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(54) **SHEET METAL PRODUCT WITH HIGH BENDABILITY AND MANUFACTURING THEREOF**
BLECHPRODUKT MIT HOHER BIEGSAMKEIT UND HERSTELLUNG DAVON
PRODUIT EN TÔLE À FLEXIBILITÉ ÉLEVÉE ET SON PROCÉDÉ DE FABRICATION

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Description

[0001] The invention refers to a method of manufacturing a sheet metal product.

[0002] Magnesium alloys and sheet metal products manufactured thereof have a high industrial potential, for example in light weight designs.

[0003] A preferred field of application of such alloys in the prior art is the vehicle industry, for example automotive and aircraft industry. Here, magnesium alloys are a preferred material for sheet metal products.

[0004] Magnesium alloys typically comprise a very low density, even below the density of aluminum and only 25 % of that of steel. Magnesium alloys have a high stiffness, high specific strength and good damping capacity. These and further known advantageous properties of magnesium alloys, such as good machinability, make them highly attractive for light weight design.

State of the art

[0005] A known manufacturing method for sheet metal products is rolling. State-of-the-art-magnesium-alloys used for industrially established strips, such as AZ31, show a low formability at ambient temperature. As a consequence, it is necessary that the rolling process is conducted at elevated temperatures, often in combination with a low thickness reduction degree of the sheet metal strip per rolling pass. This leads to an increased number of rolling passes and hence higher effort which also results in higher production costs.

[0006] Additionally, as a result of the rolling process performed on conventional magnesium alloys, a strong crystallographic texture is formed in which the basal planes of the grains are preferentially oriented parallel to the rolling plane. Such crystallographic texture significantly hinders the deformability along the strip thickness so that a high planar anisotropy is caused. Thus the mechanical properties of the sheet metal product are adversely affected and strip forming operations, especially in bending operations such as hemming, become difficult.

[0007] Twin roll casting is a manufacturing method that shows good potential for the production of magnesium strips with improved structural and mechanical properties at affordable costs.

[0008] From the patent document EP 3 205 736 B1 a method of manufacturing a sheet metal product based on a magnesium alloy can be gained. The sheet metal product comprises a high formability at low temperature in combination with a widely adjustable spectrum of mechanical strength. Additionally, the disclosed manufacturing method results in low costs and allows for producing a sheet material product absent of any strong segregation within the microstructure.

[0009] Further known examples of sheet metal products and magnesium alloys can be gained from the documents DE 11 2014 002 336 T5, JP 2006 028 548 A2 and EP 2 644 728 A2.

[0010] US 2015/047756 A1 discloses Mg-Ca-Zn alloys comprising 0.15 or 0.3 atom% Ca and 0.3, 0.45, 0.6, 0.91.2, 1.5 or 1.8 atom % Zn. The molten Mg-Ca-Zn alloy is subjected to gravity casting, homogenization treatment and hot extrusion.

[0011] The present invention aims at providing a method of manufacturing a sheet metal product having high bendability.

Description of the invention

[0012] The defined objectives are achieved by the subject-matter of the claim 1. Preferred embodiments of the invention can be gained from the features of the dependant claims and from the description.

[0013] The method of manufacturing a sheet metal product, comprises the following steps:

a) providing a molten magnesium alloy consisting of

- 0.2 wt% to 2 wt% Zn,
- an amount of Ca,
- 0.0 wt% to 0.3 wt% Zr,
- 0.0 wt% to 1.0 wt% rare earth elements and/or Sr,
- unavoidable impurities, and
- the balance being Mg

b) forming a strip in a twin roll casting process,

c) performing a warm rolling process on the strip and

d) performing a subsequent heat treatment on the strip at 250°C to 450°C for 0,5 min to 60 min.

[0014] According to the invention, the amount of Ca is chosen from an interval [0.1 wt%, 0.4 wt%].

[0015] In the context of this application, specification of an interval in the format [X, Y[means that the boundary value

X is included in the interval, whereas the boundary value Y is excluded from the interval, but all values below Y down to X are included. Accordingly, specification of an interval in the format [X, Y] means that both boundary values X, Y and all values between X and Y are included in the interval.

[0016] Compared to the teaching of EP 3 205 736 B1, the method of the invention has revealed a surprising technical effect, if the amount of Ca is reduced below 0.4 wt%. Due to extensive research with amounts of Ca below 0.4 wt% it has been found that the sheet metal product that is manufactured in the method of the invention has significantly improved bendability and corrosion resistance.

[0017] One aspect of the invention claimed herein is to adopt the teaching of EP 3 205 736 B1 and modify the alloy used, especially under modification of the amount of Ca to a value below 0.4 wt%.

[0018] The advantageous effects to bendability especially contribute to bending processes performed at demanding bending ratios. The bending ratio is defined as a ratio of a bending radius and a thickness of the sheet metal product. Demanding bending ratios are for example required in hemming processes. The advantageous effect of the invention beneficially applies to such bending processes, even at low temperatures.

[0019] A corrosion rate of a sheet metal product manufactured by the method of the invention, for example indicated by a salt solution immersion test at room temperature, can be 0.43 mm/year or less. Tested with the same testing method, a reference magnesium alloy comprising 0.6 wt% Zn and 0.6 wt% Ca, which is beyond the scope of the invention, has a corrosion rate of 2.6 mm/year.

[0020] This underlines the enhanced durability of the sheet metal product of the invention. Especially in the automotive industry this is an important requirement as the duration of a life cycle of a vehicle is often limited by corrosion effects.

[0021] The method of the present invention provides a highly formable and highly corrosion resistant sheet metal product, based on an Mg-Zn-Ca alloy system, even if no rare earth elements, Sr or Zr are used. Further, the sheet metal manufacturing via twin roll casting ensures environmental and economic benefits.

[0022] Especially in the automotive industry, the sheet metal products obtainable by the method of the invention, are beneficial, for example for automobile components. This is due to the fact that a sheet bending operation, for example hemming, can be conducted at a low temperature with a decreased tendency of plastic instability compared to the conventional Mg-based alloys and Mg-alloys containing a high amount of Ca, particularly of at least 0.4 wt% or above.

[0023] However, research has revealed that the sheet metal products obtainable by the method of the invention are beneficial in other technical fields, as well. Accordingly, an aspect of the invention covers to apply them to biomedical implants due to the excellent biocompatibility of the alloy system.

[0024] The use of the specific magnesium alloy in the method of the invention results in excellent formability, especially in bending operations, along with corrosion resistance and homogeneous distribution of alloying elements of the sheet metal product of the invention, while the strength level can be adjusted within a wide range, at low production costs.

