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EFFECT OF THE QUENCHING RATE ON SUSCEPTIBILITY TO INTERCRYSTALLINE CORROSION OF HEAT- TREATED 24S ALUMINUM ALLOY SHEET

By Hugh L. Logan

ABSTRACT

The effect of the quenching rate of the 24S aluminum alloy upon its behavior in an accelerated corroding solution ($\text{NaCl} + \text{H}_2\text{O}_2 + \text{H}_2\text{O}$) was determined. Specimens cooled from a temperature above 400°C at a rate in excess of 815° to $1,110^\circ\text{C}/\text{sec}$ (increasing with increasing copper content of the alloy) were susceptible only to the pitting type of corrosion. Specimens cooled at a rate less than 300° to $400^\circ\text{C}/\text{sec}$ (increasing with increasing copper content) and specimens cooled slowly to a temperature below 400°C before quenching were subject to severe intercrystalline corrosion. For cooling rates between the above ranges there was a gradual change from one type of corrosion to the other.

Cooling rates were determined by means of a thermocouple and an Einthoven string galvanometer.

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I. INTRODUCTION

There are two commercial aluminum alloys of the duralumin type that are widely used in aircraft structures in this country. Both alloys are ordinarily used in the heat-treated condition. The principal alloying constituents are copper, magnesium, manganese, and silicon, the chief difference in composition of the two being in the copper and magnesium content. Because of its higher strength, the alloy containing the relatively larger amounts of copper and magnesium is now usually preferred in aircraft structures. The designation of this alloy, 24S, by its manufacturer, the Aluminum Company of America, is generally used in referring to this material.

The recommended heat treatment for any aluminum alloy consists in: (a) heating to form a solid solution of the essential alloy constituents in the aluminum; (b) cooling rapidly from the solution tempera-

ture to approximately room temperature; (c) aging at room temperature or at some optimum elevated temperature. The recommended solution heat-treatment temperature for the 24S alloy is $493^{\circ} \pm 5^{\circ}$ C. The aging effect (hardening) is completed in about 4 days at room temperature.

Without surface protection, this alloy is not immune to corrosion, and the severity of the corrosion damage varies greatly according to the environment. The most damaging corrosion is that which penetrates along the grain boundaries, causing a significant decrease in strength and ductility out of all proportion to the outward, visible evidence of the severity of the damage. However, if cooled from the solution temperature at a sufficiently rapid rate, the alloy is immune to intercrystalline corrosive attack, even in severely corrosive environments.

Very little published information is available concerning the rates, in quantitative terms (degrees per unit of time), at which it is necessary to cool the 24S alloy from the solution temperature in order to avoid susceptibility to intercrystalline corrosion. In the recommended procedures for the heat treatment, the most specific statement concerning the cooling rate is that the alloy shall be "quenched in cold water." In industrial heat-treating operations, in which large quantities of material are handled at one time, wide variations in cooling rates are to be expected—not only because of differences in the temperature of the cooling water but also because of unavoidable difficulties in cooling every portion of a large piece, or every piece of a large batch, uniformly at the same rate, even if the cooling water is at a properly "cold" temperature. Procedures other than plunging the material into cold water may cool the alloy at rates entirely too slow to provide immunity to intercrystalline corrosion.

Drastic cooling, in the endeavor to render the alloy immune to intercrystalline corrosion, may result in distortion of the quenched material and necessitate expensive straightening operations. In many cases it would be desirable to fabricate a structure from material in the soft or annealed condition and subsequently to heat-treat it, if the structure could be cooled slowly enough to minimize distortion and still rapidly enough to insure immunity to intercrystalline corrosion.

The strength and hardness of the heat-treated alloy are not significantly affected by the cooling rate for a wide range of rates, including those which render the alloy susceptible to severe intercrystalline corrosion. Results of tensile and hardness tests generally do not indicate whether or not the alloy was cooled from the solution temperature with sufficient rapidity to prevent intercrystalline corrosion.

This report¹ describes the method used at the National Bureau of Standards for determining cooling rates of specimens of 24S aluminum alloy sheet cooled from the recommended solution temperature by "quenching" in water maintained at different temperatures, and also gives results of a study to determine the relations between the cooling rates and susceptibility to intercrystalline corrosion. The minimum cooling rates that would provide immunity to intercrystalline corrosion were also determined for the specimens available.

¹ A preliminary report was presented before the American Physical Society, April 29, 1939. *Phys. Rev.* **55**, 1139 (1939).

II. EXPERIMENTAL PROCEDURE

1. MATERIALS

It is generally believed that the mode of combination and distribution of the copper, rather than of the magnesium and manganese, in the alloys of the duralumin type, is the basic factor that determines whether or not the alloys are susceptible to intercrystalline corrosion, and furthermore, that the rate of cooling from the solution temperature has an important effect on the mode of combination and distribution of the copper in these alloys. It was considered important in determining the critical cooling rates of the commercial 24S alloy to obtain data on alloys of different copper contents. Through the courtesy of the Aluminum Company of America, sheet material, 0.040 in. thick, and in the annealed condition, was furnished in the compositions given in table 1.

