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(54) Title: PROCESS OF PRODUCING 5XXX SERIES ALUMINUM ALLOYS WITH HIGH MECHANICAL PROPERTIES THROUGH TWIN-ROLL CASTING

(57) Abstract: Present invention concerns a method for making fine-grained, formable aluminium alloy strips containing (by weight) essentially between 0,5-6,5 %Mg, 0-0,50 %Si, 0-0,60 %Fe, 0-1,2 %Mn, 0-0,50 %Cr, by twin-roll casting to a thickness ranging between 4 and 6,5 mm and cold rolling the strips to an intermediate gauge and reroll annealing the intermediate gauge material. The reroll-annealed material is then cold rolled to a final sheet gauge followed by a final recrystalizing or back annealing. The combination of controlled casting parameters, controlled amounts of Fe, Si, Mn, Cr and Mg and reroll and final annealing temperatures results in an improved sheet product in terms of finer grain size, higher elongation and formability, age softening and better corrosion resistance. Homogenization may be performed at 420°C to 550°C for a period of 4 to 15 hours and recrystallization is performed at 280°C to 375°C for a period of not less than 4 hours and not more than 8 hours.

PROCESS OF PRODUCING 5XXX SERIES ALUMINUM ALLOYS WITH HIGH MECHANICAL PROPERTIES THROUGH TWIN-ROLL CASTING

FIELD OF THE INVENTION

The present invention is directed to a process for the production of 5XXX series aluminum alloys, from continuously cast aluminum strip suitable for using in automotive and transportation applications, exhibiting superior or at least equivalent mechanical, microstructural, corrosion resistance and formability properties than those of similar alloys produced by the DC casting routes.

BACKGROUND OF THE INVENTION

Weight reduction is a primary goal in transportation industry including especially automotive and marine technologies not only to improve fuel economy, but also to improve performance, safety & durability and to reduce emissions. The use of light-weight materials is one of the most promising ways of achieving this goal and aluminum currently offers the greatest potential for cost-effective weight savings in automotive body structures. Aluminum has the advantage over competitive materials due to a very attractive combination of density, strength, formability and ease of recycling. Although there is extensive use of aluminum in die-cast parts, wrought aluminum has so far been confined to relatively few applications.

Aluminum, with only one-third the density of steel and a better strength-to-density ratio, could provide weight reductions of nearly 50% when used in place of steel in automotive sheet applications. In addition, the fabrication, assembling and recycling practices for aluminum components are largely the same as those employed for steel, making aluminum particularly favorable for these applications. The major barrier to the widespread use of aluminum in high-volume automotive applications has not been its technical shortcomings, but its high cost, which is roughly four to five times that of sheet steel. Production of aluminum sheet by the strip casting route rather than by the conventional DC casting and hot mill method offers an opportunity to substantially reduce this cost, which could lead to an increase in its use. While block and belt casting have received some attention, the potential of Twin Roll Casting (TRC) process in the manufacture of aluminum sheet for automotive structural applications has so far been overlooked. Recently, there has been a growing interest in using TRC as a method to produce low-cost/high-

quality aluminum sheet for such applications. Production of aluminum sheets having Mg content between 3.0 and 5.0 % by direct chill (DC) casting method was proposed by Yamada et. al in US patent 4,826,737. Mg content of the alloy was varying between 0,5 and 3,8 in another application proposed by Wong in US patent 3,661,657. The production process of that invention, however, is based on DC casting method, as well.

In spite of the successful use of 5XXX series aluminum alloys in stamping, press shop and other forming operations of DC cast aluminum ingots, economic and energy considerations would favor the manufacture of the these alloys by continuous strip casting. In this process the molten metal is cast and solidified into a thin strip of 6 mm or less in thickness so that subsequent rolling is reduced and costly step of hot rolling is eliminated. Compared to the previous applications, such as in US 4,235,646 by Neufeld et al., wherein the casting and final gauge of the end-product is limited to certain thicknesses, present invention allows production of the as-cast strip between 3 to 7 mm and various thickness of the end products having soft and H2X, H3X tempers.

Properties required of aluminum sheet for automotive applications are high strength, good formability, weldability and corrosion resistance and are met largely by a number of Al-Mg (5XXX series) alloys that are the subject of the present invention. Al-Mg alloys have been used to form auto body trim parts, doors, hood, truck vessels, fuel tanks, pressurized air vessels of trucks, truck tanks, ships and their infrastructure and superstructure, dump truck bodies, cryogenic vessels and LPG tanks.

