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(54) **6XXX SERIES ALUMINIUM ALLOY SHEETS, PLATES OR BLANKS WITH IMPROVED FORMABILTY**

(57) The invention concerns a process for producing a sheet or a plate or a blank, comprising the following successive steps: (a) casting a 6xxx alloy comprising, in wt.%: Si: 1.25 - 1.45 ; Fe: ≤ 0.30 ; Cu: ≤ 0.15 ; Mn: 0.01 - 0.15 ; Mg: 0.25 - 0.40 ; Cr: 0.03 ; Ni: ≤ 0.04 ; Zn: ≤ 0.15 ; Ti: 0.01 - 0.10 ; other elements: < 0.05 each and < 0.15 in total ; rest aluminium; (b) heat treating; (c) hot rolling; (d) cold rolling; (e) optionally inter-annealing between hot rolling and cold rolling and/or during cold rolling and/or after cold rolling; (f) solution heat treating; (g) quenching; (h) optionally pre-aging; (i) shearing without any milling step.

Description

FIELD OF THE INVENTION

[0001] The present invention relates to 6xxx series aluminium alloy sheets, plates or blanks and their method of production, particularly useful for the automotive industry. An application could be a door opening panel (DOP) of a vehicule, for example a car.

BACKGROUND OF THE INVENTION

[0002] The automotive industry uses more and more aluminium alloys, in particular in view of lighweighting the final vehicle.

[0003] Various aluminium alloys are used in the form of sheets, plates or blanks for automotive usages. Among these alloys, 6xxx series aluminium alloys are the most commonly used. For example, a known alloy could be AA6111-T4, that combines interesting chemical and mechanical properties such as hardness, strength, and formability. The ranges disclosed in the Teal Sheets of the Aluminum Association are as follows: 0.6-1.1% Si ; <0.40% Fe ; 0.50-0.9% Cu ; 0.10-0.45% Mn ; 0.50-1.0% Mg ; <0.10% Cr ; <0.15% Zn ; <0.10% Ti.

[0004] Other 6xxx series aluminium alloys have been developed, for example in JP3872753 B2, that discloses an aluminum alloy having the following composition, in weight percentages: Mg: 0.2 to 1.5%, ; Si: 0.4 to 2.0% ; Fe: 0.001 to 1.0% ; Mn: 0.01 to 2.0% ; Cr: 0.001 to 1.0% ; and the balance Al with inevitable impurities. Another example may be found in JP4495623 B2, that discloses an aluminium alloy having the following composition, in weight percentages: Si: 0.1 to 2.5% ; Mg: 0.1 to 3.0% ; and the balance Al with inevitable impurities. Still another example may be found in Sergey F. Golovashchenko et al., "Trimming and sheared edge stretchability of automotive 6xxx aluminum", Journal of Materials Processing Tech. 264 (2019), pp.64-75, that discloses an aluminium alloy having the following composition, in weight percentages: 0.80% Si ; 0.14% Fe ; 0.06% Cu ; 0.08% Mn ; 0.61% Mg ; 0.03% Cr ; 0.01% Zn ; 0.03% Ti. Still another example may be found in Nicholas Robert Kalweit, "Edge Stretch Performance of 6DR1 Aluminum in Typical Automotive Blanking Conditions", A thesis submitted in the University of Michigan-Dearborn, 2017, that discloses an aluminium alloy having the following composition, in weight percentages: 0.50-1.00% Si ; <0.30% Fe ; <0.20% Cu ; <0.15% Mn ; 0.40-0.80% Mg ; <0.10% Cr ; <0.10% Zn ; <0.10% Ti ; <0.05% other elements each ; <0.15% other elements in total.

[0005] But the control of the composition ranges of the aluminium alloy does not seem enough to assure sufficient formability performance in each part of the sheets, plates or blanks, in particular in the area of the sheared edges. It is indeed known that formability of sheared edges decreases after cutting. Formability may for example be evaluated by a stretchability test that is described in the example part.

[0006] It has been shown that the process of production of the sheets, plates or blanks has to be taken into account. In particular:

- Stretchability was found to decrease with increasing cutting clearances; optimal clearances were defined at clearances below 30% of the thickness of the sheared sheet;
- Elongation was found to decrease with increasing edge radius of the upper trim tool; optimal radius in upper trim tool was identified to be a radii below 0.14 mm;
- Removal of sheared edge initial plastic strain may significantly enhance the subsequent sheared edge stretchability;
- Prestrain was found to have significant effects on stretchability;
- Deburring or solution heat treatment of samples sheared with excessive clearance may increase stretchability;
- Trimming process with scarp support was found to improve sheared edge stretchability. (see X.H. Hu et al. "Predicting tensile stretchability of trimmed AA6111-T4 sheets", Computational Materials Science 85 (2014), pp.409-419;

[0007] Quochung B. Le et al. "Analysis of sheared edge formability of aluminum", Journal of Materials Processing Technology 214 (2014), pp.876-891;

[0008] Nan Wang et al. "Mechanism of fractureof aluminum blanks subjected to stretching along the sheared edge", Journal of Materials Processing Technology 233 (2016), pp.142-160;

[0009] Nicholas Robert Kalweit, "Edge Stretch Performance of 6DR1 Aluminum in Typical Automotive Blanking Conditions", A thesis submitted in the University of Michigan-Dearborn, 2017).

[0010] Despite all these solutions, it remains a need for a material and a process that allow to obtain an acceptable compromise between the process simplification and the performance of the obtained sheet, plate or blank, in particular in a formability point of vue, more particularly in a stretchability point of view.

SUMMARY OF THE INVENTION

[0011] The inventors have surprisingly found a solution where the milling step, generally done after blanking and prior to stamping a sheet, plate or blank, may be omitted. As known, the shearing process introduces damage to the material and decreases its formability, more specifically, decreases its stretchability, for example illustrated by tensile elongation, compared to a milled edge. The omission of the milling step may allow for cost-savings and increased production speed.

