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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : C22F	A2	(11) International Publication Number: **WO 00/34544**
		(43) International Publication Date: 15 June 2000 (15.06.00)

(21) International Application Number: PCT/IB99/02116

(22) International Filing Date: 6 December 1999 (06.12.99)

(30) Priority Data:
09/208,762 10 December 1998 (10.12.98) US

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(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
Without international search report and to be republished upon receipt of that report.

(54) Title: ALUMINUM ALLOY SHEET HAVING HIGH ULTIMATE TENSILE STRENGTH AND METHODS FOR MAKING THEIR OWN

(57) Abstract

An aluminum sheet and a process for manufacturing an aluminum sheet are provided. The process involves batch annealing and produces a sheet exhibiting a high level of ultimate tensile strength for a given level of magnesium content and elongation. The process involves: (a) producing an aluminum ingot comprised of at least 3.0 % by weight magnesium based on the total weight of the ingot (mass), (b) homogenizing the ingot at a temperature of between 900 °F and 1200 °F, (c) hot rolling the ingot at a temperature of between 570 °F to 680 °F to produce a first intermediate product, (d) cold rolling the first intermediate product to produce a second intermediate product, (e) heat treating the second intermediate product at a temperature of at least 600 °F to produce a third intermediate product, and (f) cold rolling the third intermediate product to produce the aluminum sheet. The sheet exhibits a relatively high ultimate tensile strength for a given level of magnesium and a given level of elongation.

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ALUMINUM ALLOY SHEET HAVING HIGH ULTIMATE TENSILE STRENGTH AND METHODS FOR MAKING THEIR OWN

Background Invention

1. Field of the Invention

The present invention relates to processes for making aluminum sheet and sheets made thereby, and more particularly relates to processes for making high strength, high magnesium aluminum sheets and sheets made thereby involving batch annealing.

2. Description of the Related Art

In conventional manufacturing processes for obtaining aluminum sheet, there is generally a trade off between the ultimate tensile strength, magnesium content and elongation of a material. For example increasing the cold work of the sheet generally results in increased ultimate tensile strength with a decrease in elongation. And as a further example, decreasing the cold work generally results in a decrease in ultimate tensile strength with a corresponding increase in elongation. Increasing magnesium content can improve the ultimate tensile strength of the alloy, but typically causes a corresponding increase in the cost of the alloy.

As set out below, flash annealing processes have been developed to address some of the problems that have heretofore been associated with batch annealing, but flash annealing typically requires an additional handling step of unwinding and re-winding with flash annealing, whereas batch annealing does not require this additional handling.

In contrast to the batch annealing process of the present invention, various flash annealing processes, also referred to as continuous annealing processes, have existed and

require the additional step of continuously passing the sheet through a heating means as a single web to provide a heat up rate of the sheet at a greatly increased rate over that of batch annealing. Examples of such flash annealing processes include Palmer et al. U.S. Patent 5,362,341, issued November 8, 1994, which is incorporated herein by reference; and additional continuous annealing processes are disclosed in Tanaka et al. U.S. Patent 5,062,901, issued November 5, 1991; Tanaka et al. U.S. Patent 5,240,522, issued August 31, 1993; Tanaka et al. U.S. Patent 4,968,356, issued November 6, 1990; Wyatt-Mair et al. U.S. Patent 5,470,405 issued November 28, 1995; Wyatt-Mair et al. U.S. Patent 5,496,423 issued March 5, 1996; Wyatt-Mair et al. U.S. Patent 5,514,228 issued May 7, 1996; Tahara et al. U.S. Patent 5,512,111 issued April 30, 1996; Shoiji et al. U.S. Patent 5,518,558 issued May 21, 1996. Satou et al. U.S. Patent 5,578,114 issued November 26, 1996 involves a continuous casting process; Sanford et al. U.S. Patent 5,547,524 issued August 20, 1996 discloses a process for producing a structurally hardened plate involving heating opposite edges at various temperatures; Gen et al. U.S. Patent 5,616,189 issued April, 1997 discloses a process involving flash annealing; Bekki, et al. U.S. Patent 5,605,586 discloses a process involving flash annealing; Kamat U.S. patent 5,634,991 issued June 3, 1997 discloses a process involving annealing at the rate of heat up at 75 degrees per hour; all of which are incorporated herein by reference.

