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(54) A PRODUCTION METHOD FOR A FLAT METAL PLATE

HERSTELLUNGSVERFAHREN EINER FLACHEN METALLPLATTE

PROCÉDÉ DE PRODUCTION D'UNE PLAQUE MÉTALLIQUE PLATE

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Description

[0001] The invention relates to a production method for manufacturing a flat metal plate.

[0002] A flat metal plate is generally produced by hot-rolling a cast metal block to form a thin, plate-shaped metal layer. When using the term metal plate, it generally indicates that the thickness of the metal layer is greater than 6 mm, or 6mm or more. With thinner layer thicknesses, the term metal sheet or sheet metal is generally used. In the ASTM A480M standard and the Bureau of Indian Standards ICS 77.140.01, for example, the threshold value between metal plate and metal sheet is defined as a thickness of 5 mm. In ISO 6929:2013(en) standard, points 1.3.2.1.2 and 1.3.2.2.2, this threshold value is defined as a thickness of 3 mm. In European standard EN10051, a range of thicknesses, from 2 mm to 25 mm, is given for metal sheets / metal plates. The term flat in the context of flat metal plate is intended to mean that the metal plate has a virtually rectangular cross section whose width is much greater than the thickness. The width of the flat metal plate is generally greater than 0.6 m and may increase to, for example, more than 2 m, whereas the thickness will remain lower than 2 to 3 cm.

[0003] Large amounts of hot-rolled metal plate are transported in the form of metal coils. These metal coils may have a weight of several tens of tonnes and have an inner diameter of, for example, 0.5 m to 1 m and have an outer diameter of, for example, more than 2 m and may thus contain several hundreds of metres of metal plate in wound form. The flat metal plate is subsequently uncoiled from the metal coil by means of a production process and cut into pieces at right angles to the direction of movement of the flat metal plate so that a cut flat metal plate of a specific length along the direction of movement is obtained. These cut flat metal plates have a length, for example, in the range from 0.8 m to 15 m, for example 6 m. These cut metal plates are used, for example, in further production steps in which smaller parts are cut from this metal plate, such as for example by means of laser cutting. In this case, the metal plate is cut by means of a high-power laser. Since the head of such a laser moves at only a limited distance from the surface of the metal plate, the metal plate has to meet specific requirements regarding minimum flatness and maximum curvature in order to be considered for such an operation.

[0004] In addition, not only the metal plate, but also the smaller parts cut therefrom have to satisfy specific requirements regarding minimum flatness and maximum curvature. Although the cut metal plate may overall satisfy these requirements when all residual stresses in the metal plate compensate one another to a sufficient degree, the uneven local distribution of residual stresses across the metal plate may result in the cut-out part having a much greater curvature and lower flatness. This problem may occur, in particular with relatively thick metal plates, to such a degree that there is a risk of deformations occurring suddenly during the cutting process when cutting the part and damaging the laser head.

[0005] It is clear that these problems may occur not only with a laser-cutting process, but with any other metal-treatment process in which smaller parts are made from such a metal plate, as a result of which the desired quality of the part to be produced cannot be ensured.

[0006] A production method for manufacturing a flat metal plate of a specific thickness which is uncoiled from a metal coil is known, for example, from CA940431.

[0007] In general, this production process comprises the following steps:

- uncoiling the metal plate from the metal coil using an uncoiler;
- subsequently flattening the metal plate by means of a flattening apparatus having alternating flattening rollers which are configured to deform the metal plate according to a specific alternating curvature with respect to the direction of movement of the metal plate; and
- subsequently cutting the metal plate into pieces at right angles to the direction of movement (M) by means of a cutting device, so that a cut flat metal plate of a specific length along the direction of movement is obtained.

[0008] According to this production process, the flattening apparatus is adjusted in such a way that the determined alternating curvature has a maximum surface strain of the metal plate along the direction of movement in the range from 0.6% to 3.0%, for metal plates having a specific thickness in the range from 4.5 mm to 16 mm. See for example Fig. 4 of CA940431. In order to give an indication of the curvature, the maximum deviation a at right angles to the direction of movement was determined over a length of 3 m of the metal plate for parts which were cut from the metal plate and had a length L of 3 m and a width b of 150 mm. As can be seen in Figs 6 to 11, these parts were cut out at various locations across the width of the metal plate. It can clearly be seen in Figs 7, 8, and 11 that, for the cut parts, the largest maximum deviation a for all parts cut from the metal plate may approach 10 mm. This means that it is not possible with this method to guarantee that such parts can be cut from the metal plate and consistently produce a curvature having a maximum deviation a of less than 10 mm for a length L of 3 m or, in other words, a maximum curvature having a maximum deviation of less than approximately 3 mm per length L of 1 m of the metal plate along the direction of movement for metal plates having a specific thickness which is greater than 4.5 mm. Not even if the maximum curvature of the overall cut metal plate results in a maximum deviation according to a cross section along the direction of movement which is less than 3 mm per length L of 1 m along the direction of movement.

[0009] As described in the first paragraph on page 2 of CA940431, it was not possible to guarantee such a maximum curvature for the parts cut out of the metal plate when using a production method comprising the following steps:

- uncoiling the metal plate from the metal coil using an uncoiler;
- subsequently cold-rolling the metal plate by means of a skin-pass roller with opposite skin-pass rollers which are configured to achieve a specific skin-pass elongation of the metal plate along the direction of movement of the metal plate;
- subsequently flattening the metal plate by means of a flattening apparatus with alternating flattening rollers which are configured to deform the metal plate according to a specific alternating curvature with respect to the direction of movement of the metal plate,

in which the specific alternating curvature has a maximum surface strain of the metal plate along the direction of movement which is at most 0.6%.

[0010] This is confirmed, for example, by JP 2000-176504 A where, for example, Table 1 clearly shows that such a production process for metal sheets having a relatively limited thickness using a specific skin-pass elongation in the range from 0.5% to 2% and the specific alternating curvature of the flattening apparatus with a maximum surface strain 0.2% to 0.5%, can only achieve a maximum curvature of 0.40% or approximately 4 mm of deviation per length of 1 m for a thickness of 5.6 mm for the smallest width of the steel plate of 650 mm. It should furthermore be noted that this relates to the maximum curvature for the uncut steel plate and that the curvature for smaller parts cut therefrom can be expected to be significantly greater. Furthermore, it is also clear from Fig. 1 that the steel strip is coiled up again after the production method to form a metal coil instead of the metal plate being cut into pieces at right angles to the direction of movement by means of a cutting device, so that a cut flat metal plate of a specific length along the direction of movement is obtained. This is an additional drawback since the results of such a production process with respect to optimum flatness and minimum curvature along the direction of movement of the metal plate are thus at least partly nullified by the longitudinal residual stresses introduced by the plastic deformation of the metal plate which has been coiled up again.

[0011] In addition, JP 2007-330996 A shows that when the surface strain in the flattening apparatus is greater than 1%, as indicated in the sixth column, even metal sheets having a limited thickness of 2 to 2.5 mm may become damaged at the surface, resulting in a deterioration of the surface quality, see the penultimate column.

[0012] These two documents confirm that there is still a need for a production process which is able to produce metal plates of relatively great thickness, more particularly metal plates of a thickness greater than or equal to 8 mm, and also metal plates having a relatively high yield point, more particularly a yield point higher than 400 N/mm^2, in which the flatness of the overall cut metal plate and the distribution of the longitudinal residual stresses within the metal plate are of such a nature that a higher degree of flatness and a lower maximum curvature can be guaranteed when cutting smaller parts from such a metal plate.

[0013] According to a first aspect of the invention, a production method for manufacturing a flat metal plate of a specific thickness which is uncoiled from a metal coil is provided, which comprises the following steps:

- uncoiling the metal plate from the metal coil using an uncoiler;
- subsequently cold-rolling the metal plate by means of a skin-pass roller with opposite skin-pass rollers which are configured to achieve a specific skin-pass elongation of the metal plate along the direction of movement of the metal plate;
- subsequently flattening the metal plate by means of a flattening apparatus with alternating flattening rollers which are configured to deform the metal plate according to a specific alternating curvature with respect to the direction of movement of the metal plate; and
- subsequently cutting the metal plate into pieces at right angles to the direction of movement by means of a cutting device, so that a cut flat metal plate of a specific length along the direction of movement is obtained,

CHARACTERIZED IN THAT

- the alternating curvature is such that it results in a plastification ratio of 55% or more, in which said plastification ratio is determined by the ratio across the thickness of the metal plate between:
- the plastic zones of material of the metal plate which is plastically deformed; and
- the elastic zone of material of the metal plate which is only elastically deformed at the location of the maximum curvature of the alternating curvature; and
- the skin-pass elongation is such that it results in a translation ratio of 15% or more at the location of the alternating curvature, the translation ratio being determined by the ratio across the thickness of the metal plate between:
- the translation of the elastic zone at the location of the maximum curvature of the alternating curvature; and
- half the thickness of the metal plate.