[0025] The Zn content is chosen from 0.2 wt% to 2 wt%, preferably 0.4 wt% to 2 wt%, further preferred from 0.2 wt% to 1 wt% and even further preferred from 0.4 wt% to 1 wt% to decrease the tendency towards embrittlement and increase low-temperature formability.

[0026] According to the invention, the Ca content is less than 0.4 wt%. Preferably the Ca content is chosen within a range from 0.1 wt% to 0.39 wt%, that has revealed best contribution to bendability at different amounts of Zn.

[0027] Preferably small quantities of Zr are added to the magnesium alloy in order to achieve grain refinement and to remove at a large extent any directional solidification. Preferably, the magnesium alloy comprises a Zr content of 0.01 wt% to 0.3 wt%, further preferred from 0.02 wt% to 0.08 wt%.

[0028] Preferably the magnesium alloy contains small quantities of rare earth elements and/or Sr. Some preferred rare earth elements are Sc, Y, La or Gd. Preferably the magnesium alloy comprises 0.1 wt% to 1 wt%, further preferred 0.2 wt% to 0.8 wt% and further preferred 0.4 wt% to 0.6 wt% of rare earth elements and/or Sr, related to the total amount of rare elements and Sr. This additionally weakens the texture and improves the mechanical strength of the manufactured sheet metal product.

[0029] In a preferred embodiment of the method of the invention a ratio Zn/Ca is chosen from an interval [2/3, 5/1]. In this range, the amount of a Mg₂Ca phase in the alloy is significantly reduced.

[0030] While Mg-Zn-Ca based alloys known from the prior art have been developed with a focus on texture weakening, considering an optimal Zn/Ca ratio leads to significant additional improvement.

[0031] Preferably the Zn/Ca ratio is chosen from an interval [1/1, 5/1], e.g. Mg - 0.6Zn - 0.2Ca wt%. In this interval, research by the applicant has revealed an optimal range that shows best formability results. At a ratio Zn/Ca of less than 1/1 the Mg₂Ca phase becomes increasingly dominant and leads to a lower limit of the preferred range at a ratio of 2/3. At a ratio Zn/Ca of more than 5/1, the Zn content leads to decreased rollability, for example in case of more than 1 wt% Zn at 0.2 wt% Ca.

[0032] The present invention clearly shows that the benefits of Mg - Zn - Ca alloys can be significantly enhanced by optimization of Zn/Ca ratio, such as texture weakening, improved rollability and high formability. Furthermore, a less amount of secondary phases occurs, which is controllable by the Zn/Ca ratio as a part of the present invention. This is also beneficial to improve the corrosion resistance.

[0033] The absence of segregation zones within the strip, which results from the controlled chemical composition, especially the Zn/Ca ratio, enables the subsequent rolling and annealing at various conditions that lead further to a wider spectrum in the resulting mechanical properties.

[0034] Table 1 below shows a selection of alloys a that have been tested on bendability and corrosion resistance and delivered very good results. This will be demonstrated in more detail later.

Table 1

Alloy nominal (in the format Mg-...wt%Zn-...wt%Ca-...wt%Zr)	Ratio nominal (in the format ... wt%Zn/ ... wt%Ca)	Reference
Mg-0.2Zn-0.3Ca	2/3	1
Mg-0.6Zn-0.2Ca	3/1	2
Mg-0.8Zn-0.2Ca	4/1	3
Mg-1Zn-0.2Ca	5/1	4
Mg-1Zn-0.2Ca-0.02Zr	5/1	5
Mg-0.6Zn-0.2Ca-0.07Zr	3/1	6

[0035] In a further preferred embodiment of the method of the invention subsequent to the heat treatment of step d), a bending operation e) is performed on the sheet metal product.

[0036] Due to the excellent bendability of the sheet metal product a wide range of bending operations can be applied, including very demanding hemming operations.

[0037] In a further preferred embodiment of the method of the invention the bending operation e) is performed at a bending ratio of 0.5 or above.

[0038] Preferably the bending ratio is chosen from an interval [0.8, 2.2].

[0039] Of course, the bending ratio may be chosen at a value of more than 2.2 since higher bending ratios lead to decreased technical requirements.

[0040] However, due to the excellent formability of the alloy in the method of the invention it is preferred to exploit the manufacturing possibilities offered by the given interval. Here, tightly folded sheet metal products are achievable by the method of the invention.

[0041] On the contrary, other alloys known in the art require higher bending ratios, in particular above 2.2, in order to produce a bent sheet metal product that is free of cracks.

[0042] In a further preferred embodiment of the method of the invention the bending operation e) is performed at a temperature chosen from an interval [room temperature, 200 °C]. Preferably the temperature is chosen from an interval [120 °C, 180 °C]. Preferably the temperature is chosen at 160 °C.

[0043] Preferably a bending ratio of not more than 2.2 is chosen at room temperature. Further preferred, a bending ratio of not more than 0.8 is chosen at 160 °C. Certainly, the given temperatures can always be combined with a higher bending ratio than in the previous examples, as technical requirements for a crack-free manufacturing decrease. Accordingly, the invention identifies the lower limits of the bending ratio for certain temperatures in order to achieve a crack-free sheet metal product.

[0044] Research done by the applicant has revealed that an excellent process window for the bending operation exists between a bending ratio of 0.8 at 160 °C and a bending ratio of 2.2 at room temperature, wherein room temperature typically ranges from 18 °C to 22 °C.

[0045] It is with respect to the used Mg-Zn-Ca system unique to the invention that bending operations can be performed on a strip a combination of a small bending ratio and a low temperature, for example at the bending ratio of 0.8 and the temperature of 160 °C or at the bending ratio of 2.2 at room temperature.

[0046] The improved formability does not deteriorate at the temperature range from room temperature to 200 °C, i.e. no plastic instability during the forming operation at elevated temperature occurs.

[0047] In a preferred embodiment of the method of the invention subsequent to the twin roll casting process of step b), an initial heat treatment b') is performed on the strip.

[0048] This advantageously dissolves inter-dendritic and inter-granular precipitates.

[0049] Preferably the initial heat treatment of step b') is performed at 400 °C to 500 °C for 30 min to 1440 min, preferably 300 min to 1440 min.

[0050] In a preferred embodiment of the method of the invention the warm rolling process of step c) is performed at 200 °C to 450 °C, further preferred 250 °C to 450 °C and further preferred 300 °C to 400 °C.

[0051] Experiments have shown that rolling a temperature below 250 °C causes edge cracking, while grain coarsening

occurs at rolling temperatures above 450 °C.