TABLE 1.—Compositions of 24S alloy sheet

Alloy number	Copper	Magnesium	Manganese	Iron	Silicon	Aluminum (by difference)
	%	%	%	%	%	%
A05.....	4.05	1.49	0.64	0.28	0.19	93.35
A27.....	4.27	1.51	.65	.27	.19	93.11
A64.....	4.64	1.61	.63	.27	.21	92.64

2. DETERMINATIONS OF COOLING RATES

Specimens $\frac{1}{2}$ by $\frac{1}{2}$ in. were cut from the 0.04-in. sheets of the three compositions given in table 1. The temperatures of the specimens during heat treatment were measured with Chromel-Alumel thermocouples peened into 0.018-in. holes drilled into the specimens, as shown in figure 1. The thermocouple circuit was completed through the specimen itself, and the results are based on the assumption that the indicated temperature is that at the surface of the specimen, at the point of contact. Calculation shows that the surface temperature in a specimen of the dimensions used does not differ by more than 3° C from that of the center, for the cooling rates plotted in figure 3. The specimens were heated in air in a vertical electrical resistance tube furnace at the solution temperature ($493^{\circ} \pm 5^{\circ}$ C) for 30 minutes. The thermocouple wires and insulating tubing served as a support for lowering the specimens into the quenching bath placed immediately below the furnace tube.

The rapid changes in temperature that occurred in the specimens during quenching were recorded photographically as time-temperature cooling curves by means of an Einthoven string galvanometer and auxiliary apparatus shown in figure 2. The thermocouple wires from the specimen were connected in series with the galvanometer string, which was a tungsten wire (0.0002- to 0.0003-in. diameter) located vertically in the horizontal magnetic field in the galvanometer, *G*. The current in the thermocouple circuit caused deflections of the "string" in the magnetic field that (resistance of the circuit remaining constant) are proportional to the emf, and therefore to the temperature, inasmuch as the temperature-emf relation of the thermocouple

is practically a straight line. The computed change in the resistance of the thermocouple, in the range 20° to 500° C, was so small compared to the resistance of the whole circuit that it was within the experimental error and could be neglected. The motion of the "string", magnified 500 times, was recorded by its shadow in the beam of light coming through the lens system $C-C'$, on a moving strip of photographic paper in the camera, R . A rotating sector, I , driven in synchronism with an electric tuning fork, interrupted the light beam at intervals of 0.04 second and thus produced a time scale on the recording paper. A grating mounted in the camera reproduced the temperature scale. Time intervals could be estimated to 0.01 second and temperature to 2½° C. The apparatus was calibrated before the quenching of each specimen by recording on the photographic paper the zero position of the string (zero emf) and the position of the string when the emf (determined by a potentiometer) of the thermocouple at the heat-treating temperature was applied to it. The use of this apparatus for measuring cooling rates of steels in different quenching media has been described elsewhere.^{2 3}

To obtain different quenching rates on specimens of the same size, quenched from the same temperature, it was necessary to change the temperature of the quenching bath. Obviously the lower the temperature of the quenching bath, the more rapid the cooling rate for specimens of the same size. In water at 22° C, quenching rates as high as 10,000° C/sec were obtained; and in water at 80° C, the cooling rates were reduced to approximately 1,100° C/sec.

The cooling rates obtained in this investigation at the various quenching water temperatures would not necessarily be obtained with specimens of different sizes or shapes, or with a mass of water which was not large compared with the mass of the specimens.

Typical cooling curves obtained by quenching specimens in water at different temperatures are shown in figures 5 and 6. The temperature of the specimens decreased very slightly (3° to 10° C) between the time of withdrawal from the furnace and the time of quenching. The specimens cooled rapidly during the quenching until, after 0.05 to 3 seconds, they had reached a temperature of approximately 120° C. There was then an abrupt decrease in the cooling rate, and during the next 3 to 10 seconds the specimens reached the temperature of the quenching medium.

The cooling rates given in this paper are average rates for the interval between the beginning of the "quench," approximately 490° C, and the temperature at which rapid cooling ceased, 115° to 125° C in most cases.

Numerous experiments indicated that the rate of cooling below a temperature of about 120° C had little or no influence on the susceptibility of the 24S alloy sheet to intercrystalline corrosion, provided the cooling rate above this temperature was sufficiently rapid.

All of the specimens used in the work described here were quenched in a quantity of water large enough with respect to the mass of the specimen so that no significant temperature increase occurred in the water. With the small specimens used (½ by ½ by 0.04 in.) it can be shown by calculation that the temperature gradients in the specimens

² H. J. French and O. Z. Klopsch, *Quenching diagrams for carbon steels in relation to some quenching media for heat treatment*. Trans. Am. Soc. Steel Treating 6, 251 (1924).

³ T. G. Digges, *Influence of austenitic grain size on the critical cooling rate of high-purity iron-carbon alloys*. J. Research NBS 24, 723 (1940) RP1308.