[0014] This production method succeeds in equalizing longitudinal residual stresses even for metal plates, for a larger part of the thickness of the metal plate than was hitherto possible. In addition, this production method ensures that even for metal plates of such thickness, the uniformity of the longitudinal residual stresses can be guaranteed, so that it is ensured that parts can be cut from such a plate which have a maximum curvature which results in a deviation of 3 mm per length of 1 m along the direction of movement of the metal plate. This is caused by the synergetic effect of a sufficiently high plastification ratio caused by the flattening apparatus and a specific selected skin-pass which results in a sufficiently large translation ratio. As will be described below in more detail, this results in a guaranteed and hitherto unachieved equalization of the longitudinal residual stresses across a greater part of the thickness of the metal plate. The reason for this is that, at the location of the flattening apparatus, this synergetic effect causes the elastic zone to move closer to the compression side of the curve. This therefore means that the elastic zone, after passing through the alternating curve, alternately moves to that side of the metal plate which is in contact with the alternating flattening rollers of the flattening apparatus. This means alternately, i.e. to the top side and bottom side of the metal plate. As a result thereof, a larger part of the thickness of the metal plate alternately ends up in the plastic zone after passing through the alternating curve, which is necessary for equalization of the longitudinal residual stresses, as a result whereof the longitudinal residual stresses are thus equalized across a greater part of the thickness of the metal plate.

[0015] This production method is particularly advantageous when the thickness of the metal plate has been determined to be greater than or equal to 8 mm. This production method is also particularly advantageous in the case of metal plates in which the yield point of the metal plate is higher than 400 N/mm^2, preferably higher than 600 N/mm^2. For example, in the case of metal plates having a yield point of 700 N/mm^2 and higher, or 1000 N/mm^2 and higher.

[0016] According to a preferred embodiment, it is provided that:

- the thickness of the metal plate is less than 30 mm, for example 10 mm to 25 mm, preferably 12 mm to 18 mm;
- the alternating curvature is such that it results in a plastification ratio of 60% or more at the location of the maximum curvature of the alternating curvature; and
- the skin-pass elongation is such that, at the location of the alternating curvature, it results in a movement of the elastic zone over 20% or more of the thickness of the metal plate at the location of the maximum curvature of the alternating curvature.

[0017] With such a production method, it is possible to guarantee that virtually the entire thickness alternately ends up in the plastic zone which results in an optimum equalization of the longitudinal residual stresses in the metal plate and a guaranteed minimum curvature of the parts cut from the metal plate.

[0018] According to a preferred embodiment, it is provided that:

- the specific skin-pass elongation is at most 5%; and
- the specific alternating curvature has a maximum surface strain of the metal plate along the direction of movement which is at most 1 %.

[0019] This makes it possible to equalize the residual longitudinal stresses in an optimum manner, even for a metal plate of such thickness, and additionally to guarantee a good surface quality of the metal plate.

[0020] According to an embodiment of the invention:

- the specific skin-pass elongation is at most 4.5%, for example 0.2% to 4.5%.
- the maximum surface strain of the metal plate along the direction of movement is at most 0.6%, for example 0.05% to 0.5%.

[0021] This further optimizes the distribution of the internal stresses and the surface quality of the metal plate.

[0022] According to an embodiment, the production method furthermore comprises the following additional step:

- after uncoiling the metal plate using the uncoiler and cold-rolling the metal plate using the skin-pass roller, preparatory flattening of the metal plate by means of a preparatory flattening apparatus with alternating preparatory flattening rollers which are configured to reduce the curvature of the metal plate along the direction of movement to a value below a specific flatness tolerance, in which the specific flatness tolerance results in a maximum deformation of 20 mm at right angles to the direction of movement, measured per length of 1 m of the metal plate along the direction of movement.

[0023] This results in a further optimization of the surface treatment by the skin-pass roller since the flatness of the metal plate on the entry side of the skin-pass walls ensures a more homogenous surface treatment.

[0024] According to an embodiment, the specific alternating curvature contains a specific plurality of alternating curves. Preferably, the specific plurality of alternating curves is three to ten, preferably five to eight. Preferably, the specific alternating curvature virtually comprises a damped sinusoid along the direction of movement.

[0025] Such a flattening in combination with the skin-pass operation not only ensures a suitable flatness tolerance, but also a more homogenous distribution of the internal stresses in the metal plate having such a thickness.

[0026] According to an embodiment, the production method furthermore comprises the following additional step:

- determining an elongation correlation function for the skin-pass elongation and a flattening correlation function for the alternating curvature as a function of the thickness of the metal plate and the associated plastification ratio and translation ratio;

- actuating the skin-pass roller by an elongation correlation module as a function of the elongation correlation function; and
- actuating the flattening apparatus by a flattening correlation module as a function of the flattening correlation function.

[0027] Preferably, the elongation correlation function and the flattening correlation function are furthermore determined as a function of the thickness and/or the yield point of the metal plate.

[0028] In this way, it becomes possible to obtain parts cut from the metal plate which have a guaranteed very limited curvature in an efficient and consistent way.

[0029] According to a second aspect of the invention, a production line is provided for manufacturing a flat metal plate of a specific thickness which is uncoiled from a metal coil according to the production method according to the first aspect of the invention, the production line comprising:

- an uncoiler for uncoiling the metal plate from the metal coil;
- a skin-pass roller for subsequently cold-rolling the metal plate using opposite skin-pass rollers which are configured to produce a specific skin-pass elongation of the metal plate along the direction of movement of the metal plate; and
- a flattening apparatus for subsequently flattening the metal plate using alternating flattening rollers which are configured to deform the metal plate according to a specific alternating curvature with respect to the direction of movement of the metal plate,
- a cutting device for subsequently cutting the metal plate into pieces at right angles to the direction of movement (M), so that a cut flat metal plate of a specific length along the direction of movement (M) is obtained,

CHARACTERIZED IN THAT

- the alternating curvature is such that it results in a plastification ratio of 55% or more, in which said plastification ratio is determined by the ratio across the thickness of the metal plate between:
- the plastic zones of material of the metal plate which is plastically deformed; and
- the elastic zone of material of the metal plate which is only elastically deformed at the location of the maximum curvature of the alternating curvature; and
- the skin-pass elongation is such that it results in a translation ratio of 15% or more at the location of the alternating curvature, the translation ratio being determined by the ratio across the thickness of the metal plate between:
- the translation of the elastic zone at the location of the maximum curvature of the alternating curvature; and
- half the thickness of the metal plate.

[0030] This production line is particularly advantageous if the specific thickness of the metal plate is greater than or equal to 8 mm. This production line is also particularly advantageous in the case of metal plates in which the yield point of the metal plate is higher than 400 N/mm^2, preferably higher than 600 N/mm^2. For example, in the case of metal plates having a yield point of 700 N/mm^2 and higher, or 1000 N/mm^2 and higher.

[0031] According to a third aspect of the invention, a flat metal plate produced according to the production method according to the first aspect of the invention is provided.

[0032] The invention will now be described in more detail by way of example and with reference to embodiments illustrated in the drawings, in which:

- Fig. 1 diagrammatically shows an embodiment of the production line for manufacturing a flat metal plate of a specific thickness which is uncoiled from a metal coil according to the production method according to the invention; and
- Fig. 2 diagrammatically shows a side view of a cut flat metal plate produced using the production line from Fig. 1;
- Fig. 3 shows a top view of the metal plate from Fig. 2;
- Fig. 4 diagrammatically illustrates how the maximum curvature of parts cut from the metal plate from Figs 3 and 4 can be determined;
- Figs 5 and 6 illustrate the effect of the production method according to the prior art;
- Figs 7 and 8 illustrate the effect of the production method according to the invention;
- Fig. 9 shows an embodiment of the elongation correlation function and the flattening correlation function;
- Fig. 10 shows a selection of suitable steel plates for use with the production method according to the invention.

[0033] Fig. 1 shows a production line 1 for manufacturing a flat metal plate 10 of a specific thickness 12 which is uncoiled from a metal coil 20 according to the production method which will be described below in more detail. As can be seen in Fig. 1, the production line 1 comprises an uncoiler 30 for uncoiling the metal plate 10 from the metal coil 20. It is clear in this case that the diameter of the metal coil 20 diminishes while the metal coil 20 is being uncoiled, often from more than 2 metres, diagrammatically illustrated by a solid line, to the minimum inner diameter which is normally somewhere between 1 m and 0.5 m, as is diagrammatically illustrated by a dashed line.

[0034] After uncoiling the metal plate 10 from the metal coil 20 using the uncoiler 30, the metal plate 10 is fed to a preparatory flattening apparatus 60 with alternating preparatory flattening rollers 62, as is diagrammatically illustrated. This preparatory flattening apparatus 60 ensures that the metal plate 10 is fed to the subsequent skin-pass roller 40 along the direction of movement M, irrespective of the changing diameter of the metal coil 20. Furthermore, the flattening rollers 62 of the preparatory flattening apparatus 60 ensure that the curvature of the metal plate 10 is reduced along the direction of movement M to a value below a specific flatness tolerance during preparatory flattening. A suitable specific flatness tolerance results in a maximum deformation of 20 mm at right angles to the direction of movement M measured per length of 1 m of the metal plate 10 along the direction of movement M. Such a flatness tolerance ensures optimum effectiveness of the successive operation by the skin-pass roller 40.

[0035] This skin-pass roller 40 subsequently cold-rolls the metal plate 10 using opposite skin-pass rollers 42 which are configured to produce a specific skin-pass elongation 44 of the metal plate 10 along the direction of movement M of the metal plate 10. The skin-pass elongation 44 may be determined, for example by means of a pair of length sensors 82, 84 on the entry side and exit side of the skin-pass roller 40, in which the percentage difference between the measurements of these two length sensors 82, 84 is a measure of the specific skin-pass elongation 44. As is diagrammatically illustrated, the length sensors are coupled to a controller 80 which, on the basis of these measurements, controls the pressure which is exerted on the skin-pass rollers 42, so that the desired skin-pass elongation 44 is achieved.

