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(54) Rolled aluminium alloy strip for forming and method for making.

(57) Rolled strips of aluminum alloy having improved formability and bake hardening ability are suitable for use as automobile body sheets by mechanically forming the strips and baking paint coatings thereto. The alloy consists essentially of, in percents by weight, 1.2-2.5% of Si, 0.15-1.5% of Mg, 0.1-1.5% of Cu, less than 0.2% of Fe, less than 0.05% of each of Mn, Cr, Zr and V, the total amount of Mn, Cr, Zr and V being less than 0.10%, and the balance of aluminum. The strips have a conductivity of up to 50% IACS and a mean grain size of up to 100 μm at a surface. The strips are prepared by casting a molten aluminum alloy, heating the alloy at 480 to 560°C, hot rolling the alloy into a strip such that the residence time in the temperature range of from 480°C to 400°C during hot rolling following the heating step is within 30 minutes, and a solution treatment step including heating the rolled strip at a rate of at least 5°C/sec. to a temperature of 480 to 560°C, holding the strip at the temperature within 60 seconds, and sequentially cooling at a rate of at least 5°C/sec.

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This invention relates to a rolled aluminum alloy strip adapted for mechanical forming and a method for preparing the same. More particularly, it relates to a rolled aluminum alloy strip which can be readily shaped for use in applications where easy forming and high strength are required and paint coatings are applied and baked prior to use, for example, automobile body sheets, various shaped parts and articles.

BACKGROUND OF THE INVENTION

Heretofore, cold rolled steel strips have been commonly used as automobile body sheets. For meeting the demand for a reduced body weight, investigations are currently made on the use of rolled aluminum alloy strips. Since automobile body sheets are press formed and coated and baked with paint prior to use, the requirements include ease of mechanical forming or working, especially improved elongation and bulging, freedom from a Luders band during forming, high strength, and bake hardening ability to accomplish high strength after baking of paint coatings. Additional requirements include firm adhesion of baked paint coatings and corrosion resistance after paint coating.

Many aluminum alloy strips are known to be formed into articles requiring strength. They are generally classified into the following groups in terms of alloy components.

(a) Fully annealed form of 5052 alloy (2.2-2.8% Mg, 0.15-0.35% Cr, the balance of Al and incidental impurities) and 5182 alloy (0.20-0.50% Mn, 1.0-5.0% Mg, the balance of Al and incidental impurities) which are non-heat-treated Al-Mg series alloys.

(b) T4 or T6 treated form of 2036 alloy (2.2-3.0% Cu, 0.1-0.4% Mn, 0.3-0.6 Mg, the balance of Al and incidental impurities) which is a heat treated Al-Cu alloy.

(c) T4 treated form of heat treated Al-Mg-Zn-Cu alloy. The aluminum alloys of this type include alloys of Japanese Patent Application Kokai Nos. 141409/1977, 103914/1978 and 98648/1982. Also included is Al-4.5%Mg-0.38%Cu-1.46%Zn-0.18%Fe-0.09%Si alloy described in Nikkei New Material, No. 8 (April 7, 1986), pages 63-72, especially page 64.

(d) T4 treated form of 6009 alloy (0.4-0.8% Mg, 0.6-1.0% Si, 0.15-0.6% Cu, 0.2-0.8% Mn, the balance of Al and incidental impurities) and 6010 alloy (0.6-1.0% Mg, 0.8-1.2% Si, 0.15-0.6% Cu, 0.2-0.8% Mn, the balance of Al and incidental impurities) which are heat treated Al-Mg-Si alloys. This form of alloy is described in Japanese Patent Publication No. 39499/1984. Also included is the T4 treated form of AC120 alloy disclosed in Japanese Patent Publication No. 15148/1986.

These forms of prior art aluminum alloys are, however, difficult to fully satisfy all the above-mentioned requirements for automobile body sheets.

Alloys (a) are insufficient in strength, tend to develop a Luders band during shaping, and lose strength during paint baking. Alloys (b) are rather difficult to shape and lose strength during paint baking. Alloys (c) are not satisfactory in forming, especially bending, and lose strength during paint baking. Among alloys (d), 6009 alloy has poor strength and 6010 alloy is insufficient in elongation and bending.

The inventors proposed Al-Mg-Si-Cu alloys in Japanese Patent Application Kokai Nos. 201748/1986 and 201749/1986. Although these Al-Mg-Si-Cu alloys are satisfactory in many of the requirements for automobile body sheets, there is a desire to further improve their bake hardening and forming abilities. More particularly, the Al-Mg-Si-Cu alloys of our previous proposal have a bake hardening ability, that is, increase their strength upon baking of paint coatings, but have the propensity that in general, improving formability leads to a lowering of bake hardening ability whereas improving bake hardening ability causes crystal grains to grow massive, resulting in a lowering of formability. It was thus believed difficult to satisfy both of bake hardening ability and formability.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a new and improved rolled aluminum alloy strip which is improved in bake hardening, that is, exhibits high strength after baking of paint coatings, and is easy to mechanically work or form. Another object is to provide a method for preparing such a rolled aluminum alloy strip.