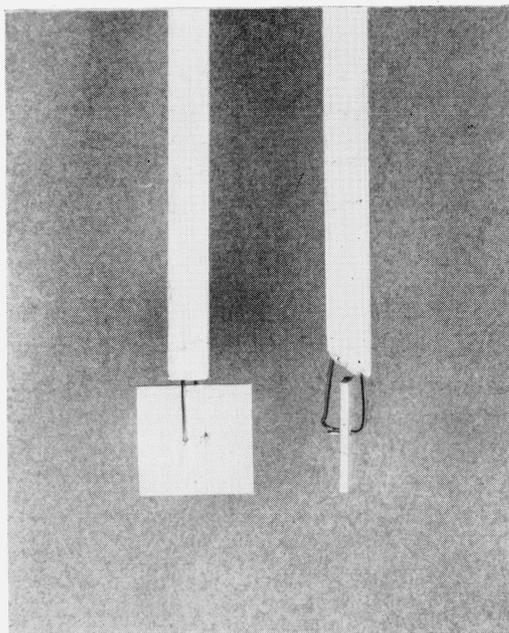


FIGURE 1.—Arrangement of thermocouple wires on specimen during heating and cooling cycle.

Wires serve as support for specimen in furnace and in quenching bath. $\times 1$.

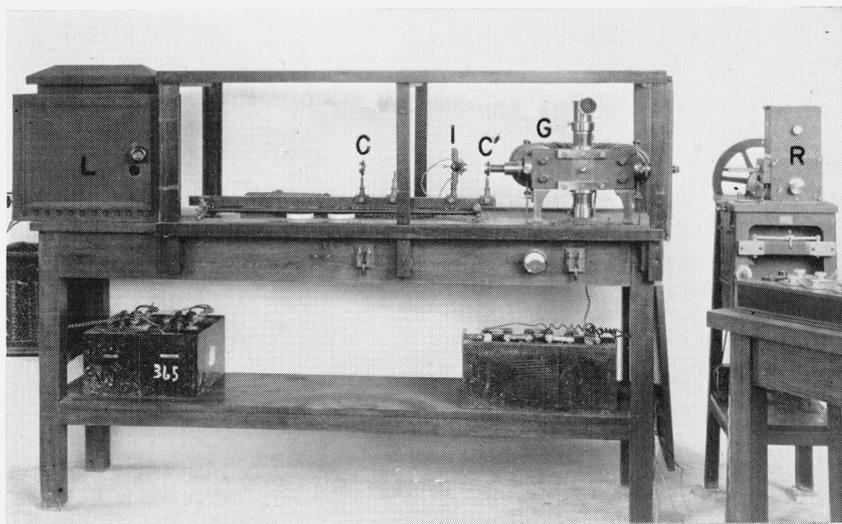


FIGURE 2.—Einthoven string galvanometer and photographic recorder.

G, galvanometer with "string" mounted in the large vertical tube. *C-C'*, lens system for light beam from *L*. *I*, sector disk interrupting the light beam to establish time intervals. *R*, camera containing moving strip of photographic paper.

were not great enough to make any significant difference between the cooling rate of the interior of the specimen and that at the sides, where the thermocouple wires were attached.

3. CORROSION TESTS

To determine the differences in corrosive attack on the alloy cooled at different rates, the specimens, after aging at room temperature, were immersed for 48 hours in a water solution containing 57 g of NaCl and 100 ml of H_2O_2 (3-percent solution) per liter. The solution was renewed after the first 24-hour period. The kind and extent of the corrosion damage were observed by metallographic examination of cross sections of the corroded specimens. Although the severity of the corrosion obtained in a laboratory test of this kind cannot be correlated with that obtained in service for any given length of time, the test is considered reliable to show whether or not the material is susceptible to intercrystalline corrosion in a severely corrosive environment.

III. RESULTS

1. EFFECT OF COOLING RATE UPON SUSCEPTIBILITY TO INTER-CRYSTALLINE CORROSION

The unprotected 24S alloy in any condition was severely corroded during 48 hours' immersion in the oxidizing salt solution. The corrosion obtained on the various specimens was divided into three general classes, namely: (1) pitting; (2) pitting and traces of intercrystalline corrosion; (3) severe intercrystalline corrosion. The type of corrosion obtained with any particular specimen depended primarily upon the cooling rate and the copper content of the alloy. The results obtained on the specimens investigated are given in table 2 and figure 3.

TABLE 2.—Cooling rates obtained on specimens of 24S aluminum alloy sheet and corresponding types of corrosion

Copper content	Range of cooling rates	Quenching water temperature	Number of specimens	Number of specimens susceptible to—		
				Pitting corrosion only	Pitting and traces of intercrystalline corrosion	Severe intercrystalline corrosion
%	°C/sec	°C				
4.05	815 to 1,325	83 to 86	12	12	0	0
4.27	935 to 10,000	22 to 87	13	13	0	0
4.64	1,110 to 1,645	80 to 83	4	4	0	0
4.05	540 to 785	85 to 87	8	5	3	0
4.27	585 to 875	84 to 90	13	6	7	0
4.64	690 to 1,090	83 to 86	11	7	4	0
4.05	305 to 525	84 to 93	12	0	10	2
4.27	305 to 545	85 to 91	10	0	8	2
4.64	405 to 670	84 to 91	11	0	8	3
4.05	145 to 260	93 to 95	4	0	0	4
4.27	95 to 300	90 to 98	12	0	0	12
4.64	120 to 395	85 to 99	4	0	0	4

On specimens quenched at rates greater than those represented by curve A, figure 3 (815° to 1,110° C/sec), only the pitting type of attack

was obtained with no intercrystalline penetration from the bottoms of the pits. This type of corrosive attack is illustrated in figure 4, *A* and *B*, showing cross sections of corroded sheet.

