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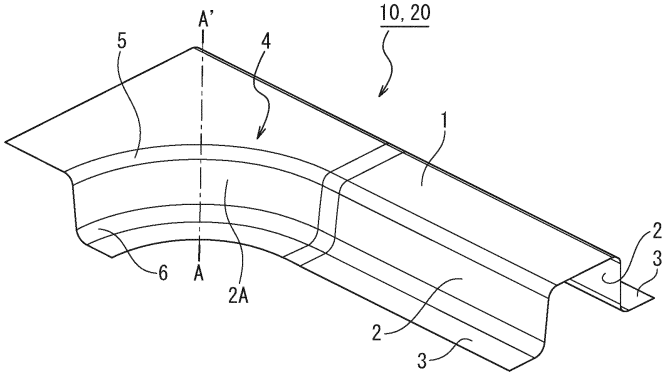
(54) PRESS FORMED COMPONENT AND METHOD FOR MANUFACTURING SAME

(57) Provided are a press formed component that does not easily cause wrinkling on a vertical wall portion of a curved portion in a component shape having an L-shape, a T-shape, or the like when viewed in a plan view and a method for manufacturing the same. A press formed component (20) includes a top sheet portion (1), a vertical wall portion (2) continuous to the top sheet portion (1), and a flange portion (3) and also includes a curved portion (4) in which when viewed in a plan view, at least a part of a boundary portion (5) between the top sheet portion (1) and the vertical wall portion (2) is displaced to the vertical wall portion (2) side and curved concavely toward a longitudinal direction. In a cross-sectional shape of the curved portion (4), an inclination angle θ [deg] of the vertical wall portion (2) with respect to the top sheet portion (1) satisfies expression (1) below:

$$(1-\sin\theta)/\cos\theta > 0.95 \quad \ldots (1) \tag{1}$$

FIG. 1



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Description

Technical Field

[0001] The present invention relates to a press formed component including a portion having an L-shape, a T-shape, or the like in a plan view, which is used as, for example, a skeleton component of an automobile, and to a method for manufacturing the same. Here, the component L-shaped or T-shaped in a plan view includes a curved portion in which a boundary portion between a top sheet portion and a vertical wall portion is displaced to the vertical wall portion side and curved concavely toward a longitudinal direction.

Background Art

[0002] A front pillar, a center pillar, or the like, which is a vehicle body skeleton component of an automobile, is a product usually including an L-shaped or T-shaped portion in a plan view. When manufacturing such a product from a metal sheet by press forming, drawing forming (drawing) or bending forming (bending) is usually used.

[0003] Drawing forming is usually performed using a die composed of a die, a punch, and a blank holder (wrinkle presser) . In drawing forming, a metal sheet is subjected to drawing by, for example, reducing a distance between the punch and the die while pressing a periphery of the metal sheet by the die and the blank holder.

[0004] Adopting drawing forming is likely to cause cracking and wrinkling when press forming an L-shaped or T-shaped component. Particularly, in recent years, high tensile strength steel sheets tend to be often applied as materials of press formed components in order to achieve safety improvement and weight reduction in automobile vehicle bodies. Such high-strength metal sheets cannot be expected to have as much ductility as mild steel sheets, so that the difficulty of performing drawing forming while suppressing cracking is higher. Additionally, in general, after drawing forming is performed while pressing the periphery of a metal sheet by a blank holder, an excess part of the metal sheet is trimmed to obtain a formed component. Due to that, drawing forming requires use of a metal sheet having a larger area than an area to be the formed component, which reduces yield.

[0005] On the other hand, bending forming is usually performed using a die composed of a punch, a pad, and a die. In bending forming, for example, bending using the die is performed on a metal sheet while sandwiching the metal sheet by the punch and the pad. Since bending forming does not use a blank holder, yield is higher as compared with drawing forming. In addition, bending forming is generally more advantageous against cracking than drawing forming. However, in bending forming, the metal sheet is not pressed by a blank holder, so that wrinkles are more likely to occur than in drawing forming.

