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(54) **METHOD FOR MANUFACTURING STEEL PIPE AND PRESS MOLD USED IN SAID METHOD**

(57) Provided are a method of producing a steel pipe by performing bending on a plate material, and a press die used in the method.

A method of producing a steel pipe in which a plate material having an end bending portion is subjected to at least one bending along its widthwise direction to form a preformed body having a U-shaped cross-section, an open pipe with a gap portion in a longitudinal direction is formed by adding a bending force to the preformed body to press the preformed body, and end surfaces of the gap portion of the open pipe are butt-joined to each other to form a steel pipe, the method including: providing a lightly-bent portion to which very slight curvature is applied as compared to other regions, or providing a non-bent portion in which the bending is omitted, in at least a part of the plate material, in performing bending on the plate material; and applying the bending force to a part spaced apart at least from the center of the lightly-bent portion or the non-bent portion in a width end portion direction of the plate material by amount of $W/4$ (where, W is a width size of the plate material), without constraining the lightly-bent portion or the non-bent portion, in pressing the preformed body into the open pipe.

FIG. 1

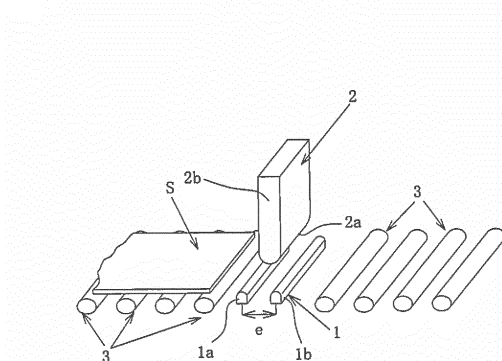
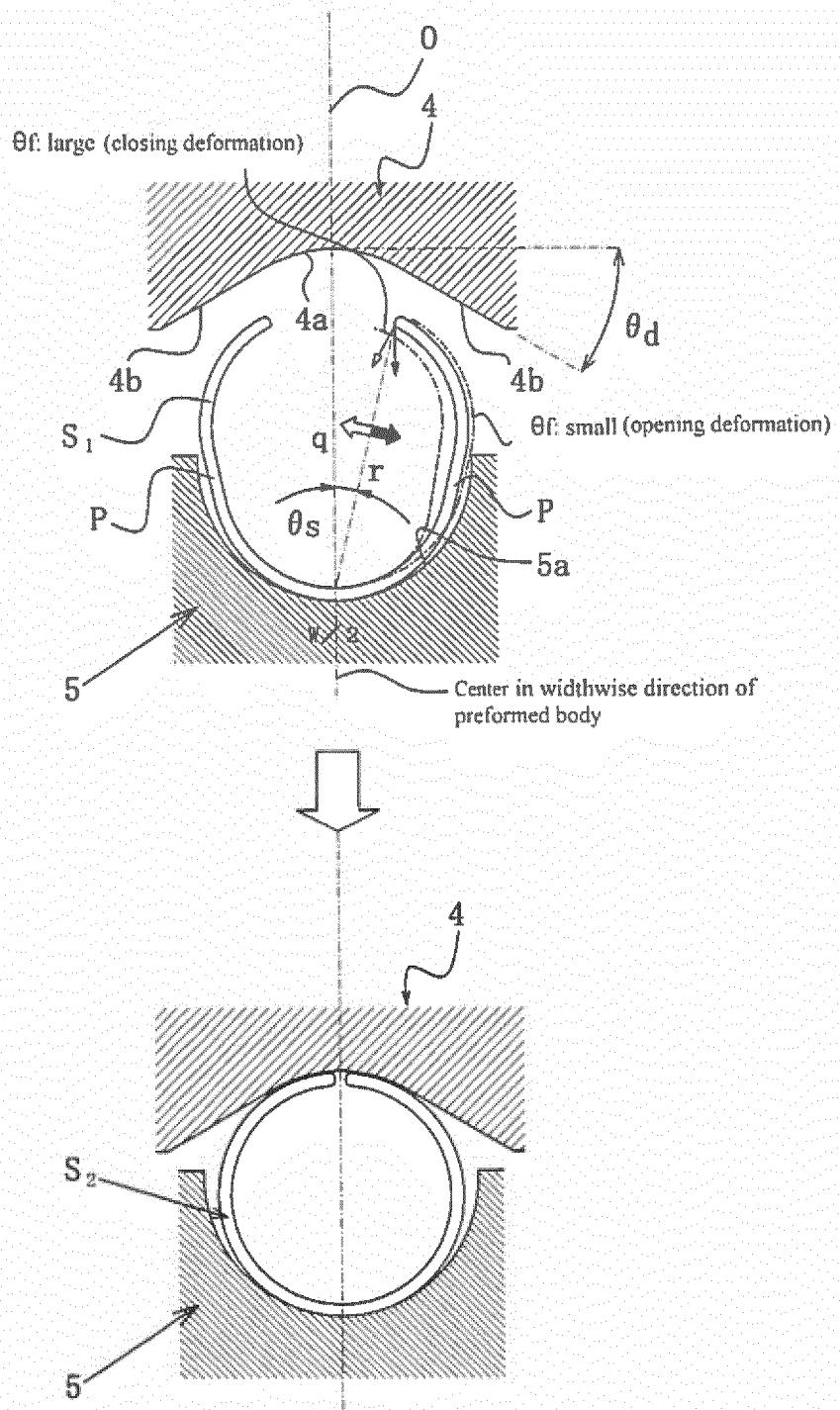


FIG. 5



Description

TECHNICAL FIELD

[0001] The present invention relates to a method suitable for producing a thick and large-diameter steel pipe used for a line pipe or the like, wherein a plate material is formed into a preformed body having a U-shaped cross-section by bending, the preformed body is pressed into an open pipe with a gap at plate width end portions faced each other in a longitudinal direction thereof, and the end surfaces of the gap portion are joined to each other into a steel pipe, and a press die used for the method.

BACKGROUND ART

[0002] As a technique for producing a thick and large-diameter steel pipe used for a line pipe or the like, a so-called UOE forming technique is widely used which presses a steel plate having a predetermined length, width and plate thickness into a U-shape, press-forms the steel plate into an O-shape to make an open pipe, thereafter its gap portion is butt-jointed by welding, and enlarges its diameter (so-called pipe expansion) to further improve the roundness.

[0003] In the above-described UOE forming technique, however, since there is a need for a high pressing force in the process of pressing the steel plate to form the steel plate into a U-shape and an O-shape, it cannot help using a large-scale press machine.

[0004] Therefore, recently, a technique for decreasing the pressing force has been considered upon producing this kind of steel pipe.

[0005] As a prior art related to this point, Patent Document 1 discloses a method of preliminarily forming a material in a C-shape forming process and a U-shape forming process, then performing an O-shape forming process thereon, so that a deformation mode of the material to be formed becomes fitting to dies at both top and bottom portion in the O-shape forming process. Further, Patent Document 2 discloses a method of changing a position of a butted part of a U-shaped steel plate to dies by performing a plurality of O-shape presses on the U-shaped steel plate and also rotating the U-shaped steel plate during the O-shape press, and Patent Document 3 discloses a method of performing the O-shape press on a member formed into a U-shape by a U-shape press with an insert liner which is applied for larger outer diameter pipe to an intermediate outer diameter.

[0006] As other prior arts, Patent Document 4 discloses a forming method in which a strain detector capable of detecting the inclination or distortion of a bending member mounted on a slide is disposed, the bending member is disposed in a tiltable or parallel-movable manner corresponding to the detection of the inclination or distortion by the strain detector, and the bending member is inclined or parallel moved to be subjected to press-forming so that an amount of distortion is smaller than an amount of inclination or an amount of distortion of the bending member when press-forming a material to be formed into a pipe shape. Patent Document 5 discloses a method of forming a slit pipe equipped with a non-circular preform by performing the slight forming compared to other bending steps in at least one bending step of acting on the inner surface of the plate material on left and right with respect to a center defined by a longitudinal axis of an upper tool that enters a plate material to be progressively formed, and thereafter, forming a finished slit pipe by appropriately applying a pressing force acting on an area formed slightly in advance on both sides of the center from the outside to the non-circular preform. Furthermore, Patent Document 6 discloses a method of forming a pipe with a closed slit portion, by applying the plastic deformation only to the flat portion of at least one location in the preformed body having a flat portion between at least two bent portions bent to a predetermined pipe curvature.

PRIOR ART DOCUMENTS

PATENT DOCUMENTS

[0007]

- Patent Document 1: JP-A-S55-139117
- Patent Document 2: JP-A-H11-285729
- Patent Document 3: JP-A-2002-178025
- Patent Document 4: JP-A-2005-21907
- Patent Document 5: JP-A-2012-250285
- Patent Document 6: US Patent No. 4,149,399

SUMMARY OF THE INVENTION

TASK TO BE SOLVED BY THE INVENTION

[0008] Meanwhile, the conventional press-forming techniques have problems as described below, and hence there is still room for improvement.

[0009] That is, in Patent Documents 1 to 3, a circumferential length on a forming surface of the die is set to be substantially equal to the width size of a plate material (a raw plate), and the plate material is formed into a pipe shape by bringing an extending portion of the material into contact with a forming surface of the die during deformation of the O-shape press to adjust it into a shape of the forming surface of the die. However, when a contact portion with the die is increased, the pressing force is gradually increased, and there is a need for a large press machine.

[0010] In a technique particularly aimed at a thick and high-strength material, a large pressing force is needed and thus the material is not completely pressed in the O-shape press, whereby a degradation of the shape cannot be avoided.

[0011] Meanwhile, according to the methods described in Patent Documents 4, 5 and 6, although they do not accompany an increase in pressing force as in Patent Documents 1 to 3, since the material to be formed or the non-circular preform is separately formed on each of left and right sides, when the amount of deformation differs on the left and right sides, there is a risk of formation of a step difference (offset) in the gap portion or the slit portion serving as a welded portion. Further, in these methods, the deformation is locally concentrated when trying to deform a shape to a desired shape at one time, and there is a fear of worsening the roundness. Accordingly, deformations of several times are inevitable, and there is also a limit in efficient production.

[0012] The present invention is to provide a producing method of efficiently producing a steel pipe having high roundness without requiring an excessive bending force (load), and a press die used in the method.

SOLUTION FOR TASK

[0013] The present invention is a method of producing a steel pipe by subjecting a plate material which is bent at width end portion to at least one bending along its widthwise direction to provide a preformed body having a U-shaped cross-section, pressing the preformed body by applying a bending force to thereby form an open pipe with a gap portion in its longitudinal direction, and butt-joining end surfaces of the gap portion of the open pipe to each other, characterized in that a lightly-bent portion to which a very slight curvature is applied as compared to other regions or a non-bent portion in which the bending is omitted is provided in at least a part of the plate material in a process performing the bending on the plate material, and a bending-force is applied to a part spaced apart from the center of the lightly-bent portion or the non-bent portion in a direction to width end of the plate material by amount of $W/4$ (where W is a width size of the plate material) without constraining the lightly-bent portion or the non-bent portion in a process pressing the preformed body into the open pipe. Here, the open pipe refers to a pipe body of a state in which the plate material is formed into a cylindrical shape and a gap portion is formed between plate end portions facing each other.

[0014] In the method of producing a steel pipe having the above configuration, the following specific means are preferable for solving the problem of the present invention:

- 1) The center of the lightly-bent portion or the non-bent portion is provided in a part including a part spaced apart from the width end portion of the plate material by amount of $W/4$;
- 2) The length of the lightly-bent portion or the non-bent portion along the widthwise direction of the plate material is not more than 10% of the plate width;
- 3) When applying the bending force to press the preformed body, the preformed body is supported at a part not on the line of action of the bending force, and when the opening angle of the preformed body defined based on the part supporting the preformed body is defined by θ_s and the angle of the line of action of the bending force applied to the preformed body is defined by θ_f , the pressing of the preformed body is started under a condition of $\theta_f > \theta_s$;
- 4) At the time of pressing of the preformed body, a press die provided with a forming surface of not coming into contact with the lightly-bent portion or the non-bent portion is used;
- 5) At the time of pressing of the preformed body, the bending force is simultaneously applied to a part each spaced apart from the center of the lightly-bent portion or the non-bent portion toward the width end of the plate material by amount of $W/4$; further,
- 6) At the time of pressing of the preformed body, a forming center of the press die used for pressing of the preformed body coincides with a center in the widthwise direction of the preformed body; and
- 7) The preformed body is held in a U-shaped posture with its opening portion facing upward, and is supported at the center in the widthwise direction located at its lowermost end.