[0052] In a preferred embodiment of the method of the invention the strip formed in the twin roll casting process of step b) and prior to step c) measures 1 mm to 5 mm, preferably 2 mm to 5 mm in thickness and 100 mm to 2000 mm in width. Such range of strip thickness and width, which is available using the specific magnesium alloy composition in the method of the invention, is advantageous in terms of cost efficiency of the sheet metal product production and wide applications, e.g. in various automotive components.

[0053] In a preferred embodiment of the method of the invention, a temperature of the molten magnesium alloy is controlled to be 680 °C to 750 °C and a peripheral speed of rolls used in the twin roll casting process of step b) is controlled to be 0.7 m/min to 3.5 m/min, preferably 1 m/min to 3.5 m/min.

[0054] This leads to advantageous quality of the strip in combination with a high efficiency of the twin roll casting process of step b).

[0055] Microstructures and mechanical properties of the sheet metal product can be flexibly tuned in the warm rolling process of step c) and in the subsequent heat treatment of step d). In the warm rolling process of step c) the thickness of the strip is reduced. Preferably, the warm rolling process of step c) is conducted in multiple passes leading to a stepwise reduction of the thickness of the strip. The thickness of the strip can be reduced to the desired thickness of the sheet metal product.

[0056] Preferably the strip is heated up to its rolling temperature in-between of different passes of the warm rolling process of step c). Thereby, the warm rolling process of step c) introduces deformation and recrystallization of the strip. A higher deformation energy is introduced by a lower rolling temperature as well as for higher degree of thickness reduction in a pass, which beneficially influences the recrystallization process. A high deformation energy assists a homogeneous formation of recrystallization nuclei that leads to fast recrystallization and a higher homogeneity of the microstructure. Depending on the speed of recrystallization, the microstructural homogeneity of the final sheet metal product obtained by the method of the invention can be easily tuned.

[0057] Further, by adjusting a duration of the final heat treatment of step d) the grain size of the material can be tuned. A longer duration of the final heat treatment of step d) leads to an increased grain size and a shorter duration leads to a decreased grain size. Along with an increased size of the grains the mechanical strength of the sheet metal product is decreased. Along with a decreased size of the grains the mechanical strength of the sheet metal product is increased. In this way the mechanical strength of the sheet metal product can be easily tuned.

[0058] This means that the method of the invention advantageously allows for tuning the microstructure and homogeneity of the sheet metal product by adjusting the process parameters of the warm rolling process of step c) and the subsequent heat treatment of step d). In this way the mechanical properties of the sheet metal product can be easily tuned.

[0059] In a preferred embodiment of the method of the invention, subsequent to the warm rolling process of step c) a cold rolling process c') is carried out on the strip. This means that a very high amount of deformation energy is introduced to and stored in the strip. Preferably the cold-rolling-process of step c') is performed at a temperature below 150 °C. More preferably the temperature is chosen in a range from 25° C to 100° C, more preferred from 25° C to 50° C. In other words, it is mostly preferred to perform the cold-rolling-process of step c') at ambient temperature.

[0060] By performing the cold rolling process of step c'), an advantageous, very fine grain structure with an increased homogeneity of the sheet metal product can be achieved in the final heat treatment of step d), due to a large number of recrystallization nuclei. Additionally, the achievable spectrum of grain sizes (and therefore mechanical strength) is significantly enhanced. This means that the average grain size in the material of the sheet metal product as well as its strength is predominantly determined by the warm rolling process of step c) and duration of the subsequent heat treatment of step d).

[0061] In a preferred embodiment of the method of the invention, the thickness of the strip is reduced by a rolling degree of 0.05 to 0.3 in the warm rolling process of step c) and/or the cold rolling process of step c'). The rolling degree refers to the deformation degree introduced by the rolling in one pass. The rolling degree is calculated by $\ln(t_{n-1}/t_n)$, wherein t_{n-1} is the thickness of the strip before the n^{th} rolling step and t_n is the thicknesses of the strip after the n^{th} rolling step.

[0062] Experiments have shown that this leads to an advantageous ratio of the amount of deformation energy introduced to the strip as well as a reasonable total processing time required to reach the desired thickness. Preferably the rolling degree is 0.05 to 0.3.

[0063] The thickness of the sheet metal product is determined by the thickness of the strip in the last rolling pass conducted. Depending on the embodiment of the method of the invention this may be the warm rolling process of step c) or the cold rolling process of step c'). The thickness of the sheet metal product can be adjusted as desired. Preferably the thickness of the final sheet metal product measures 0.2 mm to 3.5 mm, more preferably 0.8 mm to 2.0 mm.

[0064] This is a proper range of thickness for most applications, for example in the automotive industry.

[0065] In a preferred embodiment of the method of the invention the content of unavoidable impurities is less than 50 ppm in total in all process steps. The tolerable value individually refers to the content of each unavoidable impurity contained in the magnesium alloy. Some very critical impurities are Fe, Cu and Ni. The content of the unavoidable impurities is preferably controlled in all process steps a) to d), as well as b') and c') of the method of the invention.

[0066] The sheet metal product obtained by the method of the invention may be applied in transport industry or as biomedical implants.

[0067] The sheet metal product has an ultimate tensile strength in the range from 200 MPa to 325 MPa and/or a yield strength in the range from 125 MPa to 275 MPa while a low-temperature formability measures at least 6 on the Erichsen index.

[0068] The tensile strength of the sheet metal product can be tested at room temperature and a strain rate of $10^{-3}/s$ using a tensile sample having a gauge length of 25 mm. The Erichsen index is referred to as an index indicating formability of a sheet metal sample. The Erichsen index is the displacement of a spherical punch obtained at the moment of fracture of the sheet metal sample fixed at a blank holding force of 10 kN. The spherical punch has a diameter of 20 mm and moves at speed of 5 mm/min.

[0069] It is an advantage of the sheet metal product obtained by the method of the invention that a broad range of mechanical properties is covered while the low-temperature formability remains on a very high level throughout. This makes the sheet metal product of the invention highly attractive for applications in the transportation industry. In a vehicle structure, for example a car body, each component bears different mechanical specifications thus requiring a broad range of mechanical properties referring to the sheet metal product used for the component. Some examples are mounting structures and outer skin panel parts. The sheet metal product of the invention is thus capable of covering a wide spectrum of requirements and fields of applications without the need of changing the alloy system.

[0070] In a preferred embodiment the sheet metal product obtained by the method of the invention comprises a grain size in a range from 3 μm to 30 μm . As the mechanical strength of the sheet metal product of the invention strongly depends on the grain size, a wide spectrum of mechanical strength can be covered.

