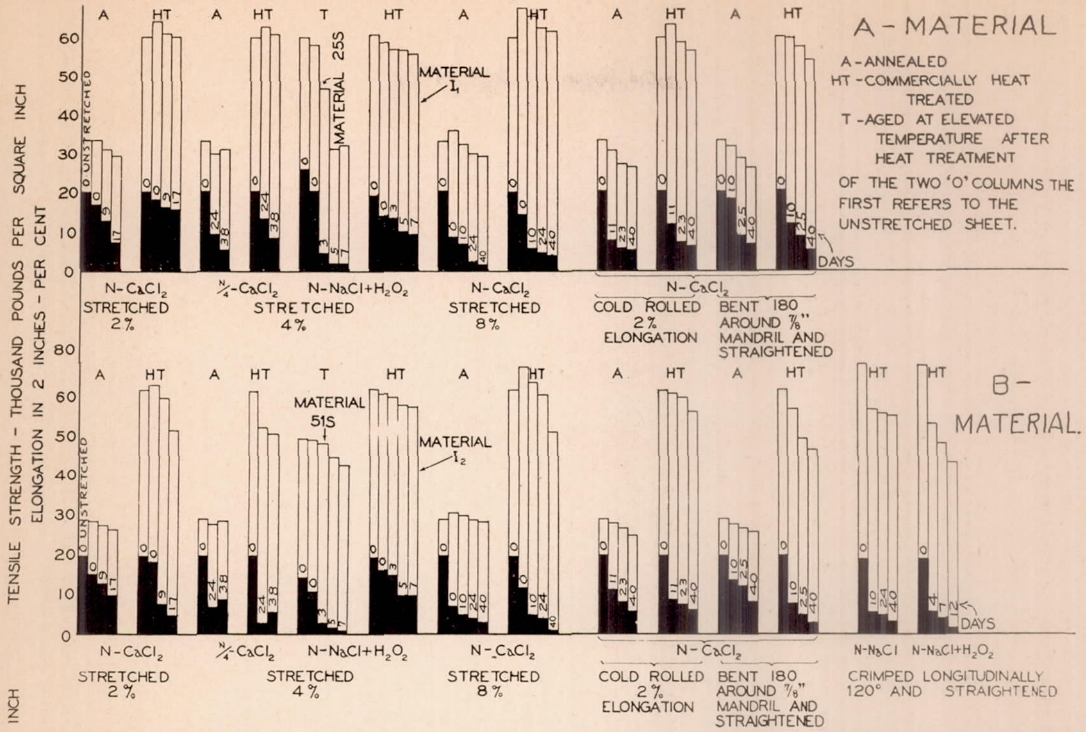


Fig. 1

Effect of cold-working upon the corrosion resistance of sheet duralumin.

The total height of the rectangle represents the ultimate tensile strength, that of the shaded portion, the elongation in this and succeeding figures. 14-gage sheet was used throughout unless stated otherwise.