[0015] Further, according to the present invention, there is provided a press die preferably used in the producing

method having the above configuration, wherein the press die includes a pair of the bending bodies configured to interpose the preformed body therebetween, and the bending bodies have a forming surface having a cross-sectional shape that does not come into contact with the lightly-bent portion or the non-bent portion during pressing of the preformed body.

[0016] In the press die having the above configuration, the following specific means is preferable for solving the problem of the present invention:

1) At least one of the bending bodies has a circular arc surface having a width center that coincides with the forming center of the press die, and a forming surface having an inclined surface which leads to each of both ends of the circular arc surface and is directed toward the forming center of the press die.

[0017] Further, the circular arc surface has a central angle of not less than 28° , an angle formed between the inclined surface and a straight line intersecting with the straight line passing through a widthwise center of the circular arc forming surface is preferably not less than 14° , and a surface having a radius of not more than 1.2 times the diameter of a steel pipe to be produced may be applied as the circular arc surface.

EFFECTS OF THE INVENTION

[0018] According to the method of producing a steel pipe of the present invention, in a case where a plate material having an end bending portion is subjected to at least one bending along its widthwise direction to provide a preformed body having a U-shaped cross-section, an open pipe with a gap portion in its longitudinal direction is formed by applying a bending force to the preformed body to press the preformed body, and end surfaces of the gap portion of the open pipe are butt-joined to each other to form a steel pipe, a lightly-bent portion to which a very slight curvature is applied as compared to other regions or a non-bent portion in which the bending is omitted is provided in at least a part of the plate material in a process performing the bending on the plate material, and the bending force is applied to a part spaced apart at least from the center of the lightly-bent portion or the non-bent portion in a width end portion direction of the plate material by amount of $W/4$ (where W is a width size of the plate material) without constraining the lightly-bent portion or the non-bent portion in a process of pressing the preformed body into the open pipe. Therefore, it is possible to efficiently form a steel pipe having high roundness with a relatively small bending force.

[0019] According to the method of producing a steel pipe having the above-described configuration, since the lightly-bent portion or the non-bent portion is provided at a part spaced apart from a width end portion of the plate material by amount of $W/4$, when the preformed body having a U-shaped cross-section is pressed into an open pipe, the part is not restricted by the press die, and thus, it is possible to suppress an increase in forming reaction force.

[0020] According to the method of producing a steel pipe of the present invention, since a length of the lightly-bent portion or the non-bent portion along the widthwise direction of the plate material is not more than 10% of the plate width dimension, it is possible to obtain an open pipe having a small open amount of the butted portion, while maintaining the dimensional accuracy.

[0021] According to the method of producing a steel pipe of the present invention, at the time of pressing of the formed body by applying a bending force thereto, the preformed body is supported at a part at least away from an extension line on which the bending force acts, and the pressing of the preformed body is started under the condition of $\theta_f > \theta_s$ in which an opening angle of the preformed body defined based on the part supporting the preformed body is defined by θ_s , and an angle of the bending force is defined by θ_f , so that the lightly-bent portion or the non-bent portion is deformed so as to extend outward.

[0022] According to the method of producing a steel pipe of the present invention, at the time of pressing of the preformed body, since the press die provided with a forming surface not coming into contact with the lightly-bent portion or the non-bent portion is used, it is possible to press the preformed body while decreasing the bending force.

[0023] According to the method of producing a steel pipe of the present invention, since the bending force is simultaneously applied to parts (two locations) spaced apart from the center of the lightly-bent portion or the non-bent portion toward the width end of the plate material by amount of $W/4$ at the time of pressing of the preformed body, an offset in which the end surfaces greatly differ in the gap portion is not formed.

[0024] According to the method of producing a steel pipe of the present invention, since the forming center of the press die used in the pressing of the preformed body matches with the width center of the preformed body at the time of pressing of the preformed body, it is possible to evenly bend a portion corresponding to the width end of the plate material in the gap portion of the open pipe on the left and right sides, and a large offset is not formed in the gap portion.

[0025] According to the method of producing a steel pipe of the present invention, since the preformed body is held in a U-shaped posture and is supported at its lowermost end (the center in the widthwise direction of the preformed body), it is possible to symmetrically deform the preformed body on the boundary of the center in the widthwise direction, and it is possible to obtain an open pipe with high roundness.

[0026] According to the press die used in the method of producing a steel pipe of the present invention, the press die is constituted by a pair of bending members interposing the preformed body therebetween, and a forming surface having a cross-sectional shape which does not come into contact with the lightly-bent portion or the non-bent portion during pressing of the preformed body is formed in the bending member. Thus, the forming reaction force is decreased, and it is possible to efficiently produce the steel pipe.

[0027] Further, according to the press die of the present invention, since at least one of the bending members has a circular arc surface having a width center matching the forming center of the press die, and a forming surface having a slope leading to each of both ends of the circular arc surface and directed toward the forming center of the press die, it is possible to obtain a steel pipe with high roundness without forming a step in the gap portion.

[0028] In the press die of the present invention, when the central angle of the circular arc surface is set to not less than 28° , and the angle between the inclined surface and the straight line intersecting with a straight line passing through the widthwise center of the circular arc forming surface is set to not less than 14° , at the time of pressing of the preformed body, it is possible to reliably extend the lightly-bent portion or the non-bent portion toward the outside.

[0029] Furthermore, according to the press die of the present invention, the lightly-bent portion or the non-bent portion is not restricted by the forming surface of the press die by setting the circular arc surface to have the diameter of not more than 1.2 times the diameter of the steel pipe to be produced at the time of pressing of the preformed body, whereby the forming reaction force can be decreased.

BRIEF DESCRIPTION OF THE DRAWINGS

[0030]

FIG. 1 is a diagram schematically illustrating a preferred punch and die used to form a preformed body having a U-shaped cross-section.

FIG. 2 is a diagram schematically illustrating a preferred press die used to form an open pipe.

FIG. 3 is a diagram illustrating a specific forming condition when forming a plate material into a preformed body having a U-shaped cross-section.

FIG. 4 is an enlarged diagram illustrating a cross-section of the preformed body having the U-shaped cross-section.

FIG. 5 is a diagram illustrating a state in which the preformed body having the U-shaped cross-section is pressed into an open pipe.

FIG. 6 is a graph showing a relation between an amount of roundness variation/an outer diameter and (a length of lightly-bent portion or non-bent portion)/a plate width.

FIG. 7 is a graph showing a relation between an opening (mm) of a gap portion and (a length of lightly-bent portion or the non-bent portion)/a plate width.

FIG. 8 is a graph showing a relation between an opening (mm) of the U-shaped cross-section and (a length of lightly-bent portion or the non-bent portion)/a plate width.

FIG. 9 is an enlarged diagram illustrating essential portions of an upper die.

FIG. 10 is a graph showing a relation between an angle θ_d of a forming surface of the upper die and a direction θ_f of force.

FIG. 11 is a diagram illustrating a biting situation of the upper die.

FIG. 12 is a diagram illustrating a state in which a gap is formed between the upper die and the preformed body.

FIG. 13 is a graph showing a relation between (a radius of the circular arc surface of the upper die / a radius of the steel pipe) and the residual index.

FIG. 14 is a graph showing a relation between (a radius of the circular arc surface of the lower die / a radius of the steel pipe) and (forming load/load when the lightly-bent portion or the non-bent portion is freely bent).

FIG. 15 is a diagram illustrating the contact situation between the upper die and the lower die.

EMBODIMENTS FOR CARRYING OUT THE INVENTION

[0031] Hereinafter, the present invention will be more specifically described with reference to the drawings.

[0032] FIGs. 1 and 2 are diagrams schematically illustrating a preferred punch and die and a preferred press die, respectively, that are used in the practice of the method of producing a steel pipe according to the present invention.

[0033] The punch and die shown in FIG. 1 is used when forming a plate material into a preformed body having a U-shaped cross-section by bending the plate material along its widthwise direction, and the press die shown in FIG. 2 is used when forming the preformed body into an open pipe having a gap in the longitudinal direction by applying a bending force to the preformed body having the U-shaped cross-section.

[0034] Reference number 1 in FIG. 1 denotes a die disposed in a conveying path of the plate material S. The die 1 is configured with a pair of left and right rod-like members 1a and 1b that supports the plate material S at two locations

along its feeding direction and enables a change in an interval e between the rod-like members 1a and 1b depending on the size of the steel pipe to be produced.

[0035] Moreover, reference number 2 denotes a punch which is movable in a direction of moving close to or away from the die 1. The punch 2 includes a punch tip 2a having a downward convex forming surface that comes into direct contact with the plate material S to bend the plate material S into a concave shape, and a punch support 2b that is connected to the rear (upper end) of the punch tip 2a with the same width thereof to support the punch tip 2a.

[0036] Although a specific structure of the punch support 2b is not illustrated, its upper end portion is connected to a driving device such as hydraulic cylinder, and the punch support 2b can apply a bending force to the punch tip 2a by the driving device. Further, reference number 3 denotes a roller for forming the conveying path of the plate material S.

[0037] Further, reference number 4 in FIG. 2 denotes an upper die (bending tool), and reference number 5 denotes a lower die which mates with the upper die 4 (bending tool). The preformed body (which has a U-shaped cross-section) formed by the die 1 and the punch 2 is located between the upper die 4 and the lower die 5, and a bending force is applied to the preformed body to form an open pipe.

[0038] The upper die 4 may have a circular arc surface 4a having a width center that matches the forming center thereof, and a forming surface (inclined surface) 4b connected to each of both ends of the circular arc surface 4a and having a slope directed toward the forming center side of the press die. The lower die 5 may have a forming surface that does not come into contact with the lightly-bent portion or the non-bent portion during pressing of the preformed body. Further, the upper die 4 may have a press die having a forming surface that does not come into contact with the lightly-bent portion or the non-bent portion during pressing of the preformed body. As the lower die 5, it is possible to apply one that includes a circular arc surface having a width center matching the forming center thereof, and an inclined surface which is connected to each of both ends of the circular arc surface and is directed toward the forming center side of the press die.

[0039] In order to form the plate material S as a starting material into a tubular shape, first, end bending (also referred to as crimping) is performed on the width end portion of the plate material S.

[0040] The end bending is performed on a plate width end portion that is harder to bend as compared to the case of performing the bending using the die 1 and the punch 2, and it is possible to obtain a steel pipe in which high roundness is secured by providing an end bending portion by this forming.

[0041] Further, the roundness of the steel pipe is an indicator that indicates how much the cross-sectional shape of the steel pipe is close to a circle. Specifically, for example, when the produced steel pipe is equally divided into twelve sections or twenty-four sections in the circumferential direction at any pipe length position to measure the outer diameters at the opposite positions, and a maximum diameter and a minimum diameter thereof is defined by $D_{\max}$ and $D_{\min}$, respectively, the roundness = $D_{\max} - D_{\min}$ is defined. This indicates that as the roundness comes closer to 0, the cross-sectional shape of the steel pipe has a shape that is closer to a perfect circle.

[0042] The plate material S provided with the end bending portion is mounted on the die 1 as shown FIG. 1, and bending (3-point bending) is applied over the entire region as illustrated in FIG. 3, while intermittently feeding the plate material S by a predetermined feed amount, thereby forming the plate material into a preformed body which has a U-shaped cross-section as a whole.

[0043] Around a portion of the preformed body S_1 obtained by the bending, especially, a part each spaced apart from the width end portion by amount of $W/4$, a lightly-bent portion to which the slight curvature is applied as compared to other regions or a non-bent portion P in which the bending is omitted is provided as shown in Fig. 4 by enlarging its cross-section.

[0044] The lightly-bent portion P can be provided by pressing while decreasing the bending amount applied by the punch 2, and the non-bent portion P can be provided by omitting the bending of the punch 2 while increasing the feeding of the plate material S.

[0045] Further, FIG. 3 specifically illustrates an example of a case of performing the bending and the feeding of the plate material S on the plate material S previously subjected to edge bending, sequentially from the top to the bottom of the left column, from the top to the bottom of the center column, and further from the top to the bottom of the right column, and the arrow assigned to each of the punch 2 and the plate material S in FIG. 3 illustrates the moving direction of the punch 2 and the plate material S at each stage.

[0046] As the punch 2 which performs bending on the plate material S, it is possible to use, for example, a punch having a substantially inverted T-shape in which the width of the punch tip 2a is larger than the width (thickness) of the punch support 2b. In this case, it is possible to bend a larger area with respect to the plate material by single step bending as compared to the configuration in which the width of the punch tip 2a is almost the same as the width (thickness) of the punch support 2b illustrated in FIG. 1, whereby the bending times can be decreased.

