ALUMINUM BASE ALLOY

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No Drawing. Application January 13, 1958
Serial No. 708,351

5 Claims. (Cl. 75—142)

This invention relates to high strength aluminum base
alloys and more particularly to certain compositions
which retain a relatively high strength when heated to
and held at elevated temperatures.

The properties and performance of aluminum and
aluminum base alloy products at room temperature
are well-known, and it is also known that castings and
forsgings of certain alloys have served well in reciproc-
cating-type internal combustion engines for such parts as
pistons, cylinder heads and cylinder barrels when the
barrels are provided with a ferrous metal liner. With
the development of high speed aircraft and other ma-
chines that are exposed to or develop high temperatures,
there has been a demand for aluminum base alloys which
will have a higher strength than the commercial com-
positions heretofore available. There has been a par-
ticular need for high strength alloys which can withstand
aerodynamic heating for short periods of time. In ad-
tion to the requirement for higher strength there has
been a need for alloys which have a greater resistance
to creep at elevated temperatures than previous composi-
tions. Such alloys should also be amenable to being
rolled or otherwise converted into articles having rela-
tively thin sections.

It is, therefore, an object of this invention to pro-
vide an aluminum base alloy that possesses a high
strength and resistance to creep at elevated tempera-
tures and that can still be readily worked.

Another object is to provide an aluminum base alloy
in which the solution heat treated and age hardened
condition retains its room temperature properties to a high
degree when heated to elevated temperatures below about
400°F.

Still another object is to provide an aluminum base
alloy which in addition to possessing a high strength
and resistance to creep at elevated temperatures also has
a higher modulus of elasticity than is exhibited by pre-
vious commercial aluminum base alloys.

These and other objects and advantages are realized in
aluminum base alloy consisting essentially of alumi-
num, from 3 to 9% copper, 0.15 to 1.0% manganese,
0.02 to 0.5% cadmium, 0.2 to 3% lithium, 0.05 to 2.0%
magneus and the usual impurities associated with aluminum
where the alloy has been rolled, forged, ex-
truded, pressed or otherwise worked and then heat treated.

To attain the maximum strength at elevated tempera-
tures, the wrought alloy should receive a solution heat
heat treatment followed by age hardening above room tem-
perature. In this condition an alloy consisting essentially of
aluminum, 4.5% copper, 0.5% manganese, 0.3% mag-
nesia, 0.15% cadmium and 1% lithium will develop a
tensile strength at 300°F. of 74,000 p.s.i., a yield strength
of 46,000 p.s.i. and an elongation of 19%. In any case,
the wrought alloy of this invention in the heat treated
and precipitation condition possesses a higher tensile
and yield strength than the same alloy without cadmium,
lithium and magnesium. Furthermore, it has a typical
resistance to creep at 300°F. of 0.005 in./in. for a period
of 100 hours under a stress of 58,000 p.s.i. At room
temperature the new alloy has a modulus of elasticity
of 11.2x10⁶ p.s.i., as compared to only 10.4x10⁶ p.s.i.
for similar aluminum base alloys containing copper as the
chief added alloy component.

The alloy can be hot and cold worked by conventional
practices in a manner similar to other high strength
aluminum alloys.

To achieve the desired properties the several elements
must be used in the indicated proportions. If less than
3% copper is present, the alloy will not have the re-
quired strength while an alloy containing more than 9% copper
is not readily rolled or otherwise worked. In the
preferred practice of the invention the copper content is
kept between 4.5 and 6%.

The manganese component is also essential to de-
veloping high strength at elevated temperatures and
should be present in amounts of 0.15 to 1.0%. Larger
amounts interfere with working of the alloy.

The cadmium, lithium and magnesium components
appear to interact in a manner not understood to increase
the strength above that provided by the copper and man-
ganese components alone. Although the melting points
of cadmium and lithium are much lower than those of
aluminum and these elements therefore might be ex-
pected to be detrimental to a high strength at elevated
temperatures, it has, nevertheless, been found that they,
in combination with magnesium, have a beneficial effect
upon the strength of the aluminum-copper-manganese
base composition. Furthermore, the susceptibility to
oxidation of these elements does not appear to detract
from the performance of the alloy at elevated tem-
peratures.