The various flash annealing processes have typically required the additional step of unwinding and re-winding the coil of aluminum sheet. This winding is both time consuming and costly and the aluminum sheet can be damaged in the process, all of which add to the cost of the product. Batch annealing does not required that the aluminum sheet be unwound, and is thus very desirable. However, conventional batch processing has not obtained the desired combination of high ultimate tensile strength for a given level of elongation and magnesium level. For example, strength levels exceeding 448 MPa (65,000 psi) are currently not available in Al-Mg sheet products, as partially shown in the table provided below in the detailed description.

Consequently there is a need and a desire to provide a batch annealing process in the production of aluminum sheet which will provide a high ultimate tensile strength for a given level of elongation and magnesium level. There is also a desire to increase the ultimate tensile strength for a given magnesium level and the elongation percent in order to permit a reduced gauge thickness of sheet made by the present process to effectively perform as a relatively larger conventional gauge thickness of sheet made by a conventional batch annealing process.

Summary of the Invention

The present invention involves a process for manufacturing an aluminum sheet. The process involves: (a) producing an aluminum ingot (mass) comprising of at least 2.0% by weight magnesium based on the total weight of the ingot (mass), (b) homogenizing the ingot (mass) at a temperature of between 482°C-649°C (900°F and 1200°F), (c) hot rolling the ingot (mass) at a coiling temperature of between 288°C–382°C (550°F to 720°F) to produce a first intermediate product, (d) cold rolling the first intermediate product to produce a second intermediate product, (e) batch heat treating (annealing) the second intermediate product at a temperature of at least 316°C (600°F) to produce a third intermediate product, (f) cold rolling the third intermediate product to produce said aluminum sheet, and (g) optionally post processing the aluminum sheet by annealing the aluminum sheet at 93°C–382°C (200-720°F). The present invention provides the advantage of a relatively high ultimate tensile strength for a given level of elongation and magnesium thereby permitting higher performance of product for given applications. The high ultimate strength levels are achieved by cold working a fine grain microstructure which is developed in the annealing step (e) subsequent to a minimum of 50% cold working reduction in step (d). The annealing step may be batch annealing or strip annealing. The present process also allows for batch anneal to develop a fine grain microstructure without continuous annealing or flash annealing which typically involves unwinding of coils and additional effort.

Brief Description of the Drawings

Figure 1 is a schematic diagram of the process according to the present invention.

Detailed Description of the Invention

The process according to the present invention is illustrated in Figure 1 which involves first producing an ingot (12) by the process (10) of the present invention. The ingot may also be referred to as a mass in the event that continuous casting is employed. In the event that an ingot is utilized, the ingot may need to be scalped (14) followed by or prior to preheating (16). After preheating, the product from the preheat step is hot rolled (18) followed by a minimum of 45% cold rolling (20). After cold rolling, the product is then subjected to batch annealing (heat treating) (22) and is then further cold rolled (24) to produce the aluminum sheet (26). The aluminum sheet can be post processed using a final annealing by heating the sheet to 93°C–382°C (200-720°F).

The alloy composition utilized for the ingot (mass) and the alloy sheet of the present invention has a magnesium level of at least 2%, for example 2 to 7% by weight based on the total weight of the composition (ingot, mass, sheet), more preferably a level of 3 to 6% by weight based on the total weight of the composition (ingot, mass, sheet). Supplemental alloy additions in the composition preferably involve manganese at a level of 0.20 to 1.5 weight percent based on the total weight of the composition; silicon at a level of less than or equal to 0.3 weight percent based on the total weight of the composition; iron at a level of less than or equal to 0.4 weight percent based on the total weight of the composition; chromium present at a level of less than or equal to 0.25 weight percent based on the total weight of the composition; zinc present at a level of 1.8 weight percent or less based on the total weight of the composition; scandium present at a level of less than or equal to 0.5 weight percent; zirconium

present at a level of less than or equal to 0.5 weight percent; with all other alloy additions being present at a level of less than or equal to 2 weight percent, and preferably all other ingredients being a level of less than 0.2 weight percent individually, with the balance of the composition being aluminum.