[0036] After the skin-pass roller 40, the metal plate 10 is fed to a flattening apparatus 50 along the direction of movement M. This flattening apparatus 50 comprises alternating flattening rollers 52 which are configured to deform the metal plate according to a specific alternating curvature 54 with respect to the direction of movement M of the metal plate 10 in order to thus flatten the metal plate 10. This is achieved by actuating the flattening apparatus in such a manner that the alternating curvature 54 causes a maximum surface strain 56 on the expansion side of the metal plate 10 along the direction of movement M in an alternating manner. That is to say alternately on the top side and bottom side of the metal plate 10, in each case when this respective side is situated opposite that side which comes into contact with the flattening roller 52. It is clear that a so-called negative surface strain will occur on the compression side of the metal plate which is in contact with the flattening roller 52. By alternately subjecting the opposite zones of the metal plate to positive and negative strain, the longitudinal residual stresses in the metal plate are equalized, as will be described below in more detail. Such a flattening apparatus 50 can also be referred to as a levelling apparatus 50 or leveller 50, and the flattening rollers 52 could also be referred to as plurality of levelling rollers 52. The function of such a flattening apparatus 50 referred to above as flattening the metal plate 10, could also be referred to as levelling the metal plate 10 by means of such a levelling apparatus 50 or leveller 50.

[0037] Subsequently, the metal plate 10 is cut into pieces at right angles to the direction of movement M by means of a cutting device 70. In this way, a cut flat metal plate 10 of a specific length 14 along the direction of movement M is obtained. These cut flat metal plates have a length, for example, in the range from 0.8 m to 15 m, for example 6 m. Preferably, the cutting device makes it possible to keep the conveying speed of the metal plate 10 along the direction of movement M virtually constant, so that the effects of the skin-pass roller 40 and the flattening apparatus 50 can thus be provided on the metal plate 10 based on the assumption that the time during which all zones of the metal plate 10 will be subjected thereto will be virtually constant along the direction of movement M.

[0038] Optionally, the cut metal plate 10 may subsequently be subjected to different subsequent operations, such as for example transportation, stacking or packaging operations, in which the cut metal plates 10 are grouped to form suitable packs 90 for further storage or transportation. Also in this case, it is important for the cut metal plates 10 to be treated with a sufficient degree of care, so that no substantial deformations occur during these operations which could adversely affect the flatness and the distribution of the residual stresses.

[0039] As is diagrammatically illustrated in Fig. 1, it is obvious that optionally additional sensor may be fitted in order to supply that information so as to optimize the production process via the controller 80. Thus, a flatness sensor 86 is for example illustrated downstream of the flattening apparatus 50 to provide information to the controller 80 which is representative of the resulting flatness of the metal plate 10 after the skin-pass and flattening operation. This may, for example, be a suitable distance sensor which is able to determine the fluctuation in the relative deviation transversely with respect to the direction of movement M and with respect to the surface of the metal plate 10, for example at different locations along the width 16 of the metal plate 16. In this way, a flatness profile can be compiled for the metal plate 10 on the basis of which the settings of the production process can be verified and/or adjusted by the controller 80 to guarantee a desired flatness.

[0040] A side view and a top view of a metal plate produced according to the production process illustrated in Fig. 1 is illustrated in Figs 2 and 3, respectively. This production process is particularly advantageous in the case of metal plates 10 whose thickness 12 is greater than or equal to 8 mm. Although the production process may also be used for other metals, it is particularly suitable for hot-rolled steel plates which are situated on a metal coil 20. Suitable hot-rolled steel plates have a tensile strength, for example, in the range from 300 to 700 N/mm^2 or more, an elastic limit or yield point in the range from 200 to 600 N/mm^2 or more. The production method is particularly advantageous when the yield point of the metal plate is higher than 400 N/mm^2, preferably higher than 600 N/mm^2. For example in the case of metal plates having a yield point of 700 N/mm^2 and higher, or 1000 N/mm^2 and higher. The most optimum production method for such steel plates 10 is one where the thickness 12 of the metal plate 10 is less than 30 mm, for example 10 mm to 25 mm, preferably 12 mm to 18 mm. The width 16 of the flat metal plate 10 is generally greater than 0.6 m and may be as much as, for example, more than 2 m. Such cut flat metal plates 10 have a length in the range of, for example, 0.8 m to 15 m. For the illustrated example in Figs 2 and 3, the length is assumed to be approximately 5 m.

[0041] In order to determine a figure for the maximum curvature of parts 11 cut from this metal plate 10, elongate parts 11 are cut out at various locations along the width 16 of the metal plate 10, as is illustrated in Fig. 3, and virtually extend along the direction of movement M. Such parts 11 have, for example, a length of 3 m and a width of 3 mm. An indication for the maximum curvature of the parts 11 is then formed, as is illustrated in Fig. 4, by the part whose deviation 18 transversely with respect to the direction of movement M is greatest. This deviation 18 may be expressed as a deviation per metre of the length of the cut part. In this example, where the length of the part 11 is 3 m and a maximum deviation 18 of less than 9 mm can be guaranteed via the production method, the maximum deviation can thus be described as being 3 mm per 1 m of length of the part cut out of the metal plate.

[0042] If the metal plate 10 is only subjected to a flattening operation by the flattening apparatus 50, then Figs 5 and 6 diagrammatically show the effect on the longitudinal strain ε and the associated longitudinal stress σ distributed across the thickness 12 of the metal plate 10 at the location of the respective alternating flattening rollers 52 which cause a maximum surface strain at the top side 214 and the bottom side 216 of the flat metal plate 10, respectively.

[0043] Fig. 5 shows a side view of the metal plate 10 at the location of the maximum curvature of the alternating curvature 54, where a maximum surface strain is caused at the top side 214 of the metal plate, that is to say at the location of the flattening roller 52 which comes into contact with the bottom side 216 and produces the maximum curvature of the alternating curvature 54 there by its relative position with respect to the upstream and downstream flattening roller 52, viewed along the direction of movement M. As illustrated, the strain will decrease virtually linearly, from a positive maximum surface strain at the location of the top side 214 of the metal plate 10 to virtually no strain virtually halfway along the thickness 12 of the metal plate 10 in order to decrease further in linear fashion and produce a negative surface strain at the location of the bottom side 216 of the metal plate which virtually corresponds, as an absolute value, to the positive maximum surface strain. This therefore means that the neutral fibre 200 of the metal plate 10, where the strain at bending is virtually zero, is situated approximately halfway along the thickness 12 of the metal plate. In other words, the distance 224 between the neutral fibre 200 and the top side 214 of the metal plate 10, as well as the distance 226 between the neutral fibre 200 and the bottom side 216 of the metal plate 10 is virtually half of the thickness 12 of the metal plate 10.

[0044] Fig. 6 shows a side view of the metal plate 10 at the location of the maximum curvature of the alternating curvature 54, where a maximum surface strain is caused at the bottom side 216 of the metal plate 10, that is to say at the location of the flattening roller 52 which comes into contact with the top side 214 and produces the maximum curvature of the alternating curvature 54 there by its relative position with respect to the upstream and downstream flattening roller 52, viewed along the direction of movement M. As illustrated, the strain will decrease virtually linearly, from a positive maximum surface strain at the location of the top side 214 of the metal plate 10 to virtually no strain virtually halfway along the thickness 12 of the metal plate 10 in order to decrease further in linear fashion and produce a negative surface strain at the location of the bottom side 216 of the metal plate which virtually corresponds, as an absolute value, to the positive maximum surface strain. As in Fig. 5, this therefore means that the neutral fibre 200 of the metal plate 10, where the strain at bending is virtually zero, is situated approximately halfway along the thickness 12 of the metal plate. In other words, the distance 224 between the neutral fibre 200 and the top side 214 of the metal plate 10, as well as the distance 226 between the neutral fibre 200 and the bottom side 216 of the metal plate 10 is virtually half of the thickness 12 of the metal plate 10.

[0045] In order to achieve good equalization of the longitudinal residual stresses in the metal plate 10, it is important to alternately subject as many metal fibres of the metal plate 10 as possible to a plastic deformation during the flattening process in order thus to equalize the length of these metal fibres of the metal plate and equalize longitudinal residual stresses. On the other hand, the maximum surface strain of the metal plate is limited by a maximum value, at which the risk of damage to the surface is no longer acceptable. As a result thereof, an elastic zone 202 is produced around the neutral fibre 200 of the metal plate in which the strain is insufficient to cause a stress which results in a plastic deformation. Between the top surface 214 and this elastic zone 202, there is a plastic zone 204 in which the strain is sufficiently large to cause stresses which result in plastic deformation. Between the bottom side 216 and the elastic zone 202, such a plastic zone 206 is also present, as is illustrated in Figs 5 and 6.

[0046] Figs 5 and 6 furthermore clearly show that, during a known flattening operation, the fibres of the metal plate in this elastic zone 202 are not subjected to alternating plastic deformations when passing through the alternating curvature 54, which leads to the fact that the residual longitudinal stresses are insufficiently equalized at the location of this elastic zone 202. With relatively thick metal plates 10, in particular when the thickness 12 of the metal plate 10 is greater than or equal to 8 mm, the forces which result therefrom become so great that they prevent a further improvement of the guaranteed flatness of parts cut out of the metal plate 10. Furthermore, as the thickness of the metal plate increases, it also becomes more difficult to reach a sufficiently high plastification ratio 100, of for example 70% or more, as will be described in more detail below.