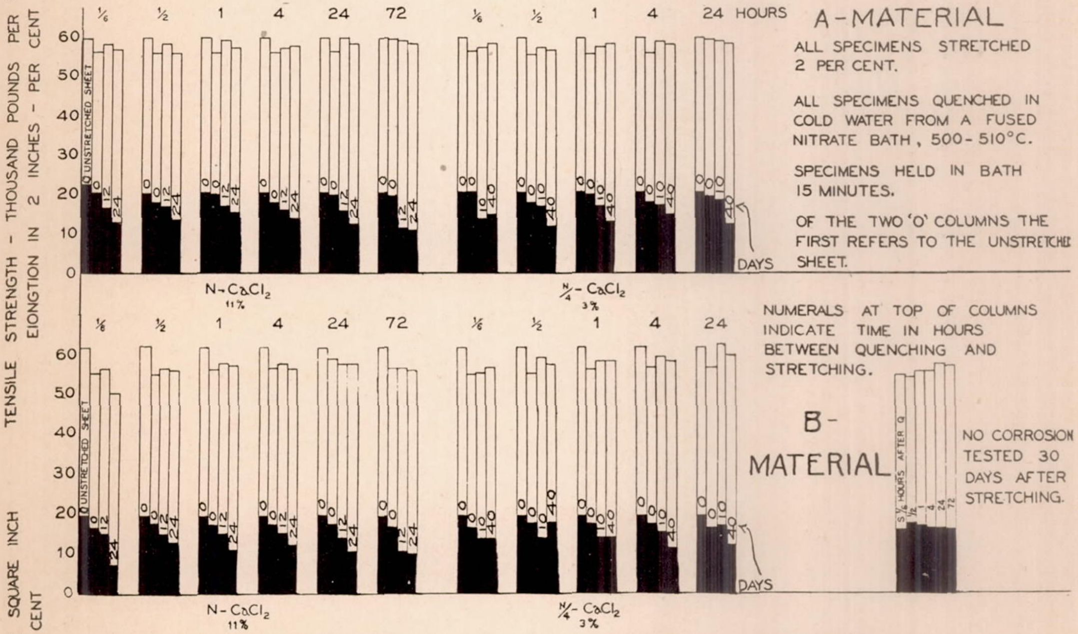


Fig. 3

Corrosion resistance of cold-worked sheet duralumin, the deformation being done by streching at successively increasing intervals of time after quenching.

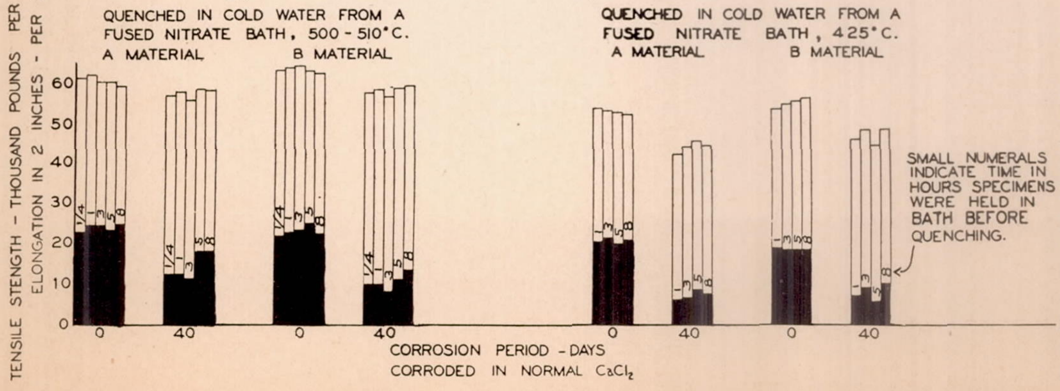


Fig. 4

Effect of varying the temperature of heating and the heating period prior to quenching on the corrosion-resistance of heat-treated sheet duralumin.

