Innovation, Sciences et Développement économique Canada
Office de la Propriété Intellectuelle du Canada

Innovation, Science and Economic Development Canada
Canadian Intellectual Property Office

CA 3088915 C 2021/08/03

(11)(21) **3 088 915**

(12) BREVET CANADIEN CANADIAN PATENT

(13) **C**

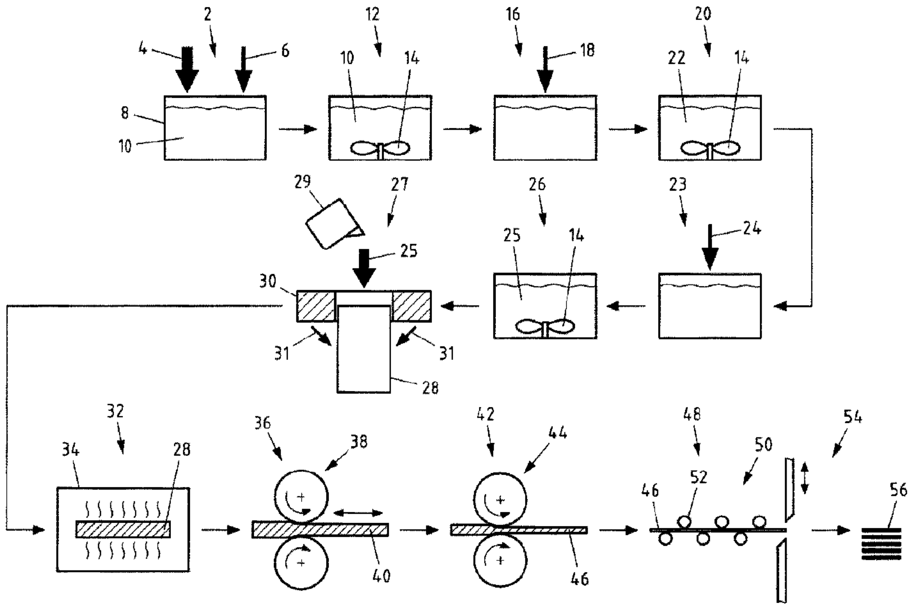
(86) **Date de dépôt PCT/PCT Filing Date:** 2019/01/15
(87) **Date publication PCT/PCT Publication Date:** 2019/07/25
(45) **Date de délivrance/Issue Date:** 2021/08/03
(85) **Entrée phase nationale/National Entry:** 2020/07/15
(86) **N° demande PCT/PCT Application No.:** EP 2019/050899
(87) **N° publication PCT/PCT Publication No.:** 2019/141666
(30) **Priorité/Priority:** 2018/01/16 (EP18151840.8)

(51) **Cl.Int./Int.Cl.** *C22C 21/06* (2006.01), *C22C 21/08* (2006.01)

(72) **Inventeurs/Inventors:**
DROSTE, WERNER, DE;
ENGLER, OLAF, DE;
KUHNKE, KATRIN, DE;
MILLER-JUPP, SIMON, GB;
ROSNER-KUHN, MICHAEL, DE;
PRITZLAFF, REINHARD, DE;
LENTZ, MARTIN CHRISTOPH, DE;
GODDARD, DAVID, GB

(73) **Propriétaire/Owner:**

(54) **Titre :** ALLIAGE D'ALUMINIUM, PROCEDE DE FABRICATION D'UN PRODUIT PLAT EN ALUMINIUM, PRODUIT PLAT EN ALUMINIUM ET SON APPLICATION
(54) **Title:** ALUMINIUM ALLOY, METHOD FOR PRODUCING AN ALUMINIUM FLAT PRODUCT, ALUMINIUM FLAT PRODUCT AND USE THEREOF



(57) **Abrégé/Abstract:**

An aluminium alloy is provided for superplastic aluminium flat products, wherein the aluminium alloy has the following composition: 0.03 wt.% ≤ Si ≤ 0.10 wt.%, Fe ≤ 0.4 wt.%, Cu ≤ 0.1 wt.%, 0.5 wt.% ≤ Mn ≤1.0 wt.%, 5.2 wt.% ≤ Mg ≤ 5.5 wt.%, 0.05 wt.% ≤ Cr ≤

Canada http://opic.gc.ca · Ottawa-Hull K1A 0C9 · http://cipo.gc.ca OPIC CIPO
OPIC · CIPO 191

(73) **Propriétaires(suite)/Owners(continued):** HYDRO ALUMINIUM ROLLED PRODUCTS GMBH, DE

(74) **Agent:** BORDEN LADNER GERVAIS LLP

(57) **Abrégé(suite)/Abstract(continued):**

0.25 wt.%, Zn ≤ 0.25 wt.%, Ti ≤ 0.20 wt.%, Na ≤ 2 ppm, unavoidable impurities individually ≤ 0.05 wt.%, in total ≤ 0.15 wt.%, remainder aluminium. A method is provided for producing an aluminium flat product, in particular a superplastic aluminium flat product, in which an aluminium melt is provided from the above-mentioned aluminium alloy, in which the aluminium melt is cast to form an ingot, in which the ingot is hot rolled to form a hot strip, in which the hot strip is cold rolled to form a cold strip, and in which the cold strip is levelled.

Abstract

An aluminium alloy is provided for superplastic aluminium flat products, wherein the aluminium alloy has the following composition: 0.03 wt.% ≤ Si ≤ 0.10 wt.%, Fe ≤ 0.4 wt.%, Cu ≤ 0.1 wt.%, 0.5 wt.%≤ Mn ≤ 1.0 wt.%, 5.2 wt.% ≤ Mg ≤ 5.5 wt.%, 0.05 wt.% ≤Cr ≤ 0.25 wt.%, Zn ≤ 0.25 wt.%, Ti≤ 0.20 wt.%, Na ≤ 2 ppm, unavoidable impurities individually ≤ 0.05 wt.%, in total ≤ 0.15 wt.%, remainder aluminium. A method is provided for producing an aluminium flat product, in particular a superplastic aluminium flat product, in which an aluminium melt is provided from the above-mentioned aluminium alloy, in which the aluminium melt is cast to form an ingot, in which the ingot is hot rolled to form a hot strip, in which the hot strip is cold rolled to form a cold strip, and in which the cold strip is levelled.

Aluminium alloy, method for producing an aluminium flat product, aluminium flat product and use thereof

The invention relates to an aluminium alloy for superplastic aluminium flat products, a method for producing a superplastic aluminium flat product, and a superplastic aluminium flat product and its use.

In recent years, the production of components by superplastic forming has become increasingly important. In superplastic forming, a so-called superplastic starting material suitable for this process is heated to a forming temperature of typically 450-520 °C in the case of aluminium alloys and shaped with high degrees of forming of, in some cases, several 100 %. By means of superplastic forming it is possible to produce even complex workpieces in only one forming step and with high dimensional accuracy.

A typical method of superplastic forming is, for example, so-called blow moulding, in which a sheet-like starting material is forced by pressurising with a fluid, in particular a gas, into a die having a negative shape to the shape to be produced. While superplastic forming is conventionally carried out at low strain rates of the order of magnitude of $10^{-4}s^{-1}$, recent developments go in the direction of high speed superplastic forming with very high strain rates.

The alloy AA 5083, for example, is known as a superplastic material, which can be used to produce products by means of superplastic forming.

Furthermore, in the article "Chronicling the development of a high strength 5xxx-based superplastic aluminium alloy" by SP Miller-Jupp, Mat. Sci. For. 838-839 (2016) pp. 208-213, the development of an AA 5456-based superplastic alloy is described.

The object of the present invention is to provide an aluminium alloy, a method for producing an aluminium flat product and an aluminium flat product having improved properties in superplastic forming.

This object is achieved according to the invention by an aluminium alloy, in particular for superplastic aluminium flat products, wherein the aluminium alloy has the following composition:

Si ≤ 0.4 wt.%,
Fe ≤ 0.4 wt.%,
Cu ≤ 0.1 wt.%,
0.5 wt.% ≤ Mn ≤ 1.0 wt%,
4.7 wt.% ≤ Mg ≤ 5.5 wt.%,
0.05 wt.% ≤ Cr ≤ 0.25 wt.%,
Zn ≤ 0.25 wt.%,
Ti ≤ 0.20 wt.%,

unavoidable impurities individually ≤ 0.05%, in total ≤ 0.15%, the remainder aluminium. The aluminium alloy can be used in particular to produce an aluminium product by superplastic forming of an aluminium flat product from the aluminium alloy.

The Na content of the aluminium alloy is preferably max. 2 ppm (i.e. max 0.0002 wt.%), more preferably max. 1.4 ppm, in particular max. 1.0 ppm. It has been found that the sodium content in the aluminium alloy must be kept extremely low, since otherwise edge tearing may occur during hot rolling of the ingot. This is particularly the case if the aluminium alloy has a high Mg content of 5.2 wt. % or more. In order to achieve the low aforementioned Na contents, a chlorine treatment of the melt can, for example, be carried out.

The aforementioned object is furthermore achieved according to the invention by a method for producing an aluminium flat product, in particular a superplastic aluminium flat product, in which an aluminium melt is provided from the aforementioned aluminium alloy, in which the aluminium melt is cast into an ingot, in which the ingot is hot-rolled to form a hot strip, in which the hot strip is cold-rolled to form a cold strip, and in which the cold strip is levelled.

Furthermore, the aforementioned object is achieved according to the invention by an aluminium flat product, in particular a superplastic aluminium flat product, which can be produced or is produced by the afore-described method.

The aforementioned object is furthermore achieved according to the invention by the use of the aforedescribed aluminium flat product for producing an aluminium product by superplastic forming of the aluminium flat product, in particular by means of blow moulding.

It has been found that a superplastic aluminium flat product that is particularly well suited for superplastic forming can be produced by the aforedescribed method and the aforedescribed aluminium alloy. In particular, a heat treatment of the aluminium flat product during the heating to the forming temperature for superplastic forming leads to the formation of a fine microstructure, so that high degrees of forming without defects can be achieved. The forming temperature in the superplastic forming is preferably in the range of 450 °C to 520 °C. The total elongation during superplastic forming is preferably at least 100%.

As a superplastic aluminium flat product is understood in particular an aluminium flat product that has a strain rate sensitivity m of at least 0.3, where $m = \frac{d\ln(\sigma)}{d\ln(\dot{\varepsilon})}$, σ is the yield strength, and $\dot{\varepsilon}$ is the strain rate. A strain rate sensitivity $m \geq 0.3$ is typically achieved only in a certain strain rate range, e.g. in the range of $10^{-4}\,s^{-1}$ to $10^{-3}\,s^{-1}$, in which the aluminium flat product is superplastic.

The method is used to produce an aluminium flat product. The aluminium flat product may in particular be a strip or a sheet.

In the method an aluminium melt of the aforedescribed aluminium alloy is provided. The provision of the aluminium melt is performed in particular by adjusting the composition of the aforedescribed aluminium alloy in an aluminium furnace by melting primary aluminium, optionally scrap metal and other additives.