The amount of cadmium required, 0.02 to 0.5%, is
relatively small, but, nevertheless, essential in the total
composition. Larger amounts are undesirable because of
the possible presence of free or uncombined cadmium
which is detrimental to the working characteristics of
the alloy. The lithium content is also relatively small
and must be within the range of 0.2 to 3%. Less than
0.2% does not afford any significant improvement in
the alloy while more than 3% offers no further increase
in properties at room temperature at or at 300°F.
The third element of the group, magnesium, must be present
in an amount of at least 0.05% to obtain the desired
strength but more than 2% is unnecessary and makes
working difficult. It is preferred, however, to employ
0.15 to 0.6% of this element to obtain optimum properties.

Although cadmium is preferred as the element to be
used in combination with lithium and magnesium, it may
be replaced in whole or in part by one or more of the
elements mercury, tin, indium and thallium in amounts
of 0.02 to 0.3% each, the total of these and cadmium
not exceeding 0.75%. These elements and cadmium
therefore constitute a related group of metals at least one
of which must be employed in the alloy to achieve the
desired properties referred to above. It should be under-
stood, however, that in substituting one or more of the
elements for cadmium the strength and resistance to creep
may not be as high as that obtained when cadmium is
used, but still these properties are superior to those found
in similar compositions devoid of lithium, magnesium
and the equivalent of cadmium.

Under some conditions of casting it may be desirable
to add certain elements to the alloy to refine the grain
size in the ingot. For this purpose at least one element

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45
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of the group composed of boron, titanium, vanadium and zirconium may be employed in amounts of 0.002 to 0.05% boron, 0.01 to 0.25% titanium, 0.02 to 0.3% zirconium and 0.01 to 0.1% vanadium, the total amount of all of these elements not exceeding 0.5%.

The silicon impurity content of the alloy may be as high as 0.6% without adverse effect upon the strength of the alloy at elevated temperatures, but it is preferred to maintain a maximum of 0.2%. The iron impurity should not exceed about 0.6%.

To attain the high strength properties at elevated temperatures the alloy should receive a solution heat treatment of 1 to 12 hours at 290 to 980° F., be quenched and then be aged for 5 to 200 hours at 275 to 350° F. The solution temperature used is governed by solidus temperatures for the specific alloys being treated. The beneficial effect of the thermal treatment upon the strength at elevated temperatures is surprising since it would be anticipated that further exposure to temperature at which age hardening occurs would cause over-aging with resultant loss in strength.

If desired, the aged alloy product may be cold worked to further increase the tensile and yield strength and hardness.

The alloy possesses the remarkable property of undergoing a relatively small decrease in strength when heated to a temperature on the order of 300° F. as compared to the properties at room temperature. Furthermore, the alloy can be repeatedly heated to such a temperature and cooled to room temperature without any substantial detrimental effect upon the strength at elevated temperatures. This behavior of the alloy is particularly valuable for skin coverings of high speed aircraft which are subject to aerodynamic heating. In such service the alloy may be quickly heated and cooled and, hence, is imperative that the structural portions of the aircraft retain their high strength properties during repeated flights.

The improvement in tensile and yield strength and resistance to creep exhibited by alloys of this invention is illustrated in the following comparison between them and a commercial alloy composed essentially of aluminum, copper, manganese and titanium which has been proposed for use at elevated temperatures. The latter composition may be regarded as representative of alloys which do not contain cadmium, lithium and magnesium. The composition of the alloys tested is given in Table I below, the balance of the alloy in each case consisting of aluminum.