[0047] After a preformed body S_1 having a U-shaped cross-section is obtained, in order to form the preformed body S_1 into an open pipe, the preformed body S_1 is pressed using the upper die 4 and the lower die 5 illustrated in FIG. 2.

[0048] At the time of pressing of the preformed body S_1 , the preformed body S_1 is held in a U-shaped posture so that an opening portion faces upward, and is located on the lower die 5 so that its lowest end, that is, the center in the

widthwise direction becomes a support part. Thus, as illustrated in FIG. 5, the bending force is simultaneously applied to two locations of the width end portions of the plate material S which are parts spaced apart from the lightly-bent portion or the non-bent portion P toward the width end by amount of $W/4$ by the upper die 4.

[0049] In such pressing, since the preformed body S_1 is supported on the lower die 5 at a part at least away from the line of action of the bending force, and the lightly-bent portion or the non-bent portion P is not constrained by the press die, the preformed body S_1 is formed into a tubular shape without requiring excessive bending force.

[0050] As the lower die 5, in the present invention, although one having a forming surface that does not constrain the lightly-bent portion or the non-bent portion P is used, when the forming surface is a circular arc surface having a concave shape, it can be achieved by setting a larger diameter than the diameter of the steel pipe to be produced. Further, the forming surface may be a flat surface with which the preformed body S_1 linearly comes into contact.

[0051] In the stage of pressing the preformed body S_1 into an open pipe of the present invention, the bending force is applied at least to a part away from the center of the lightly-bent portion or the non-bent portion P by amount of $W/4$, the reason of which is as follows.

[0052] That is, the bending moment (M) when the whole preformed body S, has a circular shape is $F \cdot r \cdot \cos \phi$ (F: bending force, r: radius of circle) at a position of an angle ϕ from the position applied with the bending force, and becomes maximum at the position away from the position applied with the bending force by 90° , and the deformation also becomes maximum. Therefore, by applying the bending force to the position away from the center of the lightly-bent portion or the non-bent portion P by 90° , that is, $1/4$ of the entire circumference, the lightly-bent portion or the non-bent portion P is effectively deformed. At this time, the bending moment is maximum at the position away from the applying position of the bending force by 90° and it becomes smaller as going away from this position. In order to allow the sufficient plastic deformation to occur in the lightly-bent portion or the non-bent portion P, the bending force is preferably applied by amount of $W/4 \pm 0.07 W$.

[0053] Further, in the present invention, the center of the lightly-bent portion or the non-bent portion P is provided in a part including a part away from the width end portion of the plate material S by amount of $W/4$, the reason of which is as follows.

[0054] That is, as described above, although the bending force is preferably applied to a position apart from the center of the lightly-bent portion or the non-bent portion P in the width end direction of the plate material by amount of $W/4$, since its shape is changed at the step of forming the preformed body S_1 into an open pipe, a contact position with the upper die 4 is changed, and the position applied with the bending force is also changed. When the lightly-bent portion or the non-bent portion P is provided at a position spaced apart from the width end portion of the plate material S by amount of $W/4$, a position applied with the bending force is always a width end portion of the plate material S, and the lightly-bent portion or the non-bent portion P are most deformed. Thus, it is possible to give deformation to the lightly-bent portion or the non-bent portion P by single bending without changing the bending position. Further, in order to give a sufficient deformation to the lightly-bent portion or the non-bent portion P, the lightly-bent portion or the non-bent portion P is preferably provided in a range of $W/4 \pm 0.07W$ from the position applied with the bending force, that is, the width end portion of the plate material.

[0055] In the present invention, when the lightly-bent portion is provided in a part of the plate material S, particularly, in a part including the part away from the width end portion of the plate material S by amount of $W/4$, or when the non-bent portion P in which bending is omitted is provided in bending the plate material S, the length L (see FIG. 4) along the widthwise direction of the plate material S of the lightly-bent portion or the non-bent portion P is preferably set to not more than 10% of the plate width. The reason is as follows.

[0056] That is, when applying the bending force to the preformed body S_1 of a U-shaped cross-section having the lightly-bent portion or the non-bent portion P of the length L at the part spaced apart from the lightly-bent portion or the non-bent portion P by amount of $W/4$, bending moment acts on the lightly-bent portion or the non-bent portion P, and the portion is deformed.

[0057] The bending moment (M) when the whole preformed body S_1 becomes a circular shape is $F \cdot r \cdot \cos \phi$ (F: bending force, r: radius of circle) at the position of the angle ϕ from the position applied with the bending force, and bending moment becomes maximum at the position spaced apart from the position applied with the bending force by 90° , and the amount of deformation is also the maximum. However, the amount of deformation is not uniform in the lightly-bent portion and the non-bent portion P. Therefore, the obtained open pipe has irregularities, rather than a uniform circular arc.

[0058] Here, as for a tubular material of an API standard Gr. X65 and a thickness of 38.1 mm, a relation between a value obtained by dividing the length L of the lightly-bent portion or the non-bent portion P of the shaped body S_1 having the U-shaped cross-section by the plate width and a value obtained by dividing an irregularity amount by the outer diameter of the tubular material is investigated. As illustrated in FIG. 6, as the length of the lightly-bent portion or the non-bent portion P is longer and the outer diameter is smaller, the irregularity amount is also larger. In the tubular material having the outer diameter of 559 mm, when the length of the lightly-bent portion or the non-bent portion P exceeds 10% of the plate width, the irregularity amount exceeds 1.5% of the outer diameter.

[0059] In the API standard which is a general standard of the line pipe, although the shape correction of a tube

expansion ratio (rate for expanding the diameter) of about 1.5% is observed in the tube expanding process after joining (welding) the gap portion, when the irregularity amount exceeds 1.5% of the outer diameter, the dimensional accuracy of the finished product may be impaired. Therefore, in the present invention, the length L of the lightly-bent portion or the non-bent portion P along the widthwise direction of the plate material S is preferably set to not more than 10% of the plate width. Furthermore, in order to provide sufficient deformation to the lightly-bent portion or the non-bent portion P, the length L is preferably in the range of $W/4 \pm 0.07 W$ from the position applied with the bending force.

[0060] Further, when the length L of the lightly-bent portion or the non-bent portion P becomes longer, the difference in the gap portion of the open pipe increases by the spring back when releasing the bending force as illustrated in FIG. 7 and the butt-joining between the end surfaces may become difficult, which may cause restriction in some cases.

[0061] FIG. 8 is a graph showing a relation between the interval (opening of U-shaped cross-section) of the opening portion of the preformed body S_1 having a U-shaped cross-section and the length L of the lightly-bent portion or the non-bent portion P. Although the dimensional accuracy is better as the length L of the lightly-bent portion or the non-bent portion P becomes smaller, since the opening interval of the preformed body S_1 also becomes smaller, when the opening interval is smaller than the width of the punch 2, it is not possible to raise the punch 2 after the final bending (the last state of FIG. 3), and it is difficult to detach the preformed body S_1 from the press machine. Therefore, the lower limit of the length L is set depending on the size of the applied device or the steel pipe to be produced. For example, when a pipe having an outer diameter of 559 mm is produced by a press machine having the punch 2 having a width of 150 mm, L/W is required to be not less than 0.05.

[0062] In the present invention, when the opening angle defined based on the part on which the preformed body S_1 is supported is defined as θ_s , and the angle of the bending force applied to the preformed body S_1 is defined as θ_f , the pressing of the preformed body S_1 is started under a condition of $\theta_f > \theta_s$. However, the part in which the preformed body S_1 is supported by satisfying this condition is not existent on the line of action of the bending force, and the lightly-bent portion or the non-bent portion P can reliably extend toward the outside with relatively small bending force.

[0063] Further, when the widthwise center of the preformed body is located at the lowermost end (part on which the preformed body is supported) in the U-shaped posture in which the opening portion of the preformed body is located upward, and the straight line q which symmetrically bisects the preformed body through the widthwise center is defined as a reference line, the opening angle θ_s of the preformed body S_1 is defined as an angle formed between the reference line and the straight line r connecting the widthwise center (W/2) of the preformed body and the widthwise end portion of the preformed body S_1 (see FIG. 5). Further, the angle (direction of the bending force) θ_f of the bending force is determined by the press die shape and the friction coefficient, when the angle (angle to the horizontal plane) of the forming surface of the press die is defined as θ_d , and the friction coefficient of the press die surface is defined as μ , the angle θ_f is determined as $\theta_f = \theta_d - \tan^{-1}(\mu)$ (see FIG. 9).

[0064] When the forming surface of the upper die 4 is configured to include a circular arc surface 4a having a width center that matches the forming center O of the press die, and a pair of forming surfaces 4b which is connected to each of both ends of the circular arc surface 4a and is directed toward the forming center O side of the press die, the forming surfaces 4b may be a straight inclined surface or a curved inclined surface.

[0065] The central angle θ_c of the circular arc surface 4a is set in the range of not less than 28° , and the forming surface 4b is deformed so as to reliably extend the lightly-bent portion or the non-bent portion P to the outside at the time of pressing of the preformed body S_1 . Therefore, it is possible to set the angle θ_d formed with the straight line intersecting with the straight line passing through the widthwise center of the circular arc surface 4a in the range of not less than 14° (see FIG. 2).

[0066] The reason of desirably setting the central angle θ_c of the circular arc surface 4a of the upper die 4 to not less than 28° is as follows. FIG. 10 illustrates the result of a relation between the angle θ_d of the forming surface 4b of the upper die 4 and the direction θ_f (angle of the bending force) of force obtained for a general lubrication state (the case of the friction coefficient of 0.1).

[0067] As seen from FIG. 10, the larger the angle θ_d of the forming surface of the upper die 4 is, the larger the direction θ_f of force is, and lightly-bent portion or the non-bent portion P easily extends outward. For example, when a pipe having an outer diameter of 559 mm is produced by a press machine having the width of the punch 2 of 150 mm (an example of a minimum dimension of paragraph (0055)), the minimum value of L/W is 0.05, and the opening angle θ_s of the preformed body S_1 is 9° . At this time, if the press die angle θ_d is not less than 14° , the direction θ_f of power is larger than the opening angle θ_s of the preformed body S_1 . In addition, the opening angle θ_s of the preformed body S_1 is geometrically determined by the ratio of the length L and the plate width W of the lightly-bent portion or the non-bent portion P, and when the L/W increases, the opening angle θ_s of the preformed body S_1 also increases. Thus, in some cases, it may be necessary to further increase the central angle θ_c of the circular arc surface 4a of the upper die 4.

[0068] Meanwhile, when the angle θ_d of the forming surface 4b of the upper die 4 is large, the opening portion of the press die becomes smaller than the maximum width of the preformed body S_1 having a U-shaped cross-section, and as illustrated in FIG. 11, since the upper die 4 may bite into the preformed body S_1 and scratch it, its upper limit is determined depending on a maximum width of the preformed body S_1 .

[0069] At the time of pressing of the preformed body S_1 , when the bending force is simultaneously applied to each of the parts (two locations) spaced apart from the lightly-bent portion or the non-bent portion P toward the width end (width end of the preformed body S_1) of the plate material S by amount of $W/4$, it is effective to mate the forming center O of the press die used for the pressing of the preformed body S_1 with the widthwise center $W/2$ of the preformed body S_1 , whereby an occurrence of a step difference (offset) in the gap portion of the open pipe S_2 can be avoided.

[0070] The circular arc surface 4a of the upper die 4 may be set to the radius of not more than 1.2 times the diameter of the steel pipe to be produced. The reason is as follows.

[0071] When the radius of the circular arc surface 4a of the upper die 4 is small, as illustrated in FIG. 12, a space is formed between the upper die 4 and the preformed body S_1 during forming, there is a risk of mis-alignment of the end surface in the gap portion, and its lower limit is defined depending on the shape near the plate end defined by the end bending so that the contact is possible in the range of about the plate thickness from the plate end.

[0072] FIG. 13 shows a relation between (the radius of circular arc surface 4a of the upper die 4/the radius of the steel pipe) and the index (residual index) in which the lightly-bent portion or the non-bent portion P is left (not bent to circular) as it is. When the radius of the circular arc surface 4a of the upper die 4 increases, the restriction is insufficient, and thus, the lightly-bent portion or the non-bent portion P remains as it is. When the residual index 1.0 is defined as a reference value, in order not to exceed the reference value, the radius of the circular arc surface 4a of the upper die 4 is desirably suppressed to not more than 1.2 times the radius of the steel pipe to be produced.