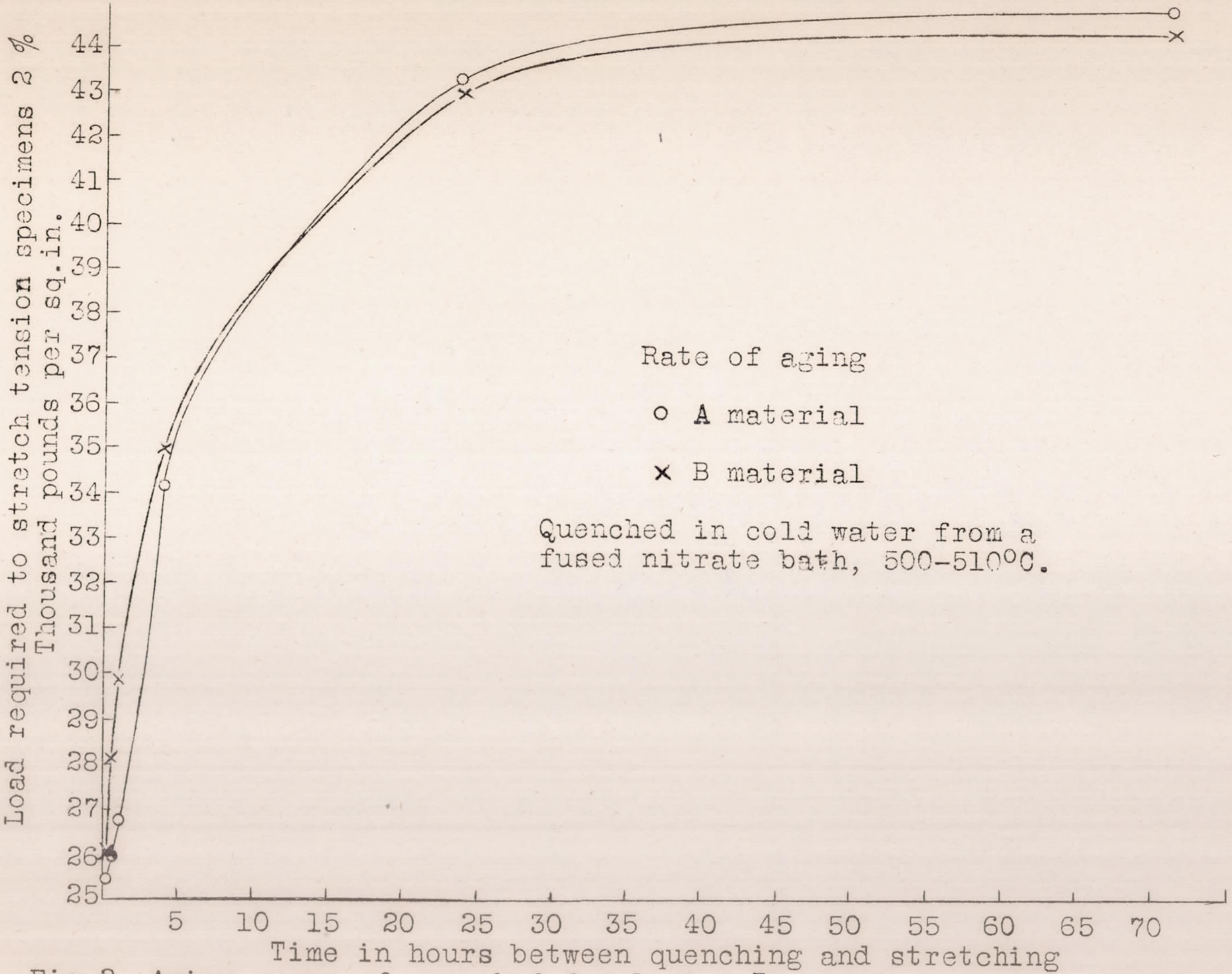


Fig.2 Aging curve of quenched duralumin. The load required to stretch the material 2 per cent in 2 inches has been used as a measure of the aging effect.