[0047] A solution is provided by the production process described with reference to the embodiment from Fig. 1, in which it is only necessary to produce an alternating curvature 54 during the flattening operation which is such that it results in a plastification ratio 100 of 55% or more in order to achieve a sufficient degree of equalization of the longitudinal residual stresses, as will now be described in more detail with reference to Figs 7 and 8. This plastification ratio 100 is determined by the ratio across the thickness of the metal plate 10 between:

- the plastic zones 204, 206 of material of the metal plate 10 which is plastically deformed; and
- the elastic zone 202 of material of the metal plate 10 which is only elastically deformed at the location of the maximum curvature of the alternating curvature 54.

[0048] Fig. 7 is similar to Fig. 5 and shows the metal plate at the location of a maximum surface strain on the top side 214 of the metal plate 10 and Fig. 8 is similar to Fig. 6 and shows the metal plate at the location of a maximum surface strain on the bottom side 216 of the metal plate 10 during the flattening operation.

[0049] However, it has been found that specific skin-pass elongations and the associated distribution of the residual longitudinal stresses due to the skin-pass operation resulted in a shift of the neutral fibre 200 in the direction of the compression side, that is to say the bottom side 216 in Fig. 7 and the top side 214 in Fig. 8, during a subsequent flattening operation. This made it possible to choose the skin-pass elongation 44 in such a manner as a function of the subsequent alternating curvature 10, that it results in a translation ratio 220 of 15% or more at the location of the alternating curvature 54. This translation ratio 220 is determined by the ratio along the thickness of the metal plate (10) between:

- the translation of the elastic zone 202 at the location of the maximum curvature of the alternating curvature 54; and
- half of the thickness 12 of the metal plate 10.

[0050] This means that the skin-pass elongation is chosen in such a manner that, in Fig. 7, the distance between the top side 214 and the elastic zone 202, or the thickness of the plastic zone 204, increases by 15% with respect to half the thickness 12 of the metal plate. It is evident that the distance between the elastic zone 202 and the bottom side 216, or the thickness of the plastic zone 206, then decreases by 15% with respect to half the thickness 12 of the metal plate 10. In other words, the distance 224 between the neutral fibre 200 and the top side is virtually 10% greater than half the thickness 12 and the distance 226 between the neutral fibre 200 and the bottom side 216 is virtually 15% smaller than half the thickness 12 of the metal plate 10. It is clear that by using the effect of the specific skin-pass elongation which results in such an alternating translation of the elastic zone 202 along the thickness 12 of the metal plate 10, a greater part of the thickness 12 of the metal plate 10 is subjected to a strain which results in sufficiently high stresses which lead to a plastic deformation. It is clear from Figs 7 and 8 that the ratio of this zone with respect to the thickness 12 of the metal plate 10 virtually corresponds to the sum of the plastification ratio and translation ratio, that is to say the sum of 55% or more and 15% or more, i.e. 70% or more, which, until now, was not achievable for metal plates of a thickness of 8 mm or more in a simple and practical manner, in particular if such metal plates are steel plates having a relatively high yield point, for example higher than 400 N/mm^2.

[0051] According to a preferred embodiment, this production process according to the invention is applied to metal plates having a thickness 12 which is less than 30 mm, for example 10 mm to 25 mm, preferably 12 mm to 18 mm. In such cases, the alternating curvature 54 is chosen in such a manner that it results in a plastification ratio of 60% or more at the location of the maximum curvature of the alternating curvature 54. Additionally, the skin-pass elongation 44 is set so that, at the location of the alternating curvature 54, it results in a displacement of the elastic zone 202 across 20% or more of the thickness 12 of the metal plate at the location of the maximum curvature of the alternating curvature 54. It is clear that this results in a sum of the plastification ratio and translation ratio of 100% or more, which means that virtually the entire thickness 12 of the metal plate 10 is subjected to sufficiently high stresses to cause a plastic deformation, which makes a degree of equalization of the longitudinal residual stresses possible which was hitherto unknown.

[0052] In order to be able to actuate the skin-pass roller 40 and the flattening apparatus 50 in a consistent manner by means of the controller 80, according to a preferred embodiment, use is made of an elongation correlation function 140 for the skin-pass elongation 44 and of a flattening correlation function 150 for the alternating curvature 54 as a function of the thickness 12 of the metal plate 10 and the associated plastification ratio 100 and translation ratio 220. Subsequently, the skin-pass roller 40 is actuated by an elongation correlation module 142 as a function of this elongation correlation function 140 and the flattening apparatus 50 is actuated by a flattening correlation module 152 as a function of the flattening correlation function 140. As is illustrated in Fig. 1, the elongation correlation module 142 and the flattening correlation module 152 may form part of the controller 80. It is clear that additional parameters can be used to determine the elongation correlation function 140 and the flattening correlation function 150, such as for example the yield point of the metal plate 10, the width of the metal plate, etc.

[0053] This elongation correlation function 140 and the flattening correlation function 150 can be realized in a simple manner, for example by means of a reference table, such as that illustrated by way of example in Fig. 9.

[0054] However, it is clear that other suitable embodiments are possible, such as for example determining suitable formulas which make it possible for the controller to calculate the maximum surface strain and the skin-pass elongation as a function of the parameters indicated above.

[0055] The specific skin-pass elongation which results in a desired translation ratio for a specific alternating curve can be determined experimentally or by means of simulations, for example by means of a finite element analysis.

[0056] Generally, suitable values for the skin-pass elongation and the maximum surface strain, in particular for applying the production process on the types of steel plates according to the ASTM standard, as illustrated in Fig. 10, are found in the following ranges:

- the skin-pass elongation 44 is at most 6%; and
- the alternating curvature 54 has a maximum surface strain 56 of the metal plate 10 along the direction of movement M which is at most 1 %.

[0057] More particularly, for hot-rolled steel plates having a tensile strength in the range from 300 to 700 N/mm^2 or higher and an elastic limit or yield point in the range from 200 to 600 N/mm^2 or higher, the skin-pass elongation and maximum surface strain should be in the following ranges:

- the skin-pass elongation 44 is at most 4.5%, for example 0.2% to 4.5%.
- the alternating curvature has a maximum surface strain 56 of the metal plate 10 along the direction of movement M of at most 0.6%, for example 0.05% to 0.5%.

[0058] In order to achieve an optimum equalization of the longitudinal residual stresses, the alternating curvature 54 of the flattening apparatus 50 comprises a plurality of alternating curves 58, for example three to ten, preferably five to eight. Furthermore, it is also advantageous if the alternating curvature 54 has a virtually damped sinusoid along the direction of movement M. In this way, the longitudinal residual stresses, after a first phase in which all fibres are subjected to plastic deformations across virtually the entire thickness 12, are gradually subjected to increasingly smaller alternating stresses which, in a second phase of the flattening operation, only result in increasingly smaller alternating elastic deformations, which results in a further optimization of the equalization of the residual longitudinal stresses.

[0059] It is clear that combinations of the above-described embodiments and further variant embodiments are possible without deviating from the scope of protection of the invention as defined in the claims.

Claims

1. Production method for manufacturing a flat metal plate (10) of a thickness (12) of 6mm or more which is uncoiled from a metal coil (20), comprising the following steps:

- uncoiling the metal plate (10) from the metal coil (20) using an uncoiler (30);
- subsequently cold-rolling the metal plate (10) by means of a skin-pass roller (40) with opposite skin-pass rollers (42) which are configured to achieve a skin-pass elongation (44) of the metal plate (10) along the direction of movement (M) of the metal plate (10);
- subsequently flattening the metal plate (10) by means of a flattening apparatus (50) with alternating flattening rollers (52) which are configured to deform the metal plate according to an alternating curvature (54) with respect to the direction of movement (M) of the metal plate (10); and
- subsequently cutting the metal plate (10) into pieces at right angles to the direction of movement (M) by means of a cutting device (70), so that a cut flat metal plate (10) of a specific length (14) along the direction of movement (M) is obtained,

CHARACTERIZED IN THAT

- the alternating curvature (54) is such that it results in a plastification ratio (100) of 55% or more, in which said plastification ratio (100) is determined by the ratio across the thickness of the metal plate (10) between:
  - the plastic zones (204, 206) of material of the metal plate (10) which is plastically deformed; and
  - the elastic zone (202) of material of the metal plate (10) which is only elastically deformed at the location of the maximum curvature of the alternating curvature (54); and
- the skin-pass elongation (44) is such that it results in a translation ratio (220) of 15% or more

at the location of the alternating curvature (54), the translation ratio (220) being determined by the ratio across the thickness of the metal plate (10) between:

- the translation of the elastic zone (202) at the location of the maximum curvature of the alternating curvature (54); and
- half the thickness (12) of the metal plate (10).

2. Production method according to Claim 1, **characterized in that** the thickness (12) of the metal plate (10) is greater than or equal to 8 mm.

3. Production method according to Claim 1 or 2, **characterized in that** the yield point of the metal plate (10) is greater than 400 N/mm^2, preferably greater than 600 N/mm^2.

4. Production method according to one or more of the preceding claims, **characterized in that**:

- the thickness (12) of the metal plate (10) is less than 30 mm, for example 10 mm to 25 mm, preferably 12 mm to 18 mm;
- the alternating curvature (54) is such that it results in a plastification ratio of 60% or more at the location of the maximum curvature of the alternating curvature (54); and
- the skin-pass elongation (44) is such that, at the location of the alternating curvature 54, it results in a displacement of the elastic zone (202) across 20% or more of the thickness (12) of the metal plate at the location of the maximum curvature of the alternating curvature (54).

5. Production method according to one or more of the preceding claims, **characterized in that**:

- the skin-pass elongation (44) is at most 5%; and
- the alternating curvature (54) has a maximum surface strain (56) of the metal plate (10) along the direction of movement (M) which is at most 1 %.