Severe intercrystalline corrosion was obtained on the specimens cooled at rates falling on or below curve *C*, figure 3. Typical examples are shown in figure 4, *E* and *F*. The corrosive attack was very severe at the grain boundaries and resulted in a general loss of cohesion, with entire grains or crystals dropping away from the main body of the

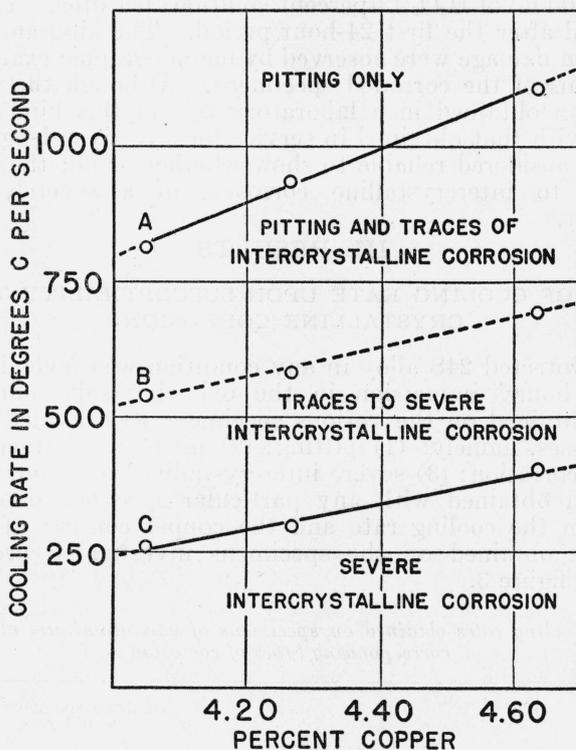


FIGURE 3.—Type of corrosion obtained on 24S alloy sheet of different copper contents quenched at different rates.

Specimens cooled at rates above curve *A* were immune to intercrystalline corrosion; rates between curves *A* and *B* made specimens susceptible to pitting or to pitting with traces of intercrystalline corrosion; specimens cooled at rates below curve *B* were susceptible to intercrystalline corrosion in some degree, and at rates below curve *C*, to severe intercrystalline attack.

material. The cooling rates on or below curve *C* (260° to 395° C/sec) all of which produced the condition resulting in severe intercrystalline attack, were obtained by quenching the specimens in water near the boiling point. Cooling rates obtained by allowing the specimens to cool from the solution temperature in still air, or in the air blast from a fan (velocity 900 to 1,200 ft/min), were 5° to 12° C/sec. These specimens also were susceptible to very severe intercrystalline corrosion.

There was a gradual change from pitting to the predominantly intercrystalline type of corrosion in the specimens of the three compositions of table 1, as the cooling rates were decreased from the values on or above curve *A* to those on or below curve *C*, figure 3.

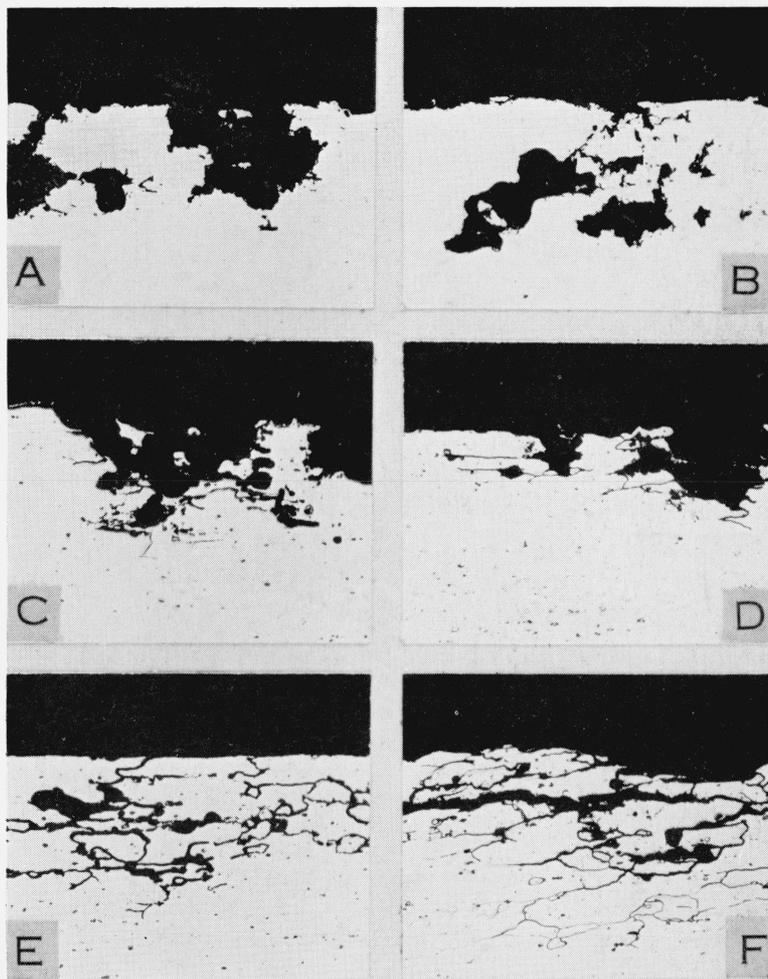


FIGURE 4.—Cross sections of specimens of 24S aluminum alloy sheet showing penetration of corrosion from the exposed surfaces of the sheet, after immersion in the $\text{NaCl} + \text{H}_2\text{O}_2$ solution.