[0073] Next, when the lower die 5a has a circular arc surface 5a in which a forming surface has a concave shape, as illustrated in Fig. 5, there is a need to use one larger than the external diameter of the steel pipe to be produced so that the preformed body S_1 having a U-shaped cross-section fits into the press die.

[0074] FIG. 14 is a graph showing a relation between (the radius of the circular arc surface 5a of the lower die 5/the radius of the steel pipe) and (the forming load/the load when the lightly-bent portion or the non-bent portion P is freely bent). When the radius of the circular arc surface 5a of the lower die 5 is small, since the lightly-bent portion or the non-bent portion P is restricted by the press die during forming of the preformed body S_1 , the forming load increases. In particular, when the radius of the circular arc surface 5a of the lower die 5 is less than 1.05 times the diameter of the steel pipe to be produced, the forming load rapidly increases. Therefore, the radius of the circular arc surface 5a of the lower die 5 is desirably not less than 1.05 times the diameter of the steel pipe to be produced. When the radius of the circular arc surface 5a of the lower die 5 is set to not less than 1.07 times the diameter of the steel pipe to be produced, it can be suppressed to not more than twice of the load applied when forming the preformed body S_1 in a non-restriction state.

[0075] When the radius of the circular arc surface 5a of the lower die 5 is large, as illustrated in FIG. 15, since the contact with the upper die 4 is unavoidable, a desired pressing rate is not attained, the deformation of the lightly-bent portion or the non-bent portion P may be insufficient or the opening amount of the gap portion may increase, so that it is necessary to select the lower die 5 depending on the shape of the upper die 4. When using the lower die 5 having the circular arc surface 5a having the concave shape, it is possible to directly use the die used when producing the steel pipe by the UO method without any change, and there is no need for producing the die. However, as long as it is possible to avoid the restrictions of the lightly-bent portion or the non-bent portion P, those having the same configuration as the upper die 4 may be applied.

[0076] Further, although an example in which the forming surface (inclined surface) 4b is made up of a circular arc surface 4a and the forming surface (inclined surface) 4b is adopted as the upper die 4, as long as it is possible to satisfy the condition $\theta_s > \theta_f$ at the time of starting of pressing, a press die equipped with a forming surface formed with the circular arc surface 5a such as the lower die 5 may be used, and is not limited to the illustrated configuration.

[0077] As the lower die 5, it is possible to use one such as die 1 illustrated in FIG. 1 which supports the preformed body S_1 at two points or a roller-type die. Even when using the die, since the lightly-bent portion or the non-bent portion P is not restricted by the forming surface of the press die during pressing, the preformed body S_1 can be formed into a tubular shape with a relatively small bending force.

[0078] Thereafter, the open pipe S_2 obtained by pressing using the upper die 4 and the lower die 5 mutually abuts the end surfaces of the gap portion, is welded by a welding machine (a joining means) and is further formed into a steel pipe by being expanded as required.

[0079] As the welding machine (a joining means), for example, a welding machine made up of three kinds of welding machines, such as a tack welding machine, an inner surface welding machine and an outer surface welding machine, is applied. In the welding machine, the tack welding machine continuously brings the butted surfaces into close contact with each other at the appropriate positional relation by cage rolls, and welds the close-contact portions over its entire length.

[0080] Next, the tack pipe is welded (submerged arc welding) from the inner surface of the butted portion by the inner surface welding machine, and is further welded (submerged arc welding) from the outer surface of the butted portion by the outer surface welding machine.

[0081] The positional relation between the welding machine (the joining means) and the press die (the upper die 4

and the lower die 5) for pressing the preformed body S_1 is not particularly limited, and can be arbitrarily changed.

EXAMPLE 1

[0082] In order to form the steel pipe with a diameter of 36 inches using a line pipe steel plate (API grade X60) having a thickness of 38.1 mm and a width of 2711 mm, the material is placed on a die in which an interval of a rod-like member is set to 450 mm, and bending of the three-point bending is performed from the position of 1120 mm from the width center of the plate material, with a plate material feeding pitch of 224 mm and 11 bending times (five times from the paper right end, and five times from the left end) by a punch having a forming surface of a radius of 308 mm. At that time, the bending amount is set to an amount in which the punch tip reaches a position of 15.8 mm from the line connecting the uppermost part of the rod-like member, and bending is performed by 30° for a time. However, at the position of 672 mm from the width center of the plate material (at the time of third feeding from the right end, and third feeding from the left end), the bending is not performed, and the non-bent portion is formed at the position of 571 to 795 mm. Next, while holding the preformed body having the U-shaped cross-section obtained by bending in a U-shaped posture so that the opening portion faces upward, when pressing the preformed body into an open pipe until an inter-apex distance (the apex of the R part is an uppermost part of the circular arc surface in the upper die, and a lowermost part of the circular arc surface in the lower die) of a R part of the press die reaches 880 mm, using an upper die having a circular arc surface of a radius R: 457.2 mm and a central angle θ_c : 60° and a flat surface leading to the circular arc surface at the angle θ_d : 30° and a lower die having a concave circular arc surface of a radius R: 502.9 mm, the degree of the decrease of the bending force of the press die, the opening amount in the gap portion of the open pipe, the amount of offset, and the roundness of the steel pipe after welding are investigated.

[0083] As a result, after performing the U-shape press at a standard condition, by performing the O-shape press at the compression ratio of 0.2% using a press die of the radius R: 452.6 mm, as a result of being compared to the case (conventional method) of producing the steel pipe of an outer diameter of 36 inches and a thickness (wall thickness) of 38.1 mm, when producing the steel pipe according to the present invention, it is confirmed that the bending force of the O-shape press is decreased to about 15% as compared to the conventional method.

[0084] In addition, it becomes clear that the steel pipe can be obtained in which the opening amount in the gap portion of the open pipe is 21 mm, the amount of offset after welding (steel pipe) is 0.1 mm, the roundness is 5.2 mm and a difference to an outer diameter of 36 inches is only 0.6%.

EXAMPLE 2

[0085] As in Example 1, in order to form a steel pipe with a diameter of 36 inches using a line pipe steel plate (API grade X60) having a thickness of 38.1 mm and a width of 2711 mm, the material is placed on a die in which an interval of a rod-like member is set to 450 mm, and bending of the three-point bending is performed by 30° for a time, from the position of 1120 mm from the width center of the plate material, with a plate material feeding pitch of 224 mm and 11 bending times (five times from the paper right end, and five times from the left end) by a punch having a forming surface of a radius of 308 mm. At that time, the bending amount is set to an amount in which the punch tip reaches a position of 15.8 mm from the line connecting the uppermost part of the rod-like member, and bending is performed by 30° for a time. However, at the position of 672 mm from the width center of the plate material (at the time of third feeding from the right end, and third feeding from the left end), the lightly-bent portion is formed at the position of 571 to 795 mm, while decreasing the bending amount to 8.8 mm and performing the bending of 10° .

[0086] Next, while holding the preformed body having the U-shaped cross-section obtained by bending in a U-shaped posture so that the opening portion faces upward, when pressing the preformed body into an open pipe until an inter-apex distance (the apex of the R part is the uppermost part of the circular arc surface in the upper die, and the lowermost part of the circular arc surface in the lower die) of the R part of the press die reaches 880 mm, using the upper die having a circular arc surface of a radius R: 457.2 mm and a central angle θ_c : 60° and a flat surface leading to the circular arc surface at the angle θ_d : 30° , and the lower die having a concave circular arc surface of a radius R: 502.9 mm, the degree of pressing of the bending force of the press die, the opening amount in the gap portion of the open pipe, the amount of offset, and the roundness of the steel pipe after welding are investigated.

[0087] As a result, after performing the U-shape press at a standard condition, by performing the O-shape press at the compression ratio of 0.2% using a press die of the radius R: 452.6 mm, as a result of being compared to the case (conventional method) of producing the steel pipe of an outer diameter of 36 inches and a thickness (wall thickness) of 38.1 mm, when producing the steel pipe according to the present invention, it is confirmed that the bending force of the O-shape press is decreased to about 15% as compared to the conventional method.

[0088] Further, it becomes clear that the steel pipe can be obtained in which the opening amount in the gap portion of the open pipe is 16 mm, the amount of offset after welding (in steel pipe) is 0.1 mm, the roundness is 8.2 mm, and a difference to an outer diameter of 36 inches is only about 0.9%.

EXAMPLE 3

[0089] In order to form a steel pipe with a diameter of 42 inches using a line pipe steel plate (API grade X80) having a thickness of 44.5 mm, a width of 3180 mm and a length of 12.2 mm, the material is placed on the die in which the interval of the rod-like members is set to 500 mm, and bending of the three-point bending is performed by a punch having a forming surface with a radius of 360 mm, and a preformed body having a U-shaped cross-section with different position and length of the non-bent portion from the width end portion is prepared.

[0090] Next, the lower die having a concave circular arc surface having a radius R: 609.6 mm is installed on the rod-like member, and the preformed body having the U-shaped cross-section obtained by bending is pressed from the outside into an open pipe until an inter-apex distance (the apex of the R part is the uppermost part of the circular arc surface in the upper die, and the lowermost part of the circular arc surface in the lower die) of the R part of the press die reaches 1027 mm.

[0091] In the case of pressing the preformed body into the open pipe, the bending force of the press die, the opening amount and the amount of offset in the gap portion of the open pipe, and the roundness of the steel pipe after welding are investigated. The results are shown in Table 1 together with the bent position and the shape of the preformed body.

Table 1

No	Press condition	Shape of preformed body		Index of press condition (ratio to plate width)				Result			
	Bending force addition position [mm]	Center position of non-bent portion [mm]	Length of non-bent portion [mm]	Distance between bending force addition position and center of non-bent portion	Center position of non-bent portion	Length of non-bent portion	Load [MN]	Roundness [mm]	Amount of offset [mm]	Opening [mm]	
1	477	986	318	0.16	0.31	0.10	27	18.1	1.5	60	
2	382	986	318	0.19	0.31	0.10	23	13.9	0.8	50	
3	286	986	318	0.22	0.31	0.10	20	8.5	0.9	80	
4	191	986	318	0.25	0.31	0.10	18	7.5	0.6	100	
5	95	986	318	0.28	0.31	0.10	16	10.7	0.8	120	
6	0	986	318	0.31	0.31	0.10	15	13.9	1.0	150	
7	95	890	318	0.25	0.28	0.10	16	10.7	0.6	90	
8	0	795	318	0.25	0.25	0.10	17	5.3	0.7	80	
9	0	700	318	0.22	0.22	0.10	20	9.6	0.5	120	
10	0	604	318	0.19	0.19	0.10	23	14.9	0.7	100	
11	0	509	318	0.16	0.16	0.10	28	17.1	1.0	110	
12	0	795	127	0.25	0.25	0.04	17	7.5	0.2	60	
13	0	795	191	0.25	0.25	0.06	18	9.1	0.5	70	
14	0	795	254	0.25	0.25	0.08	18	11.2	0.7	80	
15	0	795	382	0.25	0.25	0.12	18	10.1	1.0	120	
16	0	795	445	0.25	0.25	0.14	19	19.2	0.9	140	

[0092] As in Nos. 2 to 6, when adding the bending force to a position spaced apart from the center of the non-bent portion by 0.19 to 0.31 of the plate width, the roundness and the amount of offset are good. However, in No. 1 of 0.16 which is close to the non-bent portion, the roundness is 18.1 mm which exceeds 1.5 % of the product diameter, and the amount of offset is also 1.5 mm which is larger than the other cases.

[0093] In addition, as the addition position of the bending force is away from the non-bent portion, the bending force becomes smaller.

[0094] In addition, as in Nos. 7 to 10, when setting the non-bent portion from the plate width end portion in the range of 0.28 to 0.19, the satisfactory roundness is obtained, but in No. 11 in which the non-bent portion is close to the plate width end portion, the roundness is 17.1 mm which exceeds 1.5% of the product diameter.

[0095] In addition, as in Nos. 12 to 15, when the length of the non-bent portion is not more than 0.12 of the plate width, the satisfactory roundness is obtained, but in No. 16 in which the length of the non-bent portion is large, the roundness is 19.2 mm which exceeds 1.5% of the product diameter.

EXAMPLE 4

[0096] In order to form a steel pipe with a diameter of 42 inches using a line pipe steel plate (API grade X80) having a thickness of 44.5 mm, a width of 3180 mm and a length of 12.2 mm, the material is placed on the die in which the interval of the rod-like members is set to 500 mm, and bending of the three-point bending is performed by a punch having a forming surface with a radius of 360 mm, and a preformed body having a U-shaped cross-section with different position and length of the non-bent portion from the width end portion is prepared.