6. Production method according to one or more of the preceding claims, **characterized in that**:

- the skin-pass elongation (44) is at most 4.5%, for example 0.2% to 4.5%.
- the alternating curvature has a maximum surface strain (56) of the metal plate (10) along the direction of movement (M) of at most 0.6%, for example 0.05% to 0.5%.

7. Production method according to one or more of the preceding claims, **characterized in that** the production method furthermore comprises this additional step:

- after uncoiling the metal plate (10) using the uncoiler (30) and cold-rolling the metal plate (10) using the skin-pass roller (40), preparatory flattening of the metal plate (10) by means of a preparatory flattening apparatus (60) with alternating preparatory flattening rollers (62) which are configured to reduce the curvature of the metal plate (10) along the direction of movement (M) to a value below a specific flatness tolerance (64), in which the specific flatness tolerance (64) results in a maximum deformation of 20 mm at right angles to the direction of movement (M), measured per length of 1 m of the metal plate (10) along the direction of movement (M).

8. Production method according to one or more of the preceding claims, **characterized in that** the alternating curvature (54) comprises a plurality of alternating curves (58).

9. Production method according to Claim 8, **characterized in that** the plurality of alternating curves (58) is three to ten, preferably five to eight.

10. Production method according to one or more of the preceding claims, **characterized in that** the alternating curvature (54) comprises a virtually damped sinusoid along the direction of movement (M).

11. Production method according to one or more of the preceding claims, **characterized in that** the production method furthermore comprises this additional step:

- determining an elongation correlation function (140) for the skin-pass elongation (44) and a flattening correlation function (150) for the alternating curvature (54) as a function of the thickness (12) of the metal plate (10) and the associated plastification ratio (100) and translation ratio (220);
- actuating the skin-pass roller (40) by an elongation correlation module (142) as a function of the elongation correlation function (140); and
- actuating the flattening apparatus (50) by a flattening correlation module (152) as a function of the flattening correlation function (140).

12. Production method according to Claim 11, **characterized in that** the elongation correlation function (140) and the flattening correlation function (150) are furthermore determined as a function of the thickness and/or the yield point of the metal plate (10).

13. Production method according to one or more of the preceding claims, **characterized in that** the metal plate (10) is a steel plate.

Patentansprüche

1. Produktionsverfahren zum Herstellen eines flachen Metallblechs (10) mit einer Dicke (12) von 6 mm oder mehr, das von einer Metallrolle (20) abgewickelt wird, umfassend die folgenden Schritte:

- Abwickeln des Metallblechs (10) von der Metallrolle (20) mit einem Abwickler (30);
- anschließend Kaltwalzen des Metallblechs (10) mit einem Nachwalzwerk (40) mit gegenüberliegenden Nachwalzen (42), die zum Erzielen einer Nachwalzdehnung (44) des Metallblechs (10) entlang der Bewegungsrichtung (M) des Metallblechs (10) ausgebildet sind;
- anschließend Glätten des Metallblechs (10) mit einer Glättvorrichtung (50) mit abwechselnden Glättwalzen (52), die zum Verformen des Metallblechs entsprechend einer abwechselnden Krümmung (54) in Bezug auf die Bewegungsrichtung (M) des Metallblechs (10) ausgebildet sind; und
- anschließend Schneiden des Metallblechs (10) in Teile rechtwinklig zur Bewegungsrichtung (M) mit einer Schneidvorrichtung (70), so dass ein geschnittenes, flaches Metallblech (10) einer bestimmten Länge (14) entlang der Bewegungsrichtung (M) erzielt wird,

DADURCH GEKENNZEICHNET, DASS

- die abwechselnde Krümmung (54) so beschaffen ist, dass sie zu einem Plastifizierungsverhältnis (100) von 55 % oder mehr führt, wobei das Plastifizierungsverhältnis (100) bestimmt wird vom Verhältnis über die Dicke des Metallblechs (10) zwischen:
- den plastischen Zonen (204, 206) von Material des Metallblechs (10), das plastisch verformt wird; und
- der elastischen Zone (202) von Material des Metallblechs (10), das an der Stelle der maximalen Krümmung der abwechselnden Krümmung (54) ausschließlich elastisch verformt wird; und
- die Nachwalzdehnung (44) so beschaffen ist, dass sie zu einem Verschiebungsverhältnis (220) an der Stelle der abwechselnden Krümmung (54) von 15% oder mehr führt, wobei das Verschiebungsverhältnis (220) bestimmt wird vom Verhältnis über die Dicke des Metallblechs (10) zwischen:
- der Verschiebung der elastischen Zone (202) an der Stelle der maximalen Krümmung der abwechselnden Krümmung (54); und
- der halben Dicke (12) des Metallblechs (10).

2. Produktionsverfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** die Dicke (12) des Metallblechs (10) größer als oder gleich 8 mm ist.

3. Produktionsverfahren nach Anspruch 1 oder 2, **dadurch gekennzeichnet, dass** die Fließgrenze des Metallblechs (10) größer als 400 N/mm^2 ist, vorzugsweise größer als 600 N/mm^2.

4. Produktionsverfahren nach einem oder mehreren der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass**:

- die Dicke (12) des Metallblechs (10) weniger als 30 mm, beispielsweise 10 mm bis 25 mm, vorzugsweise 12 mm bis 18 mm, beträgt;
- die abwechselnde Krümmung (54) so beschaffen ist, dass diese zu einem Plastifizierungsverhältnis von 60 % oder mehr an der Stelle der maximalen Krümmung der abwechselnden Krümmung (54) führt; und
- die Nachwalzdehnung (44) so beschaffen ist, dass diese an der Stelle der abwechselnden Krümmung 54 zu einer Verschiebung der elastischen Zone (202) über 20 % oder mehr der Dicke (12) des Metallblechs an der Stelle der maximalen Krümmung der abwechselnden Krümmung (54) führt.

5. Produktionsverfahren nach einem oder mehreren der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass**:

- die Nachwalzdehnung (44) höchstens 5 % beträgt; und
- die abwechselnde Krümmung (54) eine maximale Oberflächenspannung (56) des Metallblechs (10) entlang der Bewegungsrichtung (M) aufweist, die höchstens 1 % beträgt.

6. Produktionsverfahren nach einem oder mehreren der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass**:

- die Nachwalzdehnung (44) höchstens 4,5%, beispielsweise 0,2 % bis 4,5 % beträgt;
- die abwechselnde Krümmung eine maximale Oberflächenspannung (56) des Metallblechs (10) entlang der Bewegungsrichtung (M) von höchstens 0,6 %, beispielsweise 0,05 % bis 0,5 %, aufweist.

7. Produktionsverfahren nach einem oder mehreren der vorhergehenden Ansprüche, **dadurch gekenn-**

zeichnet, dass das Produktionsverfahren ferner diesen zusätzlichen Schritt umfasst:

- nach dem Abwickeln des Metallblechs (10) mit dem Abwickler (30) und Kaltwalzen des Metallblechs (10) mit dem Nachwalzwerk (40) vorbereitendes Glätten des Metallblechs (10) mit einer Vorbereitungsglättvorrichtung (60) mit abwechselnden Vorbereitungsglättwalzen (62), die zum Verringern der Krümmung des Metallblechs (10) entlang der Bewegungsrichtung (M) auf einen Wert unterhalb einer spezifischen Ebenheitstoleranz (64) ausgebildet sind, wobei die spezifische Ebenheitstoleranz (64) zu einer maximalen Verformung von 20 mm im rechten Winkel zur Bewegungsrichtung (M), gemessen pro Länge von 1 m des Metallblechs (10) entlang der Bewegungsrichtung (M), führt.

8. Produktionsverfahren nach einem oder mehreren der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** die abwechselnde Krümmung (54) eine Vielzahl von abwechselnden Kurven (58) umfasst.

9. Produktionsverfahren nach Anspruch 8, **dadurch gekennzeichnet, dass** die Vielzahl von abwechselnden Kurven (58) drei bis zehn, vorzugsweise fünf bis acht, beträgt.

10. Produktionsverfahren nach einem oder mehreren der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** die abwechselnde Krümmung (54) eine nahezu gedämpfte Sinuskurve entlang der Bewegungsrichtung (M) umfasst.

11. Produktionsverfahren nach einem oder mehreren der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** das Produktionsverfahren ferner diesen zusätzlichen Schritt umfasst:

- Bestimmen einer Dehnungskorrelationsfunktion (140) für die Nachwalzdehnung (44) und einer Glättungskorrelationsfunktion (150) für die abwechselnde Krümmung (54) als eine Funktion der Dicke (12) des Metallblechs (10) und des verknüpften Plastifizierungsverhältnisses (100) und Verschiebungsverhältnisses (220);
- Betätigen des Nachwalzwerks (40) durch ein Dehnungskorrelationsmodul (142) als eine Funktion der Dehnungskorrelationsfunktion (140); und
- Betätigen der Glättvorrichtung (50) durch ein Glättungskorrelationsmodul (152) als eine Funktion der Glättungskorrelationsfunktion (140).

12. Produktionsverfahren nach Anspruch 11, **dadurch gekennzeichnet, dass** die Dehnungskorrelationsfunktion (140) und die Glättungskorrelationsfunktion (150) ferner als eine Funktion der Dicke und/oder der Fließgrenze des Metallblechs (10) bestimmt werden.

13. Produktionsverfahren nach einem oder mehreren der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** das Metallblech (10) ein Stahlblech ist.