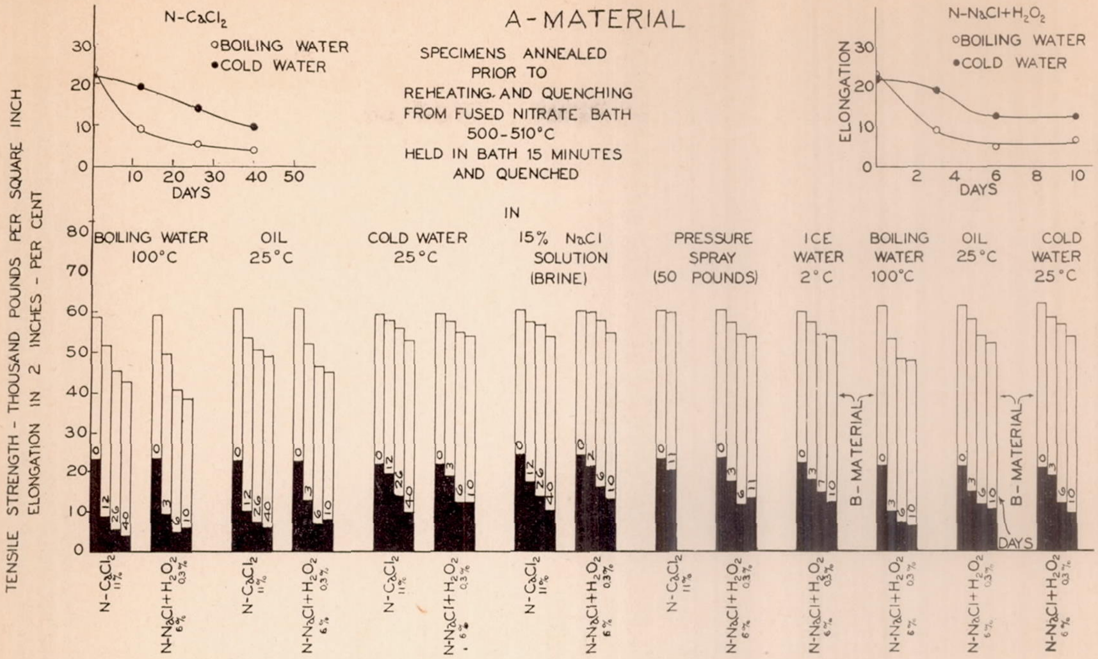


Fig. 5 Effect of varying the quenching rate, by use of different media, upon the corrosion-resistance of heat treated sheet duralumin.

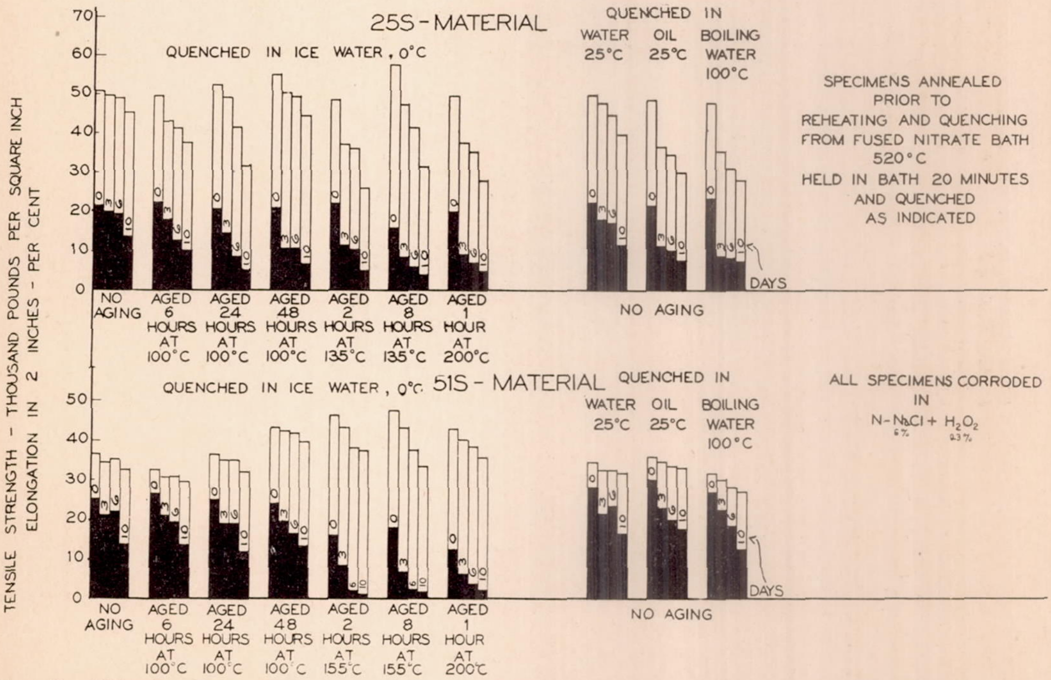


Fig. 7 Effect of accelerated aging on the corrosion resistance of high-strength aluminum alloy sheet (25S and 51S).