A and B, pitting attack; C and D, traces of intercrystalline corrosion at the bottoms of pits; E and F, severe intercrystalline corrosion. Unetched. $\times 100$.

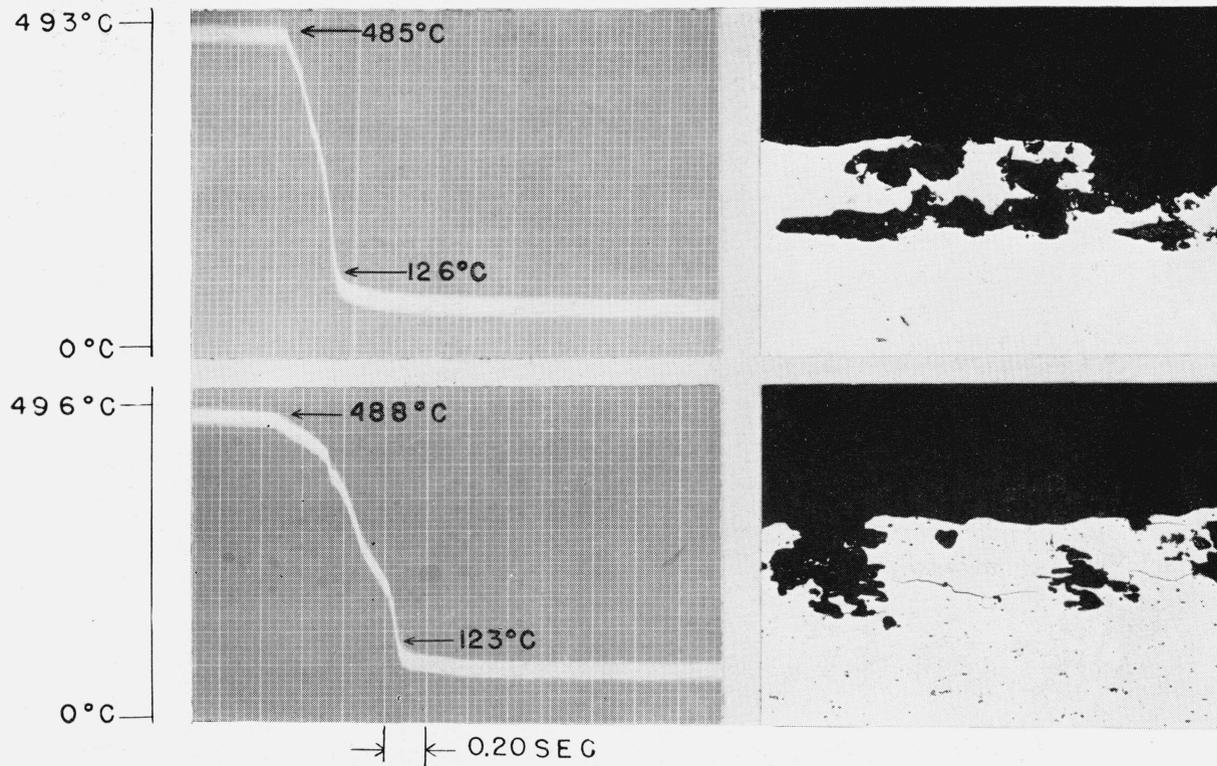


FIGURE 5.—Typical cooling curves and the kind of corrosion obtained on the 24S alloy sheet in oxidizing salt solution.

Upper curve, cooling rate 1,330° C/sec, between 485° and 126° C; temperature of quenching bath, 80° C; pitting corrosion. Lower curve, cooling rate 600° C/sec, between 488° and 123° C; temperature of quenching bath, 90° C; pitting with traces of intercrystalline attack. Photomicrographs show sections normal to corroded surface. Unetched. $\times 85$.

