(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 597 322 A1

(12) EUROPEAN PATENT APPLICATION

published in accordance with Art. 153(4) EPC

(43) Date of publication:
22.01.2020 Bulletin 2020/04

(21) Application number: **18767918.8**

(22) Date of filing: **06.03.2018**

(51) Int Cl.:
B21D 5/01 *(2006.01)*

(86) International application number:
PCT/JP2018/008489

(87) International publication number:
WO 2018/168563 (20.09.2018 Gazette 2018/38)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(30) Priority: **15.03.2017 JP 2017049680**

(71) Applicant: **JFE Steel Corporation**
Tokyo 100-0011 (JP)

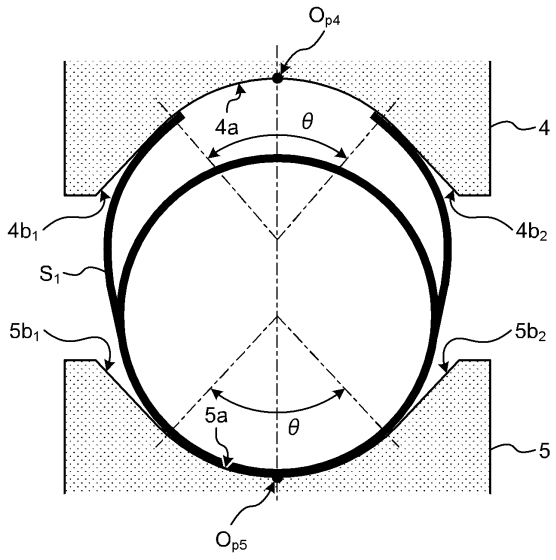
(72) Inventors:
- **HORIE, Masayuki**
  Tokyo 100-0011 (JP)
- **MIWA, Toshihiro**
  Tokyo 100-0011 (JP)
- **TAMURA, Yukuya**
  Tokyo 100-0011 (JP)
- **MIYAKE, Masaru**
  Tokyo 100-0011 (JP)

(74) Representative: **Hoffmann Eitle**
Patent- und Rechtsanwälte PartmbB
Arabellastraße 30
81925 München (DE)

(54) PRESS MOLD AND METHOD FOR MANUFACTURING STEEL PIPE

(57) A press die for use in a steel pipe forming process of bending a plate material to form a preformed body having a U-shaped cross section, pressing the preformed body to form an open pipe, which is a tubular body having a seam gap portion in a longitudinal direction, and thereafter joining the seam gap portion to form a steel pipe. The press die includes a pair of dies. The preformed body is installed in one of the pair of dies such that the other die is opposed to a U-shaped open side of the preformed body, and the preformed body is pressed while the preformed body is held between the pair of dies. A surface of each die to be in contact with the preformed body has an arc portion having a diameter equal or substantially equal to an outer diameter of the steel pipe such that an arc center is located at a position coincident with a bending center of the die. The arc portion in each die has a central angle equal to or larger than 70 degrees, and a total angle of the central angles of the dies is smaller than 360 degrees.

FIG.5



EP 3 597 322 A1

Description

Field

[0001] The present invention relates to a press die for use in a steel pipe forming process and a method of manufacturing a steel pipe using the press die.

Background

[0002] UOE forming techniques are widely used to form steel pipes. In the UOE forming techniques, a steel plate is first pressed into a U shape and then pressed into an O shape to form an open pipe, which is a tubular body having a seam gap portion between plate edge portions opposed to each other in a circumferential direction. The seam gap portion of the open pipe is butted and joined by welding to form a steel pipe, which is then expanded such that the diameter of the steel pipe is increased. The UOE forming technique, however, requires a high press force in the process of press-bending a steel plate into a U shape or an O shape to form an open pipe and inevitably requires the use of a large-scale press machine.

[0003] Then, in manufacturing a steel pipe, there is a technique for forming an open pipe with a reduced press force. For example, a press-bending process is in practical use, in which the edge portions in the width direction of a steel plate are bent to produce edge bent portions, and thereafter three-point press bending is performed multiple times with a punch supported on a punch support and a die to shape the steel plate into an approximately circular shape. The open amount of the seam gap portion of the open pipe formed by the press bending process is larger than the width of the punch support. If the open amount is too large, the force required for butting the plate edge portions opposed to each other and closing the seam gap portion is increased in order to weld the seam gap portion. A larger facility is then required for closing the seam gap portion. In addition, after the seam gap portion with an excessively large open amount is welded, the welded portion receives a force caused by springback to open the seam gap portion and tends to suffer a weld defect. If the force is too large, the welded portion is broken.

[0004] Techniques for reducing the open amount of the seam gap portion of an open pipe after press bending are disclosed in Patent Literature 1 to 4. Patent Literature 1 discloses a technique for reducing the open amount of the seam gap portion of an open pipe by providing a pivotable coupling portion between the punch front end and the punch support to reduce the width of the punch support. Patent Literature 2 discloses a technique for reducing the open amount of the seam gap portion of an open pipe by providing gap holding means for restricting movement of a plate material in a direction orthogonal to the punch moving direction, and applying a large press in the final bending without the plate edge portions coming into contact with the punch support. Patent Literature 3 discloses a technique for reducing the open amount of the seam gap portion of an open pipe by measuring the gap between the plate edge portion and the punch support after the final pressing-down process and minimizing the gap. Patent Literature 4 discloses a technique for reducing the open amount of the seam gap portion of an open pipe irrespective of variation in shape produced in the press bending process, in which the amount of pressing-down by the punch in a final step is determined based on the point of time when the distance between the plate edge portions becomes a predetermined value at the time of pressing-down in the final bending process.

[0005] Unfortunately, the techniques disclosed in Patent Literature 1 to 4 fail to reduce the open amount of the seam gap portion of an open pipe to a width smaller than the width of the punch support. Then, the techniques for reducing the open amount of the seam gap portion by additionally processing the open pipe after press bending are disclosed in Patent Literature 5 to 9. Patent Literature 5 discloses a technique of forming a pipe with a smaller load by hot-pressing a steel pipe after press bending. Patent Literature 6 discloses a technique of press-bending, in which a distortion detector is disposed to detect a tilt or distortion of a pressing member attached to a slide, the pressing member is disposed so as to be able to tilt or translate in response to detection of a tilt or distortion by the distortion detector, and when the blank material is pressed into a pipe shape, the pressing member is tilted or translated for the amount of tilt or inclination of the pressing member so as to reduce the amount of distortion. Patent Literature 7 discloses a technique in which a slit tube having a non-circular preform is formed by shaping slightly, compared to other bending steps, in at least one bending step acting on the inner face of a plate material on the right and left sides with respect to the center defined by the longitudinal axis line of an upper-side tool going into the plate material progressively shaped, and the slit tube is then completed by properly in each case adding a pressing force acting on the areas previously shaped slightly at both sides of the center to the noncircular preform from outside. Patent Literature 8 discloses a technique in which, in a blank having a flat portion between portions bent into at least two pipe curvatures, plastic deformation is applied to at least one flat portion into a predetermined curvature to form a pipe with a closed slit portion. Patent Literature 9 discloses a method of forming a pipe with a closed slit portion. The method includes providing a lightly bent portion with a curvature slighter than other regions or providing a non-bent portion in which bending is omitted, to form a preformed body, and applying a bending force without constraining the lightly bent portion or the non-bent portion, in pressing the preformed body into

an open pipe. In applying the bending force, it is recommended that the preformed body is held in a die in a U-shaped posture with its opening portion facing upward, and is supported at its lowermost end.

Citation List

Patent Literature

[0006]

Patent Literature 1: Japanese Patent Application Laid-open No. 2004-82219
Patent Literature 2: Japanese Patent Application Laid-open No. 2011-56524
Patent Literature 3: WO2014/188468
Patent Literature 4: WO2014/192043
Patent Literature 5: Japanese Patent Application Laid-open No. 2005-324255
Patent Literature 6: Japanese Patent Application Laid-open No. 2005-21907
Patent Literature 7: Japanese Patent Application Laid-open No. 2012-250285
Patent Literature 8: U.S. Patent No. 4149399
Patent Literature 9: WO2016/084607

Summary

Technical Problem

[0007] Unfortunately, the technique disclosed in Patent Literature 5 incurs a significant cost increase if thermal energy consumption involved in heating is included. Moreover, in this technique, if a plate material produced through a thermo-mechanical processing step is used for achieving strength, toughness, and weldability, the characteristics of the material may be impaired. In the techniques disclosed in Patent Literature 6 to 8, the blank material or the noncircular preform is formed separately on the right side and the left side. If the amount of deformation is different between the right and the left, a level difference (misalignment) may be produced at the seam gap portion or the slit portion serving as a welded portion. In these techniques, deformation into a desired shape in a single step causes local concentration of deformation, which may deteriorate the roundness of the steel pipe. For this reason, deformation in multiple steps is inevitable and poses a limit on efficient forming. In the technique disclosed in Patent Literature 9, since the radius of the lower die is larger than the pipe outer diameter, the lowermost portion of the preformed body in a U-shaped posture is bent back, causing a deformation that opens the gap portion. This may prevent reduction of the gap of the slit portion.

[0008] The present invention is made in view of the problems above. An object of the present invention is to provide a press die and a method of manufacturing a steel pipe for efficiently forming a steel pipe with high roundness.

Solution to Problem

[0009] To solve the problem and achieve the object, in a press die for use in a steel pipe forming process according to the present invention, the steel pipe forming process including forming a preformed body having a U-shaped cross section by bending a plate material, forming an open pipe that is a tubular body having a seam gap portion in a longitudinal direction of the open pipe by pressing the preformed body, and forming a steel pipe by joining the seam gap portion, the press die is used in a step of the pressing the preformed body into the open pipe. The press die includes: a pair of dies including a first die and a second die, wherein the preformed body is set on the second die such that the first die is opposed to a U-shaped open side of the preformed body, and the preformed body is pressed while the preformed body is held between the pair of dies; and an arc portion formed in a surface of each die to be in contact with the preformed body such that an arc center is located at a position coincident with a bending center of the die, the arc portion having a diameter equal or substantially equal to an outer diameter of the steel pipe, wherein the arc portion in each die has a central angle equal to or larger than 70 degrees, and a total of the central angles of the arc portions of both dies is smaller than 360 degrees.

[0010] Moreover, in the press die according to the present invention, each die includes linear portions or small-curvature arc portions having a curvature smaller than the arc portion, the linear portions or the small-curvature arc portions being connected to both ends of the arc portion in an arc direction.

[0011] Moreover, in the press die according to the present invention, the central angles of the arc portions of both dies are equal to each other.

[0012] Moreover, a method of manufacturing a steel pipe according to the present invention is a method including: forming a preformed body having a U-shaped cross section by bending, at least once, a plate material having been

subjected to edge crimping at both ends in a width direction of the preformed body; forming an open pipe that is a tubular body having a seam gap portion in a longitudinal direction by pressing the preformed body; and forming a steel pipe by joining the seam gap portion, wherein the preformed body in the pressing is shaped such that central angles in ranges inscribed in arcs having a diameter equal or substantially equal to an outer diameter of a steel pipe are 70 degrees or larger with midpoints of the arcs being a butted portion of both plate width ends and a lowermost portion of the U-shaped cross section, and wherein the preformed body in the pressing is shaped such that a total of the central angles in the ranges inscribed in the arcs having the diameter equal or substantially equal to the outer diameter of the steel pipe is smaller than 360 degrees.

[0013] Moreover, in the method of manufacturing a steel pipe according to the present invention, the preformed body is not in contact with dies at portions outside the ranges inscribed in the arcs.

[0014] Moreover, in the method of manufacturing a steel pipe according to the present invention, the central angles in the ranges inscribed in the arcs are equal between a central angle in a range with the midpoints of the arcs being the butted portion of both plate width ends and a central angle in a range with the midpoints of the arcs being the lowermost portion of the U-shaped cross section.

[0015] Moreover, in the method of manufacturing a steel pipe according to the present invention, the press die according to the present invention is used.

Advantageous Effects of Invention

[0016] The press die and the method of manufacturing a steel pipe according to the present invention achieves an advantageous effect where it is possible to efficiently form the steel pipe with high roundness.

Brief Description of Drawings

[0017]

FIG. 1 is an external perspective view of a die and a punch for use in forming a preformed body having a U-shaped cross section through a press bending process according to an embodiment.

FIG. 2 is a diagram illustrating the procedure for forming a preformed body having a U-shaped cross section through a press bending process.

FIG. 3 is a cross-sectional view of the preformed body having a U-shaped cross section.

FIG. 4 is a diagram schematically illustrating the process of forming an open pipe by performing O-ing pressing on the preformed body.

FIG. 5 is an illustration of arc portions, linear portions, and central angles of an upper die and a lower die.

FIG. 6 is graph illustrating the relation between the open amount of the seam gap portion of the open pipe and the constraining angle, in conjunction with a press load.

FIG. 7 is a diagram schematically illustrating a deformation state when the open pipe is formed using the upper die and the lower die with a constraining angle of 0 degrees.