In the preferred process, an ingot of aluminum is produced and is scalped. The ingot (mass) is then preferably homogenized by raising the temperature of the ingot to the range of 482°C to 649°C (900°F to 1200°F) and holding the temperature within that range 482°C to 649°C (900-1200°F) for a time of less than or equal to 30 hours and preferably between 10 and 30 hours. The ingot (mass) temperature is then lowered to the range of 482°C to 538°C (900°F to 1000°F) and maintained within this range for a time period of at least one hour. Following preheat, the ingot (mass) is preferably hot rolled at a coiling temperature of between 293°C (560°F) and 360°C (680°F), or more broadly between 288°C (550°F) and 382°C (720°F), to produce a first intermediate product. A suitable initial thickness of the first intermediate product is for example 6,2 mm (0.25″).

The first intermediate product is then cold rolled to produce a second intermediate product having a thickness of less than 50% of the thickness of the first intermediate product and more preferably less than 45% of its thickness, and preferably the cold rolling is done at a temperature of less than or equal to 204°C (400°F) to produce the second intermediate product. The second intermediate produce is then heat treated by batch annealing.

Batch annealing is accomplished by heating the entire wound coil of aluminum sheet as compared to flash annealing which involves annealing a single layer (web) of the sheet by unwinding the coil and annealing a particular portion of the sheet by passing the sheet through a heat treating station and then re-winding the coil. The present batch annealing avoids the requirement of having to unwind and re-wind the coil.

The annealing (batch annealing) according to the present invention occurs at a

temperature of at least 304°C (580°F) and preferably above 315°C (600°F), and more preferably within the range of 332°C (630°F) and 371°C (700°F), for a period of at least two hours to produce a third intermediate product. This product has an average grain diameter of less than 19 microns (ASTM of 8.5 or greater number), for example a grain size of ASTM 11, or more broadly ASTM 8.5 to 12, and for example between ASTM 9 and 11 as measured by ASTM E112. The grain size of 8.5 corresponds to a grain size of about 18.9 microns, consequently, and the grain size are preferably less than 18.9 microns.

Following the batch annealing, the third intermediate product is cold rolled to produce an aluminum sheet having a thickness of from 20 to 80% (preferably 50 to 80%) of the thickness of the second intermediate sheet (a total reduction of 20 to 90%) to produce an aluminum sheet having an ultimate tensile strength of at least 380 MPa [55,000 pounds per square inch-(psi)] as measured by ASTM B557, and typically resulting in an ultimate tensile strength of between 414 MPa (60,000 psi) and 686 MPa (85,000 psi), for example 510 MPa (74,000 psi), and having an elongation of between 4 and 7%.

The present invention also provides high strength alloys without the need for the addition of relatively expensive, excessive levels of strengthening additives, and without the need to impart significant cold work to the product to achieve the strength level. The reduced level of cold work needed to produce such high strength aluminum alloy is in part due to the very fast hardening rate exhibited by the batch annealed sheet (coil) of the present invention.

Optionally, a final anneal at for example 93°C (200°F) to 382°C (382°F) for a time in excess of two hours may be utilized to further increase the formability of the sheet with some sacrifice in the tensile strength.

In more detail, the process for manufacturing an aluminum sheet comprises: (a) producing an aluminum ingot (mass) comprised of at least 2.0% by weight magnesium based on the total weight of the ingot, (b) homogenizing the ingot at a temperature of between 482°C

(900°F) and 649°C (1200°F), (c) hot rolling the ingot at a coiling temperature of between 299°C (570°F) to 360°C (680°F) to produce a first intermediate product, (d) cold rolling the first intermediate product to produce a second intermediate product, (e) annealing the second intermediate product at a batch anneal temperature of at least 316°C (600°F) to produce a third intermediate product, and (f) cold rolling the third intermediate product to produce a fine grain aluminum sheet. Optionally a final anneal of the aluminum sheet may be performed to increase the elongation properties of the aluminum sheet by annealing the aluminum sheet at a temperature between 93 and 382°C (200 and 720°F).