According to the present invention, there is provided rolled aluminum alloy strip adapted for forming having improved bake hardening ability and formability. The aluminum alloy consists essentially of, in percents by weight, 1.2 to 2.5% of Si, 0.15 to 1.5% of Mg, 0.1 to 1.5% of Cu, less than 0.2% of Fe, less than 0.05% of Mn, less than 0.05% of Cr, less than 0.05% of Zr, less than 0.05% of V, the total amount of Mn, Cr, Zr and V being less than 0.10%, and the balance of aluminum. The strip has an electric conductivity of up to 50% IACS and a mean crystal grain size of up to 100 μm at a surface.

According to another aspect of the invention, there is provided a method for preparing a rolled aluminum alloy strip adapted for forming having improved bake hardening ability and formability. A molten aluminum alloy of the above-defined composition is cast by a semi-continuous casting technique. The alloy is heated at a temperature of 480 to 560°C in a heating furnace and then hot rolled into a strip such that the temperature of the alloy being hot rolled drops to 400°C or lower within 30 minutes from the emergence of the alloy from the heating furnace. A subsequent solution heat treatment step includes heating the rolled strip at a heating rate of at least 5°C/sec. to a temperature of 480 to 560°C, holding the strip at the temperature within 60 seconds, and sequentially cooling at a cooling rate of at least 5°C/sec., whereby the rolled strip has an electric conductivity of up to 50% IACS and a mean crystal grain size of up to 100 μm at a surface. Cold rolling may be carried out between the hot rolling step and the solution heat treatment step.

Also contemplated herein is a rolled aluminum alloy strip for forming prepared by the inventive method.

DETAILED DESCRIPTION OF THE INVENTION

The rolled strip of the present invention is of an aluminum alloy consisting essentially of, in percents by weight, 1.2 to 2.5% of Si, 0.15 to 1.5% of Mg, 0.1 to 1.5% of Cu, less than 0.2% of Fe, less than 0.05% of Mn, less than 0.05% of Cr, less than 0.05% of Zr, less than 0.05% of V, the total amount of Mn, Cr, Zr and V being less than 0.10%, and the balance of aluminum and incidental impurities.

The contents of the respective elements are limited for the following reason. All percents are by weight unless otherwise stated.

Si:

Silicon which forms Mg_2Si with magnesium is effective in improving strength through precipitation hardening and at the same time, contributes to an improvement in formability, especially elongation. Less than 1.2% of Si fails to provide a sufficient improvement in strength. Formability improves as the silicon content increases in excess of the stoichiometric ratio of Mg_2Si. However, beyond 2.5% of Si, the formability improvement is no longer enhanced and formability, especially bending is rather deteriorated. For this reason, Si is limited to the range of 1.2% to 2.5%. If copper which is effective for strength improvement is not added in excess of 0.3%, Si should preferably be added in excess of 1.5%. If 0.3% or more of Cu is present, a silicon content of 1.2 to 1.5% is sufficient to provide strength.

Mg:

In the co-presence of silicon, magnesium forms Mg_2Si to impart strength as described above. Less than 0.15% of Mg is insufficient to improve strength. In excess of 1.5%, work hardening is enhanced too much and workability, especially elongation is reduced. For this reason, Mg is limited to the range of 0.15% to 1.5%.

Cu:

Copper is effective in improving strength and formability, especially elongation. Less than 0.1% of Cu is less effective whereas more than 1.5% of Cu provides extremely high strength at the sacrifice of formability. For this reason, Cu is limited to the range of 0.1% to 1.5%. In order for copper to fully exert its function of improving strength, 0.3% or more of Cu should preferably be added.

Fe:

Iron contributes to crystal grain refinement, but lowers formability, especially bending. This tendency becomes outstanding with an iron content of 0.2% or more. Iron should be limited to less than 0.2% for formability. Mn, Cr, Zr, V:

These transition elements are effective in refining recrystallized grains, but adversely affect formability if present in excess. If their content exceeds 0.05% alone or 0.10% in total, formability becomes insufficient. Therefore, the content of the respective elements should be less than 0.05% and the total content of these elements should be less than 0.10%.

The balance is aluminum. There may be present incidental impurities other than the above-mentioned elements.