[0012] Obtaining a satisfying formability notably allows to successfully stamp the sheet, plate or blank. An unsuccessful stamp is herein defined by having a split occuring during the stamping process resulting in the obtained piece to be scrapped.

[0013] The proposed solution uses an alloy having an increased global formability, as well as an improved local formability resulting in an overall increase in the work-hardening capacity, and combines it with a hard quenching step before the shearing step without any milling step.

[0014] An object of the invention is a process for producing a sheet or a plate or a blank, comprising the following successive steps:

(a) casting a 6xxx alloy comprising, in wt.%:

Si:	1.25 - 1.45	; preferably 1.30 - 1.40
Fe:	≤ 0.30	; preferably 0.10 - 0.20
Cu:	≤ 0.15	; preferably ≤ 0.09
Mn:	0.01- 0.15	; preferably 0.05 - 0.10
Mg:	0.25-0.40	; preferably 0.30-0.35
Cr:	≤ 0.03	; preferably ≤ 0.02
Ni:	≤ 0.04	; preferably ≤ 0.03
Zn:	≤ 0.15	; preferably ≤ 0.10
Ti:	0.01 - 0.10	; preferably 0.01- 0.04
other elements:		< 0.05 each and < 0.15 in total
rest aluminium;		

(b) heat treating;
(c) hot rolling;
(d) cold rolling;
(e) optionally inter-annealing between hot rolling and cold rolling and/or during cold rolling and/or after cold rolling;
(f) solution heat treating;
(g) quenching;
(h) optionally pre-aging
(i) shearing without any milling step.

[0015] Another object of the invention is a sheet or plate or blank obtained according to the process of the present invention, characterised in that it has an improved sheared edge stretchability compared to non-milled previous sheets or plates or blanks.

[0016] Another object of the invention is the use of a sheet or plate or blank of the present invention to produce a vehicle part.

DESCRIPTION OF THE FIGURES

[0017]

[Figure 1]: Figure 1 is a scheme of the half-dog bone sample used for measuring the sheared edge stretchability according to the examples illustrating the present invention, with the dimensions expressed in mm. Thickness of the sample was 0.9 mm. Reference number **1** corresponds to the shear line, i.e. the line along which the shearing takes place, resulting in a final width of 12.5 mm.

[Figure 2]: Figure 2 is a schematic cross-section of the shearing die at different stages, showing main stages of shearing operation. Reference number **2** corresponds to the pad allowing to fix the sample. Reference number **3** corresponds to the fixed lower shearing tool. Reference number **4** corresponds to the upper shearing tool that translates up and down to shear the sample. Reference number **5** corresponds to the clearance, i.e. the gap between the lower and the upper shearing tools (3, 4) as a percentage of the sample thickness. Reference number **6** corresponds to the sample to be sheared. Reference number **7** corresponds to the moving direction of the upper shearing tool.

[Figure 3]: Figure 3 is a theoretical tensile test curve, representing the evolution of stress as a function of strain, showing how the sheared edge stretchability of a sample is determined. Reference number **8** corresponds to the uniform elongation (UE). Reference number **9** corresponds to the sheared edge stretchability (E_{SE}). Reference number **10** corresponds to the total elongation (TE). Reference number **11** corresponds to 95% of the maximum force ($0.95F_{max}$).

DESCRIPTION OF THE INVENTION

[0018] All aluminium alloys referred to in the following are designated using the rules and designations defined by the Aluminum Association in Registration Record Series that it publishes regularly, unless mentioned otherwise.

[0019] Metallurgical tempers referred to are designated using the European standard EN-515.

[0020] Static tensile mechanical characteristics, in other words, the ultimate tensile strength R_m (or UTS), the tensile yield strength at 0.2% plastic elongation $R_{p0,2}$ (or TYS), and elongation A% (or E%), are determined by a tensile test according to NF EN ISO 6892-1.

[0021] The present invention deals in particular with the notion of *"shear"/"shearing"*. As is known by the person skilled in the art, different equivalent terms may be used when talking about shear/shearing. Some of them are the terms *"trim"/"trimming"* and *"cut"/"cutting"*.

Process

[0022] According to the invention, an ingot is prepared by casting, typically Direct-Chill casting (or DC casting), using 6xxx series aluminium alloys of the invention. The ingot thickness is preferably at least 250 mm, or at least 350 mm and preferentially a very thick gauge ingot with a thickness of at least 400 mm, or even at least 500 mm or 600 mm in order to improve the productivity of the process. Preferably the ingot is from 1000 to 3000 mm in width and 2000 to 8000 mm in length. Preferably the ingot is scalped.

[0023] Then the ingot is heat-treated, generally from 500 to 600°C and up to 35 hours.

[0024] The heat-treating step may comprise an homogenizing step. The homogenisation of the plate is carried out at a temperature from 500°C to 600°C. In one embodiment, the homogenisation temperature is from 520°C to 600°C or 580°C or 560°C. In another embodiment, the temperature of the homogenisation is from 540°C to 600°C or 580°C or 560°C. Advantageously, the homogenisation time is at least 1 hour. In one embodiment, the maximum homogenization time is at most 48 hours or 46 hours or 44 hours or 43 hours or 42 hours or 41 hours. In another embodiment, the homogenisation time is at least 2 hours and at most 48 hours or 46 hours or 44 hours or 43 hours or 42 hours or 41 hours. In another embodiment, the homogenisation time is at least 4 hours and at most 48 hours or 46 hours or 44 hours or 43 hours or 42 hours or 41 hours. In another embodiment, the homogenisation time is at least 6 hours and at most 48 hours or 46 hours or 44 hours or 43 hours or 42 hours or 41 hours. In another embodiment, the homogenisation time is at least 8 hours and at most 48 hours or 46 hours or 44 hours or 43 hours or 42 hours or 41 hours. In another embodiment, the homogenisation time is at least 10 hours and at most 48 hours or 46 hours or 44 hours or 43 hours or 42 hours or 41 hours.

