

Hardenable Al-Mg-Si-based aluminum alloy

Field of the invention

The invention relates to a hardenable Al-Mg-Si-based aluminum alloy.

Description of the prior art

In order to improve the thermosetting capability of A6061 Al-Mg-Si-based aluminum alloy which is age-hardened at room temperature, WO2013/124472A1 suggests adding to the solid solution of the aluminum alloy a vacancy-active trace element, namely tin (Sn) and/or indium (In).

In addition, it is known ("Statistical and thermodynamic optimization of trace-element modified Al-Mg-Si-Cu Alloys", Stefan Pogatscher et al.) that certain main and minor alloying elements of the A6061 aluminum alloy reduce the solubility of tin or indium in aluminum alloy, which negatively affects the storage stability at room temperature of the 6xxx aluminum alloys. For example, an increased content of Mg, Si, Cu or Zn in the 6xxx aluminum alloy should reduce the solubility, whereas an increased content of Fe, Ti and Mn increases the solubility. In addition, interaction effects, e.g. between Si and Mg and/or between Cu and Mg, also play an important role in the solubility of Sn in the aluminum alloy.

However, the main and minor alloying elements can not be arbitrarily varied in their content in the aluminum alloy, because in addition to a desirable high thermosetting capability other mechanical and/or chemical requirements - such as formability, strength, ductility and/or corrosion resistance - need to be met. This requires, for example, high concentrations of main alloying elements in the aluminum alloy in order to form certain hot precipitations.

In the setting of the composition of an Al-Mg-Si-based aluminum alloy, countercurrent proportions are therefore usually required for the main and secondary alloying elements - on the one hand, those quantity proportions which are beneficial for the solubility of Sn in the aluminum alloy in order to ensure high storage stability at room temperature, and on the other hand those quantity proportions which ensure high mechanical and/or chemical characteristics or properties of the aluminum alloy, but which usually adversely affect the solubility of Sn.

Summary of the invention

It is therefore the object of the invention to modify a hardenable Al-Mg-Si-based aluminum alloy with Sn as a trace element in the composition such that a high mechanical and chemical property of the aluminum alloy can be combined after hot age-hardening with high storage stability at room temperature. In addition, the aluminum alloy should be particularly suitable for the use of secondary aluminum.

The invention solves this problem in that the aluminum alloy comprises from 0.6 to 1% by weight of magnesium (Mg), from 0.2 to 0.7% by weight of silicon (Si), from 0.16 to 0.7% by weight of iron (Fe), from 0.05 to 0.4% by weight of copper (Cu), a maximum of 0.15% by weight (or from 0 to 0.15% by weight) of manganese (Mn), a maximum of 0.35% by weight (or from 0 to 0.35% by weight) of chromium (Cr), a maximum of 0.2% by weight (or from 0 to 0.2% by weight) of zirconium (Zr), a maximum of 0.25% by weight (or from 0 to 0.25% by weight) of zinc (Zn), a maximum of 0.15% by weight (or from 0 to 0.15% by weight) of titanium (Ti), 0.005 to 0.075% by weight of tin (Sn) and/or indium (In), and the remainder aluminum and production-related unavoidable impurities, wherein the ratio of the weight percentages of Si/Fe is less than 2.5 and the content of Si is determined according to the equation $\text{wt.\% Si} = A + [0.3 * (\text{wt.\% Fe})]$, with the parameter A being in the range of 0.17 to 0.4% by weight.

As a result of the rule of restricting the Si content to 0.2 to 0.7% by weight and the Fe content to 0.16 to 0.7% by weight and adjusting the Si content to the Fe content, the storage stability and the thermosetting capability of the Al-Mg-Si-aluminum alloy can be particularly favorably influenced if this adjustment meets both the ratio of the weight percentages of Si/Fe less than 2.5 and the equation $\text{wt.\% Si} = A + [0.3 * (\text{wt.\% Fe})]$, with the parameter A being in the range of 0.17 to 0.4% by weight.

An aluminum alloy tuned so closely in Si and Fe content, which tuning can be recognized, for example, in the hatched area in Fig. 1, can, because of the upper limit of said provision, ensure sufficient solubility of tin and/or indium in the solid solution of the aluminum alloy, which slows down the precipitation behavior during cold age-hardening and thus promotes the storage stability of the aluminum alloy. In addition, due to the lower limit in the tuning, adequate precipitation behavior during hot age-hardening is to be expected, whereby high strength values can be achieved in the hot age-hardening and the aluminum alloy itself can achieve or improve those mechanical and chemical properties which are known from 6xxx aluminum alloy with a higher content of main and secondary alloy elements.

