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(54) **AGE-HARDENABLE ALUMINIUM ALLOYS**

AUSHÄRTBARE ALUMINIUM-LEGIERUNGEN

ALLIAGES A L'ALUMINIUM A DURCISSEMENT PAR VIEILLISSEMENT

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Description

[0001] This invention concerns AA5000 series alloys with the addition of Cu that can be retained in a solution treated condition after hot working, for example by hot rolling on a hot mill or by hot extruding.

[0002] In the art AA5000 series alloys are usually regarded as non-heat treatable alloys i.e. they are not regarded as age hardenable. The addition of Cu to these alloys renders them age hardenable, as described in EP-A-0773303, EP-0616044 and EP-A-0645655. However these known methods also require a formal solution treatment.

[0003] The novel feature of this invention is the discovery that for certain Cu - containing AA5000 series alloys sufficient solution treatment occurs during hot working, for example hot rolling, to render the alloys age hardenable without a further expensive solution treating step. This gives a very significant economic advantage especially for commodity products such as can end stock, automotive sheet products, or extruded products such as structural sections.

[0004] EP-A-0605947 describes manufacturing can body sheet using two sequences of continuous operations. The described additional steps of uncoiling the hot coiled sheet, quenching the sheet without intermediate cooling, cold rolling and re-coiling the sheet are required, but these additional steps are not needed in the method of the present invention.

[0005] WO-A-99/39019 describes a method for making can end and tab stock but annealing of the sheet is required as a separate operation after hot rolling which is not needed in the method of the present invention.

[0006] WO-A-98/01593 describes a process for producing aluminium alloy can body stock but again a separate annealing step is required.

[0007] JP-A-100121179 describes aluminium alloy sheet for carbonated beverage can lids but a formal solution heat treatment is required, which is not needed in the method of the present invention.

[0008] US-A-5655593 describes aluminium alloy sheet manufacture in which the hot strip is cooled rapidly to minimise the precipitation of the alloying elements. This teaching of rapid cooling is contrary to that of the present invention.

[0009] US-A-3464866 describes a process for obtaining aluminium alloy conductors but again teaches rapid cooling.

[0010] In accordance with the present invention there is provided a method of producing an age-hardenable aluminium alloy comprising the steps of:

(a) casting an alloy of a composition comprising the following expressed in weight percent:

Magnesium	1.0 to 4.0
Copper	0.1 to 0.6
Manganese	up to 0.8
Iron	up to 0.5
Silicon	up to 0.3
Chromium	up to 0.15%
Titanium	up to 0.15%, preferably up to 0.05%
Boron	from 0 up to 0.05, preferably up to 0.01
Balance	Aluminium with incidental impurities

(b) optionally homogenising the cast alloy,

(c) hot working the casting at an initial temperature of at least 400°C, to form an intermediate product, wherein at least part of the hot working is carried out whilst the casting is at a temperature above the solvus temperature of the alloy,

(d) cooling the intermediate product during hot working or in a subsequent step at a rate of less than 5°C/min such that at least a partially recovered or recrystallised structure is formed and that sufficient copper is retained in solid solution in the alloy to cause an age hardening effect on the alloy if phase precipitation takes place during the alloy's subsequent thermal history, and

(e) optionally allowing or arranging for phase precipitation to occur in the alloy.

[0011] Preferably after the said hot working step the intermediate product is generally maintained at a temperature below the solvus temperature of the alloy, provided that if the intermediate product is heated above the alloy's solvus temperature then cooling thereof is effected at a rate less than 2°C/sec.

[0012] By the term "the solvus temperature of the alloy" is meant the temperature below which under equilibrium conditions the copper begins to be removed from solid solution to form a precipitate. However, as to the rate of copper removed that will depend on the kinetics of the reaction.

[0013] The precipitation phase if formed is believed to be S phase (an AlCuMg phase) or its metastable precursors.

[0014] The alloy may be cast by DC casting to form an ingot or by continuous casting, for example in a belt caster or a twin roll casting machine, to form a sheet.

[0015] The cast and preferably homogenised alloy can be extruded but for the production of can end stock it is generally hot rolled. After casting the preferred steps are:

optionally homogenising the casting at a temperature of at least 480°C, and preferably 500 to 600°C, so that substantially all of the magnesium and copper in the casting are in solid solution,

optionally hot rolling the casting, optionally with re-heating of the casting to above the alloy's solvus temperature, preferably at least 450°C, to take substantially all of the magnesium and copper present into solid solution,

hot rolling the casting with a rolling mill entry temperature of the casting of at least 400, and preferably from 450° to 580°C,

continuing rolling the casting to the desired thickness to form a sheet so that at least part of the rolling reduction is carried out above the solvus temperature of the alloy and cooling the alloy, either while rolling or subsequently, slow enough so as to form at least a partially recovered or recrystallised structure but fast enough to ensure that sufficient of the Cu is retained in solid solution to provide an age hardening effect if a subsequent precipitation treatment is carried out,

optionally cold rolling the hot rolled sheet, and optionally age hardening the cold rolled alloy, wherein preferably after the essential hot rolling step the rolled ingot is always maintained at a temperature below its solvus temperature.

[0016] During cold rolling, the metal temperature generally rises to about 100-200°C as it is passed through the mill. Conventionally after cold rolling, the metal is coiled and being so massive the coiled metal takes a long time to cool down to room temperature. Phase precipitation and hardening can occur during this cooling down period without the need forcibly to cool the coil. Additional cooling can, however, be used if required. If desired after cold rolling re-heating can be effected if desired, for example to control the amount of cold work in the alloy. If this re-heating takes the alloy above its solvus temperature then cooling is preferably effected at a rate less than 2°C/sec to avoid distortion or to avoid the need for a separate quench stage.

[0017] As an alternative to batch DC casting, the alloy could be cast continuously by for example belt casting or twin roll casting. These techniques allow thin strip to be produced of a thickness of generally as low as 5mm, and sometimes as low as 2mm. Such thin cast strip may or may not require homogenisation before hot rolling since it tends to cool so quickly that the Cu and Mg present are likely to remain in solid solution.

