**ABSTRACT**

The subject of the invention is an extruded product, of the bar or rod or tube type, with very good precision-turning properties, made of a wrought precision-turning aluminium alloy of the following composition: 0.8\(\leq\)Si\(\leq\)1.5%, optionally 1.0\(\leq\)Si\(\leq\)1.5%, 1.0\(\leq\)Fe\(\leq\)1.8%, optionally 1.0\(\leq\)Fe\(\leq\)1.5%; Cu: <0.1%; Mn: <1%; optionally <0.6%; Mg: 0.6-1.2%, optionally 0.6-0.9%; Ni: <3.0%, optionally 1.0-20%; Cr: <0.25%; Ti: <0.1%; other elements <0.05% each and 0.15% in total; and the balance aluminium. The subject of the invention is also a precision-turning part obtained from the extruded product as defined above.
AA 6XXX ALUMINUM ALLOY FOR PRECISION TURNING

FIELD OF THE INVENTION

[0001] The invention relates to the field of precision-turned parts obtained from simple extruded products, essentially of the bar or rod type, made of an AA6xxx aluminum having a chemical composition which is optimized as a function of the suitability for extrusion and precision turning, and which, in particular, lacks elements with a low melting point, such as, particularly lead, bismuth, indium and tin.

[0002] Moreover, the mechanical properties, the properties of resistance to corrosion, and the suitability for anodizing of such parts are similar to those obtained from precision turning alloys containing lead, of the AA6262 or AA2011 type.

STATE OF THE ART

[0003] Unless otherwise indicated, all the values pertaining to the chemical composition of the alloys are expressed in wt %.

[0004] Moreover, all the aluminum alloys referred to are named, unless otherwise indicated, using the names defined by the Aluminum Association in the Registration Record Series which it publishes regularly.

[0005] Precision turning relates to the field of large-series manufacture of parts which are generally produced by removing material from bars or rods made of metal.

[0006] The latter are generally obtained by extrusion from billets, particularly in the case of aluminum alloys.

[0007] The parts are thus produced at high production rates in cutting machines with manual or digital control.

[0008] The productivity and the state of the surface as well as the dimensional precision of the final part are the principal objectives associated with this type of manufacturing.

[0009] The parts so produced are used in various fields, from clock making to medical equipment, to the fields of transport (aeronautics, railroad, car) and industry (electrical, electronic, hydraulic . . . ).

[0010] Numerous factors influence the suitability for precision turning:

[0011] First, obviously, the nature of the material itself, its chemical composition and its metallurgical state, but also the nature of the cutting tool and the parameters associated with the process.

[0012] These factors are highly interdependent and it is thus imperative to associate an appropriate plan of machining procedure with a given alloy.

[0013] The first aluminum alloys used for precision turning from 1930 to 1960 were AA6xxx and AA2xxx alloys containing lead and bismuth, besides the usual elements of the composition for these series.

[0014] These elements, due to their low solubility in aluminum and their low melting point, melt as a result of the heating caused by the machining operation and consequently they form soft spots in a harder matrix made of aluminum.

[0015] The positive result so obtained resides in the fragmentation of chips of small size during said machining or precision turning operation.

[0016] This fragmentation allows a rapid removal of the material, and thus a gain in productivity, but also a removal of the heat produced, thus preventing a potential degradation of the final surface state of the part.

[0017] However, due to the toxicity problems connected with the presence of lead, European laws increasingly limit the admissible content in alloys, particularly aluminum alloys, and in particular in alloys intended for precision turning.

[0018] The most recent law dates from July 2008 and limits the lead concentration of aluminum alloys to 0.4% in the field of cars and of electrical and electronic equipment.

[0019] For several years, industrialists have been preparing for this development, and they have already developed precision turning alloy types with low lead content, and even lead free types.

[0020] Their composition is based on the presence of substitute elements which also have a low melting point, such as, tin, bismuth or indium.

[0021] These developments have been described notably in the article by S. Sirrar “X6030, a new lead free machining alloy” published in 1996 in the journal Materials Science Forum, Volumes 217-222, pages 1795-1800.