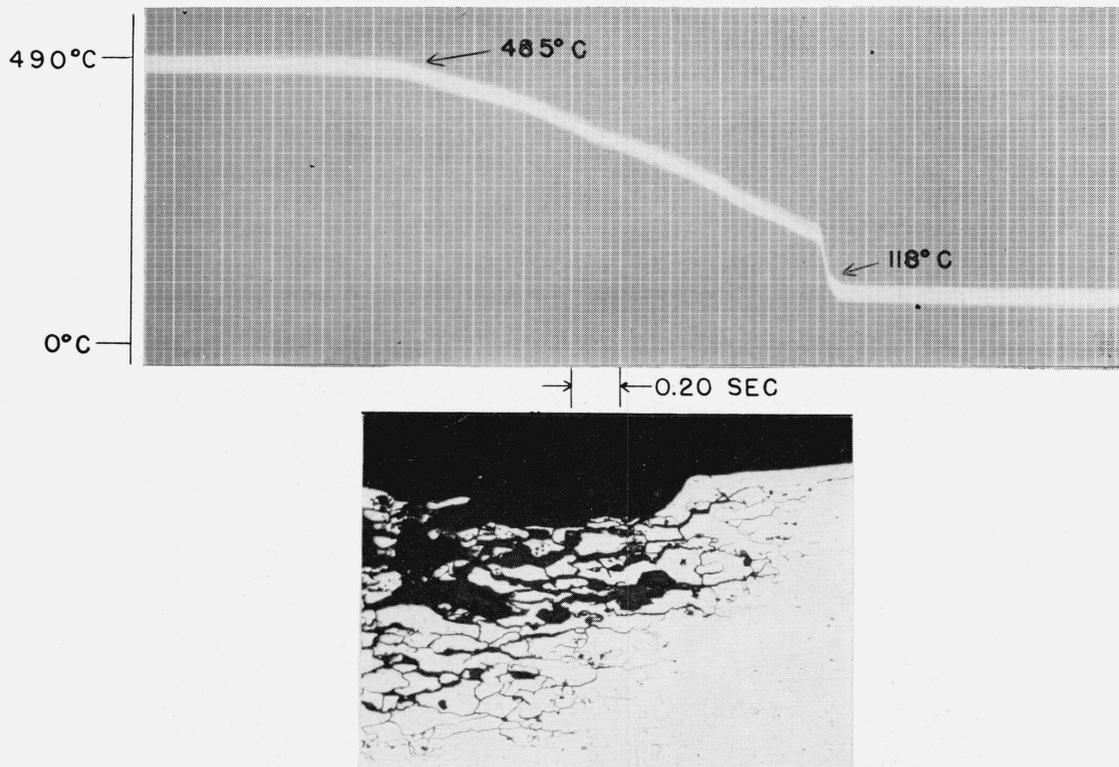


FIGURE 6.—Typical cooling curves and the kind of corrosion obtained on the 24S alloy sheet in oxidizing salt solution. Cooling rate 205° C/sec, between 485° C and 118° C. Temperature of quenching bath, 97° C. Severe intercrystalline corrosion. Photomicrograph shows section normal to corroded surface. Unetched. $\times 85$.

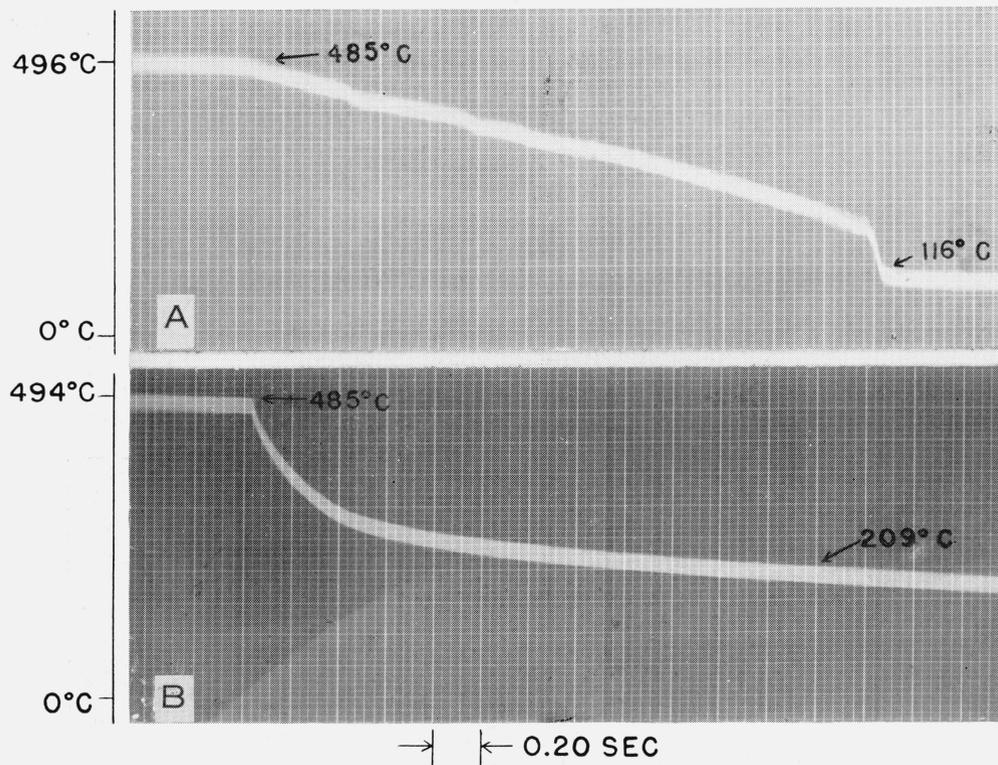


FIGURE 7.—Cooling curves obtained by quenching in water and in oil, at 98° C.

Lack of inflections in oil-quench curve B indicate that inflections in water-quench curve A were caused by formation and rupturing of steam layer on surface of specimen in water.

