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DEVELOPMENT OF CAST ALUMINUM ALLOYS FOR ELEVATED-TEMPERATURE SERVICE

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Battelle Memorial Institute

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SUMMARY

An experimental investigation was conducted to develop an aluminum alloy for service at elevated temperatures. The development work was divided into three parts to determine: (1) The effects of heat treatment and exposure to elevated temperatures on the tensile properties of the various alloys subsequently cooled to room temperature; (2) the effect of various alloy additions on the room-temperature and elevated-temperature properties of aluminum, 6-percent-magnesium alloys; and (3) the improvement in high-temperature creep properties of some of the optimum compositions.

From the results of the investigation an experimental alloy that appeared to be optimum was found. The composition of this alloy and an approximate comparison of its properties with two commercial alloys are presented in tabular form.

INTRODUCTION

This report contains a brief review of the work done and the results obtained on the investigations leading to the development of an aluminum alloy for service at elevated temperatures. At the start of the investigation it was known that the aluminum alloys containing a substantial amount of magnesium have good high-temperature strength, but their thermal conductivities are lower than that of Y alloy. Because it was believed that the intended applications were of such a nature that heat dissipation would be a relatively unimportant factor, the object of the investigation was directed toward the development of an aluminum-magnesium alloy having mechanical properties substantially superior to other aluminum alloys now employed for service at elevated temperature.

More specifically, the object of the investigation was to develop an aluminum alloy with about 6 percent magnesium which has substantially better tensile properties than Alcoa 142, otherwise known as Y alloy, and having better resistance to creep at elevated temperatures than the existing commercial or known experimental aluminum-base alloys containing magnesium in substantial amounts.

This work was conducted at Battelle Memorial Institute under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics.

GENERAL PROCEDURE

An alloy of aluminum containing 6 percent magnesium was employed as a base material and the development work was divided into three major portions. The first portion of the alloy development was concerned with the effects of heat treatment and the effects of exposure to elevated temperatures on the tensile properties of the various alloys subsequently cooled to room temperature. This phase of the work was confined to aluminum alloys containing 6 percent magnesium with various combinations of manganese, nickel, and copper which were found to have fairly good room-temperature properties in preliminary investigations. The second portion of the experimental work dealt with investigations carried out in a systematic manner to determine the effect of various alloy additions on the room-temperature and elevated-temperature tensile properties of aluminum, 6-percent-magnesium alloys. This phase of the work was, of course, conducted simultaneously with the first portion, but a longer time was required. The second phase of the work resulted in the accumulation of a very large amount of data on the effects of the various alloy additions which led to the selection of certain optimum compositions.

With the information obtained in the second part of the investigation as a background, the third portion of the work was concerned with the improvement in the high-temperature creep properties of some of the optimum compositions as previously developed. Because of the large number of compositions for which creep data were desired, the creep tests were necessarily limited to durations of 100 to 150 hours. The use of such a short test period is not to be recommended except for a preliminary appraisal in order that the trend of effect of the various compositions on the creep properties may be indicated. The available time permitted a few tests for durations of about 500 hours on some alloys that were evidently the best among the many tested. In general, the longer tests did not change the indications obtained from the shorter tests, but tests of at least 500-hour duration for more of the alloys would make more certain the comparisons between the creep properties of the various compositions. In this phase of the program, it was necessary also to obtain tensile properties at room temperature and at 600° F in order to supplement the creep data.

EXPERIMENTAL WORK

One of the first difficulties encountered in the early development work with the 6-percent-magnesium alloys was the tendency of the alloy to react with the moisture in the green sand molds. The seriousness of this sand reaction varied from mold to mold but, in general, the surface unsoundness which resulted would entirely obviate any useful comparison of the properties of the sand-cast tensile bars of various compositions.

It was found that an addition of 0.005 percent beryllium, when added to the 6-percent-magnesium melt, would entirely eliminate this trouble from sand reaction. The amount of beryllium required is not critical, but it should not be much in excess of 0.005 percent. Otherwise, high beryllium content will produce a characteristic sand reaction with the green sand mold. These beryllium additions were made to all the melts by the employment of an aluminum-beryllium alloy containing 1 to 1.25 percent beryllium. When scrap was melted, no additional beryllium was required.

In order to avoid variations in grain size, a grain refiner was added to all the experimental compositions. It was found that titanium was very effective, and an addition of either 0.01 percent boron plus 0.02 percent titanium or 0.08 percent titanium alone was used for this purpose. Either of these additions resulted in consistently fine grain size, usually of the order of 0.01 to 0.02 inch.

In order to avoid variations in the cleanliness and gas content of the melt, all experimental melts were fluxed with chlorine for about 15 minutes, while the temperature was maintained between 1325° and 1350° F. This treatment invariably produced a high melt quality, and difficulties with pinhole porosity and variations attributable thereto were avoided. Furthermore, the aluminum-magnesium alloys have a tendency to contain dross. The treatment of the melt with chlorine facilitated removal of dross and also effected a good separation of the dross from the top of the melt before it was poured.

Although aluminum alloys containing 6 percent magnesium are not normally considered to be amenable to heat treatment, it was found that some of the compositions were very markedly improved by solution heat treatment. This was especially true of the aluminum, 6-percent-magnesium alloys containing copper without nickel. Furthermore, these benefits of the solution heat treatment were retained in the alloy after it was exposed for long periods at temperatures of 650° F. This effect is in contrast to the effect of exposure to high temperature on the room-temperature and elevated-temperature properties of Alcoa 142 alloy. It was also desirable to stabilize or substantially stabilize the castings prior to testing at 600° F. Consequently, shortly after the initial phases of the investigation, all experimental compositions were solution heat-treated for 16 hours at 810° F, quenched in cold water, and stabilized or aged for 24 hours at 650° F before testing them at room temperature or at 600° F. Many of the alloys were also tested in the as-cast or as-cast and aged conditions.

Except when complete data were required throughout a temperature range, all high-temperature tensile tests and creep tests were conducted at 600° F.

Alloy Additions Investigated

A total of 23 different metallic elements was added to various aluminum, 6-percent-magnesium base alloys to determine their effect upon the room-temperature tensile properties, the tensile properties at 600° F, and the creep properties at 600° F. Both tensile and creep properties at 600° F were not obtained for some of the alloys. These 23 elements are as follows:

Antimony
Beryllium
Boron
Cadmium
Calcium
Cerium
Chromium
Cobalt
Copper
Iron
Lithium
Magnesium
Manganese
Molybdenum
Nickel
Silicon
Silver
Titanium
Tungsten
Uranium
Vanadium
Zinc
Zirconium

The range in composition of each of these elements investigated, the various combinations of elements employed, the optimum content of each of the elements, and the room-temperature tensile properties of the optimum composition of each are indicated in tables 1 to 11. Because all sand castings tend to vary somewhat in their tensile properties from melt to melt, and even from test to test from the same melt, the more promising combinations were repeatedly prepared in order to establish firmly their effects. A total of 524 room-temperature tensile tests were made; usually two bars of each composition and occasionally even a larger number were tested.

Since a four-bar test casting was employed, two bars were available for room-temperature tests and two for high-temperature tensile tests. Nearly all the compositions listed in tables 1 to 11 were also subjected to a stabilizing treatment consisting of 24 hours at 650° F; after this treatment tensile properties were obtained at 600° F. On the basis of these tensile tests at room temperature and at 600° F, the effects of the principal alloying elements may be summarized as follows:

Effect of magnesium content.- Between the limits of 4 and 6 percent magnesium in the experimental alloys, very little difference was noted in the tensile strength at 600° F. In the heat-treated condition, the room-temperature properties are improved in alloys containing up to about 11 percent magnesium. In the heat-treated and stabilized condition, however, 6 percent magnesium is the optimum content for maximum room-temperature tensile properties. At concentrations above 6 percent magnesium, the tensile strength at 600° F decreased rapidly, and precipitated aluminum-magnesium compound could be noted at the grain boundaries.

Some tests were carried out with alloys containing 4, 5, and 6 percent magnesium; the alloys were otherwise similar since all contained 1.5 percent copper, 1 percent manganese, with grain refiner and beryllium additions. The effects of stabilization after 1, 4, and 10 days at 575° and 650° F were determined after solution heat treatment. The alloy with 4 percent magnesium showed no appreciable change in the room-temperature properties with increasing time at either of the stabilization temperatures. The 5-percent-magnesium alloy showed a slight gain in ultimate strength at room temperature after all stabilizing treatments extending beyond the 24-hour period, but the yield strength was not affected. On the other hand, the 6-percent-magnesium alloys showed a slight decrease in ultimate strength and hardness after all stabilizing treatments which were prolonged beyond the 24-hour period. This adverse effect of prolonged heating at 575° or 650° F was slight and it indicates that, in general, the alloys containing up to 6 percent magnesium are structurally stable in this temperature range. This is in marked contrast to heat-treated Alcoa 142 or Y composition which undergoes structural changes with exposures to these temperatures, with a consequent decrease in tensile, yield, and hardness values.

Effect of manganese content.- Manganese up to 1.5 percent can be tolerated in the 6-percent-magnesium alloys, and the optimum content of approximately 1 percent is a very desirable addition. However, an aluminum alloy containing only 6 percent magnesium and 1 percent manganese has rather poor ductility at 600° F because of the large amount of cracking which occurs under tension with relatively little elongation.

Effect of copper content.- Copper added to an aluminum-base alloy containing 6 percent magnesium and 1 percent manganese improves the ductility at both room temperature and at high temperature, particularly since the cracking which occurs in tensile bars broken at 600° F is substantially eliminated by the copper addition. In place of the numerous small cracks, uniform elongation and considerable necking down at the fracture occur. The alloy containing the copper is also subject to marked improvement by a solution heat treatment, followed by an aging or stabilizing treatment consisting of 24 hours at 650° F. As a result, the optimum copper addition of 1.5 percent produces a marked improvement in the room-temperature tensile properties of the solution heat-treated and stabilized alloy.

Effect of nickel content.- Nickel may be substituted for copper either alone or combined with iron. About 2 percent nickel with 1 percent iron, or 1 percent nickel with normal iron content as an impurity, appears to be the optimum composition for the aluminum-magnesium-nickel alloys. The room-temperature tensile properties of these alloys are not improved by heat treatment, and are moderately low. The aluminum, 6-percent-magnesium, 1-percent-manganese, 2-percent-nickel, 1-percent-iron alloy, however, has good tensile properties at 600° F.