[0022] Similarly, the patents EP07937324 and EP 1214456 of the Reynolds Metal Company claim alloys of the AA6xxx and AA2xxx families with the addition of tin and indium, and of the AA6xxx family, respectively, with the addition of bismuth only, or of bismuth and tin.

[0023] Similarly, the application EP 761834 of Kaiser Aluminum relates to alloys of the AA6xxx series with the addition of tin and of bismuth, while the applications EP 0964070 and EP 0982410 of Alusuisse relate to alloys of the AA2xxx series with the addition of tin, or of bismuth and of tin, respectively.

Problem Posed

[0024] The above-mentioned alloys containing substitute elements with low melting point, such as, tin, bismuth or indium, do not exhibit exactly the same performances during precision turning as the alloys that contain lead, but the total prohibition of lead may occur in the relatively near future.

[0025] Moreover, these alloys sometimes pose problems of fragility due to the complete wetting of the joints of grains during the precision turning by the phases originating from the substitute elements with low melting point.

[0026] A solution to this problem consists of the use of an alloy whose aluminum-based matrix contains harder particles, which at the origin of the creation and propagation of cracks during the precision turning operation, said cracks promoting the fragmentation of the chips.

[0027] The type of the particles and their distribution evidently have a particularly marked effect on the behavior of the alloy during the precision turning, but also on the wear of the cutting tools used for this operation.

[0028] The solutions of this type that are known from the prior art all are based on the addition of silicon at a minimum content of 1.5%, which corresponds to the limit of solubility of silicon in aluminum.

[0029] The silicon alloy so constituted comprises hard phases based on silicon, which are the origin of the creation and propagation of the above-mentioned cracks. Indeed, said phases prevent the sticking of the grains during the deformation induced by the machining operation, or precision turning, which gives rise to cavities, and then to cracks, and thus promotes the fragmentation of the chips.

[0030] The effect of other elements, such as, in particular, iron, manganese and nickel, separately, has also been the
subject of investigations, but it does not make it possible to achieve performances similar to those of the alloys containing lead in a significant quantity.


[0032] On the other hand, combining silicon at a high content (≥1.5%) and another element, such as iron or copper, for example, at a significant content, has been reported to be entirely beneficial on the behavior during precision turning.

[0033] Thus, the applications JP 9249931, U.S. Pat. No. 6,059,902 and JP2002206132 of Kobe Steel relate to alloys with very good machinability and based on a silicon content of more than 1.5%, in combination with the presence of manganese or copper, or iron and chromium.

[0034] These various solutions, however, present the disadvantage, in connection with the presence of silicon at a relatively high content, of having a nonoptimized suitability for extrusion, associated notably with the risk of burning during this operation, which is reflected in surface defects of the final product.

SUBJECT OF THE INVENTION

[0035] Thus, the subject of the invention is an extruded product, the bar or rod or tube type, which presents a very good suitability for precision turning, without the addition of silicon at contents greater than or equal to 1.5%, made of a wrought precision turning aluminium alloy having the following chemical composition, expressed in wt %:

[0036] 0.8≤Si≤1.5%, preferably: 1.0≤Si≤1.5%

[0037] 1.0<Fe≤1.8%, preferably: 1.0<Fe≤1.5%

[0038] Cu: <0.1%

[0039] Mn: <1%, preferably <0.6%

[0040] Mg: 0.6-1.2%, preferably 0.6-0.9%

[0041] Ni: <3%, preferably 1.0-2.0%

[0042] Cr: <0.25%

[0043] Ti: <0.1%

[0044] other elements <0.005% each and 0.15% in total, and the balance aluminum.

[0045] Finally, another object of the invention is a precision-turned piece produced from the extruded product as defined above.

DESCRIPTION OF THE FIGURES

[0046] FIG. 1 represents the extrusion pressures, in MPa, obtained for an identical length of billet, depending on the various alloys tested: 6xxx according to the invention, AA6262 and HSi as reference, the compositions of which are given in the chapter “Examples.”