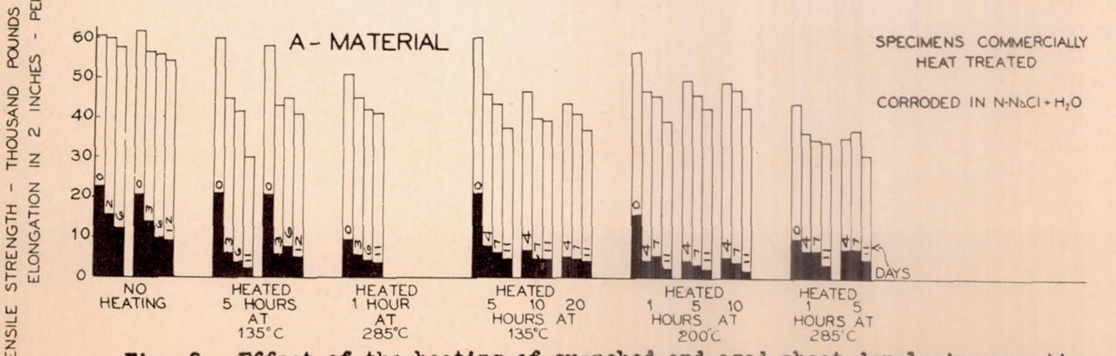
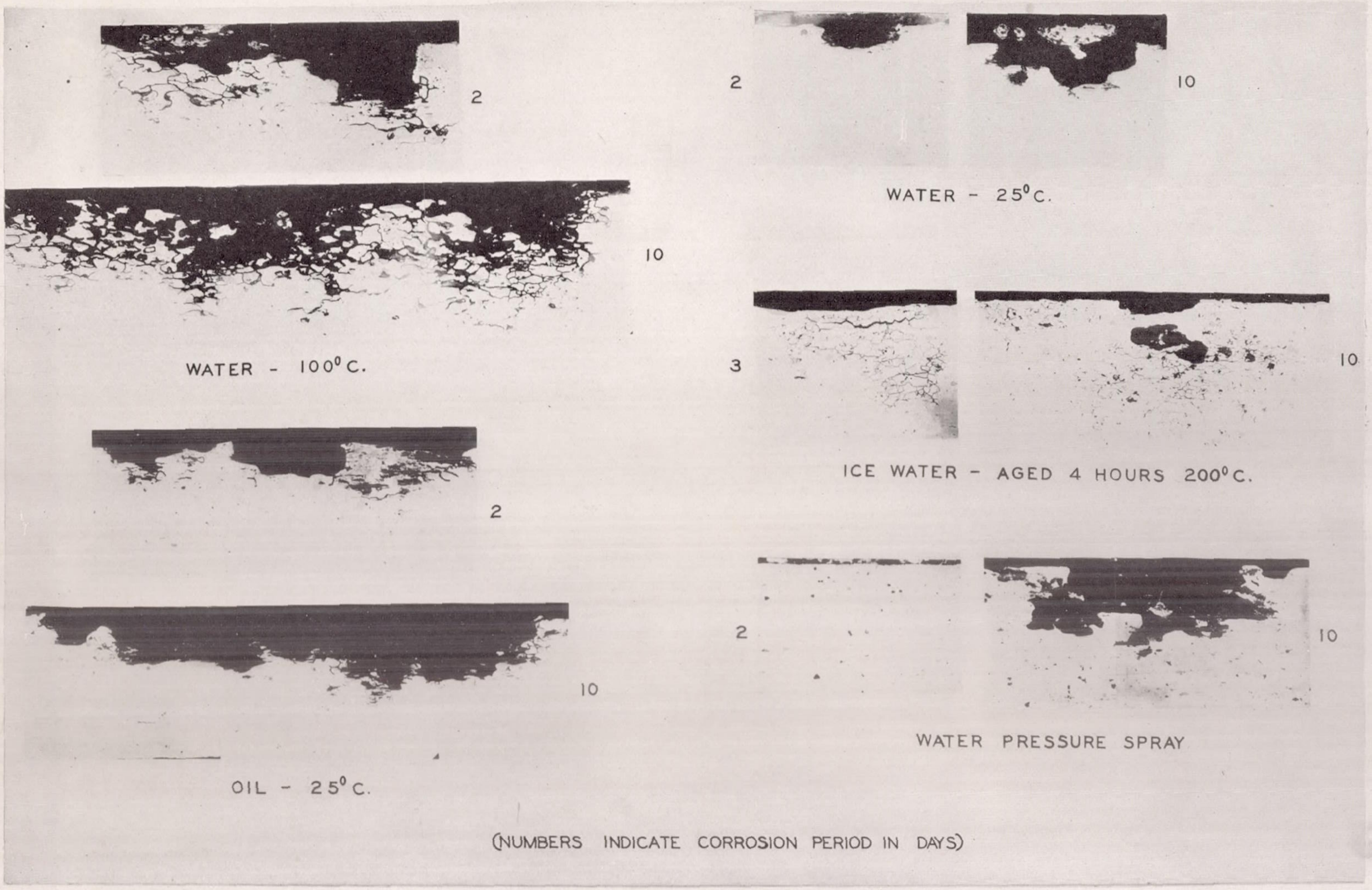