Effect of copper and nickel content.- Copper and nickel together in most proportions appear inferior to either alone. The best proportions of copper and nickel were found to be 1.5 percent nickel and 0.5 percent copper, corresponding to Alcoa 254, or the reverse of these proportions. Both of these alloys, containing either 1.5 percent nickel and 0.5 percent copper, or 0.5 percent nickel and 1.5 percent copper, can be improved somewhat by a solution heat treatment, but to a much lesser extent than the experimental alloy with 1.5 percent copper without nickel.

Effect of titanium content.- Titanium is a very potent grain refiner for the alloys of the type being investigated. Approximately 0.02 percent titanium is sufficient to obtain consistent grain refinement but the effectiveness increases with increasing titanium content up to about 0.15 percent. About 0.2 percent titanium appeared to be mildly beneficial to the room-temperature properties but amounts up to 0.4 percent titanium apparently have no additional beneficial effect on the tensile strength at room temperature or at 600° F.

Effect of boron content.- Boron in conjunction with titanium is quite useful as a grain-refining constituent. Good grain refinement, however, can be obtained in the aluminum, 6-percent-magnesium alloys with titanium alone. Furthermore, probably no beneficial effects on conductivity would be obtained by using a low-boron, low-titanium combination in place of 0.10 percent titanium.

Effect of beryllium content.- As pointed out earlier in this report, beryllium is an essential component of these alloys when they are to be cast in ordinary foundry green sand. The use of 0.005 percent beryllium apparently eliminates sand reaction entirely, thereby considerably improving the foundry characteristics of this type of alloy.

Optimum Compositions

On the basis of the tensile properties of the various compositions at room temperature and at 600° F, the following five alloys were selected as being worthy of consideration for further development:

Alloy	Mg (percent)	Mn (percent)	Cu (percent)	Ni (percent)	Ti (percent)	Be (percent)	Fe (percent)
1	6	1	1.5	0	0.08	0.005	---
2	6	1	---	1	.08	.005	---
3	6	1	---	2	.08	.005	1.0
4	6	1	1.5	.5	.08	.005	---
5	6	1	.5	1.5	.08	.005	---

Most of these alloys were prepared from 99.7 percent aluminum. The first of these was considered to have the greatest possibilities. After a solution heat treatment and a stabilization treatment consisting of 24 hours at 650° F, this alloy would consistently show the following mechanical properties:

Property	Room temperature	600° F
Tensile strength, psi	35,000	13,000
Yield strength, psi	24,500	10,000
Elongation, percent in 2 in.	2.5	20
Brinell hardness number	80	------

After complete stabilization or, at least, after 480 hours at 650° F prior to testing at 600° F, the tensile strength and yield values obtained at 600° F would not drop more than 1000 pounds per square inch from the above values. As indicated later, substantial improvements have been made in this composition by suitable additions.

Alloy 2 did not respond to solution heat treatment and, as a result, the room-temperature tensile properties were substantially lower and the tensile properties at 600° F were slightly superior to those obtained on alloy 1.

Alloy 3 had relatively poor yield strength at room temperature but, nevertheless, had slightly the highest yield strength at 600° F of any of the other alloys. This composition did not respond to solution heat treatment and, as a result, the room-temperature tensile properties were relatively low.

The composition of alloy 4 is similar to Alcoa 254 composition, except that a grain refiner has been added and beryllium has been added to eliminate sand reaction, thereby improving the foundry characteristics when green sand molds are used. In general, then, the first of the five alloys listed has the best room-temperature properties and the best properties at all temperatures up to and including 500° F. The other four alloys have similar properties at all temperatures and all five alloys have similar tensile properties at 600° F. Alloy 3, however, has slightly the lowest room-temperature properties and slightly the highest tensile properties at 600° F.

Because of the higher tensile properties obtained by alloy 1 at room temperature, the main emphasis on further development was placed on this composition. Some emphasis was also placed on alloy 2.

Improvement in Resistance to Creep at Elevated Temperatures

The existing data and the data obtained in the short-time creep tests performed on this project definitely indicate that the aluminum, 6-percent-magnesium alloys of the Alcoa 254 type have poor resistance to creep at 600° F. Of the five compositions listed which appeared to have some promise, alloys 1 and 2 were subjected to further development in order to improve their tensile properties at room temperature and at 600° F, as well as to improve considerably their resistance to creep at 600° F. Accordingly, the third phase of the experimental program, described previously, was initiated and the effects of many minor elements and combinations of minor elements were investigated in an effort to improve the creep properties.

The short-time creep tests, previously described, were made on experimental alloy compositions, and on Alcoa 142 and Alcoa 254, for purposes of comparison. These short-time tests were carried out at 600° F, using a load of 1300 pounds per square inch for periods generally up to 100 to 150 hours, though some tests were continued for longer periods. The bulk of this work was done by using as base materials alloy 1 containing 6 percent magnesium, 1 percent manganese, 1.5 percent copper, with added grain refiner and beryllium, and alloy 2 containing 6 percent magnesium, 1 percent nickel, and 1 percent manganese. It was, of course, necessary also to obtain tensile properties at room temperature and at 600° F. The entire series of experimental compositions prepared for creep testing is included in table 12. This table shows the heat number, the intended composition of the alloy, the tensile properties at room temperature, the maximum grain size, the tensile properties at 600° F, and some data on the creep properties at 600° F employing a load of 1300 pounds per square inch. A number of elements were found to have beneficial effects on the creep properties of the two base compositions.

Typical time-deformation curves for the creep tests run at 600° F and 1300 pounds per square inch are shown in figure 1. The relative merits of Alcoa 142, Alcoa 254, and an experimental alloy are graphically shown. This figure also shows the beneficial effects on the rate of deformation obtained by the use of various amounts of zirconium in a base alloy containing 6 percent magnesium, 1.5 percent copper, 1 percent manganese, with the usual amounts of grain refiner and beryllium. Figure 2 is a graphical representation of the more important creep data listed in table 12. This figure shows the minimum creep rate and the total deformation at 100 hours obtained on alloys of various compositions.

Zirconium in amounts from 0.05 to 0.25 percent increases the resistance of the base alloy to creep and tends to increase the room-temperature strength unless the grain size also increases. If a grain-size increase occurs with the addition of 0.02 percent titanium, grain refinement may often be restored by increasing the titanium content to 0.08 percent. Titanium, in conjunction with zirconium, appears to have a slight tendency to decrease the resistance to creep at 600° F. Vanadium additions of 0.1 percent in combination with 0.25 percent zirconium produce excellent room-temperature properties, good high-temperature properties, and excellent resistance to creep. Vanadium in greater amounts appeared to have a favorable effect on the high-temperature tensile strength but somewhat decreased the room-temperature tensile strength.

It is emphasized that limited time has not permitted so complete an evaluation of the creep properties of these alloys as may be desirable. Since the creep tests on the experimental alloys were run at one stress and one temperature only, additional tests of at least 500 hours on the better alloys should be run over a range of stresses at 600° F and possibly also at several other temperatures of interest.

Tensile Properties of Stabilized British and Other Alloys

During the course of the high-temperature tensile testing, specimens of alloys for elevated-temperature service developed by the Royal Aircraft Establishment were received for testing. Two alloys were received, each in the wrought and chill-cast condition. Specimens of these four alloys, in addition to Alcoa 142, Alcoa 254, and an experimental alloy containing 6 percent magnesium, 1.5 percent copper, and 1 percent manganese, with grain refiners and beryllium, were stabilized as follows:

For test at	Stabilizing treatment
Room temperature	None
400° F	480 hr at 575° F
500° F	480 hr at 575° F
600° F	480 hr at 650° F
700° F	96 hr at 700° F

Previous to these stabilization treatments, other specimens of the alloys were prepared as follows and tested in the indicated condition at room temperature:

Alloy	Condition
RAE alloys	As received
Alcoa 142	Heat-treated and aged
Alcoa 254	Aged 8 hr at 400° F
Experimental alloy	Heat-treated and stabilized 24 hr at 650° F

The compositions of the various alloys are listed in table 13. The results obtained on these compositions are listed in table 14 and are graphically represented by figures 3, 4, and 5.

It should be noted that the experimental cast alloy compared favorably with the other two sand-cast compositions, Alcoa 142 and 254, and even with the chill-cast British alloys. This experimental alloy, however, is not the optimum composition which was later developed, since the experimental composition did not contain zirconium or vanadium. If the experimental alloy had contained 0.1 percent vanadium and 0.25 percent zirconium, both the tensile properties at room temperature and at 600° F would be slightly superior to those shown in figures 3, 4, and 5.

SUMMARY OF RESULTS

On the basis of the experimental work conducted on an aluminum-base sand-cast alloy for elevated-temperature service, the following composition appears to be optimum:

Element	Addition (percent)
Magnesium	6
Manganese	1
Copper	1.5
Vanadium	.1
Zirconium	.25
Titanium	.08
Beryllium	.005
Aluminum (99.5 percent)	Balance

The following table shows the approximate comparative properties of this experimental alloy with Alcoa 142 (heat-treated and aged) and Alcoa 254 alloys which have been stabilized at 650° F for 20 days.

Property	Alloy		
	Alcoa 142-HTA[a]	Alcoa 254-T2[a]	Experimental alloy-HTS[a]
Tensile strength at room temperature, psi	26,000	26,000	[b]35,000
Yield strength at room temperature, psi	15,600	25,000	[b]25,000
Elongation at room temperature, percent in 2 in.	2.0	2.0	[b]3.0
Brinell hardness number at room temperature	62	84	[b]86
Tensile strength at 600° F, psi	8900	12,750	[b]12,750
Yield strength at 600° F, 0.2 percent offset, psi	5800	10,000	[b]10,000
Elongation at 600° F, percent in 2 in.	16	20	[b]40
Minimum creep rate at 600° F, 150-hr test[c]	0.00014	0.00075	0.00005
Total deformation at end of 100 hr, percent	[d]0.045	[d]0.123	[d]0.045
Estimated thermal conductivity, C.G.S. units[e]	0.33	0.22	0.22
Resistance to corrosion[e]	Fair	Good	Good
General foundry characteristics[e]	Good	Difficult	Fair

[a] Stabilized at 650° F, for 20 days prior to test at room temperature or at 600° F.

[b] Estimated properties after stabilizing 20 days at 650° F on the basis of properties after 24 hr at 650° F.

[c] Stabilized only 24 hr at 650° F prior to test and load of 1300 psi employed at 600° F in short-time creep test.

[d] Includes elastic deformation.

[e] Estimated, not measured on this project.