FIG. 8 is a graph illustrating the relation between the constraining angle and the roundness of a steel pipe before pipe expanding when the seam gap portion of the open pipe is closed by welding.

FIG. 9 is a graph illustrating the relation between the constraining angle and the press load.

FIG. 10 is a graph illustrating the result of the open amount of the seam gap portion of the open pipe when the individual constraining angles of the upper die and the lower die are changed.

FIG. 11 is a graph illustrating the result of the roundness of a steel pipe before pipe expanding that is formed by closing the seam gap portion of the open pipe by welding when the individual constraining angles of the upper die and the lower die are changed.

FIG. 12 is a graph illustrating the result of the press load when the individual constraining angles of the upper die and the lower die are changed.

FIG. 13 is a graph illustrating the result of the open amount of the seam gap portion when the constraining angle of the upper die and the constraining angle of the lower die are the same and the length of a lightly bent portion or an unbent portion of the preformed body after press bending is changed.

FIG. 14 is a graph illustrating the result of the roundness of a steel pipe before pipe expanding when the constraining angle of the upper die and the constraining angle of the lower die are the same and the length of the lightly bent portion or the unbent portion of the preformed body after press bending is changed.

FIG. 15 is a graph illustrating the result of the press load when the constraining angle of the upper die and the constraining angle of the lower die are the same and the length of the lightly bent portion or the unbent portion of the preformed body after press bending is changed.

FIG. 16 is a graph illustrating the result of the open amount of the seam gap portion of the open pipe when the arc

portion radiuses of the upper die and the lower die are changed.

FIG. 17 is a graph illustrating the result of the press load when the arc portion radiuses of the upper die and the lower die are changed.

Description of Embodiments

[0018] An embodiment of a press die and a method of manufacturing a steel pipe using the press die according to the present invention will be described below. FIG. 1 is an external perspective view of a die 1 and a punch 2 for use in forming a preformed body having a U-shaped cross section through a press bending process according to the present embodiment. The die 1 is disposed in a conveyance path including a plurality of conveyance rollers 3 for a plate material S and includes a pair of left and right rod-shaped members 1a and 1b for supporting the plate material S at two points along the plate material conveyance direction. A distance e between the rod-shaped members 1a and 1b in the plate material conveyance direction can be changed according to the size of a finished steel pipe.

[0019] The punch 2 is movable in a direction closer to or away from the die 1 and includes a downwardly projecting punch front end 2a for pressing a plate material S and a punch support 2b continuous to the back surface (upper end surface) of the punch front end 2a with the same width for supporting the punch front end 2a. The punch support 2b has an upper end coupled to not-illustrated driving means. The driving means applies a pressing force to the punch front end 2a.

[0020] FIG. 2 illustrates the procedure for forming a preformed body S_1 having a U-shaped cross section through a press bending process. This procedure specifically illustrates an example in which a plate material S subjected to edge crimping in advance is bent and the plate material S is fed in order from the top to the bottom in the left column in FIG. 2, then from the top to the bottom in the middle column in FIG. 2, and finally to the right column in FIG. 2. The arrows given to the punch 2 and the plate material S in FIG. 2 indicate the direction in which the punch 2 or the plate material S moves in each stage.

[0021] To form a plate material S into a tubular shape using the plate material S as a starting material, first, edge crimping is performed on the plate material S in advance. This edge crimping is performed for a width end portion, which is relatively difficult to bend, compared with the bending performed on the plate material S using the die 1 and the punch 2. When edge bent portions are provided at the width end portions of the plate material S by the edge crimping, a steel plate with high roundness can be easily obtained, compared with when no edge bent portion is provided. The roundness of a steel pipe is an index representing how close to a circle the cross-sectional shape of the steel pipe is, and is a value indicated by a ratio obtained by dividing the difference between the maximum and the minimum of the amount of variation from an approximate arc on the entire circumference of a steel pipe by the steel pipe diameter. For example, a steel pipe having an outside diameter D is divided into 8 equal parts, 12 equal parts, 16 equal parts, or 24 equal parts in the circumferential direction of the pipe at any given pipe length, and the outside diameters at opposed positions are measured. When the maximum diameter and the minimum diameter of the measured outside diameters are D_{max} and D_{min}, respectively, the roundness [%] is defined by $\{(D_{max}-D_{min})/D\}\times 100$. As the roundness is closer to zero, the cross-sectional shape of the steel pipe is closer to a perfect circle.

[0022] The plate material S provided with the edge bent portions is placed on the die 1 illustrated in FIG. 1. While the plate material S is intermittently conveyed at a predetermined feeding amount, bending (three-point bending) is performed over the entire plate material S through the procedure illustrated in FIG. 2 to form a preformed body S_1 having a U-shaped cross section as a whole.

[0023] FIG. 3 is a cross-sectional view of the preformed body S_1 having a U-shaped cross section. As illustrated in FIG. 3, an unbent portion P not subjected to bending is provided at a part of the preformed body S_1, in particular, around a section W/4 away from each of the width end portions. This unbent portion P can be provided by increasing the feeding amount of the plate material S and omitting the pressing by the punch 2. At a part of the preformed body S_1, in particular, around a section W/4 away from each of the width end portions, a lightly bent portion having a curvature smaller than other portions (provided with a slight curvature compared with other portions) may be provided instead of an unbent portion P. In this case, in the following description "unbent portion P" may read "lightly bent portion", if necessary. The lightly bent portion can be provided by applying a smaller amount of pressing by the punch 2 than on other portions.

[0024] The punch 2 illustrated in FIG. 1 and FIG. 2 has an I shape in which the width of the punch front end 2a in the plate material conveyance direction is equal to the width of the punch support 2b in the plate material conveyance direction. However, the shape of the punch 2 is not limited to this. For example, a punch 2 having an approximately inverse T shape may be used, in which the width of the punch front end 2a in the plate material conveyance direction is larger than the width of the punch support 2b in the plate material conveyance direction. If the width of the punch support 2b in the plate material conveyance direction is the same, the punch 2 having an approximately inverse T shape can press a larger area of the plate material S in a single press, compared with the punch 2 having an I shape, thereby reducing the number of times of pressing.

[0025] Once the plate material S is bent by press bending to form the preformed body S_1 having a U-shaped cross

section, O-ing pressing is performed to press-bend the preformed body S_1 into an O shape using an upper die 4 and a lower die 5 as illustrated in FIG. 4, thereby forming an open pipe S_2, which is a tubular body having a seam gap portion G between the width end portions opposed to each other in the circumferential direction.

[0026] The procedure for performing O-ing pressing on the preformed body S_1 to form the open pipe S_2 will now be described with reference to FIG. 4. First of all, as illustrated in FIG. 4(a), the preformed body S_1 is set in the lower die 5 such that the upper die 4 and the U-shaped open side of the preformed body S_1 are opposed to each other (such that the U-shaped open side of the preformed body S_1 faces upward), and the preformed body S_1 is held between the upper die 4 and the lower die 5. As illustrated in FIG. 5, the surfaces of the upper die 4 and the lower die 5 that may be in contact with the preformed body S_1 have arc portions 4a and 5a, respectively, with a diameter equal or substantially equal to the outer diameter of the steel pipe to be formed and with a central angle θ. Hereinafter, the central angle θ of the arc portions 4a and 5a will be referred to as constraining angle. The arc portion 4a has an arc center at a position coincident with the bending center O_{p4} of the upper die 4. The arc portion 5a has an arc center at a position coincident with the bending center O_{p5} of the lower die 5. The upper die 4 has linear portions $4b_1$ and $4b_2$ connected to both ends in the arc direction of the arc portion 4a. The lower die 5 has linear portions $5b_1$ and $5b_2$ connected to both ends in the arc direction of the arc portion 5a. In place of the linear portions $4b_1$, $4b_2$, $5b_1$, and $5b_2$, the upper die 4 and the lower die 5 may have small-curvature arc portions having a curvature smaller than that of the arc portions 4a and 5a.

[0027] In the present invention, it is preferable that the linear portions connected to the arc portion are symmetric with respect to the bending center that is the center of the arc portion from the view point of increasing symmetry of the finished steel pipe. Likewise, it is preferable that the small-curvature arc portions in place of the linear portions connected to the arc portion are symmetric with respect to the bending center that is the center of the arc portion from the view point of increasing symmetry of the finished steel pipe.

[0028] Subsequently, the preformed body S_1 held between the upper die 4 and the lower die 5 is pressed down by the upper die 4 and subjected to O-ing pressing as illustrated in FIG. 4(b). Here, the portions of the preformed body S_1 that are opposed to the arc portions 4a and 5a of the upper die 4 and the lower die 5 are constrained by the upper die 4 and the lower die 5, whereas the unbent portions P of the preformed body S_1 are not constrained by the upper die 4 and the lower die 5. Thus, the open pipe S_2 as illustrated in FIG. 4(c) can be formed with a pressing force smaller than the pressing force required when the entire circumference of the preformed body S_1 is constrained by the upper die 4 and the lower die 5.

[0029] Here, in the present embodiment, when the open pipe S_2 is formed by performing O-ing pressing on the preformed body S_1 using the upper die 4 and the lower die 5, the pressing force is applied to a part W/4 away from the center of the unbent portion P toward the width end portion in the preformed body S_1. The reason for this is as follows. When the entire preformed body S_1 is shaped into a circle, the bending moment is $M = F \cdot r \cdot \cos\varphi$ (F: pressing force, r: radius of circle) at a position where the central angle is away from the pressed portion by an angle φ, and is largest at a position away from the pressed portion by 90 degrees, where the deformation is also largest. The pressing force is then applied to a position away from the center of the unbent portion P by 90 degrees, that is, by 1/4 of the entire circumference, whereby the unbent portion P is effectively deformed. Here, the bending moment is largest at a position away from the position receiving the pressing force by 90 degrees and decreases as the distance from this position increases. Based on this, it is preferable to apply a pressing force to a section away from the center of the unbent portion P toward the width end portion by $W/4 \pm 0.07W$ in order to produce sufficient plastic deformation in the unbent portion P.

[0030] In the present embodiment, the center of the unbent portion P is provided at a section including the position away from the width end portion by W/4. The reason for this is as follows. Although it is preferable to apply a pressing force to a section away from the center of the unbent portion P toward the width end portion by W/4 as described above, the contact position between the upper die 4 and the preformed body S_1 changes, and the position receiving the pressing force also changes, because the shape of the preformed body S_1 changes in a stage of forming the preformed body S_1 into the open pipe S_2. When the unbent portion P is provided at a section including the position away from the width end portion by W/4 in the preformed body S_1, the portion receiving the pressing force is always the width end portion of the preformed body S_1, so that the unbent portion P is most deformed. By doing so, it is possible to apply deformation to the unbent portion P in a single press, without changing the pressed position. Furthermore, it is preferable to provide the unbent portion P in a range of $W/4 \pm 0.07W$ from the position receiving the pressing force, that is, the width end portion of the preformed body S_1.

[0031] Since the plate width end portions are in contact with the upper die 4 in the initial state of pressing as illustrated in FIG. 4(a) and FIG. 4(b), it is preferable that the unbent portion P is provided at a section including a section away from the width end portion of the preformed body S_1 by W/4.

[0032] FIG. 6 is a graph illustrating the relation between the open amount of the seam gap portion G of the open pipe S_2 and the constraining angle, in conjunction with a press load. The relation between the open amount and the constraining angle illustrated in FIG. 6 and the press load are those obtained when a steel pipe with a tensile strength of 630 [MPa], an outer diameter of 660.4 [mm], and a pipe thickness of 40.0 [mm] is formed by welding both edges of the open pipe S_2 and thereafter performing shape correction by pipe expanding at a pipe expanding ratio of 1 [%].

[0033] The preformed body S_1 after press bending is provided with an unbent portion P having a length of W/12 at a portion W/4 from each of the plate width ends on both sides, and this preformed body S_1 is held between the upper die 4 and the lower die 5 with the same constraining angle. The pressing amount is set such that the distance between the portions of W/2 of the open pipe S_2 is equal to the diameter before pipe expanding (the amount of pressing-down in O-ing pressing is set such that the longitudinal diameter agrees with the diameter before pipe expanding). As can be seen from FIG. 6, the larger the constraining angle is, the smaller the open amount of the seam gap portion G of the open pipe S_2 is.

[0034] FIGS. 7(a) to 7(c) are diagrams schematically illustrating a deformation state when the open pipe S_2 is formed using the upper die 4 and the lower die 5 with a constraining angle of 0 degrees. When the constraining angle of the upper die 4 and the lower die 5 is 0 degrees, the arc portions 4a and 5a are arcs having a diameter 1.16 times as large as the steel pipe outer diameter such that the upper die 4 is in contact only with both edges of the preformed body S_1 and the lower die 5 is in contact only with the plate width center portion of the preformed body S_1. As illustrated in FIG. 7(a), the diameter of the arc portion 5a of the lower die 5 is larger than the steel pipe diameter such that when the cross section of the preformed body S_1 is compared to a clock, the 6 o'clock portion alone is in contact with the lower die 5. Because of this, as illustrated in FIG. 7(b), the 6 o'clock portion of the preformed body S_1 and the vicinity thereof are bent back to conform to the arc portion 5a of the lower die 5 during O-ing pressing, and the radius of curvature becomes larger than the steel pipe diameter. As a result, after O-ing pressing, as illustrated in FIG. 7(c), the open amount of the seam gap portion G of the open pipe S_2 is large, in combination with the springback at the 3 o'clock portion and the 9 o'clock portion of the preformed body S_1.

