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# (54) Method for manufacturing an aluminium alloy intended to be used in automotive manufacturing

(57) A method for manufacturing an aluminum alloy in a continuous in-line sequence, comprising the steps of providing a continuously-cast thin aluminum alloy strip, in-line hot rolling the continuously-cast strip, and annealing of the hot rolled continuously cast strip to O-temper having a yield point elongation less than 0.6%, characterized in that the aluminum alloy is used in the manufacturing of an automobile.

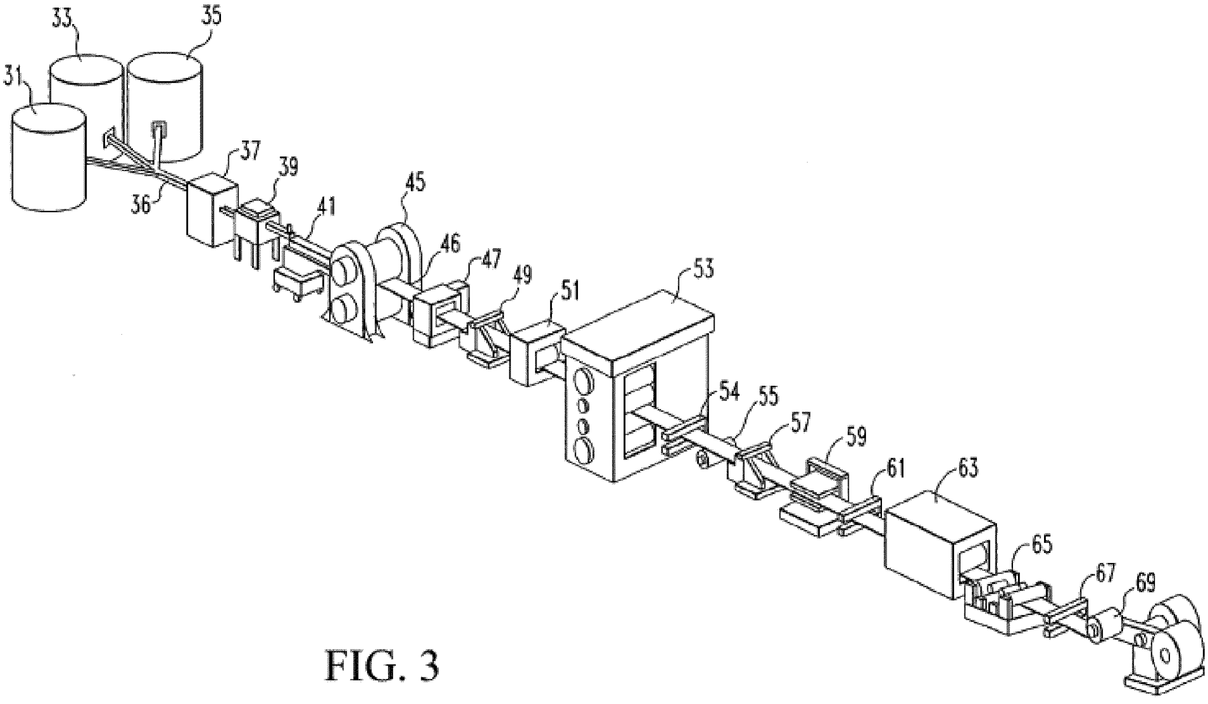

FIG. 3

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## Description

### FIELD OF THE INVENTION

**[0001]** The present disclosure relates to uses of continuously cast aluminum-magnesium alloy sheets components in automotive manufacturing. In particular embodiments, the sheet is annealed to an O-temper and has a yield point elongation less than 0.6%.

**[0002]** The present disclosure also relates to methods for manufacturing an aluminum alloy in a continuous in-line sequence wherein the aluminum alloy is adapted and intended to be used in the manufacturing of an automobile. The present disclosure also relates to the use of an aluminum alloy manufactured with such a method for components in automotive manufacturing.

### BACKGROUND INFORMATION

**[0003]** Conventional methods of manufacturing of aluminum alloy sheet for use in commercial applications are known.

**[0004]** For example, U.S. Patent No. 7,182,825 discloses a method of making aluminum alloy sheets in a continuous in-line process. The entire contents of U.S. Patent No. 7,182,825 is incorporated herein in full. A continuously-cast aluminum alloy strip is optionally quenched, hot or warm rolled, annealed or heat-treated in-line, optionally quenched, and preferably coiled, with additional hot, warm, or cold rolling steps as needed to reach the desired gauge. The process can be used to make aluminum alloy sheet of T or O temper.

**[0005]** U.S. Patent No. 6,672,368 discloses a method of continuously-casting aluminum alloy strips. The entire contents of U.S. Patent No. 6,672,368 is incorporated herein in full. The method includes continuous casting aluminum alloys between a pair of rolls. Molten aluminum alloy is delivered to a roll bite between the rolls and passes into the roll nip - or point of minimum clearance of between the rolls - in a semi-molten state. A solid strip of cast aluminum alloy exits the nip at speed ranging from 25 to 400 feet per minute; alternatively from 50 feet per minute to 350 feet per minute.

**[0006]** U.S. Patent No. 5,655,593 describes a method of making aluminum alloy sheet where a thin strip is cast (in place of a thick ingot) which is rapidly rolled and continuously cooled for a period of less than 30 seconds to a temperature of less than 350°F. U.S. Patent No. 5,772,802 describes a method in which the aluminum alloy cast strip is quenched, rolled, annealed at temperatures between 600° and 1200°F for less than 120 seconds, followed by quenching, rolling and aging.

**[0007]** U.S. Patent No. 5,356,495 describes a process in which the cast strip is hot-rolled, hot-coiled and held at a hot-rolled temperature for 2-120 minutes, followed by uncoiling, quenching and cold rolling at less than 300°F, followed by recoiling the sheet.

### SUMMARY OF THE INVENTION

### BRIEF DESCRIPTION OF THE DRAWINGS

**[0008]** The present disclosure is further illustrated by the following drawings in which:

| | |
|---|---|
| Figure 1: | is a flow chart of the steps of the method of the present disclosure, in one embodiment; |
| Figure 2: | depicts the as-cast microstructure of Al + 3.5% Mg alloy in transverse direction; |
| Figure 3: | is a schematic diagram of one embodiment of the apparatus used in carrying out the method of the present disclosure; |
| Figure 4: | is an additional embodiment of the apparatus used in carrying out the method of the present invention. This line is equipped with four rolling mills to reach a finer finished gauge; |
| Figure 5: | is an illustrative embodiment of tensile curves illustrating a correlation between tensile stress tests and yield point extension; |
| Figure 6: | is a graphical representation of electrical conductivity measurements of strips versus anneal temperature; |
| Figure 7: | is a graphical representation of yield strength measurements of strips versus anneal temperature; |
| Figure 8: | illustrates micrographs of partially recrystallized grain structure in an AA5182 sample; |

| | |
|---|---|
| Figure 9: | illustrates micrographs of recrystallized grain structure in an AA5182 sample in accordance with the below examples; |
| Figure 10: | illustrates stress-strain curves; |
| Figure 11: | illustrates micrographs of a grain structure of a sheet in accordance with the below examples; |
| Figure 12: | illustrates micrographs of a grain structure of continuously annealed coils in accordance with the below examples; |
| Figure 13: | illustrates micrographs of a grain structure after batch anneal for inline hot rolled sheets in accordance with the below examples; and |
| Figure 14: | illustrates second phase particles and grain structures of sheets made in accordance with the below examples. |

## DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

**[0009]** The present disclosure provides a use for an aluminium alloy sheet manufactured in a continuous in-line sequence. The present disclosure also provides a method for manufacturing an aluminum alloy in a continuous in-line sequence wherein the aluminum alloy is adapted and intended to be used in the manufacturing of an automobile. The present disclosure also provides a use of an aluminum alloy manufactured with such a method for components in automotive manufacturing.

**[0010]** The continuous in-line sequence for manufacturing the aluminium alloy sheet comprises: (i) providing a continuously-cast thin aluminum alloy strip as feedstock; (ii) optionally, quenching the feedstock to the preferred hot or warm rolling temperature; (iii) hot or warm rolling the quenched feedstock to the desired final thickness; (iv) annealing or solution heat-treating the feedstock in-line and optionally off-line, depending on alloy and temper desired; and (v) optionally, quenching the feedstock, after which it is preferably tension- leveled and coiled. This method results in an aluminum alloy sheet having the desired dimensions and properties. In an embodiment, the aluminum alloy sheet may be coiled for later use. This sequence of steps is reflected in the flow diagram of Figure 1, which shows a continuously-cast aluminum alloy strip feedstock 1 which is optionally passed through shear and trim stations 2, optionally quenched for temperature adjustment 4, hot-rolled 6, and optionally trimmed 8. The feedstock may be then either annealed 16 followed by suitable quenching 18 and optional coiling 20 to produce 0 temper products 22, or solution heat treated 10, followed by suitable quenching 12 and optional coiling 14 to produce T temper products 24. The annealing step 16 may be done in-line or off-line. The solution heat treatment step 10 may be done in-line or off-line. As can be seen in Figure 1, the temperature of the heating step and the subsequent quenching step will vary depending on the desired temper.

**[0011]** As used herein, the term "anneal" refers to a heating process that causes recrystallization of the metal to occur, producing uniform formability and assisting in earing control. Typical temperatures used in annealing aluminum alloys range from about 600° to 900 ° F.

**[0012]** Also as used herein, the term "solution heat treatment" refers to a metallurgical process in which the metal is held at a high temperature so as to cause the second phase particles of the alloying elements to dissolve into solid solution. Temperatures used in solution heat treatment are generally higher than those used in annealing, and range up to about 1060°F. This condition is then maintained by quenching of the metal for the purpose of strengthening the final product by controlled precipitation (aging).

**[0013]** As used herein, the term "feedstock" refers to the aluminum alloy in strip form. The feedstock employed in the practice of the present invention can be prepared by any number of continuous casting techniques well known to those skilled in the art. A preferred method for making the strip is described in US 5,496,423 issued to Wyatt-Mair and Harrington. Another preferred method is as described in US Patent 6,672,368. The continuously-cast aluminum alloy strip preferably ranges from about 0.06 to 0.25 inches in thickness, more preferably about 0.08 to 0.14 inches in thickness. Typically, the cast strip will have a width up to about 90 inches, depending on desired continued processing and the end use of the sheet.

**[0014]** Figure 2 illustrates an as-cast microstructure of Al + 3.5% Mg alloy in transverse direction. The single solid strip of Figure 2 includes three general regions, or layers, including two shell regions and center layer sandwiched therebetween. In an embodiment, continuous casting results in a strip wherein the central layer constitutes between 20 to 60 percent, optionally 20 to 30 percent, of the total thickness of the strip. The molten aluminum alloy, upstream of the nip, has an initial concentration of alloying elements including peritectic forming alloying elements and eutectic forming alloying elements. Alloying elements which are peritectic formers with aluminum are Ti, V, Zr and Cr. All other alloying elements are eutectic formers with aluminum, such as Si, Fe, Ni, Zn, Mg, Cu and Mn. During solidification, dendrites typically have a lower concentration of eutectic formers than the surrounding mother melt and higher concentration of peritectic formers. Thus, in the center region upstream of the nip, the small dendrites are thus partially depleted of eutectic formers while the molten metal surrounding the small dendrites is somewhat enriched in eutectic formers. Consequently, the solid central layer of the strip, which contains a large population of dendrites, is depleted of eutectic formers (typically by up to about 20 weight percent, such as about 5 to about 20 wt. %) and is enriched in peritectic formers (typically by up to about 45 percent such, as about 5 to about 45 wt. %) in comparison to the concentration of the eutectic formers and the peritectic formers in each of the metal of the shell regions. United States Patent No. 6,672,368 includes additional disclosure regarding continuously casting that is suitable for use in connection with this disclosure.