[0047] FIG. 2 represents the axial cutting pressures, in MPa, during the drilling tests, as a function of the cutting speed in m/min, for a constant drilling advance of 0.15 mm/turn, and for the various tested alloys as defined above.

[0048] FIG. 3 represents the axial pressures in MPa as a function of the drilling advance in mm/turn, for a constant cutting speed of 55 m/min, and for the same tested alloys.

DESCRIPTION OF THE INVENTION

[0049] The invention is based on the observation by the applicant that it is possible to obtain a very good suitability for precision turning, without the addition of silicon at contents greater than or equal to 1.5%, in contrast to the prior art, by ensuring the presence in a sufficient quantity of intermetallic phases with iron, which are dispersed in a homogeneous manner.

[0050] This characteristic enables indeed the fragmentation of the chips, which is required for this purpose during the operation of precision turning.

[0051] Said intermetallic phases are of the Al<sub>11</sub>Fe<sub>4</sub>(Mn,Ni)<sub>4</sub>S<sub>i</sub>, type, the presence of Mn and Ni being optional since they contribute by creating particles which are also advantageous for precision turning.

[0052] The simple extruded products, i.e., of the bar, rod or tube type, according to the invention, present a behavior during precision turning that is similar to the products of the prior art made from alloys of the series AA6262 or AA2011, both of which contain lead and bismuth.

[0053] Moreover, the mechanical properties, the properties of resistance to corrosion, and the suitability to anodizing of the products according to the invention are similar to those obtained from said alloys.

[0054] As far as the constitutive elements of the alloy type of the products according to the invention, their contents are justified by the following considerations:

[0055] Silicon: a minimum content of 0.8% is necessary to obtain a sufficient structural hardening via the Mg-Si phase, taking into account the “trapping” of this element in the intermetallic phases of the AlFeSi type, which are characteristic for the alloys according to the invention. It is preferred to raise this minimum to 1%.

[0056] The content is strictly less than 1.5%, to limit the risks of burning due to the elevation of the temperature during the extrusion operation, which is reflected notably in surface defects of the extruded product.

[0057] Iron: together with silicon, it is one of the major elements of the alloys according to the invention. Indeed, its concentration determines the quantity of the above-mentioned secondary phases, which are in particular the basis of the behavior in precision turning. To this effect, a minimum that is strictly greater than 1.0% is required.

[0058] The upper limit of 1.8% makes it possible to avoid the precipitation of the primary iron phases during the casting of the billets, which reduces their suitability for the extrusion.

[0059] An even more preferred maximum is 1.5%.

[0060] Manganese: optional, it can participate in the formation of secondary phases which are advantageous for the behavior during precision turning. Its content is limited to 1.0% due to the fact that it has an unfavorable effect on the suitability for extrusion. An even more preferred maximum is 0.6%.

[0061] Magnesium: with the silicon, it participates in the structural hardening via the Mg2Si phase. For this purpose, a minimum of 0.6% is required.

[0062] Its content is limited to 1.2%, an excessively marked hardening having an unfavorable effect on the suitability for extrusion. An even more preferred maximum is 0.9%.

[0063] Nickel: like manganese, it can participate in the formation of secondary phases which are advantageous for the behavior during precision turning. Its content is limited to 3.0% to avoid the formation of primary phases which have a fragility inducing effect.

[0064] A preferred range is 1.0-2.0%.

[0065] Copper: its content must be less than 0.1%, because of its strong hardening effect which is disadvantageous with regard to the suitability for extrusion.
Chromium: it is an antirecrystallization element which, like manganese, can form secondary phases that influence the granular structure of the alloy. Its content is kept below 0.25%, because of its unfavorable impact with regard to the suitability for extrusion.

Titanium: this element acts according to two combined modes: on the one hand, it promotes the refining of the primary aluminum grain, and, on the other hand, it influences the distribution of the above-mentioned secondary phases.

However, its content is limited to 0.1%, because of its unfavorable impact with regard to the suitability for extrusion.