[0006] Some countermeasure technologies against these forming defects have been proposed. For example, PTL 1 describes a press forming method for an automobile skeleton component including a top sheet portion, a vertical wall portion continuous thereto, and a flange portion and having a shape curved in an L-shape. In PTL 1, a metal sheet having a shape such that an end of a part of the metal sheet corresponding to a lower side of the L-shape is within the top sheet portion is placed on a die, and the top sheet portion is pressed by a pad to suppress out-of-plane deformation or buckling of the metal sheet. In PTL 1, while, in the suppressed state, sliding at least a part of a region of the metal sheet corresponding to the top sheet portion on a portion of the die corresponding to the top sheet portion, a vertical wall portion and a flange portion are press formed by a bending die.

[0007] Additionally, in PTL 2, conditions that no body wrinkles occur on a vertical wall portion are indicated by limiting a component shape, including an angle between a vertical wall curved portion and a direction orthogonal to a flange portion, a length from an inner edge of a flange surface to a central part of a shock mark generated in the vertical wall curved portion, and a central angle of a curved fan shape on a horizontal plane of the vertical wall curved portion.

Citation List

[0008] Patent Literature

[0009]

PTL 1: JP Pat. No. 5796560
PTL 2: JP H09-66320 A

Summary of Invention

Technical Problem

[0010] Performing press forming under the condition described in PTL 1 can suppress cracking in the flange portion

and wrinkling on the top sheet portion in the portion curved inward in a plan view (also referred to as curved inner side) in the L-shape. However, in the method described in PTL 1, wrinkles occur on the vertical wall portion on the curved inner side depending on the shape of the press component. The occurrence of wrinkles spoils the appearance of a product or can cause a defect during welding with another component at the position of the vertical wall portion.

[0011] Additionally, a body wrinkle countermeasure technology described in PTL 2 is effective for a press formed component including a top sheet surface, a vertical wall portion continuous to the top sheet surface, and a flange portion and also including a curved portion in which when viewed in a plan view, at least a part of a boundary between the top sheet surface and the vertical wall portion is displaced to the vertical wall portion side and curved convexly toward a longitudinal direction. However, the form of occurrence of the wrinkles assumed in the description of PTL 2 is different from that of wrinkles occurring on a vertical wall portion in an L-shaped or T-shaped press formed component including a top sheet surface, the vertical wall portion continuous to the top sheet surface, and a flange portion and also including a curved portion in which when viewed in a plan view, at least a part of a boundary between the top sheet surface and the vertical wall portion is displaced to the vertical wall portion side and curved concavely toward a longitudinal direction, as is often seen in automobile skeleton components. Furthermore, an accurate value of the length from the inner edge of the flange surface to the central part of the shock mark, which is a parameter to be used when defining the component shape, can only be confirmed by measuring in an actually press formed component. Therefore, in PTL 2, the occurrence of wrinkles cannot be predicted at a pre-stage of press forming designed so that no wrinkles occur on the vertical wall portion in the component.

[0012] The present invention has been made in view of the above problems, and it is an object of the present invention to provide a press formed component capable of suppressing wrinkling on a vertical wall portion of a curved portion in a component shape having an L-shape, a T-shape, or the like when viewed in a plan view and a method for manufacturing the same.

Solution to Problem

[0013] To achieve the above object, an aspect of the present invention is a press formed component including a top sheet portion, a vertical wall portion continuous to the top sheet portion, and a flange portion and also including a curved portion in which when viewed in a plan view, at least a part of a boundary portion between the top sheet portion and the vertical wall portion is displaced to the vertical wall portion side and curved concavely toward a longitudinal direction, in which, in a cross-sectional shape of the curved portion, an inclination angle θ [deg] of the vertical wall portion with respect to the top sheet portion satisfies expression (1) below:

$$(1-\sin\theta)/\cos\theta > 0.95 \ldots (1)$$

[0014] Additionally, another aspect of the present invention is a press formed component including a top sheet portion, a vertical wall portion continuous to the top sheet portion, and a flange portion and also including a curved portion in which when viewed in a plan view, at least a part of a boundary portion between the top sheet portion and the vertical wall portion is displaced to the vertical wall portion side and curved concavely toward a longitudinal direction, in which when, in a cross-sectional shape, a height of the vertical wall portion is defined as H [mm], an inclination angle of the vertical wall portion with respect to the top sheet portion as θ [deg], a curvature radius at the boundary portion between the top sheet portion and the vertical wall portion as Rp [mm], a curvature radius at a boundary portion between the vertical wall portion and the flange portion as Rd [mm], and a curvature radius of the curved portion in the plan view as r [mm], the inclination angle θ of the vertical wall portion in the curved portion satisfies expression (2) below, and further, the curved portion satisfies expression (3) below or satisfies expressions (4) and (5) below:

$$0.85 < (1-\sin\theta)/\cos\theta \leq 0.95 \ldots (2)$$

$$(r-H\cdot\tan\theta)/(r-(H/\cos\theta)) < 1.5 \ldots (3)$$

$$1.5 \leq (r-H\cdot\tan\theta)/(r-(H/\cos\theta)) < 5.0 \ldots (4)$$

$$Rd > Rp \ldots (5)$$

[0015] In addition, another aspect of the present invention is a press formed component including a top sheet portion, a vertical wall portion continuous to the top sheet portion, and a flange portion and also including a curved portion in which when viewed in a plan view, at least a part of a boundary portion between the top sheet portion and the vertical wall portion is displaced to the vertical wall portion side and curved concavely toward a longitudinal direction, in which when, in a cross-sectional shape, a height of the vertical wall portion is defined as H [mm], an inclination angle of the vertical wall portion with respect to the top sheet portion as θ [deg], a curvature radius at the boundary portion between the top sheet portion and the vertical wall portion as Rp [mm], a curvature radius at a boundary portion between the vertical wall portion and the flange portion as Rd [mm], and a curvature radius of the curved portion at the boundary portion between the top sheet portion and the vertical wall portion in the plan view as r [mm], the inclination angle θ of the vertical wall portion in the curved portion satisfies expression (6) below, and further, the curved portion satisfies expression (7) below or satisfies expressions (8) and (9) below.

$$(1-\sin\theta)/\cos\theta \leq 0.85 \ldots (6)$$

$$(r-H\cdot\tan\theta)/(r-(H/\cos\theta)) < 1.4 \ldots (7)$$

$$1.4 \leq (r-H\cdot\tan\theta)/(r-(H/\cos\theta)) < 2.00 \ldots (8)$$

$$Rd > Rp \ldots (9)$$

[0016] The press formed component according to each aspect of the present invention may be manufactured by, for example, bending forming or drawing forming.

Advantageous Effects of Invention

[0017] According to the aspects of the present invention, by simply specifying the shape condition of the press formed component shape, there can be provided a press formed component capable of suppressing the occurrence of wrinkles on the vertical wall portion of the curved portion in the component shape having an L-shape, a T-shape, or the like when viewed in the plan view.

Brief Description of Drawings

[0018]

FIG. 1 is a diagram illustrating an example of a formed component shape according to an embodiment based on the present invention;
FIG. 2 is a diagram illustrating another example of the formed component shape;
FIG. 3 is a diagram illustrating shape parameters in a cross-sectional shape of a cross section taken along line A-A' of FIG. 1;
FIG. 4 is a diagram illustrating a shape parameter in a plan view;
FIG. 5 is a diagram illustrating deformations in a curved portion during forming;
FIG. 6 is a schematic diagram illustrating movement of a material during forming;
FIG. 7 is a diagram illustrating a region where shear deformation occurs in a vertical wall portion during forming;
FIG. 8 is a diagram illustrating elongation deformation in a flange portion during forming;
FIG. 9 is a diagram illustrating changes in a material flow due to a relationship between a curvature radius of a boundary portion between a top sheet portion and the vertical wall portion and a curvature radius of a boundary portion between the vertical wall portion and the flange portion;
FIG. 10 is a diagram illustrating regions with and without occurrence of wrinkles;
FIG. 11 is a diagram illustrating an example of a die;
FIG. 12 is a diagram illustrating a formed component shape in an Example; and
FIG. 13 is a diagram illustrating the structure of a die used in the Example.