The produced molten aluminium is cast in the method into an ingot, especially by DC (direct chill) casting. The ingot is preheated for the hot rolling. Alternatively, a separate ingot homogenisation may be carried out prior to preheating, in order to obtain a more uniform structure.

The ingot is then hot rolled to form a hot strip, preferably at a temperature in the range of 280 °C to 550 °C, in particular a hot strip temperature (i.e. at hot strip thickness) in the range of 280 °C to 350 °C is set. The hot strip is then cold-rolled to form a cold strip.

After cold rolling the cold strip is levelled. During levelling of the cold strip, the cold strip is fed through a plurality of mutually offset levelling rollers to achieve a flatness suitable for the superplastic forming.

Various embodiments of the aluminium alloy, the method, the aluminium flat product and its use are described hereinafter, wherein the individual embodiments apply in each case individually to the aluminium alloy, the method, the aluminium flat product and the use. Furthermore, the individual embodiments can also be combined with each other.

In one embodiment the aluminium melt has a Si content of 0.03-0.10 wt.% and/or an Fe content of 0.05-0.15 wt.%. Silicon and iron are dispersoid formers and are therefore basically advantageous for achieving a fine grain structure for the superplastic forming. However, it has been found that silicon and iron can form coarse intermetallic phases, in particular AlSiFeMn phases, with a size of more than 20 μm or even more than 30 μm, which lead to pore formation during the superplastic forming and consequently in particular adversely affect the mechanical properties of the aluminium product produced from the aluminium flat product. The Si content of the aluminium alloy is therefore preferably limited to 0.10 wt.% and the Fe content of the aluminium alloy preferably to 0.15 wt.%.

A silicon content below 0.03 wt.% or an iron content below 0.05 wt.% can be achieved only at great expense in industrial aluminium alloys, as a result of which the production costs of the aluminium flat product and of the aluminium product produced therefrom would be greatly increased. At the same time it was found that with silicon and iron contents in the aforementioned ranges, a fine grain structure for the superplastic forming can be achieved with still acceptably low pore formation during superplastic forming.

In a further embodiment the Cu content of the aluminium alloy is at most 0.05 wt.%. In this way the corrosion resistance of the alloy is not adversely affected. Furthermore, due to the low Cu content the yield strength at elevated temperatures is kept low, which has a positive effect on the superplastic forming.

In a further embodiment the aluminium alloy has an Mn content of 0.7 wt.% to 1.0 wt.%. It has been found that manganese in the aluminium alloy acts as a strong dispersoid-forming agent, so that a large number or density of fine dispersoids in the aluminium flat product is produced by a relatively high content of manganese of at least 0.7 wt.%. It has been found that these manganese dspersoids hinder grain growth, so that after the superplastic forming of an aluminium flat product produced from the aluminium alloy a fine-grain structure is present despite the high forming temperatures.

In a further embodiment the aluminium alloy has a magnesium content of 5.2 wt.% to 5.5 wt.%. It has been found that a stabilisation of the grain sizes can be achieved by an increased magnesium content of at least 5.2 wt. %, thereby further improving the superplastic properties of the aluminium flat product. Furthermore, an improved strength combined with still good rollability is achieved by the increased magnesium content in the specified range. In particular, the magnesium content in this range improves the strength of an aluminium product produced from the aluminium flat product after superplastic forming.

In a further embodiment the aluminium alloy has a zinc content of at most 0.06 wt.% and/or a titanium content in the range of 0.015-0.03 wt.%. It has been found that a zinc content of up to 0.06 wt.% and a titanium content of up to 0.03 wt.% do not adversely affect the properties for the superplastic forming of the aluminium flat product. A titanium content is even desirable up to a limited extent as a grain refiner, in particular with a content of at least 0.015 wt.%.

In a further embodiment the aluminium alloy has a boron content of at most 50 ppm (i.e. at most 0.005 wt.%) and/or a calcium content of at most 15 ppm (i.e. at most 0.0015 wt.%) and/or a lithium content of at most 15 ppm (i.e. at most 0.0015 wt.%). Titanium borides act as a grain refiner during casting and thus have a beneficial effect on the rolling process and also the homogeneity of the product, wherein a boron content of at most 50 ppm does not adversely affect the properties for the superplastic forming of the aluminium flat product. Calcium and lithium, like sodium, promote the formation of edge cracks and thereby adversely affect the rollability, especially during hot rolling.

In a further embodiment of the method the aluminium melt is provided by melting together a preliminary aluminium melt with additives so as to achieve the composition of the molten aluminium to be provided, in particular the aforedescribed composition, wherein at least two of the alloying elements Cr, Mn and Ti, preferably all three alloying elements Cr, Mn and Ti, are charged separately from one another.

In order to produce an aluminium melt with a specific alloy composition from starting material, for example primary aluminium and/or aluminium scrap, the starting material is first melted in a melting furnace to form a preliminary aluminium melt and then - typically according to a pre-calculated charge make-up – is melted together with suitable additives, in particular of alloying metal, master alloys, scrap and/or suitable additives, so as to achieve the desired alloy composition.

It has been found that with the simultaneous addition of several of the dispersoid formers Cr, Mn and Ti, coarse particles, in particular Al(Mn,Fe,Cr)Si particles, can formed, which may furthermore contain Mg, Ti and V, which accordingly lead to coarse particles with a size of more than 20 μm or even more than 30 μm in the aluminium flat product, so that defects and/or increased pore formation may occur in the superplastic forming of the aluminium flat product, which can adversely affect the mechanical properties of the aluminium product produced from the aluminium flat product.

By charging at least two of the alloying elements Cr, Mn and Ti, preferably all three alloying elements Cr, Mn and Ti, separately from one another, the formation of these coarse particles can be prevented. Separately charging two alloying elements is understood to mean that the additives to be added in order to adjust the desired content of one of the two alloying elements and the additives to be added in order to adjust the desired content of the other of the two alloying elements, are added at different times to the preliminary aluminium melt. If for example titanium boride rods are added to the preliminary aluminium melt in order to adjust the Mn content and pieces of an Mn-containing master alloy are added in order to adjust the Ti content, then the titanium boride rods and the master alloy pieces are preferably melted together with the preliminary aluminium melt at different times.

Preferably, a mixing of the aluminium melt in the melting furnace, in particular by means of stirring, takes place between the addition of the additives for a first of the alloying elements Cr, Mn and Ti and the addition of the additives for a second of the alloying elements Cr, Mn and Ti. Preferably, after addition of the additives for the first of the alloying elements Cr, Mn and Ti the preliminary aluminium melt is mixed in the melting furnace until an aluminium melt having a homogeneous composition has been obtained. The homogeneity of the preliminary aluminium melt in the melting furnace is sufficient if the chemical analysis of the melt matches the charge make-up for the first of the alloying elements Cr, Mn and Ti. The sampling to determine the homogeneity preferably takes place in three different areas of the melting furnace. In the above example a homogenisation of the preliminary aluminium melt by stirring is accordingly preferably carried out after the addition of titanium boride and before adding the pieces of the master alloy, until a matching Ti content is achieved in three different regions of the melting furnace.

When a first of the alloying elements Cr and Mn and a second of the alloying elements Cr and Mn (i.e. in each case the respective other alloying element) are charged separately, the content of the second of the alloying elements Cr and Mn during the charging of the first of the alloying elements Cr and Mn in the preliminary aluminium melt is preferably at most 0.05 wt. %. If for example Mn is charged first followed by Cr, the Cr content in the aluminium melt during the charging of Mn is preferably at most 0.05 wt. %. This has proved to be advantageous to counteract the formation of coarse particles.

The temperature of the preliminary molten aluminium during the charging of Cr is preferably more than 740 °C, especially at least 750 °C. In this way Cr can be distributed very uniformly in the aluminium melt.

Mg is preferably charged only after Cr, Mn and/or Ti, preferably as the last element. Furthermore, the temperature of the preliminary molten aluminium during the charging of Mg is preferably less than 740° C, in particular at most 730° C. In this way the desired Mg content can be better adjusted since the Mg content can be reduced at elevated temperatures or premature addition by melting loss.

In a further embodiment a scrap content of less than 5 wt. %, preferably less than 1 wt.%, in particular less than 0.1 wt.% is used to provide the aluminium melt. It has been found that even small amounts of certain accompanying elements and impurities from the scrap fraction can lead to the formation of large particles in the aluminium melt and in the aluminium flat product produced therefrom, which, being nucleating agents, contribute to pore formation and thus to damage during superplastic forming. The scrap content in the production of the aluminium melt is therefore preferably kept as low as possible or the addition of scrap is preferably completely dispensed with. Accordingly, the aluminium melt is preferably produced in particular in that essentially primary aluminium is melted, optionally with additives, to obtain the desired composition.

In a further embodiment the degree of rolling in cold rolling in total is generally in the range of 70% to 80%. In a corresponding embodiment, the aluminium flat product is in the H18 state, preferably in the H19 state, according to DIN EN 515. Due to the high degree of forming in cold rolling, a high dislocation density is introduced into the material. This results in that the material of the aluminium flat product when heated for the superplastic forming spontaneously recrystallises with a very fine microstructure, which is advantageous for superplastic forming.

The cold rolling is carried out in particular without intermediate annealing. If an intermediate annealing is however performed, the aforementioned degree of rolling in cold rolling refers to the total degree of rolling after the last intermediate annealing.

The final thickness of the cold strip is preferably in the range of 1 - 3 mm. In order to achieve the advantageous high degree of rolling during cold rolling, the hot strip thickness is preferably in the range of 3 to 15 mm, in particular in the range of 4 to 12 mm.

The degree of rolling in the last cold rolling pass is preferably less than 33%. The H18 and H19 states can thus be produced without having any adverse effects on the superplastic forming. In addition, surface defects, in particular chatter marks, are avoided by limiting the degree of rolling in the last pass.

In a further embodiment, the levelling of the cold strip is performed by levelling rollers with a diameter of more than 60 mm. It has been found that by using larger levelling rollers undesirable surface defects after the superplastic forming can be avoided.

In a further embodiment, the cold strip is cut into sheets after levelling without intermediate coiling. In this way, the flatness of the strip achieved by levelling is not made worse again, so that a second levelling process can be dispensed with. This is particularly advantageous if the cold strip was levelled with levelling rollers with a diameter of more than 60 mm and thus with a reduction or even avoidance of surface defects. The possible introduction of surface defects in a second, possibly customer-side levelling process, can be avoided in this way.

The strip temperature between the cold rolling and the cutting into sheets is kept in the range below 200 °C, preferably below 50 °C, in particular at room temperature of, for example, about 20 °C. In this way a premature recovery by reducing the dislocations introduced by the cold rolling in the aluminium flat product is avoided, so that a strong recrystallisation effect with a fine microstructure can occur only when heating the sheet for the superplastic forming.