### Table I

<table>
<thead>
<tr>
<th>Composition of alloys</th>
<th>Cu</th>
<th>Mn</th>
<th>Li</th>
<th>Cd</th>
<th>Mg</th>
<th>Ti</th>
<th>Fe</th>
<th>Si</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alloy A</strong></td>
<td>0.35</td>
<td>0.53</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td><strong>Alloy B</strong></td>
<td>0.45</td>
<td>0.63</td>
<td>0.53</td>
<td>0.53</td>
<td>0.53</td>
<td>0.53</td>
<td>0.53</td>
<td>0.53</td>
</tr>
<tr>
<td><strong>Alloy C</strong></td>
<td>0.55</td>
<td>0.70</td>
<td>0.63</td>
<td>0.63</td>
<td>0.63</td>
<td>0.63</td>
<td>0.63</td>
<td>0.63</td>
</tr>
<tr>
<td><strong>Alloy D</strong></td>
<td>0.65</td>
<td>0.80</td>
<td>0.70</td>
<td>0.70</td>
<td>0.70</td>
<td>0.70</td>
<td>0.70</td>
<td>0.70</td>
</tr>
<tr>
<td><strong>Alloy E</strong></td>
<td>0.75</td>
<td>0.90</td>
<td>0.80</td>
<td>0.80</td>
<td>0.80</td>
<td>0.80</td>
<td>0.80</td>
<td>0.80</td>
</tr>
</tbody>
</table>

The alloys were melted, cast and forged to 3/8" diameter rods which were cut into lengths suitable for later machining into standard tensile test bars and creep test specimens. The forged bars of alloy A were solution heat treated two hours at 1000° F., quenched in water and aged 12 hours at 375° F. The bars of the remaining alloys with the exception of alloy D were solution heat treated two hours at 960° F., quenched in water and aged 12 hours at 320° F. Alloy D was heat treated at 940° F. The difference in solution heat treatment was dictated by the difference in composition, a lower temperature being employed to treat the improved alloys in order to avoid incipient fusion of any low melting constituents.

### Table II

<table>
<thead>
<tr>
<th>Tensile properties at room and elevated temperatures</th>
<th>ROOM TEMPERATURE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alloy</strong></td>
<td><strong>Tensile Strength, p.s.i.</strong></td>
</tr>
<tr>
<td>A</td>
<td>48,000</td>
</tr>
<tr>
<td>B</td>
<td>69,800</td>
</tr>
<tr>
<td>C</td>
<td>74,800</td>
</tr>
<tr>
<td>D</td>
<td>75,100</td>
</tr>
<tr>
<td>E</td>
<td>65,400</td>
</tr>
<tr>
<td>F</td>
<td>75,100</td>
</tr>
</tbody>
</table>

**AT 300° F.**

| **Alloy** | **Tensile Strength, p.s.i.** | **Yield Strength, p.s.i.** | **Elongation, Percent** |
| A          | 48,000            | 33,000            | 17               |
| B          | 69,800            | 56,100            | 15               |
| C          | 74,800            | 57,100            | 14               |
| D          | 75,100            | 57,100            | 11               |
| E          | 65,400            | 58,400            | 14               |
| F          | 75,100            | 57,100            | 11               |

**AT 400° F.**

| **Alloy** | **Tensile Strength, p.s.i.** | **Yield Strength, p.s.i.** | **Elongation, Percent** |
| A          | 48,000            | 33,000            | 17               |
| B          | 69,800            | 56,100            | 15               |
| C          | 74,800            | 57,100            | 14               |
| D          | 75,100            | 57,100            | 11               |
| E          | 65,400            | 58,400            | 14               |
| F          | 75,100            | 57,100            | 11               |

It is apparent that alloys of this invention not only had much higher room temperature properties but maintained a higher level of strength at 300° F. and 400° F. than the aluminum-copper-manganese base alloy with the exception of alloy E exposed 100 hours at 400° F. Alloy E, it should be noted, contained only 0.75% lithium whereas the other alloys contained 1% or more of that element. In particular it is to be seen that the tensile strength of the improved alloys was reduced less than 15% by heating to 300° F. and less than 30% upon heating to 400° F. This is a relatively small change as compared to many commercial aluminum base alloys. It is also noteworthy that the copper content of alloys B, C, D, E and F was lower than in alloy A and yet a higher strength was attained thus further emphasizing the benefit gained from the presence of lithium, cadmium and magnesium.