[0071] In a preferred embodiment, the sheet metal product obtained by the method of the invention comprises at least one mechanical property that does not vary by more than 30 % in all planar directions of the sheet metal product. The term mechanical property herein refers to actual material properties, rather than to sheer geometrical properties. Preferably a number of mechanical properties do not vary by more than 30 %. Preferably the mechanical property or the mechanical properties do not vary by more than 20 %, further preferred 10 % and further preferred 5 %. In other words, the sheet metal product of the invention advantageously comprises isotropic properties. Some important mechanical properties referred to are the ultimate strength, the yield strength and the low-temperature formability.

[0072] All embodiments mentioned in this application can be advantageously combined as long as nothing is stated to the contrary.

[0073] The invention is further described by the following embodiments and the figures according to the embodiments. It is illustrated in:

Figures 1a-c a preferred embodiment of a bending operation in step e) of the method of the invention (Figure 1a) and respective results of hemming examinations (Figure 1c) compared to the prior art (Figure 1b);

Figures 2a-f results of measures of stretch formability of different alloys used in the method of the invention;

Figures 3a-d results of bendability examinations on different alloys from Figures 2a-f exposed to a bending operation in step e) of the method of the invention ;

Figure 4 correlation of a bending ratio and temperature in a bending operation of step e) of the method of the invention; and

Figures 5a-c backscatter electron images of a sheet metal product produced by the method of the invention.

[0074] Figure 1a illustrates a sheet metal product 10, manufactured according to steps a) to d) of the method of the invention.

[0075] The sheet metal product 10 obtained according to the invention consists of an alloy specified by Reference 2 in Table 1 from the description above and accordingly comprises 0.6 wt% Zn and 0.2 wt% Ca in a Mg matrix.

[0076] As can be seen in Figure 1a, a bending operation according to step e) of the method of the invention is performed on the inventive sheet metal product 10. To demonstrate the excellent bendability of the sheet metal product 10 in this example, a hemming operation is performed on the sheet metal product 10, connecting the sheet metal product 10 to another sheet metal product 12.

[0077] The hemming operation is done at a bending ratio (r/t) of about 0.83, resulting from an initial bending radius r of the sheet metal product 10 of 1 mm and a thickness t of the sheet metal product 10 of 1.2 mm. A temperature T during the hemming operation is set to 160 °C.

[0078] In Figure 1b, results of hemming examinations on a number of sheet metal products 14 according to the prior art are shown, herein a AZ31 sheet metal product 14. The sheet metal product 14 has been machined in a hemming

operation, which, apart from the alloy and some of the temperatures T , was identical to the bending process of Figure 1a.

[0079] There are results of three hemming operations shown, wherein the hemming operation on the sheet metal product 14 on top has been performed at a temperature T of 220 °C, the hemming operation on the sheet metal product 14 in the middle has been performed at a temperature T of 200 °C and the hemming operation on the lower sheet metal product 14 has been performed at a temperature T of 160 °C.

[0080] As can be gained from Figure 1b, the AZ31 sheet metal product 14 in the middle shows first cracks 16 in the material, which occurred at a temperature T of 200 °C. The lower AZ31 sheet metal product 14 shows severe cracks 16 at 160 °C.

[0081] In Figure 1c, results of hemming examinations referring to the hemming operation from Figure 1a are shown. The temperature in this experiment was set to 160°C for all sheets.

[0082] The sheet metal product 10 according to the invention is shown on top. It is clearly visible, that no cracks are in the material, on the contrary to the prior art AZ31 sheet metal product 14 shown in the lower part of Figure 1b. This is due to the significantly enhanced bendability of the sheet metal product 10 according to the invention.

[0083] Further in Figure 1c, another sheet metal product 18 is shown, which has been manufactured identically with sheet metal product 10, but from an alloy comprising 0.6 wt% Ca, thereby not lying within the scope of the invention. Here, the significant effect of the amount of Ca can be seen, leading to significant cracks 16 at an amount of 0.4 wt% Ca or more.

[0084] Figures 2a-f show results of measures of stretch formability of different alloys used in the method of the invention. The scales shown in Figures 2a-f are in cm. The measures of stretch formability took place by measuring deformation height h of different sheet metal products 10 according to the invention.

[0085] In Figure 2a it is exemplarily shown how the deformation height h is measured. In the following, Table 2 puts the results of the measures in context to Table 1 in the main description, thus designating the respective alloy.

Table 2

h [mm]	Sub-Figure of Figure 2	Reference in Table 1
18	Figure 2a	1
24	Figure 2b	2
18	Figure 2c	3
22	Figure 2d	4
19.2	Figure 2e	5
22	Figure 2f	6

[0086] The sheet metal products 10 with Reference 2 in Table 1 clearly show the best stretch formability and is the same sheet metal products 10 as shown in Figure 1c. The sheet metal products 10 of Reference 2 represent a preferred embodiment of the sheet metal product 10 of the invention.

[0087] Now turning to Figures 3b-d, results of bendability examinations on different sheet metal products 10 from Figures 2a-f are shown, with the sheet metal products 10 being exposed to another embodiment of a bending operation of step e) of the method of the invention. In this bending operation a bending ratio r/t at 0.83 and a temperature of 160°C were chosen. However, in this case no hemming operation was performed, but bending each sheet metal product 10 by about 90°.

[0088] The alloys of the sheet metal products 10 in Figures 3b to 3d correspond to References 2 to 4 in Table 1 in this order.

[0089] As can be seen in Figures 3b to 3d, none of the sheet metal products 10 comprises any cracks in the material after bending, since all the shown sheet metal products 10 have been manufactured in the method of the invention.

[0090] Figure 3a shows a sheet metal product 10 made of an alloy based on Reference 1 in Table 1 but modified with regard to the ratio Zn/Ca which lies below 2/3. This means the ratio Zn/Ca ranges slightly below the preferred range of the method of the invention.

[0091] As can be seen in Figure 3a, the respective alloy reveals a first tendency towards forming cracks 16 under the demanding bending ratio of about 0.83 in this example.

[0092] Figure 4 illustrates correlation 22 of a bending ratio r/t and a temperature T in a bending operation of step e) of the method of the invention. The correlation 22 shows that crack-free bending is possible in a process window between a bending ratio r/t of 2.2 at 20 °C and a bending ratio r/t of 0.8 at 160 °C. Here, energy-efficient bending and a high-quality sheet metal product 10 are achievable at the same time. Inside the process window, for technically practical purposes and to achieve a crack-free sheet metal product 10, a linear correlation 22 can be assumed.

[0093] At temperatures lower than 20 °C the achievable bending ratio r/t progressively increases due to embrittlement of the material. At temperatures higher than 160 °C, even lower bending ratios r/t than 0.8 are achievable due to additional thermal activation. However, lower temperatures are desirable for industrial manufacturing.