Battelle Memorial Institute
Columbus, Ohio, May 1, 1946

TABLE 1.- RANGE IN ALLOY CONTENT INVESTIGATED, OPTIMUM VALUE, AND ROOM-TEMPERATURE PROPERTIES OBTAINED ON BASE ALLOY OF ALUMINUM CONTAINING 6 PERCENT MAGNESIUM

Added element[1]	Addition (percent)			Optimum property	
	Maximum	Minimum	Optimum	Tensile strength (psi)	Elongation (percent)
None, ac				30,100	6.0
Cerium, ac	5.0	0	0	------	---
Manganese, HTS	1.5	.05	1.0	33,800	3.4
Cobalt, ac	.75	0	.25	32,800	8.8
Copper, ac	13.0	0	12.0	37,000	.6
Copper, HTS	13.0	0	6.0	36,500	1.0
Antimony, ac	2.0	0	.5	33,000	8.8
Nickel, ac	2.5	0	0	------	---
Zinc, ac	5.0	0	0	------	---

[1] ac, as cast; HTS, solution heat-treated and stabilized.

TABLE 2.- RANGE IN MAGNESIUM CONTENT INVESTIGATED, OPTIMUM VALUE, AND ROOM-TEMPERATURE PROPERTIES OBTAINED ON ALUMINUM-BASE ALLOY CONTAINING 1 PERCENT MANGANESE

Added element	Addition (percent)			Optimum property	
	Maximum	Minimum	Optimum	Tensile strength (psi)	Elongation (percent)
Magnesium, HTS[1]	10.0	2.0	6.0	32,800	2.8

[1] After solution heat treatment and 6 hours' stabilization at 650° F.

TABLE 3.- RANGE IN ALLOY CONTENT INVESTIGATED, OPTIMUM VALUE, AND ROOM-TEMPERATURE TENSILE PROPERTIES OBTAINED ON ALUMINUM-BASE, 6-PERCENT-MAGNESIUM, 1-PERCENT-MANGANESE ALLOY

Added element[1]	Addition (percent)			Optimum property	
	Maximum	Minimum	Optimum	Tensile strength (psi)	Elongation (percent)
Titanium, ac	0.20	0	0.20	34,700	5.0
Copper, ac	3.0	0	0	------	---
Copper, acS	3.0	0	2.5	31,650	---
Copper, HTS[2]	5.0	0	1.5	37,000	2.8
Copper, HTA	3.0	0	1.5	38,700	2.0
Nickel, ac	3.0	0	0	30,900	4.0
Silver, HTS	4.0	.5	.5	28,100	2.0

[1] ac, as cast; acS, as cast and stabilized 24 hr at 650° F;
HTS, solution heat-treated and stabilized 24 hr at 650° F;
HTA, solution heat-treated and aged.

[2] Average of 16 tensile bars from eight heats.

TABLE 4.- RANGE IN ALLOY CONTENT INVESTIGATED, OPTIMUM VALUE, AND ROOM-TEMPERATURE TENSILE PROPERTIES OBTAINED ON ALUMINUM, 6-PERCENT-MAGNESIUM ALLOY CONTAINING IRON, NICKEL, AND MANGANESE

Added element[1]	Addition (percent)			Optimum property	
	Maximum	Minimum	Optimum	Tensile strength (psi)	Elongation (percent)
Base alloy: 6 percent Mg, 2 percent Ni, plus grain refiners					
None, ac				27,900	2.0
Iron, ac	1.0	0	1.0	29,750	1.5
Base alloy: 6 percent Mg, 1 percent Fe, plus grain refiners					
Nickel, ac	2.0	0.5	1.5	30,800	2.5
Base alloy: 6 percent Mg, 1.5 percent Ni, 1 percent Fe, plus grain refiners					
Manganese, ac	0.75	0	0.25	32,900	2.0
Base alloy: 6 percent Mg, 2 percent Ni, 1 percent Fe, 1 percent Mn, plus grain refiners					
None, HTS				29,900	1.4
Zirconium, HTS	0.1	0.1		26,900	1.7

[1] ac, as cast; HTS, solution heat-treated and stabilized 24 hr at 650° F.

TABLE 5.- RANGE IN IRON AND NICKEL CONTENT INVESTIGATED, OPTIMUM VALUE, AND ROOM-TEMPERATURE TENSILE PROPERTIES OF ALUMINUM-BASE ALLOY CONTAINING 5 PERCENT MAGNESIUM

	Addition (percent)			Optimum property	
Added element[1]	Maximum	Minimum	Optimum	Tensile strength (psi)	Elongation (percent)
Base alloy: 5.0 percent Mg, 0.1 percent Si, 0.03 percent Ti, 0.01 percent B, 0.05 percent Mn, 0.005 percent Be, balance Al					
Iron, ac	4.11	0.32	1.0	32,375	8.2
Base alloy: 5.0 percent Mg, 2.5 percent Fe, 0.1 percent Si, 0.03 percent Ti, 0.01 percent B, 0.05 percent Mn, 0.005 percent Be, balance Al					
Nickel, ac	4.0	0	2.0 0	28,400 28,000	1.75 3.5

[1] ac, as cast.

TABLE 6.- RANGE IN ALLOY CONTENT INVESTIGATED, OPTIMUM VALUE, AND ROOM-TEMPERATURE TENSILE PROPERTIES OBTAINED ON ALUMINUM-BASE ALLOY CONTAINING 6 PERCENT MAGNESIUM, 1 PERCENT NICKEL, 1 PERCENT MANGANESE, PLUS GRAIN REFINERS

	Addition (percent)			Optimum property	
Added element[1]	Maximum	Minimum	Optimum	Tensile strength (psi)	Elongation (percent)
None, HTS				32,100	2.7
Copper, HTS	2.0	0	1.5	31,100	1.3
Iron, HTS	1.0	1.0		28,100	1.9
Cobalt, HTS	.75	0	.25 .75	30,900 31,750	2.0 1.7
Zirconium, HTS	.5	0	.5 .2	31,700 31,000	1.8 2.2
Cerium, HTS	1.0	0	None	------	---
Antimony, HTS	1.0	0	0	------	---
Chromium, HTS	.5	.25	None	------	---
Tungsten, HTS	1.0	.12	.12	29,400	2.0
Molybdenum	1.0	.12	.12	30,850	1.4

[1] HTS, solution heat-treated and stabilized 24 hr at 650° F.

TABLE 7.- EFFECT OF MINOR ADDITIONS OF TWO OR MORE ELEMENTS TO ALUMINUM-BASE ALLOY CONTAINING 6 PERCENT MAGNESIUM, 1 PERCENT NICKEL, 1 PERCENT MANGANESE, PLUS GRAIN REFINERS

Added elements[1]	Addition (percent)			Optimum property	
	Maximum	Minimum	Optimum	Tensile strength (psi)	Elongation (percent)
Base alloy: 6 percent Mg, 1 percent Ni, 1 percent Mn, 0.25 percent Zr, plus grain refiners					
Vanadium, HTS	0.4	0.1	0.1	27,700	1.7
Base alloy: 6 percent Mg, 1 percent Ni, 1 percent Mn, 0.5 percent Sb, plus grain refiners					
Zirconium, HTS	0.1	0.1		30,150	1.5
Tungsten, HTS	.1	.1		30,525	1.8
Molybdenum, HTS	.1	.1		28,450	2.0
Calcium, HTS	.1	.1		26,470	1.7
Base alloy: 6 percent Mg, 1 percent Ni, 1 percent Mn, 0.1 percent Zr, plus grain refiners					
Calcium, HTS	0.1	0.1		26,470	

[1] HTS, solution heat-treated and stabilized 24 hr at 650° F.

TABLE 8.- RANGE IN ALLOY CONTENT INVESTIGATED, OPTIMUM VALUE, AND ROOM-TEMPERATURE TENSILE PROPERTIES OBTAINED ON ALUMINUM-BASE ALLOY CONTAINING 6 PERCENT MAGNESIUM, 1.5 PERCENT COPPER, 1.5 PERCENT NICKEL, 1 PERCENT MANGANESE, PLUS GRAIN REFINERS

Added element[1]	Addition (percent)			Optimum property	
	Maximum	Minimum	Optimum	Tensile strength (psi)	Elongation (percent)
None, ac				29,000	1.6
None, acA				28,000	1.8
None, acS				29,370	1.4
None, HT				30,550	1.2
None, HTA				32,600	1.3
None, HTS				30,400	1.7
Chromium, HTS	0.5	0.25	None	------	---
Cobalt, HTS	1.0	0	.5	35,300	---
Antimony, HTS	.5	0	.25	29,850	1.2
Titanium, HTS	.4	.1	.20	29,900	---

[1] ac, as cast; acA, as cast and aged 8 hr at 400° F; acS, as cast and stabilized 24 hr at 650° F; HT, solution heat-treated; HTA, solution heat-treated and aged; HTS, solution heat-treated and stabilized 24 hr at 650° F.

TABLE 9.- RANGE IN ALLOY CONTENT INVESTIGATED, OPTIMUM VALUE, AND ROOM-TEMPERATURE TENSILE PROPERTIES OBTAINED ON ALUMINUM-BASE ALLOY CONTAINING 6 PERCENT MAGNESIUM, 1.5 PERCENT COPPER, 0.5 PERCENT NICKEL, PLUS GRAIN REFINERS

Added element[1]	Addition (percent)			Optimum property	
	Maximum	Minimum	Optimum	Tensile strength (psi)	Elongation (percent)
Silver, HTS	2.0	0.25	0.25	30,600	1.3
Zinc, HTS	1.0	0	.5	32,700	2.0
Silicon, HTS	1.0	0	.25	31,650	1.0
Cobalt, HTS	.5	.5		29,150	1.5
Antimony, HTS	.5	.5		31,800	2.0
Cerium	.5	.5		23,900	.5
Base alloy: 4 percent Mg, 1.5 percent Cu, 0.5 percent Ni, plus grain refiners					
Zinc, HTS	2.0	0	2.0	27,250	1.5

[1] HTS, a solution heat treatment and stabilization for 24 hr at 650° F.

TABLE 10.- RANGE IN ALLOY CONTENT INVESTIGATED, OPTIMUM VALUE, AND ROOM-TEMPERATURE TENSILE PROPERTIES OBTAINED ON ALUMINUM-BASE ALLOY CONTAINING 6 PERCENT MAGNESIUM, 1.5 PERCENT COPPER, 1 PERCENT MANGANESE

Added element[1]	Addition (percent)			Optimum property	
	Maximum	Minimum	Optimum	Tensile strength (psi)	Elongation (percent)
Nickel, HTS	2.5	0	0.5	35,000	3.0
Nickel, ac	2.0	0	0	------	---
Chromium, HTS	.5	.25	None	------	---
Chromium, ac	.5	.25	None	------	---
Cobalt, HTS	1.0	0	0	------	---
Cobalt, ac	1.0	0	0	------	---
Cerium, HTS	3.0	0	0	------	---
Antimony, HTS	.5	0	0	------	---
Molybdenum, HTS	.5	.25	.25	33,100	2.1
Zirconium, HTS	.2	.1	.1	39,200	2.4
Calcium, HTS	.5	.003	.06	38,800	2.9
Cadmium, HTS	2.0	.1	None	------	---
Zirconium, HTS	.5	0	.1	39,850	3.4
Lithium, HTS	1.0	0	0	------	---

[1] ac, as cast; HTS, solution heat-treated and stabilized 24 hr at 650° F.