[0025] The homogenizing step may optionally comprise, after the first stage mentioned above, a second stage from 420°C to 550°C of a maximum duration of 4 hours. In one embodiment, this second stage has a temperature from 550°C to 440°C or 460°C or 480°C or 500°C or 520°C or 540°C. In another embodiment, this second stage has a temperature from 540°C to 440°C or 460°C or 480°C or 500°C or 520°C. In another embodiment, said second stage has a temperature from 520°C to 440°C or 460°C or 480°C or 500°C. In another embodiment, said second stage has a temperature from 500°C to 440°C or 460°C or 480°C. In another embodiment, this second stage has a temperature from 480°C to 440°C or 460°C. In another embodiment, this second stage has a temperature from 460°C to 440°C.

[0026] The ingot may then generally either be cooled to room temperature and then reheated to a hot rolling start temperature below the homogenisation temperature or the ingot may be cooled directly from the homogenisation temperature to the hot rolling start temperature. Direct cooling to the hot rolling start temperature is preferably carried out at a direct cooling rate of at least 150°C/h. Advantageously the direct cooling rate is at most 500°C/h.

[0027] After the heat-treating step, the ingot is transferred, at the hot rolling start temperature, to the hot rolling mill. The hot rolling start temperature is typically from 360°C to 560°C. In one embodiment, the hot rolling start temperature is at least 360°C and at most 550°C or 540°C or 530°C or 500°C or 450°C or 410°C. In another embodiment, the hot rolling start temperature is at least 370°C and at most 560°C or 550°C or 540°C or 530°C or 500°C or 450°C or 410°C In another embodiment, the hot rolling start temperature is at least 380°C and at most 560°C or 550°C or 540°C or 530°C or 500°C or 450°C or 410°C. In another embodiment, the hot rolling start temperature is at least 390°C and at most 560°C or 550°C or 540°C or 530°C or 500°C or 450°C or 410°C. In another embodiment, the hot rolling start temperature is at least 480°C and at most 560°C or 550°C or 540°C or 530°C. In another embodiment, the hot rolling start temperature is at least 490°C and at most 560°C or 550°C or 540°C or 530°C. In another embodiment, the hot rolling start temperature is at least 500°C and at most 560°C or 550°C or 540°C or 530°C. In another embodiment, the hot rolling start temperature is at least 510°C and at most 560°C or 550°C or 540°C or 530°C.

[0028] The hot rolling step is generally done in two successive steps in order to obtain a sheet with a first hot rolling step on a reversible rolling mill also known as roughing mill up to a thickness of typically from 12 to 40 mm and a second hot rolling step on a tandem mill also known as finishing mill up to a thickness of typically from 3 to 12 mm. A tandem mill is a rolling mill in which several cages supporting rolling mill rolls, typically 2, 3, 4 or 5 rolls, act successively ("in tandem"). The first step on a reversible mill can be carried out on one or even two reversible mills placed successively.

[0029] The hot rolling end temperature is from 250°C to 450°C. The cooling between the beginning and the end of the hot rolling process is the result of the usual heat exchange of the plate and then the strip or sheet with the air at the ambient temperature of the plant, with the equipment of the hot rolling mill, such as, for example, but not limited to, the rolls or the conveyor rollers, as well as with the usual lubricating or cooling fluids. In one embodiment, the hot rolling end temperature is at least 270°C and at most 450°C or 400°C or 380°C or 360°C or 340°C or 320°C or 300°C. In another embodiment, the hot rolling end temperature is at least 300°C and at most 450°C or 400°C or 380°C or 360°C or 340°C or 320°C. In another embodiment, the hot rolling end temperature is at least 320°C and at most 450°C or 400°C or 380°C or 360°C or 340°C. In another embodiment, the hot rolling end temperature is at least 340°C and at most 450°C or 400°C or 380°C or 360°C. In another embodiment, the hot rolling end temperature is at least 360°C and at most 450°C or 400°C or 380°C. In another embodiment, the hot rolling end temperature is at least 380°C and at most 450°C or 400°C. In another embodiment, the hot rolling end temperature is at least 400°C and at most 450°C. Controlling this temperature may allow to control the rate of recrystallisation.

[0030] Cold rolling is done after the hot rolling step to further reduce the thickness of the aluminium sheets. The sheet directly obtained after cold rolling is referred to as the cold rolled sheet. The cold rolled sheet thickness is typically from 0.5 to 2.5 mm and preferably from 0.7 to 2 mm.

[0031] In an embodiment, the cold rolling reduction is at least 40% or at least 50% or at least 60%. Typically, the cold rolling reduction is at most 99% or 98% or 97% or 96% or 95% or 94% or 93% or 92% or 91% or 90%.

[0032] Optionally, an inter-annealing step is done between the hot rolling step and the cold rolling step and/or during the cold rolling step and/or after the cold rolling step. According to an embodiment, the temperature of the inter-annealing step, done between the hot rolling step and the cold rolling step or during the cold rolling step, is from 300°C to 500°C or 450°C or 400°C or 380°C. According ot an embodiment, the temperature of the inter-annealing step, done between the hot rolling step and the cold rolling step or during the cold rolling step, is from 340°C to 500°C or 450°C or 400°C or 380°C. This inter-annealing step is preferably carried out on the sheet wound into a coil.

[0033] After the cold rolling step, according to an embodiment, the cold rolled sheet may be annealed in order to obtain a fully recrystallized microstructure, preferably in a continuous annealing line. Preferably the continuous annealing line is operated in such a way that a temperature of at least 310°C, preferably at least 320°C and at most 590°C or preferably at most 580°C is reached by the sheet.

[0034] Typically, the continuous annealing line is operated such that the heating rate of the sheet is at least 10°C/s and the time above 320°C is from 5 s to 25 s. The coiling temperature after annealing is preferably up to 100°C, preferably up to 95°C and more preferably from 80°C to 90°C. Alternatively, the annealing may be carried out by batch annealing at a temperature of at most 590°C.

