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ALUMINUM ALLOY

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This application is a continuation-in-part of my copending application Serial No. 389,020, filed April 17, 1941. The invention relates to alloys, and particularly to aluminum base alloys suitable for casting and working, and having high strength at ordinary and elevated temperatures.

It is an object of this invention to produce alloys having relatively high elongation and relatively high tensile strength.

It is a further object of this invention to provide a relatively light alloy which may be easily cast and machined, which may be used at elevated temperatures without a rapid deterioration of desirable properties, and which may be readily treated with anodic treatment to give excellent lustre and finish.

It is a still further object of this invention to provide an alloy having a relatively high proportional limit and relatively high fatigue strength, and in which these properties may be obtained without heat treatment.

When magnesium and zinc are added to aluminum in the proper proportions, a ternary compound of aluminum, magnesium and zinc is formed, which compound is soluble in solid solution in the aluminum. The presence of this compound in a relatively small amount greatly improves the characteristics of aluminum and produces an alloy having high strength combined with high ductility, good casting, rolling, extruding and forging properties, and good color. In calculating the amount of magnesium and zinc that should be present in the aluminum alloy to form the desired percentage of ternary compound, only magnesium which is not combined with silicon is to be calculated, as it is only such magnesium that is available to combine with zinc and aluminum to form the ternary compound.

The ternary compound is said by some investigators to have a composition having substantially the formula $Al_3Mg_7Zn_6$, and other investigators have considered the formula for the ternary compound as being $Al_2Mg_3Zn_3$. It will be seen that the amounts of magnesium and zinc relative to each other are quite similar in both formulae. The magnesium and zinc should be present in about the proportion necessary to form the ternary compound of either formulae or, preferably, the ratio of the magnesium to zinc in the alloy should be between the ratios in the formulae.

An excess of zinc, over and above that which cooperates with magnesium and aluminum to form a ternary compound according to the above formula having the greatest proportion of zinc, increases the brittleness and decreases the ductility of the alloy. For this reason it is undesirable that zinc be present in quantities substantially greater than the amount to react to form such a ternary compound with magnesium and aluminum. The most desirable properties are obtained when the magnesium and the zinc are proportioned so that the ratio of magnesium (uncombined with any silicon) to zinc is about equal to the ratio represented by the formula $Al_2Mg_3Zn_3$, or somewhat larger as represented by the formula $Al_3Mg_7Zn_6$. A small amount of magnesium may be provided to replenish losses that may occur when the alloy metal is remelted.

Magnesium adds to the hardness and machining qualities of the alloy and, as above stated, should be present in an amount sufficient to combine with the zinc and aluminum present. In greater quantities, magnesium tends to make the alloy sluggish, decreasing castability.

The improved aluminum alloys may have the ternary compound of aluminum, zinc and magnesium present in an amount ranging from about 2% to 20%, the preferred range being between about 3% and 15%. At room temperature the ternary compound goes into solid solution in aluminum alloys in an amount of about 2%. The percentage in solid solution increases at high temperatures and decreases upon cooling, the excess precipitating out. Aluminum alloys containing the ternary compound may, therefore, be advantageously heat treated to improve their properties.

A small amount of silicon is usually present in aluminum alloys and up to 1.5% silicon may be present in the alloys of the present invention. If the alloys are to be rolled or worked the silicon should be low, from about the minimum obtainable quantity of .04% or .05% to about .7%. More than .7% is frequently desirable in casting alloys. Silicon combines with magnesium in preference to most elements, each part by weight of silicon combining with about 1.75 parts, by weight, of magnesium to form Mg_2Si. At least sufficient magnesium is therefore added to the alloy to combine with the silicon uncombined with any calcium to form Mg_2Si, and in addition to combine with all the zinc and form the ternary compound according to the formula $Al_2Mg_3Zn_3$. Mg_2Si is more stable than the ternary compound above mentioned and may be maintained in solid solution in aluminum alloys in an amount up to about 1.85%, which is the quantity of Mg_2Si present if the silicon is present in the alloy, and acts as a hardener which is sometimes desirable in conjunction with the ternary compound. Mg_2Si does not, however, make as efficient use of the magnesium as does the above mentioned ternary compound. Therefore, it is desirable to have the magnesium present on the rich side to prevent the silicon from being present in excess and taking magnesium away from the ternary compound.