It is to be noted that many conventional aluminum alloys contain zinc as an impurity or an additive element. Zinc does not adversely affect workability and bake hardening ability as long as its content is 2.0% or less. Therefore, inclusion of up to 2.0% of Zn is acceptable. Also, minor amounts of Ti or Ti and B are added to some of conventional aluminum alloys for refining cast ingot crystal grains. The rolled aluminum alloy strip of the invention accepts addition of minor amounts of Ti or Ti and B for the same purpose. When titanium is added, less than 0.01% is not effective and more than 0.15% allows development of primary crystals $TiAl_3$ which are detrimental to formability. For this reason, titanium should preferably be in the range of 0.01 to 0.15%. When boron is added together with titanium, less than 1 ppm of B is ineffective whereas above 500 ppm, B forms coarse grains of TiB_2 which are detrimental to formability. Therefore, boron should preferably be in the range of 1 to 500 ppm. In the aluminum alloy of the invention, addition of Be in minor amounts is acceptable. Beryllium is effective, especially when an alloy containing Mg is melted, for suppressing oxidation of the molten metal and for preventing contaminants such as oxide particles from mixing into the material. Higher Be contents in excess of 100 ppm are economically meaningless since its effect is saturated. Thus the Be content should desirably be limited to 100 ppm or less.

The rolled aluminum alloy strip of the present invention is defined not only by the above-mentioned alloy composition, but also by an electric conductivity of up to 50% IACS and a mean crystal grain size of up to 100 μm at a surface.

The conductivity is related to the quantity of solid solution in the alloy matrix in that the higher the quantity of solid solution, the lower becomes the conductivity. Then conductivity provides a check on the quantity of solid solution. In the aluminum alloy strip of the invention, Mg, Si and Cu should be present in solid solution form as much as possible because a larger quantity of solid solution of these elements allows the elements to precipitate during baking of paint coatings, contributing to a strength improvement after baking of paint coatings, that is, higher bake hardening ability. If the quantity of Mg, Si and Cu in solid solution form is so small that the conductivity may exceed 50% IACS, then the alloy will increase a little its strength after baking of paint coatings, that is, has poor bake hardening ability. To secure sufficient bake hardening ability, a sufficient quantity of solid solution to provide a conductivity of 50% IACS or lower is necessary.

The surface crystal grain size is related to skin roughening during forming. A mean grain size of up to 100 μm minimizes skin roughening whereas a mean grain size in excess of 100 μm leads to skin roughening, detracts from the appearance of a shaped member and in some cases, causes fracture during forming. For this reason, a mean grain size of up to 100 μm on a surface is necessary.

Next, the manufacture of a rolled aluminum alloy strip in accordance with the present invention is described.

First, a molten alloy of the above-defined composition is prepared in a conventional manner. It is then cast into a slab of rectangular cross section by a semi-continuous casting or direct chill (DC) casting technique. The casting rate is not critical although a rate of about 25 to 250 mm/min. is often employed.

The slab is often subject to soaking prior to hot rolling, desirably by heating it at a temperature of 480 to 560°C for about 1/2 to 48 hours. This soaking is effective not only in eliminating any heterogeneity in the slab to improve formability as in the manufacture of conventional aluminum alloys, but also in causing some elements to enter into solid solution to enhance the effect of a subsequent solution heat treatment or even if they precipitate, in rendering the precipitates finer to facilitate a subsequent solution heat treatment. If the soaking temperature is lower than 480°C or the holding time is less than 1/2 hour, Mg_2Si insufficiently enters into solid solution and a hardened phase of Mg_2Si or the like becomes coarser during soaking, which phase is difficult to convert into solid solution within a short time by the subsequent solution treatment. This results in poor strength after baking of paint coatings. If the temperature at which the slab is heated exceeds 560°C, eutectic melting occurs. A soaking temperature over 48 hours detracts from economy.

Subsequent to the soaking heat treatment, the slab is subject to preheating again in a heating furnace, immediately followed by hot rolling. The preheating immediately before hot rolling requires heating in the temperature range (480 to 560°C) associated with the solution treatment, preferably at relatively higher temperatures within the temperature range, so that the solid solution state of Mg_2Si achieved by heating of the slab as mentioned above is maintained as much as possible or even if Mg_2Si precipitates, finer precipitates may develop. It is to be noted that this preheating is simply to bring the slab to the above-defined temperature ready for hot rolling to start and does not require to hold the slab for some time at the temperature. If desired, the heat treatment for soaking may be directly followed by preheating for hot rolling without once cooling the slab after the soaking heat treatment.