[0035] According to the present invention, the sheet is then solution heat treated, generally in a continuous furnace and then quenched. The solution temperature is preferably from 500°C to 600°C or 590°C or 580°C or 570°C or 560°C. In one embodiment, the solution temperature is at least 520°C and at most 600°C or 590°C or 580°C or 570°C or 560°C. In another embodiment, the solution temperature is at least 540°C and at most 600°C or 590°C or 580°C or 570°C or 560°C. In another embodiment, the solution temperature is at least 550°C and at most 600°C or 590°C or 580°C or 570°C or 560°C. In another embodiment, the solution temperature is at least 560°C and at most 600°C or 590°C or 580°C or 570°C. The solution time is from 10 s to 60 s. Quenching may be done with air or water, preferably with water. For example, air quenching may be done with a strong air flow and water quenching with a water spray (for example flat jets and/or conic jets). The quenching speed is up to 1300°C/s and at least 30°C/s, preferably at least 40°C/s, preferably more than 200°C/s, preferably more than 300°C/s. In an embodiment, the temperature of the water used for the quenching step is from 30 to 60°C, preferably from 35 to 50°C. In an embodiment, the pressure of the water used for the quenching step is at most 80 psi or 70 psi or 60 psi or 50 psi or 40 psi or 30 psi or 25 psi. In another embodiment, the pressure of the water used for the quenching step is at least 5 psi and at most 80 psi or 70 psi or 60 psi or 50 psi or 40 psi or 30 psi or 25 psi. In another embodiment, the pressure of the water used for the quenching step is at least 10 psi and at most 80 psi or 70 psi or 60 psi or 50 psi or 40 psi or 30 psi or 25 psi. In another embodiment, the pressure of the water used for the quenching step is at least 15 psi and at most 80 psi or 70 psi or 60 psi or 50 psi or 40 psi or 30 psi or 25 psi. Preferably, the sheet temperature at the beginning of the quenching step is from 480 to 570°C, for example 490°C or 500°C or 510°C or 520°C or 530°C or 540°C or 550°C or 560°C. Preferably, the sheet temperature at the end of the quenching step is from 50 to 160°C, for example 60°C or 70°C or 80°C or 90°C or 100°C or 110°C or 120°C or

130°C or 140°C or 150°C.

[0036] Optionally, the sheet may then be pre-aged. The pre-aging is achieved by coiling the sheet at a temperature from 50°C to 100°C. In one embodiment, the pre-aging temperature is at least 60°C and at most 100°C or 95°C or 90°C or 85°C or 80°C or 75°C or 70°C or 65°C. In another embodiment, the pre-aging temperature is at least 65°C and at most 100°C or 95°C or 90°C or 85°C or 80°C or 75°C or 70°C. In another embodiment, the pre-aging temperature is at least 70°C and at most 100°C or 95°C or 90°C or 85°C or 80°C or 75°C. In another embodiment, the pre-aging temperature is at least 75°C and at most 100°C or 95°C or 90°C or 85°C or 80°C. In another embodiment, the pre-aging temperature is at least 80°C and at most 100°C or 95°C or 90°C or 85°C. In another embodiment, the pre-aging temperature is at least 85°C and at most 100°C or 95°C or 90°C. In another embodiment, the pre-aging temperature is at least 90°C and at most 100°C or 95°C. In a further embodiment, the pre-aging temperature is at least 95°C and at most 100°C. The pre-aging takes place during the natural cooling of the coil in the ambient temperature of the workshop for a period of 8 hours to 24 hours.

[0037] The strip may therefore be in the T4 temper and matures at room temperature from 72 hours to 6 months.

[0038] Optionally, there may be a pre-straining step of 0-5% before the bake hardening step, in particular in the case of laboratory scale experiments, for example to simulate a stamping step. After annealing and/or solutionising and/or quenching and/or pre-aging and/or tempering, the sheet is sheared to obtain a plate or a blank, without any milling step before being formed to its final shape by stamping. It could then optionally be painted and bake hardened, for example at 160 to 200°C during 10 to 30 minutes.

Alloy

[0039] The inventors have found improved 6xxx aluminium alloy sheets which have an increased global formability as well as an improved local formability, in particular an improved sheared edge stretchability. The quantities and properties of each element of the alloy used according to the present invention are described hereinafter.

[0040] **Si:** Silicon is, together with magnesium, the main alloying element in aluminium-magnesium-silicon systems (AA6xxx series) to form the hardening precipitates Mg2Si or Mg5Si6, which contribute to the structural hardening of these alloys. According to the present invention, the Si content is from 1.25 and 1.45 wt.%. A higher content may degrade the bendability. In one embodiment, the minimum Si content is 1.25 wt.% and the maximum is 1.44 wt.% or 1.43 wt.% or 1.42 wt.% or 1.41 wt.% or 1.40 wt.%. In another embodiment, the minimum Si content is 1.26 wt.% and the maximum is 1.45 wt.% or 1.44 wt.% or 1.43 wt.% or 1.42 wt.% or 1.41 wt.% or 1.40 wt.%. In another embodiment, the minimum Si content is 1.27 wt.% and the maximum is 1.45 wt.% or 1.44 wt.% or 1.43 wt.% or 1.42 wt.% or 1.41 wt.% or 1.40 wt.%. In another embodiment, the minimum Si content is 1.28 wt.% and the maximum is 1.45 wt.% or 1.44 wt.% or 1.43 wt.% or 1.42 wt.% or 1.41 wt.% or 1.40 wt.%. In another embodiment, the minimum Si content is 1.29 wt.% and the maximum is 1.45 wt.% or 1.44 wt.% or 1.43 wt.% or 1.42 wt.% or 1.41 wt.% or 1.40 wt.%. In another embodiment, the minimum Si content is 1.30 wt.% and the maximum is 1.45 wt.% or 1.44 wt.% or 1.43 wt.% or 1.42 wt.% or 1.41 wt.% or 1.40 wt.%.