The present method produces an aluminum alloy sheet having 2% or greater magnesium with ultimate tensile strengths in excess of 380 MPa (55,000 psi). A fine grain size, specifically 8.5 or greater as measured by ASTM E112 prior to the final cold work is critical in the processing method in order to enhance the strain hardening characteristics through increasing grain boundary area. Material produced by the present process may find suitable applications such as, but not limited to, flat sheet blanks, boat/ship stock, automotive brackets and structural applications. A suitable process may involve having ingots produced under direct chill or continuous casting.

A suitable chemical composition of material is as follows: no less than 2% by weight magnesium and no more than 6.0% by weight magnesium, no less than 0.20 weight percent manganese and no more than 1.5% by weight manganese, no more than 0.35 weight percent silicon, no more than 0.48 weight percent iron, no more than 0.25 weight percent chromium and no more than 1.8 weight percent zinc; scandium present at a level of less than or equal to 0.5 weight percent; zirconium present at a level of less than or equal to 0.5 weight percent; with additional components each being less than 0.2 weight percent and then the balance being aluminum based on the total weight of the aluminum ingot.

In the preferred process, the ingots are scalped sufficiently to remove cast surface and ingots are prepared for hot rolling. The ingots are then homogenized by heating to

a temperature range of 900°F to 1200°F (480°C to 648°C) and holding (maintaining) the ingots' temperature in this range for up to 30 hours, then cooling to 900°F to 1000°F (480°C to 537°C) and holding at that temperature for no less than 1 hour prior to hot rolling. The ingots may optionally be hot rolled without the final cooling step.

A suitable process involves, having the slabs hot rolled at a coiling temperature of no less than 299°C (570°F) and no greater than 360°C (720°F). The coils are then cold rolled to reduce the web thickness by at least 50%. After cold rolling, the coils are heat treated above 315°C (600°F) for at least 2 hours. During this heat treatment, the fine grains are nucleated, which provide for strengthening during subsequent cold rolling through increasing the strain hardening component of the material. The coils are then cold rolled at an additional 50 to 80% to make the final product thickness and take advantage of the increased grain boundary area created during the prior heat treatment.

The maximum strength levels obtained using the present process have generally not been achieved in prior batch processes and are not available in Aluminum-Magnesium sheet alloys. Conventionally, high strengths have been achieved through alloy additions and/or imparting significant cold work of the material with the resultant disadvantages as set out above. For example, an alloy having 4.6% Mg (by total weight) and 0.7-1.0% Mn, with 60% final cold work plus annealing at 132°C (270°F) for 2 hours according to the present inventive process has a 38 MPa (5,500 psi) ultimate strength level advantage over the same alloy (4.6% Mg and 0.7-1.0% Mn) cold rolled 80% made according to industry standard practice. In another test 5182 Alloy (commonly used for can lid stock) containing about 4.6% Mg and .38% Mn cold rolled about 63% according to the present inventive process has the same strength about 386-400 MPa (56,000-58,000 psi, Ultimate Tensile Strength) as the alloy has cold rolled 90% according to industry standard practice.

The following table shows some additional mechanical property limits of non-heat treatable alloys according to Aluminum Industry standards:

TABLE 1

Alloy and Temper	Specified Thickness inches (mm)	Tensile Strengths-MPa (KSI)				Elongation (%)
		ULTIMATE		YIELD		
		(Min)	(Max)	(Min)	(Max)	
5086-H38	0.006-(0,15mm) 0,20 -(0,5 mm)	324 (47)		262 (38)		3
5154-H38	0.006-(0,15mm) 0,05 -(1,25mm)	310 (45)		241 (35)		3
5154-H38	0.051-(1,25mm) 0,113-(2,8mm)	310 (45)		241 (35)		4
5154-H38	0.114-(2,8mm) 0,128-(3,2mm)	310 (45)		241 (35)		5
5086-H18 (Sheet)	0.006-(0,15mm) 0,019-(0,47mm)	359 (52)	407 (59)	331 (48)		
5086-H19 (Sheet)	0.006-(0,15mm) 0,019-(0,47mm)			359 (52)		2
5086-H191 (Sheet)	0.006-(0,15mm) 0,019-(0,47mm)	373 (54)		345 (50)		2
5086-H39 (Sheet)	0.006-(0,15mm) 0,019-(0,47mm)	359 (52)		297 (43)		3

As a further step, a final anneal may be performed, the temperature range of the final annealing will depend on the desired properties of the aluminum alloy.