INDUSTRIAL APPLICABILITY

Present invention relates to an aluminum alloy with high mechanical properties and method for its manufacture. Therefore, the invention has industrial applicability in the field of processing metals.

SUMMARY OF THE INVENTION

In accordance with the objective of the present invention, a wrought Al-Mg alloy sheet produced through Twin Roll Casting technique and accordingly processed to its final gauge aiming to provide superior or at least equivalent

microstructural, mechanical, corrosion resistance and formability properties compared to their counter parts produced by DC casting and mill route is provided. The sheet product contains essentially between 0,5-6,5 %Mg, 0, 0-0,50 % Si, 0, 0-0,60 % Fe, 0, 0-1,2 % Mn, 0, 0-0,50%Cr by weight.

BRIEF DESCRIPTION OF FIGURES

Figure 1, is the flowchart showing the casting process according to the present invention,

Figure 2-a, is the flowchart showing cold rolling and annealing processes according to an embodiment of the invention where no homogenization treatment is applied.

Figure 2-b, is the flowchart showing cold rolling and annealing processes according to another embodiment of the invention where a homogenization treatment is applied immediately after casting.

Figure 2-c, is the flowchart showing cold rolling and annealing processes according to a further embodiment of the invention where a homogenization treatment is applied following a cold rolling process.

Figure 3, shows photographs of very fine discrete particles near the surface of (a) Alloy A, (c) Alloy B and (e) Alloy C in as-cast materials where interdendritic network of primary phases in the interior of the same strips are shown for (b) Alloy A, (d) Alloy B and (f) Alloy C.

Figure 4, shows photographs of the staining observed after 96 hrs exposure to salt spray, on following samples (a) DC-cast A, (b) DC-cast B (c) strip cast A w/homog, (d) strip cast A w/o homog., (e) strip cast B w/homog., (f) strip cast B w/o homog. and (g) strip cast C w/homog.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is directed to a process for the preparation of 5XXX series aluminum alloys, from continuously cast aluminum strip suitable for using in automotive and other transportation applications, exhibiting superior or at least equivalent mechanical, microstructural, corrosion resistance and formability properties than those of similar alloys produced by the DC casting routes.

When compared to the DC casting and hot mill method, Twin Roll Casting technology has a relatively shorter process route (Fig. 1) with less working of the

metal. As is claimed in number of publications, the processing route, that comprises DC casting and successive hot mill operations, is envisioned as a unique way for the production of 5XXX series aluminum alloys in different thickness.

As will hereinafter be illustrated, it has been determined that in the strip casting of 5XXX series aluminum alloys, control of the casting speed, melt temperature, cast sheet thickness, alloy composition and critical positioning of the caster tip (that is a ceramic structure delivering the molten metal in between the caster rolls) with respect to the centerline of the caster rolls, called set-back, render to obtain appropriate as-cast sheet tailored with optimum microstructural and mechanical properties. These features are the first essential and basic requirements of the material that will be processed in certain routes to achieve desired mechanical performance in the final product. Control of the cold roll, recovery and recrystallization anneal will result in twin-roll cast aluminum sheet exhibiting superior or at least equivalent microstructural, mechanical, corrosion resistance and formability properties than those of sheets produced through DC casting and subsequent hot mill operations. Chemical composition of the alloys that will be presented in the body of this application is given in Table 1.

Table 1. The chemical composition of the alloys.

ALLOY	Si,%	Fe,%	Cu,%	Mn,%	Mg,%	Cr,%	Al,%
A	0.125	0.286	0.030	0.059	2.536	0.163	96.71
B	0.177	0.328	0.043	0.365	4.210	0.153	94.63
C	0.165	0.307	0.037	0.286	3.062	0.067	95.98

The microstructure of the as-cast strip is characterized by a dendritic structure of the aluminum solid solution with the primary phases marking the dendrite boundaries. The interdendritic network of the primary phases is well defined in the interior of the strip whereas it is deteriorated somewhat and is replaced by a very fine dispersion of discrete particles near the surface. The dendritic structure is quite uniform across the thickness of all strip samples. The microstructural features, i.e. dendrite arm spacing, primary particle size, are relatively smaller at the surface and coarsened only slightly when approaching the center of the strip. However, such variations across the thickness of the 5XXX as-cast strip are not as prominent as

they are in some common foil and finstock alloys. The extent of supersaturation was largest in the alloys having high Mg content.