Fig. 8 Effect of the heating of quenched-and-aged sheet duralumin upon its corrosion resistance



(NUMBERS INDICATE CORROSION PERIOD IN DAYS)

Fig. 6 Microstructure of corroded sheet duralumin supplementing Figure 5

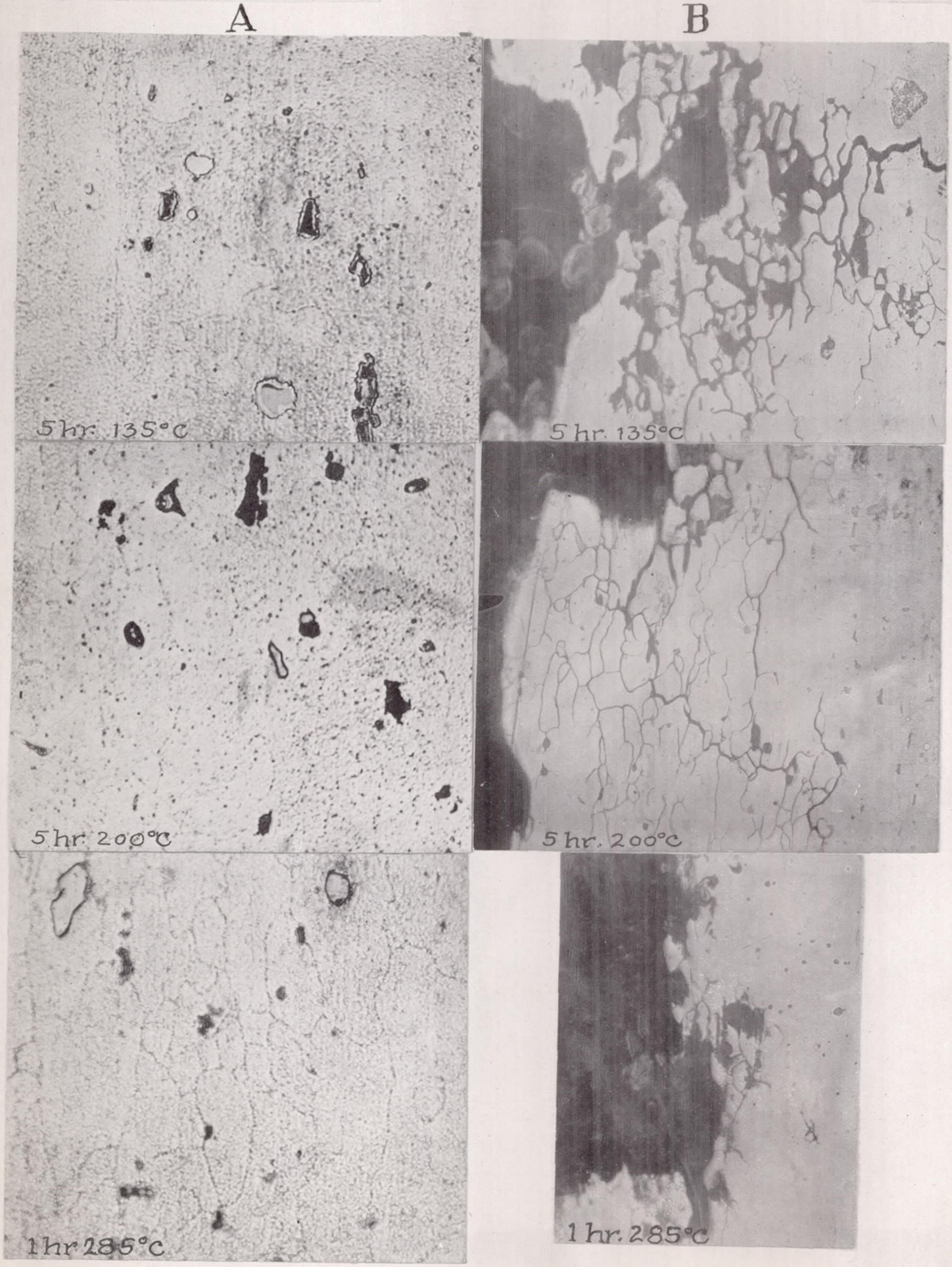


Fig. 9 Microstructure of corroded sheet duralumin, supplementing Figure 8. A, x 1000; B, x 250. Heated after aging as indicated.

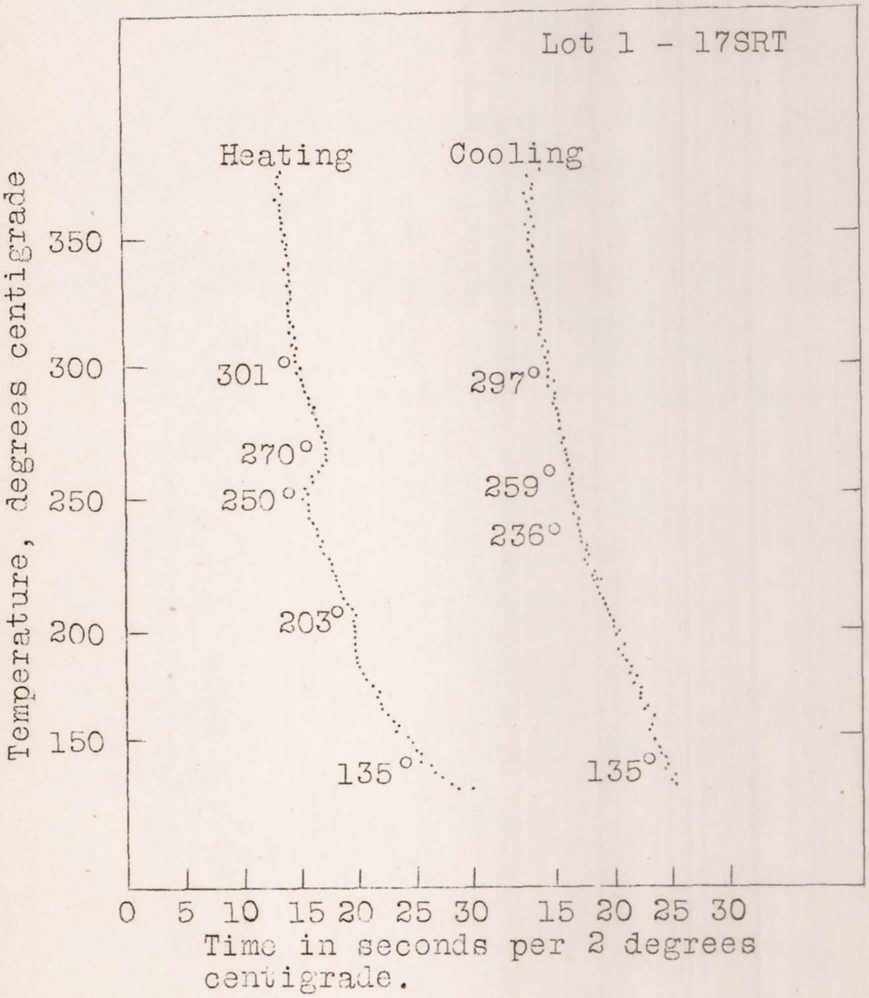


Fig.10 Thermal analysis curves of duralumin.