A cast article from an aluminum alloy, which has improved mechanical properties at elevated temperatures, has the following composition in weight percent: Silicon 14–25.0, Copper 5.5–8.0, Iron 0.05–1.2, Magnesium 0.5–1.5, Nickel 0.05–0.9, Manganese 0.05–1.0, Titanium 0.05–1.2, Zirconium 0.05–1.2, Vanadium 0.05–1.2, Zinc 0.05–0.9, Phosphorus 0.001–0.1, and the balance is Aluminum, wherein the silicon-to-magnesium ratio is 10–25, and the copper-to-magnesium ratio is 4–15. The aluminum alloy contains a simultaneous dispersion of three types of Al3X compound particles (X=Ti, V, Zr) having a L12 crystal structure, and their lattice parameters are coherent to the aluminum matrix lattice. A process for producing this cast article is also disclosed, as well as a metal matrix composite, which includes the aluminum alloy serving as a matrix and containing up to about 60% by volume of a secondary filler material.

10 Claims, 4 Drawing Sheets
FIG. 1

Aluminum atom

Coherent precipitate compound

FIG. 2

Aluminum atom

Non-coherent precipitate compound
FIG. 3

θ' particles (coherent)

S' particles (coherent)

FIG. 4

θ' particles (coherent)

S' particles (coherent)
FIG. 5

S particles (non-coherent)

θ particles (non-coherent)

100 nm

FIG. 6

θ' particles (coherent)

S' particles (coherent)

100 nm
ULTIMATE TENSILE STRENGTH (KSI)

FIG. 7
1
ALUMINUM ALLOY AND ARTICLE CAST THEREFROM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of application Ser. No. 09/606,108, filed June 19, 2000 abandoned; which is a continuation-in-part of application Ser. No. 09/218,675, filed Dec. 22, 1998, and now abandoned; which is a division of application Ser. No. 09/152,469, filed Sep. 8, 1998, and now abandoned.

ORIGIN OF THE INVENTION

The invention described herein was made in the performance of work under a NASA contract and by an employee of the United States Government. It is subject to the provisions of Public Law 96-517 (35 U.S.C. §202), and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to aluminum-silicon (Al-Si) alloys. It relates particularly to a high strength Al-Si-based alloy suitable for high temperature applications for cast components such as pistons, cylinder heads, cylinder liners, connecting rods, turbo chargers, impellers, actuators, brake calipers and brake rotors.

2. Description of the Related Art

Al-Si alloys are most versatile materials, comprising 85% to 90% of the total aluminum cast parts produced for the automotive industry. Depending on the Si concentration in weight percent (wt. %), the Al-Si alloy systems fall into three major categories: hypoeutectic (<12% Si), eutectic (12-13% Si) and hypereutectic (14-25% Si). However, most prior alloys are not suitable for high temperature applications because their mechanical properties, such as tensile strength and fatigue strength, are not as high as desired in the temperature range of 500°F-700°F. To date, many of the Al-Si cast alloys are intended for applications at temperatures of no higher than about 450°F above. Above this temperature, the major alloy strengthening phases such as the 8' (Al3Cu) and S' (Al2CuMg) phase will become unstable, rapidly coarsen and dissolve, resulting in an alloy having an undesirable microstructure for high temperature applications.

Such an alloy has little or no practical application at elevated temperatures because, when the 8' and S' become unstable, the alloy lacks the lattice coherency between the aluminum solid solution lattice and the strengthening particles lattice parameters. A large mismatch in lattice coherency contributes to an undesirable microstructure that cannot maintain excellent mechanical properties at elevated temperatures.

One approach taken by the prior art is to use fiber or particulate reinforcements to increase the strength of Al-Si alloys. This approach is known as the aluminum Metal Matrix Composites (MMC) technology. For example, U.S. Patent No. 5,620,791 relates to an MMC comprising an Al-Si alloy having dispersion of particles having L12 crystal structure in the aluminum matrix is presented. The alloy is processed using low cost casting techniques such as permanent mold, sand casting or die casting.

The alloy of the present invention maintains a much higher strength at elevated temperatures (500°F and above) than other prior art alloys, due to a unique chemistry and microstructure formulation. The methods for strengthening the alloy in the present invention include: 1) Maximizing the formation of major strengthening 8' and S' phase in the alloy, with chemical composition given as Al3Cu, Al2CuMg, respectively. 2) Stabilizing the strengthening phases at elevated temperatures by controlling the Cu/Mg ratio and by the simultaneous addition of Titanium (Ti), Vanadium (V) and Zirconium (Zr) elements. 3) Forming Al12X (X=Ti, V, Zr) compounds with L12 crystal structure for additional strengthening mechanisms at elevated temperatures.