The next step is hot rolling. The alloy is hot rolled into a strip such that the temperature of the alloy being hot rolled drops from 480°C to 400°C within 30 minutes from the emergence of the alloy from the heating furnace for preheating or combined soaking/preheating. Differently stated, the residence time in the temperature range of from 480°C to 400°C should be within 30 minutes. This prevents precipitation or coarse growth of Mg_2Si during hot rolling immediately after the emergence of the alloy from the heating furnace, thereby facilitating the subsequent solution treatment. Although the basic requirement is a residence time within 30 minutes in the temperature range of from 480°C to 400°C, it is desired to have a residence time as short as possible in order to ensure that precipitation or coarse growth of Mg_2Si is inhibited.

After the hot rolling, the rolled strip may be directly subject to a solution heat treatment whereupon the strip is available as a product ready for use. Often the hot rolling is followed by cold rolling to a desired strip thickness. If desired, intermediate annealing may be effected between the hot rolling and the cold rolling or midway the cold rolling. After the cold rolling, the rolled strip is subject to a solution treatment.

The solution heat treatment step includes a series of heating, holding and quenching steps. It is a critical step for imparting bake hardening ability to allow for strength increase after baking of paint coatings and for improving formability through recrystallization. To provide ease of mechanical forming or working, the strip should have a mean grain size of up to 100 μm at the surface, which requires that recrystallization takes place such that recrystallized grains may have a size of up to 100 μm. Since the transition elements, Mn, Cr, Zr and V themselves adversely affect formability, the content of these elements is limited to less than 0.05% for each element and to less than 0.10% in total as previously described, for the purpose of improving formability. On the other hand, a high temperature/long term solution heat treatment is generally desired to form a sufficient solid solution to provide satisfactory bake hardening ability. In the present invention, however, a high temperature/long term solution heat treatment causes recrystallized grains to grow too large to provide a grain size of up to 100 μm since the contents of Mn, Cr, Zr and V known as crystal grain refining elements or recrystallized grain stabilizing elements are limited to minimal amounts as mentioned above. For this reason, the solution heat treatment is limited to a heating rate of at least 5°C/sec., a heating temperature of 480 to 560°C, and a holding time within 60 seconds in accordance with the invention. Outside these ranges, coarse crystal grains in excess of 100 μm develop, detracting from formability. It is to be noted that a lower temperature is preferred for the solution heat treatment for obtaining finer crystal grains, but no satisfactory solid solution can form at temperatures below 480°C.

It will be understood that a higher heating rate, a relatively mild temperature and a shorter holding time are preferred from the standpoint of crystal grains. If such solution heat treatment conditions are applied to the prior art conventional process, then less solid solution forms, resulting in a conductivity of higher than 50% IACS and insufficient bake hardening ability. To eliminate this problem, the present invention employs the heating and hot rolling steps under the above-defined conditions for placing the alloy into conditions ready for the solution heat treatment, more particularly into sufficient conditions to allow a solution heat treatment under the conditions of a higher heating rate, a relatively mild temperature and a shorter holding time to achieve satisfactory solid solution formation. Differently stated, by combining heating and hot rolling steps under the specific conditions with a solution heat treatment under the specific conditions, we have succeeded in achieving a crystal grain size of up to 100 μm and a conductivity of up to 50% IACS, thus satisfying both formability and bake hardening ability at the same time. The later part of the solution heat treatment is quenching. The cooling rate is also critical to impart bake hardening ability. A cooling rate slower than 5°C/sec. provides a too low quenching effect to achieve a conductivity of up to 50% IACS. A cooling rate of at least 5°C/sec. may be accomplished by forced air cooling, mist quenching, or water quenching.

For the above-mentioned reasons, the solution heat treatment is carried out by heating the rolled strip at a heating rate of at least 5°C/sec. to a temperature of 480 to 560°C and holding the strip at the temperature for up to 60 seconds, followed by quenching at a cooling rate of at least 5°C/sec. This treatment may be accomplished by means of a coil type continuous annealing apparatus such as a gas furnace CAL and electromagnetic induction heating furnace CAL.

It is to be noted that the optional intermediate annealing between hot rolling and cold rolling or midway cold rolling may be either batchwise or continuous, with the continuous annealing being preferred for the subsequent solution heat treatment. In the case of continuous annealing, the alloy is preferably heated to a temperature of 350 to 560°C with or without holding at the temperature within 3 minutes, especially within 60 seconds. If the temperature of the intermediate annealing of the continuous mode exceeds 560°C, coarser crystal grains would develop, detracting from formability. No recrystallization would occur at temperatures below 350°C. A holding time in excess of 60 seconds entails the risk of developing coarser crystal grains if the temperature is above 480°C. If the temperature is below 480°C, such a risk does not exist and a longer holding time is acceptable, with a holding time within 3 minutes being preferred in view of efficient manufacture. In the case of intermediate annealing of the batch mode accompanied by a long heating/holding time, careful attention should be paid so as not to allow Mg_2Si grains to grow larger. It is adequate to hold at a temperature of 300 to 400°C for about 1/2 to 24 hours. If the batchwise intermediate annealing temperature exceeds 400°C, coarse grains of Mg_2Si would form to such an extent as to prevent solid solution formation during the subsequent solution heat treatment, failing to provide bake hardening ability. No recrystallization occurs at temperatures below 300°C. A holding time of less than 1/2 hour would be too short to ensure consistent manufacture whereas long time annealing beyond 24 hours only detracts from economy.