[0094] Figures 5a-c show backscatter electron images of a sheet metal product 10 produced by the method of the invention.

[0095] Figure 5a shows a sheet metal product 10 consisting of an alloy according to Reference 1 of Table 1: Mg - 0.2Zn - 0.3Ca.

[0096] Figure 5b shows a sheet metal product 10 consisting of an alloy according to Reference 2 of Table 1: Mg - 0.6Zn - 0.2Ca.

[0097] Figure 5c shows a sheet metal product 10 consisting of an alloy according to Reference 5 of Table 1: Mg - 1.0Zn - 0.2Ca alloy.

[0098] The alloy of Figure 5a has a relatively high amount of the particles 24 corresponding to Mg_2Ca phases within the matrix and at the grain boundaries.

[0099] Here, the alloy of Figure 5b, which is a preferred embodiment, has significantly less particles 24 comparing to the alloy of Figure 5a.

[0100] The amount of the particles 24 in Figure 5c is comparable to that in Figure 5b. However, in Figure 5c additional particles 26 corresponding with a $Mg_6Ca_2Zn_3$ phase are observed.

Reference signs

[0101]

10 sheet metal product
 12 sheet metal product
 14 sheet metal product
 16 crack
 18 sheet metal product
 22 correlation
 24 particles
 26 particles
 h deformation height
 r bending radius
 t thickness
 T temperature

Claims

1. Method of manufacturing a sheet metal product (10), comprising the following steps:

a) providing a molten magnesium alloy consisting of

- 0.2 wt% to 2 wt% Zn,
- an amount of Ca,
- 0.0 wt% to 0.3 wt% Zr,
- 0.0 wt% to 1.0 wt% rare earth elements and/or Sr,
- unavoidable impurities, and
- the balance being Mg

b) forming a strip in a twin roll casting process,

c) performing a warm rolling process on the strip and

d) performing a subsequent heat treatment on the strip at 250°C to 450°C for 0,5 min to 60 min,

characterized in that

the amount of Ca is chosen from an interval [0.1 wt%, 0.4 wt%].

2. Method according to claim 1, wherein a ratio Zn/Ca is chosen from an interval [2/3, 5/1].

3. Method according to one of the preceding claims, wherein subsequent to the heat treatment of step d) a bending operation e) is performed on the sheet metal product (10).
4. Method according to claim 3, wherein the bending operation e) is performed at a bending ratio (r/t) of 0.5 or above.
5. Method according to one of the claims 3 or 4, wherein the bending operation e) is performed at a temperature (T) chosen from an interval [room temperature, 200 °C].
6. Method according to one of the preceding claims, wherein subsequent to the twin roll casting process of step b) an initial heat treatment b') is performed on the strip.
7. Method according to claim 6, wherein the initial heat treatment of step b') is performed at 400 °C to 500 °C for 30 min to 1440 min.
8. Method according to one of the preceding claims, wherein the warm rolling process of step c) is performed at 200 °C to 450 °C.
9. Method according to one of the preceding claims, wherein the strip formed in the twin roll casting process of step b) and prior to step c) measures 1 mm to 5 mm in thickness and 100 mm to 2000 mm in width.
10. Method according to one of the preceding claims, wherein a temperature of the molten Magnesium alloy is controlled to be 680 °C to 750 °C and a peripheral speed of rolls used in the twin roll casting process of step b) is controlled to be 0.7 m/min to 3.5 m/min.
11. Method according to one of the preceding claims, wherein subsequent to the warm rolling process of step c) a cold rolling process c') is carried out on the strip.
12. Method according to claim 11, wherein the cold rolling process of step c') is performed at a temperature below 150 °C.
13. Method according to one of the preceding claims, wherein a thickness of the strip is reduced by a rolling degree of 0.05 to 0.3 in the warm rolling process of step c) and/or a cold rolling process c') carried out on the strip subsequent to the warm rolling process of step c).
14. Method according to one of the preceding claims, wherein the sheet metal product (10) measures 0.2 mm to 3.5 mm in thickness (t).

Patentansprüche

1. Verfahren zur Herstellung eines Blechprodukts (10), umfassend die folgenden Schritte:
 - a) Bereitstellen einer aufgeschmolzenen Magnesiumlegierung bestehend aus
 - 0,2 Gew.% bis 2 Gew.% Zn,
 - einen Anteil an Ca,
 - 0,0 Gew.% bis 0,3 Gew.% Zr,
 - 0,0 Gew.% bis 1,0 Gew.% seltene Erdelemente und/oder Sr,
 - unvermeidbaren Verunreinigungen, und
 - als Restmenge Mg
 - b) Ausbilden eines Bandes in einem Doppelwalzengussprozess,
 - c) Ausführen eines Warmwalzprozesses an dem Band und
 - d) Ausführen einer anschließenden Wärmebehandlung an dem Band bei 250 °C bis 450 °C für 0,5 min bis 60 min,
- dadurch gekennzeichnet, dass
der Anteil an Ca aus einem Intervall [0,1 Gew.%, 0,4 Gew.%] ausgewählt wird.
2. Verfahren nach Anspruch 1, wobei das Verhältnis Zn/Ca aus einem Intervall [2/3, 5/1] ausgewählt wird.

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3. Verfahren nach einem der vorhergehenden Ansprüche, wobei im Anschluss an die Wärmebehandlung von Schritt d) ein Biegevorgang e) an dem Blechprodukt (10) ausgeführt wird.
- 5 4. Verfahren nach Anspruch 3, wobei der Biegevorgang e) mit einem Biegeverhältnis (r/t) von 0,5 oder höher ausgeführt wird.
5. Verfahren nach einem der Ansprüche 3 oder 4, wobei der Biegevorgang e) bei einer aus einem Intervall [Zimmertemperatur, 200 °C] ausgewählten Temperatur ausgeführt wird.
- 10 6. Verfahren nach einem der vorhergehenden Ansprüche, wobei im Anschluss an den Doppelwalzengussprozess von Schritt b) eine anfängliche Wärmebehandlung b') am Band ausgeführt wird.
7. Verfahren nach Anspruch 6, wobei die anfängliche Wärmebehandlung von Schritt b') bei 400 °C bis 500 °C für 30 min bis 1440 min ausgeführt wird.
- 15 8. Verfahren nach einem der vorhergehenden Ansprüche, wobei der Warmwalzprozess von Schritt c) bei 200 °C bis 450 °C ausgeführt wird.
9. Verfahren nach einem der vorhergehenden Ansprüche, wobei das im Doppelwalzengussprozess von Schritt b) ausgebildete Band vor dem Schritt c) 1 mm bis 5 mm in der Dicke und 100 mm bis 2000 mm in der Breite misst.
- 20 10. Verfahren nach einem der vorhergehenden Ansprüche, wobei eine Temperatur der aufgeschmolzenen Magnesiumumlegierung auf 680 °C bis 750 °C gesteuert wird und eine Umfangsgeschwindigkeit der im Doppelwalzengussprozess von Schritt b) verwendeten Walzen auf 0,7 m/min bis 3,5 m/min gesteuert wird.
- 25 11. Verfahren nach einem der vorhergehenden Ansprüche, wobei im Anschluss an den Warmwalzprozess von Schritt c) ein Kaltwalzprozess c') an dem Band ausgeführt wird.
12. Verfahren nach Anspruch 11, wobei der Kaltwalzprozess von Schritt c') bei einer Temperatur von unter 150 °C ausgeführt wird.
- 30 13. Verfahren nach einem der vorhergehenden Ansprüche, wobei eine Dicke des Bandes um einen Abwalzgrad von 0,05 bis 0,3 in dem Warmwalzprozess von Schritt c) und/oder einem im Anschluss an den Warmwalzprozess von Schritt c) an dem Band ausgeführten Kaltwalzprozess c') reduziert wird.
- 35 14. Verfahren nach einem der vorhergehenden Ansprüche, wobei das Blechprodukt (10) 0,2 mm bis 3,5 mm in der Dicke (t) misst.