**[0015]** Referring now to Figure 3, there is shown schematically a preferred apparatus used in carrying out a preferred embodiment of the method of the present invention. Molten metal to be cast is held in melter holders 31, 33 and 35, is passed through troughing 36 and is further prepared by optional degassing 37 and filtering 39 steps. The tundish 41 supplies the molten metal to the continuous caster 45. The metal feedstock 46 which emerges from the caster 45 is moved through optional shear 47 and trim 49 stations for edge trimming and transverse cutting, after which it is passed to a quenching station 51 for adjustment of rolling temperature. The shear station is operated when the process in interrupted; while running, shear is open.

**[0016]** After optional quenching 51, the feedstock 46 is passed through a rolling mill 53, from which it emerges at the required Final thickness. The feedstock 46 is passed through a thickness gauge 54, a shapemeter 55, and optionally trimmed 57, and is then annealed or solution heat-treated in a heater 59. Following annealing/solution heat treatment in the heater 59, the feedstock 46 passes through a profile gauge 61, and is optionally quenched at quenching station 63. Additional steps include passing the feedstock 46 through a tension leveler to flatten the sheet at station 65, and subjecting it to surface inspection at station 67. The resulting aluminum alloy sheet is then coiled at the coiling station 69. The overall length of the processing line from the caster to the coiler is estimated at about 250 feet. The total time of processing from molten metal to coil is therefore about 30 seconds. Any of a variety of quenching devices may be used in the practice of the present invention. Typically, the quenching station is one in which a cooling fluid, either in liquid or gaseous form is sprayed onto the hot feedstock to rapidly reduce its temperature. Suitable cooling fluids include water, air, liquefied gases such as carbon dioxide, and the like. It is preferred that the quench be carried out quickly to reduce the temperature of the hot feedstock rapidly to prevent substantial precipitation of alloying elements from solid solution.

**[0017]** In general, the quench at station 51 reduces the temperature of the feedstock as it emerges from the continuous caster from a temperature of about 1000°F to the desired hot or warm rolling temperature. In general, the feedstock will exit the quench at station 51 with a temperature ranging from about 400° to 900°F, depending on alloy and temper desired. Water sprays or an air quench may be used for this purpose.

**[0018]** Hot or warm rolling 53 is typically carried out at temperatures within the range of about 400° to 1020°F, more preferably 700° to 1000°F. The extent of the reduction in thickness affected by the hot rolling step of the present invention is intended to reach the required finish gauge. This typically involves a reduction of about 55%, and the as-cast gauge of the strip is adjusted so as to achieve this reduction. The temperature of the sheet at the exit of the rolling station is between about 300° and 850°F, more preferably 550° to 800°F, since the sheet is cooled by the rolls during rolling. Preferably, the thickness of the feedstock as it emerges from the rolling station 53 will be about 0.02 to 0.15 inches, more preferably about 0.03 to 0.08 inches.

**[0019]** The heating carried out at the heater 59 is determined by the alloy and temper desired in the finished product. In one preferred embodiment, for T tempers, the feedstock will be solution heat-treated in-line, at temperatures above about 950°F, preferably about 980°-1000°F. Heating is carried out for a period of about 0.1 to 3 seconds, more preferably about 0.4 to 0.6 seconds.

**[0020]** In another preferred embodiment, when 0 temper is desired, the feedstock will require annealing only, which can be achieved at lower temperatures, typically about 700° to 950°F, more preferably about 800°-900°F, depending upon the alloy. Again, heating is carried out for a period of about 0.1 to 3 seconds, more preferably about 0.4 to 0.6 seconds.

**[0021]** Similarly, the quenching at station 63 will depend upon the temper desired in the final product. For example, feedstock which has been solution heat-treated will be quenched. preferably air and water quenched, to about 110° to 250°F, preferably to about 160°-180°F and then Coiled. Preferably, the quench at station 63 is a water quench or an air quench or a combined quench in which water is applied first to bring the temperature of the sheet to just above the Leidenfrost temperature (about 550°F for many aluminum alloys) and is continued by an air quench. This method will combine the rapid cooling advantage of water quench with the low stress quench of air jets that will provide a high quality surface in the product and will minimize distortion. For heat treated products, an exit temperature of 200°F or below is preferred.

**[0022]** Products that have been annealed rather than heat-treated will be quenched, preferably air- and water-quenched, to about 110° to 720°F, preferably to about 680° to 700°F for some products and to lower temperatures around 200°F for other products that are subject to precipitation of intermetallic compounds during cooling, and then coiled.

**[0023]** Although the process of the invention described thus far in one embodiment having a single step hot or warm rolling to reach the required final gauge, other embodiments are contemplated, and any combination of hot and cold rolling may be used to reach thinner gauges, for example gauges of about 0.007-0.075 inches. The rolling mill arrangement for thin gauges could comprise a hot rolling step, followed by hot and/ or cold rolling steps as needed. In such an arrangement, the anneal and solution heat treatment station is to be placed after the final gauge is reached, followed by the quench station. Additional in-line anneal steps and quenches may be placed between rolling steps for intermediate anneal and for keeping solute in solution, as needed. The pre-quench before hot rolling needs to be included in any such arrangements for adjustment of the strip temperature for grain size control. The pre-quench step is a pre-requisite for alloys subject to hot shortness.

**[0024]** Figure 4 shows schematically an apparatus for one of many alternative embodiments in which additional heating and rolling steps are carried out. Metal is heated in a furnace 80 and the molten metal is held in melter holders 81, 82. The molten metal is passed through troughing 84 and is further prepared by degassing 86 and filtering 88. The tundish 90 supplies the molten metal to the continuous caster 92, exemplified as a belt caster, although not limited to this. The metal feedstock 94 which emerges from the caster 92 is moved through optional shear 96 and trim 98 stations for edge trimming and transverse cutting, after which it is passed to an optional quenching station 100 for adjustment of rolling temperature.

**[0025]** After quenching 100, the feedstock 94 is passed through a hot rolling mill 102, from which it emerges at an intermediate thickness. The feedstock 94 is then subjected to additional hot milling 104 and cold milling 106, 108 to reach the desired final gauge.

**[0026]** The feedstock 94 is then optionally trimmed 110 and then annealed or solution heat-treated in heater 112. Following annealing/solution heat treatment in the heater 112, the feedstock 94 optionally passes through a profile gauge 113, and is optionally quenched at quenching station 114. The resulting sheet is subjected to x-ray 116, 118 and surface inspection 120 and then optionally coiled.

**[0027]** Suitable aluminum alloys for heat-treatable alloys include, but are not limited to, those of the 2XXX, 6XXX and 7XXX Series. Suitable non - heat-treatable alloys include, but are not limited to, those of the 1XXX, 3XXX and 5XXX Series. The present invention is applicable also to new and non-conventional alloys as it has a wide operating window both with respect to casting, rolling and in-line processing.

## EXAMPLES

**[0028]** Strips of AA 5182 composition (SAL1) and 0.10 inch thickness were continuously cast in a casting apparatus as described within United States Patent No. 6, 672,368. In one case, a variation was introduced to the composition of AA 5182 by increasing the Cu content outside the AA range (SAL2) for the purpose of increasing O-temper yield strength, Table 1. The strips were hot rolled in line to 0.060, 0.050 and 0.040 inch corresponding to hot reductions of 40, 50 and 60% respectively. These samples were batch annealed at temperatures between 600 and 850°F. Mechanical properties of the samples were measured by tensile tests and the yield point extension (YPE) was determined from the tensile curves following the procedure illustrated in Figure 5. Electrical conductivity measurements were made to monitor re-crystallization and precipitation out of solution in samples annealed at different temperatures. Grain structure and average grain size were determined by optical microscopy after anodizing. Selected samples from this series were subjected to simulated continuous anneal in a salt bath at 1000°F for 30 seconds after which they were cooled in still air or quenched in water. Tensile test evaluation and microscopy work were carried out on the samples as above. This family of samples was prepared with no cold work during processing.

Table 1: Chemical composition, as-cast gauge and in-line hot reduction, cold reduction and test gauge of the samples studied in the program.

| | sample/ cast | cast gauge inch | hot roll gauge inch | hot reduction % | test gauge inch | cold reduction % | chemical composition Si % | Fe % | Cu % | Mn % | Mg % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SAL1 | A | 0.099 | 0.04 | 60 | 0.04 | 0 | 0.04 | 0.11 | 0.13 | 0.48 | 4.84 |
| | B | 0.098 | 0.05 | 49 | 0.05 | 0 | 0.04 | 0.11 | 0.13 | 0.48 | 4.84 |
| | C | 0.100 | 0.06 | 40 | 0.06 | 0 | 0.03 | 0.11 | 0.12 | 0.48 | 5.09 |
| SAL2 | D | 0.098 | 0.04 | 59 | 0.04 | 0 | 0.03 | 0.11 | 0.21 | 0.47 | 4.74 |
| | G | 0.098 | 0.05 | 49 | 0.05 | 0 | 0.03 | 0.11 | 0.21 | 0.47 | 4.74 |
| | H | 0.094 | 0.06 | 36 | 0.06 | 0 | 0.03 | 0.11 | 0.25 | 0.49 | 4.82 |
| 5182 | 100804 | 0.145 | 0.118 | 19 | 0.118 | 0 | 0.08 | 0.15 | 0.02 | 0.33 | 4.74 |
| | | 0.145 | 0.118 | 19 | 0.090 | 25 | | | | | |
| | | 0.145 | 0.118 | 19 | 0.060 | 50 | | | | | |
| | | 0.145 | 0.118 | 19 | 0.030 | 75 | | | | | |
| 5182 | 100803 | 0.104 | 0.060 | 42 | 0.060 | 0 | 0.05 | 0.14 | 0.02 | 0.33 | 4.72 |
| 5182 | 110509 | 0.116 | 0.070 | 39 | 0.040 | 43 | 0.05 | 0.11 | 0.12 | 0.33 | 4.63 |
| | AA 5182, max unless stated otherwise | | | | | | 0.20 | 0.35 | 0.15 | 0.2-0.5 | 4.0-5.0 |

Notes:
1. Samples A, B and C are within AA 5182 composition range (SAL1)
2. Samples D, G and H contain higher level of Cu for additional strength (SAL2).
3. Coil from cast 110509 was continuous annealed in a heat treat line at 1000 ° F

One coil of AA 5182 composition was processed to test gauge by cold rolling. It had been hot rolled in-line from 0.116 inch to 0.070 inch thickness after which it was cold rolled to test gauge of 0.040 inch. The annealing was done in a continuous heat treat line at 1000°F after which it was forced air cooled. This coil had a cold work of 43% prior to annealing. Tensile testing and microscopy were carried out on samples of the coil.

**[0029]** A thicker strip of 0.145 inch was cast and hot rolled in-line to 0.118 inch gauge (17% hot work) and batch annealed at 850°F/2hr. Samples of this coil were then cold rolled in the laboratory to 0.090, 0.060 and 0.030 inch gauge corresponding to cold work level of 25, 50 and 75% respectively. This set of cold rolled samples was batch annealed at 750°F in a laboratory furnace and was evaluated as above by tensile testing and optical microscopy. Tensile testing was done at a strain rate of $2 \times 10^{-3}\ s^{-1}$ using standard laboratory equipment and procedures. The sensitivity of the results to strain rate was not separately studied. For selected samples, mechanical properties and YPE were determined in three directions: longitudinal, transverse and 45 degree to the rolling direction.

**[0030]** Two families of 5182 were cast as ~ 0.1 inch thick strip and were hot/warm rolled in-line to different thicknesses,

Table 1. Samples A, B and C were selected to be within the composition limits of AA 5182 (SAL1 composition). The Cu content of alloys D, G and H was increased to ~0.20% for a higher O-temper strength (composition SAL2). These latter three samples are therefore outside the AA 5182 composition limit with respect to Cu. Both families of alloys were rolled in-line to 0.06, 0.05 and 0.04 inch gauge that corresponded to hot reduction of 40, 50 and 60% respectively, Table 1. All samples were batch annealed for 2 hours at several temperatures between 600 and 850°F. The progress of annealing was assessed by tensile testing, electrical conductivity measurements and microscopy.