In a further embodiment the aluminium flat product after a heat treatment for 30 minutes at 500 °C has a yield strength $R_{p0.2}$ of at least 160 MPa, in particular at least 170 MPa, and a tensile strength R_m of at least 310 MPa, in particular at least 320 MPa. $R_{p0,2}$ and R_m are each to be determined in the tensile test according to DIN EN ISO 6892-1:2017. Additionally or alternatively, the aluminium flat product preferably has a porosity of less than 1.5%, in particular less than 1%, after a superplastic forming at a forming temperature of 515 °C, a strain rate of $2.5 \times 10^{-4}\ s^{-1}$ and a total elongation of 100%.

It has been found that, by means of the method described above, in particular by an Fe content of at most 0.15 wt.% and an Si content of at most 0.10 wt.%, and also by the preferably separate charging of Mn, Cr and preferably also Ti, the formation of coarse particles in the aluminium flat product can be avoided, which lead to pore formation during the superplastic forming. Aluminium flat products can thereby be produced with the method, which have a very low porosity after superplastic forming. The low porosity after superplastic forming, in particular combined with an Mn content of at least 0.7 wt.% and a Mg content of at least 5.2 wt.%, leads moreover to very good mechanical properties of the aluminium flat product after a heat treatment caused by the typical forming temperatures of a superplastic forming. Aluminium products with very low porosity and very good mechanical properties can thus be produced from the aluminium flat products by superplastic forming.

In a further embodiment, the aluminium flat product has after a heat treatment at 500 °C for 5 minutes a mean grain diameter of at most 15 μm. The mean grain diameters are to be determined according to ASTM E112. It has been found that an aluminium flat product can be produced by the method described above, which after a short heat treatment by setting a typical forming temperature for the superplastic forming has a correspondingly fine microstructure. This is achieved especially at the preferred Mg content of at least 5.2 wt.%, the preferred Cr content between 0.12 and 0.18 wt.%, the preferred Si content of at most 0.10 wt. %, the preferred Fe content of at most 0.05 wt.%, by the separate charging of Mn, Cr and/or Ti and by the preferred H19 state of the aluminium flat product.

In a further embodiment, the superplastic forming is carried out with a strain rate of more than 10^{-3} s^{-1}, in particular of at least 10^{-2} s^{-1}. Typically, the superplastic forming occurs at strain rates in the range of 10^{-4} to 10^{-3} s^{-1}. It has been found that the aluminium flat products produced by the described method can be superplastically formed at significantly higher strain rates without the material constricting during forming. This is achieved in particular by a strain rate sensitivity $m \geq 0.3$ even at higher strain rates of above 10^{-3} s^{-1}. In a corresponding embodiment the aluminium flat product at a strain rate of more than 10^{-3} s^{-1}, in particular of at least 10^{-2} s^{-1}, for example at least up to 5×10^{-2} s^{-1}, has a strain rate sensitivity m of at least 0.3, determined by means of the incremental strain rate tests according to Lederich (Lederich et al. "Superplastic Formability Testing" Journal of Metals Vol. 34 Issue 8, pp. 16 to 20, 1982) using the strain rates 5×10^{-4} s^{-1}, 1×10^{-4} s^{-1}, 5×10^{-4} s^{-1}, 1×10^{-3} s^{-1}, 5×10^{-3} s^{-1}, 1×10^{-2} s^{-1}, 5×10^{-4} s^{-1} and 1×10^{-1} s^{-1} as well as an ISO 20032:2007 compliant testing machine and sample geometry. The higher strain rates in superplastic forming allow shorter forming times and therefore higher forming cycles, whereby production costs can be reduced.

Further features and advantages of the method, of the aluminium flat product and its use emerge from the following description of exemplary embodiments, wherein reference is made to the respective drawing.

In the drawing

Fig. 1	shows an exemplary embodiment of the method,
Fig. 2	shows an exemplary embodiment of the use of the aluminium flat product produced by the method,
Fig. 3	shows a second exemplary embodiment for the use of the aluminium flat product produced by the method of Fig. 1,
Fig. 4	shows a micrograph of an aluminium flat product with coarse Cr-containing particles,
Figs. 5-7	show micrographs of aluminium flat products before a heat treatment (Fig. 4), after 1 minute (Fig. 5) and after 60 minutes' heat treatment at 500 °C (Fig. 6)
Fig. 8	shows a diagram with experimental results for the forming temperature-dependent strain rate sensitivity m, and
Figs. 9-10	show diagrams with test results for the yield strength $R_{p0,2}$ (Fig. 9) and tensile strength R_m (Fig. 10) at room temperature after 30 minutes' heat treatment at various temperatures.

Fig. 1 shows an exemplary embodiment of the method for producing a flat aluminium product in a schematic representation.

In a first step 2 of the method a preliminary aluminium melt is firstly prepared, in which primary metal 4 and alloying additives 6 are added to an aluminium melting furnace 8 and melted there. The use of aluminium scrap is preferably largely dispensed with for the production of the preliminary aluminium melt 10.

In the second step 12 the preliminary aluminium melt 10 is homogenised in the melting furnace 8, which is illustrated in Fig. 1 by the schematically illustrated stirrer 14.

The homogenised preliminary aluminium melt 10 in the aluminium melting furnace 8 has the following composition:

0.03 wt.% ≤ Si ≤ 0.10 wt.%,
0.05 wt.% ≤ Fe ≦ 0.15 wt.%,
Cu ≤ 0.05 wt.%,
0.7 wt.% ≤ Mn ≤ 1.0 wt.%,
Mg ≤ 1 wt.%,
Cr ≤ 0.05 wt.%,
Zn ≤ 0.06 wt.%,
0.015 wt.% ≤ Ti ≤ 0.030%,
Na ≤ 1.0 ppm,

unavoidable impurities individually up to a maximum of 0.05 wt.%, in total not more than 0.15 wt.%, remainder aluminium. The low Na content can be achieved, for example, by a chlorine treatment of the melt.

In the third step 16 chromium-containing material 18 is added to the preliminary aluminium melt 10 and the resulting (still preliminary) aluminium melt 22 is in turn homogenised in the fourth step 20 (as illustrated by the stirrer 14). The homogenised aluminium melt 22 has the following composition:

0.03 wt.% ≤ Si ≤ 0.10 wt.%,
0.05 wt.% ≤ Fe ≤ 0.15 wt.%,
Cu ≤ 0.05 wt.%,
0.7 wt.% ≤ Mn ≤ 1.0 wt.%,

Mg ≤ 1 wt.%,
0.12 wt.% ≤ Cr ≤ 0.18 wt.%,
Zn ≤ 0.06 wt.%,
0.015 wt.% ≤ Ti ≤ 0.030%,
Na ≤ 1.0 ppm,

unavoidable impurities individually up to a maximum of 0.05 wt.%, in total not more than 0.15 wt.%, remainder aluminium.

A separate charging of Mn or Ti and Cr is achieved with the described steps 2, 12 and 16. In the first step 2 the Mn content and the Ti content are firstly adjusted, while the material 18 to be added for the adjustment of the desired Cr content is added separately only in the third step 16 after a homogenisation of the preliminary melt 10 in step 12. In a similar way Ti can also be charged separately from Mn. In addition to the content of Mn and Ti, in the present example the contents of further alloying elements (in particular Si and Fe) are also adjusted in the first step 2. The charging of these alloying elements (in the present example, in particular Mn, Ti, Si and Fe) can be carried out simultaneously or also separately from one another.

In the fifth step 23 magnesium-containing material 24 is added to the preliminary aluminium melt 22, and the resulting aluminium melt 25 is in turn homogenised in the sixth step 26 (as illustrated by the stirrer 14). The homogenised aluminium melt 25 has the following composition:

0.03 wt.% ≤ Si ≤ 0.10 wt.%,
0.05 wt.% ≤ Fe ≤ 0.15 wt.%,
Cu ≤ 0.05 wt.%,
0.7 wt.% ≤ Min ≤ 1.0 wt.%,
5.2 wt.% ≤ Mg ≤ 5.5 wt.%,
0.12 wt.% ≤ Cr ≤ 0.18 wt.%,
Zn ≤ 0.06 wt.%,
0.015 wt.% ≤ Ti ≤ 0.030%,
Na ≤ 1.0 ppm,

unavoidable impurities individually up to a maximum of 0.05 wt.%, in total not more than 0.15 wt.%, remainder aluminium.

In this way, Mg is charged only after Mn/Ti and Cr, preferably as the last alloying element of the aluminium melt, in order to prevent the melting loss of Mg. To this end the temperature of the aluminium melt during the charging of Mg is also preferably less than 740° C, in particular at most 730° C. On the other hand, the temperature of the aluminium melt when charging Cr is preferably more than 740 °C, in particular at least 750 °C, in order to disperse Cr uniformly in the aluminium melt.

The aluminium melt 25 is cast in the following step 27 by direct chill casting into an ingot 28. To this end the aluminium melt 25 is poured, for example from a crucible 29, into a cooled and downwardly open frame mould 30 and solidified by spraying with water 31, resulting in the formation of the ingot 28.

In the following step 32 the ingot 28 undergoes ingot homogenisation and/or ingot preheating in a homogenising furnace 34 and in the following step 36 is hot rolled in a reversing hot rolling stand 38 for example, to form the hot strip 40, preferably at a temperature in the range of 280 °C to 550 °C, wherein in particular a hot strip temperature of 280 °C to 350 °C is adjusted. Due to the low Na content of the aluminium alloy of the ingot 28 no edge cracks are formed during hot rolling, despite the high Mg content.

In the following step 42 the hot strip 40 is cold rolled in multiple passes without intermediate annealing on one or more cold rolling stands 44, so that finally a cold strip 46 with a final thickness in the range of 1 to 3 mm is formed. The overall degree of rolling in the cold rolling is at least 70%, the degree of rolling in the last pass being less than 33%.

In the following step 48 the cold strip 46 is guided through a levelling system 50 with multiple levelling rollers 52 arranged offset to one another and is thereby levelled. The levelling rollers 52 each have a diameter of ≥ 60 mm, so that the formation of surface defects is avoided during levelling. After levelling, the cold-rolled strip 46 is cut directly into sheets 56 by means of a cutting device 54, without an intermediate coiling to a coil. This in turn avoids a unilateral buckling or elongation of the cold strip 46.

The aluminium sheets 56 produced by the method described in Fig. 1 are particularly well suited for further use in a superplastic forming process.

Fig. 2 shows an embodiment for a use of an aluminium sheet 56 produced with the method of Fig. 1 for producing a component 66 by means of superplastic forming.

In a first step 68 the aluminium sheet 56 is heated to a temperature in the range of 450 °C to 520 °C. The heating can be carried out for example as exemplified in Fig. 2, in a chamber furnace or a continuous furnace 70. Additionally or alternatively, the heating of the aluminium sheet 56 can also take place directly in a forming tool 78 for forming the aluminium sheet 56. In this case a separate furnace 70 can in particular be dispensed with.