Revendications

1. Procédé de fabrication d'un produit de feuille métallique (10), comprenant les étapes suivantes :

a) fourniture d'un alliage de magnésium fondu constitué de

- 0,2 % en poids à 2 % en poids de Zn,
- une quantité de Ca,
- 0,0 % en poids à 0,3 % en poids de Zr,
- 0,0 % en poids à 1,0 % en poids d'éléments des terres rares et/ou de Sr,
- des impuretés inévitables, et
- le reste étant Mg

b) formation d'une bande dans un processus de coulée à deux cylindres,

c) réalisation d'un processus de laminage à chaud sur la bande et

d) réalisation d'un traitement thermique subséquent sur la bande à une température de 250 °C à 450 °C pendant 0,5 min à 60 min,

caractérisé en ce que

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la quantité de Ca est choisie dans un intervalle [0,1 % en poids, 0,4 % en poids].

2. Procédé selon la revendication 1, un rapport Zn/Ca étant choisi dans un intervalle [2/3, 5/1].

5 3. Procédé selon l'une des revendications précédentes, dans lequel après le traitement thermique de l'étape d), une opération de pliage e) est réalisée sur le produit de feuille métallique (10).

4. Procédé selon la revendication 3, l'opération de pliage e) étant réalisée à un rapport de pliage (r/t) de 0,5 ou plus.

10 5. Procédé selon l'une des revendications 3 ou 4, l'opération de pliage e) étant réalisée à une température (T) choisie dans un intervalle [température ambiante, 200 °C].

6. Procédé selon l'une des revendications précédentes, dans lequel après le processus de coulée entre cylindres de l'étape b) un traitement thermique initial b') est réalisé sur la bande.

15 7. Procédé selon la revendication 6, le traitement thermique initial de l'étape b') étant réalisé à une température de 400 °C à 500 °C pendant 30 min à 1 440 min.

20 8. Procédé selon l'une des revendications précédentes, le processus de laminage à chaud de l'étape c) étant réalisé à une température de 200 °C à 450 °C.

9. Procédé selon l'une des revendications précédentes, la bande formée dans le processus de coulée entre cylindres de l'étape b) et avant l'étape c) mesurant 1 mm à 5 mm d'épaisseur et 100 mm à 2 000 mm de largeur.

25 10. Procédé selon l'une des revendications précédentes, une température de l'alliage de magnésium fondu étant réglée pour être de 680 °C à 750 °C et une vitesse périphérique de cylindres utilisés dans le processus de coulée entre cylindres de l'étape b) étant réglée pour être de 0,7 m/min à 3,5 m/min.

30 11. Procédé selon l'une des revendications précédentes, dans lequel après le processus de laminage à chaud de l'étape c), un processus de laminage à froid c') est réalisé sur la bande.

12. Procédé selon la revendication 11, le processus de laminage à froid c') étant réalisé à une température inférieure à 150 °C.

35 13. Procédé selon l'une des revendications précédentes, une épaisseur de la bande étant réduite d'un degré de laminage de 0,05 à 0,3 dans le processus de laminage à chaud de l'étape c) et/ou un processus de laminage à froid c') étant réalisé sur la bande après le processus de laminage à chaud de l'étape c) .

40 14. Procédé selon l'une des revendications précédentes, le produit de feuille métallique (10) mesurant 0,2 mm à 3,5 mm d'épaisseur (t).

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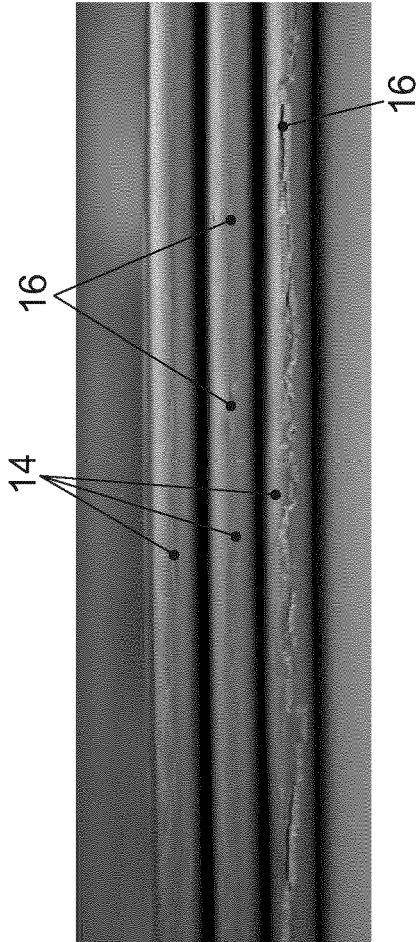