Preferably, the cold rolling immediately before the solution heat treatment is carried out to a rolling reduction of at least 30%. If the rolling reduction is below 30%, coarse grains with a size of more than 100 μm would sometimes result from recrystallization.

The thus rolled strip may be subject to natural aging in a conventional manner and if desired, leveled for providing a flat surface or removed of strain by skin pass. The strain removal, if employed, may be followed by a heat treatment as disclosed in Japanese Patent Application Kokai No. 11953/1989, FIGS. 1 and 2, for the purposes of recovering a slight loss of formability due to strain removal and preventing a change of strength with time.

The rolled aluminum alloy strip according to the present invention is generally used by forming or shaping or forming the strip as by press forming and then applying a paint coating thereto followed by baking. The paint coating is generally baked at a temperature of about 150 to 250°C. The strip can be effectively formed or worked since the mean crystal grain size on the surface is limited to 100 μm or less and the contents of Mn, Cr, Zr, V and Fe are limited. Since Mg_2Si and similar constituents have formed a sufficient solid solution to provide a conductivity of up to 50% IACS, these constituents will precipitate out to increase strength during paint baking, achieving bake hardening.

EXAMPLE

Examples of the present invention are given below by way of illustration and not by way of limitation.

Example 1

For each of alloy Nos. 1 to 5 in Table 1, a slab of 500 x 1200 x 400 mm was cast by a semi-continuous casting technique. The slab was subjected to a soaking heat treatment at 530°C for 10 hours, preheated in a heating furnace at 530°C for 2 hours or at 430°C for 2 hours as shown in Table 2, and then hot rolled into a strip of 3 mm thick. The temperature at the end of hot rolling was 280°C when the heating temperature immediately before hot rolling was 530°C and 250°C when the heating temperature immediately before hot rolling was 430°C. The time taken from the exit of the slab from the heating furnace to the end of hot rolling was 10 minutes in either case. The hot rolled strip was then cold rolled to a thickness of 1 mm and subjected to a solution heat treatment in a continuous annealing furnace. The solution heat treatment conditions included a heating/cooling rate of 30°C/sec. and holding at 520°C for 10 seconds or a heating/cooling rate of 30°C/sec. and holding at 550°C for 90 seconds. After the solution heat treatment, each rolled strip was determined for conductivity and mean crystal grain size on the surface. The results are shown in Table 2 together with main treating conditions.

The rolled strip was naturally aged for 7 to 10 days before it was measured for mechanical properties, formability and bake hardening ability. The results are shown in Table 3. The mechanical properties tested included yield strength (YS), tensile strength (TS), and elongation. Formability was evaluated in terms of Erichsen value (Er) and 180° minimum bending radius. Bake hardening was evaluated by carrying out a 175°C/1 hour heat treatment equivalent to paint baking and then determining the yield strength (YS).

Table 1

Alloy No.	Si	Mg	Cu	Fe	Mn	Cr	Zr	V	Ti	B(ppm)	Be(ppm)	Al	Remarks
	Composition (% by weight)												
1	1.70	0.60	0.73	0.09	-	-	-	-	-	-	-	bal	Invention
2	2.03	0.44	0.43	0.08	0.02	-	-	-	0.02	-	3	bal	Invention
3	1.63	0.77	0.52	0.07	-	0.02	0.01	-	0.01	5	10	bal	Invention
4	2.11	0.39	0.33	0.09	0.01	-	-	0.01	0.02	5	-	bal	Invention
5	1.71	0.62	0.71	0.32	0.17	0.09	-	-	0.02	7	-	bal	Comparison