TABLE 11.- EFFECTS OF MINOR ADDITIONS OF TWO OR MORE ELEMENTS TO ALUMINUM-BASE ALLOY CONTAINING 6 PERCENT MAGNESIUM, 1.5 PERCENT COPPER, 1 PERCENT MANGANESE, PLUS GRAIN REFINERS

Added element[1]	Addition (percent)			Optimum property	
	Maximum	Minimum	Optimum	Tensile strength (psi)	Elongation (percent)
Base alloy: 6 percent Mg, 1.5 percent Cu, 1 percent Mn, 0.25 percent Zr, plus grain refiners					
Vanadium, HTS	0.4	0.1	0.1	39,850	3.5
Chromium, HTS	.1	.1		33,700	2.0
Base alloy: 6 percent Mg, 1.5 percent Cu, 1 percent Mn, 0.1 percent Zr, plus grain refiners					
Antimony, HTS	0.5	0.5		30,450	2.0
Tungsten, HTS	.1	.1		40,100	3.7
Molybdenum, HTS	.1	.1		33,350	2.3
Calcium, HTS	.1	.1		38,500	3.1
Titanium, HTS	.15	.02	.02	38,550	4.0
Vanadium Calcium Cobalt Cerium	.05	.05		33,050	2.5
Base alloy: 6 percent Mg, 1.5 percent Cu, 1 percent Mn, .05 percent Ca, plus grain refiners					
Lithium	0.05	0.05		22,600	2.7

[1] HTS, solution heat treatment, followed by stabilization for 24 hr at 650° F.

TABLE 12.— TENSILE PROPERTIES OF SAND-CAST ALUMINUM ALLOYS

Heat number	Heat treatment (a)	Composition (percent by weight)								Properties at room temperature				Grain size (in.)	Properties at 600° F							
																			Creep tests – 1300 psi			
		Mg	Cu	Ni	Mn	Ti	B	Be	Other	Tensile strength (psi)	Yield strength (psi)	Elongation (percent)	Brinell hardness number		Tensile strength (psi) (b)	Yield strength (psi) (c)	Elongation (percent)	Reduction of area (percent)	Duration (hr)	Minimum creep rate (percent/hr)	Total deformation at 100 hours (percent)	Total deformation at completion of test (percent)
76	HTA	1.5	4.0	2.0		0.10				42,500	41,200	1.1	111	0.020								
76	HTAS	1.5	4.0	2.0		.10				26,350	11,410	3.2	60	.020	11,450	7,570	21.5	31	d 139 142	0.00010 .00018	0.045 .042	0.051 .050
185	HTA	1.5	4.0	2.0		.10				41,220	41,200	.6	117	.015								
185	HTAS	1.5	4.0	2.0		.10				24,970	13,920	2.1	62	.015	12,050	9,050	12	9.2				
74	acA	6.0	.5	1.5	1.0	.02	0.01	0.005		25,600	25,500	.8	84	.010								
74	acAS	6.0	.5	1.5	1.0	.02	.01	.005		26,600	21,700	1.6	83	.010	14,480	11,550	20	26	186	.00075	.123	.165
118	HTS	4.0	1.5	.5	1.0	.02	.01	.005		26,300	19,930	1.2	78	.010	13,250	11,440	58	50	144	.00023	.048	.062
119	HTS	5.0	1.5	.5	1.0	.02	.01	.005		26,850	22,680	1.1	80	.010	14,550	12,460	24.5	23	143	.00033	.054	.066
120	HTS	6.0	1.5	.5	1.0	.02	.01	.005		31,125	23,180	1.7	84	.010	13,180	10,890	25	24	142	.00040	.072	.085
129A	HTS	6.0	1.5	.5	1.0	.02	.01	.005	0.5 Co	29,150		1.5	80	.010	14,000	12,525	18.5	23	141	.00025	.048	.054
130A	HTS	6.0	1.5	.5	1.0	.02	.01	.005	.5 Sb	31,100	21,500	2.3	73	.05–.015	13,310	11,340	62.5	49.5	136	.00013	.050	.052
131A	HTS	6.0	1.5	.5	1.0	.02	.01	.005	.5 Ce	23,900		.5	74	.005	12,750	10,200	19.5	19	578	e.000075	.066	.105
78A	HTS	6.0	1.5		1.0	.08	.01	.005		35,300	24,550	2.6	84	.015	13,350	10,800	50.5	50	d 164 143	.00045 .00040	.074 .053	.107 .075
99A	HTS	6.0	1.5		1.0	.02	.01	.005	.1 Zr	36,000		3.1	83	.015	12,790	10,250	60	60	140	.00015	.060	.068
112A	HTS	6.0	1.5		1.0	.08	.01	.005	.1 Zr	36,310	25,050	2.7	85	.03–.05	13,590	10,420	52.5	53	504	e.000080	.050	.066
98A	HTS	6.0	1.5		1.0	.02	.01	.005	.2 Zr	33,600		2.3	76	.01–.03	12,660	9,960	23	20	118	.00027	.073	.079
111A	HTS	6.0	1.5		1.0	.02	.01	.005	.2 Zr	37,500		2.6	80	.020	14,660	11,640	56.5	54	144	.00013	.038	.039
147A	HTS	6.0	1.5		1.0	.08	.01	.005		33,100		1.7	82	.010	—	—	—	—	—	—	—	—
148A	HTS	6.0	1.5		1.0	.08	.01	.005	.05 Zr	37,680		2.7	83	.020	13,250	11,000	47.5	50.5	146	.00016	.050	.059
145B	HTS	6.0	1.5		1.0	.08	.01	.005	.1 Zr	39,850		3.4	82	.020	14,020	11,160	58	50.5	168	.00033	.071	.087
145C	HTS	6.0	1.5		1.0	.08	.01	.005	.25 Zr	36,500		2.7	83	.020	13,560	10,840	29.5	45	144	.00025	.040	.051
145D	HTS	6.0	1.5		1.0	.08	.01	.005	.5 Zr	36,400		2.4	83	.007	13,460	11,300	40	34	144	.00065	.140	.176
149A	HTS	6.0	1.5		1.0	.08	.01	.005	.25 Zr 0.1 V	38,720	25,300	3.3	87	.020	13,440	10,680	71	58.5	482	f.000032	.045	.078
g160A	HTS	6.0	1.5		1.0	.08	.01	.005	.25 Zr .25 V	33,550		1.9	83	.050	13,610	11,070	34	30	169	.00006	.031	.034
149B	HTS	6.0	1.5		1.0	.08	.02	.005	.25 Zr .4 V	32,490	24,000	2.1	81	.015	14,000	10,880	65.5	57.5	145	.00020	.035	.039
150A	HTS	6.0	1.5		1.0	.08	.01	.005	.25 Zr .1 Cr	32,470	24,920	2.2	78	.015	14,500	11,620	30.5	41	167	.00010	.042	.052
157A	HTS	6.0	1.5		1.0	.08	.01	.005	.1 Zr .5 Sb	30,450		2.0	79.6	.010	13,610	11,510	77.0	62.2	287	.00006	.040	.059
168A	HTS	6.0	1.5		1.0	.08	.01	.005	.1 Zr .1 V	37,300		2.7	83	.020	12,970	10,370	>102	>98	229	.00005	.030	.037
169A	HTS	6.0	1.5		1.0	.08	.01	.005	.1 Zr .1 W	40,100		3.7	85	.008	13,300	10,820	95.5	69	143	.00027	.078	.087
170A	HTS	6.0	1.5		1.0	.08	.01	.005	.1 Zr .1 Mo	33,350		2.3	84	.010	13,700	11,500	88	65.5	140	.00018	.062	.070
172A	HTS	6.0	1.5		1.0	.08	.01	.005	.1 Zr .1 Ca	38,500		3.1	84	.020	13,510	11,500	31	28	140	.00018	.052	.058
173A	HTS	6.0	1.5		1.0	.08	.01	.005	.1 Zr	38,550		4.0	81	.02–.03	12,860	10,880	79	66.5	140	.00008	.029	.033
173B	HTS	6.0	1.5		1.0	.08	.01	.005	.1 Zr	37,200		3.7	80	.010	13,280	11,360	67	61				
173C	HTS	6.0	1.5		1.0	.15	.01	.005	.1 Zr	37,070		3.8	78	.008	13,350	11,380	36	33				
139A	HTS	6.0	1.5		1.0	.08	.01	.005	.003 Ca	36,100		2.7	86	.015	12,800	12,100	60	60	166	.00025	.057	.080
138A	HTS	6.0	1.5		1.0	.02	.01	.005	.03 Ca	36,630		2.9	82	.015	13,500	10,670	53	51.5	136	.00023	.049	.057
137A	HTS	6.0	1.5		1.0	.08	.01	.005	.06 Ca	38,800		2.9	79	.015	12,710	10,650	67.5	54.5	211	.00022	.071	.094
136A	HTS	6.0	1.5		1.0	.08	.01	.005	.12 Ca	38,540	23,600	3.5	84	.03–.04	13,140	11,000	53	43.5	500	h.00007	.035	.065
135A	HTS	6.0	1.5		1.0	.08	.01	.005	.25 Ca	35,600		2.7	85	.020	12,690	11,550	44	42	503	i.00021	.035	.121
134A	HTS	6.0	1.5		1.0	.08	.01	.005	.5 Ca	28,080		1.5	76	.03–.04	—	—	—	—	—	—	—	—
179A	HTS	6.0	1.5		1.0	.08	.01	.005	.1 Ca .1 V	38,690		3.0	76	.020	13,140	11,390	62	63.5				

[a] HTA, heat-treated 6 hr at 960° F, quenched in boiling water, aged 8 hr at 400° F;
HTAS, same as HTA, plus 24 hr at 650° F;
acA, as-cast bars, aged 8 hr at 400° F;
acAS, same as acA, plus 24 hr at 650° F;
HTS, heat-treated 16 hr at 810° F, quenched in cold water, plus 24 hr at 650° F.

[b] All bars pulled at 0.01 in./in. gage length/min until 0.2-percent offset was passed. Rate was then increased to 0.03 in./in. gage length/min to rupture.