[0035] FIG. 8 is a graph illustrating the relation between the constraining angle and the roundness of a steel pipe before pipe expanding when the seam gap portion G of the open pipe S_2 is closed by welding. As can be understood from FIG. 8, when the constraining angle is 60 degrees, the roundness is worse than when the constraining angle is 0 degrees. However, as the constraining angle is increased, the roundness improves. When the constraining angle is 70 degrees or larger, the roundness is better than when the constraining angle is 0 degrees. It also can be understood that the roundness is most improved when the constraining angle is 100 degrees to 110 degrees.

[0036] FIG. 9 is a graph illustrating the relation between the constraining angle and the press load. As can be understood from FIG. 9, as the constraining angle increases, the press load increases. Increasing the constraining angle reduces the open amount of the seam gap portion G of the open pipe S_2, but the increased press load requires a larger size of press facility. It is therefore preferable to reduce the constraining angle in a range in which a desired open amount is obtained. For example, the constraining angle is set to 150 degrees or smaller in order to set the press load to 90 [%] or smaller of the press load required when the individual constraining angles of the upper die 4 and the lower die 5 for constraining the entire circumference of the preformed body S_1 with the upper die 4 and the lower die 5 are 180 degrees.

[0037] FIG. 10 is a graph illustrating the result of the open amount of the seam gap portion G of the open pipe S_2 when the individual constraining angles of the upper die 4 and the lower die 5 are changed. FIG. 11 is a graph illustrating the result of the roundness of the steel pipe before pipe expanding that is formed by closing the seam gap portion G of the open pipe S_2 by welding when the individual constraining angles of the upper die 4 and the lower die 5 are changed. FIG. 12 is a graph illustrating the result of the press load when the individual constraining angles of the upper die 4 and the lower die 5 are changed. In FIG. 10 to FIG. 12, the target steel pipe has a tensile strength of 630 [MPa], an outer diameter of 660.4 [mm], and a pipe thickness of 40.0 [mm], which are the same as those in FIG. 6, FIG. 8, and FIG. 9. The horizontal axis represents the average value of constraining angles of the upper die 4 and the lower die 5, and different constraining angles in the lower die 5 are represented by different symbols. In the figure, for example, "lower 60 degrees" means that the constraining angle in the lower die 5 is 60 degrees.

[0038] As can be understood from FIG. 10, irrespective of the individual constraining angles of the upper die 4 and the lower die 5, as the average value of constraining angles of the upper die 4 and the lower die 5 increases, the open amount of the seam gap portion G of the open pipe S_2 decreases. As can be understood from FIG. 11, when the constraining angle of one of the upper die 4 and the lower die 5 is smaller than 60 degrees, the roundness of the steel pipe is worse. Accordingly, although the individual constraining angles of the upper die 4 and the lower die 5 may not necessarily be equal between the upper die 4 and the lower die 5, it is desirable that the constraining angles of the upper die 4 and the lower die 5 both exceed 60 degrees in order to obtain a shape with satisfactory roundness of a steel pipe. It can also be understood from FIG. 12 that the larger the average value of constraining angles of the upper die 4 and the lower die 5 is, the larger the press load is. Therefore, when the upper limit of permissible press load is set, the range of average value of applicable constraining angles of the upper die 4 and the lower die 5 can be determined according to the upper limit value of press load.

[0039] FIG. 13 is a graph illustrating the result of the open amount of the seam gap portion G when the constraining angle of the upper die 4 and the constraining angle of the lower die 5 are the same and the length L of the unbent portion P of the preformed body S_1 after press bending is changed. FIG. 14 is a graph illustrating the result of the roundness of the steel pipe before pipe expanding when the constraining angle of the upper die 4 and the constraining angle of the lower die 5 are the same and the length L of the unbent portion P of the preformed body S_1 after press bending is

changed. FIG. 15 is a graph illustrating the result of the press load when the constraining angle of the upper die 4 and the constraining angle of the lower die 5 are the same and the length L of the unbent portion P of the preformed body S_1 after press bending is changed. In FIG. 13 to FIG. 15, the horizontal axis represents the average value of the constraining angle of the upper die 4 and the constraining angle of the lower die 5.

[0040] As can be understood from FIG. 13, irrespective of the length L of the unbent portion P of the preformed body S_1, as the average value of the constraining angle of the upper die 4 and the constraining angle of the lower die 5 increases, the open amount of the seam gap portion G decreases. It is also understood that when the average value of the constraining angle of the upper die 4 and the constraining angle of the lower die 5 is the same, the longer the length L is, the smaller the open amount is. As can be understood from FIG. 14 and FIG. 15, when the average value of the constraining angle of the upper die 4 and the constraining angle of the lower die 5 is the same, there is no significant difference in roundness and press load of the steel pipe due to the length L of the unbent portion P of the preformed body S_1. In this way, when the average value of the constraining angle of the upper die 4 and the constraining angle of the lower die 5 is the same, the open amount of the seam gap portion G of the open pipe S_2 can be reduced by increasing the length L of the unbent portion P of the preformed body S_1, without causing a difference in roundness or press load of the steel pipe due to the length L.

[0041] FIG. 16 is a graph illustrating the result of the open amount of the seam gap portion G of the open pipe S_2 when the arc portion radiuses of the upper die 4 and the lower die 5 are changed. FIG. 17 is a graph illustrating the result of the press load when the arc portion radiuses of the upper die 4 and the lower die 5 are changed. In FIG. 16 and FIG. 17, the central angles of the arc portions 4a and 5a of the upper die 4 and the lower die 5 are 45 degrees, and while the arc portion radiuses, which are the radiuses of the arc portions 4a and 5a, are changed, a steel pipe having a tensile strength of 630 MPa, an outer diameter of 660.4 [mm], and a pipe thickness of 40.0 [mm] is pressed down by O-ing pressing such that the longitudinal diameter agrees with the diameter before pipe expanding. In FIG. 16 and FIG. 17, the horizontal axis represents the ratio between the arc portion radius and the steel pipe outer radius (radius corresponding to the steel pipe outer diameter). When the arc portion radius is larger than the steel pipe outer radius, the ratio is greater than 1.0, and when the arc portion radius is smaller than the steel pipe outer radius, the ratio is smaller than 1.0.

[0042] As illustrated in FIG. 16, when the arc portion radius is equal to the steel pipe outer radius (the horizontal axis is 1.0 in FIG. 16), the open amount of the seam gap portion G is smallest. On the other hand, when the arc portion radius is larger than the steel pipe outer radius, bending-back deformation occurs at the 6 o'clock portion of the preformed body S_1 and the vicinity thereof as illustrated in FIG. 7, so that the open amount of the seam gap portion G increases as the arc portion radius increases. When the arc portion radius is smaller than the steel pipe outer radius, bending-back deformation occurs at portions where the arc portions 4a and 5a of the upper die 4 and the lower die 5 terminate, so that the open amount of the seam gap portion G increases as the arc portion radius decreases. In this way, although it is most preferable that the arc portion radius is equal to the steel pipe outer radius, the open amount of the seam gap portion G is kept to 40 [mm] or smaller when the arc portion radius is a radius equivalent to the steel pipe outer radius $\pm$3.5 [%].

[0043] However, as can be understood from FIG. 17, the press load increases as the arc portion radius decreases. In particular, when the arc portion radius is small, it is necessary to determine the radius considering the load of the press machine.

Example 1

[0044] A steel plate provided with a groove using an edge mirror and formed to have a plate width of 1928 [mm] with a length of 1000 [mm], a plate thickness of 40 [mm], and a tensile strength of 635 [MPa] was subjected to edge crimping, followed by press bending, to prepare a preformed body S_1. Subsequently, O-ing pressing was performed on this preformed body S_1 with a press machine of 30 [MN] using the upper die 4 and the lower die 5 with various constraining angles to form preformed body s A, B, and C. Table 1 to Table 3 show the shapes of the preformed bodys A, B, and C. In Table 1 to Table 3, the initial alphabets A, B, C in the "No." column indicate the shapes of preformed bodies (preformed bodies A, B, and C), and the numerals following the alphabets A, B, and C indicate a combination of the constraining angles of the upper die 4 and the lower die 5.

[0045] Table 1 shows the preformed body A provided with an unbent portion with a width of 161 [mm] (W/12) around the W/4 portion from the plate edge as Condition A. Table 2 shows the preformed body B provided with an unbent portion with a width of 321 [mm] (W/6) (the width twice that of Condition A) around the W/4 portion from the plate edge as Condition B. Table 3 shows the preformed body C provided with an unbent portion with a width of 321 [mm] around the W/6 portion from the plate edge as Condition C. The preformed bodies A, B, and C are each symmetric with respect to a straight line connecting the center of the plate edge portion and the plate width 1/2, and Table 1 to Table 3 show the value at the plate width 1/2 portion. The amount of pressing-down in O-ing pressing was set such that the distance between the outer surface side of the W/2 portion and the outer surface side of the plate edge was 654 [mm].

[0046] After the open amount of the open pipe S_2 after O-ing pressing of the preformed bodies A, B, and C was measured, the seam gap portion G of the open pipe S_2 was welded to form a steel pipe having an outer diameter of 654 [mm]. Thereafter, the diameter of the steel pipe was measured at eight points at a pitch of 22.5 degrees in the circumferential direction, and the difference between the maximum diameter and the minimum diameter was obtained. Table 1 to Table 3 also show die shape (constraining angle), press load, open amount, and roundness. Here, the roundness is a numeral obtained by dividing the difference between the maximum and the minimum by the steel pipe outer diameter (the average value of all the measured values of the diameter).

[0047] The welding machine used in this example failed to close the opening of the pipe having an open amount exceeding 40 [mm] after O-ing pressing. In this case, both ends and the center in the pipe axial direction were temporarily welded with the opening closed using another press machine, and thereafter the entire length of the seam gap portion G was main-welded. A roundness of 2.5 [%] before pipe expanding was considered acceptable. This is because if the roundness is equal to or lower than 2.5 [%] before pipe expanding, the roundness after pipe expanding is as satisfactory as 1.0 [%] or lower.

Table 1

No.	Shape of preformed body after press bending						Die shape			Result			Note
	Plate width [mm]			Bending angle [deg]			Constraining angle [deg]			Press load [MN/m]	Open amount [mm]	Roundness [%]	
	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Upper die	Lower die	Upper and lower average				
A1							150	150	150	28	5	1.5	Inventive example
A2							120	120	120	26	8	1.3	Inventive example
A3							110	110	110	24	15	0.9	Inventive example
A4							100	100	100	19	20	0.9	Inventive example
A5							90	90	90	15	28	1.0	Inventive example
A6							80	90	85	14	31	1.2	Inventive example
A7	402	160	402	65	0	73	70	90	80	12	34	1.6	Inventive example
A8							60	90	75	10	37	3.1	Comparative example
A9							80	80	80	12	35	1.5	Inventive example
A10							70	70	70	9	38	2.4	Inventive example
A11							90	60	75	10	36	3.0	Comparative example
A12							60	60	60	6	40	3.5	Comparative example

(continued)

No.	Shape of preformed body after press bending						Die shape			Result			Note
	Plate width [mm]			Bending angle [deg]			Constraining angle [deg]			Press load [MN/m]	Open amount [mm]	Roundness [%]	
	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Upper die	Lower die	Upper and lower average				
A13							0	90	45	6	45	3.3	Comparative example
A14							90	0	45	6	50	2.4	Comparative example
A15							60	0	30	5	52	*	Comparative example
A16							0	0	0	5	60	*	Comparative example

Table 2

No.	Shape of preformed body after press bending						Die shape			Result			Note
	Plate width [mm]			Bending angle [deg]			Constraining angle [deg]			Press load [MN/m]	Open amount [mm]	Roundness [%]	
	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Upper die	Lower die	Upper and lower average				
B1							150	150	150	28	1	1.5	Inventive example
B2							120	120	120	26	4	1.4	Inventive example
B3							110	110	110	24	11	1.0	Inventive example
B4							100	100	100	19	16	0. 9	Inventive example
B5							90	90	90	15	24	0.9	Inventive example
B6							80	90	85	14	27	1.1	Inventive example
B7							70	90	80	12	30	1.6	Inventive example
B8	321	321	321	59	0	61	60	90	75	10	33	3.0	Comparative example
B9							80	80	80	12	31	1.5	Inventive example
B10							70	70	70	9	34	2.4	Inventive example
B11							90	60	75	10	32	3.0	Comparative example
B12							60	60	60	6	36	3.5	Comparative example

(continued)

No.	Shape of preformed body after press bending						Die shape			Result			Note
	Plate width [mm]			Bending angle [deg]			Constraining angle [deg]			Press load [MN/m]	Open amount [mm]	Roundness [%]	
	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Upper die	Lower die	Upper and lower average				
B13							0	90	45	6	41	3.3	Comparative example
B14							90	0	45	6	46	2.4	Comparative example
B15							60	0	30	5	48	2.5	Comparative example
B16							0	0	0	5	56	*	Comparative example