Table 2

Product	Alloy No.	Preheating	Hot rolling ending temp.	Solution heat treatment/ quenching	Rolled strip		Remarks
					Conductivity (% IACS)	Grain size (µm)	
A	1	530°Cx2hr.	280°C	heat-cool 30°C/sec. 520°Cx10sec.	44.2	44	Invention
B	2	530°Cx2hr.	280°C	heat-cool 30°C/sec. 520°Cx10sec.	44.6	35	Invention
C	3	530°Cx2hr.	280°C	heat-cool 30°C/sec. 520°Cx10sec.	44.5	34	Invention
D	4	530°Cx2hr.	280°C	heat-cool 30°C/sec. 520°Cx10sec.	44.8	33	Invention
E	5	530°Cx2hr.	280°C	heat-cool 30°C/sec. 520°Cx10sec.	43.8	32	Comparison
F	1	430°Cx2hr.	250°C	heat-cool 30°C/sec. 520°Cx10sec.	52.0	42	Comparison
G	1	530°Cx2hr.	280°C	heat-cool 30°C/sec. 550°Cx90sec.	43.2	170	Comparison

Table 3

Product	Alloy No.	YS (kg/mm^2)	TS (kg/mm^2)	Elongation (%)	Er (mm)	Bending radius (mm)	Baking-equivalent heat treatment, YS (kg/mm^2)	Remarks
A	1	16.9	31.3	31	10.1	0.2	20.1	Invention
B	2	14.6	29.5	31	10.0	0	18.6	Invention
C	3	15.9	30.8	31	10.2	0.2	19.6	Invention
D	4	14.2	28.3	32	10.1	0	18.2	Invention
E	5	17.2	31.8	24	9.3	1.0	21.4	Comparison
F	1	8.2	17.8	30	10.0	0.2	11.3	Comparison
G	1	15.1	28.3	17	7.8	-	-	Comparison

As seen from Table 3, when alloys having a composition within the scope of the invention (Alloy Nos. 1

to 4) were processed into strips having a conductivity of up to 50% IACS and a mean grain size of up to 100 μm at the surface (Products A to D), all the strips were improved in formability and bake hardening as demonstrated by a high strength after the paint baking-equivalent heat treatment. In contrast, when a comparative alloy containing more Fe, Cr and Mn (Alloy No. 5) was similarly processed (Product E), the strip met the conductivity and grain size requirements, but was poor in formability. When an alloy having a composition within the scope of the invention (Alloy No. 1) was similarly processed except for a preheating temperature below 480°C before hot rolling (Product F), the strip exhibited a conductivity in excess of 50% IACS, low strength and poor bake hardening. When an alloy having a composition within the scope of the invention (Alloy No. 1) was similarly processed except for a longer solution heat treatment time (Product G), the strip was poor in formability due to coarse crystal grains.

Example 2

Alloy Nos. 6 to 10 as shown in Table 4 were processed as in Example 1 through casting-soaking heat treatment-preheating-hot rolling-cold rolling-solution heat treatment-quenching. There were obtained rolled strips of 1 mm thick. Table 5 shows treating conditions in these steps. The conductivity and surface mean grain size of these rolled strips are also shown in Table 5.

The rolled strips were naturally aged for 7 to 10 days before they were measured for mechanical properties, formability and bake hardening as in Example 1. The results are shown in Table 6.

Table 4

Alloy No.	Si	Mg	Cu	Fe	Mn	Cr	Zr	V	Ti	B(ppm)	Be(ppm)	Al	Remarks
	Composition (% by weight)												
6	1.32	0.60	0.73	0.09	-	-	-	-	-	-	-	bal	Invention
7	1.42	0.44	0.43	0.08	0.02	-	-	-	0.02	-	3	bal	Invention
8	1.33	0.77	0.52	0.07	-	0.02	0.01	-	0.01	5	10	bal	Invention
9	1.34	0.39	0.33	0.09	0.01	-	-	0.01	0.02	5	-	bal	Invention
10	1.38	0.62	0.71	0.32	0.17	0.09	-	-	0.02	7	-	bal	Comparison

Table 5

Product	Alloy No.	Preheating	Hot rolling ending temp.	Solution heat treatment/ quenching	Rolled strip		Remarks
					Conduc-tivity (% IACS)	Grain size (µm)	
H	6	530°Cx2hr.	280°C	heat-cool 30°C/sec. 520°Cx10sec.	44.0	50	Invention
I	7	530°Cx2hr.	280°C	heat-cool 30°C/sec. 520°Cx10sec.	44.8	38	Invention
J	8	530°Cx2hr.	280°C	heat-cool 30°C/sec. 520°Cx10sec.	44.7	37	Invention
K	9	530°Cx2hr.	280°C	heat-cool 30°C/sec. 520°Cx10sec.	45.0	37	Invention
L	10	530°Cx2hr.	280°C	heat-cool 30°C/sec. 520°Cx10sec.	43.6	38	Comparison
M	6	430°Cx2hr.	250°C	heat-cool 30°C/sec. 520°Cx10sec.	51.0	45	Comparison
N	6	530°Cx2hr.	280°C	heat-cool 30°C/sec. 550°Cx90sec.	43.0	180	Comparison