Revendications

1. Procédé de production pour la fabrication d'une plaque de métal plate (10) d'une épaisseur (12) de 6 mm ou plus qui est déroulée d'un rouleau de métal (20), comprenant les étapes suivantes :

- le déroulement de la plaque de métal (10) du rouleau de métal (20) à l'aide d'un dérouleur (30) ;
- ensuite le laminage à froid de la plaque de métal (10) au moyen d'un cylindre d'écrouissage (40) avec des cylindres d'écrouissage (42) opposés qui sont configurés pour parvenir à un allongement d'écrouissage (44) de la plaque de métal (10) le long de la direction de mouvement (M) de la plaque de métal (10) ;
- ensuite l'aplatissement de la plaque de métal (10) au moyen d'un appareil d'aplatissement (50) avec des cylindres d'aplatissement alternés (52) qui sont configurés pour déformer la plaque de métal selon une courbure alternée (54) par rapport à la direction de mouvement (M) de la plaque de métal (10) ; et
- ensuite le découpage de la plaque de métal (10) en pièces à angle droit par rapport à la direction de mouvement (M) au moyen d'un dispositif de découpe (70), de sorte qu'une plaque de métal plate découpée (10) d'une longueur spécifique (14) le long de la direction de mouvement (M) soit obtenue,

CARACTERISE EN CE QUE

- la courbure alternée (54) est telle qu'elle résulte en un rapport de plastification (100) de 55 % ou plus, dans lequel ledit rapport de plastification (100) est déterminé par le rapport sur l'épaisseur de la plaque de métal (10) entre :
- les zones plastiques (204, 206) de matériau de la plaque de métal (10) qui est déformée plastiquement ; et
- la zone élastique (202) de matériau de la plaque de métal (10) qui est déformée élastiquement uniquement à l'emplacement de la courbure maximale de la courbure alternée (54) ; et

- l'allongement d'écrouissage (44) est tel qu'il résulte en un rapport de translation (220) de 15 % ou plus à l'emplacement de la courbure alternée (54), le rapport de translation (220) étant déterminé par le rapport sur l'épaisseur de la plaque de métal (10) entre :
- la translation de la zone élastique (202) à l'emplacement de la courbure maximale de la courbure alternée (54) ; et
- la moitié de l'épaisseur (12) de la plaque de métal (10).

2. Procédé de production selon la revendication 1, **caractérisé en ce que** l'épaisseur (12) de la plaque de métal (10) est supérieure ou égale à 8 mm.

3. Procédé de production selon la revendication 1 ou 2, **caractérisé en ce que** la limite d'élasticité de la plaque de métal (10) est supérieure à 400 N/mm^2, de préférence supérieure à 600 N/mm^2.

4. Procédé de production selon une ou plusieurs des revendications précédentes, **caractérisé en ce que** :

- l'épaisseur (12) de la plaque de métal (10) est inférieure à 30 mm, par exemple de 10 mm à 25 mm, de préférence de 12 mm à 18 mm ;
- la courbure alternée (54) est telle qu'elle résulte en un rapport de plastification de 60 % ou plus à l'emplacement de la courbure maximale de la courbure alternée (54) ; et
- l'allongement d'écrouissage (44) est tel, qu'à l'emplacement de la courbure alternée 54, il résulte en un déplacement de la zone élastique (202) sur 20 % ou plus de l'épaisseur (12) de la plaque de métal à l'emplacement de la courbure maximale de la courbure alternée (54).

5. Procédé de production selon une ou plusieurs des revendications précédentes, **caractérisé en ce que** :

- l'allongement d'écrouissage (44) est d'au plus 5 % ; et
- la courbure alternée (54) a une déformation de surface maximale (56) de la plaque de métal (10) le long de la direction de mouvement (M) qui est d'au plus 1 %.

6. Procédé de production selon une ou plusieurs des revendications précédentes, **caractérisé en ce que** :

- l'allongement d'écrouissage (44) est d'au plus 4,5 %, par exemple de 0,2 % à 4,5 %,
- la courbure alternée a une déformation de surface maximale (56) de la plaque de métal (10) le long de la direction de mouvement (M) d'au plus 0,6 %, par exemple de 0,05 % à 0,5 %.

7. Procédé de production selon une ou plusieurs des revendications précédentes, **caractérisé en ce que** le procédé de production comprend en outre cette étape supplémentaire :

- après le déroulement de la plaque de métal (10) à l'aide du dérouleur (30) et le laminage à froid de la plaque de métal (10) à l'aide du cylindre d'écrouissage (40), l'aplatissement préparatoire de la plaque de métal (10) au moyen d'un appareil d'aplatissement préparatoire (60) avec des cylindres d'aplatissement préparatoire alternés (62) qui sont configurés pour réduire la courbure de la plaque de métal (10) le long de la direction de mouvement (M) à une valeur en dessous d'une tolérance de planéité spécifique (64), dans lequel la tolérance de planéité spécifique (64) résulte en une déformation maximale de 20 mm à angle droit par rapport à la direction de mouvement (M), mesurée par longueur de 1 m de la plaque de métal (10) le long de la direction de mouvement (M).

8. Procédé de production selon une ou plusieurs des revendications précédentes, **caractérisé en ce que** la courbure alternée (54) comprend une pluralité de courbes alternées (58).

9. Procédé de production selon la revendication 8, **caractérisé en ce que** la pluralité de courbes alternées (58) est de trois à dix, de préférence de cinq à huit.

10. Procédé de production selon une ou plusieurs des revendications précédentes, **caractérisé en ce que** la courbure alternée (54) comprend une sinusoïde quasiment amortie le long de la direction de mouvement (M).

11. Procédé de production selon une ou plusieurs des revendications précédentes, **caractérisé en ce que** le procédé de production comprend en outre ces étapes supplémentaires :

- la détermination d'une fonction de corrélation d'allongement (140) pour l'allongement d'écrouissage (44) et d'une fonction de corrélation d'aplatissement (150) pour la courbure alternée (54) en fonction de l'épaisseur (12) de la plaque de métal (10) et des rapport de plastification (100) et rapport de translation (220) associés ;
- l'actionnement du cylindre d'écrouissage (40) par un module de corrélation d'allongement (142) en fonction de la fonction de corrélation d'allongement (140) ; et

- l'actionnement de l'appareil d'aplatissement (50) par un module de corrélation d'aplatissement (152) en fonction de la fonction de corrélation d'allongement (140).

12. Procédé de production selon la revendication 11, **caractérisé en ce que** la fonction de corrélation d'allongement (140) et la fonction de corrélation d'aplatissement (150) sont en outre déterminées en fonction de l'épaisseur et/ou de la limite d'élasticité de la plaque de métal (10).

13. Procédé de production selon une ou plusieurs des revendications précédentes, **caractérisé en ce que** la plaque de métal (10) est une plaque d'acier.

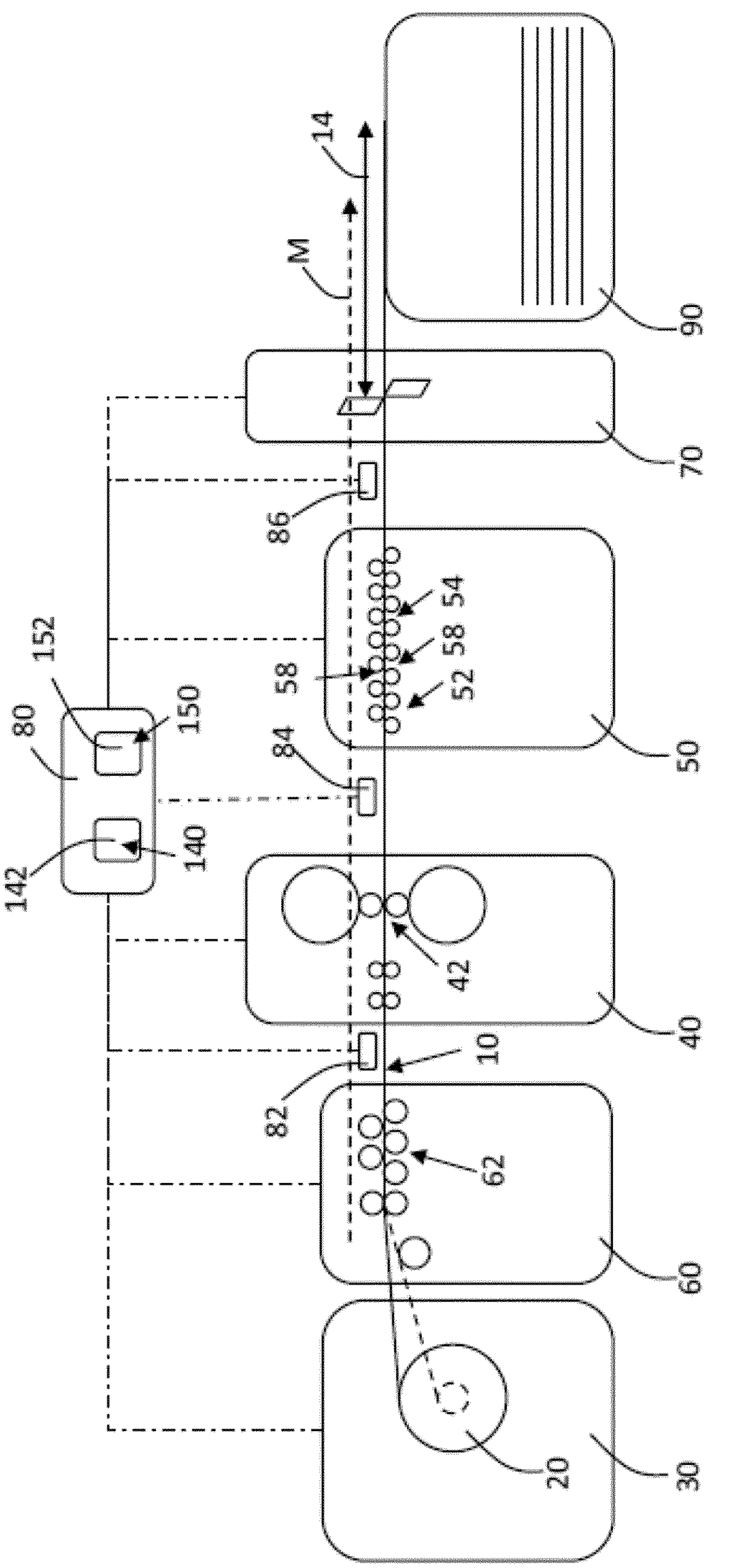
14
M
90
70
86
152
80
150
58
54
58
52
50
84
142
140
42
40
82
10
62
60
20
30