Owing to the high dislocation density introduced into the material during the cold rolling step 42 of Fig. 1, when heating the aluminium sheet 56, for example in the furnace 70 or in the tool 78, a spontaneous recrystallisation of the aluminium sheet 56 occurs with formation of a very fine microstructure, which has an advantageous effect on the subsequent superplastic forming. In contrast to a chamber furnace, in particular the heating in the tool or in the continuous furnace favoured the superplastic forming, since the transfer and residence times during which the material is exposed to high (forming) temperatures are minimised, and grain growth before the actual forming is thereby further minimised.

In a second step 72 the aluminium sheet 56 is arranged between a first die half 74 and a second die half 76 of the forming tool 78 for the superplastic forming, unless this has already happened beforehand for heating the aluminium sheet 56 in the forming tool 78. The first die half 74 has in Fig. 2 by way of example a concavity 80 and the second die half 76 has a bulge 82 corresponding thereto. However, the two die halves 74, 76 may instead also have more complex contours for producing a more complex shaped component.

In the next step 84 the two die halves 74, 76 are brought together, wherein the aluminium sheet 56 is superplastically formed. In particular, the degree of forming of the aluminium sheet 56 is locally in part 100% or more. On account of the good properties of the aluminium sheet 56 for the superplastic forming, in particular the fine and uniform microstructure, the aluminium sheet 56 does not constrict or crack despite the high degree of forming. After the two die halves 74, 76 have been separated a damage-free finished component 66 can thus be removed from the forming die 78 in the last step 86. In addition, the component 66 produced in this way also has a high surface quality without noticeable surface defects.

The properties of the aluminium sheet 56 enable the superplastic forming to be carried out very quickly. In particular, the bringing together of the two die halves 74, 76 can be effected within a few minutes, preferably in at most 5 minutes. The production time of the component 66 can thus be shortened and the cycle rate of the forming operations can be increased.

Fig. 3 shows a further exemplary embodiment for the use of an aluminium sheet 56' produced according to the method of Fig. 1 by means of superplastic forming.

In the first step 90 of the method an aluminium sheet 56', for example as illustrated by way of example in Fig. 3, is heated in a chamber furnace, a continuous furnace or a furnace of other type of construction to a temperature in the range of 450 °C and 520 °C, so that a fine grain distribution is formed. Additionally or alternatively, the heating can also take place directly in a forming tool 98.

In contrast to heating in the chamber furnace, heating in the tool or in the continuous furnace favours the superplastic forming since the transfer and residence times during which the material is exposed to high (forming) temperatures is minimised, thereby further minimising grain growth before the actual forming.

The aluminium sheet 56' is then positioned in step 92 between a first tool half 94 and a second tool half 96 of the forming tool 98 for the blow moulding, unless the aluminium sheet 56' has not already been arranged there for heating in the forming tool 98. The first tool half 94 has by way of example a concavity 100 corresponding to the target shape of the component to be produced. The illustrated shape of the first tool half 94 is merely by way of example and can be significantly more complex in practice. In the second tool half 96 a channel 102 is provided for blowing in a gas.

In the next step 104 the first and second tool halves 94, 96 are brought together and a gas 106 is blown at a pressure of for example 2 bar through the channel 102 in the region of the concavity 100 against the aluminium sheet 56', so that the aluminium sheet 56' is superplastically formed until it abuts the contour of the concavity 100. The degree of forming of the aluminium sheet 56' is locally in part 100% or more.

Because of the good properties of the aluminium sheet 56' for superplastic forming, in particular the fine and uniform microstructure, there is no constriction or tearing of the aluminium sheet 56' despite the high degree of forming. After the two mould halves 94, 96 have been separated, a damage-free finished component 110 can thus be taken out from the forming tool 98 in the last step 108. Furthermore, the component 110 produced in this way also has a high surface quality without conspicuous surface defects.

The properties of the aluminium sheet 56' enable the superplastic forming to be carried out very quickly. In particular, the gas 106 can be introduced at such a pressure through the channel 102 that the aluminium sheet 56' adopts the contour of the concavity 100 within a few minutes, preferably in at most 5 minutes. The production time of the component 110 can thus be shortened and the cycle rate of the forming operations can be increased.

In experiments, the formation of coarse particles in the aluminium melt was investigated depending on the charging of the dispersoid formers Cr, Mn and Ti.

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Na	B	Ca	Li	Al
0.060	0.126	0.001	0.576	4.282	0.185	0.004	0.017	<0.0001	0.001	0.0001	<0.0001	remainder

Table 1 (all data in wt.%)

For this purpose an aluminium melt A of the composition mentioned in Table 1 was first produced by melting primary aluminium in an aluminium melting furnace and simultaneously adding to it additives to achieve the desired Mn, Mg and Cr contents. Furthermore, an aluminium melt B of the same composition was produced, wherein Mn and Cr were charged separately, i.e., the Cr-containing additives to achieve the desired Cr content were added only after adjusting the desired Mn content and then homogenising the aluminium melt by stirring. The Cr content in the preliminary molten aluminium during the adjustment of the desired Mn content and during the subsequent homogenisation of the melt was thereby less than 0.05 wt.%, and was only later adjusted to the target value.

From each of the two aluminium melts A and B produced in different ways, ingots were cast and strips were produced by hot and cold rolling. The strips exhibited coarse particles both on the surface and in the interior, the composition of which was analysed by WDX analysis (wavelength dispersive X-ray spectroscopy). The following Table 2 shows the results of the WDX analysis on six different coarse particles (Nos. 1-6) of a strip from the aluminium melt A, of which the particles Nos. 1-4 were on the surface and the particles 5 and 6 were in the interior of the strip:

Particle No.	Mg	Al	Ti	Cr	Mn	Fe
1	607	58061	354	5232	2909	223
2	5890	57001	3339	4806	3086	280
3	7729	51707	185	4339	1356	--
4	7194	54343	403	4607	1167	--
5	445	58683	313	5020	3342	300

6	499	57399	332	5084	3089	240

Table 2

The numbers given in Table 2 are in each case pulse numbers of the WDX analysis for the respective elements. The numbers are approximately proportional to the content of the elements in the respective particle.

In addition, a microsection was prepared from a piece of the strip produced from the aluminium melt A. Fig. 4 shows an image of this polished and barked microsection. The micrograph clearly shows a coarse Cr-containing phase. The phase has a size of 46 μm × 210 μm in the microsection.

The aforedescribed WDX analyses show that the strips from the aluminium melt A had significant fractions of high-melting and sparingly soluble Cr-containing phases, in some cases also with certain proportions of Ti and Mg. Such phases (cf. Fig. 4) re-dissolve – once formed – only with difficulty and form coarse, brittle particles in the strip, which adversely affect the superplastic properties of the strip or sheet produced therefrom.

The strips from the aluminium melt B exhibited practically no coarse particles or phases, i.e. only very fine but practically no coarse Al(Mn,Fe,Cr)Si phases have formed owing to the separate charging of Mn and Cr in the melt.

The investigated alloy with the composition of Table 1 has a lower Mg content than is envisaged according to the present teaching. For alloys with a Mg content of 5 wt.-% and otherwise identical composition as in Table 1 similar results are found however, with the formation of coarse Cr-containing phases with co-charging of the alloying elements Mn and Cr and only slight or in some cases without the formation of coarse Cr-containing phases with separate charging of Mn and Cr. The separate charging of Ti has also proved to be beneficial in order to prevent the formation of coarse phases.

In further experiments, an aluminium melt C was produced having the composition shown in Table 3 below, wherein (as in the previously described aluminium melt B) Mn and Cr were charged separately from one another, with intermediate homogenisation of the melt.

Si	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**	**Ti**	**Na**	**B**	**Ca**	**Li**	**Al**
0.057	0.136	0.009	0.805	5.282	0.136	0.013	0.025	<0.0001	0.001	0.0004	<0.0001	remainder

Table 3 (all data in wt. %)

The aluminium melt C was cast into an ingot by direct chill casting. The ingot was preheated, and by subsequent hot and cold rolling without intermediate annealing a cold strip having a thickness of 1.5 mm was produced, with an overall thickness reduction in the cold rolling of 75%. The cold strip was then levelled by levelling rollers with a diameter of more than 60 mm in each case and cut into sheets.

Some of these sheets were then subjected to a heat treatment at 450 °C for various durations in order to investigate the formation of the fine grain distribution important for superplastic forming. Fig. 5 shows an image of a polished and barked microsection of one of the sheets in the hard-rolled H19 state, i.e. before the heat treatment. The grains elongated by rolling are clearly visible.

Micrographs were taken of the heat-treated sheets and the average grain diameters in each case were determined according to ASTM E112. Fig. 6 shows an image of a polished and barked microsection of a sheet heat-treated at 450 °C for 1 minute. The fine-grain microstructure with grain sizes between 5 and 15 μm and an average grain diameter of 7 μm can readily be seen. This shows that the fine-grain microstructure important for superplastic forming is achieved practically instantaneously on heating up to the temperature for superplastic forming (typically 450 °C-520 °C). Fig. 7 shows an image of a polished and barked microsection of a sheet that was heat treated at 450 °C for 60 minutes. The microstructure is just as fine-grained as in Fig. 6, with a mean grain diameter of also 7 μm. This shows the stability of the fine microstructure over time at the superplastic forming temperature. This stability is achieved in the investigated metal sheets in particular by the contents of Mn and Cr and their fine distribution in the aluminium matrix, in particular by the separate charging of Mn, Ti and Cr, which permanently prevent the growth of the aluminium grains.

Furthermore, the metallographic investigations show that the sheets have no coarse particles that would lead to pore formation during superplastic forming. This is achieved in particular by the low contents of Fe and Si as well as by the separate charging of Cr. The micrographs in Figs. 6 and 7 show that the sheets exhibit a fine-grain microstructure at the forming temperature, which has a very stable mean grain diameter even at high forming temperatures.

On the sheets as described above produced from the aluminium melt C, superplastic forming tests according to Lederich were carried out by means of the incremental strain rate test (Lederich et al. "Superplastic Formability Testing" Journal of Metals Vol. 34 Issue 8, pp. 16-20, 1982) under in each case successive use of the strain rates 5 x 10^{-4} $s^{-1,}$,1 x 10^{-4} $s^{-1,}$ 5 x 10^{-4} $s^{-1,}$ 1 x 10^{-3} $s^{-1,}$ 5 x 10^{-3} s^{-1}, 1 × 10^{-2} s^{-1}, 5 × 10^{-4} s^{-1} and 1 × 10^{-1} s^{-1} and an ISO 20032:2007 compliant testing machine and sample geometry for determining the strain rate sensitivity m at four different forming temperatures (450 °C, 475 °C, 500 °C and 525 °C). The aforementioned strain rate sequence was thus run through for a first sheet sample at a forming temperature of 450 °C, for a second sheet sample at a forming temperature of 475 °C etc. In this connection the strain rate 5 × 10^{-4} s^{-1} in the above-mentioned strain rate sequence was used a total of three times in each case to detect any hardening or softening due to the high-temperature forming.