[0041] **Fe:** Iron is generally considered as an undesirable impurity. The presence of iron-containing intermetallic compounds is generally associated with a decrease in local formability. However, very pure alloys are expensive. According to the present invention, a compromise is a Fe content of up to 0.30 wt.%.. In one embodiment, the Fe content is at least 0.05 wt.% and at most 0.30 wt.% or 0.25 wt.% or 0.24 wt.% or 0.23 wt.% or 0.22 wt.% or 0.21 wt.% or 0.20 wt.%. In another embodiment, the Fe content is at least 0.06 wt.% and at most 0.30 wt.% or 0.25% or 0.24 wt.% or 0.23 wt.% or 0.22 wt.% or 0.21 wt.% or 0.20 wt.%. In another embodiment, the Fe content is at least 0.07 wt.% and at most 0.30 wt.% or 0.25 wt.% or 0.24 wt.% or 0.23 wt.% or 0.22 wt.% or 0.21 wt.% or 0.20 wt.%. In another embodiment, the Fe content is at least 0.08 wt.% and at most 0.30 wt.% or 0.25 wt.% or 0.24 wt.% or 0.23 wt.% or 0.22 wt.% or 0.21 wt.% or 0.20 wt.%. In another embodiment, the Fe content is at least 0.09 wt.% and at most 0.30 wt.% or 0.25 wt.% or 0.24 wt.% or 0.23 wt.% or 0.22 wt.% or 0.21 wt.% or 0.20 wt.%. In another embodiment, the Fe content is at least 0.10 wt.% and at most 0.30 wt.% or 0.25 wt.% or 0.24 wt.% or 0.23 wt.% or 0.22 wt.% or 0.21 wt.% or 0.20 wt.%.

[0042] **Cu:** In the AA6xxx series alloys, copper is an element participating in the hardening precipitation but it is also known to degrade corrosion resistance. According to the present invention, the copper content is at most 0.15 wt.% or 0.14 wt.% or 0.13 wt.% or 0.12 wt.% or 0.11 wt.% or 0.10 wt% or 0.09 wt.% or 0.05 wt.%. Allowing the presence of copper in the alloy is economically attractive as it allows the recycling of aluminium scrap and waste containing copper. The presence of copper can come from both scrap and waste as such, but can also be introduced accidentally. For example, during the dismantling of an end-of-life vehicle, it is sufficient to inadvertently leave a copper wire with the aluminium parts to pollute a plate obtained with recycled aluminium alloy.

[0043] **Mn:** Manganese is an effective element for strength improvement, crystal grain refining and structure stabilization. According to the present invention, the Mn content is from 0.01 to 0.15 wt.%. When the Mn content is under 0.01 wt.%, the aforementioned effects are insufficient. On the other hand, a Mn content exceeding 0.15 wt.% may not only cause a saturation of the above effects but also cause the generation of multiple intermetallic compounds that could have an adverse effect on formability. In one embodiment, the Mn content is at least 0.01 wt.% and at most 0.14 wt.% or 0.13 wt.% or 0.12 wt.% or 0.11 wt.% or 0.10 wt.%. In one embodiment, the Mn content is at least 0.02 wt.% and at most 0.15 wt.% or 0.14 wt.% or 0.13 wt.% or 0.12 wt.% or 0.11 wt.% or 0.10 wt.%. In one embodiment, the Mn content is at least 0.03 wt.% and at most 0.15 wt.% or 0.14 wt.% or 0.13 wt.% or 0.12 wt.% or 0.11 wt.% or 0.10 wt.%. In one embodiment, the Mn content is at least 0.04 wt.% and at most 0.15 wt.% or 0.14 wt.% or 0.13 wt.% or 0.12 wt.% or 0.11 wt.% or 0.10 wt.%. In one embodiment, the Mn content is at least 0.05 wt.% and at most 0.15 wt.% or 0.14 wt.% or 0.13 wt.% or 0.12 wt.% or 0.11 wt.% or 0.10 wt.%.

[0044] **Mg:** Magnesium is one of the main alloying elements of the 6xxx series alloys and it contributes to strength improvement by combination with silicon to form the hardening precipitates Mg2Si or Mg5Si6. According to the present invention, the Mg content is from 0.25 to 0.40 wt.%. When the Mg content is under 0.25 wt.%, strength improvement may be insufficient. On the other hand, a content exceeding 0.40 wt.% may result in a strength detrimental to formability. In one embodiment, the Mg content is at least 0.25 wt.% and at most 0.39 wt.% or 0.38 wt.% or 0.37 wt.% or 0.36 wt.% or 0.35 wt.%. In one embodiment, the Mg content is at least 0.26 wt.% and at most 0.40 wt.% or 0.39 wt.% or 0.38 wt.% or 0.37 wt.% or 0.36 wt.% or 0.35 wt.%. In one embodiment, the Mg content is at least 0.27 wt.% and at most 0.40 wt.% or 0.39 wt.% or 0.38 wt.% or 0.37 wt.% or 0.36 wt.% or 0.35 wt.%. In one embodiment, the Mg content is at least 0.28 wt.% and at most 0.40 wt.% or 0.39 wt.% or 0.38 wt.% or 0.37 wt.% or 0.36 wt.% or 0.35 wt.%. In one embodiment, the Mg content is at least 0.29 wt.% and at most 0.40 wt.% or 0.39 wt.% or 0.38 wt.% or 0.37 wt.% or 0.36 wt.% or 0.35 wt.%. In one embodiment, the Mg content is at least 0.30 wt.% and at most 0.40 wt.% or 0.39 wt.% or 0.38 wt.% or 0.37 wt.% or 0.36 wt.% or 0.35 wt.%.

[0045] **Cr:** Chromium may be added for strength improvement, crystal grain refining and structure stabilization. According to the present invention, the Cr content is at most or less than 0.03 wt%, preferably at most or less than 0.02 wt.%.