To enhance formability, a final anneal may be performed in the range from 93°C (200°F) to 380°C (720°F) for at least 2 hours. The temperature and time duration for the final anneal will be determined by the level of formability required for the final product. Temperatures above 260°C (500°F) will typically be used for 0 temper products and applications requiring an extremely fin grain size, such as super-plastic-forming (SPF). These final anneals will generally reduce the ultimate tensile strength and yield while increasing the elongation.

The following examples show the increased strength of alloys made according to the present invention:

EXAMPLE 1.

Aluminum Alloy: (All percentages by weight)
4.55% Magnesium
0.98% Manganese
0.01% Copper
0.66% Silicon
0.19% Iron
0.10% Chromium
0.50% Scandium
0.50% Zirconium
<2.0% All others
Preheat according to the present invention and hot roll to a thickness of 7,25 mm (0.290") at a temperature of 343°C (650°F).

Process A (Prior Art Step). 80% cold roll aluminum alloy sheet, with no final annealing.
Resulting Ultimate Tensile Strength: 438 MPa (63,500 psi)

OR

Process B. (According to Present Invention) Cold roll aluminum alloy sheet to 2,5 mm (0.100") (60% cold work) and anneal at 93-382°C (200-720°F) for 2 hours. Additional 60% cold roll to 1 mm (0.040").
Resulting Ultimate Tensile Strength: 510 MPa (74,000 psi)

The Example shows the alternative finishing steps for the alloy. The Process A, which was practiced in prior art methods, concludes with a cold rolling and no final anneal. Process B, according to the present invention, uses a final anneal to further increase the formability of the sheet with a minor sacrifice in the tensile strength gains.

As shown in the above example, completing the post batch anneal processing by 80% cold rolling the aluminum sheet to 80% of its thickness, with no final annealing, results in a sheet having a Ultimate Tensile Strength (UTS) of about 438 MPa (63,500 psi). A sheet processed according to the current invention which has been 60% rolled and then annealed at 260-382°C (500-720°F) for 2 hours and cold rolled 60% again has a much higher UTS of 510 MPa (74,000 psi). This increased strength is significantly higher than a similar alloy processed according to the prior processes and has greater workability after the final annealing.

EXAMPLE 2 :
Aluminum Association alloy 5182 (commonly used for beverage can lids)
[comparable to the composition of Example 1, about 0.4% Manganese]

Process A (Prior Art Step): Preheat and hot roll mass as described in the detailed description. Hot roll sheet to 2,87 mm (0,115") at 332°C (630°F). Cold roll 86% to 0,4 mm (0.016").
Resulting Ultimate Tensile Strength: 386-400 MPa (56,000-58,000 psi)

OR

Process B: (According to the Present Invention) Same as Process A, but cold roll 62% to (0.043") sheet thickness. Batch anneal sheet at 332°C (630°F)
Cold roll 63% to (0.016")
Resulting Ultimate Tensile Strength: 386-400 MPa (56,000-58,000 psi)

Here again, an alloy sheet processed using a cold rolling step following the hot rolling results in a UTS of 386-400 MPa (56,000-58,000 psi) for the alloy 5182 used for beverage can lids. The batch anneal of this process alloys cold rolling to be used to roll the sheet to the final thickness of 0,4 mm (0.016") while maintaining the same UTS by increasing the formability of the alloy through annealing.

Significantly lower cold work is required to achieve same properties as prior art.