In order to determine the strain rate sensitivity m dependent on the strain rate, in each case the values for the yield stress σ measured for a sheet thickness at the different strain rates were plotted double-logarithmically against the associated strain rates and the function $F(\dot{\varepsilon}) = {}^{\ln(\sigma)}/_{\ln(\dot{\varepsilon})}$, which is dependent on the strain rate, was determined by fitting a second degree polynomial to the measured values. The derivative of the function $F(\dot{\varepsilon})$ i.e. $\frac{dF(\dot{\varepsilon})}{d\dot{\varepsilon}} = \frac{d\ln(\sigma)}{d\ln(\dot{\varepsilon})}$, or the derivative of the polynomial fitted for it, respectively, then corresponds to the strain rate sensitivity $m(\dot{\varepsilon})$ as a function of the strain rate $\dot{\varepsilon}$.

The results of the forming experiments are shown in the diagram in Fig. 8, in which the forming temperature T of the superplastic forming in °C is plotted on the X-axis and the (dimensionless) strain rate sensitivity m is plotted on the Y-axis. Here in Fig. 8 the values of the previously described determined function $m(\dot{\varepsilon})$ for the strain rates $1 \times 10^{-4}\,s^{-1}$ (+ symbols), $1 \times 10^{-3}\,s^{-1}$ (x-symbols), $1 \times 10^{-2}\,s^{-1}$ (o-symbols) and $1 \times 10^{-1}\,s^{-1}$ (squared symbols) are plotted for each forming experiment. The lines plotted in Fig. 8 connect the m-values of the four forming experiments, which were each determined respectively for the same strain rate.

As Fig. 8 shows, at the forming temperatures in the range 450 °C – 520 °C typical for superplastic forming, strain rate sensitivities $m > 0.3$ were achieved not only at the typical forming rates $10^{-4}\,s^{-1}$ to $10^{-3}\,s^{-1}$ but also at higher forming rates, in particular forming rates of $10^{-2}\,s^{-1}$ or higher. Accordingly, the sheets are suitable not only for superplastic forming at conventional strain rates, but also for high-speed superplastic forming with very high strain rates, as a result of which the forming times can be significantly reduced and thus higher production rates can be achieved.

To investigate the porosity and the mechanical properties after superplastic forming, sheets produced as described above from the aluminium melt C were superplastically formed at a forming temperature of 515 °C. with an ISO 20032:2007 compliant testing device in a uniaxial tensile test, in which the sample geometry was based on the abovementioned Standard (ISO 20032:2007 S-Type sample shape). The strain rate was $2.5 \times 10^{-4}\,s^{-1}$ and the total strain ε at the end of the forming was 100%.

On some of these sheets that were superplastically formed at a forming temperature of 515 °C, the porosity was determined by means of the metallographic microsection and cutting test in accordance with the VDG-Merkblatt (VDG leaflet) P201. The tested sheets showed a very low porosity in the range of 0.3% to 0.7%.

Furthermore, tensile tests were carried out on some of the sheets in order to determine the yield strength $R_{p0.2}$ and the tensile strength R_m according to DIN EN ISO 6892-1:2017, wherein the test was carried out transversely to the rolling direction. The tensile tests were carried out in each case after heating the sheets in order to achieve the desired microstructure for the superplastic forming. The sheets were not superplastically formed before the tensile tests.

The results of the tensile tests are shown in the diagrams in Figs. 9 and 10, in which the superplastic forming temperature T in °C is plotted on the X-axis, and the yield strength $R_{p0.2}$ and the tensile strength R_m, in each case in MPa, are plotted on the Y-axis. As the test results show, the sheets had a yield strength $R_{p0.2}$ of more than 160 MPa over the entire forming temperature range investigated, and even a yield strength $R_{p0.2}$ of more than 170 MPa at a forming temperature of 500 °C. The tensile strength of the sheets was significantly above 310 MPa, even above 320 MPa, over the entire forming temperature range investigated. The good mechanical properties after superplastic forming are due in particular to the advantageous Mn content of at least 0.7 wt. %, the advantageous Mg content of at least 5.2 wt. %, and the separate charging of Cr and Mn.

Due to the Mn content of at least 0.7 wt.% and the separate charging of Cr and Mn, in particular the formation of coarse particles and thereby a pore formation adversely affecting the mechanical properties is also reduced or even prevented in the superplastic forming. In superplastic forming there is therefore virtually no further softening over and above the softening induced by the heating, so that the measured values for $R_{p0,2}$ and R_m shown in Figs. 9 and 10 are achieved by the sheets after the heating and also the superplastically formed sheets.

Claims

1. A method for producing an aluminium flat product, the method comprising:

- providing an aluminium melt from an aluminium alloy, the aluminium alloy having the following composition:

  0.03 wt.% ≤ Si ≤ 0.10 wt.%,
  Fe ≤ 0.4 wt.%,
  Cu ≤ 0.1 wt.%,
  0.5 wt.% ≤ Mn ≤ 1.0 wt.%,
  5.2 wt.% ≤ Mg ≤ 5.5 wt.%,
  0.05 wt.% ≤ Cr ≤ 0.25 wt.%,
  Zn ≤ 0.25 wt.%,
  Ti ≤ 0.20 wt.%,
  Na ≤ 2 ppm,

  unavoidable impurities individually ≤ 0.05 wt.%, in total ≤ 0.15 wt.%, remainder aluminium,
- casting the aluminium melt to form an ingot,
- hot rolling the ingot to form a hot strip,
- cold rolling the hot strip to form a cold strip, and
- levelling the cold strip.

2. The method according to claim 1,
wherein the aluminium alloy has an Fe content of 0.05 - 0.15 wt.%.

3. The method according to claim 1 or 2,
wherein the aluminium alloy has a Cu content of max. 0.05 wt.%.

4. The method according to any one of claims 1 to 3, wherein the aluminium alloy has a Mn content of 0.7 wt.% to 1.0 wt. %.

5. The method according to any one of claims 1 to 4, wherein the aluminium alloy has a Zn content of max. 0.06 wt.%.

6. The method according to any one of claims 1 to 5, wherein the aluminium alloy has a Ti content in the range 0.015 - 0.03 wt.%.

7. The method according to any one of claims 1 to 6, wherein the aluminium alloy has a B content of max. 50 ppm.

8. The method according to any one of claims 1 to 7, wherein the aluminium alloy has a Ca content of max. 15 ppm.

9. The method according to any one of claims 1 to 8, wherein the aluminium alloy has a Li content of max. 15 ppm.

10. The method according to any one of claims 1 to 9, wherein the aluminium melt is provided by melting together a preliminary aluminium melt with additives to achieve the composition of the molten aluminium to be provided, wherein at least two of the alloying elements Cr, Mn and Ti are charged separately from one another.

11. The method according to claim 10, wherein all three alloying elements Cr, Mn and Ti are charged separately from one another.

12. The method according to any one of claims 1 to 11,
wherein the degree of rolling during cold rolling is in total in the range of 70% to 80%.

13. The method according to claim 12, wherein the degree of rolling in the last roll pass is less than 33%.

14. The method according to any one of claims 1 to 13,
wherein the cold strip is cut into sheets after levelling without intermediate coiling.

15. The method according to any one of claims 1 to 14,
wherein the levelling of the cold strip is performed by means of levelling rollers with a diameter of more than 60mm.

16. The method according to any one of claims 1 to 15, wherein the aluminium flat product is a superplastic aluminium flat product.

17. An aluminium flat product produced by a method according to any one of claims 1 to 16.

18. The aluminium flat product according to claim 17,
wherein the aluminium flat product after a heat treatment for 30 minutes at 500 °C has a yield strength $R_{p0.2}$ of at least 160 MPa and a tensile strength R_m of at least 310 MPa.

19. The aluminium flat product according to claim 18, wherein the yield strength $R_{p0.2}$ is at least 170 MPa.

20. The aluminium flat product according to claim 18 or 19, wherein the tensile strength R_m is at least 320 MPa.

21. The aluminium flat product according to any one of claims 17 to 20, wherein the aluminium flat product after a superplastic forming at a forming temperature of 515 °C, a strain rate of 2.5×10^{-4} s^{-1} and a total elongation of 100 %, has a porosity of less than 1.5%.

22. The aluminium flat product according to claim 21, wherein the porosity is less than 1%.

23. The aluminium flat product according to any one of claims 17 to 22, wherein the aluminium flat product is a superplastic aluminium flat product.

24. A use of an aluminium flat product according to any one of claims 17 to 23 for producing an aluminium product by superplastic forming of the aluminium flat product.

25. The use according to claim 24, wherein the superplastic forming comprises blow moulding.

26. The use according to claim 24 or 25, wherein the superplastic forming is performed at a strain rate of at least 10^{-3} s^{-1}.