In the present invention, key alloying elements of Ti, V and Zr are added to the Al-Si alloy to modify the lattice parameter of the aluminum matrix by forming compounds of the type Al12X having L12 crystal structures (X=Ti, V and Zr). In order to maintain high degrees of strength at high temperatures, both the aluminum solid solution matrix and the particles of Al12X compounds should have similar face-centered-cubic (FCC) crystal structures, and will be coherent because their respective lattice parameters and dimensions are closely matched. When the condition of substantial coherency for the lattice is obtained, these dispersion particles are highly stable, which results in high mechanical properties for the alloy during long exposures at elevated temperatures.

In addition to the alloy composition and microstructure, a unique heat treatment schedule is provided in order to optimize the performance for the alloy strengthening mechanisms and phases formation within the alloy. The advantages

2

It is noted that the strength for most particulate reinforced MMC materials, manufactured from an Al-Si alloy, are still inferior for high temperature applications because the major 8' and S' strengthening phases are unstable, rapidly coarsen and dissolve at high temperatures.

Another approach taken by the prior art is the use of the Ceramic Matrix Composites (CMC) technology. For example, W. Kowbel has described the use of non-metallic carbon-carbon material for making pistons to operate at high temperatures in a paper titled, "Application of Net-Shape Molded-Carbon Composites in IC engines," *Journal of Advanced Materials*, July 1996. Unfortunately, manufacturing costs employing these MMC and CMC technologies are substantially higher than those using conventional Al-Si casting, which has hampered their ability to be priced competitively with Al-Si alloys in mass production for high temperature internal combustion engine parts and brake applications.

It is accordingly a primary object of the present invention to obviate the disadvantages of the prior art technologies.

SUMMARY OF THE INVENTION

According to the present invention, an Al-Si alloy containing dispersion of particles having L12 crystal structure in the aluminum matrix is presented. The alloy is processed using low cost casting techniques such as permanent mold, sand casting or die casting.

The alloy of the present invention maintains a much higher strength at elevated temperatures (500°F and above) than other prior art alloys, due to a unique chemistry and microstructure formulation. The methods for strengthening the alloy in the present invention include: 1) Maximizing the formation of major strengthening 8' and S' phase in the alloy, with chemical composition given as Al3Cu, Al2CuMg, respectively. 2) Stabilizing the strengthening phases at elevated temperatures by controlling the Cu/Mg ratio and by the simultaneous addition of Titanium (Ti), Vanadium (V) and Zirconium (Zr) elements. 3) Forming Al12X (X=Ti, V, Zr) compounds with L12 crystal structure for additional strengthening mechanisms at elevated temperatures.

In the present invention, key alloying elements of Ti, V and Zr are added to the Al-Si alloy to modify the lattice parameter of the aluminum matrix by forming compounds of the type Al12X having L12 crystal structures (X=Ti, V and Zr). In order to maintain high degrees of strength at high temperatures, both the aluminum solid solution matrix and the particles of Al12X compounds should have similar face-centered-cubic (FCC) crystal structures, and will be coherent because their respective lattice parameters and dimensions are closely matched. When the condition of substantial coherency for the lattice is obtained, these dispersion particles are highly stable, which results in high mechanical properties for the alloy during long exposures at elevated temperatures.

In addition to the alloy composition and microstructure, a unique heat treatment schedule is provided in order to optimize the performance for the alloy strengthening mechanisms and phases formation within the alloy. The advantages
of the present invention will become apparent as the descrip-

tion thereof proceeds.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram illustrating a coherent particle that has
similar lattice parameters and crystal structure relationship
with the surrounding aluminum matrix atoms.

FIG. 2 is a diagram illustrating a non-coherent particle
having no crystal structural relationship with the surround-
ing aluminum matrix atoms. Such an alloy has little or no
practical application at elevated temperatures.

FIG. 3 is an electron micrograph showing the size and
shape of the alloy 8' and S' coherent phases for prior art
alloys as observed at room temperature.

FIG. 4 is an electron micrograph showing the size, shape
and the amount of the alloy strengthening 8' and S' coherent
phases for the alloy of this invention as observed at room
temperature.