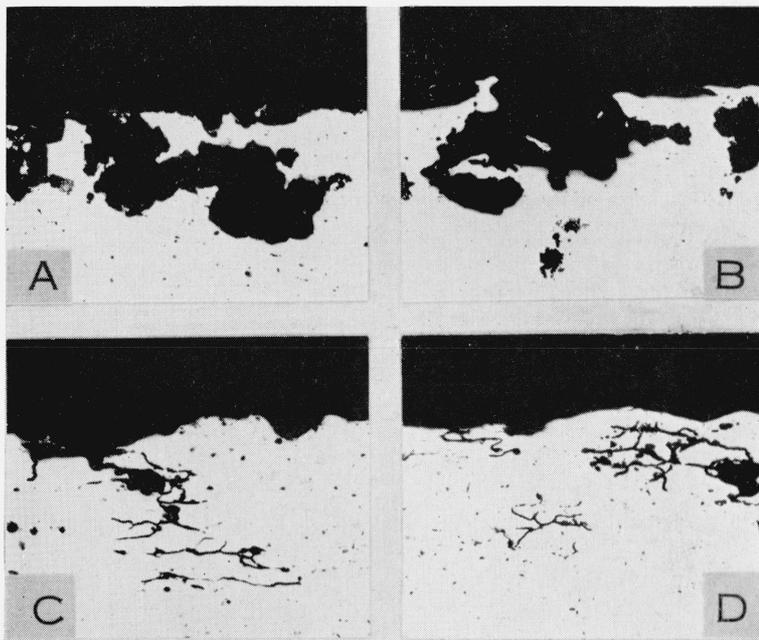


FIGURE 8.—*Type of corrosion of 24S alloy quenched in water after an intermediate air cooling following withdrawal from the furnace.*

Photomicrographs show sections normal to corroded surfaces. Unetched. $\times 100$.

A, quenched from 405°C in water at 44°C ; cooling rate $5,950^{\circ}\text{C}/\text{sec}$; pitting only. *B*, quenched from 400°C in water at 21°C ; cooling rate $4,700^{\circ}\text{C}/\text{sec}$; pitting only. *C*, quenched from 398°C in water at 25°C ; cooling rate $9,500^{\circ}\text{C}/\text{sec}$; pitting with traces of intercrystalline corrosion. *D*, quenched from 394°C in water at 43°C ; cooling rate $5,500^{\circ}\text{C}/\text{sec}$; severe intercrystalline corrosion.

For the cooling rates lying between curves *A* and *B*, the corrosion was predominantly pitting, with occasional specimens having traces of intercrystalline corrosion at the bottoms of the pits, as illustrated in figure 4, *C* and *D*. For the cooling rates lying between curves *B* and *C*, figure 3, all of the specimens contained some intercrystalline corrosion, the attack varying from traces at the bottoms of pits, as shown by *C* and *D*, figure 4, to the generally severe intercrystalline attack, such as is shown in *E* and *F*, figure 4.

It should be pointed out that there is no sharp line of demarcation between cooling rates that give one type of corrosion and another. For example, on certain specimens there were no traces of intercrystalline corrosion for cooling rates as low as curve *B*, figure 3, and on others there were traces of intercrystalline corrosion for cooling rates as high as those lying on curve *A*. The results obtained indicate that the minimum cooling rates which render the materials immune to intercrystalline corrosion lie along curve *A*.

Shown with the cooling curves, figures 5 and 6, are examples of the kinds of corrosion found on the heat-treated specimens after immersion in the oxidizing salt solution. The upper cooling curve in figure 5 was obtained on a specimen of the 24S alloy containing 4.27 percent of copper, quenched at a rate of 1,330° C/sec. This rate is well above curve *A*, figure 3, and the specimen immersed for 48 hours in the oxidizing salt solution was pitted, with no traces of intercrystalline corrosion.

The lower cooling curve in figure 5 was obtained on a similar specimen (4.27 percent of copper) quenched at a rate of 600° C/sec, which is just above curve *B*, figure 3. The corroded specimen, as shown by the photomicrograph, was pitted, with slight intercrystalline attack extending from the bottoms of the pits.

The curve shown in figure 6, was obtained on a specimen quenched at an average rate of 205° C/sec, a rate well below curve *C*, figure 3. Severe intercrystalline corrosion, as shown, was obtained on the specimen in the oxidizing salt solution.

The cooling curve of a specimen quenched in oil, heated to 98° C, was smooth compared with the one obtained by quenching in water at the same temperature, as is shown in figure 7. Smooth cooling curves were also obtained by cooling specimens in still air and in the blast from an electric fan. Lack of inflections in the curves from the oil and air quenches was interpreted as indicating that the inflections obtained in the curves for the specimens quenched in hot water, figures 5 and 6, were not caused by phase changes in the alloy, but could be attributed to the formation and rupturing of insulating layers of steam on the surfaces of the specimens in the water.

2. DELAYED QUENCHING

In any heat-treatment process, some time is necessarily consumed in transferring the material from the furnace or heating bath to the quenching bath. During this interval the specimens of aluminum alloy used in this investigation cooled at a rate of approximately 10° C/sec while exposed to the air. In handling these small specimens in laboratory equipment, the transfer from furnace to quenching bath was made in 1 second or less. In industrial operations in which a large quantity of material is handled at one time, the delay may be much longer, and before the material enters the quenching

bath, its temperature may fall considerably below that at which it was heat-treated. It was considered important to determine the effect upon the resistance to corrosion of the 24S alloy of varying the heat-treatment procedure by slowly cooling specimens to various temperatures before plunging them into the quenching bath.

Specimens of the three compositions given in table 1 were heated, with thermocouples attached (fig. 1), for 30 minutes at $493^{\circ} \pm 5^{\circ} \text{C}$, withdrawn from the furnace and permitted to cool to the temperatures given in table 3. They were then quenched in water, the temperature of which had been adjusted to give cooling rates in excess of $1,500^{\circ} \text{C}/\text{sec}$. After aging, the specimens were immersed in the sodium-chloride-hydrogen-peroxide solution to determine the kind of corrosive attack to which they were susceptible. The temperatures at the instant the specimens entered the quenching bath, and the cooling rates in the bath, were obtained from the cooling curves determined with the string-galvanometer apparatus.