[0018] The casting could be extruded using direct or indirect extrusion. Preferably the casting is homogenised as described above and then cooled to room temperature before being re-heated to 400 to 500°C for extrusion. Alternatively the casting can be cooled directly from its homogenisation temperature to the desired extrusion temperature.

[0019] The extrudate is cooled preferably with still air or with forced air. If desired, the extrudate can be re-heated to above the solvus temperature of the alloy and then cooled at a rate of less than 2°C/sec. This re-heating treatment may be needed for texture and/or grain size control. After extrusion the extrudate is generally stretched by about ½ to 2% and then aged.

[0020] The present invention has particular applicability for the production of can stock, especially can end stock (CES) which possesses a combination of high strength and formability. The combination of composition and process of the present invention overcomes many of the manufacturing difficulties of the conventional AA5182 sheet currently in use and is capable of producing CES at lower cost. It also improves the subsequent performance of the can end, most notably its scoreline corrosion resistance. The invention is particularly suitable for downgauging to produce lighter weight can ends, i.e. gauges down to say 0.150mm.

[0021] For the production of can end stock, the preferred method is to cast an ingot, homogenise it, and hot roll to, say, 2mm to form strip. A key aspect of the invention is that the strip does not need an additional solution heat treatment step. Furthermore, even if it does, the material does not need to be rapidly cooled, e.g. does not need to be quenched into water; the cooling is generally air cooled (possible forced air). The coil is then cold rolled to final gauge and lacquered.

The range (in weight percent) for the principal elements over which this invention is operable is:

Magnesium: 1.0 - 4.0 wt.%, preferably 2.0 - 4.0, still more preferably 2.5 to 4.0%

Copper: 0.1 - 0.6 wt.%, preferably 0.2 - 0.5, still more preferably 0.2 to 0.4%

Manganese	up to 0.8 wt.%, preferably up to 0.6, more preferably up to 0.5, still more preferably up to 0.4%. For some alloys a minimum Mn content of 0.1% is preferred.
Iron	up to 0.5 wt.%, preferably 0.1 - 0.3%
Silicon	up to 0.3wt.%, preferably up to 0.2%
Chromium	up to 0.15%, preferably trace
Titanium	up to 0.15, preferably up to 0.05%
Boron	up to 0.05, preferably up to 0.01%
Carbon	up to 0.05, preferably up to 0.01%

For grain refining of the casting either TiB_2 or TiC can be used, but generally not together.

[0022] The present invention will now be described in more detail with reference to the accompanying drawings in which:

Figure 1 shows a thermodynamic calculation of the solvus temperature for S-phase precipitation in $\text{Al-x}\%\text{Mg-y}\%\text{Cu-0.25Mn-0.2Fe-0.12Si}$,

Figure 2 shows the conductivity changes (%IACS) during isothermal annealing of an $\text{Al-3Mg-0.4Cu-0.25Mn-0.2Fe-0.12Si}$ alloy after solution heat treatment and cold water quenching,

Figure 3 shows the conductivity changes (%IACS) during isothermal annealing of an $\text{Al-3Mg-0.4Cu-0.25Mn-0.2Fe-0.12Si}$ alloy after solution heat treatment, cold water quenching and cold rolling, and

Figure 4 are curves showing the effect of time and temperature on the extent of recrystallisation during isothermal annealing of an $\text{Al-3Mg-0.4Cu-0.25Mn-0.2Fe-0.12Si}$ alloy after solution heat treatment, cold water quenching and cold rolling.

[0023] The theoretical basis for the present invention is as follows:

The basic premise is to select an alloy composition which will enable solute to be kept in solid solution during cooling from hot rolling temperatures (250°C to 400°C , say). The strip is then processed to bring out a precipitation hardening phase which provides extra strength. This precipitation forms preferentially on the dislocation structure introduced during cold deformation. In the case of CES this cold deformation is cold rolling, for extrusions it is stretching, and for sheet it is during forming of the sheet when it is fabricated into a component.

Although there is a thermodynamic driving force for the solute to be removed from solid solution during hot working and subsequent cooling, the nucleation and diffusion effects are such to keep a substantial amount of solute in solution, i.e. 'missing the nose of the c-curve'. Accompanying Figure 1 shows a calculation of the solvus temperatures for a range of Al-Cu-Mg alloys. This shows that the solute will stay in solid solution above the temperatures indicated. Thus, the solute can not start to come out of solid solution until the strip is at or below this temperature. It should be noted, that even if the solute does start to come out of solid solution, there may still be sufficient solute available to provide an appreciable strengthening effect during subsequent processing.

[0024] The conductivity has been determined for a $3\text{Mg-0.4Cu-0.25Mn-0.2Fe-0.12Si}$ alloy (wt.%) to demonstrate that for this type of alloy there is a barrier to nucleation and growth of the precipitates which can be commercially exploited to provide an improved balance of strength and formability. Accompanying Figure 2 shows the effect of isothermal ageing on the conductivity of a full solution heat treated and cold water quenched material subject to isothermal ageing. This shows that at temperatures below the solvus the conductivity increases (indicating Cu along with Mg removed from solid solution), but that at lower temperatures the precipitation becomes difficult. Thus, the solute can be kept in solid solution if the strip can be cooled to these temperatures sufficiently rapidly.

[0025] If there are dislocations present then the conductivity rise is more rapid, since the precipitating phase is believed to be S-phase (an AlCuMg phase), or its metastable precursors which is well-known to nucleate preferentially on dislocations. To demonstrate this, a further set of isothermal ageing experiments have been performed on the same alloy, but after solution heat treatment, cold water quenching and cold rolling. This is shown in accompanying Figure 3. In this case the conductivity drop starts to occur after a few seconds. This shows the importance of passing through this temperature regime without large numbers of dislocation present, since if the phase nucleates at these high temperatures it is likely to be relatively coarse and provide little strengthening. The example shown is an extreme example

since the strip was cold rolled to introduce a high dislocation density prior to ageing. In hot deformation the dislocation density is lower for a fixed level of macroscopic strain, thus providing fewer sites for nucleation of the precipitates.