For the creep tests, specimens of alloys A, B, C and D were employed that had received the solution heat treatment referred to above. Alloy A was tested at 400° F. but alloys B, C and D were tested at both 300 and 400° F. The creep test consisted of stressing the specimens sufficiently to cause a creep of 0.001, 0.002, 0.003 and 0.01 in./in. and final rupture. The periods of time at which the stipulated amount of creep occurred and the stresses which produced the creep are given in Table III. The stress values are the average for alloys B, C and D; the values for the individual alloys being too close together to indicate any significant difference between them.
### TABLE III

<table>
<thead>
<tr>
<th>Time under Stress, Hour</th>
<th>0.001 in./in., p.s.i.</th>
<th>0.002 in./in., p.s.i.</th>
<th>0.005 in./in., p.s.i.</th>
<th>0.01 in./in., p.s.i.</th>
<th>Stress for Rupture, p.s.i.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>65,000</td>
<td>56,000</td>
<td>56,000</td>
<td>56,000</td>
<td>70,000</td>
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<tr>
<td>1</td>
<td>58,000</td>
<td>59,000</td>
<td>59,000</td>
<td>59,000</td>
<td>67,000</td>
</tr>
<tr>
<td>10</td>
<td>56,000</td>
<td>56,000</td>
<td>56,000</td>
<td>56,000</td>
<td>63,000</td>
</tr>
<tr>
<td>100</td>
<td>54,000</td>
<td>54,000</td>
<td>54,000</td>
<td>54,000</td>
<td>58,000</td>
</tr>
<tr>
<td>1,000</td>
<td>54,000</td>
<td>54,000</td>
<td>54,000</td>
<td>54,000</td>
<td>51,000</td>
</tr>
</tbody>
</table>

### ALLOYS B, C, AND D

<table>
<thead>
<tr>
<th>Time under Stress, Hour</th>
<th>0.001 in./in., p.s.i.</th>
<th>0.002 in./in., p.s.i.</th>
<th>0.005 in./in., p.s.i.</th>
<th>0.01 in./in., p.s.i.</th>
<th>Stress for Rupture, p.s.i.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>55,000</td>
<td>56,000</td>
<td>56,000</td>
<td>56,000</td>
<td>57,000</td>
</tr>
<tr>
<td>1</td>
<td>56,000</td>
<td>57,000</td>
<td>57,000</td>
<td>57,000</td>
<td>58,000</td>
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<tr>
<td>10</td>
<td>58,000</td>
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<td>63,000</td>
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<tr>
<td>100</td>
<td>56,000</td>
<td>56,000</td>
<td>56,000</td>
<td>56,000</td>
<td>58,000</td>
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<tr>
<td>1,000</td>
<td>54,000</td>
<td>54,000</td>
<td>54,000</td>
<td>54,000</td>
<td>51,000</td>
</tr>
</tbody>
</table>

It is apparent from the test results that alloys B, C, and D had a much higher resistance to creep and stress rupture than alloy A at 400°F. It is also evident that although the values at 300°F are higher than those at 400°F, an advantage is still gained from the addition of lithium, cadmium, and magnesium to the aluminum-copper-manganese base.

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  - 2,381,219 Le Baron Aug. 7, 1945
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  - 2,784,126 Criner Mar. 5, 1957
UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 2,915,391

December 1, 1959

Charles B. Criner

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 3, line 38, for "improvement is" read -- improvement in --;
column 4, Table II, in the group headed "AT 400° F.", fifth column thereof, under the heading "Tensile Strength, p.s.i.", fourth line, for "45,303" read -- 45,300 --; column 6, line 24, for "lithius" read -- lithium --.

Signed and sealed this 17th day of May 1960.

(SEAL)
Attest:

KARL H. AXLINE
Attesting Officer

ROBERT C. WATSON
Commissioner of Patents