**[0031]** Electrical conductivity measurements are shown in Table 2. For the as-rolled material, conductivity was between 24.3 and 24.9% IACS. It increased after batch annealing and reached 28.8-29.7% at 700°F after which point further changes were small, Figure 6. Yield strength of the samples showed the opposite trend. As annealing temperatures were increased, the yield strength of the as hot rolled material reduced sharply, Figure 7. The largest reduction occurred at 750°F and higher temperatures. The fully annealed strength levels were reached only for 800 and 850°F anneals. This conclusion was supported by microscopy work which showed partially recrystallized structures at 700, 750 and 800°F anneals, Figure 8. Typical micrographs of fully annealed structures for 850°F are shown in Figure 9. Detailed measurement of mechanical properties and evaluation of YPE values in this batch of samples was therefore done on samples annealed at 850°F only. Tensile properties of the fully annealed samples measured in the longitudinal, transverse and 45 degree directions are shown in Table 2. The properties generally showed relatively little dependence on the direction of testing. The SAL2 composition did indeed increase the yield strength by about 1 ksi. In the longitudinal direction of the 0.040 inch thick sheet, for example, the YS was 20.2 ksi for sample A85 (SAL1 composition) and this increased to 21 ksi in D85 sample (SAL2).

**[0032]** The yield point elongation was evaluated from the tensile test curves only for the longitudinal direction tests, Table 3. Two tensile curves, one with a YPE of 0.52% (sample D85) and the other with no YPE (sample H85), are shown in Figure 10 as examples. The YPE values observed in the samples were respectively 0.46, 0.32 and 0.30% for the 0.060, 0.040 and 0.030 inch thick sheet samples of SAL1 composition. This indicated that the lowest YPE value corresponded to the lowest degree of hot rolling. SAL2 composition produced somewhat higher YPE with value of 0.46% for 0.050 inch sample and 0.052% for 0.040 inch sample. The 0.040 inch sample showed no discernible YPE (H85 in Table 3 and Figure 10).

**Table 2:** Electrical conductivity of SAL1 (A, B and C) and SAL2 (D, G and H) alloys in annealed state. Processing path: hot roll in-line to gauge, Table 1.

| | anneal | | gauge, inch sample | 0.04 A | 0.05 B | 0.06 C | 0.04 D | 0.05 G |
|---|---|---|---|---|---|---|---|---|
| | | | | electrical conductivity, % IACS | | | | |
| AR | as-rolled | | | 24.9 | 24.7 | 24.3 | 24.8 | 24.6 |
| 600 | batch | 600F/2hr | | 26.8 | 26.4 | 25.9 | 26.7 | 26.5 |
| 650 | batch | 650F/2hr | | 28.4 | 28.1 | 27.7 | 28.4 | 28.4 |
| 700 | batch | 700F/2hr | | 29.4 | 29.3 | 28.8 | 29.7 | 29.6 |
| 750 | batch | 750F/2hr | | 29.5 | 29.6 | 29.1 | 29.9 | 29.8 |
| 800 | batch | 800F/2hr | | 29.5 | 29.4 | 29.1 | 29.8 | 29.7 |
| 850 | batch | 850F/ hr | | 29.4 | 29.4 | 29 | 29.6 | 29.4 |
| SP 1000/30s | flash | 1000F/ 30s | | | | 24.5 | 24.8 | 24.6 |

Notes: 1. Samples A, B and C are within AA 5182 composition range (SAL1).
2. Samples D, G and H contain higher level of Cu for additional strength (SAL2).

**Table 3** Tensile properties and yield point extension (YPE) in the longitudinal direction for SAL1 (A, B and C) and SAL2 (D, G, and H) samples after furnace anneal at 850°F. The samples were prepared by in-line hot rolling only, see table 1.

| | | | longitudinal tensile properties | | | | grain size | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | hot roll gauge inch | hot reduction % | UTS ksi | YS ksi | elongation, % total | uniform | L μm | T μm | mean μm | st |
| | | | BATCH ANNEAL 850 °F / 2 hr. | | | | | | | |
| A85 | 0.04 | 60 | 44.5 | 20.2 | 22.4 | 20.6 | 46 | 18.2 | 31.9 | 0 |
| B85 | 0.05 | 49 | 44.0 | 18.8 | 21.0 | 17.8 | 48 | 26.3 | 37.0 | 0 |
| C85 | 0.06 | 40 | 44.4 | 19.0 | 21.8 | 19.5 | 56 | 30.3 | 43.0 | 0 |
| D85 | 0.04 | 59 | 45.3 | 21.0 | 21.0 | 18.8 | 37 | 18.2 | 27.6 | 0 |
| G85 | 0.05 | 49 | 45.4 | 20.2 | 21.4 | 18.9 | 43 | 21.7 | 32.6 | 0 |
| H85 | 0.06 | 36 | 47.0 | 22.2 | 20.4 | 18.1 | 56 | 31.3 | 43.5 | |
| ingot | | | 43.2 | 22.1 | 26.9 | 21.8 | 17 | | | 1 |

Notes: 1 See Table 1 for the compositions of the alloys.

**[0033]** Detailed measurements on samples of AA 5182 composition (coil 100803a7) showed that the highest YPE was observed when the pulling direction was transverse to the rolling direction. The values of YPE were 0.22, 0.20 and 0.44 % in the longitudinal, 45 degree and transverse directions respectively.

**[0034]** In all samples, the grains were pancaked in the longitudinal direction and equiaxed in the transverse direction, Figure 9. As a result, measured grain size was substantially larger in the rolling direction, Table 4. For SAL1, for example, longitudinal grain sizes were 56, 48 and 46 μm and the transverse grain sizes 30.3, 26.3 and 18.2 μm for the samples reduced by 40, 50 and 60% respectively. Similar observations applied to the modified alloys D, G and H (SAL2) which showed somewhat finer grains, Table 4. It was clear that the grains became finer, especially in the transverse section, at higher hot rolling reduction.

**[0035]** The continuous anneal procedure was simulated by dipping the samples of sheet in a salt pot at 1000°F for 30 seconds after which they were cooled either in still air or by quenching in water. Tensile properties and YPE measured in three directions on these samples are shown in Table 5. Regardless of the degree of prior hot reduction, method of cooling from anneal and direction of testing, the YPE values were all around 0.50%. The yield strength of the sheet also appeared to have somewhat increased by this anneal procedure. Most importantly, however, total elongation values increased from a level of ~21% to 26-28% range. A similar level of increase was noted also in the uniform elongation values, Table 5.

**[0036]** With respect to electrical conductivity, the samples flash annealed at 1000°F for 30 seconds in a salt bath showed virtually no change compared to the as-rolled material, Table 2 and Figure 6. Applicants believe that the sample was recrystallized as was evident from the grain structure in Figure 11. This indicated the increase in conductivity in batch annealed samples was largely due to precipitation during the anneal cycle rather than the presence of cold work. Flash anneal may have prevented the solutes from dropping out of solution as a result of which the change in conductivity was small. Additional effects could come from dissolution of the Mn precipitates and especially $Mg_2Si$ into the matrix during the flash anneal which could have balanced the increase in conductivity due to the elimination of cold work.

Table 4 Grain size of samples after batch anneal and after simulated flash anneal at 1000°F/30 s. Fabrication path: In-line hot roll to test gauge of 0.060 inch.

| alloy | sample | anneal procedure | | number of grain per mm | | mean grain size, µm | |
|---|---|---|---|---|---|---|---|
| | | | | longitudinal | through thickness | longitudinal | through thickness |
| SAL1 | A85 | batch | 850 °F/2 hr | 22 | 55 | 45 | 18 |
| | B85 | | 850 °F/2 hr | 21 | 38 | 48 | 26 |
| | C85 | | 850 °F/2 hr | 18 | 33 | 56 | 30 |
| SAL2 | D85 | batch | 850 °F/2 hr | 27 | 55 | 37 | 18 |
| | G85 | | 850 °F/2 hr | 23 | 46 | 43 | 22 |
| | H85 | | 850 °F/2 hr | 18 | 32 | 56 | 31 |
| SAL1 | C | salt pot | 1000 °F/30 s | 42 | 48 | 24 | 21 |
| SAL2 | H | | 1000 °F/30 s | 42 | 47 | 24 | 21 |

Notes: 1. See Table 1 for compositions of alloys SAL1 and SAL2.

**Table 5** Yeld point elongation (YPE) after simulated continuous anneal (1000°F/30 s) of material hot rolled in-line to gauge in comparison with material cold rolled by 43% and then continuous annealed in coil form in Danville.

| | | | | longitudinal | | | | | transverse | | | | | 45 degree | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| alloy | hotroll gauge inch | flash anneal | coaling method | UTS | YS | elongation, % | | YPE % | UTS | Y5 | elongation, % | | YPE % | UTS | YS | elongation, % | | YPE % |
| | | | | ksi | ksi | total | uniform | | ksi | ksi | total | uniform | | ksi | ksi | total | uniform | |
| SAL1 | 0.06 | 1000 °F | water | 44.0 | 21.0 | 27.5 | 24.5 | 0.52 | 43.9 | 21.2 | 26.5 | 22.1 | 0.56 | 43.0 | 20.6 | 27.5 | 22.8 | 0.53 |
| SAL1 | 0.06 | 30 s | quench | 43.9 | 21.2 | 26.2 | 21.8 | 0.54 | 44.1 | 21.6 | 27.8 | 23.1 | 0.52 | 43.0 | 20.9 | 28.0 | 24.8 | 0.51 |
| | | | *mean* | *44.0* | *21.1* | *26.9* | *23.2* | *0.53* | *44.0* | *21.4* | *27.2* | *22.6* | *0.54* | *43.0* | *20.8* | *27.8* | *23.8* | *0.52* |
| SAL2 | 0.06 | 1000°F | water | 44.8 | 22.1 | 25.4 | 24.0 | 0.51 | 47.3 | 22.5 | 27.2 | 22.6 | 0.50 | 46.3 | 22.0 | 28.6 | 24.0 | 0.50 |
| SAL2 | 0.06 | 30 s | quench | 44.8 | 21.6 | 28.8 | 26.1 | 0.51 | 47.4 | 23.1 | 27.5 | 22.6 | 0.52 | 46.6 | 22.1 | 27.8 | 22.7 | 0.51 |
| | | | *mean* | *44.8* | *21.9* | *27.1* | *25.1* | *0.51* | *47.4* | *22.8* | *27.4* | *22.6* | *0.51* | *46.5* | *22.1* | *28.2* | *23.4* | *0.51* |
| SAL2 | 0.04 | 1000°F | air cool | 43.8 | 22.3 | 27.0 | 24.2 | 0.52 | 43.9 | 21.8 | 29.9 | 27.2 | 0.51 | 43.1 | 21.7 | 31.3 | 28.4 | 0.52 |
| SAL2 | 0.04 | 30 s | | 43.8 | 21.8 | 26.3 | 24.0 | 0.52 | 43.4 | 21.9 | 26.5 | 25.1 | 0.52 | 43.2 | 21.3 | 31.7 | 23.9 | 0.52 |
| | | | *mean* | *43.8* | *22.1* | *26.7* | *24.1* | *0.52* | *43.7* | *21.9* | *28.2* | *26.2* | *0.52* | *43.2* | *21.5* | *31.5* | *26.2* | *0.52* |
| SAL2 | 0.05 | 1000°F | air cool | 44.4 | 22.0 | 24.8 | 21.7 | 0.50 | 44.3 | 21.7 | 28.4 | 23.3 | 0.52 | 43.5 | 21.6 | 28.0 | 24.4 | 0.50 |
| SAL2 | 0.05 | 30 s | | 44.6 | 22.2 | 26.4 | 22.3 | 0.49 | 44.2 | 21.9 | 25.9 | 24.0 | 0.50 | 43.6 | 21.5 | 29.6 | 26.6 | 0.50 |
| | | | *mean* | *44.5* | *22.1* | *25.6* | *22.0* | *0.50* | *44.3* | *21.8* | *27.2* | *23.7* | *0.51* | *43.6* | *21.6* | *28.8* | *25.5* | *0.50* |
| HOT ROLLED IN-LINE FROM 0.116 inch to 0.070 inch, COLD ROLLED by 43% TO ANNEAL GAUGE (Cast: 110509) | | | | | | | | | | | | | | | | | | |
| 5152 | 0.04 | | | 43.0 | 21.7 | 25.6 | 24.3 | 1.19 | 42.4 | 22.1 | 31.0 | 27.6 | 1.29 | 41.5 | 21.1 | 30.2 | 27.8 | 1.27 |
| 5182 | 0.04 | anneal in Danville | | 43.3 | 22.4 | 27.2 | 21.0 | 1.25 | 42.2 | 21.7 | 28.5 | 23.9 | 1.26 | 41.5 | 21.3 | 29.6 | 26.8 | 1.25 |
| | | | *mean* | *43.2* | *22.1* | *26.4* | *22.7* | *1.22* | *42.3* | *21.9* | *29.8* | *25.8* | *1.28* | *41.5* | *21.2* | *29.9* | *27.3* | *1.26* |
| | DPW Ingot annealed | | | 43.2 | 22.1 | 26.4 | | | 42.3 | 21.9 | 29.8 | | | 41.5 | 21.2 | 29.9 | | |

**[0037]** The grain size in the samples was found to be generally equiaxed with a mean diameter of 24 μm in the longitudinal direction and 21 μm in the thickness direction, Table 4. Representative micrographs are shown in Figure 11.