[0026] For the production of CES the hot rolling conditions are selected to ensure that the hot rolled sheet recrystallises on or before coiling or very shortly thereafter. Preferably the sheet is fully recrystallised resulting in a low dislocation density. Recrystallisation is encouraged by arranging for the minimum temperature of the sheet as it exits from the rolling mill to be 250°C, preferably 270°C and more preferably 300°C and/or arranging for the cooling rate of the sheet to be sufficiently slow to allow time for the sheet to recrystallise when in its coiled form or during coiling. In a conventional mill the coiling temperature is approximately the same as the exit rolling mill temperature. Where additional cooling means are provided after the mill the minimum coiling temperature should be in the range of minimum mill exit temperatures mentioned above. In practice acceptable cooling rates are found to be of the order of 0.1 and preferably 0.2 to 5°C/minute over the temperature range of 400-200°C. There is no need to uncoil the sheet during cooling in order, for example, to quench it.

[0027] An indication of the time required to achieve recrystallisation has been determined for a 3Mg-0.4 Cu-0.25Mn-0.2Fe-0.12Si alloy (wt.%). This material was solution heat treated, cold water quenched and cold rolled 50%. Isothermal heat treatments were performed to determine the extent of recrystallisation, as shown in Figure 4. This shows that after this deformation, full recrystallisation is possible within a few minutes at temperatures in excess of around 320°C. It should be noted that the precise details of the recrystallisation kinetics will depend on the deformation conditions and the material microstructure.

[0028] A high rolling mill exit temperature encourages precipitation of S phase or its precursors while the strip or coil is cooling. Cooling more quickly can counter this and prevent precipitation but if the exit temperature becomes too high, the cooling rate required is too fast to be practically useful. To take maximum advantage of the rapid cooling during hot rolling, the upper limit to the mill exit temperature, especially for the alloys richer in Cu and Mg, should preferably be lower than the solvus temperature of the alloy. Figure 1 gives an indication of the solvus temperature as a function of the Mg and Cu contents. Preferably the maximum exit temperature should be between 340°C and 360°, although up to 380°C is possible for some alloys.

[0029] It is important to note that the location of the nose of the c-curve for these alloys when recrystallised varies with the composition of the alloy. For example, for the alloy referred to in Figure 2, the nose of the curve is located at a time of around 100 to 1000 seconds. For dilute alloys the nose is moved to longer times whilst for more concentrated alloys the nose is moved to shorter times. The time indicated in Figure 2 compares with times of between 1 and 100 seconds for conventional age hardening systems such as AA7075, AA2017, AA6061 and AA6063. For the alloys described in the present invention, this provides longer times at temperatures below the solvus temperature in which to cool the strip and still maintain the Cu (and Mg) in solid solution. For this preferred alloy of Figure 2 it has been found that a cooling rate of 5°C/min is sufficient substantially to miss the nose of the c-curve and provide a substantial age hardening response during subsequent processing. This cooling rate can be achieved by, for example, forced air cooling of a coil. Previous art regarding solution heat treatment of these Al-Mg-Cu alloys teaches that, not only is a separate solution heat treatment stage required, but that the strip must be quenched with a cooling rate of 2°C/second or faster. For the present invention it has been found that neither of these steps need to be used, thereby providing a lower cost manufacturing route for these alloys. Likewise no separate annealing step is needed after the hot working step and before the cooling step.

[0030] This solute is then used to give a significant precipitation hardening effect during subsequent thermomechanical processing. During subsequent cold (or warm) deformation of the strip an increased dislocation density is introduced giving enhanced nucleation sites for the strengthening phase. This deformation may not be needed for all applications of this invention, since for these compositions it is known that the precipitation can also occur in the absence of dislocations, albeit at slower rates. The precipitating phase is believed to be S-phase which can form as needles or rods on the dislocation structure. In the case of CES this precipitation could occur during a separate ageing step or during the thermal history which the material would experience during deformation in, for example, strip rolling.

[0031] As shown above, it may be important to achieve rapid recrystallisation in order to remove the dislocations from the material as it cools. Mn can be added as a strengthening element and to control grain size and is therefore desirably kept as high as possible. However, Mn inhibits recrystallisation after hot rolling or during annealing, and so a maximum Mn content of 0.4% may have to be set in order to achieve full recrystallisation for some alloys under certain conditions. For many of the alloys to assist in controlling the grain size of the recrystallised sheet, it may be desirable to have a minimum of at least 0.05%Mn and preferably at least 0.1%Mn present in the alloy. Recrystallisation may also be important for crystallographic texture control in CES, but this may not be necessary if the can end tooling is modified to take significantly higher levels of earing into account. Crystallographic texture control can also be important for automotive sheet formability; another potential application of this invention.

[0032] Another feature of the composition used in the present invention is the importance of having low Fe and Si in the alloy, since this will prevent the presence of excessive numbers of coarse constituent particles in the sheet. These form during solidification and cannot be fully dissolved during homogenisation of the ingot. Although they break

up during rolling, their presence is sufficient adversely to affect formability. Since this invention has been found to produce improved formability over existing AA5182 CES, the strip may be able to tolerate higher levels of these elements, thus reducing cost. Tolerance of higher levels of Si and Fe may allow greater use of recycled aluminium scrap and this is another important aspect of this invention. Up to 0.5%Fe may be tolerated in the alloy and preferably up to 0.3%Fe. The minimum amount of Fe present will be dictated by cost and there is unlikely to be less than 0.1Fe. Silicon up to 0.3% may be present, preferably up to 0.2%.

[0033] Another advantage over conventional AA5182 CES is that the lower Mg content will also make the can end less susceptible to stress corrosion cracking (SCC), which can lead to catastrophic failure of the end under the stressed conditions which are encountered in the pressurised can. The invention described here will make the end less sensitive to these conditions, since the lower Mg content reduces beta-phase precipitation, which has been linked to SCC. Avoidance of SCC is also important in many other applications including car body sheet.

[0034] CES is currently made from AA5182 and gets its strength predominantly from a combination of solute hardening and strain hardening. This makes it difficult to roll and gives a relatively high manufacturing cost.