[0097] Next, while holding the preformed body having the U-shaped cross-section obtained by bending in a U-shaped posture so that the opening portion faces upward, when pressing the preformed body into an open pipe, until an inter-apex distance (the apex of the R part is the uppermost part of the circular arc surface in the upper die, and the lowermost part of the circular arc surface in the lower die) of the R part of the press die reaches 1027 mm, using the upper die having a circular arc surface of a radius R: 533.4 mm and a central angle θ_c : 60° and a flat surface leading to the circular arc surface at the angle θ_d : 30° , and the lower die having a concave circular arc surface of a radius R: 609.6 mm, in the state that the upper die is in contact with both plate width end portions, the degree of pressing of the bending force of the press die, the opening amount in the gap portion of the open pipe, the amount of offset, and the roundness of the steel pipe after welding are investigated. The results are shown in Table 2 together with the bent position and the shape of the preformed body. The same shapes as in Example 3 are denoted by the same No.

Table 2

No	Press condition	Shape of preformed body		Index of press condition (ratio to plate width)			Result			
	Bending force addition position [mm]	Center position of non-bent portion [mm]	Length of non-bent portion [mm]	Distance between bending force addition position and center of non-bent portion	Center position of non-bent portion	Length of non-bent portion	Load [MN]	Roundness [mm]	Amount of offset [mm]	Opening [mm]
7	0	890	318	0.28	0.28	0.10	32	8.0	0.2	110
8	0	795	318	0.25	0.25	0.10	36	4.3	0.1	100
9	0	700	318	0.22	0.22	0.10	40	8.5	0.1	90
10	0	604	318	0.19	0.19	0.10	47	11.2	0.2	100
11	0	509	318	0.16	0.16	0.10	56	16.5	0.1	80
12	0	795	127	0.25	0.25	0.04	35	6.4	0.1	70
13	0	795	191	0.25	0.25	0.06	35	5.9	0.0	70
14	0	795	254	0.25	0.25	0.08	36	5.3	0.1	90
15	0	795	382	0.25	0.25	0.12	37	6.4	0.2	130
16	0	795	445	0.25	0.25	0.14	37	17.1	0.1	140

[0098] As in Nos. 7 to 10, when setting the non-bent portion from the plate width end portion within the range of 0.28 to 0.19, the satisfactory roundness is obtained. However, in No. 11 in which the non-bent portion is close to the plate width end portion, the roundness is 16.5 mm which exceeds 1.5% of the product diameter.

[0099] In addition, as in No. 12 to 15, when the length of the non-bent portion is not more than 0.12 of the plate width, the satisfactory roundness is obtained. However, in No. 16 in which the length of the non-bent portion is large, the roundness is 17.1 mm which exceeds 1.5% of the product diameter. Furthermore, all the amount of offset is not more than 0.2 mm which is smaller than in Example 3 performing the bending one side by one side.

EXAMPLE 5

[0100] In order to form a steel pipe with a diameter of 22 inches using a line pipe steel plate (API grade X80) having a thickness of 31.8 mm, a width of 1640 mm and a length of 12.2 mm, the material is placed on the die in which the interval of the rod-like members is set to 400 mm, and bending of the three-point bending is performed by a punch having a forming surface with a radius of 188 mm, and a preformed body having a U-shaped cross-section with different position and length of the non-bent portion from the width end portion is prepared.

[0101] Next, a lower die having a concave circular arc surface having a radius R: 330.2 mm is installed on the rod-like member, and the preformed body having the U-shaped cross-section obtained by bending is pressed from the outside into an open pipe, until an inter-apex distance (the apex of the R part is the uppermost part of the circular arc surface in the upper die, and the lowermost part of the circular arc surface in the lower die) of the R part of the press die reaches 538 mm,

[0102] In the case of pressing the preformed body into the open pipe, the bending force of the press die, the opening amount and the amount of offset in the gap portion of the open pipe, and the roundness of the steel pipe after welding are investigated. The results are described in Table 3 together with the bent position and the shape of the preformed body.

Table 3

No	Press condition	Shape of preformed body		Index of press condition (ratio to plate width)			Result			
	Bending force addition position [mm]	Center position of non-bent portion [mm]	Length of non-bent portion [mm]	Distance between bending force addition position and center of non-bent portion	Center position of non-bent portion	Length of non-bent portion	Load [MN]	Roundness [mm]	Amount of offset [mm]	Opening [mm]
1	246	508	164	0.16	0.31	0.10	37	10.1	1.4	60
2	197	508	164	0.19	0.31	0.10	32	7.8	0.7	50
3	148	508	164	0.22	0.31	0.10	28	5.0	0.9	80
4	98	508	164	0.25	0.31	0.10	25	4.6	0.7	100
5	49	508	164	0.28	0.31	0.10	22	6.7	0.6	120
6	0	508	164	0.31	0.31	0.10	21	7.8	0.9	150
7	49	459	164	0.25	0.28	0.10	23	5.6	0.5	90
8	0	410	164	0.25	0.25	0.10	24	3.9	0.4	80
9	0	361	164	0.22	0.22	0.10	28	5.0	0.6	120
10	0	311	164	0.19	0.19	0.10	32	7.8	0.6	100
11	0	262	164	0.16	0.16	0.10	40	10.6	1.0	110
12	0	410	98	0.25	0.25	0.06	25	5.0	0.5	70
13	0	410	131	0.25	0.25	0.08	26	5.6	0.9	80
14	0	410	197	0.25	0.25	0.12	26	5.3	0.9	120
15	0	410	229	0.25	0.25	0.14	26	11.2	1.1	140

[0103] As in Nos. 2 to 6, when adding the bending force to a position spaced apart from the center of the non-bent portion by 0.19 to 0.31 of the plate width, both the roundness and the amount of offset are good. However, in No. 1 of 0.16 which is close to the non-bent portion, the roundness is 10.1 mm which exceeds 1.5 % of the product diameter, and the amount of offset is 1.4 mm which is larger than the other cases.

[0104] Further, as the addition position of the bending force is away from the non-bent portion, the bending force becomes smaller. Further, as in Nos. 7 to 10, when providing the non-bent portion in the range of 0.28 to 0.19 from the plate width end portion, the satisfactory roundness is obtained, but in No. 11 in which the non-bent portion is close to the plate width end portion, the roundness is 10.6 mm which exceeds 1.5% of the product diameter. Furthermore, as in Nos. 12 to 14, when the length of the non-bent portion is not more than 0.12 of the plate width, the satisfactory roundness is obtained, but in No. 15 in which the length of the non-bent portion is large, the roundness is 11.2 mm which exceeds 1.5% of the product diameter.

EXAMPLE 6

[0105] In order to form a steel pipe with a diameter of 22 inches using a line pipe steel plate (API grade X80) having a thickness of 31.8 mm, a width of 1640 mm and a length of 12.2 mm, the material is placed on the die in which the interval of the rod-like members is set to 400 mm, and bending of the three-point bending is performed by a punch having a forming surface with a radius of 188 mm, and a preformed body having a U-shaped cross-section with different position and length of the non-bent portion from the width end portion is prepared.

[0106] Next, while holding the preformed body having the U-shaped cross-section obtained by bending in a U-shaped posture so that the opening portion faces upward, when pressing the preformed body into an open pipe, until an inter-apex distance (the apex of the R part is the uppermost part of the circular arc surface in the upper die, and the lowermost part of the circular arc surface in the lower die) of the R part of the press die reaches 538 mm, using the upper die having a circular arc surface of a radius R: 279.4 mm and a central angle θ_c : 60° and a flat surface leading to the circular arc surface at the angle θ_d : 30°, and the lower die having a concave circular arc surface of a radius R: 330.2 mm, in the state that the upper die is in contact with both plate width end portions, the degree of pressing of the bending force of the press die, the opening amount in the gap portion of the open pipe, the amount of offset, and the roundness of the steel pipe after welding are investigated. The results are described in Table 4 together with the bent position and the shape of the preformed body. The same shapes as in Example 5 are denoted by the same No.

Table 4

No	Press condition	Shape of preformed body		Index of press condition (ratio to plate width)			Result			
	Bending force addition position [mm]	Center position of non-bent portion [mm]	Length of non-bent portion [mm]	Distance between bending force addition position and center of non-bent portion	Center position of non-bent portion	Length of non-bent portion	Load [MN]	Roundness [mm]	Amount of offset [mm]	Opening [mm]
7	0	459	164	0.28	0.28	0.10	46	4.7	0.0	110
8	0	410	164	0.25	0.25	0.10	50	3.1	0.2	100
9	0	361	164	0.21	0.22	0.10	55	4.5	0.1	90
10	0	311	164	0.19	0.19	0.10	65	7.3	0.2	100
11	0	262	164	0.16	0.16	0.10	78	9.8	0.3	80
12	0	410	98	0.25	0.25	0.06	50	36	0.0	70
13	0	410	131	0.25	0.25	0.08	51	3.9	0.1	90
14	0	410	197	0.25	0.25	0.12	51	3.4	0.3	130
15	0	410	229	0.25	0.25	0.14	52	10.1	0.2	140

[0107] As in Nos. 7 to 10, when providing the non-bent portion within the range of 0.28 to 0.19 from the plate width end portion, the satisfactory roundness is obtained. However, in No. 11 in which the non-bent portion is close to the plate width end portion, the roundness is 9.8 mm which exceeds 1.5% of the product diameter.

[0108] In addition, as in Nos. 12 to 14, when the length of the non-bent portion is not more than 0.12 of the plate width, the satisfactory roundness is obtained. However, in No. 15 in which the length of the non-bent portion is large, the roundness is 10.1 mm which exceeds 1.5% of the product diameter. Furthermore, all the amount of offset is not more than 0.3 mm which is smaller than in Example 3 performing bending one side by one side.

EXAMPLE 7

[0109] In order to form a steel pipe with a diameter of 36 inches using a line pipe steel plate (API grade X60) having a thickness of 38.1 mm, a width of 2711 mm and a length of 12.2 mm, the material is placed on the die in which the interval of the rod-like members is set to 450 mm, and bending of the three-point bending is performed by a punch having a forming surface with a radius of 308 mm, and a preformed body having a U-shaped cross section provided with non-bent portions of the length of 109 mm and 224 mm around the position of 683 mm from the plate width end portion is prepared.

[0110] Next, while holding the preformed body having the U-shaped cross-section obtained by bending in a U-shaped posture so that the opening portion faces upward, when pressing the preformed body into an open pipe, until an inter-apex distance (the apex of the R part is the uppermost part of the circular arc surface in the upper die, and the lowermost part of the circular arc surface in the lower die) of the R part of the press die reaches 880 mm, using the upper die having a circular arc surface of a radius R: 457.2 mm and various central angles and a flat surface leading to the circular arc surface, and the lower die having a concave circular arc surface of a radius R: 502.9 mm, in the state that the upper die is in contact with both plate width end portions, the degree of pressing of the bending force of the press die, the opening amount in the gap portion of the open pipe, and the roundness of the steel pipe after welding are investigated. Table 5 describes the results together with the length of the non-bent portion, the opening angle θ_s of the preformed body having the U-shaped cross-section, the central angle of the upper die and the angle θ_f of the bending force.

Table 5

No	Length of non-bent portion [mm]	Opening angle θ_s [degree]	Center angle of upper die θ_c [degree]	Angle of bending force θ_f [degree]	Opening [mm]	Roundness [mm]
1	109	7.2	5.0	2.1	240	-
2	109	7.2	10.0	7.1	120	15.7
3	109	7.2	15.0	12.1	40	7.1
4	224	14.4	15.0	12.1	240	-
5	224	14.4	20.0	17.1	31	6.2
6	224	14.4	30.0	27.1	21	5.2

[0111] As in Nos. 3, 5 and 6, under the condition of $\theta_f > \theta_s$, the opening amount is also small and the roundness is also good. Meanwhile, in Nos. 1, 2 and 4 of $\theta_f < \theta_s$, the opening amount is large, and in Nos. 1 and 4, the opening amount is too large to perform the welding. In addition, although the welding can be performed in No. 2, the roundness is 15.7 mm which exceeds 1.5% of the product diameter.

EXAMPLE 8

[0112] In order to form a steel pipe with various diameters of 28 to 38 inches using a line pipe steel plate (API grade X60) having a thickness of 38.1 mm and a length of 12.2 mm, bending of the three-point bending is performed, and a preformed body having a U-shaped cross section provided with a non-bent portion of 0.08 times the plate width around the position of W/4 from the plate width end portion is prepared.