Table 6

Product	Alloy No.	YS (kg/mm^2)	TS (kg/mm^2)	Elongation (%)	Er (mm)	Bending radius (mm)	Baking-equivalent heat treatment, YS (kg/mm^2)	Remarks
H	6	15.9	30.3	31	10.1	0.2	19.1	Invention
I	7	13.6	28.5	31	10.0	0	17.6	Invention
J	8	14.9	29.8	31	10.2	0.2	18.5	Invention
K	9	13.2	27.3	32	10.1	0	17.6	Invention
L	10	16.3	30.9	24	9.3	1.0	20.3	Comparison
M	6	7.6	17.1	30	10.0	0.2	10.7	Comparison
N	6	14.3	27.4	17	7.8	-	-	Comparison

As seen from Table 6, when alloys having a composition within the scope of the invention (Alloy Nos. 6

to 9) were processed into strips having a conductivity of up to 50% IACS and a mean crystal grain size of up to 100 μm at the surface (Products H to K), all the strips were improved in formability and bake hardening as demonstrated by a high strength after the paint baking-equivalent heat treatment. In contrast, when a comparative alloy containing more Fe, Cr and Mn (Alloy No. 10) was similarly processed (Product L), the strip met the conductivity and grain size requirements, but was poor in formability. When an alloy having a composition within the scope of the invention (Alloy No. 6) was similarly processed except for a preheating temperature below 480°C before hot rolling (Product M), the strip exhibited a conductivity in excess of 50% IACS, low strength and poor bake hardening. When an alloy having a composition within the scope of the invention (Alloy No. 6) was similarly processed except for a longer solution heat treatment time (Product N), the strip was poor in formability due to coarse crystal grains.

Example 3

Each of alloy Nos. 1 and 5 in Table 1 was cast and soaked as in Example 1. It was preheated in a heating furnace at 530°C for 2 hours or at 430°C for 2 hours as shown in Table 7, and then hot rolled into a strip of 3 mm thick. The temperature at the end of hot rolling was 280°C when the heating temperature immediately before hot rolling was 530°C and 250°C when the heating temperature immediately before hot rolling was 430°C. The time taken from the exit of the slab from the heating furnace to the end of hot rolling was 10 minutes in either case. Without cold rolling, the hot rolled strip was directly subjected to a solution heat treatment using a salt bath. The solution heat treatment conditions included a heating rate of at least 100°C/sec., holding at 520°C for 30 seconds, and a cooling rate of at least 200°C/sec.

After the solution heat treatment, each rolled strip was determined for conductivity and mean grain size on the surface. The results are shown in Table 7 together with main treating conditions.

The rolled strips were naturally aged for 7 to 10 days before they were measured for mechanical properties, formability and bake hardening as in Example 1. The results are shown in Table 8.

Table 7

Product	Alloy No.	Preheating	Hot rolling ending temp.	Solution heat treatment/ quenching	Rolled strip Conduc-tivity (% IACS)	Rolled strip Grain size (μm)	Remarks
P	1	530°Cx2hr.	280°C	heating ≥100°C/sec. holding 520°Cx30sec. cooling ≥200°C/sec.	44.0	48	Invention
Q	5	530°Cx2hr.	280°C	ditto	43.5	36	Comparison
R	1	430°Cx2hr.	250°C	ditto	51.5	46	Comparison

Table 8

Product	Alloy No.	YS (kg/mm^2)	TS (kg/mm^2)	Elonga-tion (%)	Er (mm)	Bending radius (mm)	Baking-equivalent heat treatment, YS (kg/mm^2)	Remarks
P	1	16.7	31.1	33	10.4	0.4	20.3	Invention
Q	5	17.0	31.5	25	9.5	1.2	21.6	Comparison
R	1	8.4	18.0	31	10.2	0.5	11.6	Comparison

The final product in this example was obtained by subjecting a strip as hot rolled directly to a solution heat treatment without cold rolling.

As seen from Table 8, when an alloy having a composition within the scope of the invention (Alloy No. 1) was processed into a strip having a conductivity of up to 50% IACS and a mean crystal grain size of up to 100 μm at the surface (Product P), the strip was improved in formability and bake hardening as demonstrated by a high strength after the paint baking-equivalent heat treatment. In contrast, when a comparative alloy containing more Fe, Cr and Mn (Alloy No. 5) was similarly processed (Product Q), the strip met the conductivity and grain size requirements, but was poor in formability. When an alloy having a composition within the scope of the invention (Alloy No. 1) was similarly processed except for a preheating temperature below 480°C before hot rolling (Product R), the strip exhibited a conductivity in excess of 50% IACS, low strength and poor bake hardening.