Table 3

No.	Shape of preformed body after press bending						Die shape			Result			Note
	Plate width [mm]			Bending angle [deg]			Constraining angle [deg]			Press load [MN/m]	Open amount [mm]	Roundness [%]	
	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Upper die	Lower die	Upper and lower average				
C1							150	150	150	28	1	1.6	Inventive example
C2							120	120	120	26	4	1.2	Inventive example
C3							110	110	110	24	11	1.0	Inventive example
C4							100	100	100	19	16	0.9	Inventive example
C5							90	90	90	15	24	1.0	Inventive example
C6							80	90	85	14	27	1.3	Inventive example
C7							70	90	80	12	30	1.6	Inventive example
C8							60	90	75	10	33	3.1	Comparative example
C9							80	80	80	12	31	1.5	Inventive example
C10	161	321	482	59	0	61	70	70	70	9	34	2.4	Inventive example
C11							90	60	75	10	32	3.0	Comparative example
C12							60	60	60	6	36	3.5	Comparative example

(continued)

No.	Shape of preformed body after press bending						Die shape			Result			Note
	Plate width [mm]			Bending angle [deg]			Constraining angle [deg]			Press load [MN/m]	Open amount [mm]	Roundness [%]	
	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Upper die	Lower die	Upper and lower average				
C13							0	90	45	6	41	3.3	Comparative example
C14							90	0	45	6	46	2.4	Comparative example
C15							60	0	30	5	48	2.5	Comparative example
C16							0	0	0	5	56	*	Comparative example
C17							180	180	180	30	0	2.6	Comparative example

[0048] In Nos. A1 to A7, A9, and A10 in Table 1, Nos. B1 to B7, B9, and B10 in Table 2, and Nos. C1 to C7, C9, and C10 in Table 3, which are in a range of examples of the present invention, the open amount is small, and the roundness is also satisfactory. In particular, the products with a constraining angle of 90 degrees to 110 degrees have a roundness of 1.0 [%] or lower even without pipe expanding. The smaller the average value of constraining angle is, the smaller the press load is.

[0049] By contrast, in Nos. A8 and A11 in Table 1, Nos. B8 and B11 in Table 2, and Nos. C8 and C11 in Table 3, in which the constraining angles of the upper die 4 and the lower die 5 are a combination of 60 degrees and 90 degrees, the open amount is small, but the roundness is bad. In Nos. A12 to A16 in Table 1, Nos. B12 to B16 in Table 2, and Nos. C12 to C16 in Table 3, in which the average value of constraining angles is 60 degrees or smaller, the open amount is large. In particular, in Nos. A15 and A16 in Table 1, No. B16 in Table 2, and No. C16 in Table 3, it was impossible to measure the roundness, because the welded portion was broken after the seam gap portion G was welded.

[0050] In a product formed using the preformed body B having an unbent portion wider than that of the preformed body A, compared with a product formed using the preformed body A, the press load and the roundness are almost the same, but the open amount is small.

[0051] In a product formed using the preformed body C in which the position of the unbent portion is closer to the plate edge than in the preformed body B, compared with a product formed using the preformed body B, the press load, the open amount, and the roundness are almost the same. In No. C17 in Table 3 in which the constraining angles of the upper die 4 and the lower die 5 are 180 degrees, although the maximum load 30 [MN/m] of the press machine was applied, the distance between the outer surface side of the W/2 portion and the outer surface side of the plate edge is 658 [mm] and the amount of pressing-down is smaller than other products. Thus, the open amount is satisfactory, but the roundness is worse. To satisfy the roundness of 2.5 [%] before pipe expanding, it may be necessary to perform O-ing pressing up to the equivalent amount of pressing-down in other products, using a larger press machine.

[0052] Although embodiments to which the present invention is applied have been described above, the present invention is not intended to be limited by the description and the drawings that are a part of the disclosure of the present invention according to the embodiments. In other words, all of other embodiments, examples, operating techniques, and the like carried out by those skilled in the art based on the embodiments are embraced in the scope of the present invention.

Example 2

[0053] A steel plate provided with a groove using an edge mirror and formed to have a width of 1639 [mm] with a length of 1000 [mm], a plate thickness of 31.8 [mm], and a tensile strength of 779 [MPa] was subjected to edge crimping, followed by press bending, to prepare a preformed body S_1. Subsequently, O-ing pressing was performed on this preformed body S_1, using the upper die 4 and the lower die 5 with various constraining angles with a press machine of 30 [MN] to form preformed bodies A, B, and C. Table 4 to Table 6 show the shapes of the preformed bodies A, B, and C. In Table 4 to Table 6, the initial alphabets A, B, C in the "No." column indicate the shapes of preformed bodies (preformed bodies A, B, and C) and the numerals following the alphabets A, B, C each indicate a combination of the constraining angles of the upper die 4 and the lower die 5.

[0054] Table 4 shows the preformed body A provided with an unbent portion with a width of 137 [mm] (W/12) around the W/4 portion from the plate edge as Condition A. Table 5 shows the preformed body B provided with an unbent portion with a width of 273 [mm] (W/6) (the width twice that of Condition A) around W/4 from the plate edge as Condition B. Table 6 shows the preformed body C provided with an unbent portion with a width of 273 [mm] around the W/6 portion from the plate edge as Condition C. The preformed bodies A, B, and C are each symmetric with respect to a straight line connecting the center of the plate edge portion and the plate width 1/2. Table 4 to Table 6 show the values at the plate width 1/2 portion. The amount of pressing-down in O-ing pressing was set such that the distance between the outer surface side of the W/2 portion and the outer surface side of the plate edge was 553 [mm].

[0055] Then, after the open amount of the open pipe S_2 after O-ing pressing of the preformed bodies A, B, and C was measured, the seam gap portion G of the open pipe S_2 was welded to form a steel pipe having an outer diameter of 553 [mm]. Thereafter, the diameter of the steel pipe was measured at eight points at a pitch of 22.5 degrees in the circumferential direction, and the difference between the maximum diameter and the minimum diameter was obtained. Table 4 to Table 6 also show die shape (constraining angle), press load, open amount, and roundness. Here, the roundness is a numeral obtained by dividing the difference between the maximum and the minimum by the steel pipe outer diameter.

[0056] The welding machine used in this example failed to close the opening of the pipe having an open amount exceeding 40 [mm] after O-ing pressing. In this case, both ends and the center in the pipe axial direction were temporarily welded with the opening closed using another press machine, and thereafter the entire length of the seam gap portion G was main-welded. The roundness of 2.5 [%] before pipe expanding, which becomes 1.0 [%] or lower through pipe expanding, was considered acceptable.

Table 4

No.	Shape of preformed body after press bending						Die shape			Result			Note
	Plate width [mm]			Bending angle [deg]			Constraining angle [deg]						
	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Upper die	Lower die	Upper and lower average	Press load [MN/m]	Open amount [mm]	Roundness [%]	
A1							150	150	150	27	3	1.5	Inventive example
A2							120	120	120	26	6	1.3	Inventive example
A3							110	110	110	23	13	0.9	Inventive example
A4							100	100	100	20	19	0.9	Inventive example
A5							90	90	90	14	25	1.0	Inventive example
A6							80	90	85	13	28	1.2	Inventive example
A7							70	90	80	11	32	1.6	Inventive example
A8	341	137	341	65	0	72	60	90	75	10	35	3.1	Comparative example
A9							80	80	80	11	33	1.5	Inventive example
A10							70	70	70	9	36	2.4	Inventive example
A11							90	60	75	10	34	3.0	Comparative example
A12							60	60	60	6	38	3.5	Comparative example

(continued)

No.	Shape of preformed body after press bending						Die shape			Result			Note
	Plate width [mm]			Bending angle [deg]			Constraining angle [deg]			Press load [MN/m]	Open amount [mm]	Roundness [%]	
	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Upper die	Lower die	Upper and lower average				
A13							0	90	45	5	43	3.3	Comparative example
A14							90	0	45	5	50	2.4	Comparative example
A15							60	0	30	4	54	*	Comparative example
A16							0	0	0	4	60	*	Comparative example

Table 5

No.	Shape of preformed body after press bending						Die shape			Result			Note
	Plate width [mm]			Bending angle [deg]			Constraining angle [deg]						
	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Upper die	Lower die	Upper and lower average	Press load [MN/m]	Open amount [mm]	Roundness [%]	
B1							150	150	150	27	0	1.5	Inventive example
B2							120	120	120	26	3	1.4	Inventive example
B3							110	110	110	23	9	1.0	Inventive example
B4							100	100	100	20	13	0.9	Inventive example
B5							90	90	90	14	22	0.9	Inventive example
B6							80	90	85	13	25	1.1	Inventive example
B7							70	90	80	11	28	1.6	Inventive example
B8	273	273	273	59	0	61	60	90	75	10	30	3.0	Comparative example
B9							80	80	80	11	29	1.5	Inventive example
B10							70	70	70	9	32	2.4	Inventive example
B11							90	60	75	10	30	3.0	Comparative example
B12							60	60	60	6	34	3.5	Comparative example

(continued)

No.	Shape of preformed body after press bending						Die shape			Result			Note
	Plate width [mm]			Bending angle [deg]			Constraining angle [deg]			Press load [MN/m]	Open amount [mm]	Roundness [%]	
	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Upper die	Lower die	Upper and lower average				
B13							0	90	45	5	40	3.3	Comparative example
B14							90	0	45	5	44	2.4	Comparative example
B15							60	0	30	4	46	2.5	Comparative example
B16							0	0	0	4	53	*	Comparative example

Table 6

No.	Shape of preformed body after press bending						Die shape			Result			Note
	Plate width [mm]			Bending angle [deg]			Constraining angle [deg]						
	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Upper die	Lower die	Upper and lower average	Press load [MN/m]	Open amount [mm]	Roundness [%]	
C1							150	150	150	27	0	1.6	Inventive example
C2							120	120	120	26	3	1.2	Inventive example
C3							110	110	110	23	9	1.0	Inventive example
C4							100	100	100	20	14	0.9	Inventive example
C5							90	90	90	14	22	1.0	Inventive example
C6							80	90	85	13	25	1.3	Inventive example
C7							70	90	80	11	28	1.6	Inventive example
C8							60	90	75	10	32	3.1	Comparative example
C9							80	80	80	11	30	1.5	Inventive example
C10	137	273	410	59	0	61	70	70	70	9	32	2.4	Inventive example
C11							90	60	75	10	30	3.0	Comparative example
C12							60	60	60	6	34	3.5	Comparative example

(continued)

No.	Shape of preformed body after press bending						Die shape			Result			Note
	Plate width [mm]			Bending angle [deg]			Constraining angle [deg]			Press load [MN/m]	Open amount [mm]	Roundness [%]	
	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Upper die	Lower die	Upper and lower average				
C13							0	90	45	5	40	3.3	Comparative example
C14							90	0	45	5	44	2.4	Comparative example
C15							60	0	30	4	45	2.5	Comparative example
C16							0	0	0	4	55	*	Comparative example
C17							180	180	180	30	0	2.6	Comparative example

[0057] In Nos. A1 to A7, A9, and A10 in Table 4, Nos. B1 to B7, B9, and B10 in Table 5, and Nos. C1 to C7, C9, and C10 in Table 6, which are in a range of examples of the present invention, the open amount is small, and the roundness is also satisfactory. In particular, the products with a constraining angle of 90 degrees to 110 degrees have a roundness of 1.0 [%] or lower even without pipe expanding. The smaller the average value of constraining angles is, the smaller the press load is.

[0058] By contrast, in Nos. A8 and A11 in Table 4, Nos. B8 and B11 in Table 5, and Nos. C8 and C11 in Table 6, in which the constraining angles of the upper die 4 and the lower die 5 are a combination of 60 degrees and 90 degrees, the open amount is small, but the roundness is bad. In Nos. A12 to A16 in Table 4, Nos. B12 to B16 in Table 5, and Nos. C12 to C16 in Table 6, in which the average value of constraining angles is 60 degrees or smaller, the open amount is large. In particular, in Nos. A15 and A16 in Table 4, No. B16 in Table 5, and No. C16 in Table 6, it was impossible to measure the roundness, because the welded portion was broken after the seam gap portion G was welded.

[0059] In a product formed using the preformed body B having an unbent portion wider than that of the preformed body A, compared with a product formed using the preformed body A, the press load and the roundness are almost the same, but the open amount is small.

[0060] In a product formed using the preformed body C in which the position of the unbent portion is closer to the plate edge than in the preformed body B, compared with a product formed using the preformed body B, the press load, the open amount, and the roundness are almost the same. In No. C17 in Table 6 in which the constraining angles of the upper die 4 and the lower die 5 are 180 degrees, although the maximum load 30 [MN/m] of the press machine was applied, the distance between the outer surface side of the W/2 portion and the outer surface side of the plate edge is 556 [mm], and the amount of pressing-down is smaller than other products. Thus, the open amount is satisfactory, but the roundness is bad. To satisfy the roundness of 2.5 [%] before pipe expanding, it may be necessary to perform O-ing pressing up to the equivalent amount of pressing-down in other products, using a larger press machine.