**[0038]** Both continuous anneal and batch anneal procedures were evaluated for cold rolled sheet. The continuous anneal test was done on a coil of 0.040 inch thick sheet in a heat treat line at a temperature of 1000°F (cast 110509). This material had been cold rolled by 43% from 0.070 inch coil hot-rolled in-line. The difference in the overall mechanical properties of this material was relatively small in comparison with the hot-rolled material subjected to simulated continuous anneal, Table 5. The YPE values measured were, however, much higher. The mean values were respectively 1.22, 1.28 and 1.26% in the longitudinal, transverse and 45 degree directions. This evaluation showed thus that YPE increases substantially if the material is subjected to cold work even at a relatively modest 43%. The grain structure was generally equiaxed, Figure 12 and Table 6. The mean grain size was 14.1 μm when measured in the thickness direction. It was somewhat larger in the rolling direction and transverse direction, 19.4 and 20.2 μm, respectively. The mean grain size for this sheet was taken as 17.9 μm, the average of the three measurements.

**[0039]** In a second set of tests, batch anneal was done on material cold rolled from 0.118 inch thick feedstock that had been made by in-line hot rolling (~ 19%) in the plant from an as-cast strip of 0.145 inch thickness. The hot rolled sheet had a mean grain size of 38 μm and produced a YPE value of 0.38% when tested in the longitudinal direction after a simulated batch anneal at 850°F/2 hr, Table 7 and Figure 13. YPE in the transverse and 45 degree directions were too small for accurate measurement. The hot rolled and annealed sheet was then cold rolled by 25, 50 and 75% after which a final anneal was done at 750 F/2h. The grain sizes were 28, 17 and 12 μm (Figure 13) and YPE in the longitudinal direction were respectively 0.34, 0.97 and 1.34%, Table 7. The yield stress of the cold worked samples increased from 16.4 ksi to 17.1 for 25% cold rolling, and to 19.1 and 20.7 ksi for 50 and 75% rolled materials, respectively.

**[0040]** The sheet evaluated was hot rolled in line from ingot to 0.135 inch gauge (3.43 mm) and then cold rolled by 56% to 1.5 mm thickness (0.060 inch) and was batch annealed at 750°F/2 hr. The grains were equiaxed with a mean size of 17 μm, Figure 14. This sheet was characterized for YPE in three directions, Table 8. **Table 6:** Grain size measurements from cast 110509. Manufacturing path: in-line hot roll from 0.116 inch as-cast gauge to 0.070 inch, cold roll to 0.040 inch, continuous anneal in Danville line at 1000°F.

| | grains intercepted in 1000 μm | | | grain size, μm | | |
|---|---|---|---|---|---|---|
| | width<br>x | thickness<br>z | length<br>y | width<br>x | thickness<br>z | length<br>y |
| | 55 | 73 | 57 | 18.2 | 13.7 | 17.5 |
| | 50 | 78 | 55 | 20.0 | 12.8 | 18.2 |
| | | 71 | 50 | | 14.1 | 20.0 |
| | 49 | 64 | 49 | 20.4 | 15.6 | 20.4 |
| | 54 | 71 | 48 | 18.5 | 14.1 | 20.8 |
| mean | **52.0** | **71.4** | **51.8** | **19.3** | **14.1** | **19.4** |
| | sample 2 from cast 110510 | | | | | |
| | 53 | 73 | 45 | 18.9 | 13.7 | 22.2 |
| | 57 | 81 | 50 | 17.5 | 12.3 | 20.0 |
| | 49 | 72 | 45 | | 13.9 | 22.2 |
| | 56 | 77 | 53 | 17.9 | 13.0 | 18.9 |
| | 53 | 74 | 52 | 18.9 | 13.5 | 19.2 |
| mean | **67.0** | **75.4** | **49.0** | **18.3** | **13.3** | **20.5** |

Table 7 Tensile properties and yield point extension (YPE) in 5182-O sheet samples with different degree of cold work after batch anneal at 850°F. As-cast strip of 0.145 inch thickness was hot rolled in-line to 0.120 inch followed by cold reduction to test gauge. (Cast 100804a3, Composition: 0.04% Si, 0.15% Fe, 0.02% Cu, 0.33% Mn, 4.74% Mg and 0.018%Ti)

| | | | | longitudinal | | | | | transverse (LT) | | | | | 45 degree | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| alloy | test gauge inch | batch anneal | cold rolling % | UTS ksi | YS ksi | elongation, % total | elongation, % uniform | YPE % | UTS ksi | YS ksi | elongation, % total | elongation, % uniform | YPE % | UTS ksi | YS ksi | elongation, % total | elongation, % uniform | YPE % |
| 879932 | 0.120 | 850 °F/2h (furnace cool) | 0 | 41.0 | 16.3 | 20.9 | 20.7 | 0.00 | 40.6 | 16.3 | 25.1 | 20.0 | 0.35 | 40.3 | 15.8 | 25.3 | 22.8 | 0.00 |
| 879932 | 0.120 | | | 40.8 | 16.3 | 20.8 | 20.8 | 0.00 | 41.0 | 16.3 | 23.6 | 18.6 | 0.29 | 40.1 | 16.1 | 27.3 | 20.7 | 0.15 |
| 879932 | 0.120 | | | 41.0 | 16.5 | 25.7 | 19.0 | 0.00 | 40.7 | 16.5 | 22.8 | 20.1 | 0.36 | 40.3 | 16.0 | 25.8 | 22.7 | 0.00 |
| 879932 | 0.120 | | | 41.4 | 16.4 | 25.3 | 19.1 | 0.00 | 41.0 | 16.4 | 25.1 | 21.5 | 0.37 | 40.2 | 15.9 | 26.1 | 22.8 | 0.00 |
| 879932 | 0.119 | | | 41.3 | 16.6 | 25.8 | 22.5 | 0.00 | 40.8 | 16.6 | 25.4 | 19.4 | 0.37 | 40.3 | 15.8 | 21.0 | 19.7 | 0.00 |
| 879932 | 0.119 | | | 41.3 | 16.4 | 25.4 | 23.5 | 0.00 | 41.2 | 16.4 | 26.7 | 21.4 | 0.37 | 40.3 | 16.1 | 22.6 | 20.7 | 0.00 |
| | | | mean | 41.1 | 16.4 | 24.0 | 20.9 | 0.00 | 40.9 | 16.4 | 24.8 | 20.2 | 0.35 | 40.2 | 15.9 | 24.7 | 21.6 | 0.03 |
| 881353-LT1 | 0.092 | 750 °F 2h | 25 | | | | | | 41.3 | 17.1 | 20.8 | 18.7 | 0.33 | | | | | |
| 881353-LT2 | 0.092 | | | | | | | | 41.3 | 17.1 | 23.4 | 20.5 | 0.34 | | | | | |
| mean | | | | | | | | | 41.3 | 17.1 | 22.1 | 19.6 | 0.34 | | | | | |
| 881354-LT1 | 0.061 | 750 °F 2h | 50 | | | | | | 41.1 | 19.1 | 22.7 | 20.3 | 0.97 | | | | | |
| 881354-LT2 | 0.061 | | | | | | | | 41.1 | 19.1 | 23.2 | 23.2 | 0.97 | | | | | |
| | | | mean | | | | | | 41.1 | 19.1 | 22.9 | 21.7 | 0.97 | | | | | |
| 881355-LT1 | 0.032 | 750 °F 2h | 75 | | | | | | 41.0 | 20.7 | 22.2 | 22.1 | 1.36 | | | | | |
| 881355-LT2 | 0.032 | | | | | | | | 41.2 | 20.7 | 25.7 | 22.4 | 1.32 | | | | | |
| | | | mean | | | | | | 41.1 | 20.7 | 23.9 | 22.3 | 1.34 | | | | | |

Notes: 1. Sample 879932 represents material hot rolled in-line from 0.145 inch as-cast gauge to 30.118 inch and furnace annealed at 850 °F.

2. Samples 881353, 881354 and 881355 were cold rolled from 879932 sheets and were furnace annealed at 750 °F.

**Table 8** Influence of testing direction on yield point extension (YPE) in 5182-O made from ingot (DPW coil number 333-421). Hot roll gauge: 0.135 inch, cold roll to final gauge (53%), furnace anneal at 750°F/2 hr.

| | test gauge inch | test direction | TYS | UTS | elongation | | grain size | YPE |
|---|---|---|---|---|---|---|---|---|
| | | | | | total | uniform | | |
| | | | ksi | ksi | % | % | µm | % |
| 879934-L1 | 0.0642 | L | 19.36 | 41.95 | 22.72 | 22.39 | 17 | 0.78 |
| 879934-L2 | 0.0643 | | 19.19 | 41.93 | 18.67 | 18.25 | 17 | 0.73 |
| 879934-45-1 | 0.0644 | 45 degree | 18.48 | 39.91 | 27.19 | 26.90 | 17 | 0.95 |
| 879934-45-2 | 0.0644 | | 18.41 | 39.48 | 26.60 | 26.29 | 17 | 0.98 |
| 879934-LT1 | 0.0646 | T | 19.17 | 40.12 | 25.6 | 25.30 | 17 | 1.02 |
| 879934-LT2 | 0.0645 | | 19.40 | 40.32 | 24.18 | 23.86 | 17 | 1.04 |

**[0041]** The longitudinal direction provided the lowest YPE values of 0.78 and 0.73 % in two samples. Highest YPE values were observed in the transverse direction that had a mean value of 1.03%. An intermediate value of 0.97 was measured in the 45 degree direction. These values are considered typical for AA 5182 made from ingot following regular plant practices for hot and cold rolling.

**[0042]** Whereas particular embodiments of this invention have been described above for purposes of illustration, it will be evident to those skilled in the art that numerous variations of the details of the present invention may be made without departing from the invention as defined in the appending claims.

## Claims

**1.** Method for manufacturing an aluminum alloy in a continuous in-line sequence, comprising:

i) providing a continuously-cast thin aluminum alloy strip;
ii) in-line hot rolling the continuously-cast strip; and
iii) annealing of the hot rolled continuously cast strip to O-temper having a yield point elongation less than 0.6%,

**characterized in that** the aluminum alloy is used in the manufacturing of an automobile.

**2.** The method of claim 1, wherein the aluminum alloy is an Al-Mg alloy.

**3.** The method of claim 1 or 2, wherein the Al-Mg alloy is an AA5182 alloy.

**4.** The method of one of the claims 1 to 3, wherein annealing the hot rolled continuously cast strip is performed in-line.

**5.** The method of one of the claims 1 to 3, wherein annealing the hot rolled continuously cast strip is performed off-line.

**6.** The method of one of the claims 1 to 4, wherein after annealing the strip has a mean average grain size of less than 50 micrometers, preferably less than 30 micrometers, and more preferably less than 25 micrometers.

**7.** The method of one of the claims 1 to 6, wherein after annealing the strip has a mean average grain size between 25 and 50 micrometers.

**8.** The method of one of the claims 1 to 6, wherein after annealing the strip has a mean average grain size 5 and 25 micrometers.