It has now been found that aluminum alloys containing magnesium (over that necessary to

combine with silicon) and zinc in the proportions to form a ternary compound are greatly improved by incorporating in the alloy .05% to 1.5% manganese, .05% to 1.5% chromium, .1% or .2% to 1.5% copper and, preferably, one or more of the grain refining elements, such as those selected from the group consisting of titanium, columbium, zirconium, boron, tungsten, molybdenum, tantalum and vanadium. The grain refiners should be present in a total amount of .005% to .5%, and the copper, manganese and chromium should preferably total less than 4%. The alloy may contain from about .1% to about 1.5% of iron.

Manganese, although it decreases the tensile strength and elongation to some degree, increases the yield strength, hardness and proportional limit of the alloy. It also makes the alloy more corrosion resistant.

Alloys containing manganese may be readily heat treated or age hardened to give somewhat superior properties, but very desirable properties are obtainable when castings are simply aged at room temperature, or when quenched from the mold and aged.

Manganese is a very effective element in the alloy and desirable improvements are noted when about .1% or even a little less, such as .05%, is present in the alloy. The preferred properties are obtained with about .2% to about .5% or .8% manganese, and in some cases it is desirable to have the manganese present in amounts as great as about 1%, or even 1.5%.

Chromium is a particularly effective alloying element in the alloy of the present invention. Although it does not appear to improve the proportional limit and yield strength of the alloy quite as much as does manganese, it increases the elongation and further increases corrosion resistance. It is, therefore, particularly advantageous that both chromium and manganese be present. As little as .05% or .1% chromium, particularly with manganese, is effective in improving the properties of the alloy, but .2% or .3% to about 1%, or even 1.5%, is desirable. When manganese is also present, the total of manganese and chromium should preferably be between about .3% and 2.5% of the alloy.

Copper functions in a somewhat different manner than do manganese and chromium. Due to the fact that copper is considerably more soluble in aluminum at high temperatures than at low temperatures, copper acts as a precipitation hardening ingredient, so an alloy containing copper is benefited more by solution heat treatment.

Small proportions of copper even without solution treatment improves the proportional limit and yield strength of the alloy. As little as .1% of copper noticeably improves the alloy, but it is preferable, especially in alloys to be solution heat treated, that about .2% to about 1.5% of copper be present. The presence of from .4% or .5% to 1.5% of copper permits a reduction in the amount of ternary compound so that a desirable alloy is produced with as little as 1% of the ternary compound.

The quantity of manganese and chromium desired in a given alloy also depends somewhat upon the quantity of copper present and upon the amount of ternary compound, a given hardness and tensile strength often being obtainable either with a relatively large amount of strength-improving metals and a relatively small amount of ternary compound, or with a relatively small amount of such metals and a relatively large amount of magnesium and zinc in the proportions of a ternary compound.

An alloy containing 2%, or even as little as 1%, of the ternary compound may be used for casting purposes. The castability, however, is improved with an increase in the amount of ternary compound and it is, therefore, preferred to have a larger percentage of the ternary compound present, such as 4% to 8% or 9% for casting purposes, 9% ternary compound containing about 5.4% zinc. When the casting is more or less intricately shaped, still greater percentages, such as 10% to 12%, of the ternary compound may be present. For alloys to be forged or shaped after casting, the ternary compound should be present in the lower ranges, such as 1% to 6% or so, as the metal is less hard with the lower percentages of the ternary compound.

A larger proportion of the ternary compound may be present in alloys which are to be given a so-called "solution treatment" than in alloys to be given only an aging treatment, or those to be quenched from the casting mold and aged at relatively low temperatures. Thus, the desirable properties of the solution heat treated alloys may be obtained when they contain the ternary compound in amounts up to 12% or so, whereas less of the ternary compound, such as 4% to 6%, is preferred in alloys which are quenched upon removal from the mold and heat treated at a low temperature, or aged at room temperature.

It has generally been considered that aluminum alloys of magnesium containing iron much above the impurity value in commercial aluminum are of little commercial value, but it has also now been found that an alloy containing the magnesium, zinc and silicon proportioned as herein described, and also containing manganese, chromium and a grain refining metal such as is set forth in the above group, is improved by the presence of iron in suitable proportion.