FIG. 5 is an electron micrograph showing the transforma-
tion of 8 and S' coherent phase, as observed in FIG. 3,
into the undesirable 8 and S noncoherent phases for the prior
art alloys after they have been exposed to 600°F for 100
hours. The 8 and S phases are noncoherent because they
become unstable rapidly coarsen and dissolve, resulting in
an alloy which has an undesirable microstructure for high
temperature applications.

FIG. 6 is an electron micrograph showing the highly
stable 8' and S' coherent phases for the alloy of this invention
after it has been exposed to 600°F for 100 hours. Unlike the
prior art, the alloy of this invention still retains the 8' and S'
cohesive phases, which are a desirable microstructure for high
temperature applications.

FIG. 7 is a chart showing a comparison of an alloy
according to the present invention with three well-known
prior art alloys (332, 390 and 413). The chart compares the
ultimate tensile strengths (tested at 500°F, 600°F and 700°F),
after exposure of all test specimens to a temperature of
500°F, 600°F, 700°F for 100 hours, respectively.

DETAILED DESCRIPTION OF THE
INVENTION

The present invention includes detailed compositional,
microstructure and processing aspects through conventional
casting processes. The Al—Si alloy of the present invention
is marked by an ability to perform in cast form, which is
suitable for elevated temperature applications. It is com-
prised of the following elements, in weight percent:

<table>
<thead>
<tr>
<th>Element</th>
<th>Weight Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon</td>
<td>14.0-25.0</td>
</tr>
<tr>
<td>Copper</td>
<td>5.5-8.0</td>
</tr>
<tr>
<td>Iron</td>
<td>0.05-1.2</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.5-1.5</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.05-0.9</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.05-1.0</td>
</tr>
<tr>
<td>Titanium</td>
<td>0.05-1.2</td>
</tr>
<tr>
<td>Zirconium</td>
<td>0.05-1.2</td>
</tr>
<tr>
<td>Vanadium</td>
<td>0.05-0.9</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.001-0.1</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>Balance</td>
</tr>
<tr>
<td>Aluminum</td>
<td>Balance</td>
</tr>
</tbody>
</table>

Silicon gives the alloy a high elastic modulus and low
thermal coefficient of expansion. The addition of silicon is
essential in order to improve the fluidity of the molten
aluminum to enhance the castability of the Al—Si alloy
according to the present invention. At a silicon level of at
least 14%, the alloy exhibits excellent surface hardness and
wear resistance properties.

Copper co-exists with magnesium and forms a solid
solution in the aluminum matrix to give the alloy age-
hardening properties, thereby improving the high tempera-
ture strength. Copper also forms the 8' phase compound
(A1,Cu), and is the most potent strengthening element in this
new alloy. The enhanced high strength at high temperatures
is affected if the copper wt % level is not adhered to.

Moreover, the alloy strength can only be maximized effec-
tively by the simultaneous formation for both of the 8'
(A1,Cu) and S' (A1,Cu,Mg) metallic compounds, using
proper addition of magnesium into the alloy relative to the
elements of copper and silicon. Experimentally, it is found
that an alloy with a significantly higher level of magnesium
will form mostly S' phase with insufficient amount of 8'
phase. On the other hand, an alloy with a lower level of
magnesium contains mostly 8' phase with insufficient
amount of S' phase.

To maximize the formation of both the 8' and S' phases,
the alloy composition was specifically formulated with
copper-to-magnesium (Cu/Mg) ratios ranging from 4 to 15,
with a minimum value for magnesium of no less than 0.5 wt
%. In addition to the Cu/Mg ratio, the silicon-to-magnesium
(Si/Mg) ratio is kept in the range of 10 to 25, preferably 14
to 20, to properly form the Mg,Si metallic compound as a
minor strengthening phase, in addition to the primary 8' and
S' phases. Moreover, the unique Cu:Mg ratio greatly
enhances the chemical reactions among aluminum (Al),
copper (Cu) and magnesium (Mg) atoms. Such chemical
reactions permit precipitation of a higher volume fraction of
the strengthening phases 8' and S' within the alloy. FIG. 4 is
an elect of the alloy strengthening 8' and S' coherent phases
for the alloy of this invention as observed room temperature.
The combination of high volume fraction and coherent 8
of the present invention, as shown in FIG. 4, lead to excep-
tional tensile strength and microstructure stability at
elevated temperatures. The average particle size of the 8
phase is less than 100 nm in diameter at room temperature.