EXAMPLE 3 :

Same alloy as in example 1.
Preheat according to the invention and hot roll to a thickness of 7,25 mm (0,290") at a temperature of 343°C (650°F).
Process A (Prior Art) : 78% cold rolling with no final annealing.
Resulting UTS : 453 MPa (65,600 psi)
YS (60,400 psi)
Elongation 4,4 %
Process B (invention) : 55 % cold rolling and annealing at 132C° (270°F) for 2 hours, developing a fine grain structure.
Resulting UTS : 475 MPa (68,800 psi)
YS : 426 MPa (61,700 psi)
Elongation : 5,5%
The process provides a greater elongation over prior art and better mechanical resistance.

EXAMPLE 4 :

Same alloy and hot rolling as in example 3.

Process A 78% cold rolling with no final annealing. The cold rolled sheet is transformed by superplastic forming (SPF)

Resulting SPF elongation : 375 %

Process B 55% cold rolling and annealing at 132°C for 2 hours to develop a fine grains structure

Resulting SPF elongation : 375 %

The process of the invention provides the same SPF elongation with significantly less cold work.

CLAIMS

What is claimed:

1. A process for manufacturing an aluminum sheet, said process comprising:

(a) producing an aluminum ingot compressing of at least 3.0% by weight magnesium based on the total weight of the ingot,

(b) homogenizing said ingot at a temperature of between 482°C (900°F) and 649°C (1200°F),

(c) hot rolling said ingot at a temperature of between 299°C (570°F) to 360°C (680°F) to produce a first intermediate product,

(d) cold roiling said first intermediate product to produce a second intermediate product,

(e) heat treating said second intermediate product at a temperature of at least 316°C (600°F) to produce a third intermediate product, and

(f) cold rolling said third intermediate product to produce said aluminum sheet.

2. The process of claim 1 wherein the step of heat treating said second intermediate product includes batch annealing said intermediate product for at least two hours at a temperature of at least 316°C (600°F).

3. The process of claim 1 wherein said homogenizing comprises (i) increasing said ingot temperature to a temperature of between 538°C (1000°F) and 649°C (1200°F) for a period of between 10 hours and 30 hours for maintaining temperature and (ii) decreasing said ingot

temperature to between 482°C (900°F) and 538°C (1000°F) and maintaining said temperature for at least one hour.

4. The process of claim 1 wherein said cold rolling of said first intermediate product results in the second intermediate product having a thickness of less than 50% of the initial thickness of the said first intermediate product.

5. The process of claim 1 wherein said cold rolling of said third intermediate product results in said aluminum sheet having a thickness of 20 to 50% of the thickness of said third intermediate product.

6. The process of claim 1 comprising the additional step of a final anneal of the aluminum sheet.

7. The process of claim 6 wherein said final anneal is performed at a temperature of 93-382°C (200°F-720°F).

8. The process of claim 6 wherein said final anneal is performed at a temperature of 260-382°C (500°F-720°F).

9. An aluminum alloy sheet made by the process of claim 1.

10. A sheet of claim 9 wherein said sheet has a ultimate tensile strength of at least 380 MPa (55,000 psi) as measured by ASTM B557.

11. The sheet of claim 10 wherein said first intermediate product has a grain size of at least 8.5 as measured by ASTM E112.

12. An aluminum alloy sheet, said sheet comprising:

(a) from 3.0 to 6% by weight magnesium based on the total weight of the sheet, said sheet having an ultimate tensile strength of at least 380 MPa (55,000 psi) as measured by ASTM B557.

13. An aluminum alloy sheet, said sheet comprising:

(a) from 4.55 to 6% by weight magnesium based on the total weight of the sheet;

(b) at least 0.98% manganese by weight;

(c) less than 3% total by weight of other alloys and impurities;

said sheet having an ultimate tensile strength of at least 469 MPa (68,000 psi) as measured by ASTM B557.