Iron in suitable amounts further increases the hardness and tensile strength of the alloy without decreasing its ductility a substantial amount. A small amount of iron thus permits one to obtain the properties desired with a smaller amount of magnesium and zinc. Iron also improves castability. These alloys containing iron may be readily heat treated or age hardened to give somewhat superior properties, but the iron in combination with manganese, chromium and the ternary elements in the above proportion is also outstanding in that almost as desirable properties are obtained when castings are aged at room temperature without a heat treatment or quenching.

Iron has generally been considered to crystallize in large platelike crystals, which weaken the alloy. Iron in the presence of the ternary compound appears to crystallize in finely dispersed form and the ternary compound also seems to be dispersed, thus producing a highly desirable alloy.

The quantity of iron desired in the alloy depends upon the quantity of other hardening ingredients present, upon the amount of ternary present, and upon what properties are most important. A given hardness and tensile strength are often obtainable with a relatively larger amount of iron and a relatively smaller amount of ternary compound, or a relatively smaller amount of iron and a relatively larger amount of ternary. Iron may be present in the alloys of the present invention in amounts between about 0.1% and about 1.5%. With the larger percent-

age of iron in the alloys, the percentages of manganese and chromium may be reduced considerably. If both manganese and chromium are present in substantial amounts and if workability, ductility and corrosion resistance are not to be impaired, the iron should be low, i. e., about 0.1% or less to about .6% or .7% of the alloy. If yield strength and high tensile strength are most important and ductility less important, the amount of iron may be greater.

The grain refining elements are particularly desirable in an aluminum alloy containing iron, copper, manganese, chromium and the ternary compound. Although the iron itself improves the properties of the alloy, the manganese, chromium, copper and grain refining elements exert a still further improvement independently of iron.

The aluminum alloys of the present invention containing magnesium, uncombined with silicon, and zinc in the proportion of a ternary compound, when cast in molds of a design such that chilling takes place substantially simultaneously in the various portions of the casting, solidify without the use of grain refining agents to form good castings. However, it has been found that certain grain refining elements substantially improve the properties of the aluminum alloys containing the ternary compound, iron, copper, manganese and chromium. This is especially true when the metal is cast in molds of more or less intricate shape where the chilling may not be so uniform throughout the casting.

The grain refiners which I have found exert greatest improvement in the properties of the alloy are members of the group consisting of boron in the amount of .005% to .1%, zirconium in the amount of .01% to .5%, tungsten in the amount of .01% to .5%, molybdenum in the amount of .01% to .5%, vanadium in the amount of .01% to .5%, titanium in the amount of .05% to .5%, columbium in the amount of .01% to .5% and tantalum in the amount of .05% to .5%. These grain refining elements should preferably be present in a total amount of from .005% to .5% and it is frequently desirable to have more than one of these elements present in a given alloy.

While the grain refiners in the above group are desirable in the alloys of the present invention, not all of the grain refiners affect the properties in the same way. The particular refiner or group of refiners selected in any given instance depends upon the particular condition which must be satisfied. The grain refiners selected from the group consisting of titanium, tungsten, molybdenum, zirconium and vanadium, and especially tungsten and molybdenum, improve both the strength and the elongation of the castings. Titanium being readily available is frequently used, but when special properties of the fabricated article are important it is desirable to select the grain refiner that is most suitable for such properties. The grain refiners boron, columbium and tantalum may advantageously be used where appearance, finish and corrosion resistance are important.

The above described hardening elements, manganese and chromium, substantially decrease the hot shortness, improve the properties of the alloy and assist in maintaining the improved properties at high temperatures such as are encountered in internal combustion engines. The above grain refining elements, particularly members of the group consisting of zirconium, tungsten, molybdenum, vanadium and titanium, also have this property particularly when present in larger amounts, such as .2% or .3% or so. It may, therefore, be desirable to have up to .5% or so of these latter elements present.

The following examples illustrate the alloys of the present invention.