Surprisingly, however, it has been found that, compared with known 6xxx aluminum alloys, comprising Sn to suppress cold age-hardening, this method can be used to observe a much slower precipitation behavior at room temperature. Although it is known that a comparatively low Si content may be responsible for delayed cold age-hardening, the tuning of the Si content according to the invention, however, leads far beyond these known effects and shows an unusually high storage stability of the aluminum alloys.

According to the invention, therefore, the advantages of a particularly high storage stability at room temperature as well as good thermosetting capability of the aluminum alloy can be combined.

In addition, this composition according to the invention may also be particularly suitable for the use of secondary aluminum for this purpose due to the comparatively high Fe content.

In general, it is mentioned that the Al-Mg-Si-aluminum alloy can comprise impurities each having a maximum of 0.05% by weight and a total of at most 0.15% by weight. In addition, it is generally mentioned that maximum weight percentages, such as those found with Mn, Cr, Zr, Zn or titanium, for example, can be considered as starting from 0.

For the sake of completeness, it is further mentioned that aluminum or an aluminum alloy, obtained from aluminum scrap, can be understood as the secondary aluminum.

The storage stability and the thermosetting capability of the aluminum alloy can be further improved when the parameter A is in the range of 0.26 to 0.34% by weight. As a result of this rule, the solubility of Sn can thus become relatively high and Si has only a low impact on cold age-hardening. This allows an unexpectedly high stability at room temperature. In addition, it can be seen that this alloy set in this way can achieve surprisingly high strength after hot age-hardening, for example by means of heat aging, although this alloy has a comparatively low Si content.

An optimum of storage stability and thermosetting capability may be exhibited when the parameter A is 0.3% by weight.

If the content of Si is determined by the equation $\text{wt.\% Si} = A + [0.3 * (\text{wt.\% Fe})] - \text{wt.\% Ti}$, the components affecting the solubility of Sn can be matched to each other in a further improved manner. In particular, Ti can form phases with Si, which can have a positive influence on the solubility of Sn. The storage stability of the aluminum alloy is thus further improved.

If the ratio of the weight percentages of Si/Fe is less than 2, by increasing the setting of Si by Fe, the content of dissolved Si in the aluminum alloy can be significantly reduced. Thus, the solubility of tin and/or indium in the solid solution of the Al-Mg-Si-aluminum alloy can be improved, which can further increase the storage stability.

A comparatively high solubility of tin and/or indium in the solid solution of the Al-Mg-Si-aluminum alloy can be achieved when the ratio of the weight percentages of Si/Mg is in the range of 0.3 to 0.9.

If the aluminum alloy has at least 0.25% by weight of copper (Cu), based on this comparatively high Cu content, it is possible to intervene in a compensatory manner with respect to the adverse effects of Mg and Si on the solubility of Sn in the solid solution of Al-Mg-Si-aluminum alloy.

An excellent storage stability of the aluminum alloy can be achieved if it has tin (Sn) in the range of 0.005 to 0.05% by weight in solid solution in the aluminum mixed crystal. In general, it is mentioned that the term "solid solution" may denote a state in which an alloying element is dispersed in a solid matrix.

Preferably, the aluminum alloy belongs to the 6xxx series. Preferably, the aluminum alloy is an EN AW-6061 aluminum alloy.

If the aluminum alloy has at most 0.05% by weight of chromium (Cr) and more than 0.05% by weight of zirconium (Zr), the quenching sensitivity for Sn can be reduced and Sn can also be retained in solid solution in the aluminum mixed crystal at comparatively low quenching rates. In addition, it is thus possible, even with heavy plates, to achieve optimum storage stability and thermosetting capability.

The aluminum alloy may contain at least 0.02% by weight of chromium (Cr) in order to possibly improve the corrosion behavior.

Detailed description of the preferred embodiments

To demonstrate the effects achieved, thin sheets of various Al-Mg-Si-based aluminum alloys (6xxx series) were produced. The compositions of the alloys investigated are listed in Table 1.

Alloys	Sn	Mg	Si	Cu	Fe	Mn	Cr	Zn	Ti
1	0.04	0.8	0.64	0.22	0.47	0.11	0.16	0.05	0.05
2	0.04	0.78	0.43	0.36	0.46	0.11	0.14	0.05	0.06

Table 1: Overview of the investigated alloys in weight percent

The aluminum alloy 1 of Table 1 essentially corresponds to a standard alloy AA6061 after addition of the trace element Sn, wherein it is conceivable to use indium or a combination of Sn and In instead of tin. Alloy 2 represents the composition according to the invention of the 6xxx series and is comparatively recycling-friendly due to the comparatively high Fe content.