Fig 1

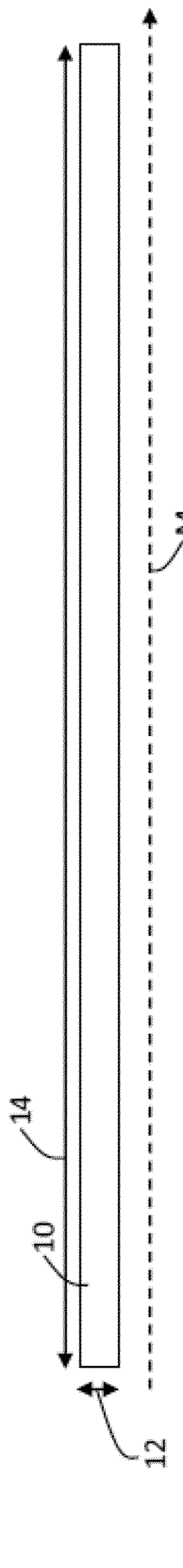
14
10
12
M

Fig 2

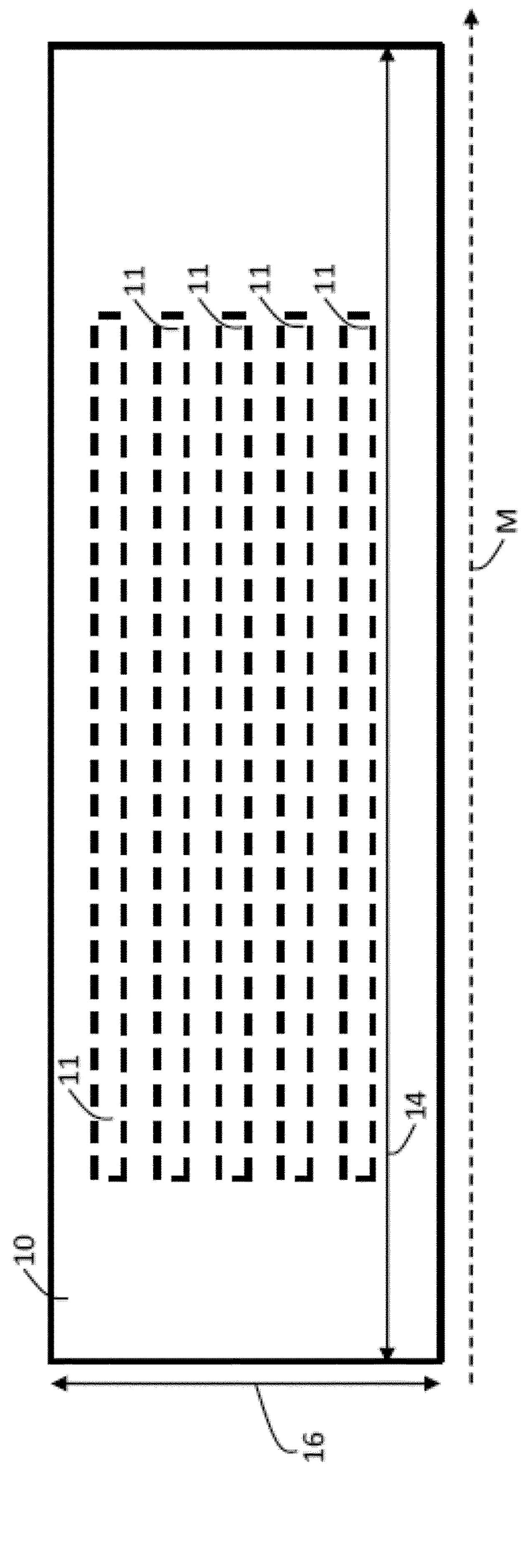

Fig 3

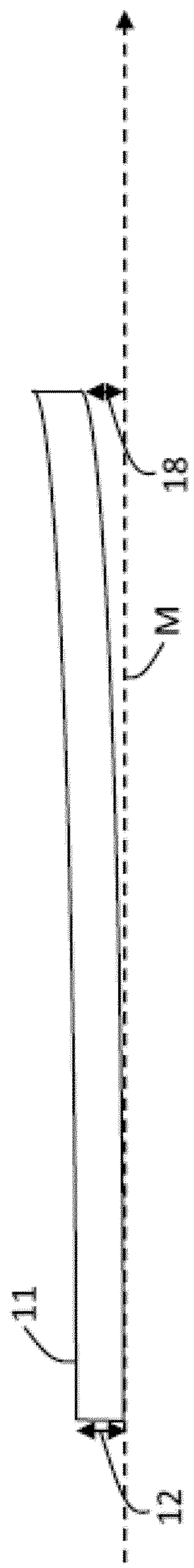

Fig 4

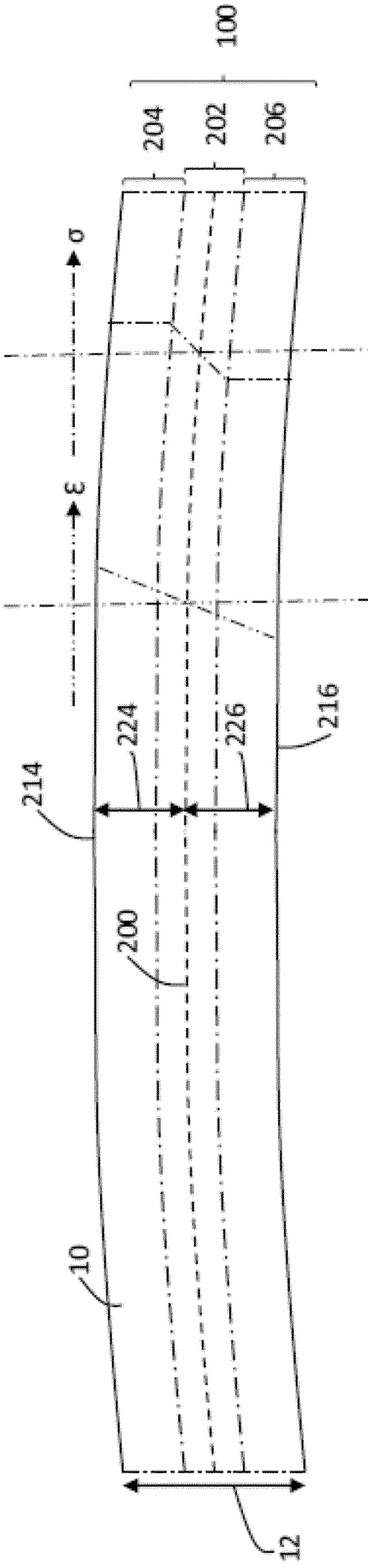
100
204
202
206
σ
ε
214
224
226
216
200
10
12

Fig 5

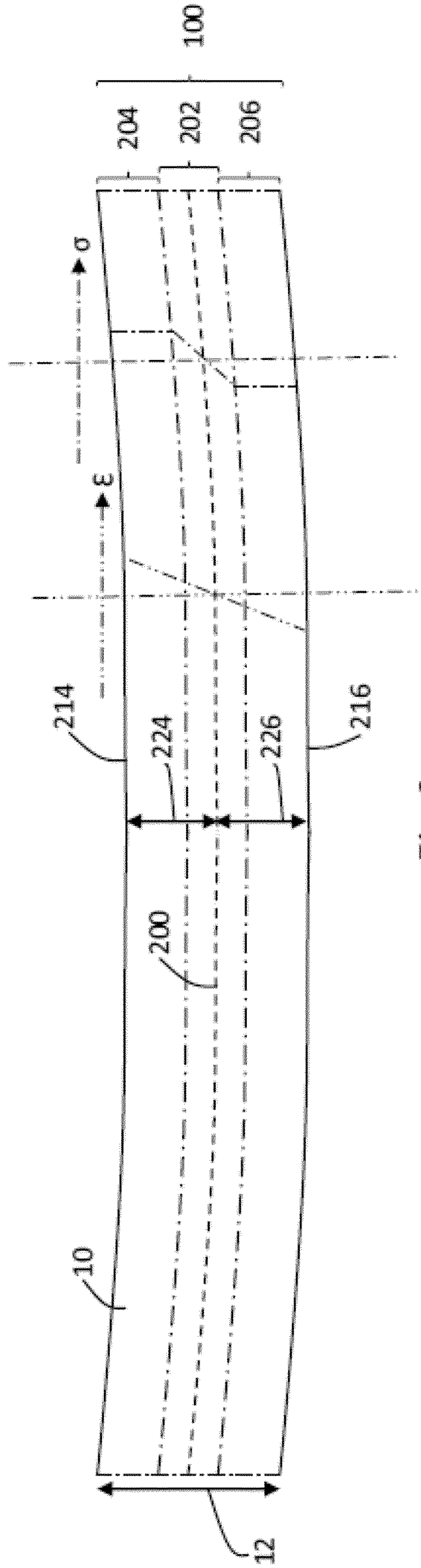
100
204
202
206
σ
ε
214
224
226
216
200
10
12