[0046] **Ni:** Nickel may be introduced by the way of recycled content. According to the present invention, the Ni content is at most, or less than, 0.04 wt%, preferably at most, or less than, 0.03 wt.%.

[0047] **Zn:** As zinc is an addition element in aluminium alloys, it is interesting to have some in the alloy of the present invention for the purpose of recycling aluminium scrap and waste, in particular from end-of-life vehicles. Indeed, Zn is used in some alloys in some components such as heat exchangers. According to the present invention, the Zn content is at most, or less than, 0.15 wt.%, preferably at most, or less than, 0.10 wt.%. The inventors have found that the invention alloy can tolerate such content of Zn without adversely affecting the properties, which is beneficial for recycling purposes.

[0048] **Ti:** Titanium is added to control the as-cast grain structure. It is known as a grain refiner. This element can also promote solid solution hardening leading to the required level of mechanical properties and it also has a favourable effect on service ductility and corrosion resistance. On the other hand, a maximum content of 0.10 wt.% of Ti is required to avoid the conditions of primary phase formation during vertical casting, which have a detrimental effect on the overall properties. According to the present invention, the Ti content is from 0.01 to 0.10 wt.% or to 0.09 wt.% or to 0.08 wt.% or to 0.07 wt.% or to 0.06 wt.% or to 0.05 wt.% or to 0.04 wt.%.

[0049] The content of other elements is less than 0.05 wt.% each and less than 0.15 wt.% in total. The other elements are typically unavoidable impurities or incidental elements added in very small quantity such as boron which can be typically added together with Ti in the form of TiB_2.

[0050] The rest of the alloy is composed of aluminium.

Use

[0051] The use of the 6xxx series aluminium sheets or plates or blanks according to the invention for automobile manufacturing is advantageous, in particular for the manufacture of a vehicle part, for example a body-in-white (BIW) part like a door or a bonnet. The method of manufacturing the BIW part therefore comprises the following successive steps:

- Supplying the strip or plate or blank according to the invention ;
- Stamping the strip or plate or blank;
- Painting, this step includes all the surface treatment, cataphoresis and painting operations known to the skilled person;
- Baking the paints, known to the skilled person as *"bake hardening"* from 15 to 30 minutes at a temperature from 170 to 200°C.

[0052] The present invention will be described in the following examples, which are for illustrative purpose and are not limitative.

EXAMPLES

[0053] The target of the material according to the present invention is to fulfil the specifications as shown in Table 1 hereinafter while having a sheared edge stretchability without any milling step that is improved over the current products.

[Table 1]

Property	Specification
Rp0.2 (30 days) (MPa)	> 97
UTS (MPa)	> 200
UE (%)	> 19%
TE (%)	> 22.5
r_{avg}	> 0.50
r_{10} 45°	≥ 0.3
Rp0.2 (180°C ; 20 min) (MPa)	> 155

Rp0.2 is the yield strength (also called the limit of elasticity) and is expressed in MPa.
UTS is the tensile strength (also called the ultimate tensile strength) and is expressed in MPa.
UE is the uniform elongation and is expressed in %.
TE is the total elongation and is expressed in %.
r_{avg} is the average Lankford coefficient. It corresponds to an average between the Lankford coefficients determined at 10% deformation, r_{10}, in the rolling direction (r_{10} RD), in the transverse direction (r_{10} TD) and 45° from the rolling direction (r_{10} 45°) according to the following formula:

$$[(r_{10}\,RD + 2{*}r_{10}\,45° + r_{10}\,TD)/4].$$

It is thus a figure without any unity.
r_{10} 45° is the Lankford coefficient (also called Lankford constant) determined at 10% deformation 45° from the rolling direction and it has not any unity.

[0054] All the preceeding characteristics are determined according to the standard EN ISO 6892-1, with three repetitions.

Example 1: Composition of the alloy

[0055] Two alloy compositions were compared: one of an existing product Ref-1 and one according to the present invention Alloy-1, which compositions are given in Table 2 hereinafter, in weight %.

[Table 2]

	Ref-1	Alloy-1
Si	0.69	1.33
Fe	0.15	0.12
Cu	0.01	0.01
Mn	0.08	0.08
Mg	0.56	0.32
Cr	0.01	0.01
Ni	0.01	-
Zn	0.01	0.01
Ti	0.04	0.04
V	0.02	-

[0056] All the properties as shown in Table 1 were measured for both alloy compositions. The sheared edge stretchability was also determined.

[0057] The sheared edge stretchability (E_{SE}) is defined as the elongation at 95% of the maximum force after the UTS whereby the width of half-dog-bone samples (see **Figure 1)** have been sheared using a 30% clearance (30% of the sheet thickness, eg: a 1mm thick sheet would yield a 0.3mm clearance) between upper and lower shearing tools (see reference numbers 3, 4 and 5 in **Figure 2).** As shown in **Figure 2,** the die used according to the present examples to shear the half-dog bone sample 6 consisted of a fixed lower shearing tool 3, a pad 2 to fix the sample 6, and a upper shearing tool 4 that translate up and down to shear the sample 6. In general, the shearing of a metal sheet consists in 3 stages A, B and C as illustrated in **Figure 2:**

- A: original sample 6;
- B: plastic deformation and penetration;
- C: fracture of the sample 6.

[0058] As is known in the art, the upper shearing tool 4 edge shape (sharpness), the lower shearing tool 3 edge shape (sharpness) and the clearance ((gap) between the lower shearing tool 3 and the upper shearing tool 4 influence the shearing process and ultimately affect the shearing edge quality.

[0059] The evaluation of E_{SE} is thus done via a tensile test in the presence of a sheared edge on a half-dog bone sample to evaluate the degredation in its ductility/formability due to the shearing process. The half-dog bone samples are single-sided tensile samples that are sheared on one side along the shear line 1 as illustrated in **Figure 1,** with the shearing die as illustrated in **Figure 2.** In the present examples, the clearance was 30% of the sample thickness. The side that was sheared is called the sheared edge.