The rolled aluminum alloy strips according to the present invention are improved in formability and bake hardening ability so that they may be readily formed or worked as by press forming without skin roughening. In addition, the strips increase their strength during baking of paint coatings, eventually offering shaped parts of very high strength having paint coatings baked thereto. The strips are thus best suited as automobile body sheets. The method of the invention is easy to produce rolled aluminum alloy strips having such improved properties in a commercially acceptable large scale.

The rolled aluminum alloy strips are suitable not only as automobile body sheets, but also in other applications where the strips are mechanically formed and coated with paint by baking, for example, as automobile parts such as wheels, oil tanks, and air cleaners, various caps, blinds, aluminum cans, household goods, meter covers, and electric equipment chassis.

The foregoing detailed description is intended to be illustrative and non-limiting. Many changes and modifications are possible in light of the above teachings. Thus, it is understood that the invention may be practiced otherwise than as specifically described herein and still be within the scope of the appended claims.

Claims

1. A rolled aluminum alloy strip adapted for forming having improved bake hardening ability and formability, consisting essentially of, in percents by weight, 1.2 to 2.5% of Si, 0.15 to 1.5% of Mg, 0.1 to 1.5% of Cu, less than 0.2% of Fe, less than 0.05% of Mn, less than 0.05% of Cr, less than 0.05% of Zr, less than 0.05% of V, the total amount of Mn, Cr, Zr and V being less than 0.10%, and the balance of aluminum, and having an electric conductivity of up to 50% IACS and a mean crystal grain size of up to 100 μm at a surface.

2. A rolled aluminum alloy strip according to claim 1 which contains from more than 1.5% to 2.5% of Si.

3. A rolled aluminum alloy strip according to claim 1 which contains 1.2 to 1.5% of Si and 0.3 to 1.5% of Cu.

4. A method for preparing a rolled aluminum alloy strip adapted for forming having improved bake hardening ability and formability, the aluminum alloy having a composition consisting essentially of, in percents by weight, 1.2 to 2.5% of Si, 0.15 to 1.5% of Mg, 0.1 to 1.5% of Cu, less than 0.2% of Fe, less than 0.05% of Mn, less than 0.05% of Cr, less than 0.05% of Zr, less than 0.05% of V, the total amount of Mn, Cr, Zr and V being less than 0.10%, and the balance of aluminum, said method comprising the steps of:
   casting a molten aluminum alloy of said composition by a semi-continuous casting technique,
   heating the alloy at a temperature of 480 to 560°C in a heating furnace,
   hot rolling the alloy into a strip such that the temperature of the alloy being hot rolled drops to 400°C or lower within 30 minutes from the emergence of the alloy from the heating furnace, and
   a solution heat treatment step including heating the rolled strip at a heating rate of at least 5°C/sec., holding the strip at a temperature of 480 to 560°C for up to 60 seconds, and sequentially cooling at a cooling rate of at least 5°C/sec., whereby the rolled strip has an electric conductivity of up to 50% IACS and a mean crystal grain size of up to 100 μm at a surface.

5. A method for preparing a rolled aluminum alloy strip according to claim 4 which further comprising a cold rolling step between the hot rolling step and the solution heat treatment step.

6. A rolled aluminum alloy strip for forming prepared by the method of claim 4 or 5, having an electric conductivity of up to 50% IACS and a mean crystal grain size of up to 100 μm at a surface.

European Patent
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EUROPEAN SEARCH REPORT

Application Number

EP 92 30 7980

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	US-A-4 808 247 (T. KOMATSUBARA ET AL) * column 4, line 28 - column 5, line 11; claim 1; table 1 * * column 1, paragraph 2 * ---	1-6	C22C21/02 C22F1/043
A	US-A-4 718 948 (T. KOMATSUBARA ET AL) * claims 1,9; table 1 * ---	1,4	
A	DE-A-3 829 911 (KABUSHIKI KAISHA KOBE SEIKO SHO) * claims 1-5 * ---	1,4,6	
A	US-A-4 424 084 (M.F. CHISHOLM) * claim 1 * ---	1,4	
D,A	PATENT ABSTRACTS OF JAPAN vol. 11, no. 30 (C-400)29 January 1987 & JP-A-61 201 749 (SUKAI ALUM KK) 6 September 1986 * abstract * ---	1,4	
A	US-A-4 897 124 (M. MATSUO ET AL) * claims 1,5-7; table 1 * ---	1,4	TECHNICAL FIELDS SEARCHED (Int. Cl.5)
P,X	EP-A-0 480 402 (SUMITOMO LIGHT METAL INDUSTRIES LIMITED) *TABLE 7 ALLOY A* * claim 1 * -----	1	C22C C22F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	10 NOVEMBER 1992	GREGG N.R.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
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