Example 3

[0061] A steel plate provided with a groove using an edge mirror and formed to have a plate width of 2687 [mm] with a length of 1000 [mm], a plate thickness of 50.8 [mm], and a tensile strength of 779 [MPa] was subjected to edge crimping, followed by press bending, to prepare a preformed body S_1. Subsequently, O-ing pressing was performed on this preformed body S_1 using the upper die 4 and the lower die 5 with various constraining angles with a press machine of 30 [MN] to form preformed bodies A, B, and C. Table 7 to Table 9 show the shapes of the preformed bodies A, B, and C. In Table 7 to Table 9, the initial alphabets A, B, C in the "No." column indicate the shapes of preformed bodies (preformed bodies A, B, and C), and the numerals following the alphabets A, B, and C indicate a combination of the constraining angles of the upper die 4 and the lower die 5.

[0062] Table 7 shows the preformed body A provided with an unbent portion with a width of 224 [mm] (W/12) around the W/4 portion from the plate edge as Condition A. Table 8 shows the preformed body B provided with an unbent portion with a width of 448 [mm] (W/6) (the width twice that of Condition A) around the W/4 portion from the plate edge as Condition B. Table 9 shows the preformed body C provided with an unbent portion with a width of 448 [mm] around the W/6 portion from the plate edge as Condition C. The preformed bodies A, B, and C are each symmetric with respect to a straight line connecting the center of the plate edge portion and the plate width 1/2. Table 7 to Table 9 show the value at the plate width 1/2 portion. The amount of pressing-down in O-ing pressing was set such that the distance between the outer surface side of the W/2 portion and the outer surface side of the plate edge was 905 [mm].

[0063] After the open amount of the open pipe S_2 after O-ing pressing of the preformed bodies A, B, and C was measured, the seam gap portion G of the open pipe S_2 was welded to form a steel pipe having an outer diameter of 905 [mm]. Thereafter, the diameter of the steel pipe was measured at eight points at a pitch of 22.5 degrees in the circumferential direction, and the difference between the maximum diameter and the minimum diameter was obtained. Table 7 to Table 9 also show die shape (constraining angle), press load, open amount, and roundness. Here, the roundness is a numeral obtained by dividing the difference between the maximum and the minimum by the steel pipe outer diameter.

[0064] The welding machine used in this example failed to close the opening of the pipe having an open amount exceeding 40 [mm] after O-ing pressing. In this case, both ends and the center in the pipe axial direction were temporarily welded with the opening closed using another press machine, and thereafter the entire length of the seam gap portion G was main-welded. The roundness of 2.5 [%] before pipe expanding, which becomes 1.0 [%] or lower through pipe expanding, was considered acceptable.

Table 7

No.	Shape of preformed body after press bending						Die shape			Result			Note
	Plate width [mm]			Bending angle [deg]			Constraining angle [deg]						
	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Upper die	Lower die	Upper and lower average	Press load [MN/m]	Open amount [mm]	Roundness [%]	
A1	560	224	560	73	0	72	150	150	150	29	7	1.4	Inventive example
A2							120	120	120	27	10	1.3	Inventive example
A3							110	110	110	25	17	1.0	Inventive example
A4							100	100	100	20	21	1.0	Inventive example
A5							90	90	90	26	29	0.9	Inventive example
A6							80	90	85	14	33	1.0	Inventive example
A7							70	90	80	12	35	1.4	Inventive example
A8							60	90	75	10	39	3.2	Comparative example
A9							80	80	80	12	36	1.4	Inventive example
A10							70	70	70	10	39	2.3	Inventive example
A11							90	60	75	11	36	3.1	Comparative example
A12							60	60	60	6	40	3.4	Comparative example

(continued)

No.	Shape of preformed body after press bending						Die shape			Result			Note
	Plate width [mm]			Bending angle [deg]			Constraining angle [deg]			Press load [MN/m]	Open amount [mm]	Roundness [%]	
	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Upper die	Lower die	Upper and lower average				
A13							0	90	45	6	45	3.3	Comparative example
A14							90	0	45	6	50	2.4	Comparative example
A15							60	0	30	5	52	*	Comparative example
A16							0	0	0	5	60	*	Comparative example

Table 8

No.	Shape of preformed body after press bending						Die shape			Result			Note
	Plate width [mm]			Bending angle [deg]			Constraining angle [deg]						
	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Upper die	Lower die	Upper and lower average	Press load [MN/m]	Open amount [mm]	Roundness [%]	
B1							150	150	150	29	3	1.5	Inventive example
B2							120	120	120	27	6	1.4	Inventive example
B3							110	110	110	25	13	1.0	Inventive example
B4							100	100	100	20	17	0.9	Inventive example
B5							90	90	90	26	24	1.0	Inventive example
B6							80	90	85	14	27	1.1	Inventive example
B7							70	90	80	12	31	1.5	Inventive example
B8	448	448	448	58	0	59	60	90	75	10	35	3.0	Comparative example
B9							80	80	80	12	32	1.4	Inventive example
B10							70	70	70	10	35	2.4	Inventive example
B11							90	60	75	11	32	3.0	Comparative example
B12							60	60	60	6	36	3.5	Comparative example

(continued)

No.	Shape of preformed body after press bending						Die shape			Result			Note
	Plate width [mm]			Bending angle [deg]			Constraining angle [deg]			Press load [MN/m]	Open amount [mm]	Roundness [%]	
	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Upper die	Lower die	Upper and lower average				
B13							0	90	45	6	41	3.3	Comparative example
B14							90	0	45	6	46	2.4	Comparative example
B15							60	0	30	5	48	2.5	Comparative example
B16							0	0	0	5	56	*	Comparative example

Table 9

No.	Shape of preformed body after press bending						Die shape			Result			Note
	Plate width [mm]			Bending angle [deg]			Constraining angle [deg]			Press load [MN/m]	Open amount [mm]	Roundness [%]	
	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Upper die	Lower die	Upper and lower average				
C1							150	150	150	29	3	1.6	Inventive example
C2							120	120	120	27	6	1.2	Inventive example
C3							110	110	110	25	13	1.0	Inventive example
C4							100	100	100	20	17	0.9	Inventive example
C5							90	90	90	26	25	1.0	Inventive example
C6							80	90	85	14	29	1.3	Inventive example
C7							70	90	80	12	31	1.6	Inventive example
C8							60	90	75	10	35	3.1	Comparative example
C9	672	448	224	59	0	61	80	80	80	12	32	1.5	Inventive example
C10							70	70	70	10	35	2.4	Inventive example
C11							90	60	75	11	32	3.0	Comparative example
C12							60	60	60	6	36	3.5	Comparative example

(continued)

No.	Shape of preformed body after press bending						Die shape			Result			Note
	Plate width [mm]			Bending angle [deg]			Constraining angle [deg]			Press load [MN/m]	Open amount [mm]	Roundness [%]	
	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Plate-edge side bent portion	Unbent portion	Plate width center-side bent portion	Upper die	Lower die	Upper and lower average				
C13							0	90	45	6	41	3.3	Comparative example
C14							90	0	45	6	46	2.4	Comparative example
C15							60	0	30	5	48	2.5	Comparative example
C16							0	0	0	5	56	*	Comparative example
C17							180	180	180	30	0	2.6	Comparative example

[0065] In Nos. A1 to A7, A9, and A10 in Table 7, Nos. B1 to B7, B9, and B10 in Table 8, and Nos. C1 to C7, C9, and C10 in Table 9, which are in a range of examples of the present invention, the open amount is small, and the roundness is also satisfactory. In particular, the products with a constraining angle of 90 degrees to 110 degrees have a roundness of 1.0 [%] or lower even without pipe expanding. The smaller the average value of the constraining angle is, the smaller the press load is.

[0066] By contrast, in Nos. A8 and A11 in Table 7, Nos. B8 and B11 in Table 8, and Nos. C8 and C11 in Table 9, in which the constraining angles of the upper die 4 and the lower die 5 are a combination of 60 degrees and 90 degrees, the open amount is small, but the roundness is bad. In Nos. A12 to A16 in Table 7, Nos. B12 to B16 in Table 8, and Nos. C12 to C16 in Table 9, in which the average value of constraining angles is 60 degrees or smaller, the open amount is large. In particular, in Nos. A15 and A16 in Table 7, No. B16 in Table 8, and No. C16 in Table 9, it was impossible to measure the roundness, because the welded portion was broken after the seam gap portion G was welded.

[0067] In a product formed using the preformed body B having an unbent portion wider than that of the preformed body A, compared with a product formed using the preformed body A, the press load and the roundness are almost the same, but the open amount is small.

[0068] In a product formed using the preformed body C in which the position of the unbent portion is closer to the plate edge than in the preformed body B, compared with a product formed using the preformed body B, the press load, the open amount, and the roundness are almost the same. In No. C17 in Table 9 in which the constraining angles of the upper die 4 and the lower die 5 are 180 degrees, although the maximum load 30 [MN/m] of the press machine was applied, the distance between the outer surface side of the W/2 portion and the outer surface side of the plate edge is 915 [mm] and the amount of pressing-down is smaller than other products. Thus, the open amount is satisfactory, but the roundness is bad. To satisfy the roundness of 2.5 [%] before pipe expanding, it may be necessary to perform O-ing pressing up to the equivalent amount of pressing-down in other products, using a larger press machine.

Example 4

[0069] To produce a steel pipe with a target outer diameter of 621 [mm] to 687 [mm], a steel plate provided with a groove using an edge mirror and formed to have a plate width of 1826 to 2032 [mm] with a length of 1000 [mm], a plate thickness of 40 [mm], and a tensile strength of 635 [MPa] was subjected to edge crimping, followed by press bending, to prepare a preformed body S_1. Subsequently, O-ing pressing was performed on this preformed body S_1 using a variety of the upper dies 4 and the lower dies 5 with an arc portion radius of 327 mm and a constraining angle of 45 degrees, with a press machine of 30 [MN] to form preformed bodies D1 to D11. Table 10 shows the bending conditions of the preformed bodies D1 to D11. The preformed bodies D1 to D11 are each provided with an unbent portion with a width of W/12 around the W/4 portion from the plate edge, according to the initial plate width W. In O-ing pressing, the pressing down was performed such that the distance between the outer surface side of the W/2 portion and the outer surface side of the plate edge attains a value corresponding to the initial plate width W as shown in Table 10. Table 10 also shows the outer diameter of the steel pipe after pressing down with O-ing press.

[0070] The open amount of the open pipe S_2 after O-ing pressing of the preformed bodies D1 to D11 was measured. Table 10 also shows the press load and the open amount as the results.

Table 10

No.	Target outer diameter [mm]	Plate width [mm]	Shape of preformed body after press bending						Die shape		Outer diameter after pressing down by O-ing press [mm]	Result	
			Plate width [mm]			Bending angle [deg]			Arc portion radius [mm]	Arc portion radius/steel pipe outer radius		Press load [MN/m]	Open amount [mm]
			Plate edge-side bent portion	Unbent portion	Plate width center-side bend portion	Plate edge-side bent portion	Unbent portion	Plate width center-side bend portion					
D1	621	1826	380	152	380	75	0	75	327	0.95	621	17	51
D2	628	1847	385	154	385					0.96	628	16	40
D3	634	1867	389	156	389					0.97	634	16	35
D4	641	1888	393	157	393					0.98	641	15	31
D5	647	1908	398	159	398					0.99	647	15	28
D6	654	1929	402	161	402					1.00	654	15	25
D7	661	1949	406	162	406					1.01	661	15	27
D8	667	1970	410	164	410					1.02	667	14	30
D9	674	1991	415	166	415					1.03	674	14	35
D10	680	2011	419	168	419					1.04	680	13	40
D11	687	2032	423	169	423					1.05	687	12	53

[0071] In No. D6 in Table 10 in which the ratio between the arc portion radius and the outer radius of the steel pipe is 1.00, the open amount is smallest, and as the steel pipe outer radius decreases or increases, the open amount increases. The open amount of 40 [mm] or smaller, which can be closed by the welding machine used in Example 1, was achieved in Nos. D2 to D10 in Table 10, and the ratio between the arc portion radius and the outer radius of the steel pipe is 0.96 to 1.04. The open amount of 50 [mm], which did not cause breakage of the welded portion in Example 1, was achieved also in Nos. D2 to D10 in Table 10, and the ratio between the arc portion radius and the outer radius of the steel pipe is 0.96 to 1.04.

[0072] Although the open amount that can be closed by welding the seam gap portion G and the open amount that does not cause breakage of the welded portion vary depending on the welding facility and the welding method, the guideline of the arc portion radiuses of the upper die 4 and the lower die 5 is 0.96 to 1.04 of the steel pipe outer radius.

Industrial Applicability

[0073] The press die and the method of manufacturing a steel pipe according to the present invention achieve the effect of efficiently forming a steel pipe with high roundness.