[c] Yield strength at 0.2-percent offset.

[d] Creep tests run in duplicate.

[e] Minimum creep rate up to 150 hr, 0.00020 percent/hr.

[f] Minimum creep rate up to 150 hr, 0.00005 percent/hr.

[g] Melt entirely produced from scrap metal.

[h] Minimum creep rate up to 150 hr, 0.00007 percent/hr.

[i] Minimum creep rate up to 150 hr, 0.00025 percent/hr.

TABLE 12.- TENSILE PROPERTIES OF SAND-CAST ALUMINUM ALLOYS – Concluded

Heat number	Heat treatment (a)	Composition (percent by weight)								Properties at room temperature				Grain size (in.)	Properties at 600° F							
		Mg	Cu	Ni	Mn	Ti	B	Be	Other	Tensile strength (psi)	Yield strength (psi)	Elongation (percent)	Brinell hardness number		Tensile strength (psi) (b)	Yield strength (psi) (c)	Elongation (percent)	Reduction of area (percent)	Creep tests - 1300 psi			
																			Duration (hr)	Minimum creep rate (percent/hr)	Total deformation at 100 hours (percent)	Total deformation at completion of test (percent)
180A	HTS	6.0	1.5		1.0	0.02	0.01	0.005	0.1 Zr, 0.05 Ca .05 V, .05 Ce .05 Co	33,050		2.5	81	0.050	13,510	11,750	71	90				
86A	HTS	6.0		1.0	1.0	.20	—	.005		32,100		2.7	78	.010	12,150	10,170	13.5	16	183	0.00053	0.065	0.073
87A	HTS	6.0	1.5	1.0	1.0	.20	----	.005		33,600		1.3	82	.010	12,100	9,580	15	17	162	.00040	.093	.116
89A	HTS	6.0		1.0	1.0	.20	.01	.005	1.0 Fe	29,815		1.9	77	.015	12,200	9,390	13	11	141	.00050	.110	.130
104A	HTS	6.0		1.0	1.0	.01	.01	.005	.1 Zr	28,500		1.9	80	.07-.08	13,400	9,880	10	13	197	.00015	.053	.066
103A	HTS	6.0		1.0	1.0	.02	.01	.005	.2 Zr	31,000		3.2	75	.020	12,400	8,440	13.5	7	216	.00017	.075	.094
151A	HTS	6.0		1.0	1.0	.08	.01	.005		26,970		1.8	78	.010	13,400	10,300	11.5	10	—	-------	----	----
152A	HTS	6.0		1.0	1.0	.08	.01	.005	.05 Zr	28,010	23,470	2.0	80	.020	13,040	10,860	11	11	168	.00018	.039	.050
151B	HTS	6.0		1.0	1.0	.08	.01	.005	.1 Zr	27,200		2.0	79	.010	13,060	10,320	10.5	12	139	.00037	.108	.120
151C	HTS	6.0		1.0	1.0	.08	.01	.005	.25 Zr	28,450		1.4	84	.015	13,190	10,140	12.5	12	165	.00017	.055	.066
151D	HTS	6.0		1.0	1.0	.08	.01	.005	.5 Zr	31,700		1.9	80	.010	12,460	10,200	12.5	13.5	200	.00030	.090	.119
153A	HTS	6.0		1.0	1.0	.08	.01	.005	.25 Zr .1 V	27,700		1.7	81	.030	13,040	11,240	11	9.5	526	[d] .000080	.030	.065
154A	HTS	6.0		1.0	1.0	.08	.01	.005	.25 Zr .25 V	27,680		2.0	85	.050	12,610	10,670	9.0	6.5	142	.00015	.050	.054
177A	HTS	6.0		1.0	1.0	.02	.01	.005	.1 Zr .1 Ca	26,470		1.9	81	.030	13,470	12,300	18	19				
109A	HTS	6.0		1.0	1.0	.02	.01	.005	.25 Cr	27,500		1.5	82	.010	12,850	10,370	10	9.5	163	.00022	.078	.098
108A	HTS	6.0		1.0	1.0	.02	.01	.005	.5 Cr	27,100		1.9	78	.01-.03	12,860	10,370	10	9.5	145	.00020	.068	.071
158A	HTS	6.0		1.0	1.0	.02	.01	.005	.12 V	29,400		2.0	81	.050	13,140	10,670	10	8.0	220	.00015	.065	.088
155A	HTS	6.0		1.0	1.0	.02	.01	.005	1.0 V	27,650		2.4	89	.010	13,190	11,870	9	10.5	171	.00030	.070	.090
163A	HTS	6.0		1.0	1.0	.02	.01	.005	.12 Mo	30,050		1.4	82	.012	13,000	11,600	11	9	146	.00025	.060	.073
164A	HTS	6.0		1.0	1.0	.08	.01	.005	.5 Sb .1 Zr	30,150		1.5	78	.012	12,970	11,300	13.5	12.5	145	.00027	.062	.074
165A	HTS	6.0		1.0	1.0	.08	.01	.005	.5 Sb .1 V	30,525		1.8	80	.010	13,740	12,070	11.5	11	173	.00020	.047	.061
166A	HTS	6.0		1.0	1.0	.08	.01	.005	.5 Sb .1 Mo	28,450		2.0	80	.015	13,560	11,700	17	18			.038	
170A	HTS	6.0		1.0	1.0	.08	.01	.005	.5 Sb .1 Ca	29,140		1.7	76	.010	13,540	11,670	9.5	9.5			.040	
102A	HTS	6.0		1.5	1.0	.02	.01	.005	1.1 Fe	26,450		1.6	80	.02-.03	14,400	>10,000	6.5	7.6	146	.00050	.119	.136
110A	HTS	5.7		1.8	1.0	.02	.01	.005	1.0 Fe	29,900		1.4	84	.008	14,125	11,985	13	15	162	.00020	.058	.070
181A	HTS	6.0		2.0	1.0	.02	.01	.005	1.0 Fe .1 Zr	26,910	19,700	1.7	80	.012	13,640	12,110	11.5	11	155	.00018	.053	.061
182A	HTS	6.0	.5	1.5	1.0	.02	.01	.005	.1 Zr	26,570	20,570	1.7	76	.02-.04	12,790	10,600	15	18	170	.00018	.044	.054

[a] HTA, heat-treated 6 hr at 960° F, quenched in boiling water, aged 8 hr at 400° F;
HTAS, same as HTA, plus 24 hr at 650° F;
acA, as-cast bars, aged 8 hr at 400° F;
acAS, same as acA, plus 24 hr at 650° F;
HTS, heat-treated 16 hr at 810° F, quenched in cold water, plus 24 hr at 650° F.

[b] All bars pulled at 0.01 in./in. gage length/min until 0.2-percent offset was passed. Rate was then increased to 0.03 in./in. gage length/min to rupture.

[c] Yield strength at 0.2-percent offset.

[d] Minimum creep rate up to 150 hr, 0.00012 percent/hr.

TABLE 13.- COMPOSITION OF STABILIZED ALLOYS

[Tensile properties of these alloys given in table 14]

Alloy	Element (Percent by weight)										
	Cu	Mn	Ni	Mg	Cr	Ti	B	Be	Si	Fe	Al
RAE 40C	2.30	1.87	5.02	0.68	0.51	0.07		0.34	0.18	0.32	Bal.
RAE 55	1.75	1.75	2.85	.73	.50	.05			.13	.20	Bal.
Alcoa 142[a]	4.00		2.00	1.50		.10			.10	.41	Bal.
Alcoa 254[a]	.50	1.05	1.50	5.99		.02	0.01	.005	.09	.16	Bal.
Experimental[a] (Heat 78)	1.50	1.05		6.00		.02	.01	.005	.09	.14	Bal.
CM 62		1.80		Bal.	Ce 6.0						

[a] Calculated or nominal compositions.

TABLE 14.– TENSILE PROPERTIES OF RAE 40C, RAE 55, ALCOA 142, ALCOA 254, AND AN EXPERIMENTAL ALLOY AT ROOM TEMPERATURE, 400°, 500°, 600°, AND AT 700° F

Alloy and bar	Test temperature (°F),	Condition prior to test	Tensile strength (psi) (a)	Proportional limit (psi)	Yield strength (psi)		Elongation (percent in 2 in.)	Reduction of area (percent) (b)	Modulus of elasticity, E
					0.1-percent offset	0.2-percent offset			
RAE 400-3	Room	Wrought as received	44,650	17,400	26,500	29,200	9.9	-----	12.2 × 10^6
RAE 40C-3	-do-	--------do---------	44,400	18,400	29,350	33,600	8.9	-----	12.2
			av.44,525	17,900	27,925	31,400	9.4		
RAE 400 4-1	-do-	Chill cast as received	40,200	20,500	33,000	36,400	0.7	-----	10.5
RAE 40C 4-3	-do-	----------do----------	38,800	20,750	33,600	36,200	0.9	-----	10.7
			av.39,500	20,625	33,300	36,300	0.8		
RAE 55-3	-do-	Wrought as received	48,400	27,800	31,550	------	7.3	-----	10.6
RAE 55-3	-do-	--------do---------	48,450	23,400	35,250	38,600	8.5	-----	11.0
			av.48,425	25,600	33,400		7.9		
RAE 55-6-2[c]	-do-	Chill cast as received	31,300	13,640	23,050	26,650	1.0	-----	11.4
RAE 55-6-2[c]	-do-	----------do----------	24,800	12,530	22,550	24,800	1.2	-----	11.0
			av.28,050	13,085	22,800	27,725	1.1		
Alcoa 142 (76-3)	-do-	Sand cast – HTA[d]	39,500	26,700	38,900	39,500	1.0	-----	11.4
Alcoa 142 (76-4)	-do-	-------do-------	45,550	27,200	39,600	42,850	1.2	-----	11.3
			av.42,520	26,950	38,250	41,175	1.1		
Alcoa 254 (74-2)	-do-	Sand cast – acA[e]	24,750	15,950	22,200	24,750	0.7	-----	10.6
Alcoa 254 (74-4)	-do-	-------do-------	26,500	16,200	22,900	25,200	0.9	-----	10.1
			av.25,620	16,075	22,550	24,975	0.8		
Exper. (78-2)	-do-	Sand cast – HPS[f]	36,500	13,500	22,000	25,050	2.7	-----	9.7
Exper. (78-4)	-do-	-------do-------	34,150	16,000	21,800	24,050	2.5	-----	11.2
			av.35,325	14,750	21,900	24,500	2.6		
RAE 400 4-4	400	Chill cast – S20[g]	14,350	3,550	8,120	9,510	1.8	0.5	9.5
RAE 400 4-3	400	-------do--------	13,300	4,020	8,660	10,550	1.4	1.0	11.6
			av.13,825	3,785	8,390	10,030	1.6	.75	
RAE 40C-2	400	Wrought – S20[g]	17,500	------	------	------	28.0	29	----
RAE 40C-3	400	------do------	18,300	5,010	8,520	9,760	31.0	33	10.0
			av.17,900				29.5	31	
RAE 55-5-2	400	Chill cast – S20[g]	17,300	7,630	11,870	13,150	1.7	1.0	9.7
RAE 55-5-3	400	-------do--------	23,200	7,000	11,900	13,100	5.1	5.5	[h]17.6
			av.20,250	7,315	11,885	13,125	3.4	2.75	
RAE 55-2	400	Wrought – S20[g]	18,100	5,250	8,750	10,100	26.0	34	10.5
RAE 55-3	400	------do------	18,800	4,260	8,120	9,370	49.0	54	10.5
			av.18,450	4,755	8,435	9,735	37.5	44	
Alcoa 254 (74-1)	400	Sand cast – acAS20[i]	22,050	------	------	------	1.1	1.0	----
Alcoa 254 (74-2)	400	----------do--------	25,400	12,120	18,800	20,550	1.0	1.2	10.0
			av.23,725				1.05	1.1	

[a] Room-temperature tests pulled at 0.02 in./in. gage length/min until extensometer was removed, then somewhat faster to rupture. All other bars were pulled at 0.01 in./in. gage length/min until 0.2-percent offset was reached, then rate was increased to 0.03 in./in. gage length/min to rupture.