[0060] Once the samples were sheared, they were then tested in traction until failure. A tensile test curve as shown in **Figure 3** was obtained for each half-dog bone sample, that allowed to evaluate E_{SE}. The tensile test for determining E_{SE} was done by following the standard ASTM E8 except for:

- the size of the sample, that was the one as shown in **Figure 1;**
- the number of repetitions: 10 to 30 instead of 3.

[0061] In **Figure 3,** the reference number 11 is the point of the curve corresponding to 95% of the maximum force after the UTS, as discussed in the definition of E_{SE} hereinabove, or to a 5% drop in the maximum force. E_{SE} 9 is the elongation corresponding to point 11 in the tensile test curve as shown in **Figure 3.** As it is a statistical process, 10 to 30 samples were tested, in each direction (rolling direction RD, transverse direction TD and 45° from rolling direction) when applicable, in order to obtain a statistically significant standard deviation (σ) and an average sheared edge stretchability (E_{SE}).σ thus corresponds to the standard deviation obtained with 10 to 30 repetitions.

[0062] The half-dog bone samples were obtained by the following process:

- casting a 6xxx alloy comprising, in wt.%, one of the alloys as described in Table 2;
- homogenizing at a temperature of about 550°C, then cooling, then preheating at a temperature of about 430°C;
- hot rolling until a thickness of 6.35 mm;
- cold rolling until a thickness of 0.9 mm (i.e. 85.8% cold reduction);
- solution heat treating at a temperature of about 560°C during about 35s;
- quenching with air at about 30°C/s until a temperature of about 60°C;
- natural pre-aging between 72 hours and 180 days;
- shearing a sample blank at dimensions 120mm x 20mm x sheet thickness;
- machining the blank to obtain the final dimensions of the half-dog bone sample a shown in **Figure 1;**
- shearing without any milling step.

[0063] The results of the mechanical properties, the sheared edge stretchability and the standard deviation σ, measured as explained above, are given in Table 3 hereinafter.

[Table 3]

Property	Ref-1			Alloy-1		
	RD	45°	TD	RD	45°	TD
Rp0.2 (30 days) (MPa)	123	120	115	119	113	114
UTS (MPa)	233	232	222	228	224	224

(continued)

Property	Ref-1			Alloy-1		
	RD	45°	TD	RD	45°	TD
UE (%)	20.5	23.0	21.5	21.5	27.0	22.5
r_{avg}				0.69		
r_{10}				0.33		
Rp0.2 (20 min ; 180°C) (MPa)	-	-	175	-	-	172
E_{SE} (%)	18.1	17.2	18.3	21.3	21.3	20.8
σ	± 1.2	± 1.2	± 1.2	± 1.4	± 1.2	± 1.1

[0064] TD means transverse direction, RD rolling direction and 45° is the angle compared to the rolling direction.

[0065] According to Table 1 and Table 3, the alloy according to the present invention Alloy-1 met all existing specifications and even showed improvement compared to the existing product Ref-1.

Example 2: Quenching conditions

[0066] The same Alloy-1 as described in Table 1 in Example 1 hereinabove was used following the same process route as in Example 1, except that three different quenching conditions were tested:

- quenching with water (1200°C/s) until a temperature of about 60°C; or
- quenching with water (600°C/s) until a temperature of about 60°C; or
- quenching with air (30°C/s) until a temperature of about 60°C.

[0067] Mechanical properties, sheared edge stretchability and the standard deviation σ were measured as described in Example 1 hereinbefore. The results obtained are given in Table 4 hereinafter.

[Table 4]

Property	Water Quenching						Air Quenching		
	1200°C/s			600°C/s			30°C/s		
	RD	45°	TD	RD	45°	TD	RD	45°	TD
Rp0.2 (30 days) (MPa)	109	102	104	108	103	104	106	98	102
UTS (MPa)	209	204	205	208	205	203	213	208	206
UE (%)	20.3	27.7	19.7	22.2	28.7	22.1	21.8	28.1	22.0
TE (%)	24.5	30.4	22.8	25.7	31.8	25.9	25.6	31.5	27.0
r_{avg}	0.53			0.54			0.53		
r_{10}	0.76	0.31	0.74	0.74	0.33	0.76	0.73	0.30	0.82
Rp0.2	-	-	194	-	-	193	-	-	182
(20 min ; 180°C) (MPa)									
E_{SE} (%)	22.4	24.9	22.5	22.0	24.7	22.6	21.4	23.2	21.1
σ	1.0	1.2	1.1	1.0	1.0	0.9	0.9	1.2	1.0

[0068] According to Table 4, water quenching seems to allow obtaining even better sheared edge stretchability than air quenching.

Claims

1. Process for producing a sheet or a plate or a blank, comprising the following successive steps:

(a) casting a 6xxx alloy comprising, in wt.%:

Si:	1.25-1.45
Fe:	≤ 0.30
Cu:	≤ 0.15
Mn:	0.01-0.15
Mg:	0.25-0.40
Cr:	≤ 0.03
Ni:	≤ 0.04
Zn:	≤ 0.15
Ti:	0.01-0.10

other elements: < 0.05 each and < 0.15 in total
rest aluminium;
(b) heat treating;
(c) hot rolling;
(d) cold rolling;
(e) optionally inter-annealing between hot rolling and cold rolling and/or during cold rolling and/or after cold rolling;
(f) solution heat treating;
(g) quenching;
(h) optionally pre-aging
(i) shearing without any milling step.

2. A process according to claim 1, wherein step (g) of quenching is a water quenching.

3. A process according to any one of the preceeding claims, wherein step (g) of quenching is done with a quenching speed up to 1200°C/s and at least 30°C/s, preferably at least 40°C/s, preferably more than 200°C/s, preferably more than 300°C/s.