The structure near the surface reveal the characteristic appearance of a deformed material in strip samples. Grains appeared more and more elongated and flattened, and the intermetallic particles more and more oriented near the surface, suggesting that the surface has experienced substantial deformation in the caster roll gap (Figure 3). Evidence of surface deformation is more prominent in the case of Alloy A and C. The smaller casting gauge selected for the latter alloy is believed to be responsible. Even a small, only as much as 0.5 mm, decrease in the casting gauge apparently has a profound effect on surface deformation. The central part of the strip, on the other hand, reveals a more or less equiaxed, uniform grain structure and a random dispersion of the primary phases. It is thus concluded that the deformation during casting was limited to the surface layers and has had little effect, if any, in the central part of the strip.

Three types of segregation patterns were identified in the as-cast strip. Alloy B strip shows traces of surface segregation with eutectic rich bands, running in the casting direction, only along the edges of the cast strip. These bands, however, do not penetrate deep into the strip and were estimated to be less than 5 μm deep in the most severe cases. It should be noted that this edge region of any cast strip is removed by an edge trimming operation during cold rolling. There is hardly any evidence of surface segregation in Alloy A and Alloy C strip. Some intergranular and centerline segregation is also observed in all strip samples. The latter occasionally produced channels of solute-rich material and is most prominent in the Alloy B. Although centerline segregation is believed to have negative effects on mechanical properties –at least to some extent-, these effects may be minimized with appropriate casting parameters.

It is concluded from the metallographic analysis of the sheet samples that the surface and intergranular segregation patterns have not survived to the final gauge. There was no evidence of surface and intergranular segregation patterns at the final gauge except for some traces of centerline segregation. The solute-rich eutectic regions at the centerline have apparently transformed into clusters of discrete particles which have largely spherodized.

To effect the most advantageous improvement in the through-thickness grain structure along with mechanical properties, such as lower yield strength, higher elongation and higher UTS (ultimate tensile strength), at the final gauge and soft temper of the material, homogenization treatment should be applied after a cold rolling pass.

Two different processing routes (Fig. 2a and 2b-2c)wherein existence of homogenization treatment determining this difference, can be applied to the as-cast strip. Homogenization treatment of the strip is performed at the temperature between 420^0 and 550 ^{0}C for a period of time, preferably not less than 4 hours and not more than 15 hours. Homogenization treatment is carried out in an inert gas atmosphere of the batch annealing furnaces. In the processing route, in which as-cast strip is subjected to homogenization treatment, two different methods are employed depending on when it is applied: While homogenization treatment can be performed at the casting gauge (Fig. 2b), it can also be applied after a first cold rolling pass that must provide at least 25% reduction in the thickness of as-cast strip (Fig. 2c). The grain structure at the final gauge is improved in a profound way when cast strip is homogenized after a cold rolling pass . The homogenized strip material is subjected to cold rolling wherein no recrystallization anneal is applied until a critical gauge. Recrystallization anneal at this critical gauge and subsequently applied predetermined amount of cold working and application of back annealing procedure at the final gauge, as a final step in the production cycle, provides strain hardened and partially annealed, H2X tempers, final products including, H22, H24, H26.

Recrystallization at the final gauge in practice of the present invention is in the range of 280^0 to about 375^0C, preferably for about 2 to 8 hours. Prior to the recrystallization anneal applied to obtain 0 temper material at the final gauge, as-cast strip is cold rolled to the final gauge without applying any intermediate annealing in processing route as shown in Fig. 2a. Similarly, the material that is subjected to the homogenization treatment, according to the processing routes shown in Fig. 2b and 2c, is also cold rolled to the aimed gauge without application of intermediate annealing. Intermediate annealing applied at the predetermined stage of the processing route is also considered as recrystallization anneal and carried out by applying the same temperature and time combination.

Back annealing temperatures to render H2X temper materials at the final gauge are in the range of 130^0-250^0C, preferably 2 to 8 hours.