**9.** The method of one of the claims 1 to 8, wherein the continuously cast strip has a thickness ranging from 0.06 to 0.25 inches before hot rolling.

**10.** The method of one of the claims 1 to 9, wherein the yield point elongation is between 0.3% and 0.52%.

**11.** The method of one of the claims 1 to 10, wherein the annealing step is performed at 850°F for 2 hours.

**12.** The method of one of the claims 1 to 11, wherein the continuously cast strip is hot rolled to a thickness between 0.040 inches and 0.060 inches.

**13.** The method of one of the claims 1 to 12, wherein the continuously cast strip is cast in a horizontal twin roll casting apparatus, the horizontal twin roll casting apparatus having a nip formed between two casting rolls, and wherein during casting a point of complete solidification of the Al-Mg alloy is formed at the nip.

**14.** The method of one of the claims 1 to 13, wherein the component is free of stretch strain marks.

**15.** Use of an aluminum alloy manufactured with a method according to one of the claims 1 to 14 for components in automotive manufacturing.

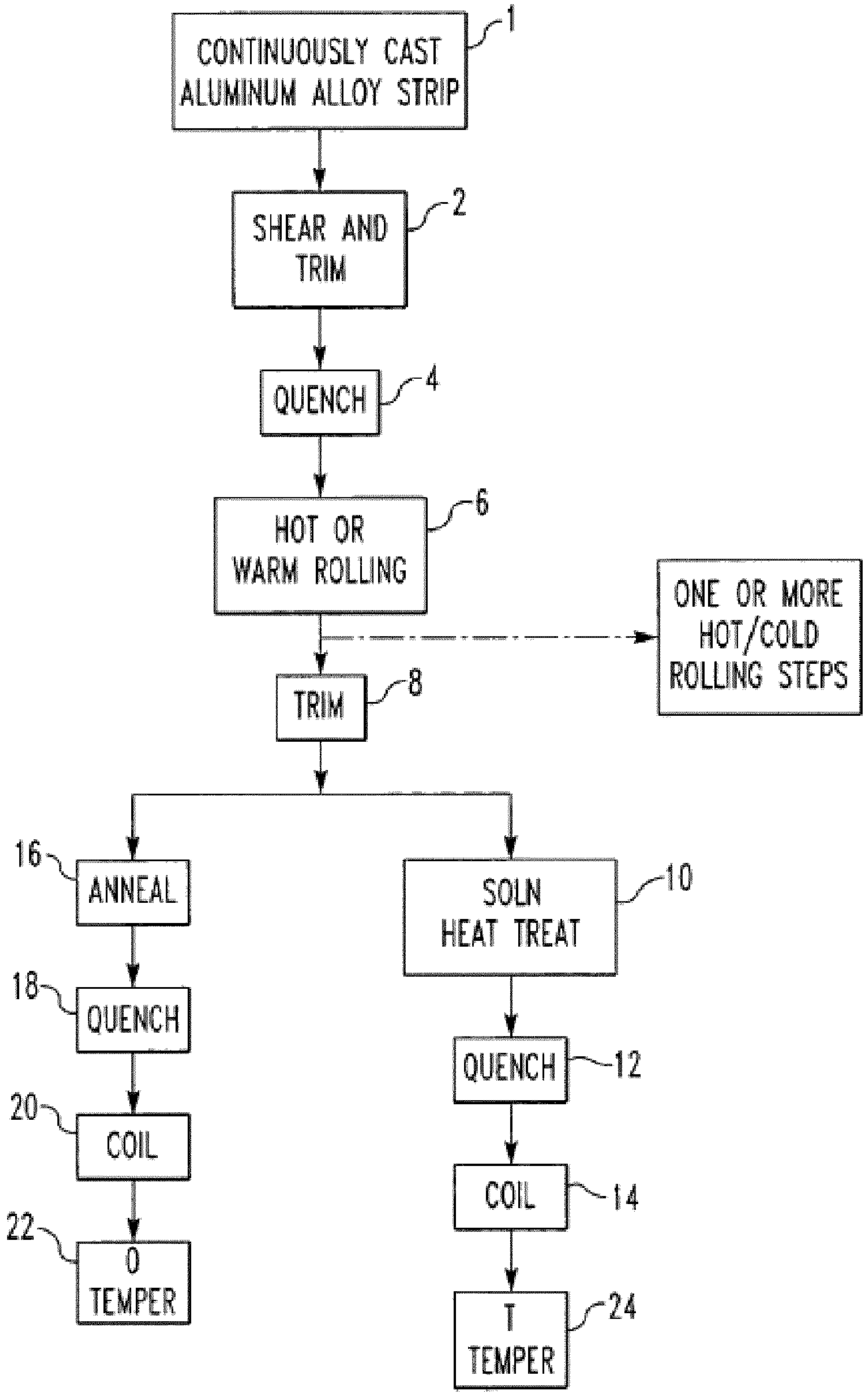
CONTINUOUSLY CAST ALUMINUM ALLOY STRIP
1
SHEAR AND TRIM
2
QUENCH
4
HOT OR WARM ROLLING
6
ONE OR MORE HOT/COLD ROLLING STEPS
TRIM
8
16
ANNEAL
18
QUENCH
20
COIL
22
O TEMPER
SOLN HEAT TREAT
10
QUENCH
12
COIL
14
T TEMPER
24