Reference Signs List

[0074]

1	die
1a	rod-shaped member
1b	rod-shaped member
2	punch
2a	punch front end
2b	punch support
3	conveyance roller
4	upper die
4a	arc portion
$4b_1$	linear portion and small-curvature arc portion
$4b_2$	linear portion and small-curvature arc portion
5	ower die
5a	arc portion
$5b_1$	linear portion and small-curvature arc portion
$5b_2$	linear portion and small-curvature arc portion

Claims

1. A press die for use in a steel pipe forming process including forming a preformed body having a U-shaped cross section by bending a plate material, forming an open pipe that is a tubular body having a seam gap portion in a longitudinal direction of the open pipe by pressing the preformed body, and forming a steel pipe by joining the seam gap portion, the press die being used in a step of the pressing the preformed body into the open pipe, the press die comprising:

   a pair of dies including a first die and a second die, wherein the preformed body is set on the second die such that the first die is opposed to a U-shaped open side of the preformed body, and the preformed body is pressed while the preformed body is held between the pair of dies; and
   an arc portion formed in a surface of each die to be in contact with the preformed body such that an arc center is located at a position coincident with a bending center of the die, the arc portion having a diameter equal or substantially equal to an outer diameter of the steel pipe, wherein
   the arc portion in each die has a central angle equal to or larger than 70 degrees, and a total of the central angles of the arc portions of both dies is smaller than 360 degrees.

2. The press die according to claim 1, wherein each die includes linear portions or small-curvature arc portions having a curvature smaller than the arc portion, the linear portions or the small-curvature arc portions being connected to both ends of the arc portion in an arc direction.

3. The press die according to claim 1 or 2, wherein the central angles of the arc portions of both dies are equal to each other.

4. A method of manufacturing a steel pipe, the method comprising:

forming a preformed body having a U-shaped cross section by bending, at least once, a plate material having been subjected to edge crimping at both ends in a width direction of the preformed body;
forming an open pipe that is a tubular body having a seam gap portion in a longitudinal direction by pressing the preformed body; and
forming a steel pipe by joining the seam gap portion,
wherein the preformed body in the pressing is shaped such that central angles in ranges inscribed in arcs having a diameter equal or substantially equal to an outer diameter of a steel pipe are 70 degrees or larger with midpoints of the arcs being a butted portion of both plate width ends and a lowermost portion of the U-shaped cross section, and
wherein the preformed body in the pressing is shaped such that a total of the central angles in the ranges inscribed in the arcs having the diameter equal or substantially equal to the outer diameter of the steel pipe is smaller than 360 degrees.

5. The method of manufacturing a steel pipe according to claim 4, wherein the preformed body is not in contact with dies at portions outside the ranges inscribed in the arcs.

6. The method of manufacturing a steel pipe according to claim 4 or 5, wherein the central angles in the ranges inscribed in the arcs are equal between a central angle in a range with the midpoints of the arcs being the butted portion of both plate width ends and a central angle in a range with the midpoints of the arcs being the lowermost portion of the U-shaped cross section.

7. The method of manufacturing a steel pipe according to any one of claims 4 to 6, wherein the press die of any one of claims 1 to 3 is used.