Example 1

An aluminum base alloy containing 6% of the ternary compound based on the formula $Al_3Mg_7Zn_6$, about .3% manganese, about .25% chromium, about .2% copper, about .2% titanium, about .2% silicon, and about .6% iron, was prepared and test bars were chill cast from this alloy. Part of the test bars were air cooled from the mold and part were quenched, and both kinds of test bars were aged seven days at room temperature. The respective tensile strengths of the aged and quenched test bars were 38,600 lbs./sq. in. and 41,300 lbs./sq. in., the respective proportional limits were 18,600 lbs./sq. in. and 17,700 lbs./sq. in., the respective yield strengths were 26,500 lbs./sq. in. and 25,500 lbs./sq. in., the Rockwell E hardness was 84.0 and 81.2, respectively, and the elongation was 5% and 7.4%, respectively.

When the copper content was about .4% the respective tensile strengths of the aged and quenched test bars were 41,700 lbs./sq. in. and 42,000 lbs./sq. in., the respective proportional limits were 19,300 lbs./sq. in. and 18,100 lbs./sq. in., the respective yield strengths were 32,400 lbs./sq. in. and 30,400 lbs./sq. in., the Rockwell E hardness was 86.9 and 83.7, respectively, and the elongation was 5.9% and 7.6%, respectively.

When the copper content was about 1% the respective tensile strengths of the aged and quenched test bars were 36,200 lbs./sq. in. and 37,600 lbs./sq. in., the respective proportional limits were 26,900 lbs./sq. in. and 19,400 lbs./sq. in., the respective yield strengths were 33,900 lbs./sq. in. and 31,800 lbs./sq. in., the Rockwell E hardness was 85.1 and 82.5, respectively, and the elongation was 2.6% and 4.8%, respectively.

Example 2

Sand cast test bars were prepared from an alloy containing about 1.72% magnesium, about 3.69% zinc, about .28% silicon, about .27% manganese, about .28% chromium, about .18% titanium, about .64% iron and about .23% copper, with the balance substantially all aluminum and minor impurities. Some of the bars were aged seven days at room temperature; others were aged ten hours at 180° C.; and a third group was aged three hours at 125° C. The aged test bars were then tested, under standard conditions.

The first group of test bars had a tensile strength of 31,700 lbs./sq. in., a proportional limit of 14,100 lbs./sq. in., a yield strength of 21,800 lbs./sq. in., a Rockwell E hardness of 73.6, and an elongation of 4.6%.

The second group had a tensile strength of 32,200 lbs./sq. in., a proportional limit of 16,300 lbs./sq. in., a yield strength of 27,600 lbs./sq. in., a Rockwell E hardness of 77.6, and an elongation of 2%.

The third group had a tensile strength of 30,300 lbs./sq. in., a proportional limit of 12,900 lbs./sq. in., a yield strength of 20,900 lbs./sq. in., a Rockwell E hardness of 70.1, and an elongation of 4.3%.

Since the molecular proportion of zinc is never more than the molecular proportion of the rela-

tively light magnesium in the ternary compound, it is seen that in addition to high strength the alloys are light in weight and are, therefore, especially adapted to aircraft construction and the like. This is particularly true when the quantity of ternary compound is sufficiently low so that the alloy may be drawn or rolled into structural members.

If the alloy contains uncombined silicon, about 1.75% magnesium is required to combine with each percent of uncombined silicon to form magnesium silicide (Mg_2Si) before any ternary compound will be formed. For example, if 2% of the ternary compound on the basis of $Al_2Mg_3Zn_3$ be desired in an alloy having .3% silicon, the amount of magnesium to be added to form the ternary compound will be .45%, or about .5%, and the magnesium to combine with .3% silicon will be about .5%, making a total of about 1%.

The magnesium and zinc in an alloy containing .7% free silicon and 20% $Al_3Mg_7Zn_6$ would be about 7% and 12%, respectively. The alloys described herein include aluminum, magnesium and zinc, the magnesium, uncombined with silicon, being proportioned to the zinc in the ranges of the formulae given for the ternary compound. The proportions for the formation of the ternary compound in the alloy exist when the magnesium is about 35% to 45% of the zinc content plus 175% of the silicon content. Most desirable properties may be obtained when the magnesium (uncombined with silicon) is in the lower portion of this range, or about 35% to 40% of the zinc.