FIG. 1b

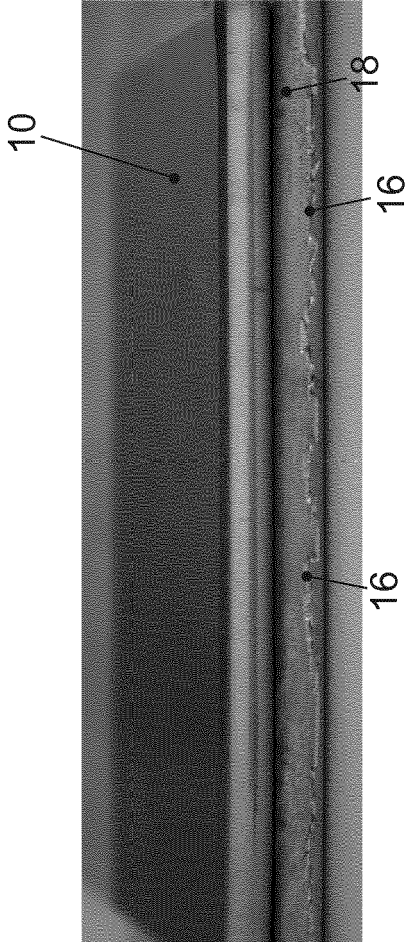


FIG. 1c

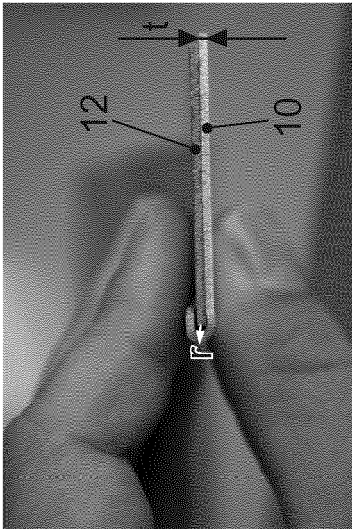


FIG. 1a

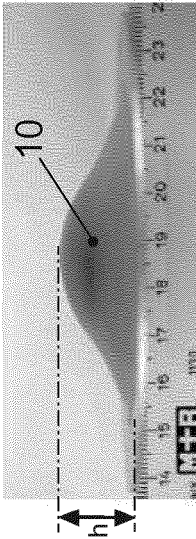


FIG. 2a

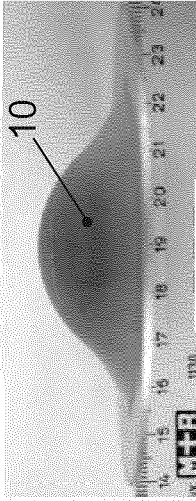


FIG. 2b

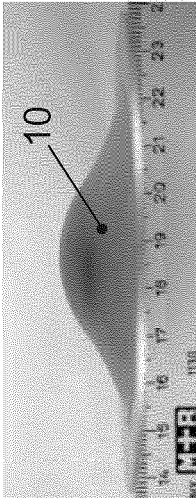


FIG. 2c

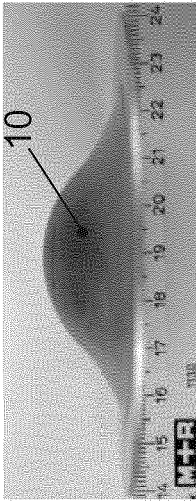


FIG. 2d

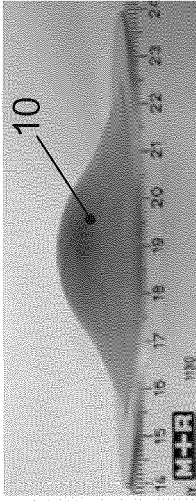


FIG. 2e

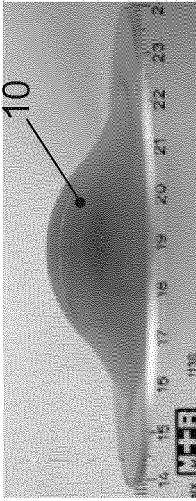
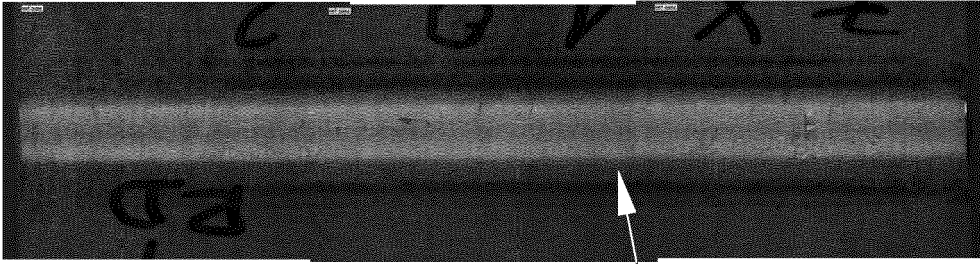
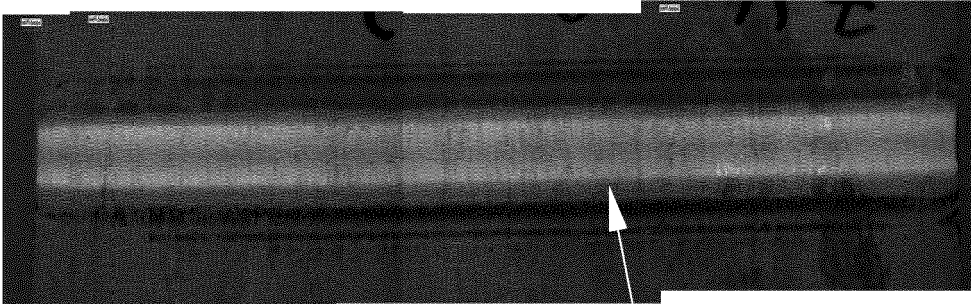


FIG. 2f



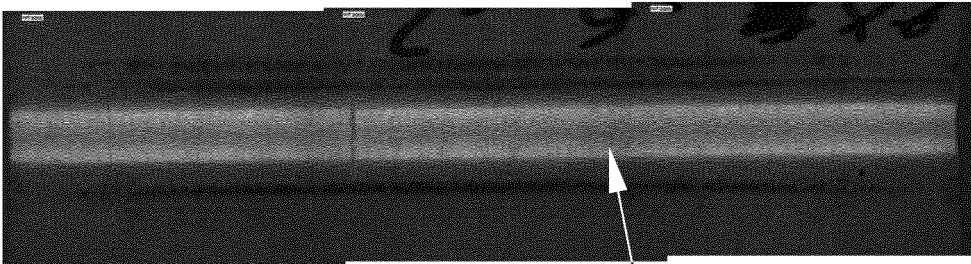
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FIG. 3d



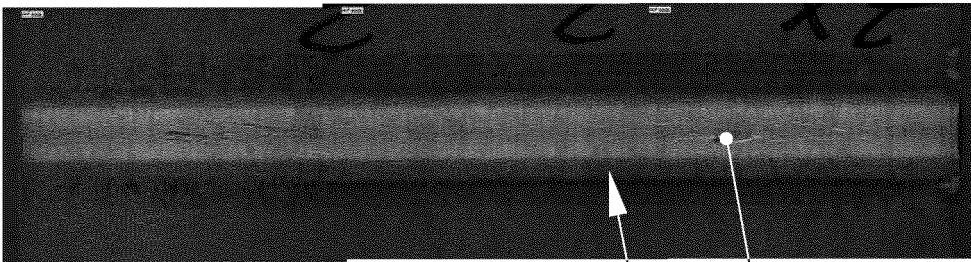
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FIG. 3c