Fig 6

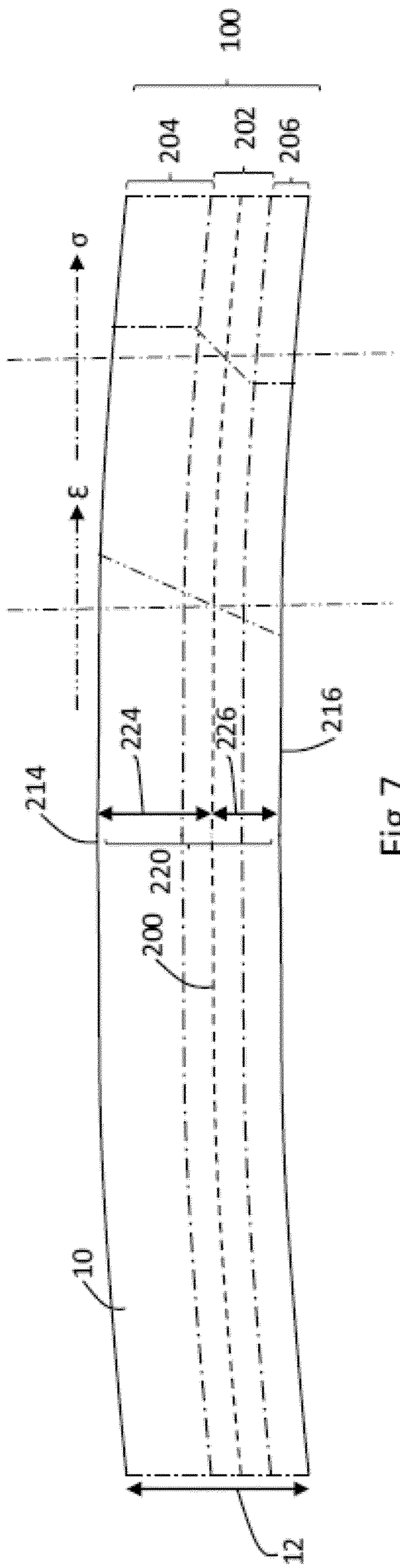
100
204
202
206
σ
ε
214
224
226
216
220
200
10
12

Fig 7

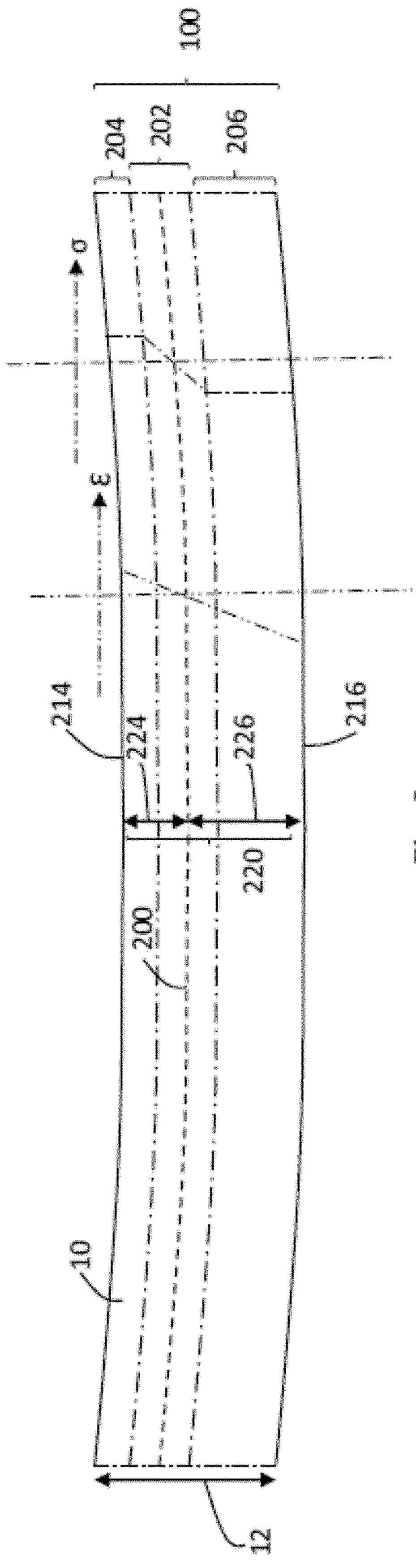
100
204
202
206
σ
ε
214
224
226
216
220
200
10
12

Fig 8

Thickness 12 (mm)	Width 16 (mm)	Plastification ratio	Maximum surface strain 56	Translation ratio	Skin-pass elongation 44	Yield point (N/mm)
9	1030	55%-65%	0.5%	16%-25%	1.5%-2.9%	390
11	1300	50%-59%	0.6%	19%-28%	1.8%-3.3%	520
14	1700	47-55%	0.6%	22%-30%	2.2%-3.7%	510

Fig. 9

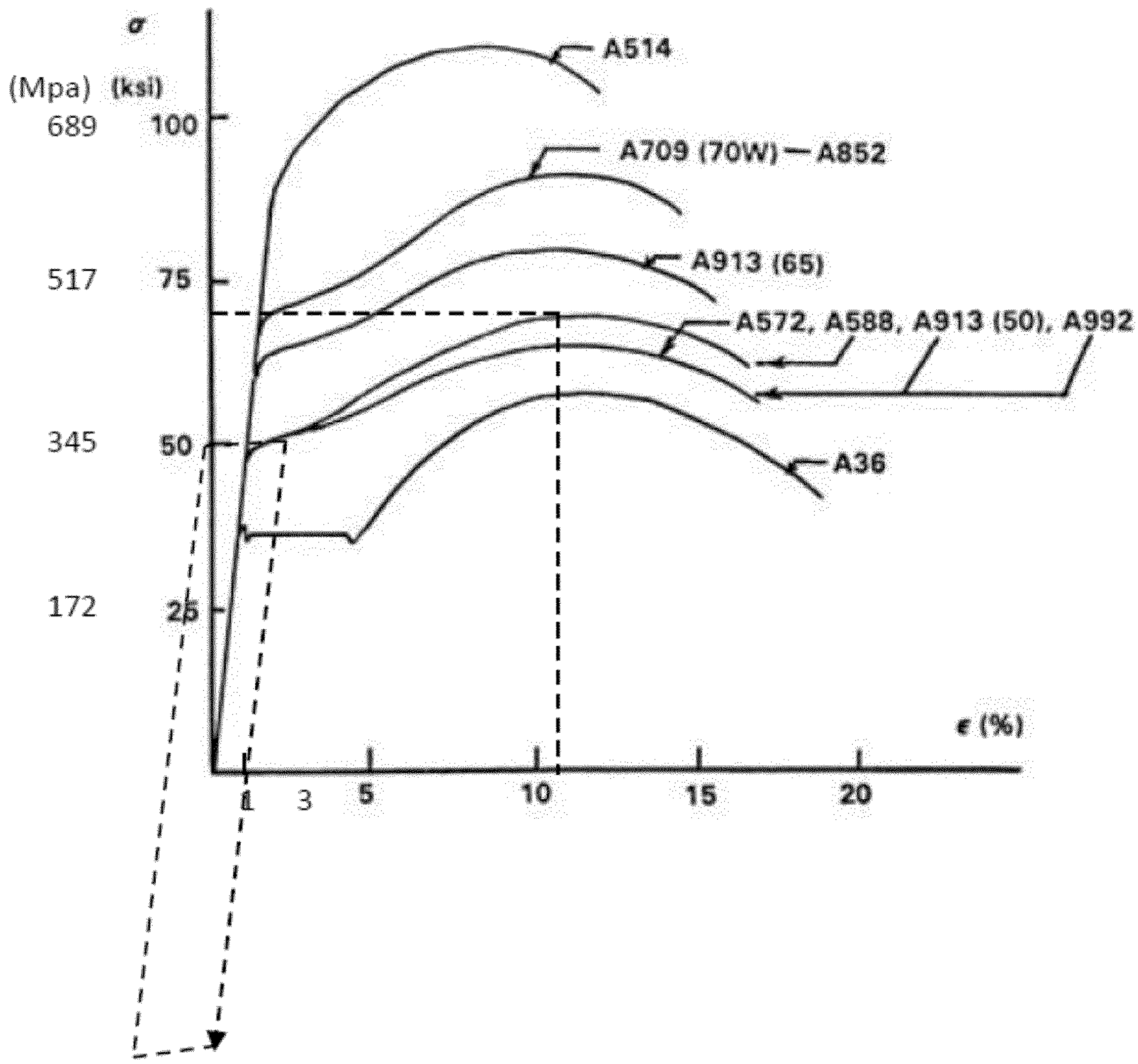
σ
(Mpa) (ksi)
689 100
517 75
345 50
172 25
A514
A709 (70W) — A852
A913 (65)
A572, A588, A913 (50), A992
A36
ϵ (%)
1 3 5 10 15 20

Fig 10

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- CA 940431 **[0006] [0008] [0009]**
- JP 2000176504 A **[0010]**
- JP 2007330996 A **[0011]**