[0035] The alloy used in the present invention has lower strength during the rolling operations, but develops its strength during subsequent thermal exposure during fabrication. Thus there is the benefit of rolling a lower strength sheet, but still enabling the desired sheet properties to be obtained ultimately. It is also possible to produce a higher strength sheet suitable for downgauging without a reduction in rollability (higher rolling loads, more difficulties in performing the rolling operation) encountered in higher Mg containing alloys such as AA5182 and AA5019A.

[0036] The present invention is also applicable to production of low cost automotive sheet where the material could be used in the hot rolled condition (Direct Hot Roll to Gauge), thereby potentially avoiding the need to solution heat treat the sheet. Alternatively, the sheet could be cold rolled to gauge, as for CES, with a final continuous anneal to impart the formability required for this application and to take the solute into solution. Cooling after annealing should be sufficiently rapid to retain substantially all of the solute in solution. Ageing could be carried out in a separate operation before or after forming, for example during the paint bake stoving of the automotive part.

[0037] Some embodiments of the present invention will now be described by way of example:

Example 1

[0038] An alloy of the following composition was cast as a 225mm x 75mm cross section DC ingot;

Magnesium	3.0 wt. %
Copper	0.4 wt. %
Manganese	0.25 wt. %
Iron	0.20 wt. %
Silicon	0.12 wt. %
Balance	aluminium with incidental impurities. The ingot was not grained refined during casting and as a consequence the Ti level was 0.0018% and B was less than 0.0001%.

[0039] This was homogenised for 2 hours at 540°C (50°C/hr heating rate), followed by laboratory hot rolling to 6mm. During this rolling stage the temperatures were only about 100-200°C, so the strip was re-solution heat treated to bring about full recrystallisation and to put the solute back into solid solution. This reproduces solute levels more like those which would be found during rolling on an industrial hot line (but prior to coiling).

[0040] Different heat treatments were then applied at this gauge. The strip was either solution heat treated (SHT) (5 minutes at 550°C) and cold water quenched (CWQ) or it was solution heat treated and then air cooled to temperatures in the range 300 to 340°C and then cooled at 1°C/min. Conductivity was measured at this stage to determine how much solute remained in solid solution. These conditions were selected to simulate the conditions which might be expected to exist during commercial use of this invention. Until the strip temperature drops below the solvus temperature for the alloy the S phase therein cannot precipitate and therefore the Cu (and Mg) would be substantially in solid solution. The strip could then be quenched at the end of hot rolling or, preferably, cooled after coiling. During this process the starting temperature could be in the range 300 to 340°C and a typical initial cooling rate would be 1°C/min. The temperature range between the solvus temperature (about 390°C for the alloy) and the coiling temperature is passed through very quickly since this is when the strip might typically be in the hot tandem mill and, hence, there is lubricant applied to the strip which acts as a coolant. This phase was simulated using the air cool from the solution heat treatment temperature.

[0041] The strip was then cold rolled to 0.24mm and given a simulation of a coil cool down to ambient temperature from 150°C at 0.4°C/min. It was then given a simulation of a lacquer curing cycle for 3 minutes at 205°C. Tensile testing was performed at each stage of the treatment and the results compared with results on conventional AA5182 CES

materials processed in the laboratory.

[0042] The effect of strength development was also studied at various stages of the laboratory simulation of the CES production route. An example is given below for this alloy which has been solution heat treated at 2mm and rolled to 0.20mm gauge. This is compared with AA5182 rolled in the laboratory using a simulation of the commercial route for that alloy. The 0.2% yield strength is shown in Table 1 below. The as-rolled strength was found to be lower than AA5182, indicating easier rolling, and the strength drop during coiling and lacquer stoving simulation was less, showing the benefits of precipitation hardening. In addition, in AA5182 CES the softest direction is usually at about 45° to the rolling direction of the sheet (softer by about 10-20 MPa) and this is believed to control the buckle pressure of the sheet. In this invention the levels of cold reduction needed to generate the desired strength level are lower and thus the weakest direction is likely to be this longitudinal value. Hence, at its best, the combination of the composition and processing route of the present invention is capable of producing a strength level approximately 45 MPa stronger than existing AA5182.

Table 1:

Comparison of properties with conventional CES		
Condition	5182 CES	This alloy
As-rolled at final gauge	430 MPa	399 MPa
As-rolled and coil annealed	358 MPa	386 MPa
As-lacquered	345 MPa	370 MPa

[0043] Conductivity results are shown in Table 2 below. This shows that the conductivity at the solution heat treatment stage is capable of being increased from 33.1 to 35.0 if the solute is allowed to be removed from solid solution, but that if the material is cooled to ambient temperature at 1°C/min from 300°C there is only a fraction of the increase in the conductivity (0.3% versus 1.9%). This implies that a significant amount of the solute is kept in solid solution, even at these cooling rates.

Table 2:

Conductivity after different heat treatments at 2mm gauge	
Condition	Conductivity (% IACS)
Solution heat treated and CWQ	33.1
Solution heat treated and Fast Air Cooled	33.1
Solution heat treated and cooled from 340°C	33.9
Solution heat treated and cooled from 320°C	33.8
Solution heat treated and cooled from 300°C	33.4
SHT, cold worked and aged 14 hours at 320°	35.0

[0044] The strength developed in these materials at final CES gauge after lacquer stoving is shown in Table 3 below. In this case the sheet has been rolled to 0.24mm. This shows that sufficient solute remains in solid solution still to give an appreciable strength CES. Bend testing has also been performed and indicates an improvement in the amount of bending which can be performed prior to failure when compared with conventional AA5182 CES.

Table 3:

Strength developed after processing to 0.24mm after various thermal treatments at 2mm 'hotband' gauge.	
Condition	0.2% Proof Stress (MPa)
Solution heat treated and CWQ	350 MPa
Solution heat treated and cooled from 340°C	327 MPa
Solution heat treated and cooled from 320°C	329 MPa

Example 2

[0045] An alloy of the following composition was DC cast for processing within an industrial plant:

Magnesium	2.9 wt. %
Copper	0.4 wt. %
Manganese	0.1 wt. %
Iron	0.20 wt. %
Silicon	0.08 wt. %
Balance	aluminium with incidental impurities. The ingots were cast with additional grain refiner.