FIG.1

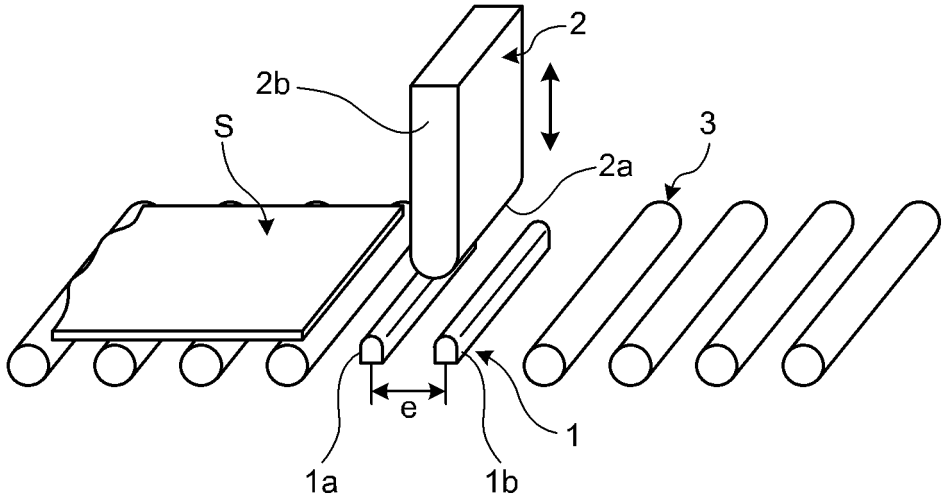


FIG.2

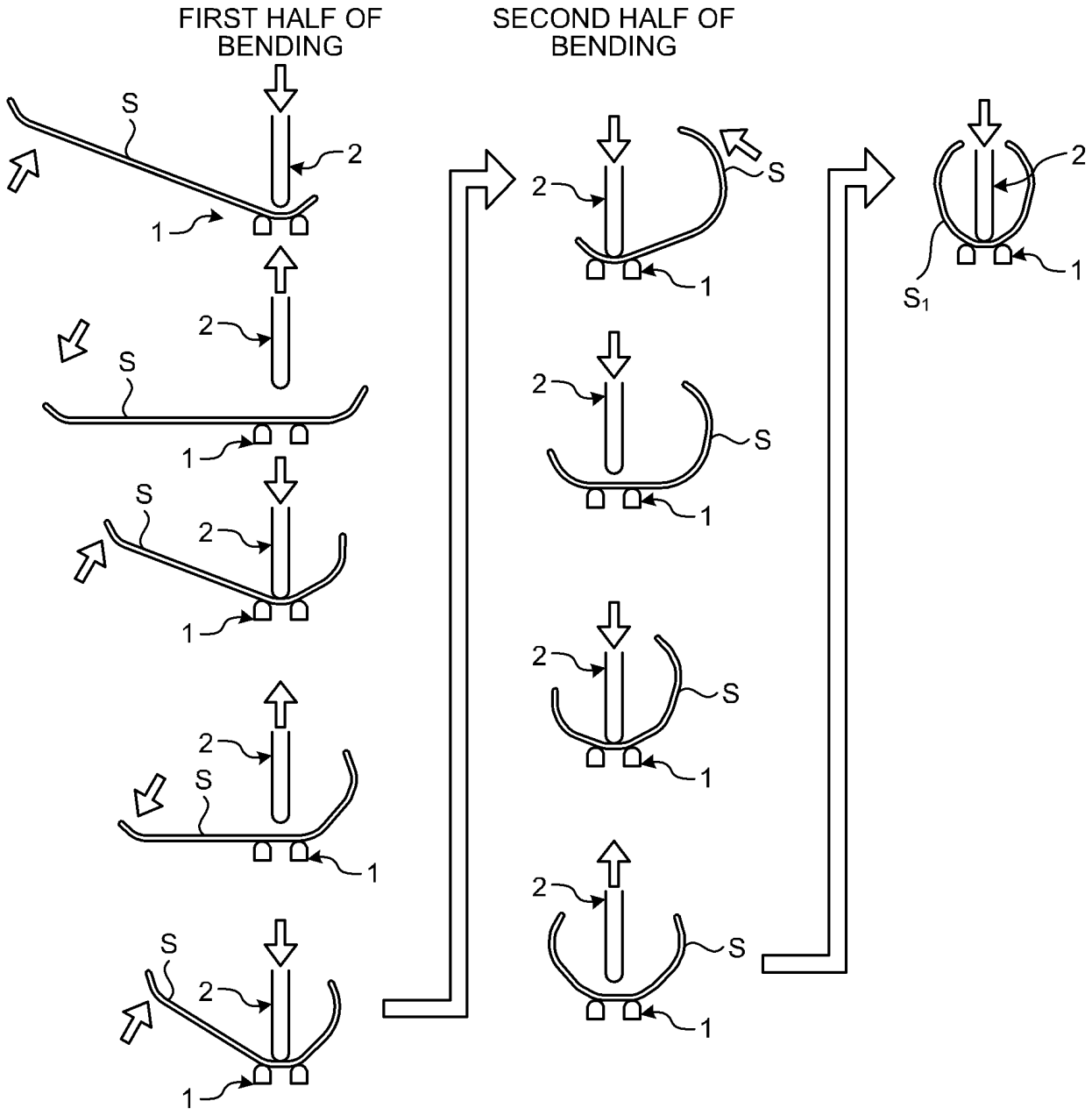


FIG.3

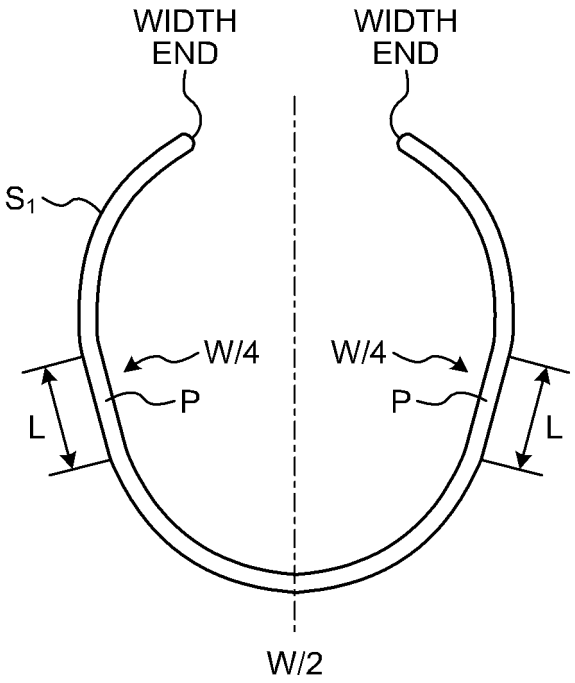


FIG.4

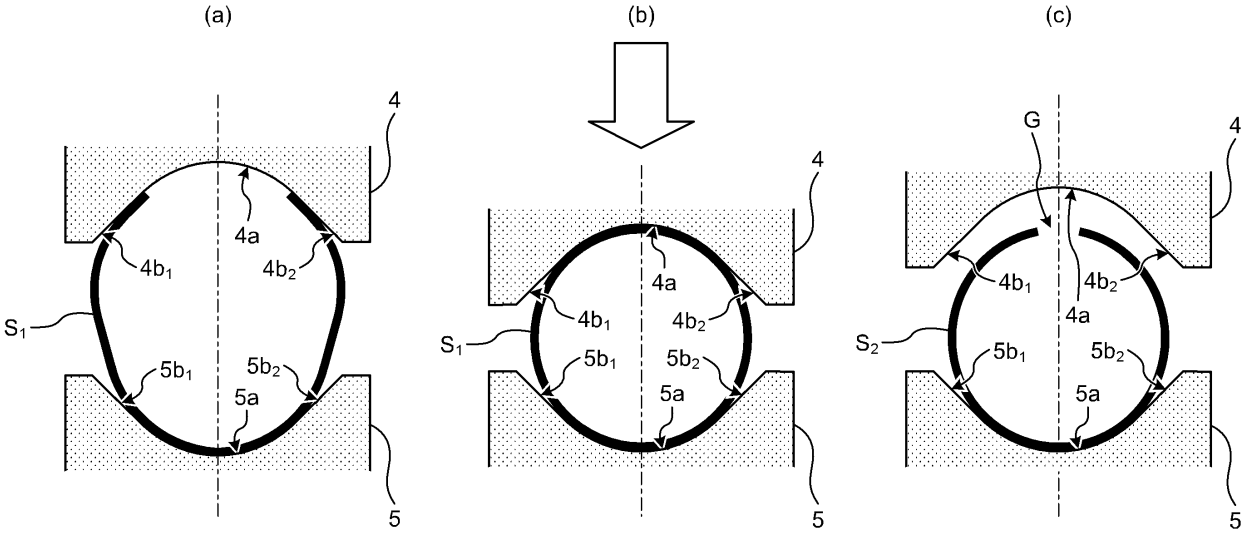


FIG.5

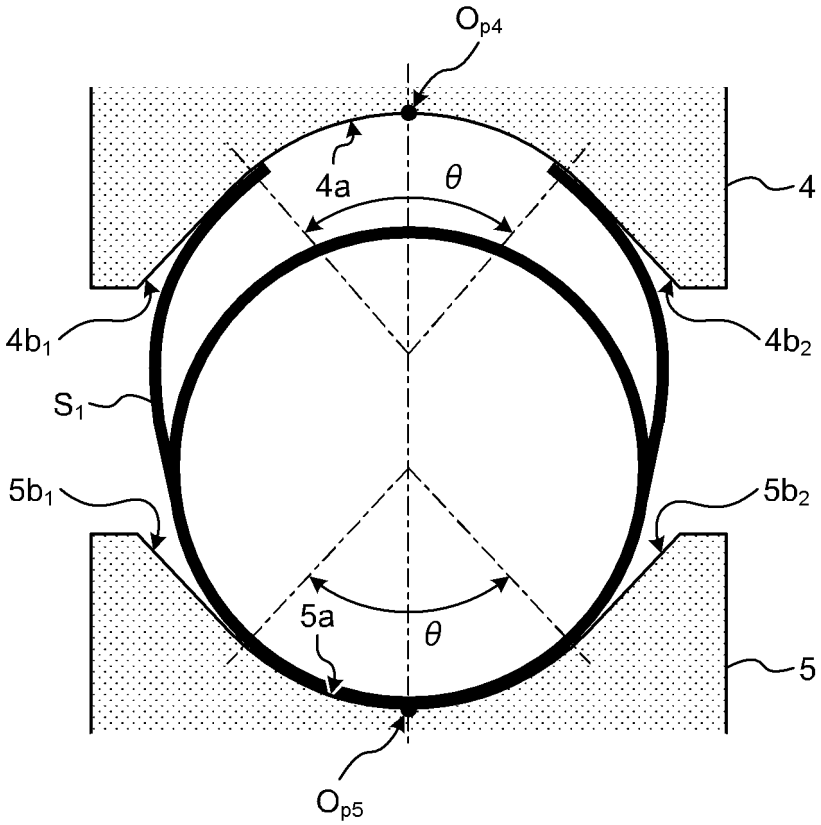

O_{p4}
4a
θ
4
$4b_1$
$4b_2$
S_1
$5b_1$
$5b_2$
5a
θ
5
O_{p5}

FIG.6

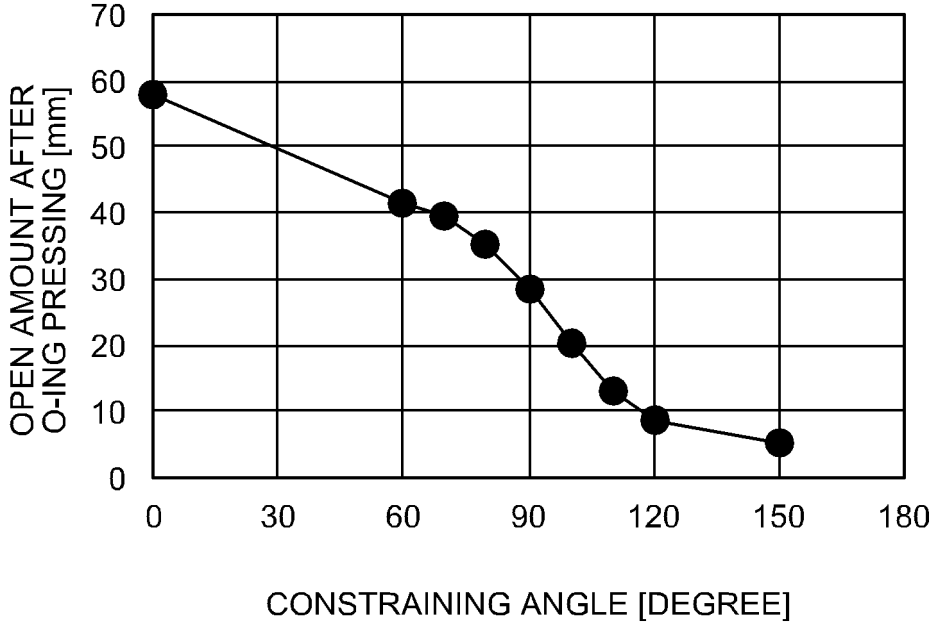

OPEN AMOUNT AFTER O-ING PRESSING [mm]
70
60
50
40
30
20
10
0
0
30
60
90
120
150
180
CONSTRAINING ANGLE [DEGREE]

FIG.7

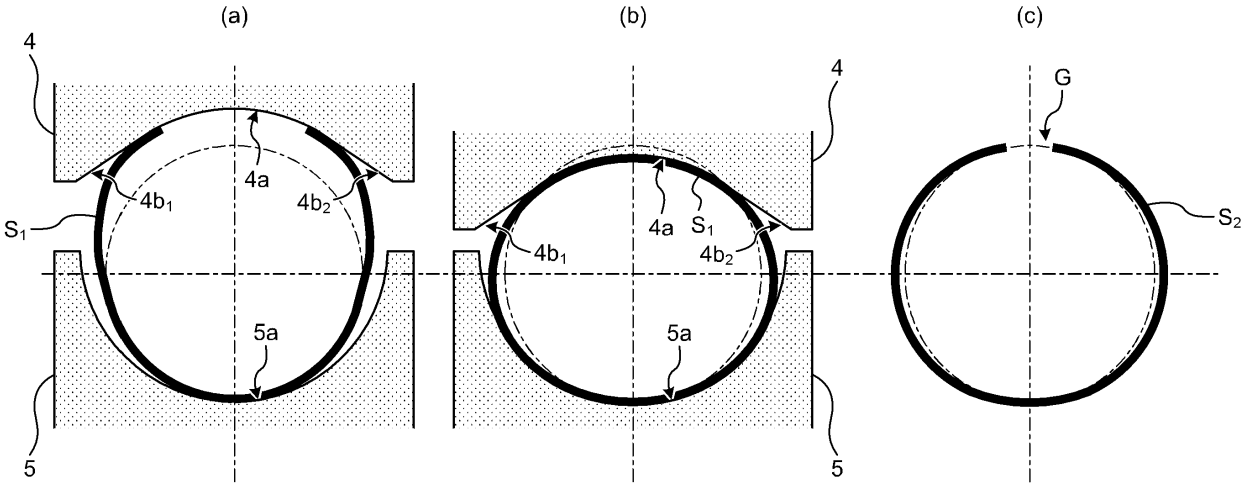


FIG.8

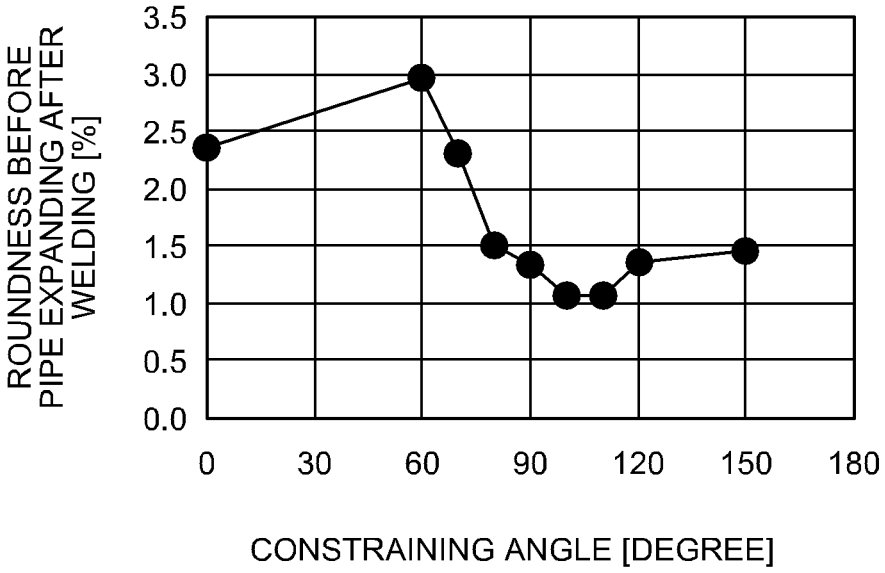

ROUNDNESS BEFORE PIPE EXPANDING AFTER WELDING [%]
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
30
60
90
120
150
180
CONSTRAINING ANGLE [DEGREE]

FIG.9

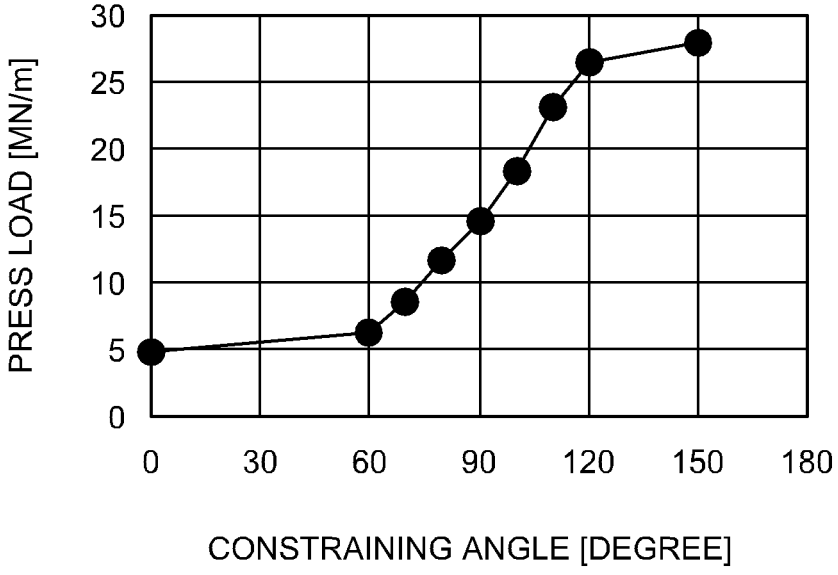

PRESS LOAD [MN/m]
30
25
20
15
10
5
0
0
30
60
90
120
150
180
CONSTRAINING ANGLE [DEGREE]

FIG.10

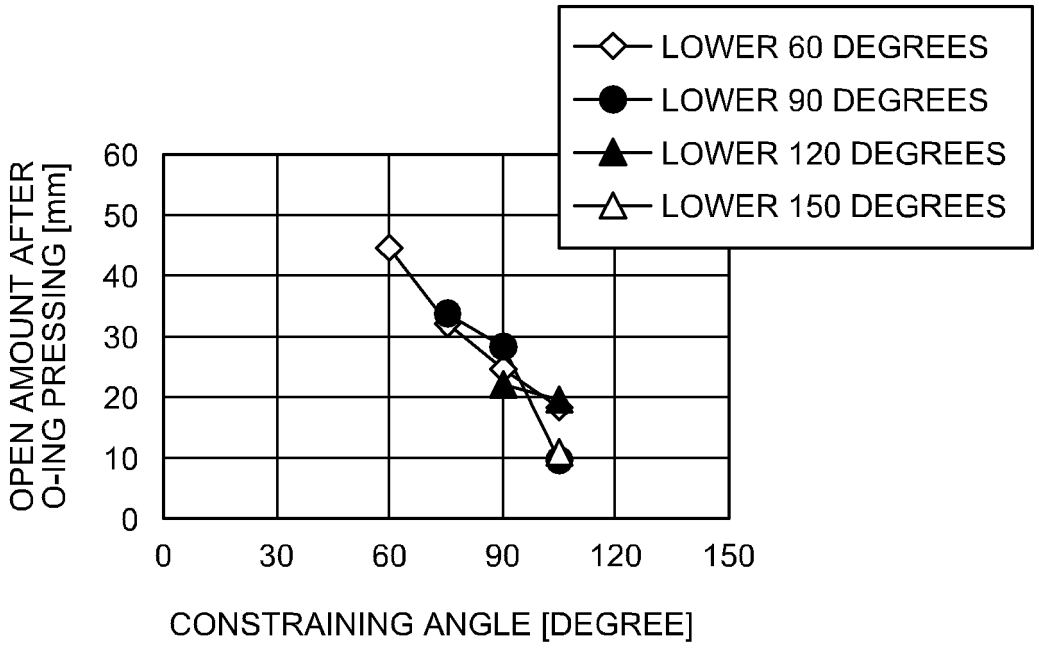

LOWER 60 DEGREES
LOWER 90 DEGREES
LOWER 120 DEGREES
LOWER 150 DEGREES
OPEN AMOUNT AFTER O-ING PRESSING [mm]
60
50
40
30
20
10
0
0
30
60
90
120
150
CONSTRAINING ANGLE [DEGREE]

FIG.11

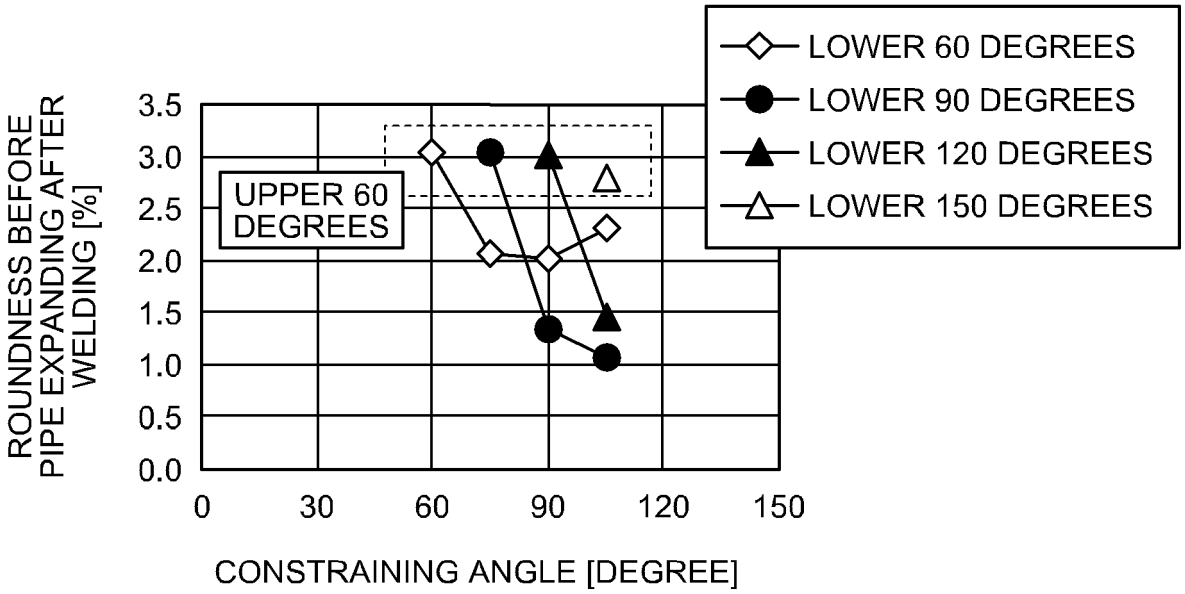

LOWER 60 DEGREES
LOWER 90 DEGREES
LOWER 120 DEGREES
LOWER 150 DEGREES
UPPER 60 DEGREES
ROUNDNESS BEFORE PIPE EXPANDING AFTER WELDING [%]
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
30
60
90
120
150
CONSTRAINING ANGLE [DEGREE]