[b] Reduction of area in tests at room temperature is too small to measure accurately.

[c] Fracture showed inclusion in bar. Specimen very unsound.

[d] Heat-treated 6 hr at 960° F, quenched in boiling water, aged 8 hr at 400° F.

[e] As cast and aged 8 hr at 400° F.

[f] Heat-treated 16 hr at 810° F, quenched in cold water, stabilized 24 hr at 650° F.

[g] As received, stabilized 480 hr at 575° F.

[h] Modulus probably in error.

[i] As cast and aged 8 hr at 400° F, stabilized 480 hr at 575° F.

TABLE 14.– TENSILE PROPERTIES OF RAE 40C, RAE 55, ALCOA 142, ALCOA 254, AND AN EXPERIMENTAL ALLOY AT ROOM TEMPERATURE, 400°, 500°, 600°, AND AT 700° F – Continued

Alloy and bar	Test temperature (°F)	Condition prior to test	Tensile strength (psi) (a)	Proportional limit (psi)	Yield strength (psi)		Elongation (percent in 2 in.)	Reduction of area (percent) (b)	Modulus of elasticity, E
					0.1-percent offset	0.2-percent offset			
Alcoa 142 (76-1)	400	Sand cast – HTAS20[j]	19,050	4,560	9,900	11,050	6.0	6.6	[h]17.0 × 10^6
Alcoa 142 (76-2)	400	--------do---------	21,650	5,020	9,660	10,800	5.0	3.1	7.6
		av.	20,350	4,790	9,780	10,925	5.5	4.85	
Exper. (78-1)	400	Sand cast – HTS20[k]	27,600	14,500	20,700	23,050	6.8	6.6	9.3
Exper. (78-2)	400	--------do--------	27,300	12,750	18,500	20,100	3.2	5.5	9.4
		av.	27,450	13,625	19,600	21,575	5.0	6.05	
RAE 400-4-4	500	Chill cast – S20[l]	11,000	3,750	6,250	7,000	3.5	2.5	5.75
RAE 40C-4-3	500	---------do------	11,100	3,830	6,890	7,650	3.0	3.0	7.65
		av.	11,050	3,790	6,570	7,325	3.25	2.75	
RAE 400-2	500	Wrought – S20[l]	10,925	5,000	7,350	8,050	46.0	53.0	9.0
RAE 400-3	500	------do------	10,840	4,870	7,160	7,840	67.0	56.0	10.3
		av.	10,880	4,935	7,255	7,945	56.5	54.5	
RAE 55-5-2	500	Chill cast – S20[l]	14,520	7,400	10,650	11,320	5.0	7.1	8.1
RAE 55-5-3	500	---------do------	13,520	7,270	10,300	11,050	6.0	4.4	12.2
		av.	14,020	7,335	10,475	11,185	5.5	5.75	
RAE 55-3	500	Wrought – S20[l]	12,350	5,300	8,050	8,900	6.0	78	8.85
RAE 55-2	500	------do------	15,300	5,100	8,930	10,700	4.0	40	11.5
		av.	13,825	5,200	8,490	9,800	5.0	59	
Alcoa 254 (74-3)	500	Sand cast – acAS20[l]	22,300	9,460	------	------	2.0	1.75	10.1
Alcoa 254 (74-4)	500	---------do--------	20,300	8,520	16,550	18,050	1.5	2.25	7.9
		av.	21,300	8,990			1.75	2.0	
Alcoa 142 (76-3)	500	Sand cast – HTAS20[j]	13,800	6,800	9,125	9,950	17.0	22	7.5
Alcoa 142 (76-4)	500	---------do--------	13,800	4,760	7,650	8,270	13.0	23	8.9
		av.	13,800	5,780	8,385	9,110	15.0	22.5	
Exper. (78-3)	500	Sand cast – HTS 20[k]	22,500	12,000	18,000	19,000	10.5	13.0	[h]17.35
Exper. (78-4)	500	--------do---------	21,300	11,500	16,500	18,200	18.0	18.0	11.5
		av.	21,900	11,750	17,250	18,600	14.25	15.5	
RAE 400-3	600	Wrought – S20[m]	7,950	3,480	5,230	5,770	53.0	69.9	10.3
RAE 40C-3	600	------do------	8,360	4,380	6,510	6,920	41.3	48.0	6.3
		av.	8,155	3,930	5,870	6,345	47.15	58.9	
RAE 40C-4-1	600	Chill cast – S20[m]	8,110	3,530	5,570	6,070	5.0	4.3	4.8
RAE 40C-4-1	600	---------do------	6,900	[n]3,610	[n]5,180	[n]5,680	5.9	3.85	[h]7.3
		av.	7,505	3,570	5,380	5,875	5.4	4.07	
RAE 55-3	600	Wrought – S20[m]	7,670	3,800	5,470	5,800	85.0	89.0	6.85
RAE 55-3	600	------do------	8,130	4,010	6,040	6,460	53.0	85.8	7.8
		av.	7,900	3,905	5,755	6,130	69.0	87.4	
RAE 55-4-1	600	Chill cast – S20[m]	10,200	5,200	7,620	8,100	25.0	53.0	8.15
RAE 55-4-3	600	---------do------	9,550	4,000	7,350	7,850	12.5	18.0	6.9
		av.	9,875	4,600	7,485	7,975	18.7	35.5	

[a] Room-temperature tests pulled at 0.02 in./in. gage length/min until extensometer was removed, then somewhat faster to rupture. All other bars were pulled at 0.01 in./in. gage length/min until 0.2-percent offset was reached, then rate was increased to 0.03 in./in. gage length/min to rupture.

[h] Modulus probably in error.

[i] As cast and aged 8 hr at 400° F, stabilized 480 hr at 575° F.

[j] Heat-treated 6 hr at 960° F, quenched in boiling water, aged 8 hr at 400° F, stabilized 480 hr at 575° F.

[k] Heat-treated 16 hr at 810° F, quenched in cold water, aged 24 hr at 650° F, stabilized 480 hr at 575° F.

[l] As received, stabilized 480 hr at 575° F.

[m] As received, stabilized 480 hr at 650° F.

[n] Values listed are questionable because of peculiarities of stress-strain curve.

TABLE 14.– TENSILE PROPERTIES OF RAE 40C, RAE 55, ALCOA 142, ALCOA 254, AND AN EXPERIMENTAL ALLOY AT ROOM TEMPERATURE, 400°, 500°, 600°, AND AT 700° F — Concluded

Alloy and bar	Test temperature (°F)	Condition prior to test	Tensile strength (psi) (a)	Proportional limit (psi)	Yield strength (psi)		Elongation (percent in 2 in.)	Reduction of area (percent) (b)	Modulus of elasticity, E
					0.1-percent offset	0.2-percent offset			
Alcoa 142 (3Y-1)[c]	600	Sand cast – HTAS20[p]	8,600	3360	5,330	5660	12.0	13.7	4.9 × 10⁶
Alcoa 142 (3Y-3)	600	--------do--------	9,310	3000	5,625	5925	20.5	20.4	6.0
		av.	8,955	3180	5,475	5790	16.2	17.0	
Alcoa 254 (73-1)	600	Sand cast – acAS20[q]	12,830	6810	10,230	----	20.0	12.2	8.0
Alcoa 254 (73-3)	600	--------do--------	12,720	6820	9,450	9650	19.0	18.1	7.7
		av.	12,775	6815	9,840		19.5	15.1	
Exper. (77-1)	600	Sand cast – HTS20[r]	12,200	6960	9,480	9670	28.6	24.4	6.5
Exper. (77-3)	600	--------do--------	11,800	5700	8,720	8850	26.4	34.0	6.85
		av.	12,000	6330	9,100	9260	27.5	29.2	
RAE 40C-2	700	Wrought – S4[s]	4,840	2710	3,460	3660	46.0	69.1	3.8
RAE 40C-2	700	------do-----	5,110	2275	3,525	3800	88.0	65.1	3.8
		av.	4,975	2490	3,490	3730	67.0	67.1	
RAE 40C-4-2	700	Chill cast – S4[s]	5,775	2150	3,950	4350	14.0	34.0	5.6
RAE 40C-4-6	700	--------do------	6,360	2590	4,650	4930	25.0	13.7	5.2
		av.	6,070	2370	4,300	4640	19.5	23.8	
RAE 55-2	700	Wrought – S4[s]	5,100	----	-----	----	61.0	56.7	-------
RAE 55-2	700	------do-----	6,200	3310	4,790	5010	46.0	52.9	5.9
		av.	5,650				53.5	54.8	
RAE 55-4	700	Chill cast – S4[s]	7,260	4310	6,090	6460	23.5	48.8	5.6
RAE 55-5	700	--------do------	8,050	4345	6,560	7025	27.0	51.4	5.15
		av.	7,655	4325	6,325	6740	25.2	50.1	
Alcoa 142 (76-1)	700	Sand cast – HTAS4[t]	5,325	1635	3,120	3370	49.5	57.6	3.9
Alcoa 142 (76-3)	700	--------do--------	5,900	2700	3,900	4175	59.0	65.1	5.0
		av.	5,610	2165	3,510	3770	54.2	61.3	
Alcoa 254 (74-2)	700	Sand cast – acAS4[u]	8,040	3900	5,750	6050	49.0	37.8	5.6
Alcoa 254 (74-4)	700	--------do--------	7,650	4000	5,720	5970	38.0	44.2	5.6
		av.	7,845	3950	5,735	6010	43.5	41.0	
Exper. (78-1)	700	Sand cast – HTS4[v]	7,650	3765	5,650	5750	83.0	59.1	7.3
Exper. (78-3)	700	--------do--------	8,420	----	-----	----	55.0	43.3	-------
		av.	8,035				69.0	51.2	

[a] Room-temperature tests pulled at 0.02 in./in. gage length/min until extensometer was removed, then somewhat faster to rupture. All other bars were pulled at 0.01 in./in. gage length/min until 0.2-percent offset was reached, then rate was increased to 0.03 in./in. gage length/min to rupture.