[0046] The ingot were homogenised at 540°C and hot rolled on a single stand reversing mill to a thickness of 38mm at which point the temperature was around 480°C. The strip was then hot rolled through a 3-stand hot tandem mill to a gauge of 2.5mm. The conditions were adjusted to give two different coiling temperatures in order to show the effects at opposite extremes of this invention. In both cases the coils were forced-air cooled, giving a cooling rate measured on the outer laps of the coil of around 0.7°C/min.

[0047] The cooler coil was processed to give a sidewall temperature of 280-290°C. In this instance the microstructure of the strip was largely unrecrystallised. As a consequence the solute was easily removed from solid solution on the pre-existing dislocation structure from the hot deformation. The conductivity of this strip is shown in Table 4, showing that the %IACS value is similar to that in which all of the precipitation has been allowed to occur. Also in Table 4 is presented the conductivity obtained by using a still-air cool on strips of the 2.5mm thick metal at the end of the hot rolling (approximately 60°C per minute), showing that at these cooling rates a significant amount of the solute can be kept in solid solution.

[0048] The hotter coil was processed to give a coil sidewall temperature of 330-340°C. Table 4 shows that in this case the forced air cooling leaves more solute in solid solution as a consequence of the fully recrystallised grain structure achieved with the higher coiling temperature. The amount of solute in solid solution with the faster cool is even higher and approaches that of the conventional solution heat treated (SHT) and cold water quenched (CWQ) material. This shows that a cooling rate of 0.7°C/min is able to keep some of the copper in solid solution, but that more rapid cooling leaves more copper in solid solution and yet is still fully recrystallised. Thus, cooling the coil with forced-air from a temperature lower than 330°C will achieve a similar effect (i.e. more solute in solid solution), since the c-curve will be substantially missed in that case too. The forced-air cooled coil was cold rolled to 0.216mm and the as-rolled tensile yield strength measured as 347 MPa.

[0049] Between these two limits of cooling temperature there will be even more solute in solid solution at the end of hot rolling and thus even higher strength sheet can be produced.

Table 4:

Conductivity after different thermomechanical treatments in an industrial plant	
Condition	Conductivity (%IACS)
Solution Heat Treated and CWQ	35.4
SHT, CWQ + 24 hrs. at 310°C	36.8
Forced-air cooled coil from 280-290°C	36.9
air cooled strip from 280-290°C	36.1
Forced-air cooled coil from 330-340°C	36.4
air cooled strip from 330-340°C	35.9

Claims

1. A method of producing an age-hardenable aluminium alloy comprising the steps of:

a) casting an alloy of a composition comprising the following expressed in weight percent:

Magnesium	1.0 to 4.0
Copper	0.1 to 0.6
Manganese	up to 0.8

(continued)

Iron	up to 0.5
Silicon	up to 0.3
Chromium	up to 0.15
Titanium	up to 0.15
Balance	Aluminium with incidental impurities

b) optionally homogenising the cast alloy,

c) hot working the casting at an initial temperature of at least 400°C to form an intermediate product, wherein at least part of the hot working is carried out whilst the casting is at a temperature above the solvus temperature of the alloy,

d) cooling the intermediate product either during hot working or in a subsequent step at a rate of less than 5°C/min such that at least a partially recovered or recrystallised structure is formed and that sufficient copper is retained in solid solution in the alloy to cause an age hardening effect on the alloy if phase precipitation takes place during the alloy's subsequent thermal history, and

e) optionally allowing or arranging for phase precipitation to occur in the alloy.

2. A method as claimed in claim 1 wherein the alloy has the following composition expressed in weight percent:

Magnesium	2.0 to 4.0
Copper	0.2 to 0.5
Manganese	up to 0.6, preferably up to 0.5
Iron	0.1 to 0.3
Silicon	up to 0.2
Chromium	up to 0.15
Titanium	up to 0.05
Boron or Carbon	up to 0.01
Balance	Aluminium with incidental impurities

3. A method as claimed in claim 2 wherein the magnesium content is 2.5 to 4.0%.

4. A method as claimed in any one of claims 1 to 3 wherein the intermediate product has a substantially fully recovered or recrystallised structure.

5. A method as claimed in any one of the preceding claims wherein the casting is homogenised before hot working at a temperature of at least 480°C, preferably 500 to 600°C, so that substantially all of the magnesium and copper in the casting are in solid solution.

6. A method as claimed in any one of the preceding claims wherein the casting is hot worked, optionally with re-heating of the casting to above the alloy's solvus temperature, and preferably at least 450°C, to take substantially all of the magnesium and copper present into solid solution.

7. A method as claimed in any one of the preceding claims wherein the hot working step is carried out when the casting has an initial temperature of from 450°C to 580°C.

8. A method as claimed in any one of the preceding claims wherein the alloy is DC cast.

9. A method as claimed in any one of the preceding claims including the step of cold rolling the hot worked casting, optionally with coiling.

10. A method as claimed in any one of claims 1 to 9 wherein the hot working is effected by extrusion.

11. A method as claimed in any one of claims 1 to 9 wherein the hot working is effected by hot rolling.
12. A method as claimed in any one of the preceding claims wherein the hot worked casting is cooled at a rate of less than 1°C/min.
13. A method as claimed in any one of the preceding claims wherein if after the said hot working step the temperature of the intermediate product exceeds the solvus temperature of the alloy then cooling of the intermediate product to a temperature below the alloy's solvus temperature is effected at a rate less than 2°C/sec.