[0113] Next, while holding the preformed body having the U-shaped cross-section obtained by bending in a U-shaped posture so that the opening portion faces upward, when pressing the preformed body into an open pipe, until an inter-apex distance (the apex of the R part is the uppermost part of the circular arc surface in the upper die, and the lowermost part of the circular arc surface in the lower die) of the R part of the press die reaches 0.96 times the outer diameter, using the upper die having a circular arc surface of a radius R: 457.2 mm and a central angle θ_c : 60° and various radiuses

leading to the circular arc surface at the angle θ_d : 30° , and the lower die having a concave circular arc surface of a radius larger than the outer diameter by 50.8 mm, in the state that the upper die is in contact with both plate width end portions, the degree of pressing of the bending force of the press die, the amount of offset in the gap portion of the open pipe, and the roundness of the steel pipe after welding are investigated. Table 6 describes the results together with the outer diameter of the steel pipe, and the ratio of the radius of the upper die to the outer radius of the steel pipe.

Table 6

No	Outer diameter of steel pipe [mm]	Radius of upper die/ outer radius of steel pipe	Roundness [mm]	Amount of offset [mm]
1	965.2	0.95	5.7	1.0
2	914.4	1.00	5.2	0.2
3	863.6	1.06	6.2	0.1
4	812.8	1.13	8.3	0.2
5	762.0	1.20	10.2	0.3
6	711.2	1.29	17.2	0.2

[0114] In Nos. 1 to 5 in which the ratio of the radius of the upper die to the outer radius of the steel pipe is not more than 1.2, the roundness is good, and smaller the ratio is, the better the roundness is. In addition, in No. 1 in which the radius of the upper die is smaller than the outer radius of the steel pipe, the amount of offset is larger than Nos. 2 to 5 in which the ratio is not less than 1.0. Meanwhile, in No. 6 in which ratio of the radius of the upper die to the outer radius of the steel pipe is large, the roundness is 17.2 mm which exceeds 1.5% of the product diameter.

EXAMPLE 9

[0115] In order to form a steel pipe with a diameter of 36 inches using a line pipe steel plate (API grade X60) having a thickness of 38.1 mm, a width of 2711 mm and a length of 12.2 mm, the material is placed on the die in which the interval of the rod-like members is set to 450 mm, and bending of the three-point bending is performed by a punch having a forming surface with a radius of 308 mm, and a preformed body having a U-shaped cross section provided with a non-bent portion of the length of 224 mm around the position of 683 mm from the plate width end portion is prepared.

[0116] Next, while holding the preformed body having the U-shaped cross-section obtained by bending in a U-shaped posture so that the opening portion faces upward, when pressing the preformed body into an open pipe, until an inter-apex distance (the apex of the R part is the uppermost part of the circular arc surface in the upper die, and the lowermost part of the circular arc surface in the lower die) of the R part of the press die reaches 880 mm, using the upper die having a circular arc surface of a radius R: 457.2 mm and a central angle θ_c : 60° and various radii R leading to the circular arc surface at the angle θ_d : 30° , and the lower die having a concave circular arc surface of various radii, in the state that the upper die is in contact with both plate width end portions, the bending force (load) of the press die is investigated. Table 7 describes a relation among deformation of the lower die, a ratio to the outer radius of the steel pipe, and the bending force.

Table 7

No	Radius of lower die [mm]	Radius of lower die / outer radius of steel pipe	Load [MN]
1	482.6	1.06	75
2	508.0	1.11	50
3	533.4	1.17	35
4	558.8	1.22	35

[0117] As the radius of the lower die is increased, its load is decreased. In Nos. 3 and 4 in which the ratio is in excess of 1.15, there is no contact with the press die, and the load is not more than half of No. 1.

INDUSTRIAL APPLICABILITY

[0118] According to the present invention, it is possible to efficiently produce a steel pipe having a high roundness, without requiring excessive pressure.

DESCRIPTION OF REFERENCE SYMBOLS

[0119]

- 1 die
- 1a rod-like member
- 1b rod-like member
- 2 punch
- 2a punch tip
- 2b punch support
- 3 roller
- 4 upper die
- 4a circular arc surface
- 4b forming surface (inclined surface)
- 5 lower die
- 5a circular arc surface
- S plate material
- S₁ preformed body
- S₂ open pipe

Claims

1. A method of producing a steel pipe in which a plate material which is bent at width end portions is subjected to at least one bending along its widthwise direction to form a preformed body having a U-shaped cross-section, an open pipe with a gap portion in a longitudinal direction is formed by adding a bending force to the preformed body to press the preformed body, and end surfaces of the gap portion of the open pipe are butt-joined to each other to form a steel pipe, the method comprising:
 - providing a lightly-bent portion to which a very slight curvature is applied as compared to other regions, or providing a non-bent portion in which the bending is omitted in at least a part of the plate material in performing the bending on the plate material; and
 - applying the bending force to a part spaced apart at least from the center of the lightly-bent portion or the non-bent portion in a width end portion direction of the plate material by amount of W/4 (where, W is a width size of the plate material) without constraining the lightly-bent portion or the non-bent portion, in pressing the preformed body into the open pipe.
2. The method of producing a steel pipe according to claim 1, wherein the center of the lightly-bent portion or the non-bent portion is provided in a part spaced apart from the width end portion of the plate material by amount of W/4.
3. The method of producing a steel pipe according to claim 1 or 2, wherein the length of the lightly-bent portion or the non-bent portion along the widthwise direction of the plate material is not more than 10% of the plate width.
4. The method of producing a steel pipe according to any one of claims 1 to 3, wherein when applying the bending force to press the preformed body, the preformed body is supported at a part not on the line of action of the bending force, and when an opening angle of the preformed body is defined as θ_s and an angle of the bending force is defined as θ_f , the pressing of the preformed body is started under the condition of $\theta_f > \theta_s$.
5. The method of producing a steel pipe according to any one of claims 1 to 4, wherein at the time of pressing of the preformed body, a press die provided with a forming surface of not coming into contact with the lightly-bent portion or the non-bent portion is used.
6. The method of producing a steel pipe according to any one of claims 1 to 5, wherein at the time of pressing of the

preformed body, the bending force is simultaneously applied to a part each spaced apart from the center of the lightly-bent portion or the non-bent portion toward the width end of the plate material by amount of $W/4$.

7. The method of producing a steel pipe according to any one of claims 1 to 6, wherein at the time of pressing of the preformed body, a forming center of the press die used for pressing of the preformed body coincides with a center in the widthwise direction of the preformed body.
8. The method of producing a steel pipe according to any one of claims 1 to 7, wherein the preformed body is held in a U-shaped posture with its opening portion facing upward, and is supported at its lowermost end.
9. A press die used in the method of producing a steel pipe according to any one of claims 1 to 8, wherein the press die includes a pair of the bending tools configured to interpose the preformed body therebetween, and the bending tools have a forming surface that does not come into contact with the lightly-bent portion or the non-bent portion during pressing of the preformed body.
10. The press die used in the method of producing a steel pipe according to claim 9, wherein at least one of the bending tools has a circular arc surface having a width center that coincides with the forming center of the press die, and a forming surface having an inclined surface which leads to each of both ends of the circular arc surface and is directed toward the forming center of the press die.