[c] Overheated during test; all values are low for this bar.

[p] As in footnote j but stabilized 480 hr at 650° F.

[q] As in footnote i but stabilized 480 hr at 650° F.

[r] As in footnote k but stabilized 480 hr at 650° F.

[s] As received, stabilized 96 hr at 700° F.

[t] As in footnote j but stabilized 96 hr at 700° F.

[u] As in footnote i but stabilized 96 hr at 700° F.

[v] As in footnote k but stabilized 96 hr at 700° F.

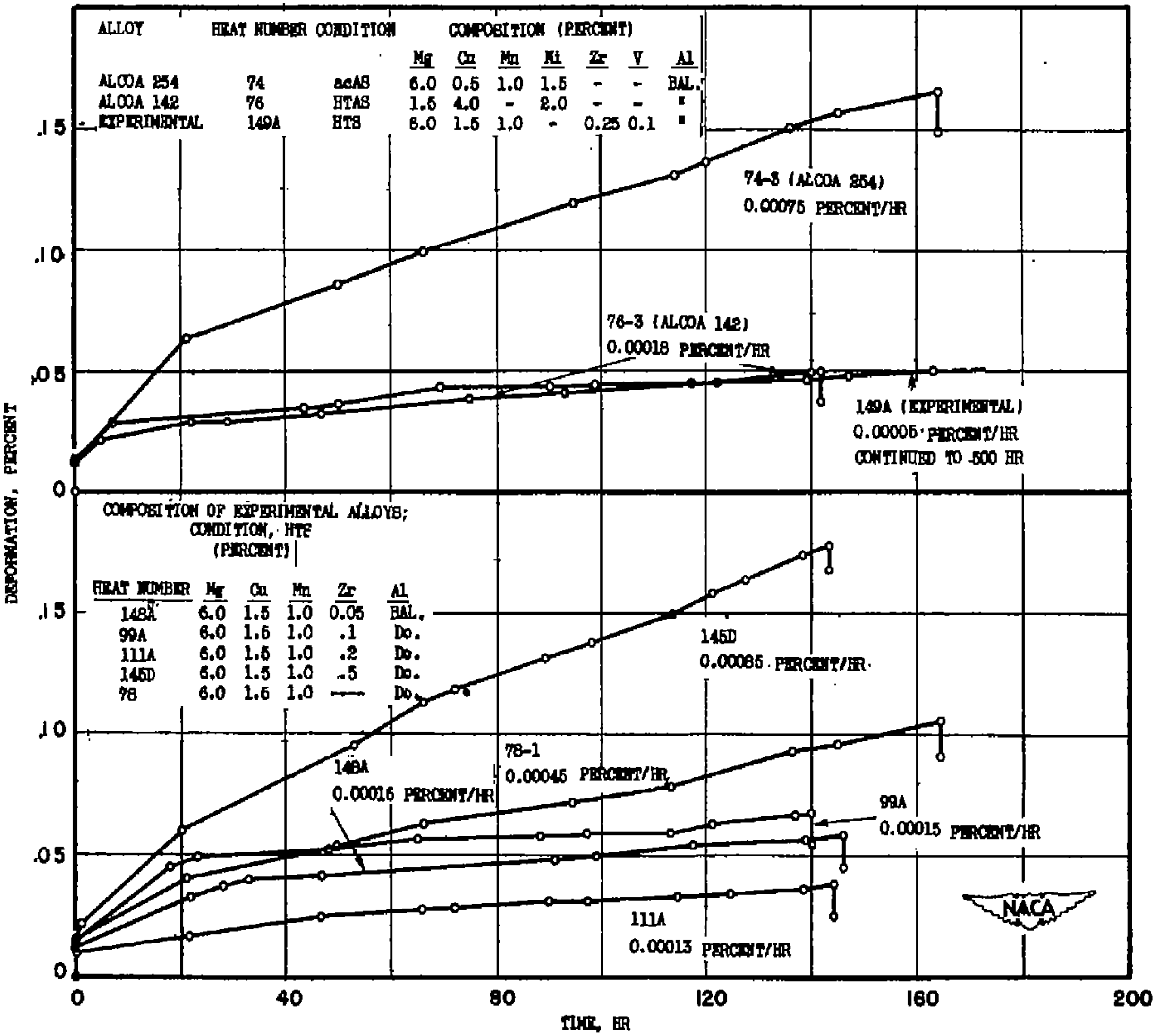

Figure 1.- Typical time-deformation curves for creep tests run at 600° F and 1300 psi on cast aluminum-base alloys.

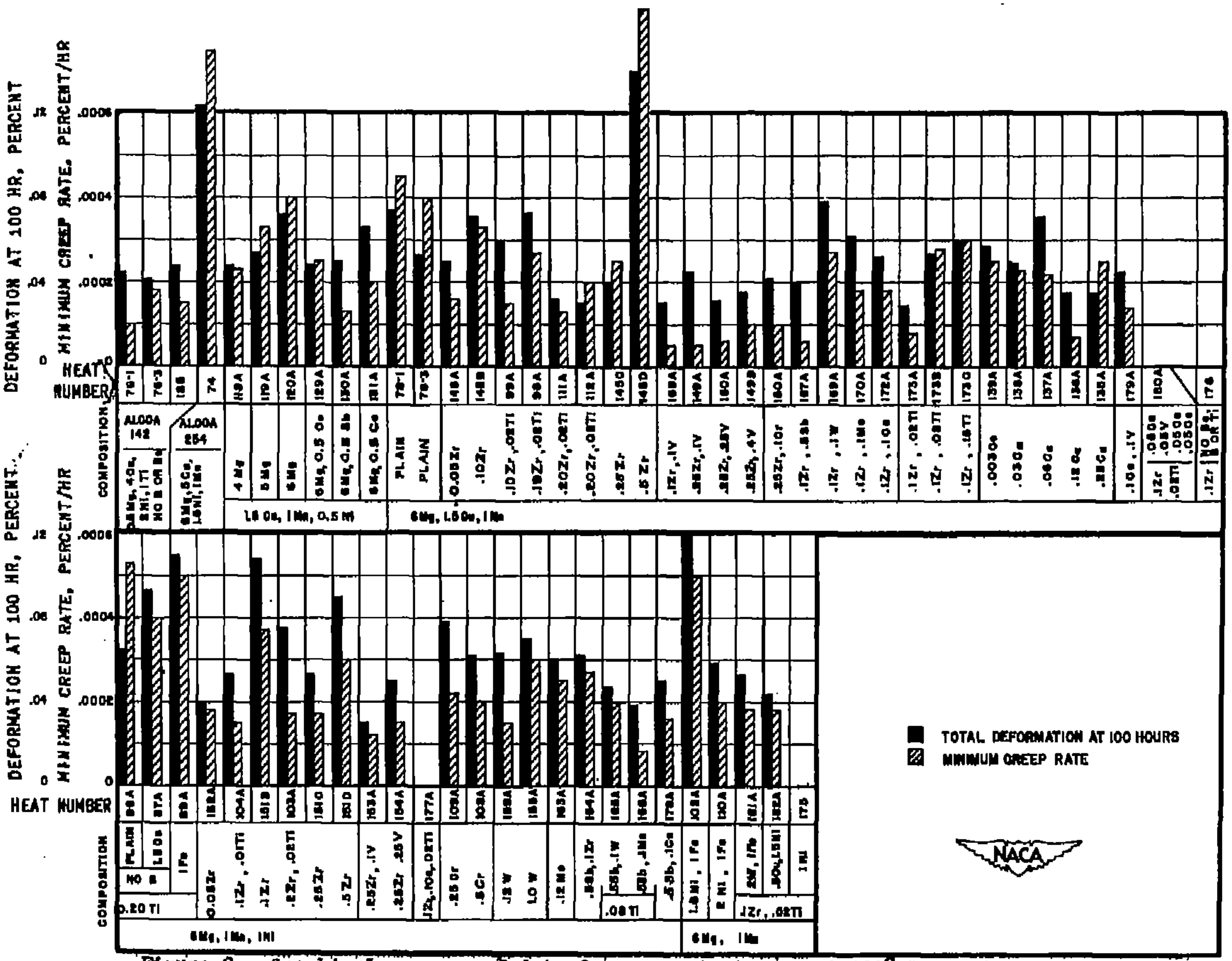

Figure 2.- Graphical summary of data for creep tests run at 600° F and 1300 psi on cast aluminum-base alloys. Unless otherwise stated, all alloys contain 0.01-percent boron, 0.005-percent beryllium, and either 0.02-percent titanium (without zirconium present) or 0.08-percent titanium (with zirconium present).