Titanium, Vanadium and Zirconium are added to the
Al—Si alloy to modify the lattice parameter of the alumi-
num matrix by forming compounds of the type Al,X having
L12 crystal structures (X=Ti, V, Zr). In order to maintain
high degrees of strength at temperatures very near to their
alloy melting point, both the aluminum solid solution matrix
and the particles of Al4X compounds have similar face-
centered-cubic (FCC) crystal structures, and are coherent
because their respective lattice parameters and dimensions
are closely matched. For example, FIG. 1 is a diagram
illustrating a coherent particle that has similar lattice param-
eters and crystal structure relationship with the surrounding
aluminum matrix atoms. The compounds of the type Al4X
(X=Ti, V, Zr) particles also act as nuclei for grain size
refinement upon the molten aluminum alloy being solidified
from the casting process. Titanium and vanadium also
function as dispersion strengthening agents, having the
L12 lattice structure similar to the aluminum solid solution, in
order to improve the high temperature mechanical proper-
ties. Zirconium also forms a solid solution in the matrix to
a small amount, thus enhancing the formation of GP
(Guinier-Preston) zones, which are the Cu—Mg rich
regions, and the 8' phase in the Al—Cu—Mg system to
improve the age-hardening properties. Although the stable 8'
(A1,Cu) is the primary strengthening phase at elevated
temperatures, the importance of having Ti, V, and Zr ele-
ments in the alloy cannot be discounted. Upon the molten
alloy being solidified from the casting process, these ele-
ments react with aluminum to form Al₅X (X=Ti, V, Zr) com-
ounds that precipitate as nucleation sites for effective
grain size refinement. Moreover, Al₅X (X=Ti, V, Zr) pre-
cipitates also function as dispersion strengthening agents,
effectively blocking the movement of dislocations and
enhance the high temperature mechanical properties. High
temperature strength characteristics of the alloy of this
invention are detrimentally affected if Ti, V, and Zr are not
used simultaneously in the proper amount for forming
Al₅(Ti, V, Zr) precipitates.

FIG. 6 is an electron micrograph showing the highly
stable θ' and S' coherent phases for the alloy of this invention
after it has been exposed to temperatures of 600° F. for 100
hours. Unlike alloys of the prior arts, the alloy of this
invention still retains the θ' and S' coherent phases, which
are a desirable microstructure for high temperature applica-
tions. Because of the unique Cu/Mg ratio for the alloy of this
invention, θ' still maintains its coherency to the matrix even
after it has been soaked at 600° F. for 100 hours. During
soaking at 600° F, θ' grew slightly in thickness but it did not
coarsen, and still maintained a small diameter (i.e., less than
60 nm) and semi-coherency to the matrix, which is critical
for achieving high strength at elevated temperatures. The
coherency between Al matrix and θ' phase creates a definite
relationship between the θ' precipitate's and the matrix's
structure. As a result, the movement of dislocation is
impeded at the interface of θ' phase and the matrix, and
significant strengthening occurs. FIG. 5 is an electron micro-
graph showing the transformation of the θ' and S' coherent
phases, as observed in FIG. 3, into the undesirable θ and S
noncoherent phases for the prior art alloys after they have
been exposed to 600° F. for 100 hours. In FIG. 5, the θ' phase
from prior art alloys coarsens significantly and loses its
cohereency at elevated temperatures, thus resulting in a
drastic loss in strength for elevated temperature applications.
FIG. 2 is a diagram illustrating a non-coherent particle
having no crystal structural relationship with the surround-
ing aluminum matrix atoms. Such an alloy has little or no
practical application at elevated temperatures.

Nickel improves the alloy tensile strength at elevated
temperatures by reacting with aluminum to form the Al₅Ni₃
and Al₅Ni compounds, which are stable metallurgical phases
to resist the degradation effects from the long-term exposure
to high temperature environments.

In order for these strengthening mechanisms to function
properly within the alloy, the casting article must have a
unique combination of chemical composition and heat treat-
ment history. The heat treatment is specifically designed to
maximize the performance of the unique chemical compo-
sition. As discussed above, the exceptional performance of
the alloy of the present invention is achieved by the combi-
nation of the following strengthening mechanisms through
a unique heat treatment schedule. The heat treatment for the
alloy of this invention was developed to maximize the formation
of θ' and S' phases in the alloy (high volume fraction), to stabilize θ' phase at elevated temperature by controlling Cu/Mg ratio, and to maximize the formation of Al₅(Ti, V, Zr) compounds for additional strengthening with mechanisms simultaneous addition of Ti, V, and Zr.