Patentansprüche

1. Verfahren zur Herstellung von aushärtenden Aluminiumlegierungen, das die folgenden Schritte umfasst:

a) Gießen einer Legierung, die das Folgende in Gewichtsprozent ausgedrückt enthält:

Magnesium	1,0 bis 4,0
Kupfer	0,1 bis 0,6
Mangan	bis zu 0,8
Eisen	bis zu 0,5
Silizium	bis zu 0,3
Chrom	bis zu 0,15
Titan	bis zu 0,15
Rest	Aluminium mit allfälligen Verunreinigungen

b) wahlweise Homogenisieren der gegossenen Legierung

c) Warmumformen des Gussstücks bei einer anfänglichen Temperatur von mindestens 400 °C , um ein Zwischenprodukt zu erhalten, wobei mindestens ein Teil der Warmumformung durchgeführt wird, während das Gussstück eine Temperatur oberhalb der Lösungstemperatur der Legierung hat,

d) Kühlen des Zwischenprodukts entweder während dem Warmumformen oder in einem darauffolgenden Schritt mit einer Geschwindigkeit von weniger als 5 °C/min , so dass mindestens eine teilweise erholte oder rekristallisierte Struktur gebildet wird, und dass in der festen Lösung in der Legierung genügend Kupfer verbleibt, um einen Aushärtungseffekt bei der Legierung hervorzurufen, wenn während der weiteren thermischen Geschichte der Legierung Phasenauskristallisierung eintritt, und

e) wahlweise Zulassen oder Herbeiführen des Eintretens von Phasenauskristallisierung in der Legierung.

2. Verfahren nach Anspruch 1, wobei die Legierung die folgende Zusammensetzung, in Gewichtsprozent ausgedrückt hat:

Magnesium	1,0 bis 4,0
Kupfer	0,2 bis 0,5
Mangan	bis zu 0,6, vorzugsweise bis zu 0,5
Eisen	0,1 bis 0,3
Silizium	bis zu 0,2
Chrom	bis zu 0,15
Titan	bis zu 0,15
Bor oder Kohlenstoff	bis zu 0,01
Rest	Aluminium mit allfälligen Verunreinigungen

3. Verfahren nach Anspruch 2, wobei der Magnesiumgehalt 2,5 bis 4 % ist.

4. Verfahren nach einem der Ansprüche 1 bis 3, wobei das Zwischenprodukt eine praktisch vollständig erholte oder rekristallisierte Struktur hat.

5. Verfahren nach einem der vorhergehenden Ansprüche, wobei das Gussstück vor der Warmumformung bei einer

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Température de au moins 480 °C, de préférence 500 à 600 °C homogénéisée, de sorte que pratiquement tout le cuivre et le magnésium dans le moulé sont en solution solide.

6. Procédé selon l'une des revendications précédentes, dans lequel le moulé est thermiquement traité, éventuellement avec un réchauffement du moulé au-dessus de la température de solution de l'alliage, et de préférence au moins à 450 °C, pour pratiquement tout le magnésium et le cuivre en solution solide.
7. Procédé selon l'une des revendications précédentes, dans lequel l'étape de traitement thermique est effectuée, lorsque le moulé a une température initiale de 450 °C à 580 °C.
8. Procédé selon l'une des revendications précédentes, dans lequel l'alliage est coulé.
9. Procédé selon l'une des revendications précédentes, dans lequel l'étape de traitement thermique comprend le laminage à froid du moulé thermiquement traité, éventuellement avec un enroulement, comprend.
10. Procédé selon l'une des revendications 1 à 9, dans lequel le traitement thermique est effectué par laminage.
11. Procédé selon l'une des revendications 1 à 9, dans lequel le traitement thermique est effectué par laminage.
12. Procédé selon l'une des revendications précédentes, dans lequel le moulé thermiquement traité est refroidi à une vitesse de moins de 1 °C/min.
13. Procédé selon l'une des revendications précédentes, dans lequel, après l'étape de traitement thermique, la température du produit intermédiaire dépasse la température de solution de l'alliage, le refroidissement du produit intermédiaire sous la température de solution à une vitesse de moins de 2 °C/sec est effectué.

Revendications

1. Procédé pour produire un alliage d'aluminium durcissable par vieillissement comprenant les étapes consistant à :

a) couler un alliage d'une composition comprenant les éléments suivants, les valeurs étant exprimées en pourcentage pondéral :

Magnésium	1,0 à 4,0
Cuivre	0,1 à 0,6
Manganèse	jusqu'à 0,8
Fer	jusqu'à 0,5
Silicium	jusqu'à 0,3
Chrome	jusqu'à 0,15
Titane	jusqu'à 0,15
Complément	Aluminium avec des impuretés accidentelles

b) éventuellement homogénéiser l'alliage coulé,

c) travailler à chaud la matière coulée à une température initiale d'au moins 400°C afin de former un produit semi-ouvré, dans lequel au moins une partie du travail à chaud est réalisée lorsque la matière coulée est à une température supérieure à la température limite de solubilité de l'alliage,

d) refroidir le produit semi-ouvré soit pendant le travail à chaud, soit au cours d'une étape ultérieure, à une vitesse inférieure à 5°C/min, de sorte qu'au moins une structure partiellement récupérée ou recristallisée se forme et qu'une quantité suffisante de cuivre reste sous forme de solution solide dans l'alliage afin d'entraîner un effet de durcissement par vieillissement de l'alliage si une précipitation de phase se produit lors de l'historique thermique ultérieur de l'alliage, et

e) éventuellement permettre ou faire en sorte qu'une précipitation de phase se produise dans l'alliage.

2. Procédé selon la revendication 1, dans lequel l'alliage possède la composition suivante, les valeurs étant exprimées en pourcentage pondéral :

Magnésium	2,0 à 4,0
Cuivre	0,2 à 0,5
Manganèse	jusqu'à 0,6, de préférence jusqu'à 0,5
Fer	0,1 à 0,3
Silicium	jusqu'à 0,2
Chrome	jusqu'à 0,15
Titane	jusqu'à 0,05
Bore ou carbone	jusqu'à 0,01
Complément	Aluminium avec des impuretés accidentelles