The aluminum alloy 1 is well outside the Si/Fe content tuned according to the invention, which is shown by way of example in Fig. 1. The aluminum alloy 2 is placed substantially centrally in this tuned Si/Fe content.

Both aluminum alloys 1 and 2 were solution-annealed in solid solution, quenched, and cold-hardened by aging at room temperature, and then hot-hardened. Solution annealing was carried out at a temperature greater than 530 degrees Celsius - quenching at a quench rate greater than 20 degrees Celsius/second. Both alloys 1 and 2 were subjected to a storage time or cold age-hardening of 180 days [d] and 30-minute hot age-hardening at different temperatures. Brinell hardness [HBW] was determined during cold aging and after hot aging.

With regard to the storage stability, it can be seen from Fig. 2 that the alloy 1 undergoes a comparatively rapidly increasing cold hardening during storage at room temperature after only 14 days - which leads disadvantageously to a comparatively high

and increasing Brinell hardness over a longer storage time and has a disadvantageous effect on forming before hot age-hardening.

In contrast, alloy 2 shows an onset of cold age-hardening only after approx. 180 days, whereby the alloy 2 according to the invention is considered to be particularly resistant to storage. Such a surprisingly high storage stability has not yet been observed with any 6xxx alloy. This leads to an unexpected, enormous gain in the manipulation time of the alloy after quenching in a soft state.

In the subsequent hot age-hardening, it can be seen in the comparison of the two alloys according to Fig. 3 that the alloy 2 initially lags behind the alloy 1 at lower aging temperatures in the Brinell hardness. At higher aging temperatures, the Brinell hardness of the alloy 1 can be significantly exceeded.

CLAIMS:

1. A hardenable Al-Mg-Si-based aluminum alloy, comprising
from 0.6 to 1% by weight of magnesium (Mg),
from 0.2 to 0.7% by weight of silicon (Si),
from 0.16 to 0.7% by weight of iron (Fe),
from 0.05 to 0.4% by weight of copper (Cu),
a maximum of 0.15% by weight of manganese (Mn),
a maximum of 0.35% by weight of chromium (Cr),
a maximum of 0.2% by weight of zirconium (Zr),
a maximum of 0.25% by weight of zinc (Zn),
a maximum of 0.15% by weight of titanium (Ti),
0.005 to 0.075% by weight of tin (Sn) and/or indium (In),
and the aluminum as the remainder as well as production-related unavoidable impurities, wherein
the ratio of the weight percentages of Si/Fe is less than 2.5
and the content of Si is determined according to the equation
$$\text{wt.\% Si} = A + [0.3 * (\text{wt.\% Fe})],$$
with the parameter A being in the range of 0.17 to 0.4% by weight.
2. Aluminum alloy according to claim 1, characterized in that the parameter A is in the range of 0.26 to 0.34% by weight.
3. Aluminum alloy according to claim 1 or 2, characterized in that the parameter A is 0.3% by weight.
4. Aluminum alloy according to claim 1, 2 or 3, characterized in that the content of Si is determined according to the equation

$$\text{wt.\% Si} = A + [0.3 * (\text{wt.\% Fe})] - \text{wt.\% Ti.}$$

5. Aluminum alloy according to one of claims 1 to 4, characterized in that the ratio of the weight percent of Si/Fe is less than 2.
6. Aluminum alloy according to one of claims 1 to 5, characterized in that the ratio of the weight percentages of Si/Mg is in the range of 0.3 to 0.9.
7. Aluminum alloy according to one of claims 1 to 6, characterized in that the aluminum alloy has at least 0.25% by weight of copper (Cu).
8. Aluminum alloy according to one of claims 1 to 7, characterized in that the aluminum alloy comprises tin (Sn) in the range of 0.005 to 0.05% by weight in solid solution in the aluminum mixed crystal.
9. Aluminum alloy according to one of claims 1 to 8, characterized in that the aluminum alloy belongs to the 6xxx series.
10. Aluminum alloy according to one of claims 1 to 9, characterized in that the aluminum alloy has a maximum of 0.05% by weight of chromium (Cr) and more than 0.05% by weight of zirconium (Zr).
11. Aluminum alloy according to one of claims 1 to 10, characterized in that the aluminum alloy has at least 0.02% by weight of chromium (Cr).