Maximum high temperature strength has been attained by
the present invention when using a T5 heat treatment con-
sisting of aging at 400 to 500° F. for four to twelve hours.
The heat treatment schedule complements the unique alloy
composition to form a maximum amount of precipitates with
uniform distribution and optimum particle size. Thus, the
present alloy has properties that are superior to the prior art
alloys, because of a unique combination of chemical com-
position and heat treatment processing.

The alloy of the present invention is processed using
conventional gravity casting in the temperature range of
about 1325° F. to 1450° F., without the aid of external
pressure, to achieve dramatic improvement in tensile
strengths at 500° F. to 700° F. However, it is anticipated that
further improvement of tensile strengths will be obtained
when the alloy of the present invention is cast using pressure
casting techniques such as squeeze casting.

An article, such as a cylinder head, engine block or a
piston, is cast from the alloy, and the cast article is then
solutionized at a temperature of 900° F. to 1000° F. for
fifteen minutes to four hours. The purpose of the solution-
ing step is to dissolve unwanted precipitates and reduce
any segregation present in the alloy. For applications at
temperatures from 500° F. to 700° F. the solutioning treat-
ment may not be required.

After solutionizing, the cast article is advantageously
quenched in a quenching medium, at a temperature within
the range of 120° F. to 300° F. most preferably 170° F. to
250° F. The most preferred quenching medium is water.
After quenching, the cast article is aged at a temperature of
425° F. to 485° F. for six to 12 hours.

FIG. 7 is a chart which illustrates the dramatic improve-
ment in the ultimate tensile strength (UTS) at elevated
temperatures for a cast article produced according to the
present invention. This table compares the tensile strengths
of articles produced according to this invention, with articles
prepared from two well known hypo-eutectic (332.0), and
eutectic (413.0), and hyper-eutectic (390.0) alloys, after
articles cast from these alloys had been exposed to 500° F.,
600° F. and 700° F., respectively, for 100 hours. The cast
articles were then tested at elevated temperatures of 500° F.,
600° F., and 700° F., respectively. It is noted that the tensile
strength of articles prepared according to this invention is
more than three times that of those prepared from the
conventional eutectic 413.0 alloy, and more than four times
that of those prepared from hypo-eutectic 332.0 alloy and
the hyper-eutectic 390.0 alloy, when tested at 700° F.

The alloy of the present invention may be used in a bulk
alloy form. It may also be used as an alloy matrix for the
making of aluminum metal matrix composites (MMC). Such
composites comprise the aluminum alloy of the present
invention as a matrix containing a filler material, which is in
the form of particles, whiskers, chopped fibers and continu-
fous fibers. One of the most popular ways to produce an
MMC is to mechanically mix and stir various ceramic
materials in the form of small particles or whiskers into a
molten aluminum alloy. This process has been called a
compo-casting or stir-casting of metal composite. In stir-
casting techniques, the approach involves mechanical mixing
and stirring of the filler material into a molten metal bath.
The equipment usually consists of a heated crucible con-
taining molten aluminum alloy, with an electric motor that
drives a paddle-style mixing impeller, that is submerged in
the molten metal. The filler material is poured slowly into
the crucible above the melt surface and at a controlled rate,
to ensure smooth and continuous feed. The temperature is
usually maintained below the liquidus temperature to keep
the aluminum alloy in a semi-solid condition in order to
enhance the mixing uniformity of the filler material.

As the mixing impeller rotates at moderate speeds, it
creates a vortex that draws the reinforcement particles
into the melt from the surface. The impeller is designed to
create a high level of shear force, which helps to remove the
7 adsorbed gases from the surface of the particles. The high shear also engulfs the particle in molten aluminum alloy, which promotes particle wetting in order to enhance the homogeneous distribution of the filler material within the MMC.

The filler materials in the metal composite should not be confused with the Al<sub>X</sub> (X=Ti, V, Zr) particles with a diameter typically less than 100 nanometers (nm) in size. The filler materials or reinforcement materials added into the aluminum MMC usually have minimum dimensions which are much greater than 500 nm, typically in the range of 1 to 20 microns.

Suitable reinforcement materials for making aluminum metal matrix composite include common materials such as Silicon Carbide (SiC), Aluminum Oxide (Al<sub>2</sub>O<sub>3</sub>), Boron Carbide (B<sub>4</sub>C), Yttrium Oxide (Y<sub>2</sub>O<sub>3</sub>), beryllium, graphite, diamond particles and mixtures thereof. These reinforcement materials are present in volume fractions up to about 60% by volume, and more preferably 5-35% by volume.