14. The aluminum alloy sheet of claim 13, further including:

(a) at least O.066% by weight silicon;

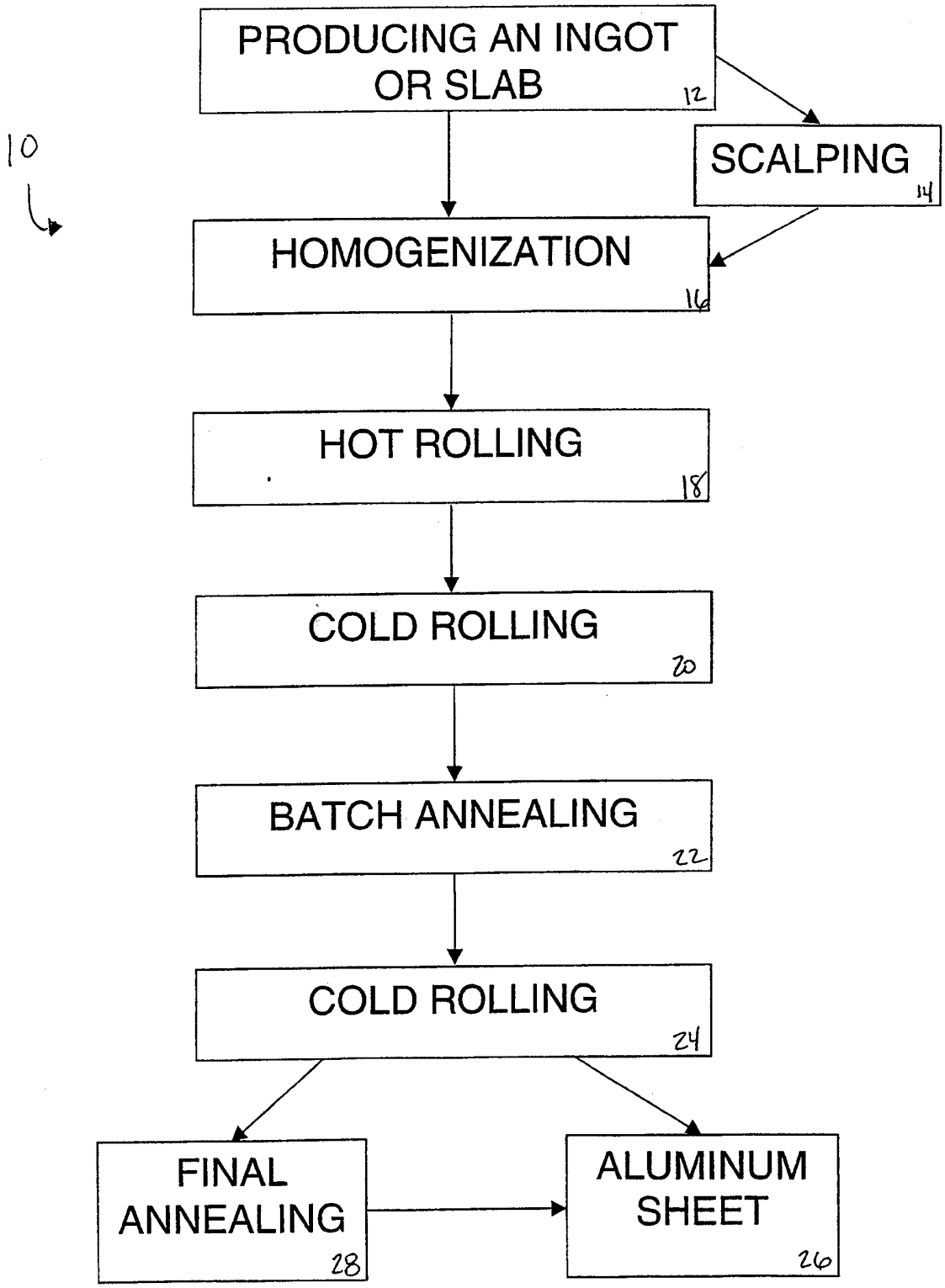
(b) at least 0.19% by weight iron;

(c) 0.1% by weight chromium;

(d) up to 0.50% by weight Scandium;

(e) up to 0.50% by weight Zirconium; and

(f) less than 2% by weight total of other alloys and impurities.


10
PRODUCING AN INGOT OR SLAB
12
SCALPING
14
HOMOGENIZATION
16
HOT ROLLING
18
COLD ROLLING
20
BATCH ANNEALING
22
COLD ROLLING
24
FINAL ANNEALING
28
ALUMINUM SHEET
26