Production routes of the final products having mechanical properties of H3X tempers principally follow the similar processing route of H2X tempers. After heating at the recrystallization temperature for the above mentioned prescribed time period, coil is subjected to final cold roll of at least 20% to attain aimed final gauge. To achieve an optimum mechanical property requirement of H3X tempers, this anneal is effected at a temperature between about 100 and 190^0C for about 2 to 6 hours.

Aforementioned processing routes of the present invention, that comprises a homogenization treatment, can be altered in the way of eliminating homogenization treatment by keeping the other down stream operations in effect (Fig. 2-a). Absence of homogenization step in the processing route does not create substantial changes in the mechanical properties, microscopic features, corrosion resistance and formability properties of the Twin Roll Cast 5XXX series alloys at different tempers (soft, strain hardened, or H2X/H3X) of final gauges. This radical alteration in the processing route provides significant contribution to the economical aspect of Twin Roll Cast 5XXX series alloys, as well.

Superior corrosion resistance of the Twin-roll cast 5XXX series alloys were tested in the same testing environment with their DC-cast counterparts. Corrosion test samples of Alloy A, Alloy B and Alloy C having 10 cm^2 test areas were exposed to a salt spray test (ASTM B-117) for 96 hrs. with their counter parts produced through DC casting route. After exposure of 96 hrs to salt spray, Twin roll cast Alloy A, Alloy B and Alloy C samples did not develop corrosion products on their surface (Figure 4).

EXAMPLE I

Aluminum alloy melt having melt composition given in Table 1-a. was prepared having the following composition:

Table 1-a *Chemical composition of Alloy A.*

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Al
A	0,125	0,286	0,030	0,059	2,536	0,163	96,71

The melt was thoroughly mixed and then in-line refining was applied with chlorine and inert gas mixture to reduce the hydrogen content of the melt below 0,20ml/100 grams of metal and its inclusion content. Hydrogen gas level was reduced to 0,12ml/100 grams of metal. The metal was cast in the form of 1750 mm wide, 5,35 mm thick industrial size coils. Prior to cold rolling operation, one of the cast coil was homogenized in inert atmosphere. Coil was cold rolled in successive passes to its final gauge of 1mm without any intermediate recrystallization anneal. Soft temper of the material was achieved with final a recrystallization anneal. Another coil was processed through the same processing route, with the exception of homogenization treatment, to the final gauge of 1mm. Tensile tests were performed on the samples prepared in three different directions with respect to the rolling direction namely; parallel, transverse and 45^0 to the rolling direction. Strain hardening exponent of the samples (n), in three different directions, were calculated from stress-strain diagram of the samples between the strain of 5 to 18%. First indication, to evaluate forming ability of the material was obtained through Erichsen Cup index values of the materials. Identical tests and characterization methods were carried out on the other coil that was not homogenized. Mechanical test results of these two coils were shown in Table 2.

Table 2. *Mechanical properties of Alloy A.*

Alloy	Process	Erichsen,mm	σ_y,MPa	σ_f,MPa	Elongation ,%	n
A	With homog.	9.8	0°/ 96 45°/ 94 90°/ 96	204 197 198	22 24 24	0.26 0.27 0.26
	Without homog.	9.6	0°/ 101 45°/ 102 90°/ 104	207 205 206	22 27 24	0.28 0.27 0.26

(1) Measured between 5-18%.

EXAMPLE II

An aluminum alloy in accordance with the present invention, designated "B" consisted essentially of the elements stated in Table 3. This alloy was cast into 5,45 mm thick strip.

Table 3. *Chemical composition of Alloy B.*

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Al
B	0.177	0.328	0.043	0.365	4.210	0.153	94.63

After necessary melt treatment operations that were carried out prior to the casting 1750 mm wide sheet was cast with the casting speed of 110 mm/min. Processes with and without homogenization treatments were applied to these industrial sized (8 ton) coils, all of which were given a recrystallization anneal at the final gauge of 1mm after a cold rolling schedule. Coils were not subjected to any intermediate anneal at any stage of the down stream process.

Mechanical properties of the material at the final gauge having soft temper were presented in Table 4. Mechanical properties of this material did not exhibit significant difference depending on the processing route applied.

Table 4. *Mechanical properties of alloy B at 1mm.*

Alloy	Process	Erichsen,mm	σ_y,MPa	σ_f,MPa	Elongation, %	n[(1)]
B	With homog.	9.3	0°/ 146 45°/ 142 90°/ 146	281 271 269	22 27 22	0.28 0.27 0.26
	Without homog.	9.1	0°/ 145 45°/ 144 90°/ 147	270 268 272	26 29 22	0.29 0.29 0.29

(1) Measured between 5-18%.