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FIG. 3b



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FIG. 3a

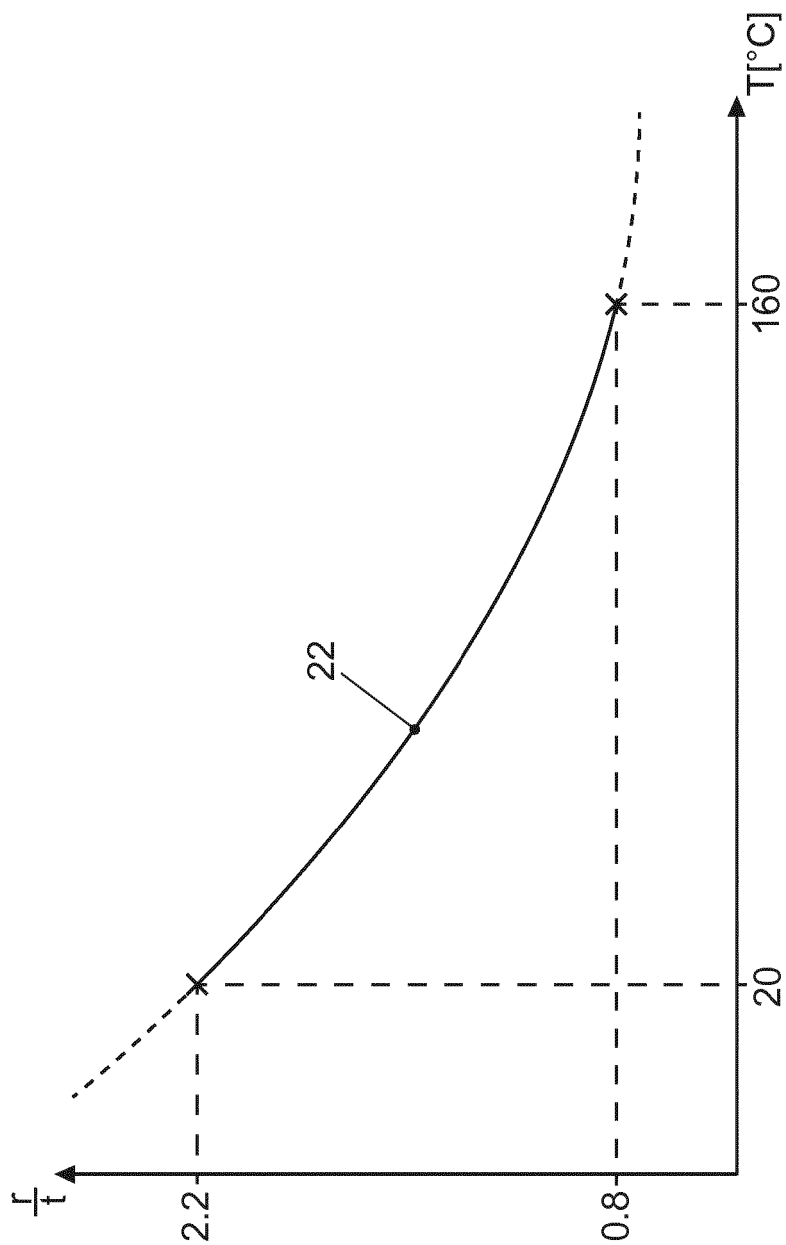


FIG. 4

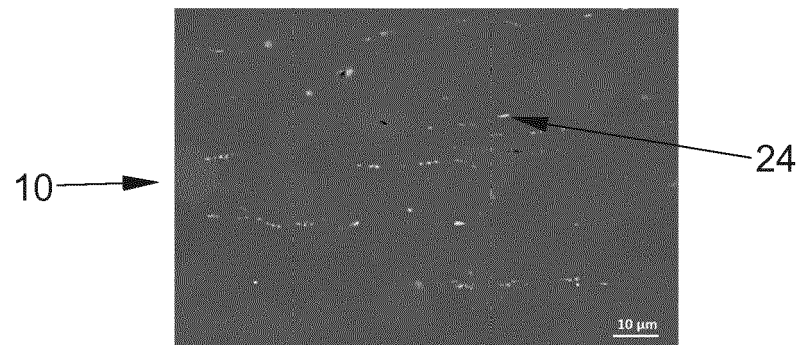


FIG. 5a

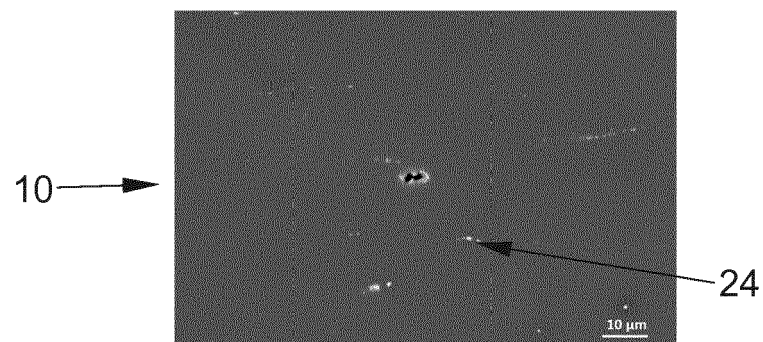


FIG. 5b

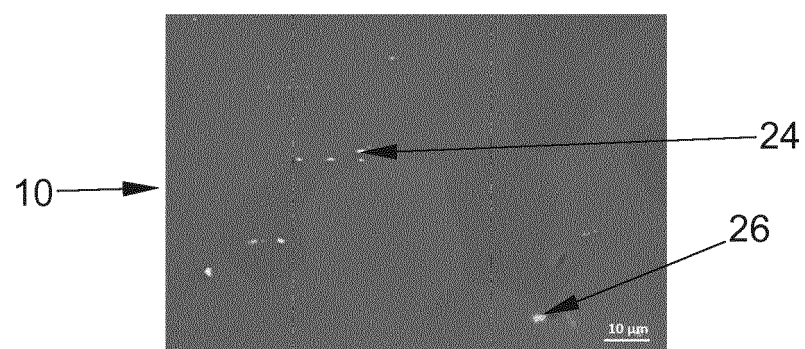


FIG. 5c

REFERENCES CITED IN THE DESCRIPTION

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