TABLE 3.—*Character of corrosive attack in oxidizing salt solution on specimens of 24S alloy allowed to cool in still air after withdrawal from heating furnace, and then quenched at a rapid rate*

[All specimens given recommended solution heat treatment, 30 minutes, at $493^{\circ} \pm 5^{\circ} \text{C}$.]

4.05 percent of copper				4.27 percent of copper				4.64 percent of copper						
Quenched when cooled to		Cooling rate		Type of corrosion	Quenched when cooled to		Cooling rate		Type of corrosion	Quenched when cooled to		Cooling rate		Type of corrosion
$^{\circ} \text{C}$	$^{\circ} \text{C}/\text{sec}$	$\text{equiv } ^{\circ} \text{F}/\text{sec}$			$^{\circ} \text{C}$	$^{\circ} \text{C}/\text{sec}$	$\text{equiv } ^{\circ} \text{F}/\text{sec}$			$^{\circ} \text{C}$	$^{\circ} \text{C}/\text{sec}$	$\text{equiv } ^{\circ} \text{F}/\text{sec}$		
430	7,800	14,040		Pitting.	419	8,200	14,760		Pitting.	433	4,550	8,190		Pitting.
418	2,150	3,870		Do.	406	-----	-----		Do.	430	6,200	11,160		Do.
414	-----	-----		Do.	405	5,950	10,710		Do.	425	7,900	14,220		Do.
404	4,900	8,820		Do.	399	1,500	2,700		Do.	423	5,100	9,180		Do.
400	4,700	8,460		Do.						414	7,150	12,870		Do.
400	4,500	8,100		Do.						405	7,100	12,780		Do.
										405	5,550	9,990		Do.
396	4,500	8,100		Inter-crystalline.	398	9,500	17,100		Inter-crystalline.	402	3,100	5,580		Inter-crystalline.
379	8,400	15,120		Do.	397	7,600	13,680		Do.	400	7,400	13,320		Do.
375	4,100	7,380		Do.	397	4,650	8,370		Do.	395	7,250	13,050		Do.
					395	2,100	3,780		Do.	392	3,600	6,480		Do.
					394	5,500	9,900		Do.					
					358	5,600	10,080		Do.					

It was demonstrated in this manner (table 3) that 400°C is the minimum temperature at which the rapid cooling of the 24S alloy must begin, if it is to be immune to intercrystalline corrosion. If the specimens entered the quenching bath at temperatures lower than this, no matter how rapid the cooling rates, they were found susceptible to intercrystalline corrosion. Evidently during the time required to cool from the solution temperature to 400°C at the slow rate obtained in still air, the reaction that causes susceptibility to intercrystalline corrosion progresses sufficiently to retain this condition permanently, no matter how rapidly the alloy is cooled thereafter.

Figure 8 shows the change in the type of corrosive attack obtained in specimens of the 24S alloy containing 4.27 percent of copper, by starting the rapid quench after the specimens had cooled in still air from the solution temperature to temperatures just above and just below 400°C . These results indicated also that the minimum tem-

perature at which the rapid cooling must be started is more critical than the minimum cooling rate for the whole interval between the solution temperature and about 120° C.

IV. SUMMARY

1. A study was made of the susceptibility of 24S aluminum alloy sheet to intercrystalline corrosion when cooled from the solution temperature at different rates by quenching in water maintained at different temperatures. Sheets of the alloy, with copper contents of 4.05, 4.27, and 4.64 percent, were made available by the Aluminum Company of America for the study.

2. Temperatures throughout the cooling were determined from photographically recorded time-temperature curves obtained with a string galvanometer and thermocouples that were attached to the specimens. Susceptibility to intercrystalline corrosion was determined by metallographic examination of the heat-treated specimens after they had been immersed in a sodium-chloride-hydrogen-peroxide solution.

3. The rate at which a specimen of 24S alloy must be cooled in order to render it resistant to intercrystalline corrosive attack varies with the copper content of the material. Specimens of the alloy containing 4.64 percent of copper, cooled at rates greater than 1,100° C/sec, were subject to pitting corrosion only, with no traces of intercrystalline corrosion. Specimens of the same material cooled at rates less than 400° C/sec were severely attacked by intercrystalline corrosion in the salt solution. Specimens cooled at intermediate rates showed both pitting and the intercrystalline type of corrosion. Pitting predominated in the specimens cooled at rates approaching the higher one, and as the cooling rate approached the slower of the two above rates, the intercrystalline attack became more severe. Similar results obtained with specimens of 24S alloy having lower copper contents showed that the lower the copper content, the lower the cooling rate required to render the material immune to intercrystalline corrosion.

4. Specimens withdrawn from the heating furnace at the recommended solution temperature of 493° C and permitted to cool in air to a temperature not below 400° C could be quenched so as to be resistant to intercrystalline corrosion; but if they were permitted to cool below this temperature before they were plunged into the quenching bath, they were subject to intercrystalline corrosion in oxidizing salt solution, regardless of the rapidity of the cooling rate in the quenching bath.

WASHINGTON, November 15, 1940.