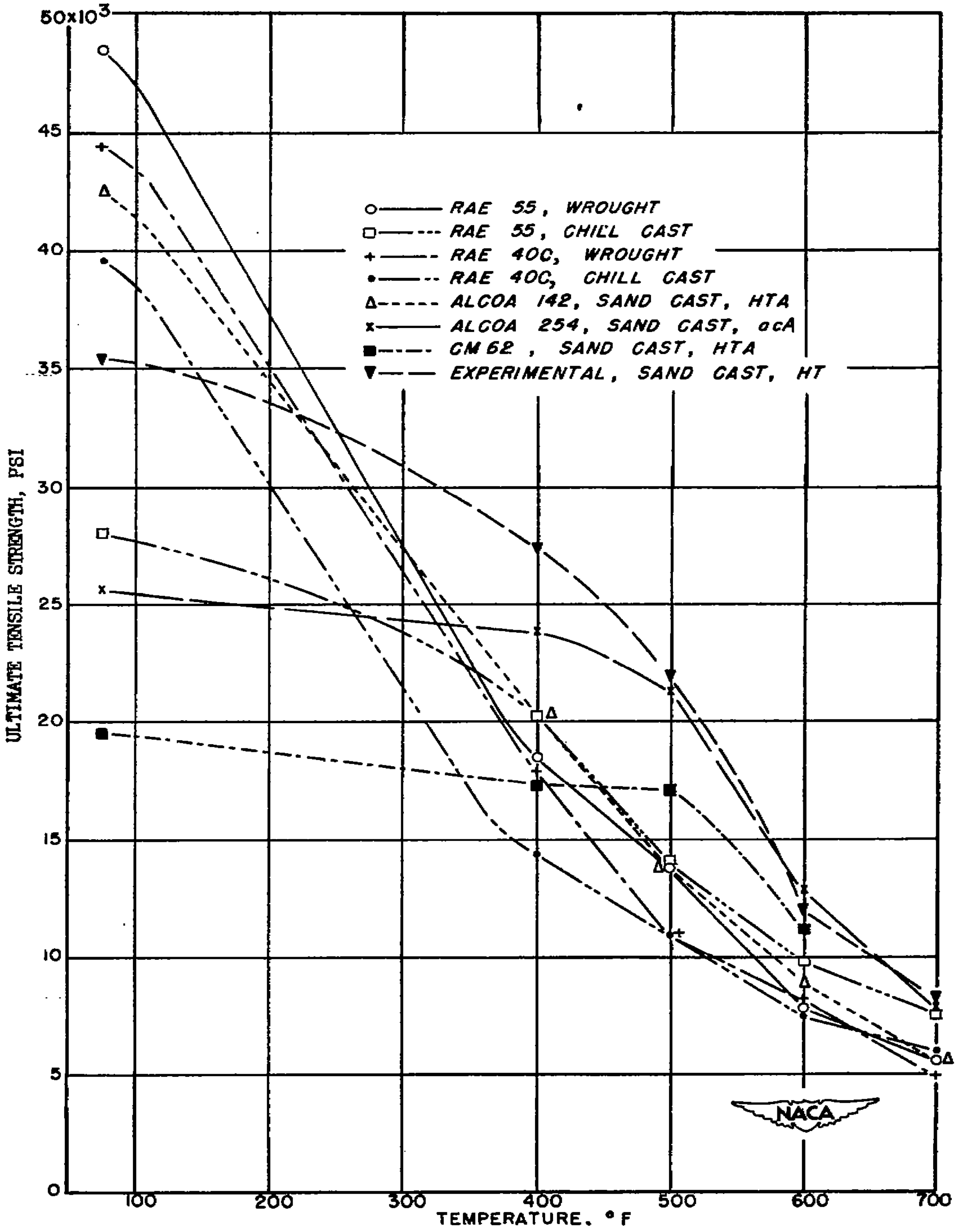

Figure 3.- Tensile strength of various alloys. All alloys stabilized prior to testing at elevated temperatures. See table 13 for compositions.

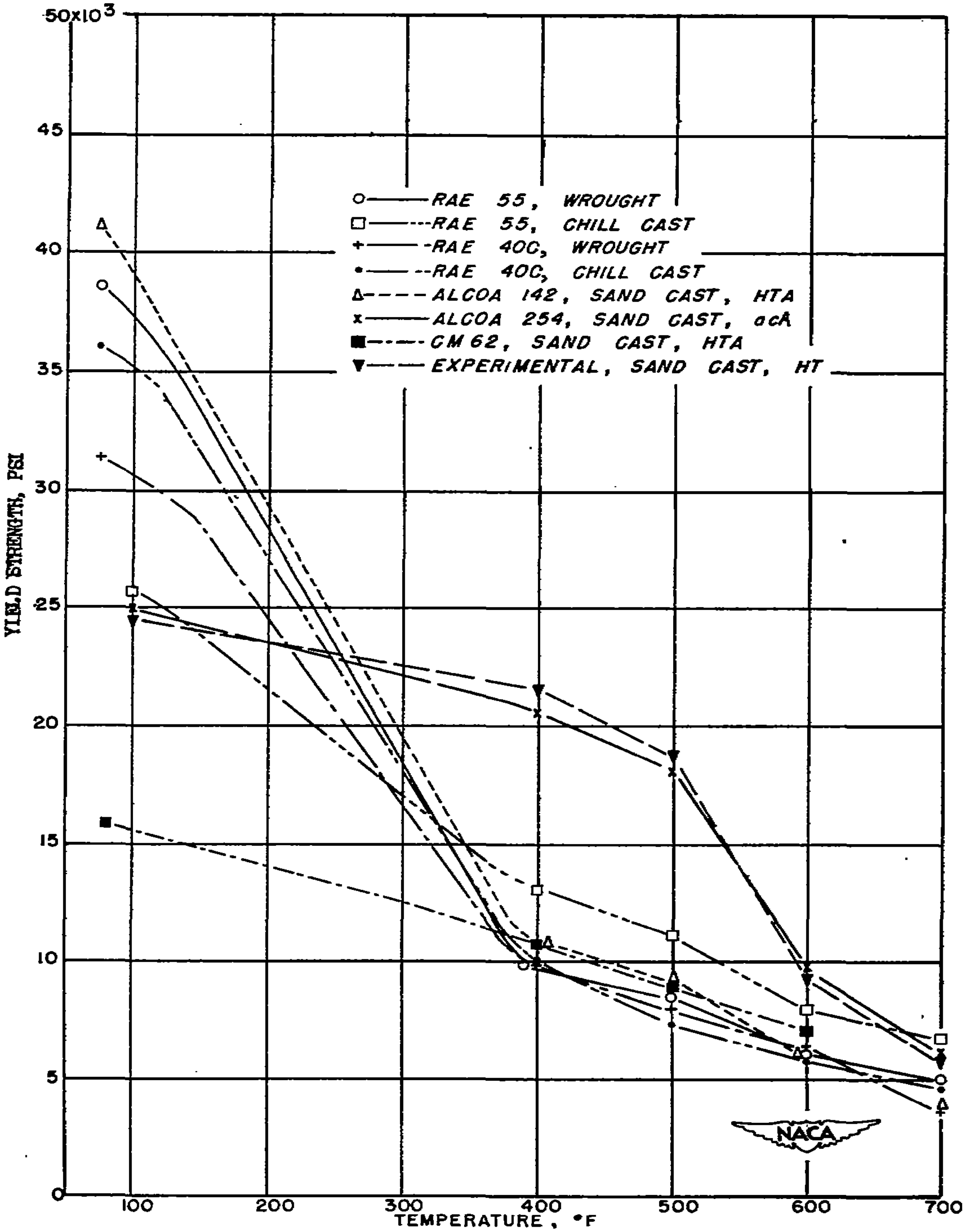

Figure 4.- Yield strength (0.2-percent offset) of various alloys. All alloys stabilized prior to testing at elevated temperatures. See table 13 for compositions.

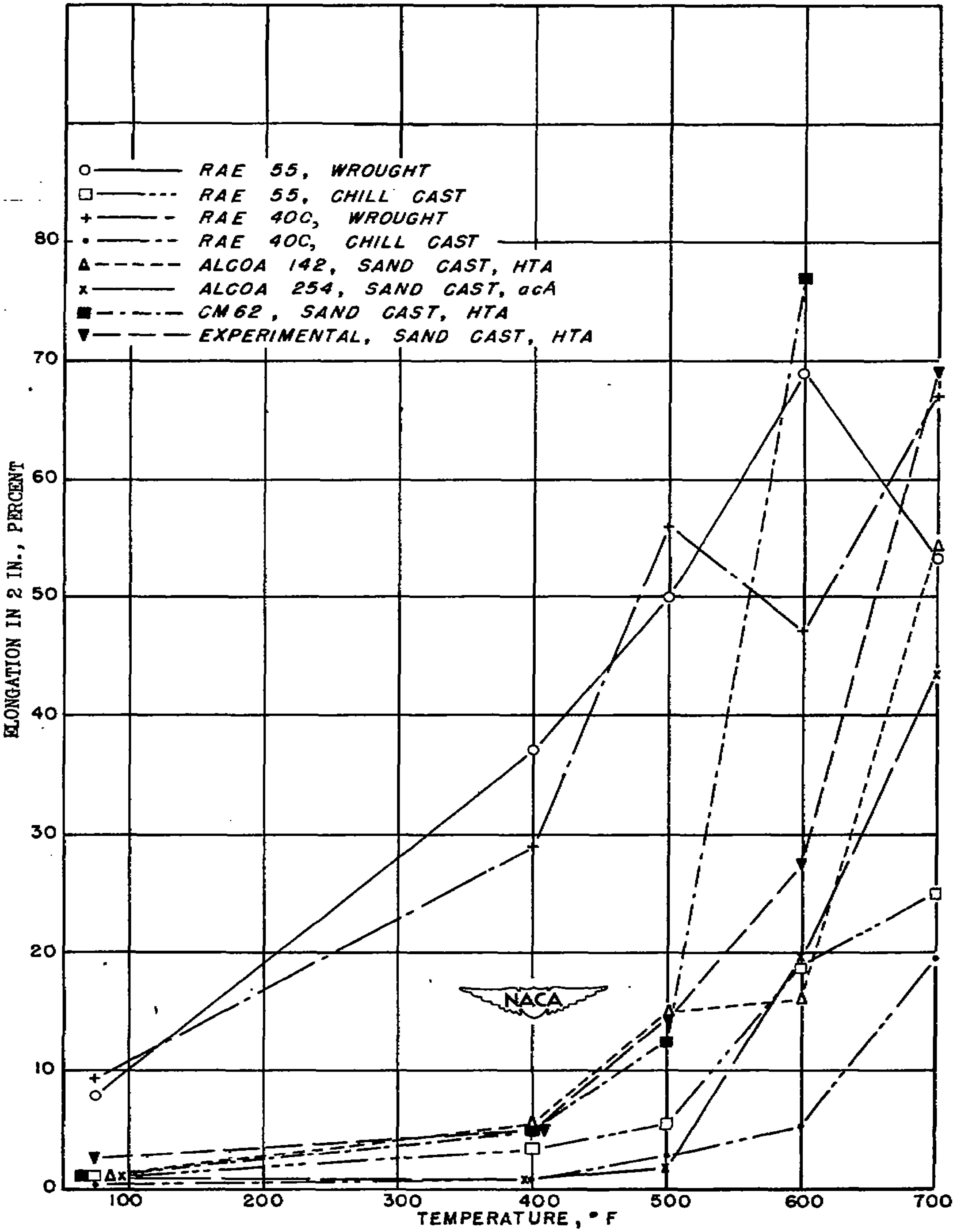

Figure 5.- Elongation of various alloys. See table 13 for chemical compositions.