FIG. 1

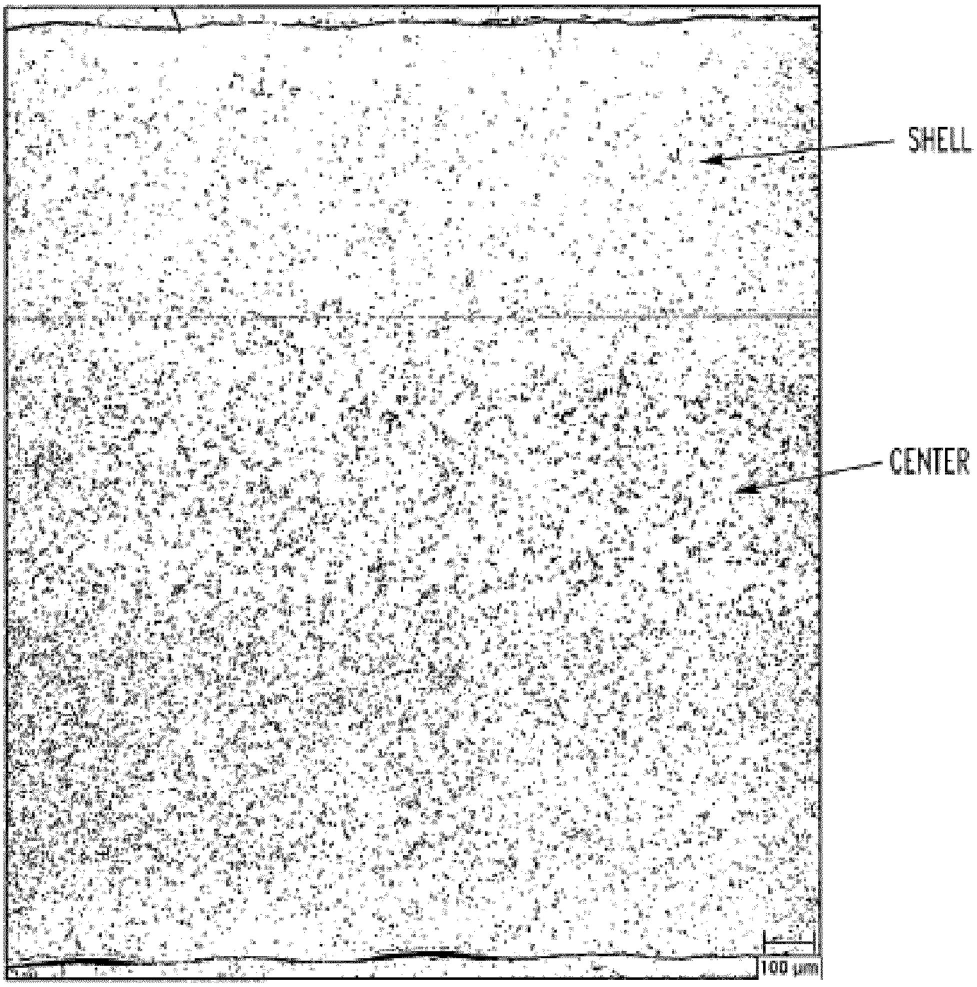

FIG. 2

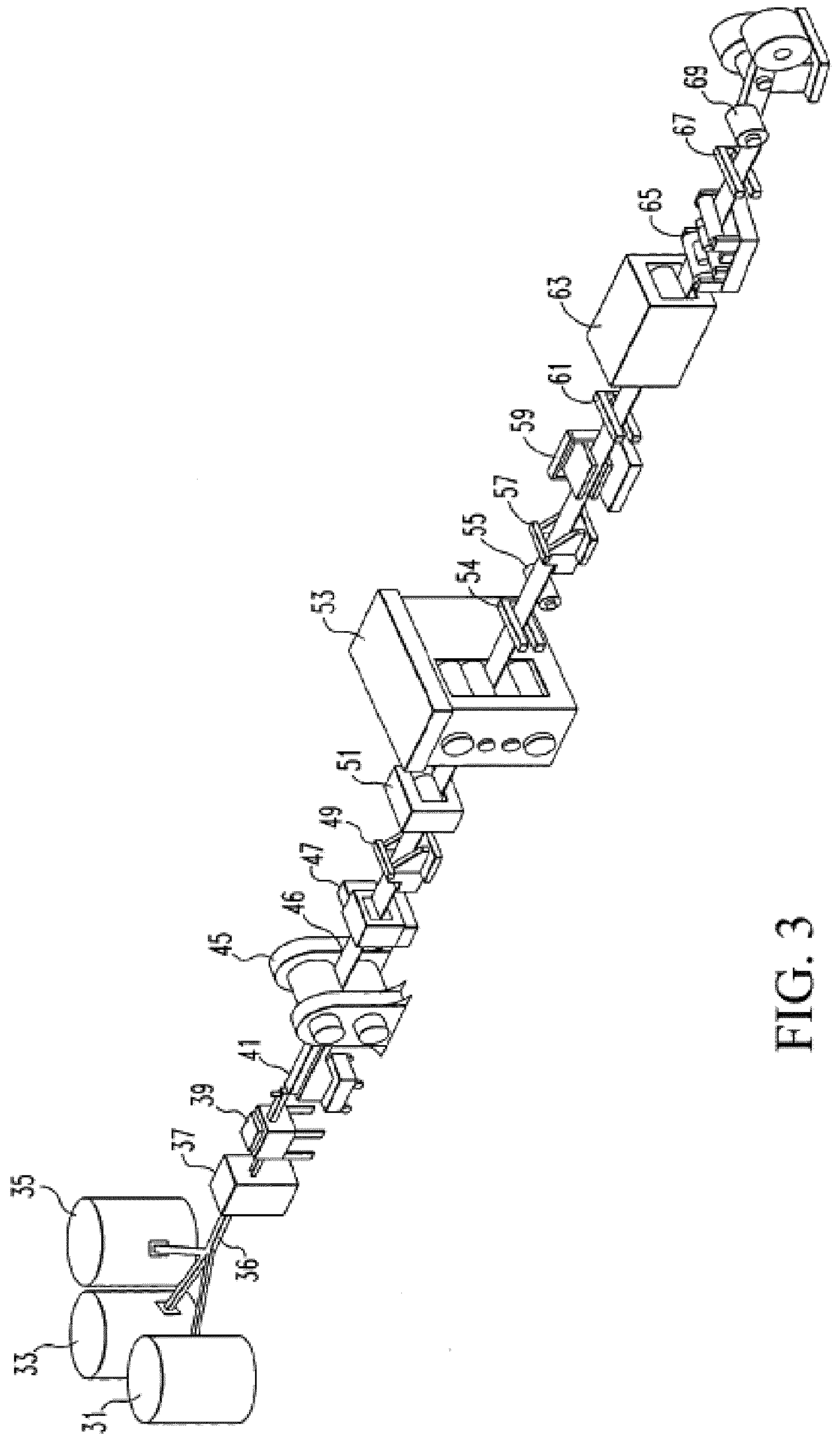

FIG. 3

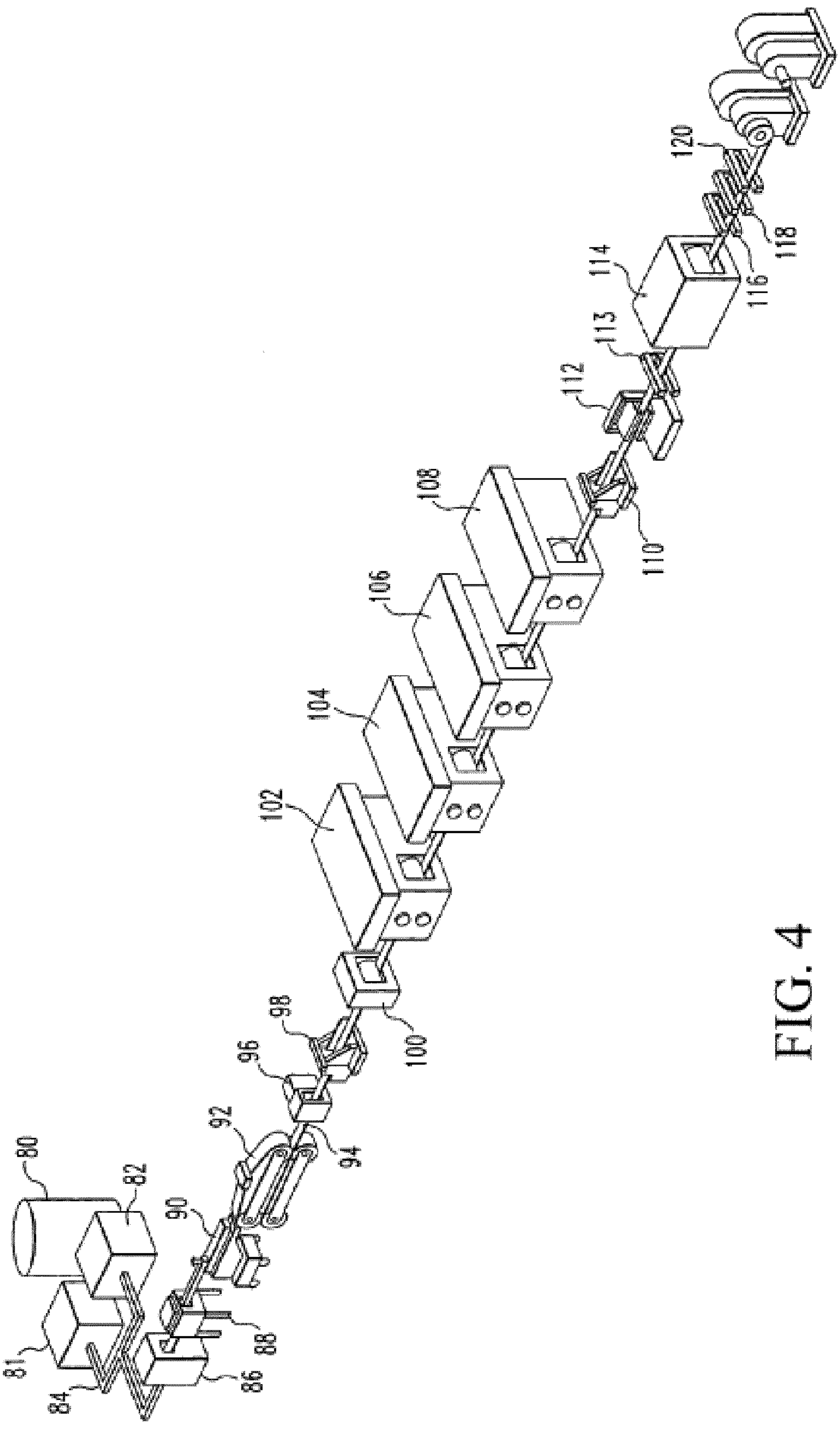
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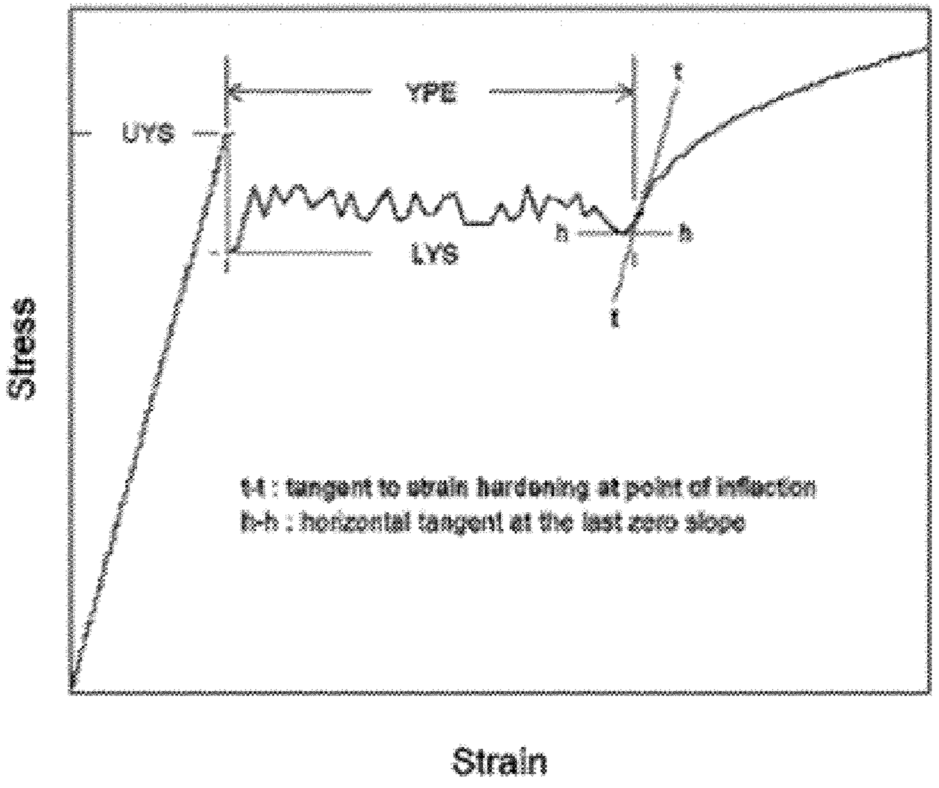
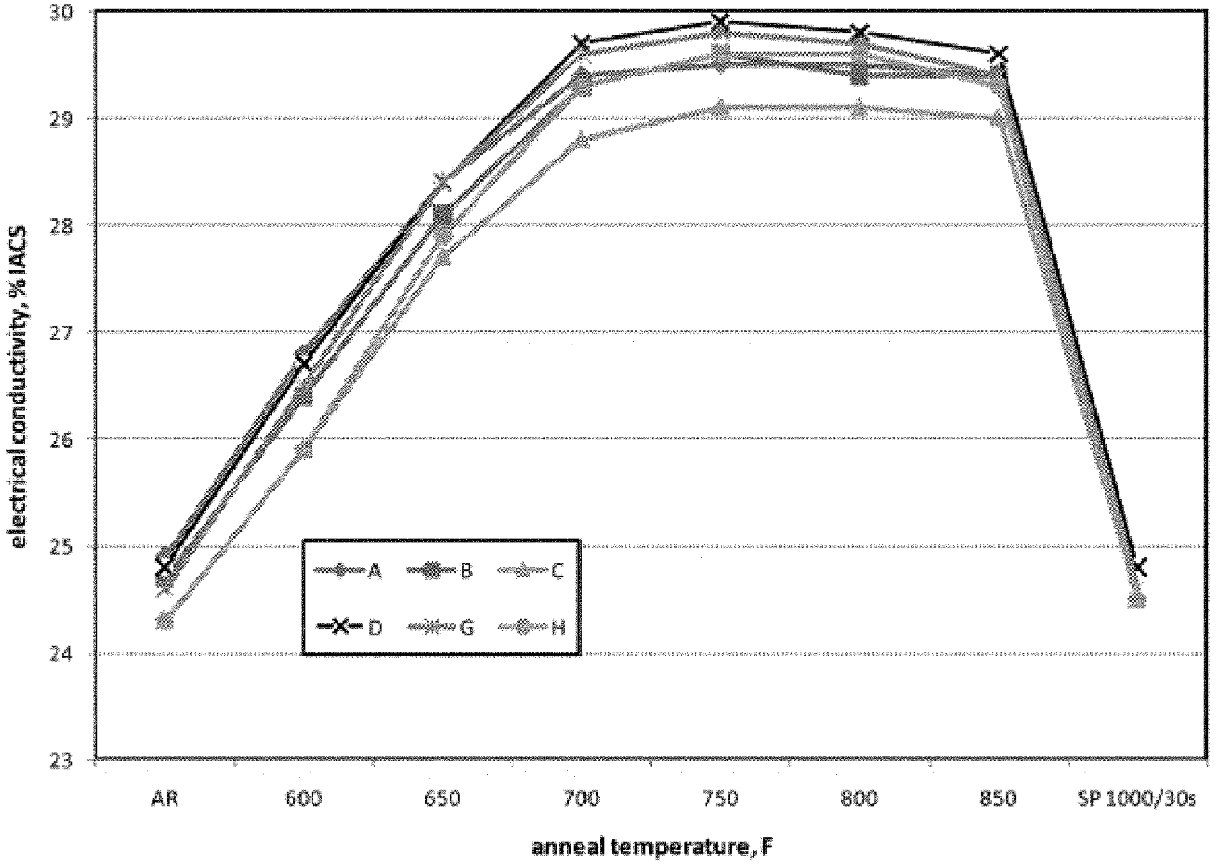
FIG. 4

# FIG. 5

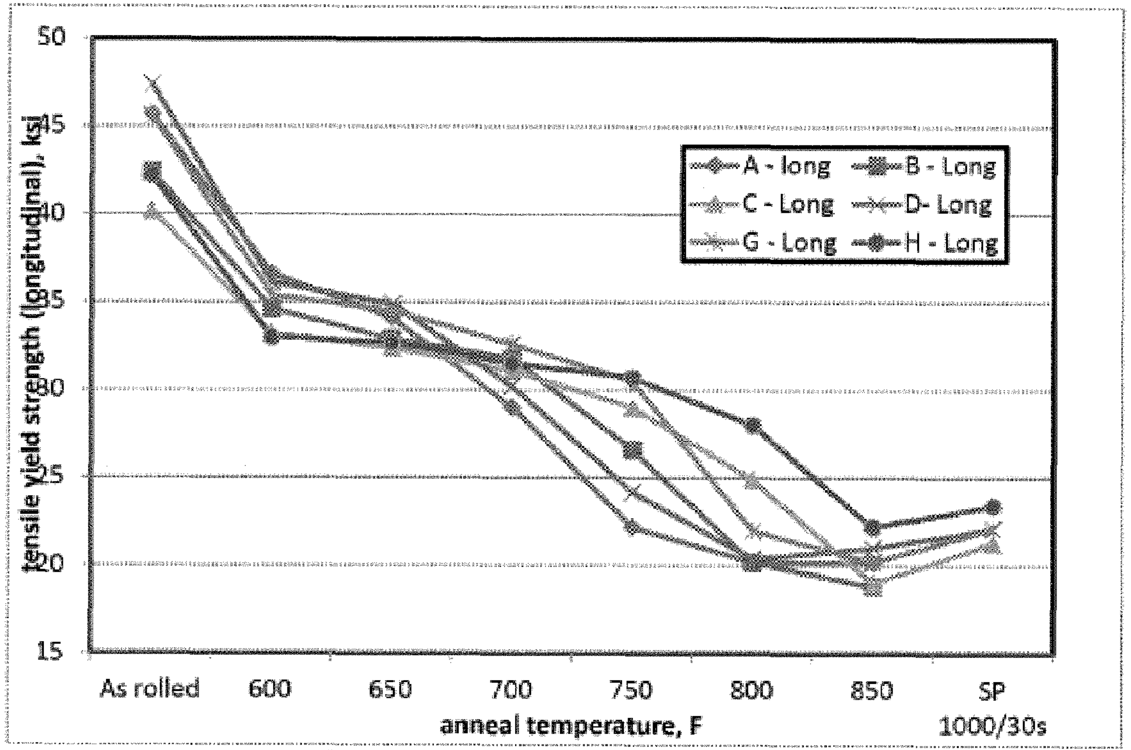
Upper yield strength (UYS), lower yield strength (LYS)
and yield point extension (YPE) estimation from a stress-strain curve