FIG.12

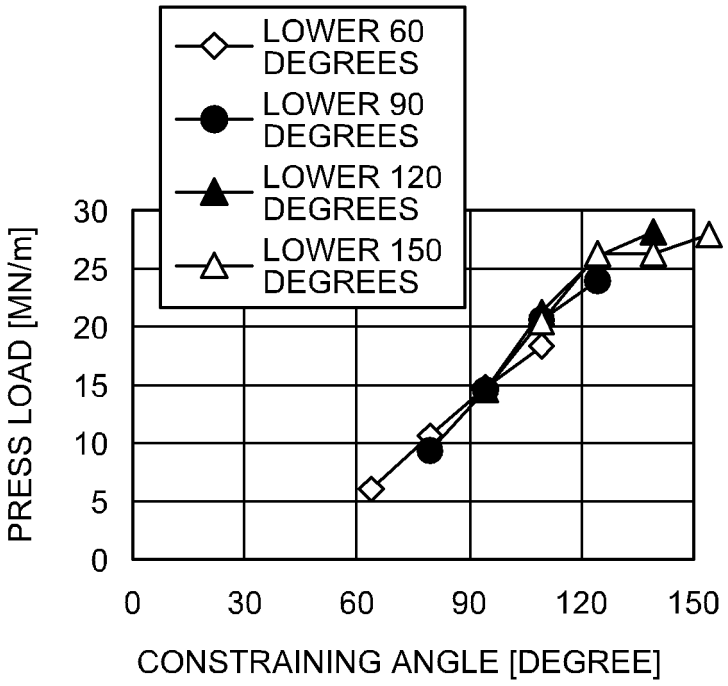

LOWER 60 DEGREES
LOWER 90 DEGREES
LOWER 120 DEGREES
LOWER 150 DEGREES
PRESS LOAD [MN/m]
30
25
20
15
10
5
0
0
30
60
90
120
150
CONSTRAINING ANGLE [DEGREE]

FIG.13

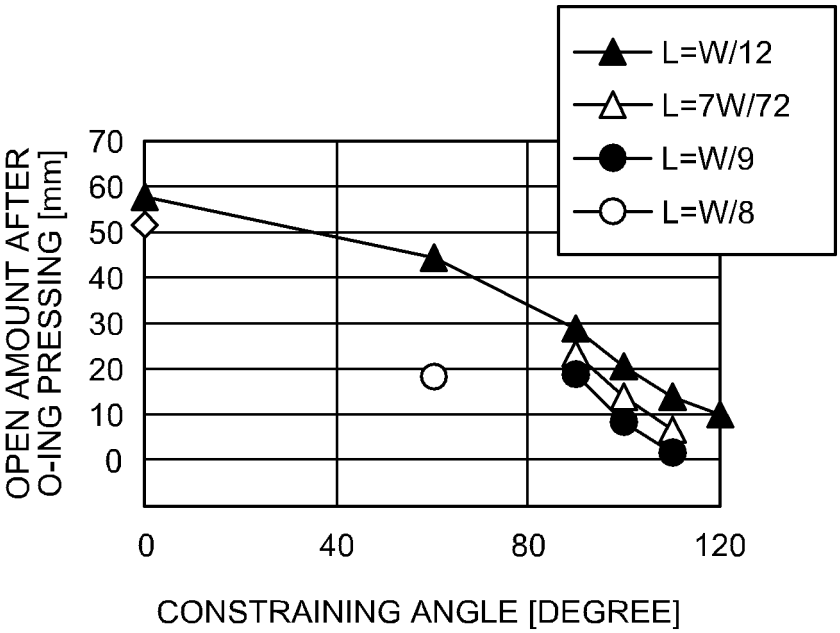

L=W/12
L=7W/72
L=W/9
L=W/8
OPEN AMOUNT AFTER O-ING PRESSING [mm]
70
60
50
40
30
20
10
0
0
40
80
120
CONSTRAINING ANGLE [DEGREE]

FIG.14

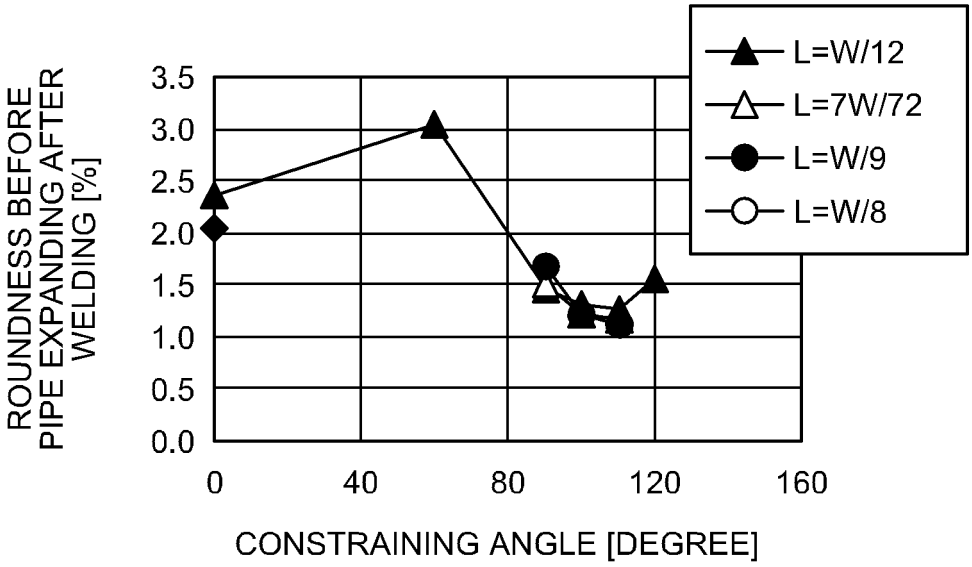

ROUNDNESS BEFORE PIPE EXPANDING AFTER WELDING [%]
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
40
80
120
160
CONSTRAINING ANGLE [DEGREE]
L=W/12
L=7W/72
L=W/9
L=W/8

FIG.15

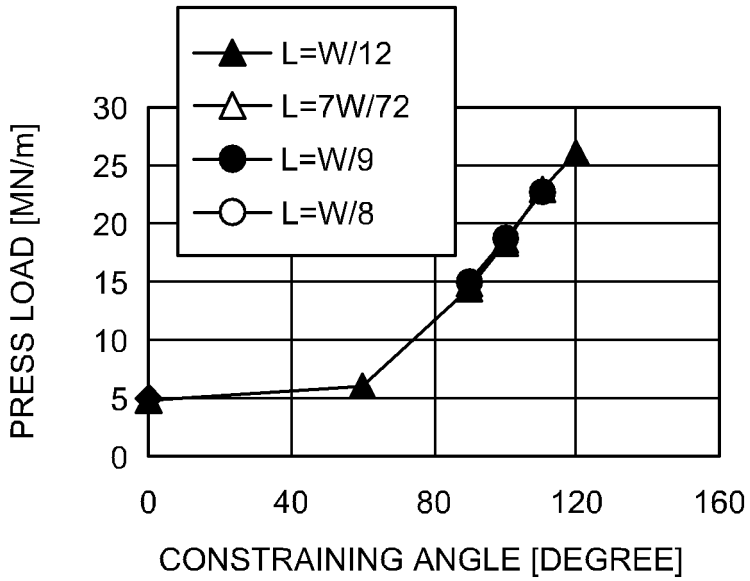

PRESS LOAD [MN/m]
30
25
20
15
10
5
0
0
40
80
120
160
CONSTRAINING ANGLE [DEGREE]
L=W/12
L=7W/72
L=W/9
L=W/8

FIG.16

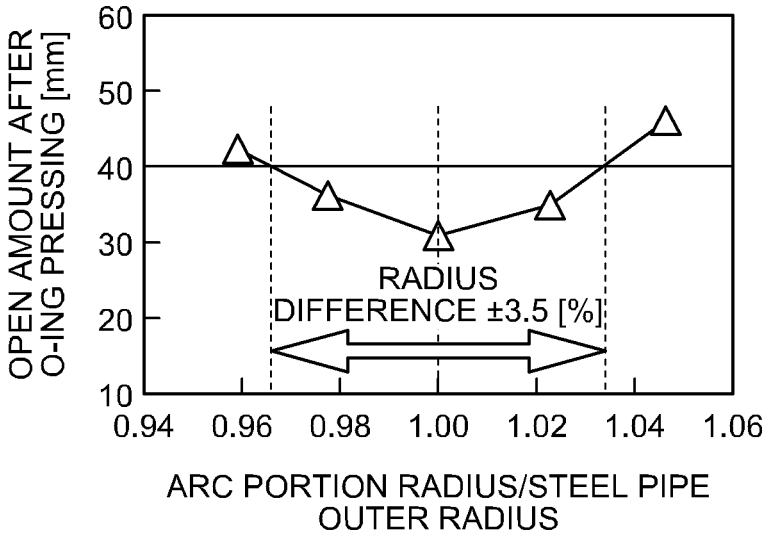
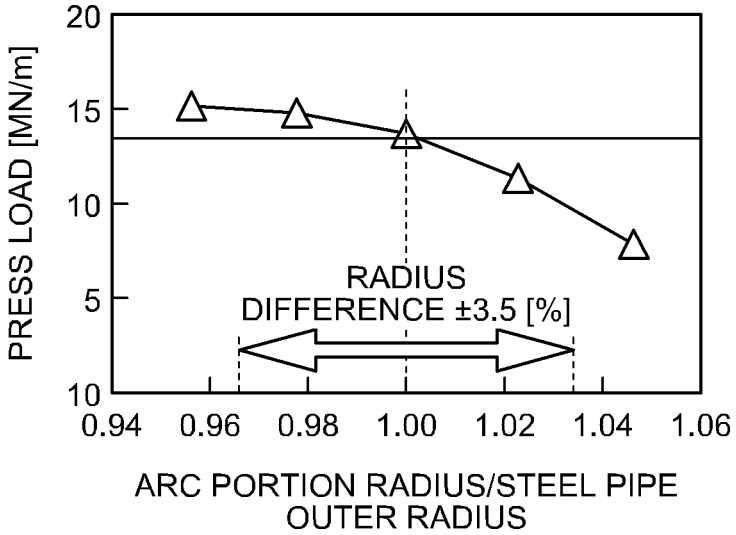

OPEN AMOUNT AFTER O-ING PRESSING [mm]
60
50
40
30
20
10
RADIUS DIFFERENCE ±3.5 [%]
0.94
0.96
0.98
1.00
1.02
1.04
1.06
ARC PORTION RADIUS/STEEL PIPE OUTER RADIUS

FIG.17


PRESS LOAD [MN/m]
20
15
10
5
10
RADIUS DIFFERENCE ±3.5 [%]
0.94
0.96
0.98
1.00
1.02
1.04
1.06
ARC PORTION RADIUS/STEEL PIPE OUTER RADIUS

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2018/008489

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. 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)
Int.Cl. B21D5/01

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

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2018
Registered utility model specifications of Japan	1996-2018
Published registered utility model applications of Japan	1994-2018

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.
X A	JP 2003-39115 A (KAWASAKI STEEL CORP.) 12 February 2003, paragraphs [0002], [0003], fig. 1 (Family: none)	1, 3-7 2
X A	JP 2002-178026 A (KAWASAKI STEEL CORP.) 25 June 2002, paragraphs [0017], [0018], fig. 1 (Family: none)	1, 3-7 2
X A	WO 2016/084607 A1 (JFE STEEL CORPORATION) 02 June 2016, paragraphs [0031]-[0076], fig. 1-15 & CA 2967914 A1, paragraphs [0031]-[0076], fig. 1-15	1, 4-5, 7 2-3, 6

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"I" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search 23.04.2018	Date of mailing of the international search report 15.05.2018
Name and mailing address of the ISA/ Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP 2004082219 A **[0006]**
- JP 2011056524 A **[0006]**
- WO 2014188468 A **[0006]**
- WO 2014192043 A **[0006]**
- JP 2005324255 A **[0006]**
- JP 2005021907 A **[0006]**
- JP 2012250285 A **[0006]**
- US 4149399 A **[0006]**
- WO 2016084607 A **[0006]**