The alloys and examples embedded above are given solely for exemplifying the invention and therefore the invention shall not be considered as being limited with the same.

CLAIMS :

1. A process suitable for producing 5XXX series aluminum alloys through twin-roll casting and subsequent cold rolling and annealing treatments characterized in that, the casting process comprises the steps of ;

(a) providing the twin-roll caster with a melt composition comprising between 0,5-6,5 %Mg, 0-0,50 % Si, 0-0,60 % Fe, 0-1,2 %Mn and 0-0,50 %Cr by weight, where the temperature of the melt is kept essentially between 690^{0}C and 715^{0}C,

(b) operating the twin-roll caster continuously under critical conditions in which the casting speed is varied between 0.8 m/min and 1.5 m/min,

(c) maintaining a set-back distance essentially between 48 mm and 65 mm, where set-back is the critical distance between the center lines of caster rolls and exit side of the molten metal from the caster tip, and

(d) casting a strip with uniform thickness adjusted within the range of 3 - 7 mm.

2. A process according to claim 1, wherein the process further comprises the steps of;

(e) applying a first cold rolling treatment to as-cast strip,

(f) allowing recrystallization at the critical gauge essentially in the range of 280^{0}C to about 375^{0}C, for a period of not less than 4 hours and not more than 8 hours, and

(g) applying a second cold rolling treatment to said strip following the recrystallization step.

3. A process according to claim 1, wherein the process further comprises the steps of;

(e) applying homogenization to said as-cast strip at a temperature ranging between 420°C to 550°C for a period of 4 to 15 hours,

(f) applying a first cold rolling treatment to said strip,

(g) allowing recrystallization at the critical gauge essentially in the range of 280^{0}C to about 375^{0}C, for a period of not less than 4 hours and not more than 8 hours, and

(h) applying a second cold rolling treatment to said strip following the recrystallization step.

4. A process according to claim 1, wherein the process further comprises the steps of;

(e) applying a first cold rolling treatment to as-cast strip,

(f) applying a homogenization treatment to said cold rolled strip at a temperature ranging between 420°C to 550°C for a period of 4 to 15 hours,

(g) applying a second cold rolling treatment to said strip,

(h) allowing recrystallization at the critical gauge essentially in the range of 280^0C to about 375^0C, for a period of not less than 4 hours and not more than 8 hours, and

(i) applying a third cold rolling treatment to said strip following the recrystallization step.

5. A process as set forth in Claims 2, 3 or 4, further comprising the step of a final annealing step suitable for producing H2X tempers, wherein said final annealing treatment is applied essentially within temperature range of 130^0-250^0C, for a period of not less than 100 minutes and not more than 8 hours.

6. A process as set forth in Claims 2, 3 or 4, further comprising the step of a final annealing step suitable for producing H3X tempers, wherein said final annealing treatment is applied essentially within the temperature range of 100^0-190^0C for a period of about 2 hours to 6 hours.

7. A process as set forth in Claim 1, further comprising a down stream processing cycle suitable for producing 0 tempers, characterized in that said down stream processing cycle comprises one of the following steps;

(i) applying a cold rolling treatment to as-cast strip and allowing recrystallization at the final gauge essentially in the range of 280^0C to about 375^0C, for a period of not less than 4 hours and not more than 8 hours, or

(ii) applying a homogenization treatment to as-cast strip at a temperature ranging between 420°C to 550°C for a period of 4 to 15 hours followed by a

cold rolling treatment to said strip and finally allowing recrystallization at the final gauge essentially in the range of 280^{0}C to about 375^{0}C, for a period of not less than 4 hours and not more than 8 hours, or

(iii) applying a first cold rolling treatment to as-cast strip before applying a homogenization treatment to said strip at a temperature ranging between 420°C to 550°C for a period of 4 to 15 hours which is followed by a cold rolling treatment to said strip and finally allowing recrystallization at the final gauge essentially in the range of 280^{0}C to about 375^{0}C, for a period of not less than 4 hours and not more than 8 hours.

8. A process as set forth in Claims 2, 3 or 4, suitable for producing H1X tempers, wherein the strip is coiled after the last cold rolling treatment.