27. The use according to claim 26, wherein the strain rate is at least $10^{-2}s^{-1}$.

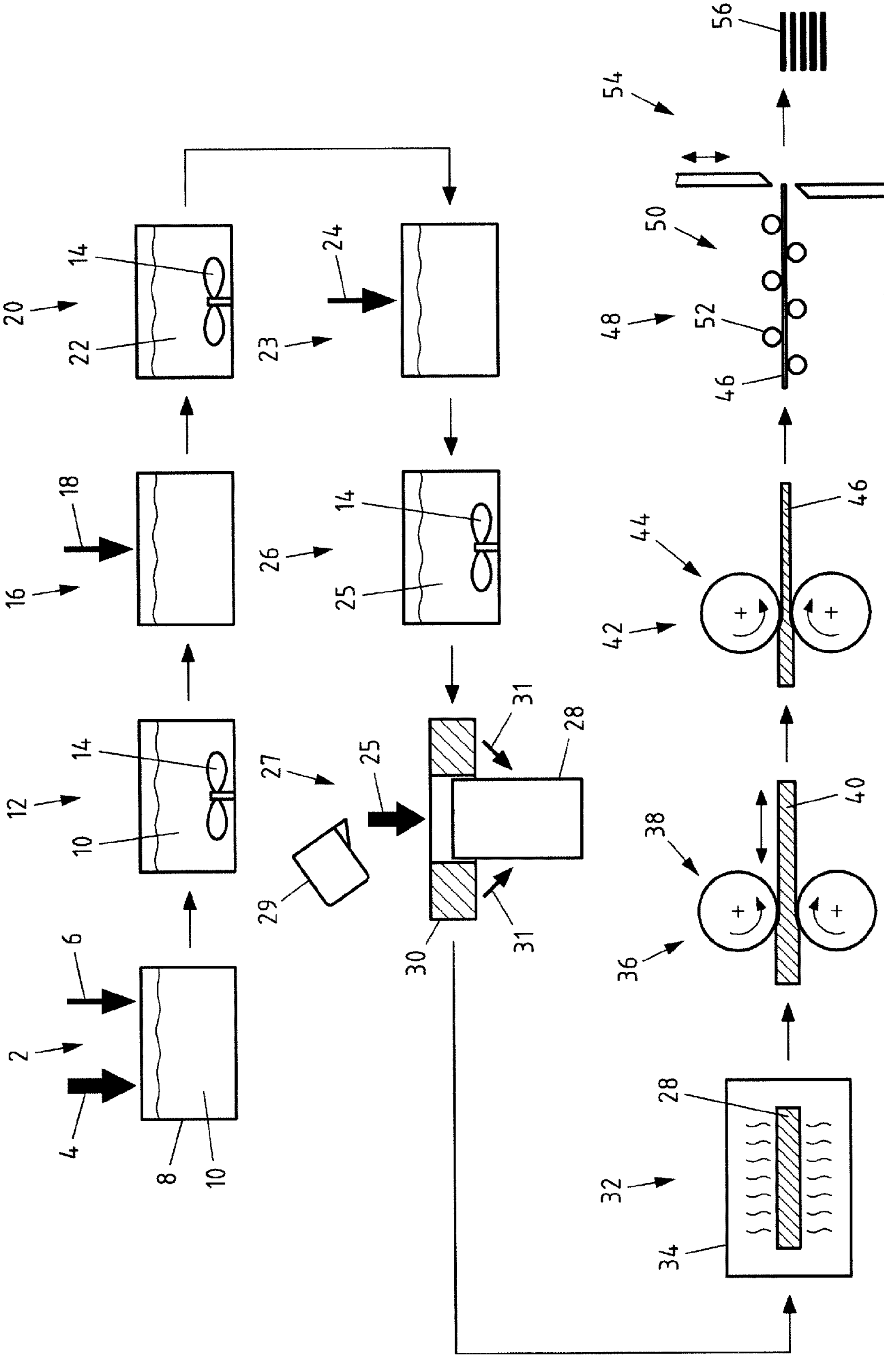

2
4
6
8
10
12
14
10
16
18
20
14
22
23
24
26
14
25
27
25
29
28
31
31
30
32
34
28
36
38
40
42
44
46
48
52
46
50
54
56