The details of the invention will be understood better with the help of the following examples which, however, are not limited in character.

EXAMPLES

In an electric furnace with crucible, three series of alloys were prepared, in the form of slugs with a conical geometry, a height 65 mm, a large diameter of 65 mm and a small diameter of 25 mm, and using the experimental casting procedure “TP-1” according to the Standard Test Procedure for Aluminum Alloy Grain Refiners 1990 of the Aluminum Association; the composition of said series is given in Table 1 below.

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Se</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Cr</th>
<th>Ni</th>
<th>Pb</th>
<th>Bi</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>6xxx</td>
<td>1.37</td>
<td>0.07</td>
<td>0.85</td>
<td>1.00</td>
<td>0.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AA6262</td>
<td>0.78</td>
<td>0.36</td>
<td>0.13</td>
<td>0.13</td>
<td>0.59</td>
<td>0.50</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H Si</td>
<td>3.86</td>
<td>0.05</td>
<td>0.60</td>
<td>0.78</td>
<td>0.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The 6xxx alloy is according to the invention, whereas the alloys AA6262 and H Si are alloys of the prior art, the first containing lead and bismuth, and the second lacking these elements, and combining a high silicon content with the presence of manganese and magnesium.

The slugs are then homogenized at a temperature of 545°C for 5h 30min.

The billets of diameter 29.6 mm and length 38 mm were machined and then extruded as bars of diameter 6.7 mm.

The extrusion was carried out under the same conditions of billet temperature of 480°C and of speed of 0.6 m/min. This relatively slow speed results from an operation of similarity due to the size of the samples of the tests compared to industrial conditions.

FIG. 1 represents the extrusion pressures of each variant for an identical length of billet. The variant according to the invention presents a better suitability for extrusion, which is reflected in a lower pressure, by approximately 20%, in comparison to the reference AA6262, and by approximately 10%, in comparison to the reference H Si.

The extruded bars were subjected to a heat treatment, of type T6, dissolution at a temperature of 560°C for 15 min, quenching in water, and tempering to achieve the maximum mechanical resistance, also known to the person skilled in the art as “peak tempering,” for 10 h at 175°C. For the 6xxx alloys according to the invention and H Si, and for 10 h at 160°C, for the AA6262 alloy.

The mechanical properties of the three variants were determined in accordance with the standard EN10002-1.

They are recapitulated in Table 2 below, namely: conventional limit of elasticity $R_{p0.2}$ and tensile strength $R_m$ in MPa and elongation at rupture $A$ in %. The minimum values, according to the standard EN 755-2, of the alloy 6262, are also indicated under the term “Min. 6262.”

<table>
<thead>
<tr>
<th>Alloy</th>
<th>$R_{p0.2}$ (MPa)</th>
<th>$R_m$ (MPa)</th>
<th>A (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6xxx</td>
<td>351</td>
<td>376</td>
<td>9</td>
</tr>
<tr>
<td>AA6262</td>
<td>360</td>
<td>407</td>
<td>13</td>
</tr>
<tr>
<td>H Si</td>
<td>404</td>
<td>419</td>
<td>8</td>
</tr>
<tr>
<td>Min. 6262</td>
<td>240</td>
<td>260</td>
<td>10</td>
</tr>
</tbody>
</table>

The mechanical properties of resistance $R_{p0.2}$ and $R_m$ of the alloy according to the invention are very similar to those of the AA6262 alloy, and slightly inferior to those of the alloy H Si, with similar elongations at rupture.

In any case, they are much superior compared to the typical minimum values, with a similar elongation.

The microstructure of the variant according to the invention was studied by scanning electron microscopy to determine the nature, dispersion and size of the intermetallic phases at the micrometer scale.

It revealed the presence in a majority proportion of a phase of the AlFeNiSi type, in the form of particles having a mean size of 3 µm with a surface fraction of 5%.

The applicant attributes the good behavior in precision turning with a favorable fragmentation of the chips to the dispersion of this relatively large surface fraction phase, in the form of particles of relatively small size.