9. An aluminum based alloy, wherein the alloy is produced in the form of cast strip according to a process of any of the preceding claims.

10. An aluminum based alloy produced according to a process of any of the preceding claims, wherein the outcome cast strip has microstructural and mechanical uniformity through its entire width ranging between 750 and 2400 mm.

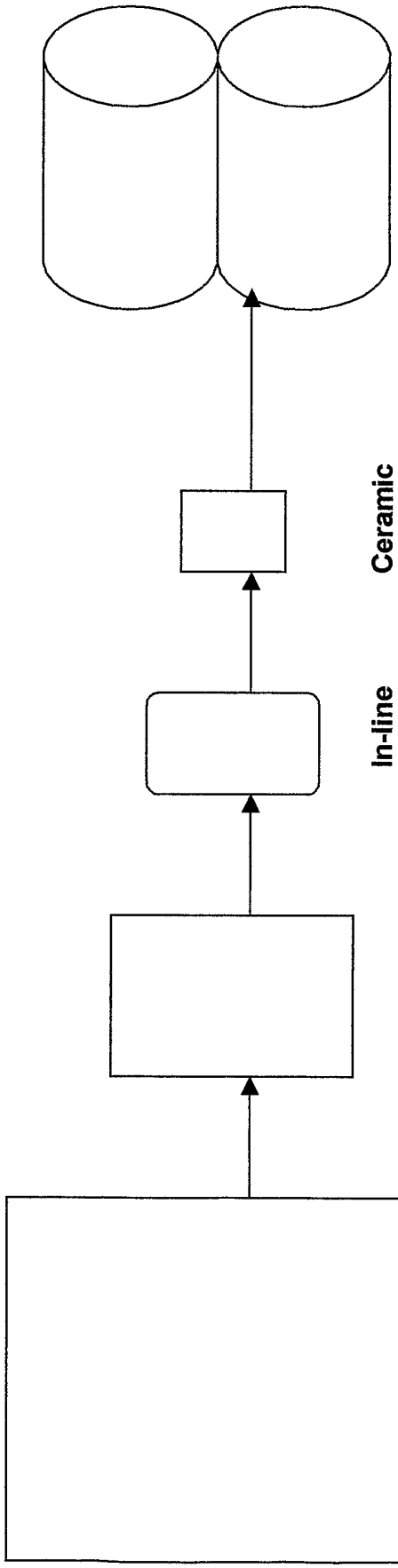


FIGURE 1 - Casting Process

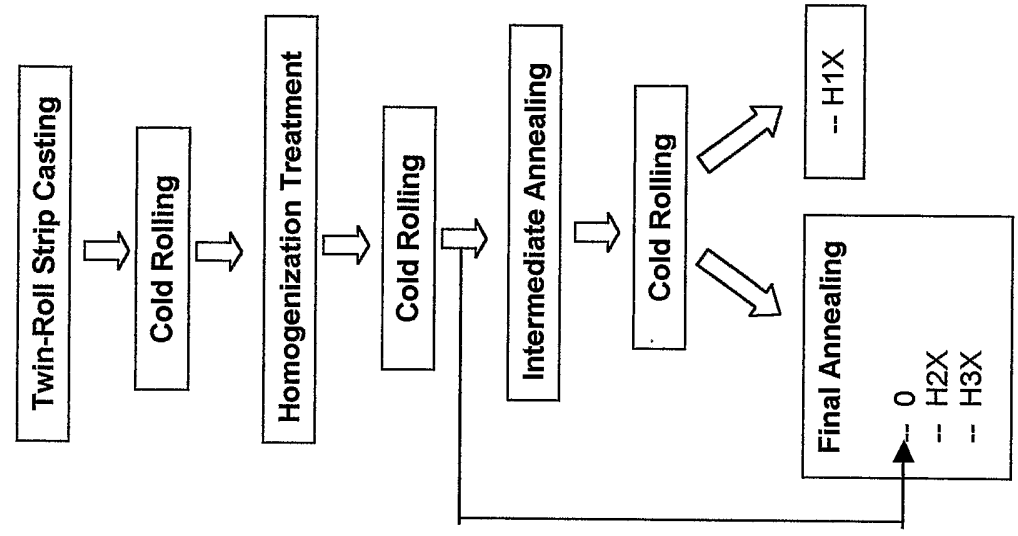


FIGURE 2-c

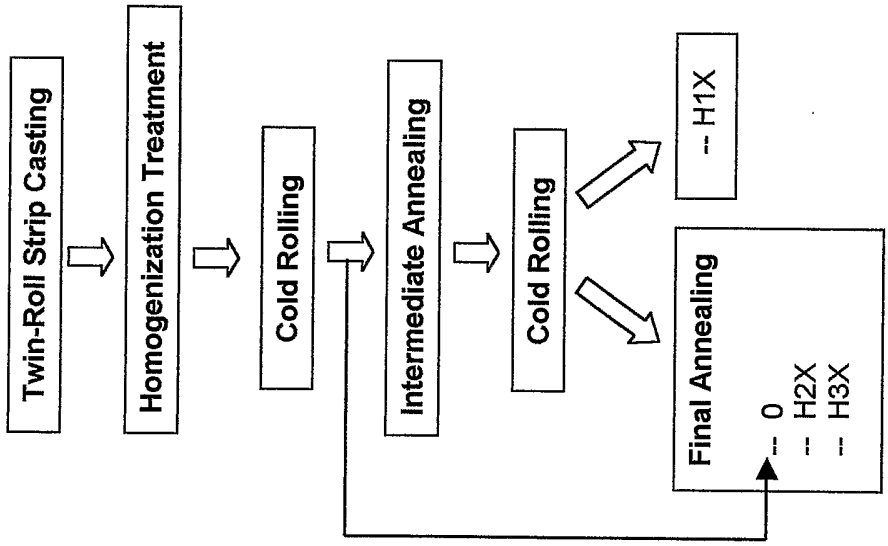


FIGURE 2-b

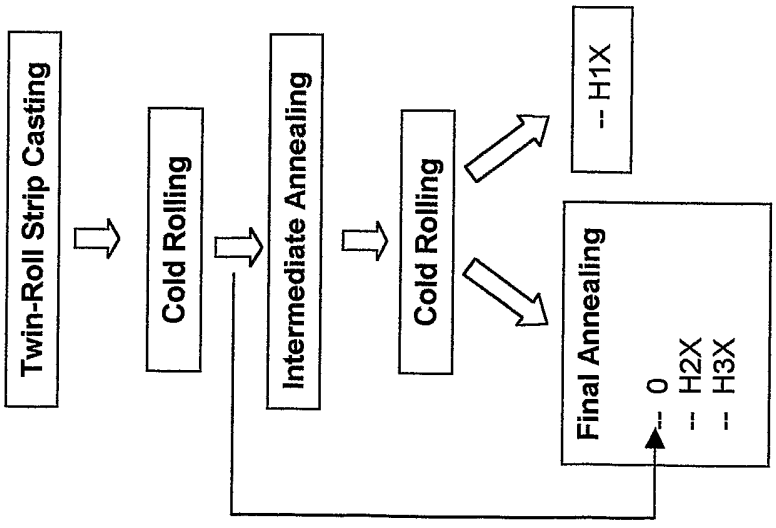


FIGURE 2-a