Fig.1

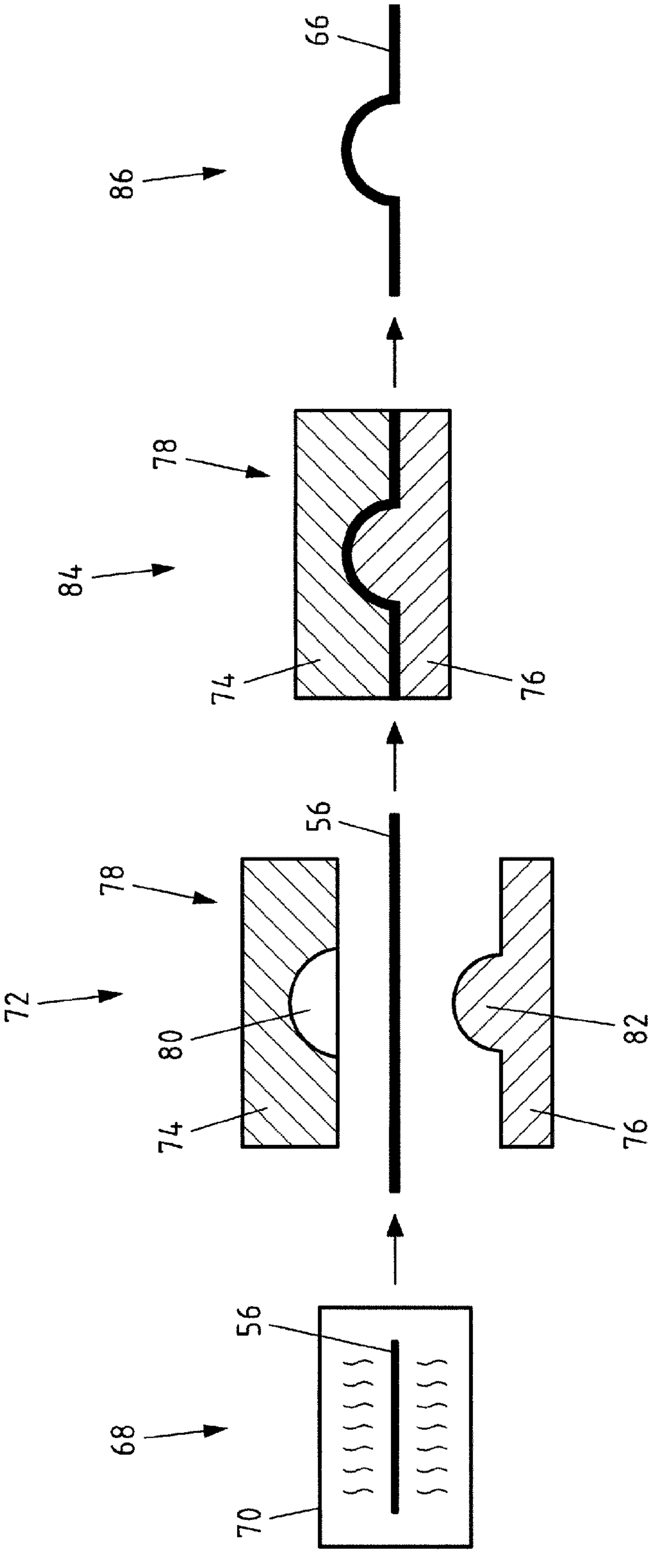


Fig.2

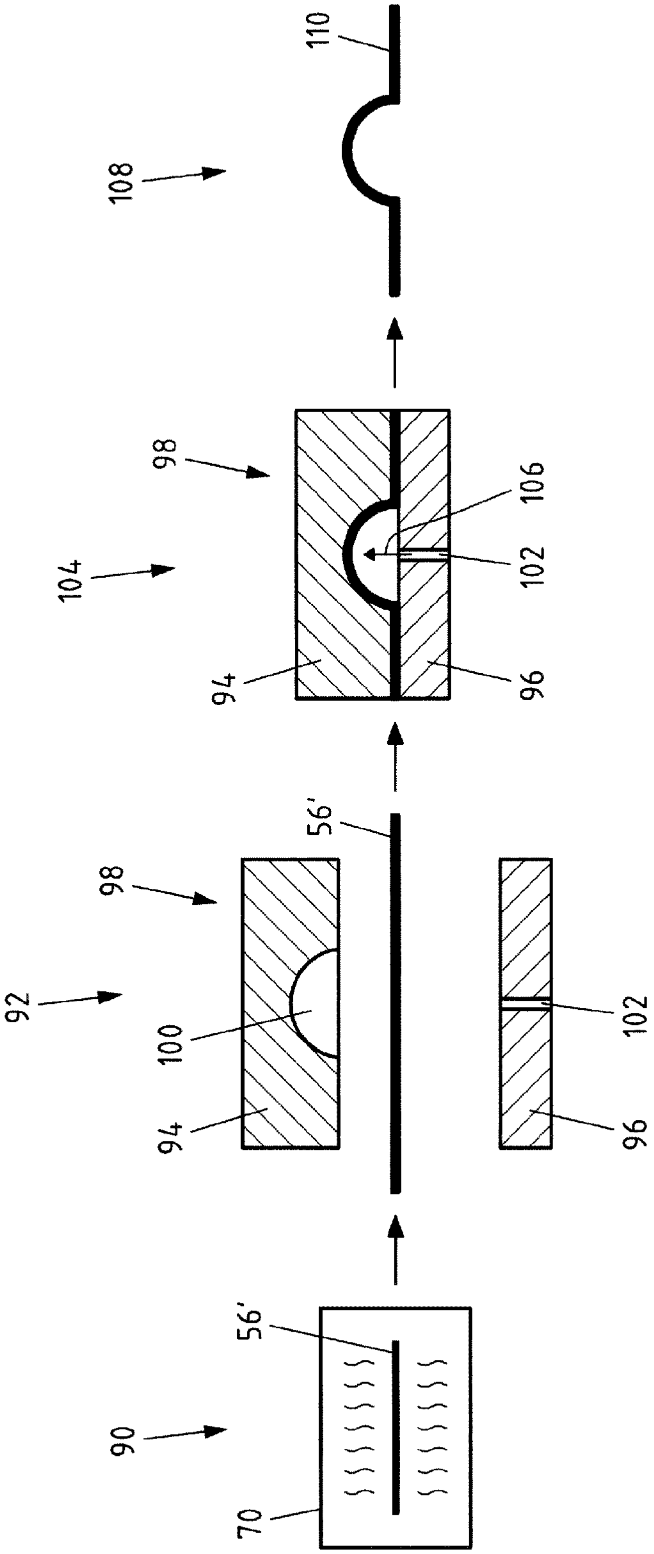


Fig.3

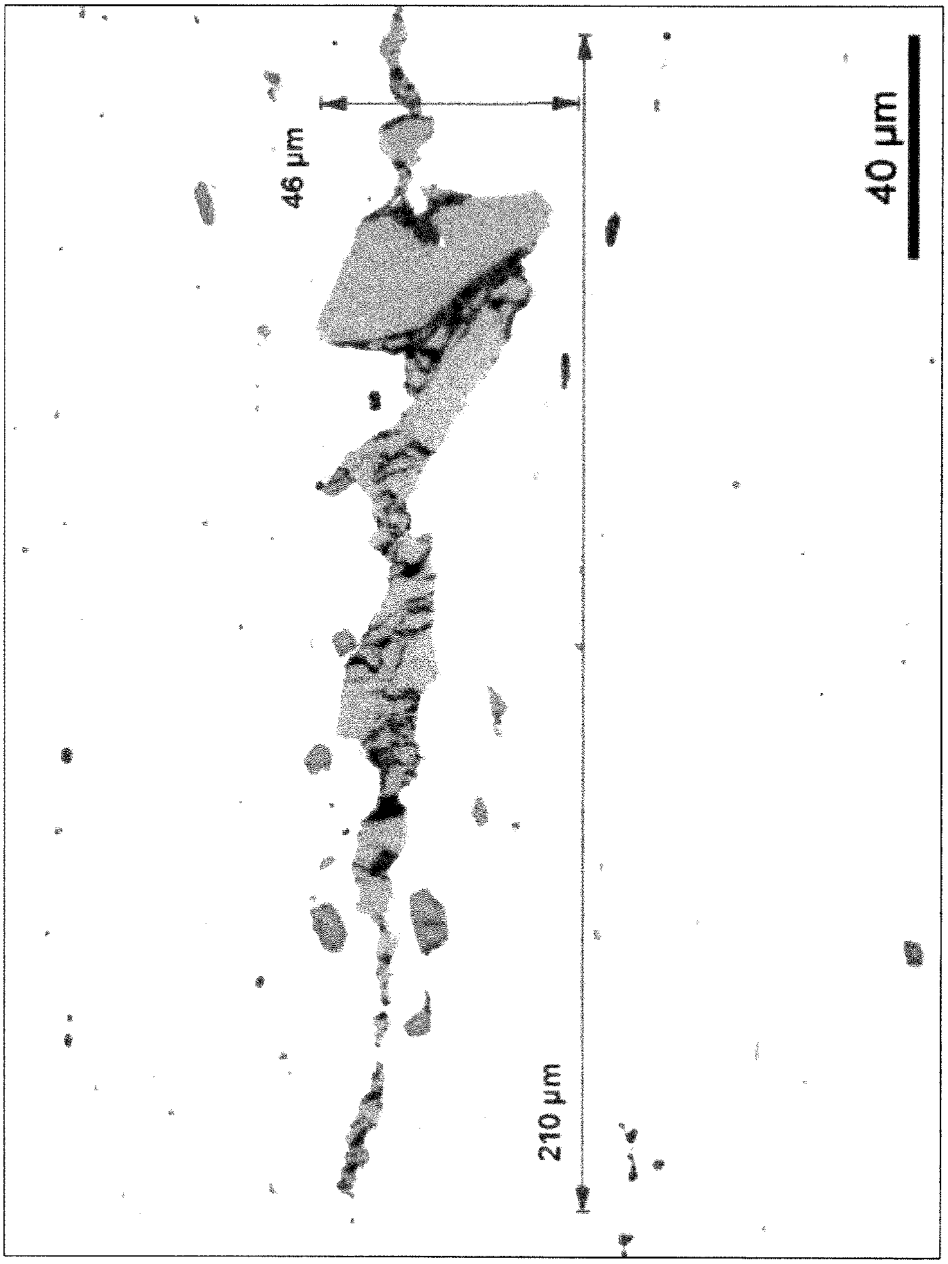


Fig.4

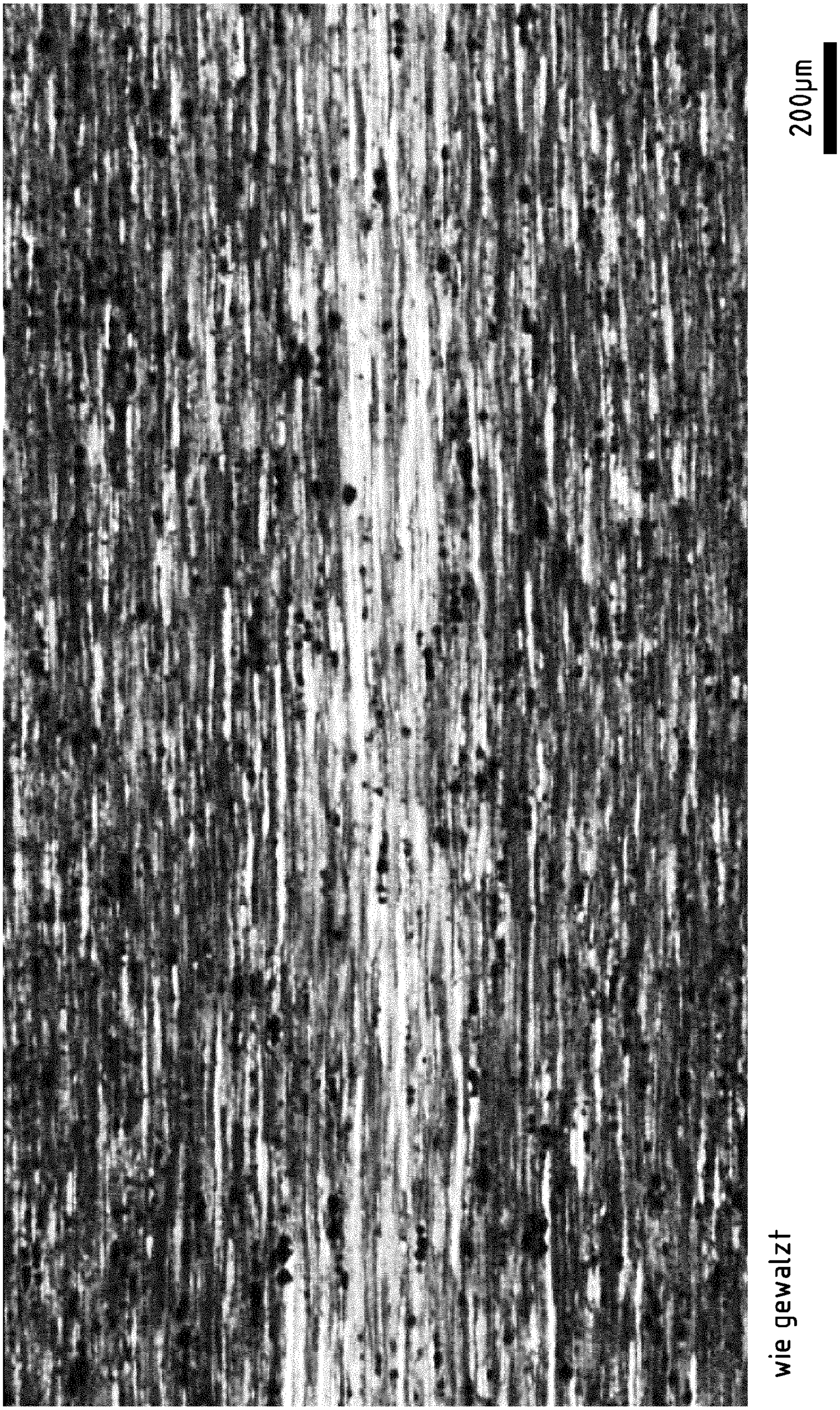


Fig.5

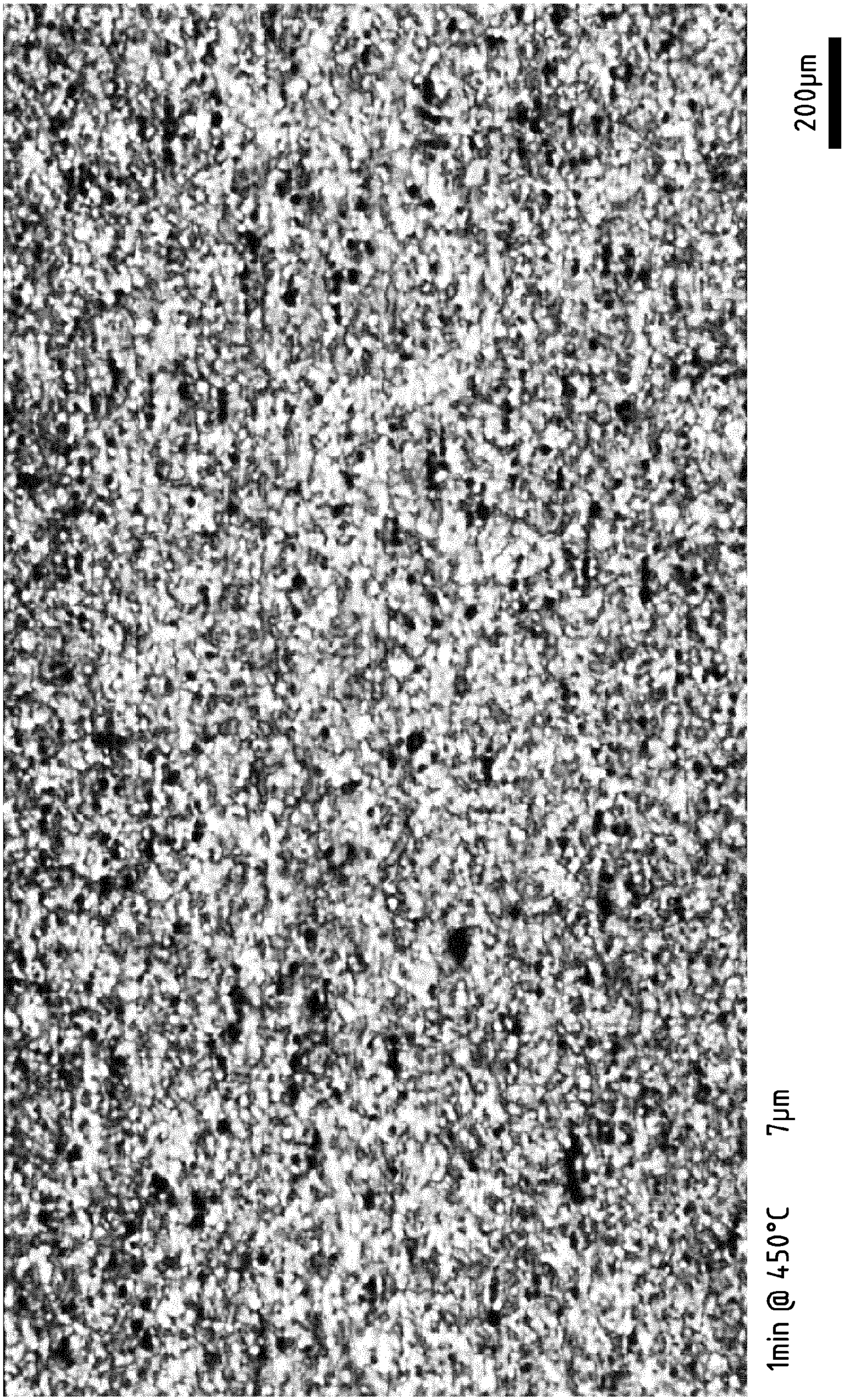


Fig.6

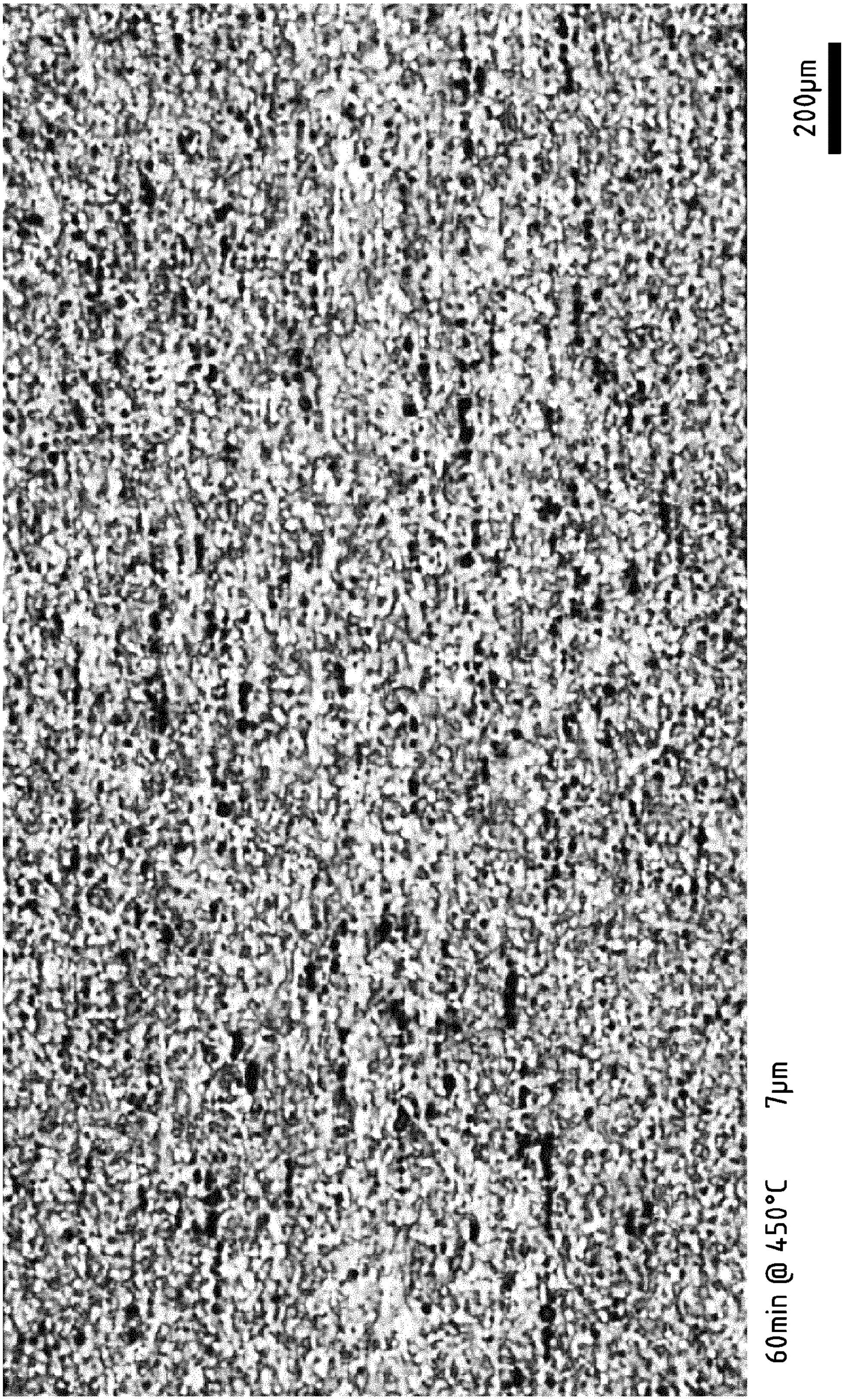


Fig.7

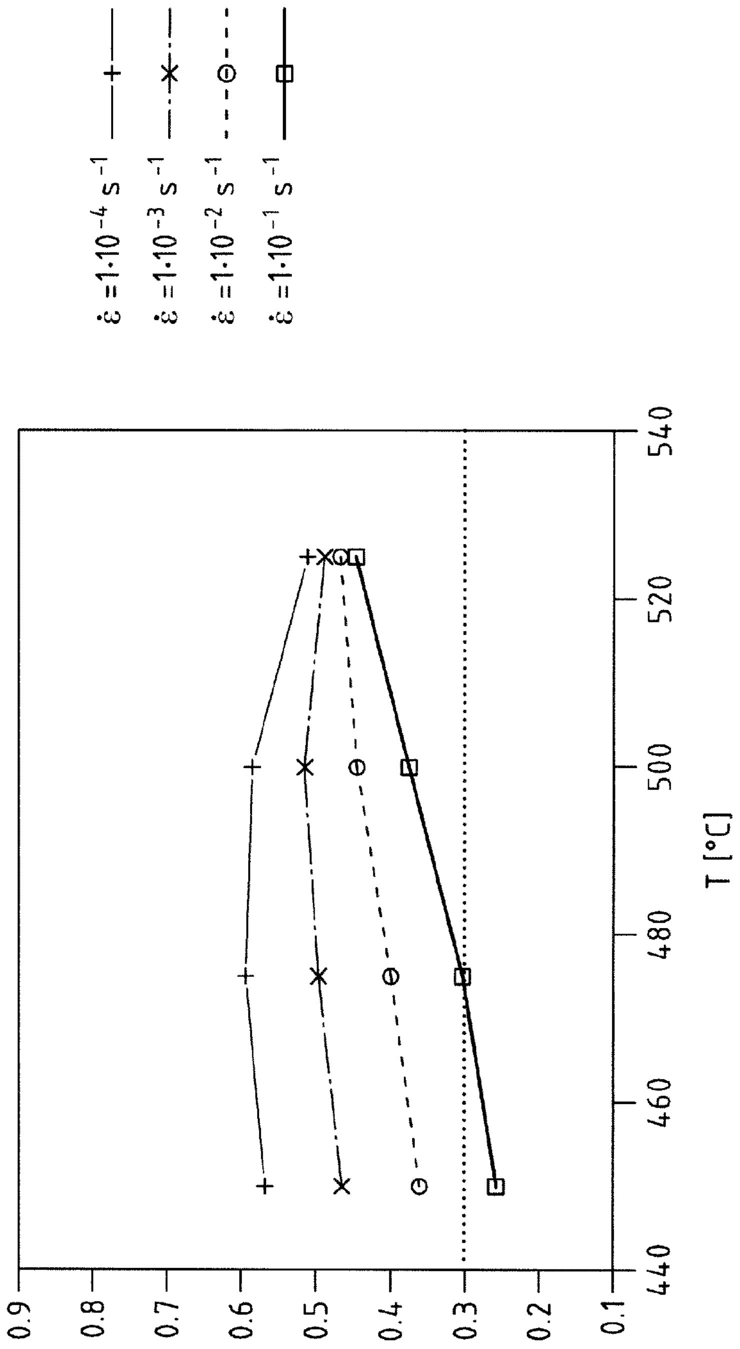

$\dot{\varepsilon} = 1\cdot10^{-4}\ s^{-1}$
$\dot{\varepsilon} = 1\cdot10^{-3}\ s^{-1}$
$\dot{\varepsilon} = 1\cdot10^{-2}\ s^{-1}$
$\dot{\varepsilon} = 1\cdot10^{-1}\ s^{-1}$