The present invention has been specified in detail with respect to certain preferred embodiments thereof. It is understood that variations and modifications in this detail may be effected without departing from the spirit and scope of the present invention, as defined in the hereto-appended claims.

We claim:

1. A cast article from an aluminum alloy, which has improved mechanical properties at elevated temperatures, the cast article having the following composition in weight percent:

<table>
<thead>
<tr>
<th>Element</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon</td>
<td>14-25.0</td>
</tr>
<tr>
<td>Copper</td>
<td>5.5-8.0</td>
</tr>
<tr>
<td>Iron</td>
<td>0.05-1.2</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.5-1.5</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.05-0.9</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.05-1.0</td>
</tr>
<tr>
<td>Titanium</td>
<td>0.05-1.2</td>
</tr>
<tr>
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</tr>
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<td>Phosphorus</td>
<td>0.001-0.1</td>
</tr>
<tr>
<td>Aluminum</td>
<td>Balance</td>
</tr>
</tbody>
</table>

wherein the silicon-to-magnesium (Si/Mg) ratio is 10-25, and the copper-to-magnesium (Cu/Mg) ratio is 4-15.

2. A cast article as in claim 1, comprising an aluminum solid solution matrix containing a simultaneous dispersion of three types of Al<sub>X</sub> compound particles (X=Ti, V, Zr) having a L1<sub>2</sub> crystal structure and lattice parameters which are coherent to the aluminum matrix lattice.

3. A cast article as in claim 2, wherein the aluminum solid solution matrix contains a simultaneous dispersion of three types of Al<sub>X</sub> compound particles (X=Ti, V, Zr), whose average size is less than about 100 nm in diameter.

4. A cast article as in claim 2, wherein the aluminum solid solution matrix contains a simultaneous dispersion of two types of particles from θ' and S' phases, and wherein the average particle size of the θ' phase is less than 300 nm in diameter at room temperature.

5. A cast article as in claim 4, wherein the average size of the θ' phase particle is less than 250 nm after soaking at 600°F for 100 hours.

6. A cast article as in claim 4, wherein the θ' phase remains semi-coherent to the matrix after soaking between 600°F and 700°F for 100 hours.

7. A metal matrix composite comprising an aluminum alloy having the following composition in weight percent:

<table>
<thead>
<tr>
<th>Element</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
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<td>Silicon</td>
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<td>Phosphorus</td>
<td>0.001-0.1</td>
</tr>
<tr>
<td>Aluminum</td>
<td>Balance</td>
</tr>
</tbody>
</table>

wherein the silicon-to-magnesium (Si/Mg) ratio is 10-25, and the copper-to-magnesium (Cu/Mg) ratio is 4-15; the aluminum alloy comprising Al<sub>X</sub> (X=Ti, V, Zr) compound particles with L1<sub>2</sub> crystal structure in an aluminum solid solution, and the aluminum alloy serving as a matrix containing up to about 60% by volume of a secondary filler material having a geometry selected from the group consisting of particles, whiskers, chopped fibers or continuous fibers.

8. The metal matrix composite of claim 7, wherein the secondary filler material is selected from the group consisting of Silicon Carbide (SiC), Aluminum Oxide (Al<sub>2</sub>O<sub>3</sub>), Boron Carbide (B<sub>4</sub>C), Yttrium Oxide (Y<sub>2</sub>O<sub>3</sub>), graphite, diamond particles, and is present in volume fraction between 5% and 35% by volume.

9. An aluminum alloy having the following composition in weight percent:

<table>
<thead>
<tr>
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<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon</td>
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<tr>
<td>Manganese</td>
<td>0.05-1.2</td>
</tr>
<tr>
<td>Titanium</td>
<td>0.05-1.2</td>
</tr>
<tr>
<td>Zirconium</td>
<td>0.05-1.2</td>
</tr>
<tr>
<td>Vanadium</td>
<td>0.05-1.2</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.05-0.9</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.001-0.1</td>
</tr>
<tr>
<td>Aluminum</td>
<td>Balance</td>
</tr>
</tbody>
</table>

wherein the silicon-to-magnesium (Si/Mg) ratio is 10-25, and the copper-to-magnesium (Cu/Mg) ratio is 4-15.

10. An aluminum alloy as in claim 9, comprising an aluminum solid solution matrix containing a simultaneous dispersion of three types of Al<sub>X</sub> compound particles (X=Ti, V, Zr) having a L1<sub>2</sub> crystal structure and lattice parameters which are coherent to the aluminum matrix lattice.