FIG. 1

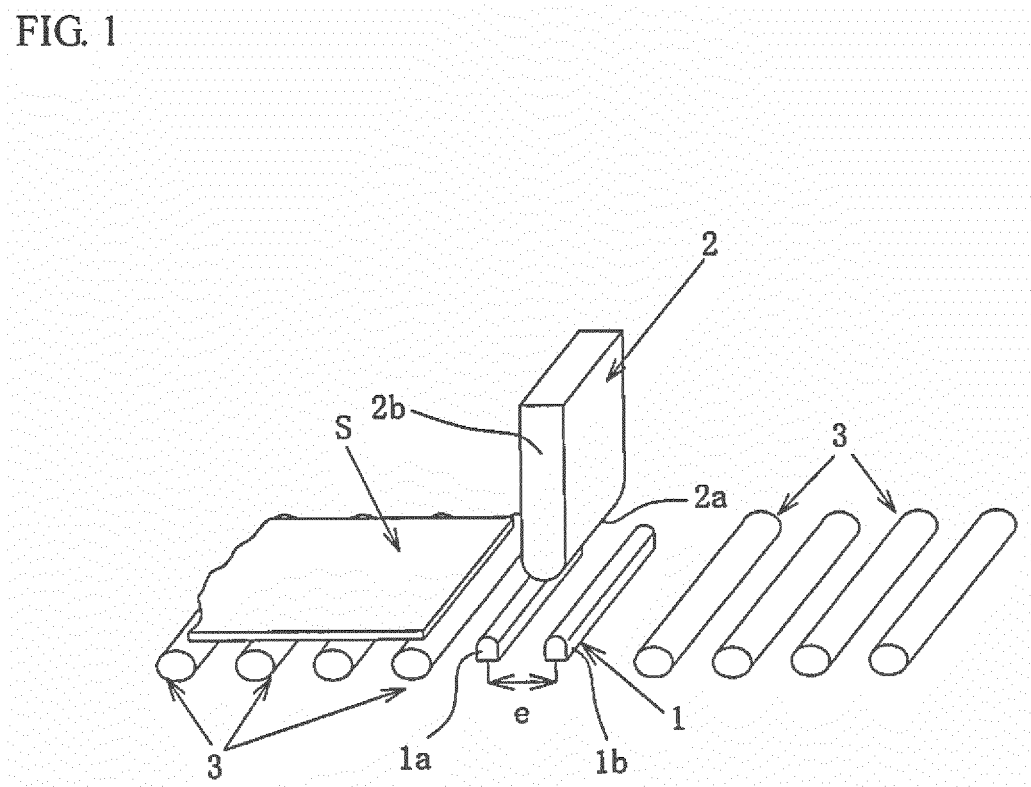


FIG. 2

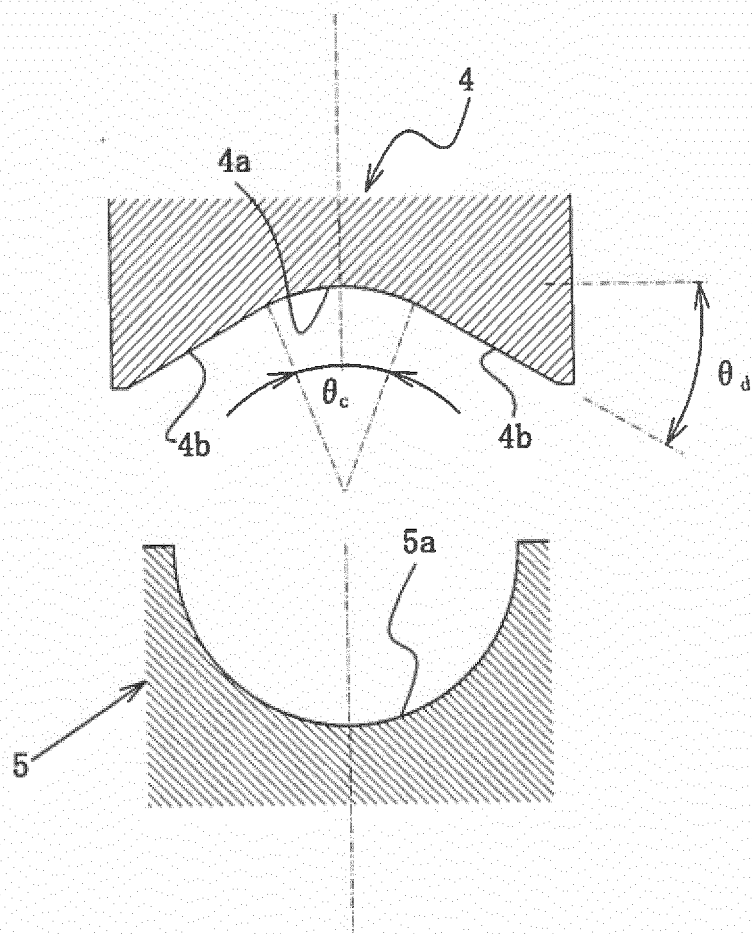


FIG. 3

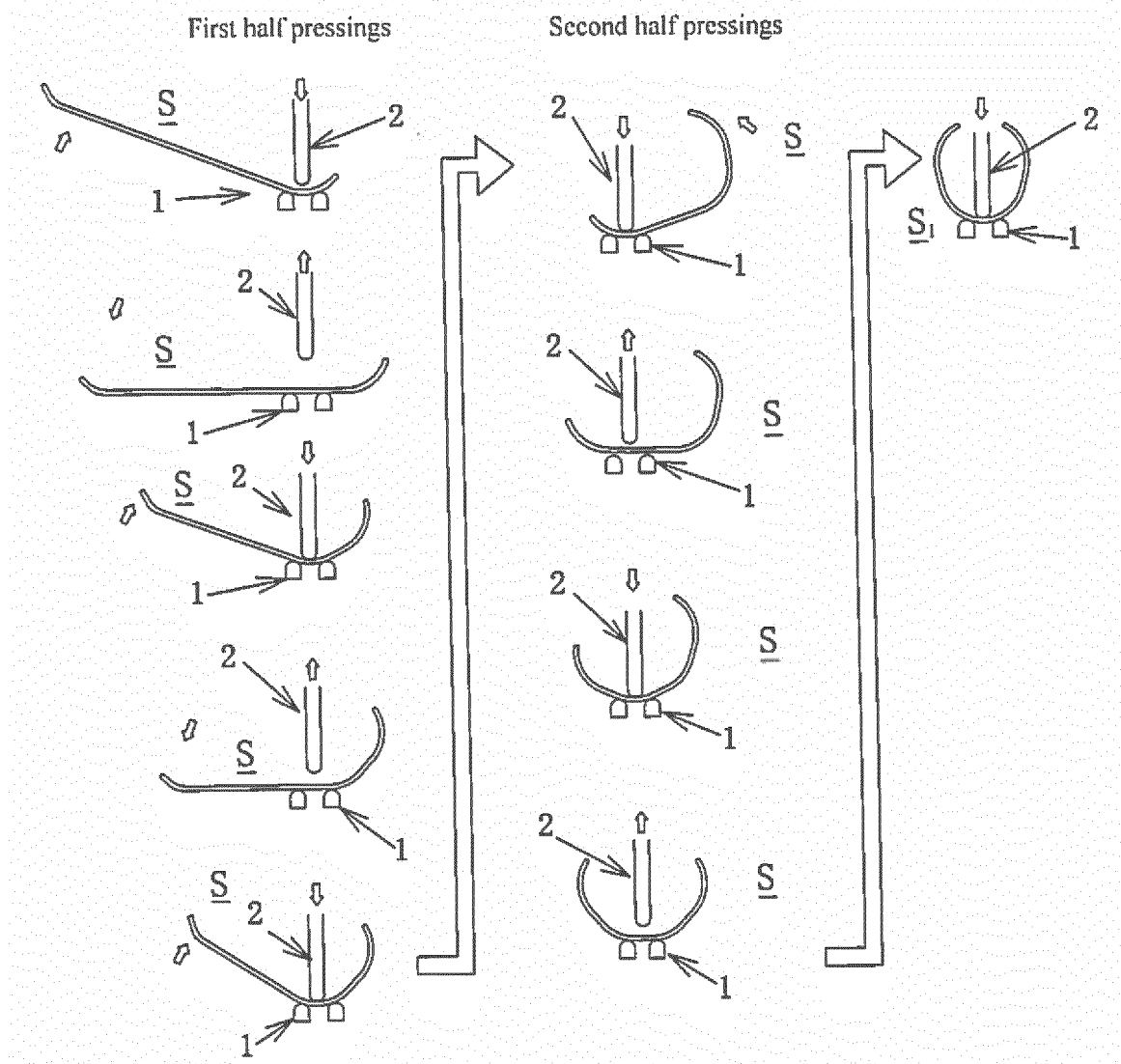


FIG. 4

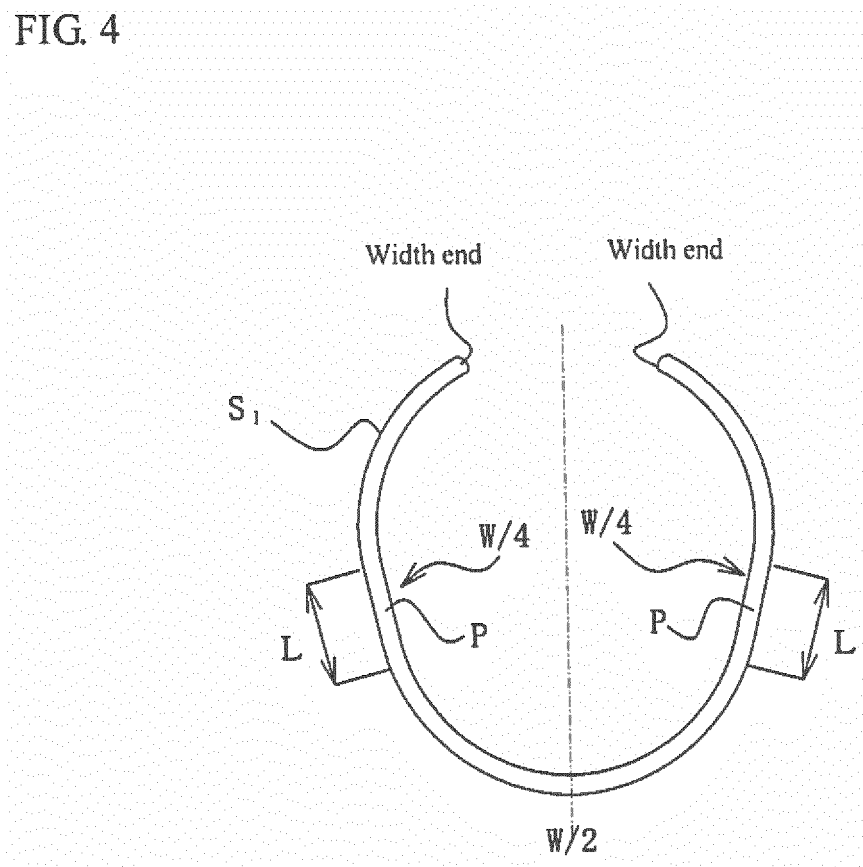


FIG. 5

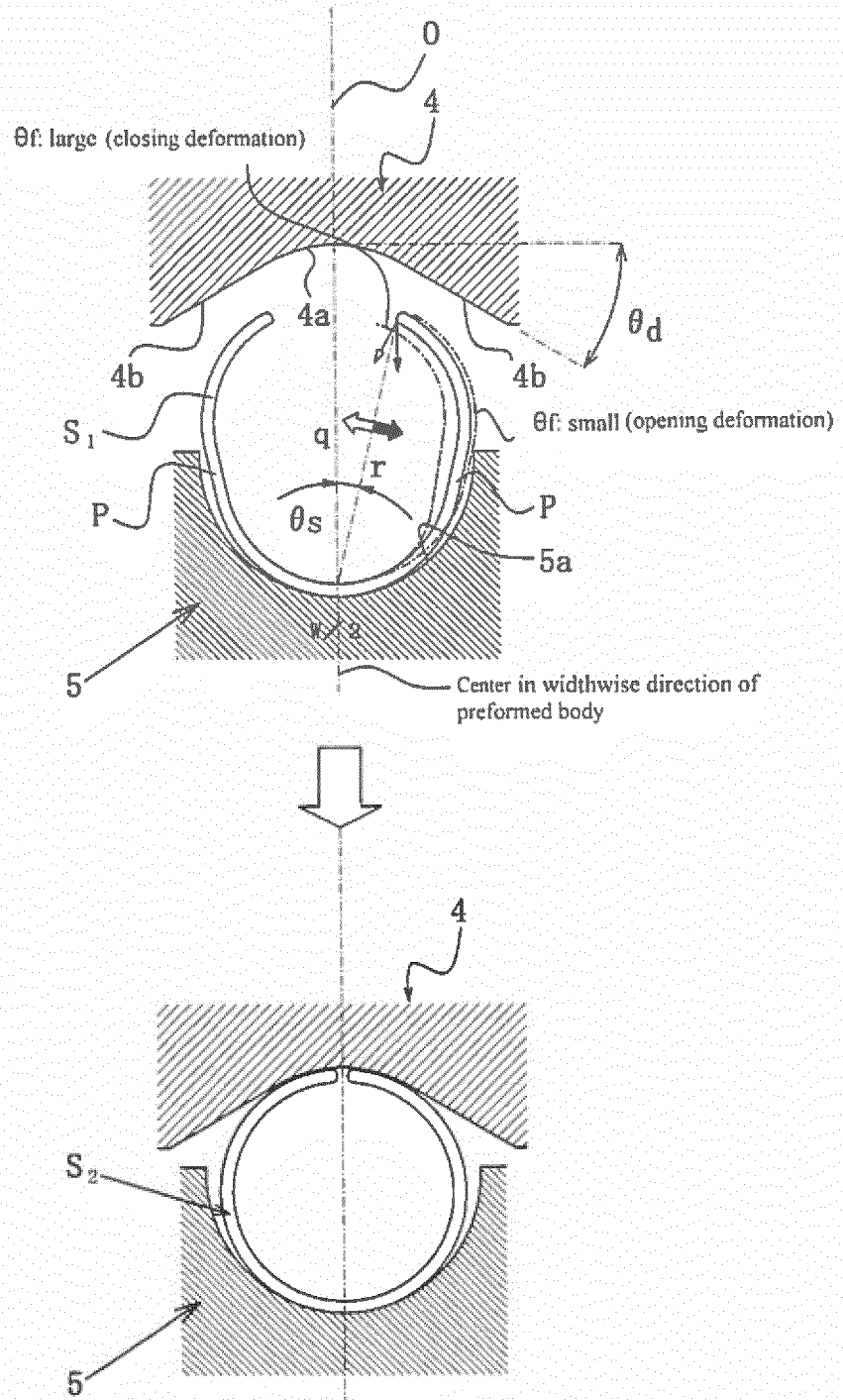


FIG.6

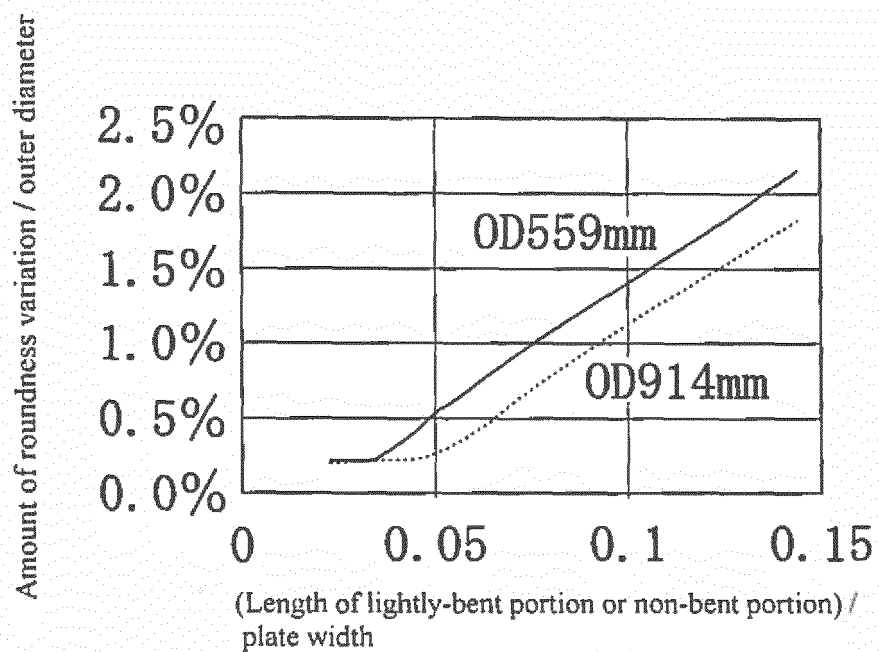


FIG.7

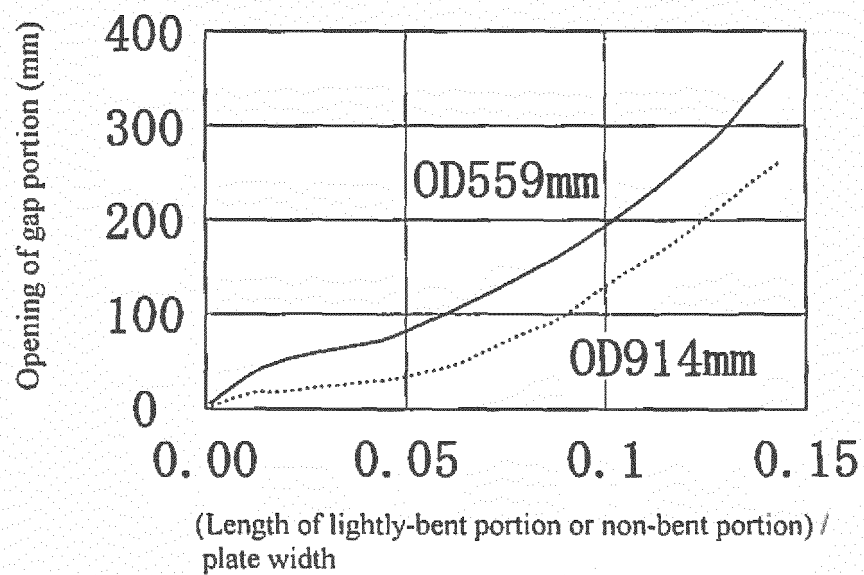


FIG. 8

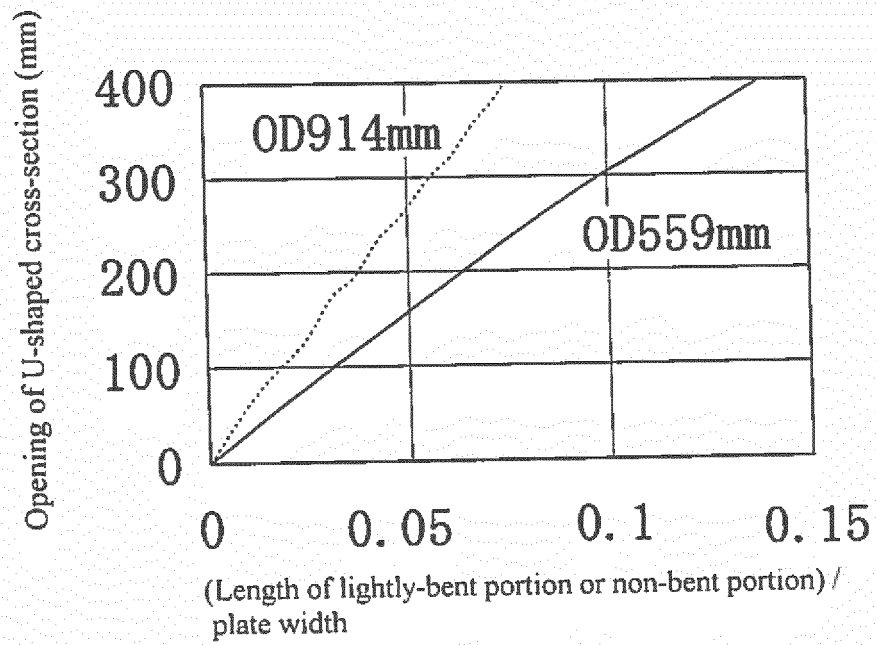


FIG. 9

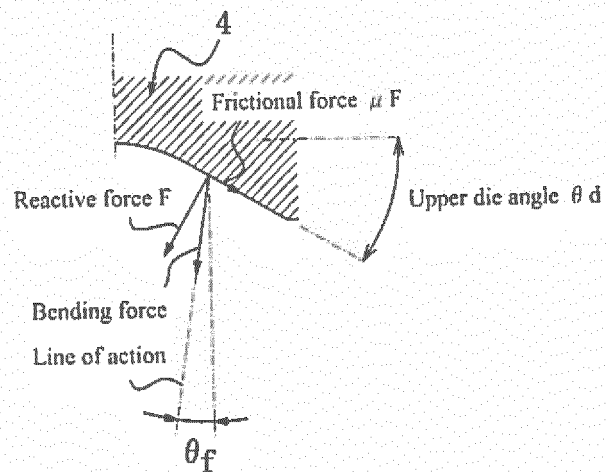


FIG. 10

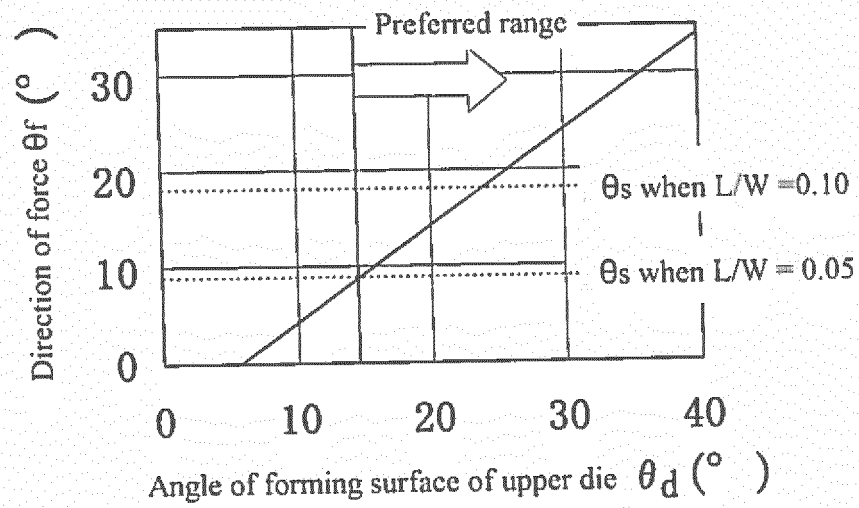


FIG. 11

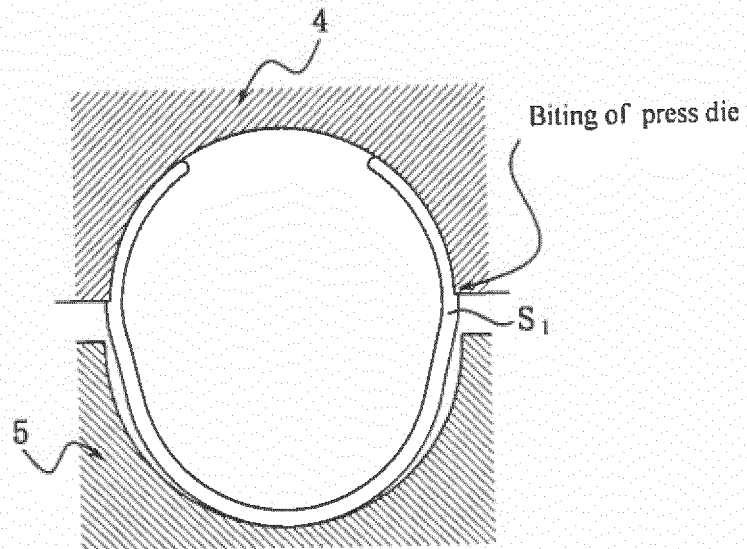


FIG. 12

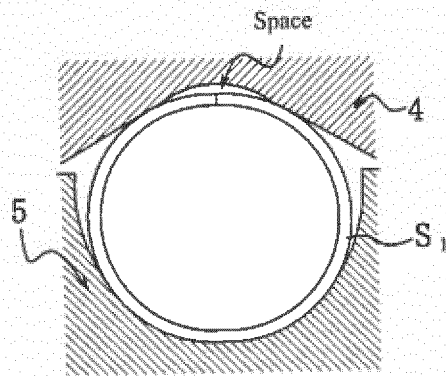


FIG. 13

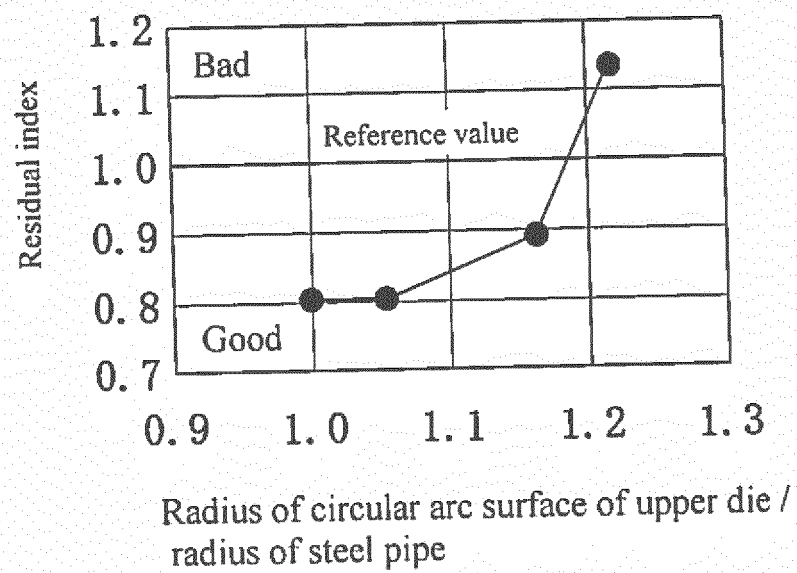


FIG. 14

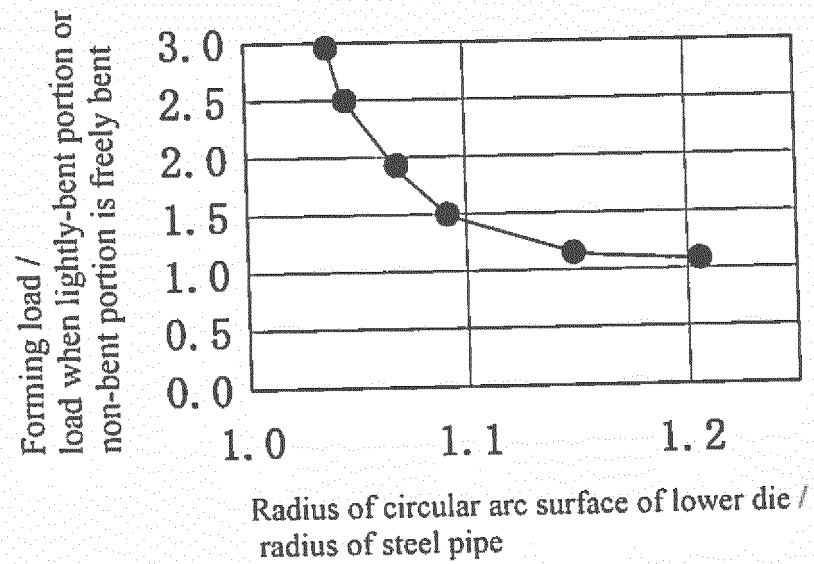
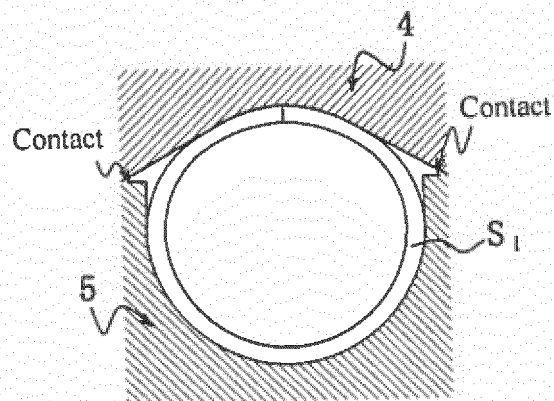


FIG. 15



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2015/081818

A. CLASSIFICATION OF SUBJECT MATTER

B21D5/01 (2006.01) i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B21D5/01, B21C37/08

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2016

Kokai Jitsuyo Shinan Koho 1971-2016 Toroku Jitsuyo Shinan Koho 1994-2016

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 53-112260 A (NKK Corp.), 30 September 1978 (30.09.1978), specification, page 1, lower right column, line 9 to page 2, upper left column, line 6; fig. 1 to 2 (Family: none)	1-10
A	US 2479336 A (H-P-M DEVELOPMENT CORP.), 16 August 1949 (16.08.1949), column 3, lines 20 to 24; fig. 2 to 4 (Family: none)	1-10