4. A process according to any one of the preceeding claims, wherein the sheet temperature at the beginning of the quenching step is from 480 to 570°C and preferably, the sheet temperature at the end of the quenching step is from 50 to 160°C.

5. A process according to claim 2, wherein the pressure of the water used for the quenching step is at most 80 psi or 70 psi or 60 psi or 50 psi or 40 psi or 30 psi or 25 psi.

6. A process according to any one of the preceeding claims, wherein the Si content of the 6xxx alloy is 1.30 - 1.40 wt.%.

7. A process according to any one of the preceeding claims, wherein the Mg content of the 6xxx alloy is 0.30 - 0.35 wt.%.

8. A process according to any one of the preceeding claims, wherein the 6xxx alloy comprises, in wt.%:

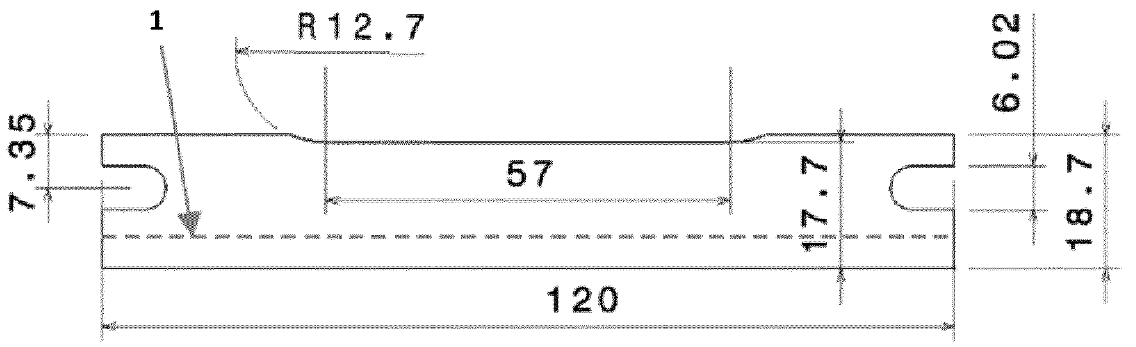
Si:	1.30 - 1.40
Fe:	0.10 - 0.20
Cu:	≤ 0.09
Mn:	0.05 - 0.10
Mg:	0.30 - 0.35
Cr:	≤ 0.02
Ni:	≤ 0.03
Zn:	≤ 0.10
Ti:	0.01 - 0.04

other elements: < 0.05 each and < 0.15 in total
rest aluminium.

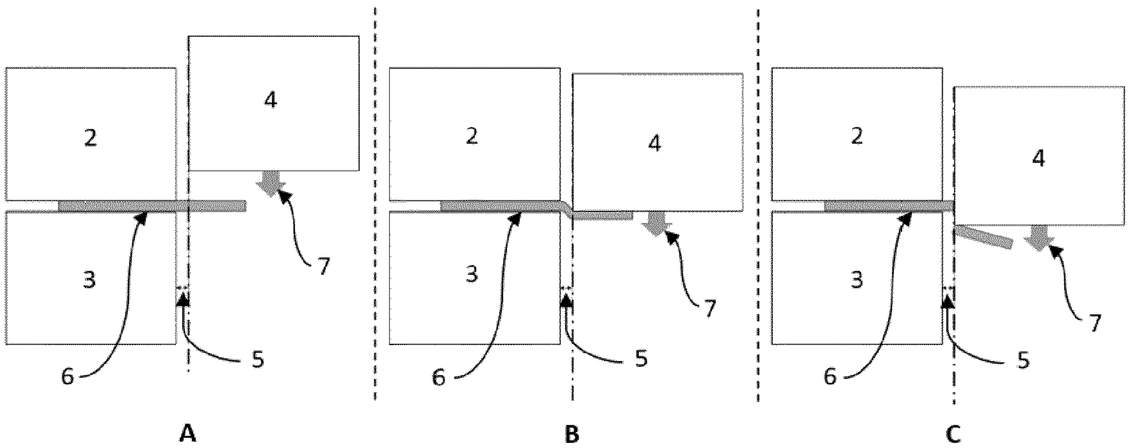
9. Sheet or plate or blank obtained according to the process of any one of the preceeding claims, **characterised in that** it has an improved sheared edge stretchability compared to non-milled previous sheets or plates or blanks.

10. Use of a sheet or plate or blank according to the preceeding claim to produce a vehicle part.

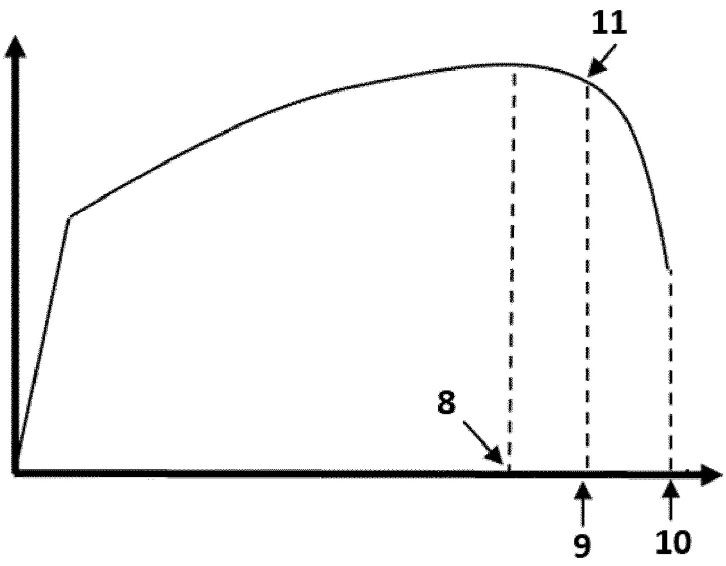
[Figure 1]



[Figure 2]



[Figure 3]



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EUROPEAN SEARCH REPORT

Application Number
EP 21 21 1696

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The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
The Hague	12 May 2022	Chebeleu, Alice

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