ε
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
440
460
480
500
520
540
T [°C]

Fig.8

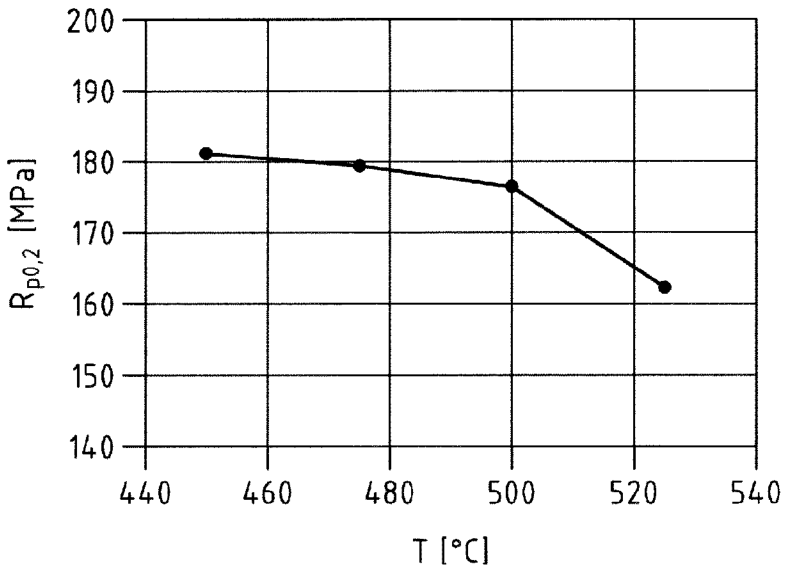

200
190
180
170
160
150
140
$R_{p0,2}$ [MPa]
440
460
480
500
520
540
T [°C]

Fig.9

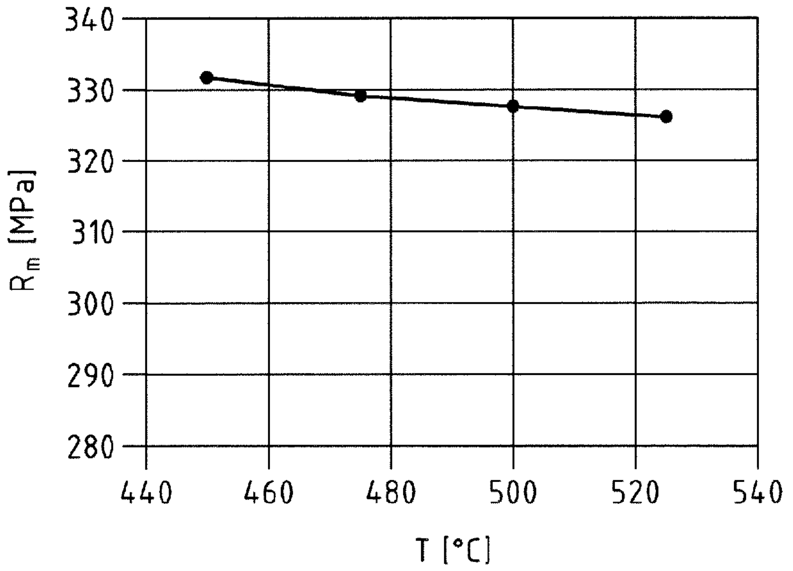
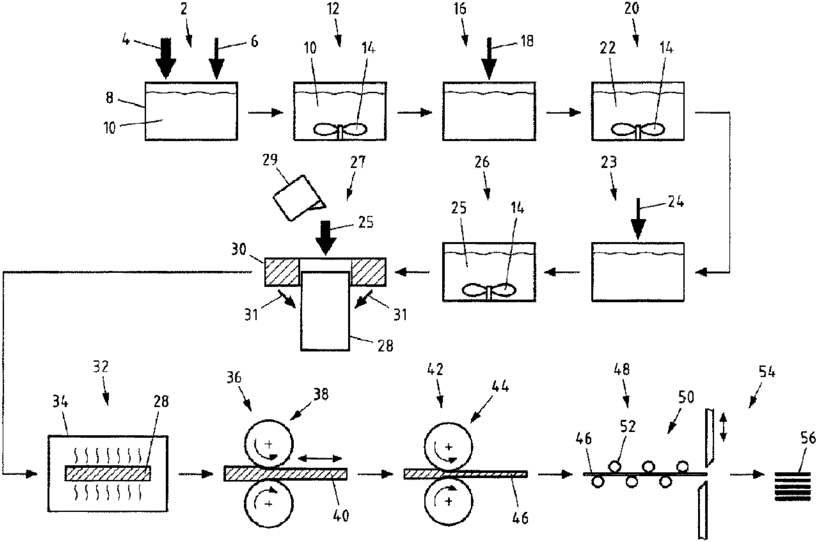

340
330
320
310
300
290
280
R_m [MPa]
440
460
480
500
520
540
T [°C]

Fig.10


2
4
6
8
10
12
10
14
16
18
20
22
14
29
27
26
23
25
14
24
25
30
31
31
28
32
34
28
36
38
40
42
44
46
48
50
52
46
54
56