In the above examples of alloys of the present invention it is to be noted that excellent tensile strength and hardness are obtainable in a relatively short time by aging at room temperature. A very astounding fact has been discovered, however, in connection with these alloys, namely, that the tensile strength may increase up to approximately 50% of its initial value by aging at room temperature for relatively long periods of time, such as a few months. The same improvement in tensile strength can, of course, be obtained relatively quickly by aging at temperatures above room temperature.

To obtain properties even of the same order of magnitude in aluminum base alloys commonly in use, one has to resort to a solution and aging heat treatment, whereas in alloys of the present invention it is not necessary to solution heat treat for improvement in properties.

The alloys of the present invention have good fatigue and tensile strength and a relatively high proportional limit, even at relatively high temperatures; they have to be heat treated if it is desired to improve and modify their properties, although such heat treatment is not required; and they have sufficient ductility and hardness so that they can be rolled or formed into sheets, rods, wire, structural shapes, castings, machine parts, etc. These alloys have a desirable color and are suitable for many uses, among them being the production of castings which are shaped or formed to some extent after casting. The alloys having the lower percentages of ternary compound may even be forged at room temperature and are thus useful for many special purposes.

As pointed out above, grain refiners are usually desirable in alloys of the present invention. However, it has been found that the alloys of the present invention have relatively high strength, high proportional limit and ductility without solution heat treatment, even in the absence of the grain refiners. The alloys may be cast, rolled, forged or otherwise shaped with or without grain refiners.

It is to be understood that, in considering the amount of zinc and magnesium to add to aluminum alloys to form the ternary compound of aluminum, magnesium and zinc in the alloy, such magnesium as is necessary to combine with the uncombined silicon is not to be considered as part of the magnesium necessary to form the specified amount of ternary compound.

It is to be understood that the particular compounds disclosed and the procedure set forth are presented for purposes of explanation and illustration, and that various equivalents can be used, and modifications of said procedure can be made, without departing from my invention as defined in the appended claims.

What I claim is:

1. An aluminum alloy containing magnesium, zinc, about .1% to 1.5% iron, about .05% to 1.5% manganese, about .05% to 1.5% chromium, about .1% to 1.5% copper, silicon in an amount up to 1.5%, and one or more grain refining metals, with the balance substantially all aluminum and minor impurities, the amount of zinc in the alloy being about .6% to 7.2%, and the amount of magnesium in the alloy uncombined with silicon being about 35% to 45% of the zinc content, the total magnesium being within the range of about .4% to 7%.

2. An aluminum alloy containing magnesium, zinc, about .1% to 1.5% iron, about .05% to 1.5% manganese, about .05% to 1.5% chromium, about .1% to 1.5% copper, silicon in an amount up to 1.5%, and one or more grain refining metals in a total amount of .005% to about .5%, with the balance substantially all aluminum and minor impurities, the amount of zinc in the alloy being about .6% to 7.2%, and the amount of magnesium in the alloy uncombined with silicon being about 35% to 45% of the zinc content, the total magnesium being within the range of about .4% to 7%.

3. The alloy of claim 1 in which the zinc content is about 1.2% to 6% and the magnesium content is within the range of about .5% to 6%.

4. The alloy of claim 1 in which the zinc content is about 1.2% to 4.8%, the magnesium content is within the range of about .5% to 5%, and the copper content is within the range of .2% to 1.5%.

5. The alloy set forth in claim 2 in which the copper is present in the amount of .1% to .5%.

6. The alloy set forth in claim 2 in which titanium is present in the amount of .05% to .5%.

7. The alloy set forth in claim 2 in which zirconium is present in the amount of .01% to .5%.

8. The alloy set forth in claim 2 in which molybdenum is present in the amount of .01% to .5%.

9. An aluminum alloy containing magnesium, zinc, about .1% to 1.5% iron, about .05% to 1.5% manganese, about .05% to 1.5% chromium, about .1% to 1.5% copper, and silicon in an amount up to 1.5%, with the balance substantially all aluminum and minor impurities, the amount of zinc in the alloy being about .6% to 7.2%, and the amount of magnesium in the alloy uncombined with silicon being about 35% to 45% of the zinc content, the total magnesium being within the range of about .4% to 7%.

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