The machinability was characterized by means of the drilling test according to the standard NFE66-520-8.

The resulting values of the cutting pressure for different cutting speeds and advance speeds are reported in FIGS. 2 and 3.

Three variants present a stable operation range over the entire relatively large range of cutting speeds (from 10 to 140 m/min).

The variant AA6262 of the prior art requires approximately 20% less force in comparison to the alloy according to the invention, and also in comparison to the alloy H Si of the prior art, and this for a constant drilling advance of 0.15 mm/turn (FIG. 2) and approximately 10% less for a constant cutting speed of 55 m/min (FIG. 3).

Taking into account the error levels associated with the measurements of forces, this difference, although significant, remains small, and the behaviors of the different variants may be considered to be similar.

The fragmentation of the chips was ranked in accordance with the same European standard NFE66-520-8, from A.1, most favorable case, to D.6, most unfavorable case.
The scores given in the present case are: A.1: “Elementary-Fragmented with bevel,” B.6: “Short-Helicoi
dal” and C.6: “Medium-long-helicoi dal,” according to the said standard.

These scores were obtained for different drilling advance speeds from 0.05 to 0.3 mm/turn, and for the same cutting speed of 55 m/min. The results are recapitulated in Table 3 below.

<table>
<thead>
<tr>
<th>Advance</th>
<th>0.05</th>
<th>0.1</th>
<th>0.15</th>
<th>0.2</th>
<th>0.25</th>
<th>0.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA6262</td>
<td>B.6</td>
<td>B.6</td>
<td>A.1</td>
<td>A.1</td>
<td>A.1</td>
<td>A.1</td>
</tr>
<tr>
<td>Si</td>
<td>C.6/B.6</td>
<td>B.6</td>
<td>B.6</td>
<td>A.1</td>
<td>A.1</td>
<td>A.1</td>
</tr>
</tbody>
</table>

These results reveal few differences, in terms of fragmentation of the chips during the drilling tests, between the alloy according to the invention and the alloys of the prior art, whether

1. An extruded product made of a wrought precision turning aluminum alloy having the following chemical composition, expressed in wt %:
   - 0.8≤Si≤1.5%
   - 1.0≤Fe≤1.8%
   - Cu: ≤0.1%
   - Mn: ≤1%
   - Mg: 0.6-1.2%
   - Ni: ≤3.0%
   - Cr: ≤0.25%
   - Ti: ≤0.1%
   - other elements ≤0.005% each and 0.15% in total, and the balance aluminum.

2. An extruded product according to claim 1, wherein the silicon content is greater than or equal to 1.0%.

3. An extruded product according to claim 1, wherein the iron content is greater than 1.0 and up to 1.5%.

4. An extruded product according to claim 1, wherein the manganese content is less than 0.6%.

5. An extruded product according to claim 1, wherein the magnesium content is 0.6-0.9%.

6. An extruded product according to claim 1, wherein the nickel content is 1.0-2.0%.

7. A precision-turned part made from an extruded product according to claim 1.

8. A precision-turned part made from an extruded product according to claim 2.

9. A precision-turned part made from an extruded product according to claim 3.

10. A precision-turned part made from an extruded product according to claim 4.

11. A precision-turned part made from an extruded product according to claim 5.

12. A precision-turned part made from an extruded product according to claim 6.

13. An extruded product according to claim 2, wherein the iron content is greater than 1.0 and up to 1.5%.

14. An extruded product according to claim 2, wherein the manganese content is less than 0.6%.

15. An extruded product according to claim 3, wherein the manganese content is less than 0.6%.

16. An extruded product according to claim 5, wherein the magnesium content is 0.6-0.9%.

17. An extruded product according to claim 3, wherein the magnesium content is 0.6-0.9%.

18. An extruded product according to claim 4, wherein the magnesium content is 0.6-0.9%.

19. An extruded product according to claim 2, wherein the nickel content is 1.0-2.0%.

20. An extruded product according to claim 3, wherein the nickel content is 1.0-2.0%.

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