3. Procédé selon la revendication 2, dans lequel la teneur en magnésium va de 2,5% à 4,0%.
4. Procédé selon l'une quelconque des revendications 1 à 3, dans lequel le produit semi-ouvré a une structure essentiellement entièrement récupérée ou recristallisée.
5. Procédé selon l'une quelconque des revendications précédentes, dans lequel la coulée est homogénéisée avant le travail à chaud à une température d'au moins 480°C, de préférence de 500°C à 600°C, de sorte qu'essentiellement tout le magnésium et le cuivre dans la matière coulée soit sous forme de solution solide.
6. Procédé selon l'une quelconque des revendications précédentes, dans lequel la coulée est travaillée à chaud, éventuellement avec un réchauffage de la coulée à une température supérieure à la température limite de solubilité de l'alliage et de préférence à au moins 450°C, afin d'obtenir essentiellement tout le magnésium et le cuivre présents sous forme de solution solide.
7. Procédé selon l'une quelconque des revendications précédentes, dans lequel l'étape de travail à chaud est réalisée lorsque la coulée est à une température initiale allant de 450°C à 580°C.
8. Procédé selon l'une quelconque des revendications précédentes, dans lequel l'alliage est une coulée semi-continue.
9. Procédé selon l'une quelconque des revendications précédentes, comprenant l'étape de laminage à froid de la matière coulée travaillée à chaud, éventuellement avec cintrage.
10. Procédé selon l'une quelconque des revendications 1 à 9, dans lequel le travail à chaud est effectué par extrusion.
11. Procédé selon l'une quelconque des revendications 1 à 9, dans lequel le travail à chaud est effectué par laminage à chaud.
12. Procédé selon l'une quelconque des revendications précédentes, dans lequel la coulée travaillée à chaud est refroidie à une vitesse inférieure à 1°C/min.
13. Procédé selon l'une quelconque des revendications précédentes, dans lequel si, après ladite étape de travail à chaud, la température du produit semi-ouvré dépasse la température limite de solubilité de l'alliage, alors un refroidissement du produit semi-ouvré à une température inférieure à la température limite de solubilité est effectué à une vitesse inférieure à 2°C/sec.