☒ Further documents are listed in the continuation of Box C.☐ See patent family annex.

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Date of the actual completion of the international search
25 January 2016 (25.01.16)Date of mailing of the international search report
02 February 2016 (02.02.16)Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2015/081818

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 60-130419 A (Taiho Kogyo Co., Ltd.), 11 July 1985 (11.07.1985), specification, page 1, lower left column, line 18 to page 2, upper left column, line 1; fig. 1 to 2 (Family: none)	1-10
A	US 1387199 A (PHILADELPHIA BRONZE BEARING & TUBE CO.), 09 August 1921 (09.08.1921), specification, page 1, lines 65 to 85; fig. 3 (Family: none)	1-10
A	JP 55-139117 A (Nippon Steel Corp.), 30 October 1980 (30.10.1980), specification, page 3, upper right column, line 12 to lower left column, line 10; fig. 2 (Family: none)	1-10
A	JP 2012-250285 A (SMS Meer GmbH), 20 December 2012 (20.12.2012), entire text; all drawings & EP 2529849 A2 & CN 102806245 A & RU 2012122452 A & BR 102012012992 A2	1-10
A	US 4149399 A (AB CARBOX), 17 April 1979 (17.04.1979), entire text; all drawings & DE 2800823 A1 & SE 7700221 A	1-10

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REFERENCES CITED IN THE DESCRIPTION

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- JP 2012250285 A [0007]
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