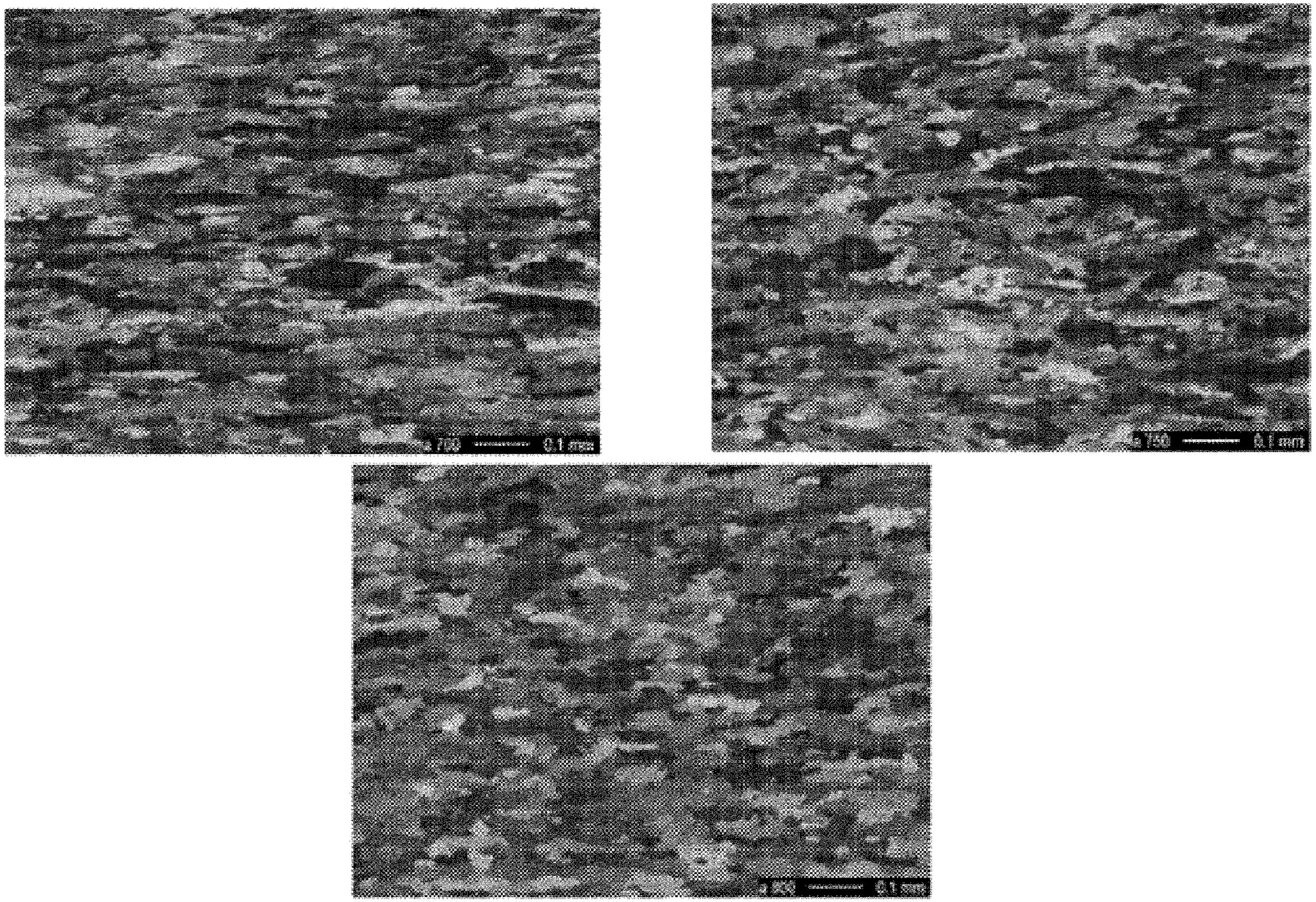
Electrical conductivity of samples after furnace anneal at several different temperatures and after simulated continuous anneal (SP1000/30s). All material was prepared by hot rolling only (see Table 1).

FIG. 6



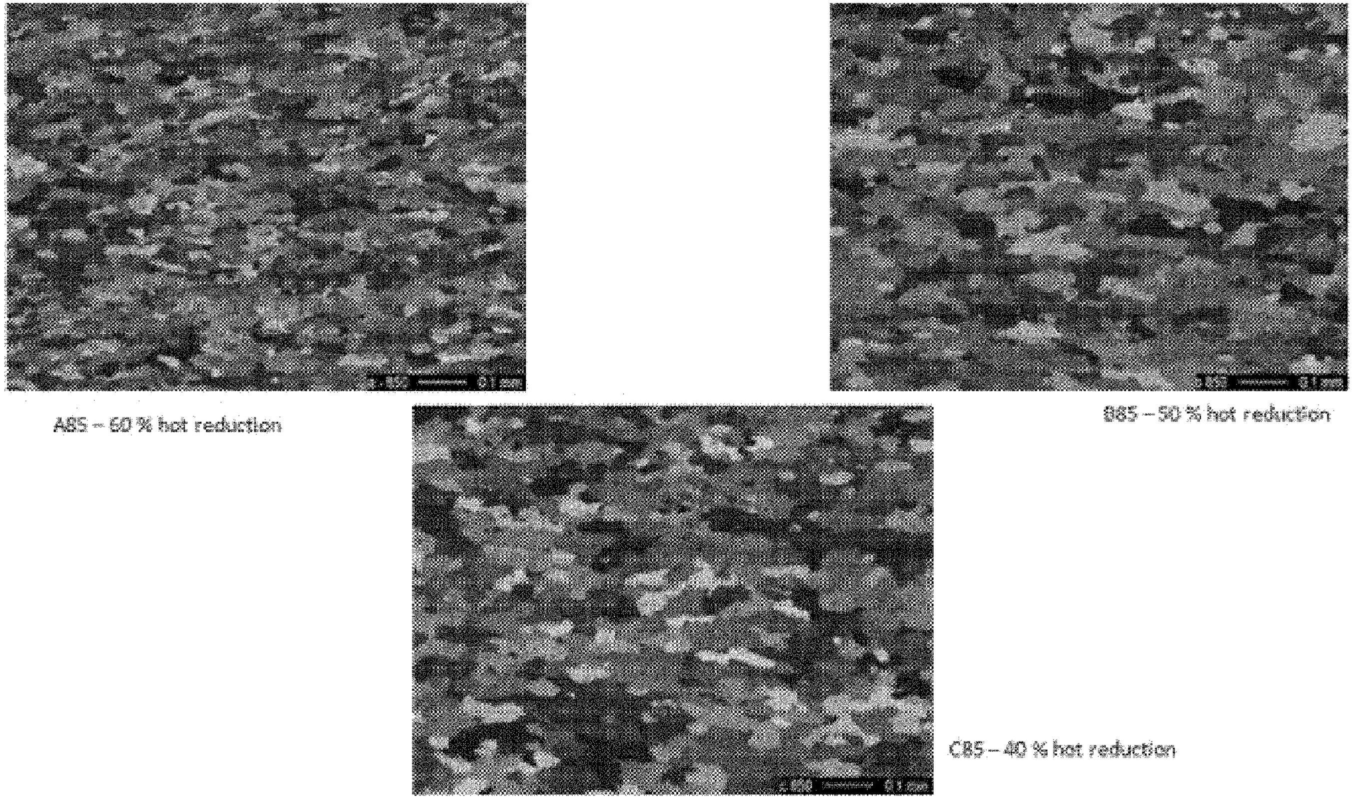
Tensile yield strength (longitudinal) after furnace anneal at several different temperatures and after simulated continuous anneal at 1000 F/30 s.

FIG. 7



Partially recrystallized grain structure in AA5182 samples prepared by 60% hot reduction after batch annealing at 700, 750 and 800°F/2 hr (longitudinal), clockwise.