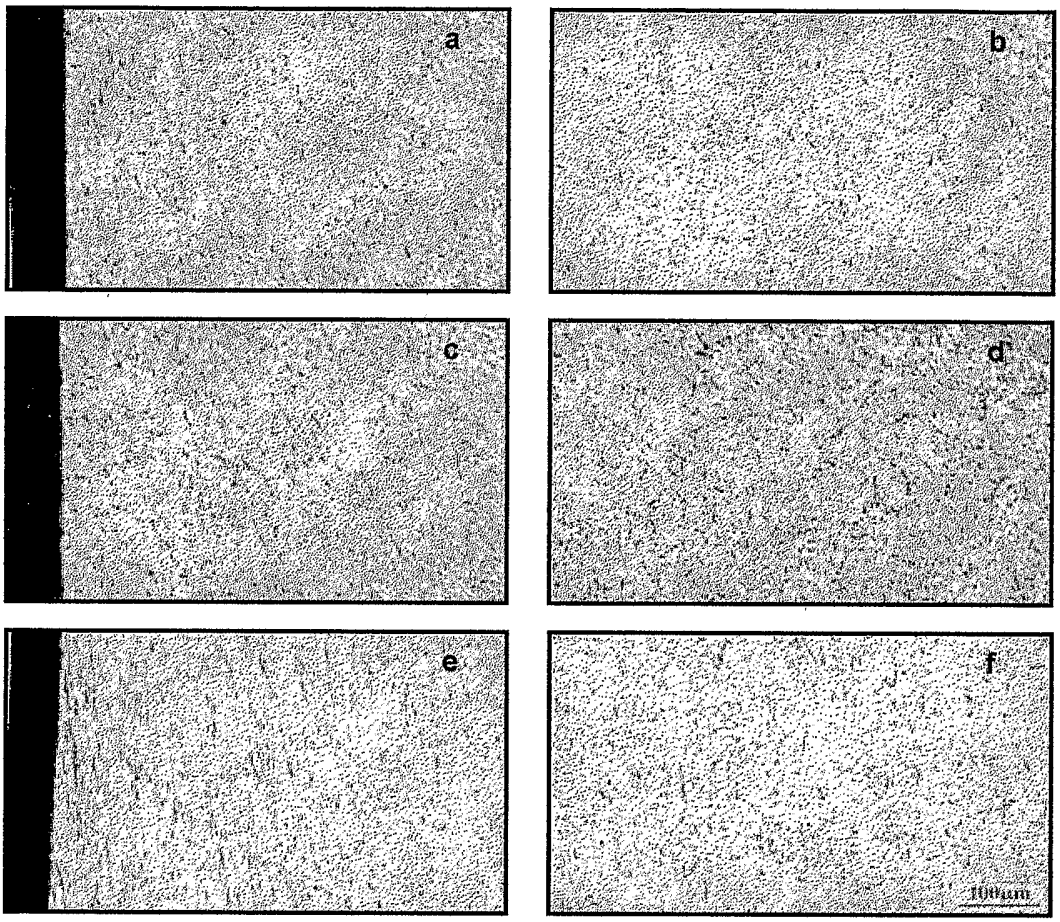


FIGURE 3

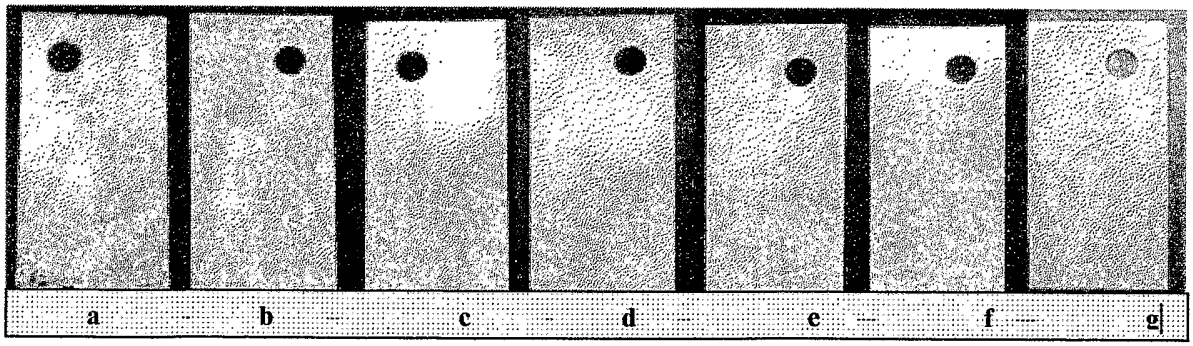


FIGURE 4

INTERNATIONAL SEARCH REPORT

International Application No
PCT/TR 01/00046

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 C22F1/047 B22D11/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 C22F B22D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, COMPENDEX, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	BERG B S ET AL: "Gauge reduction in twin-roll casting of an AA5052 aluminium alloy: the effects on microstructure" PROCEEDINGS OF THE 14TH INTERNATIONAL SCIENTIFIC CONFERENCE ON ADVANCED MATERIALS & TECHNOLOGIES;ZAKOPANE, POL MAY 17-21 1995, vol. 53, no. 1-2, 17 May 1995 (1995-05-17), pages 65-74, XP002200137 J Mater Process Technol;Journal of Materials Processing Technology Aug 1995 Elsevier Science B.V., Amsterdam, Netherlands	1,9,10
Y	2.2. Experimental methods,Table 1; 3.2. Recrystallization	2-8
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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
27 May 2002	11/06/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Bjoerk, P

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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