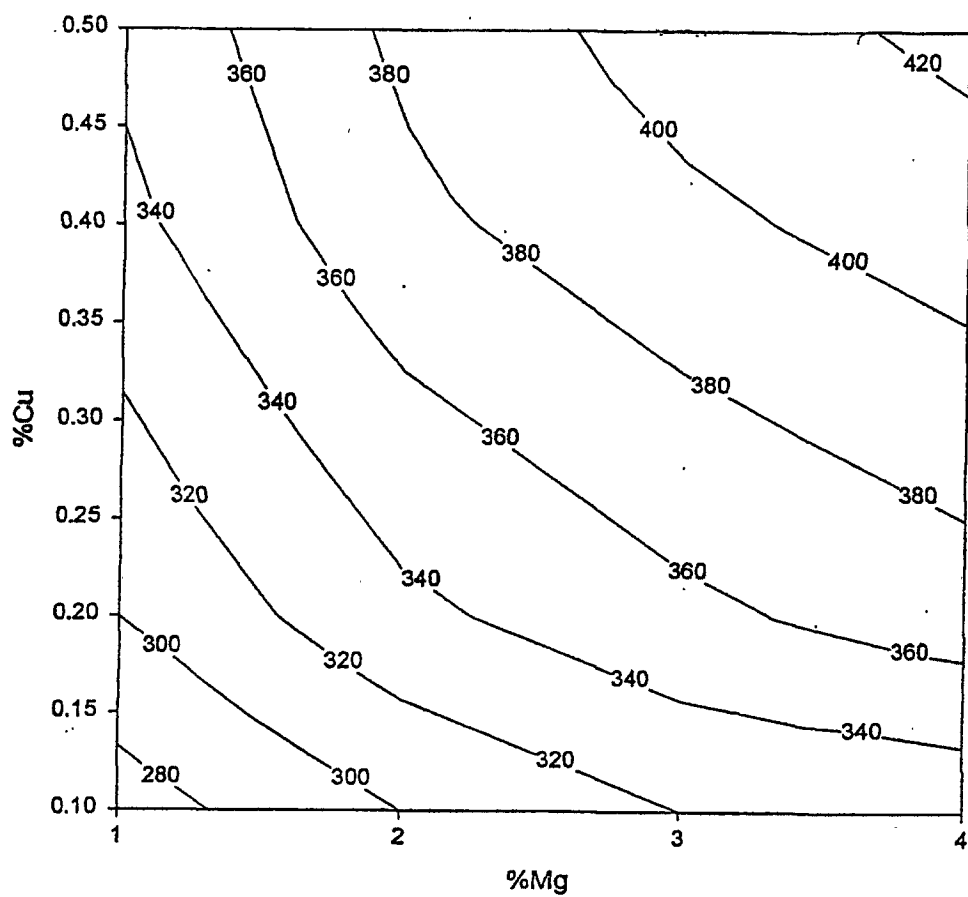


Figure 1

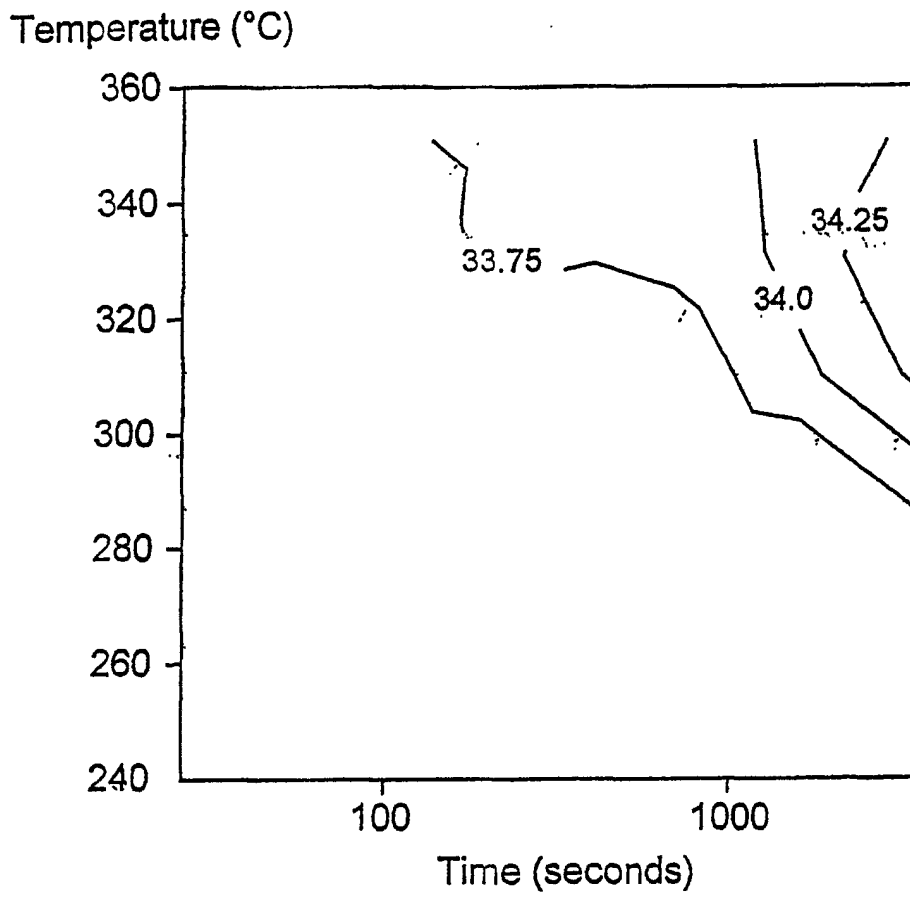


Figure 2

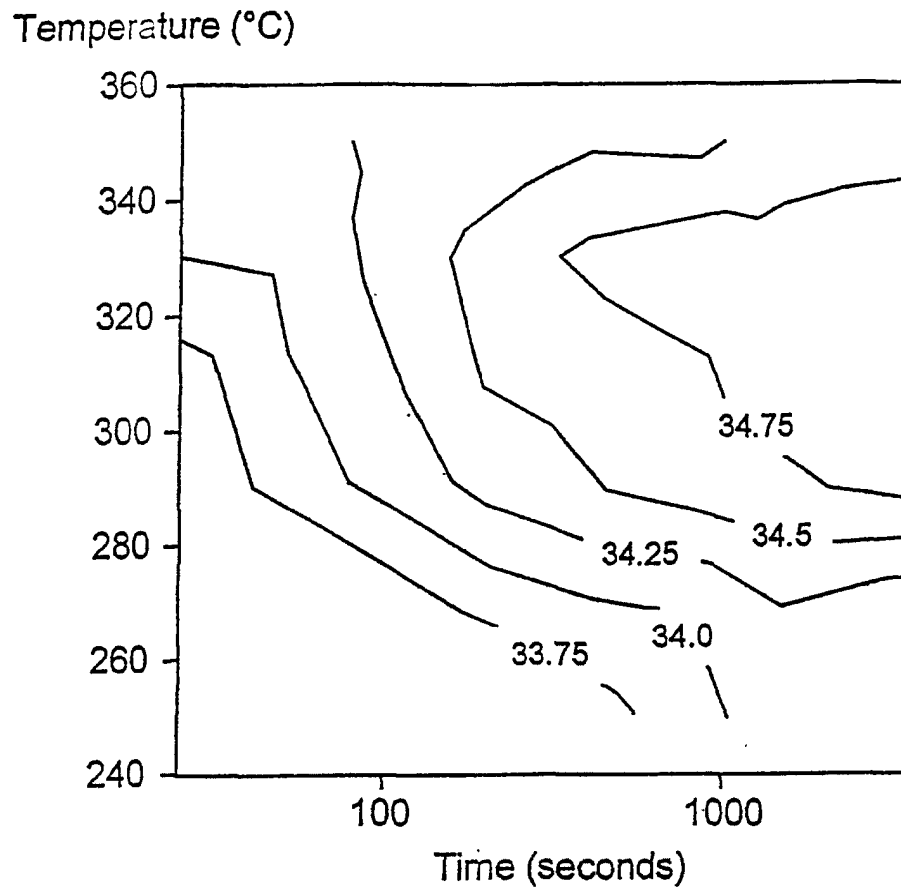


Figure 3

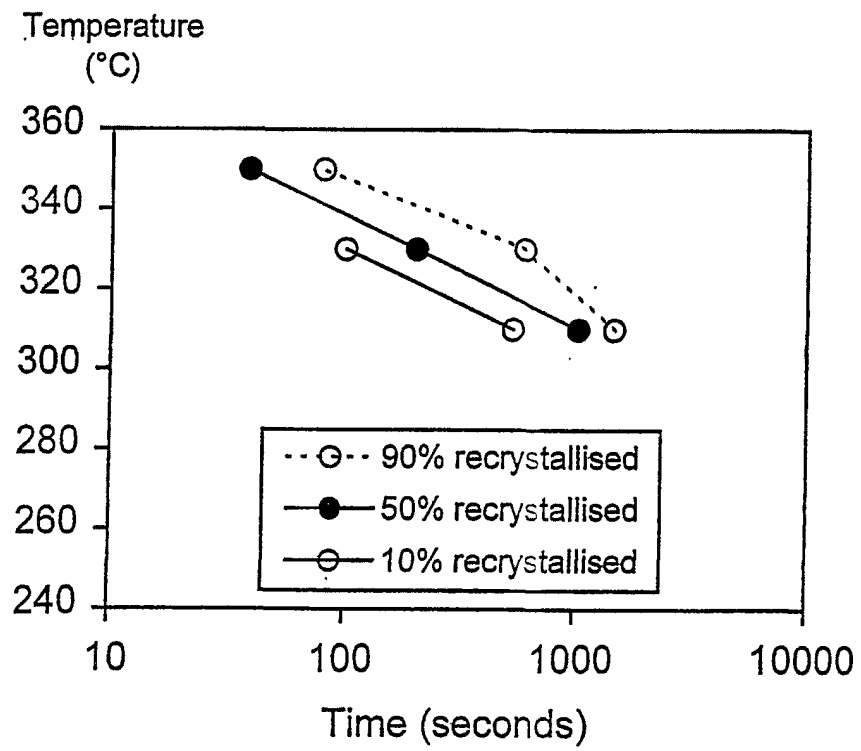


Figure 4