FIG. 8



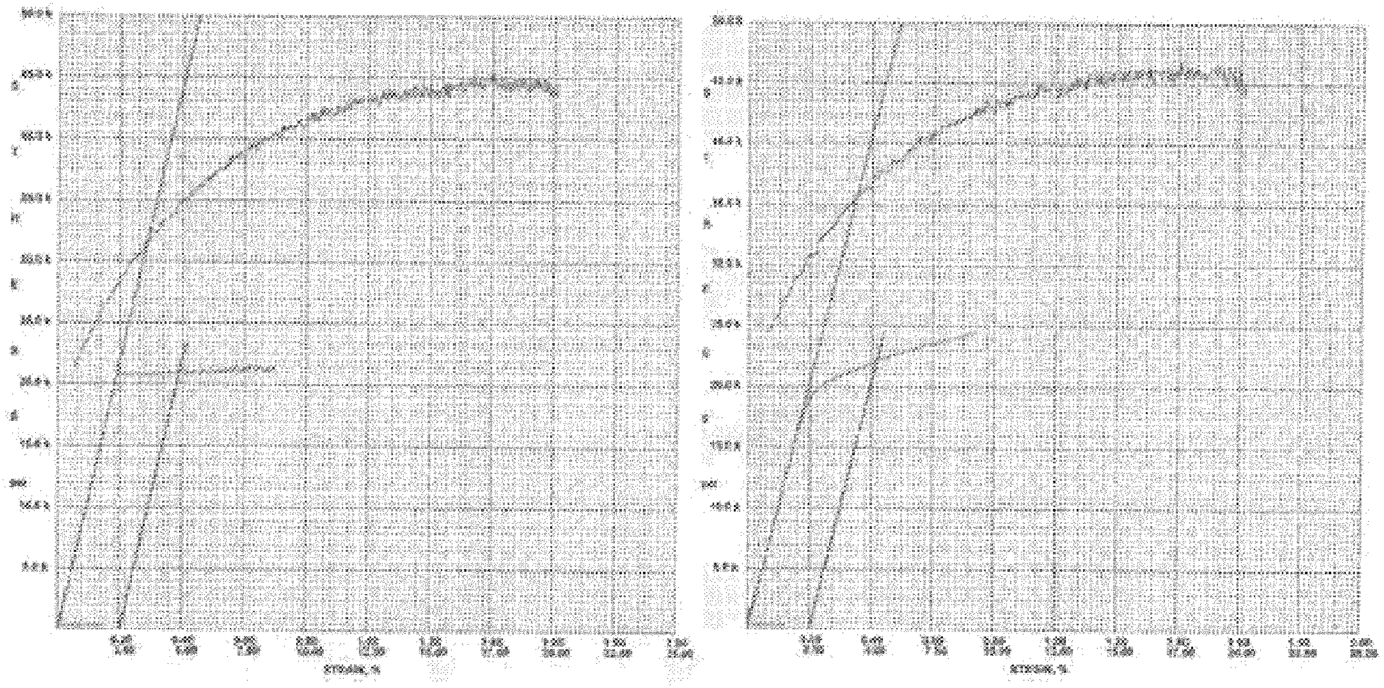
A85 – 60 % hot reduction

B85 – 50 % hot reduction

C85 – 40 % hot reduction

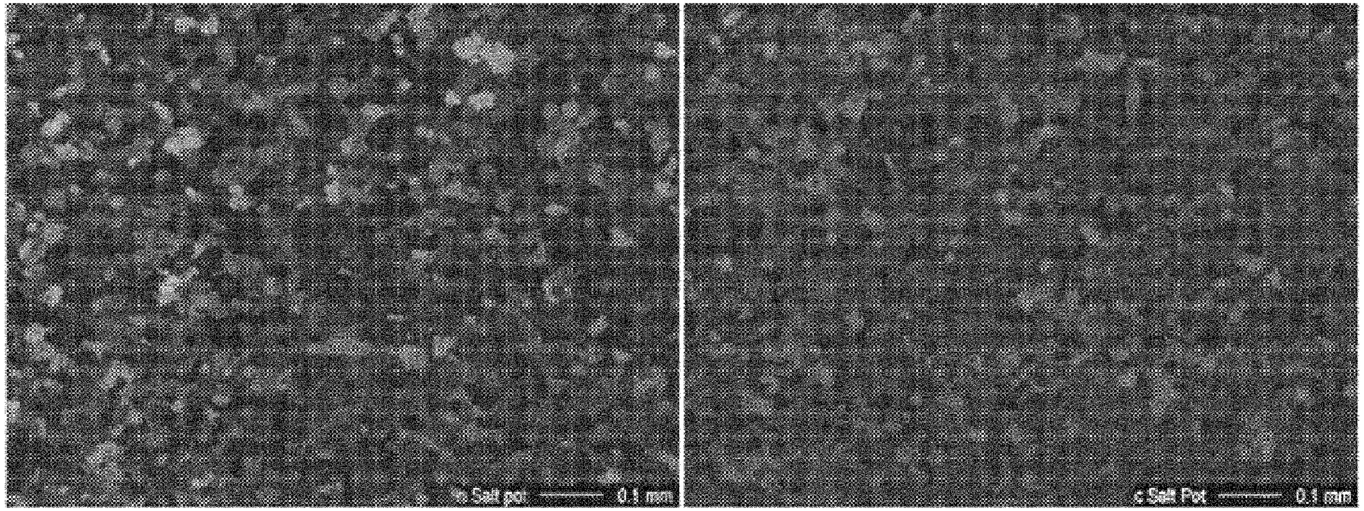
Recrystallized grain structure in AA5182 samples with different hot reduction after batch annealing at 850°F/2 hr (longitudinal).

FIG. 9



Typical tensile stress- strain curves in the longitudinal direction. D85 (left) showed a YPE of 0.52% whereas H85 showed no discernable YPE. Note the Portevin – Le Chatelier serrated flow in the plastic strain regime.

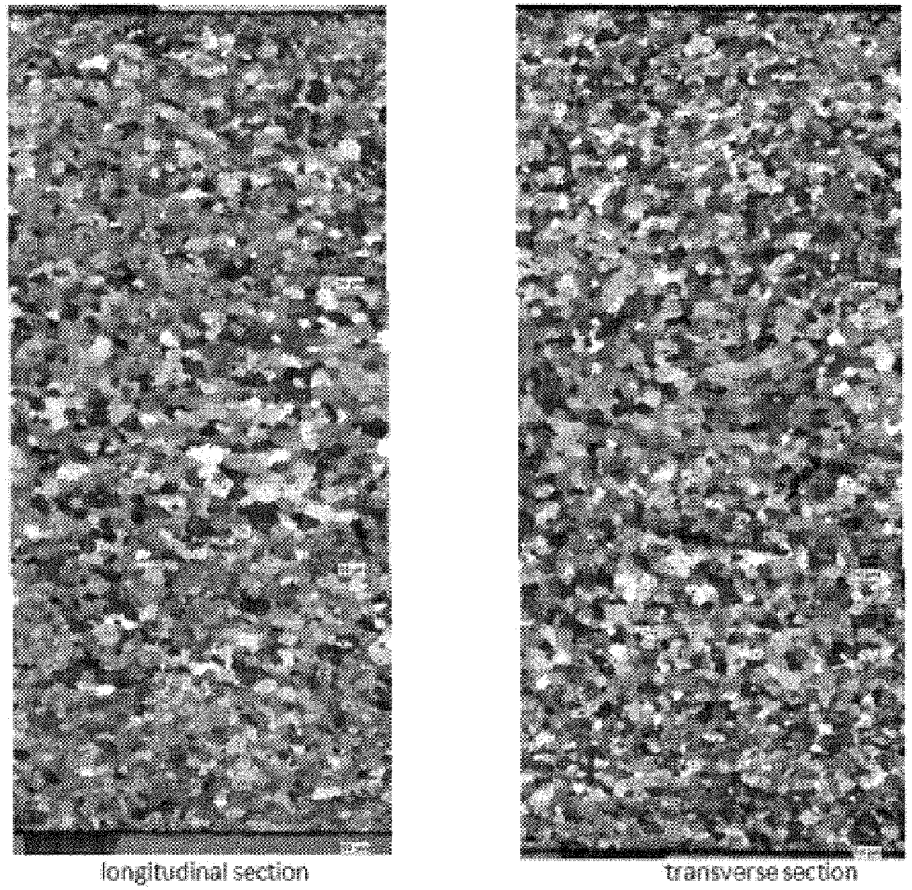
FIG. 10



Grain structure of 0.060 inch sheet prepared by 40% in-line hot rolling after simulated flash anneal at 1000°F/ 30 s in a salt bath.

Sample H (SAL2 ,modified 5182, 0.21%Cu) ,
Sample C (SAL1, 5182, Cu=0.12%)

FIG. 11

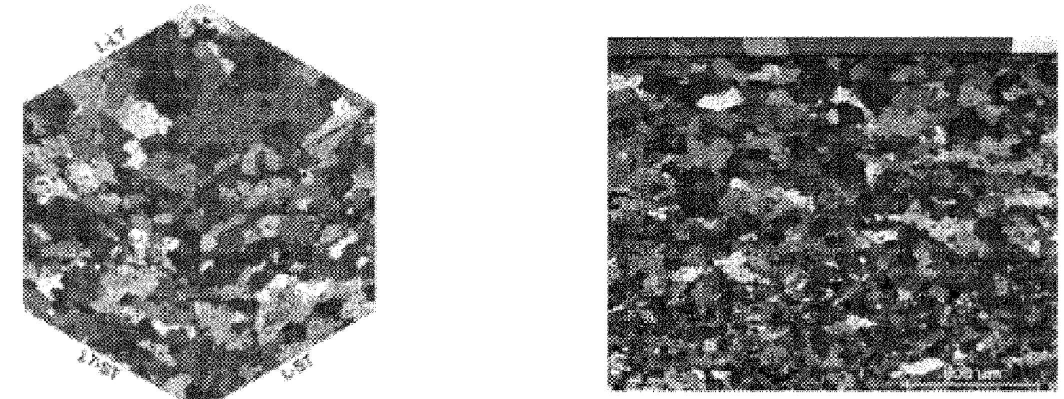


longitudinal section

transverse section

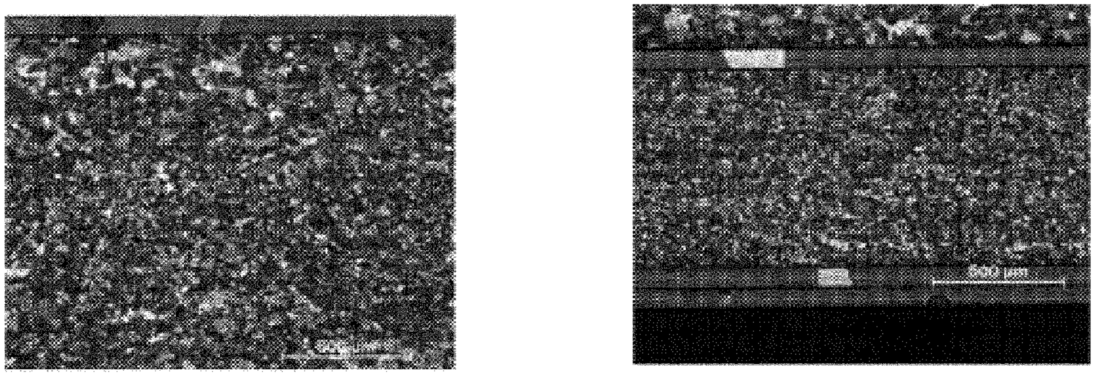
Grain structure in continuously annealed coils from cast 110509. This material was hot-rolled in-line from 0.116 inch as-cast gauge to 0.070 inch, cold rolled in Davenport to 0.040 inch test gauge. Continuous anneal was done in Danville heat treat line at 1000°F after which forced air cooling was applied.

FIG. 12



No cold work (879932) – **38 µm**

**25% CW** (881353) - **28 µm**



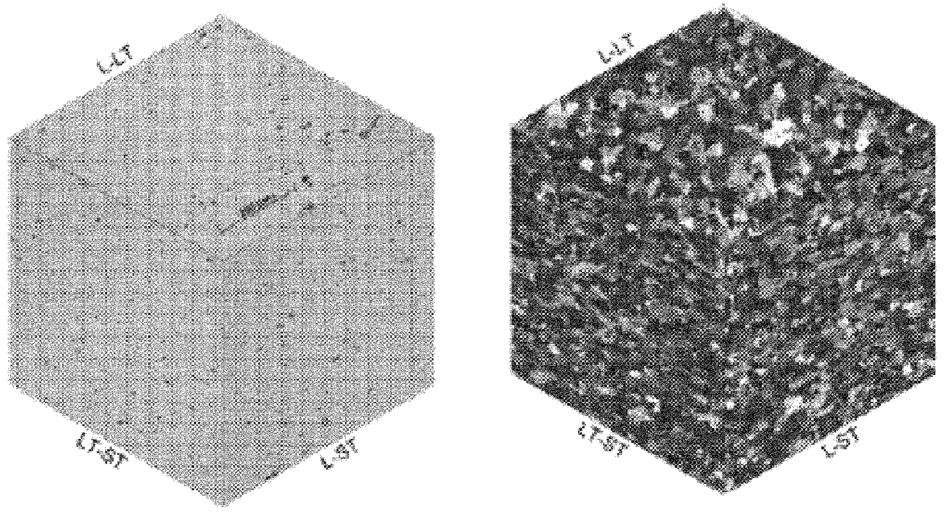
**50% CW** (881354) - **17 µm**

**75% CW** (881355) - **12 µm**

Grain structure after batch anneal at 850°F/2hr for in-line hot rolled sheet of 0.118 inch thickness and after cold rolling by 25, 50 and 75% followed by batch anneal at 750°F/2 hr.

FIG. 13

879934 (1.5 mm)



**grain dia=17 µm**

Second phase particle size (left) and grain structure (right) in 5182 –O sheet of 1.5 mm thickness made from ingot in Davenport and batch annealed at 750°F/2 hr.

FIG. 14

Europäisches Patentamt
European Patent Office
Office européen des brevets

## EUROPEAN SEARCH REPORT

Application Number
EP 13 17 8860

### DOCUMENTS CONSIDERED TO BE RELEVANT

| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (IPC) |
|---|---|---|---|
| X,D | US 2005/211350 A1 (UNAL ALI [US] ET AL) 29 September 2005 (2005-09-29)<br>* the whole document *<br>* paragraphs [0057], [0081], [0084] *<br>----- | 1-15 | INV.<br>B22D11/00<br>C22F1/04<br>C22F1/047 |
| X | WO 98/40528 A1 (ALCAN INT LTD [CA]; WYCLIFFE PAUL [CA]; LUCE EDWARD STANLEY [CA]) 17 September 1998 (1998-09-17) | 1-12,14, 15 | |
| A | * page 3, lines 10-13 *<br>* page 6, lines 22-31 *<br>* page 7, lines 24-30; figures 2, 5, 7a; table 3 *<br>* page 10, lines 12-16, 30-34 *<br>* page 11, lines 9-11, 12-14, 25-31; claims 1,4,12,13,16,18; tables 1,4 *<br>* page 12, lines 23-24 *<br>----- | 13 | |
| A | US 6 391 127 B1 (WYATT-MAIR GAVIN F [US] ET AL) 21 May 2002 (2002-05-21)<br>* the whole document *<br>----- | 1-15 | |
| A | US 2003/150587 A1 (LI ZHONG [US] ET AL) 14 August 2003 (2003-08-14)<br>* the whole document *<br>----- | 1-15 | |

TECHNICAL FIELDS SEARCHED (IPC)

B22D
C22F

The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| Munich | 7 October 2013 | Nikolaou, Ioannis |

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