Description of Embodiments

[0019] Next, embodiments of the present invention will be described with reference to the drawings.

[0020] As illustrated in FIG. 1, the present embodiment targets a press formed component 20 having a component shape including a top sheet portion 1, a vertical wall portion 2 continuous to the top sheet portion 1, and a flange portion 3 and also including a curved portion 4 in which when viewed in a plan view, at least a part of a boundary portion 5 between the top sheet portion 1 and the vertical wall portion 2 is displaced to the vertical wall portion 2 side and curved concavely toward a longitudinal direction. Such a press formed component 20 is, for example, a component having an L-shape or a T-shape in a plan view.

[0021] The phrase "being displaced to the vertical wall portion 2 side and curved concavely toward the longitudinal direction" means that the boundary portion 5 between the top sheet portion 1 and the vertical wall portion 2 is curved in such a manner that a curvature radius as viewed from the vertical wall portion 2 side along the longitudinal direction is smaller. In the present specification, such a component shape of the press formed component 20 including the curved portion 4 in which the at least a part is displaced to the vertical wall portion 2 side and curved concavely toward the longitudinal direction is referred to also as a curve-containing component shape 10.

[0022] Hereinafter, the press formed component will be mainly described by exemplifying the curve-containing component shape 10 having an L-shape in a plan view, as illustrated in FIG. 1. In other words, in the press formed component, the component shape including the curved portion 4 (a left side portion in FIG. 1) formed in such a manner that, when viewed in a plan view, one widthwise side of the top sheet portion 1 is curved so as to project to the vertical wall portion 2 side toward a longitudinal end is an example of the curve-containing component shape 10.

[0023] Another example of the curve-containing component shape 10 to which the present embodiment is applicable may be a component shape curved in a T-shape when viewed in a plan view, as illustrated in FIG. 2. The example of FIG. 2 is an example in which both widthwise ends of the top sheet portion 1 are curved so as to project in the widthwise direction to form the curved portion 4 on each side individually. Note that the present embodiment is also applicable even to a component shape in which the vertical wall portion 2 is formed only on one widthwise side of the top sheet portion 1.

[0024] Here, the present inventors conducted intensive and extensive studies about shape conditions of the press formed component 20 capable of suppressing the occurrence of wrinkles on a vertical wall portion 2A of the curved portion 4 even when bending forming a metal sheet used as a material into the curve-containing component shape 10 including the curved portion 4. Note that bending forming (bending) is usually performed using a die composed of a die, a punch, and a pad. As a result of the studies, it was found that in the case of a component shape in which values of geometric elements that determine the shape of the curved portion 4 in the curve-containing component shape 10 are set within a certain range, no wrinkles occur on the vertical wall portion on a curved inner side in the curved portion 4 even when bending is performed while pressing the metal sheet by a pad 31 and a punch 32. The geometric elements that determine the shape of the curved portion 4 are a height of the vertical wall portion 2, an angle between the top sheet portion 1 and the vertical wall, a curvature radius of a fillet at the boundary potion 5 between the top sheet portion 1 and the vertical wall, a curvature radius of a fillet at a boundary portion 6 between the vertical wall portion 2 and the flange portion 3, and a curvature radius of the curved portion 4 on an L-shaped inner side in a plan view.

[0025] The present invention has been made based on such findings.

<Curve-Containing Component Shape 10>

[0026] Here, regarding the shape of the curved portion 4 (the shape of the curved inner side) in the curve-containing component shape 10, in a cross-sectional shape as illustrated in FIG. 3, the height of the vertical wall portion 2 is defined as H [mm], an inclination angle of the vertical wall portion 2 with respect to the top sheet portion 1 as θ [deg], the curvature radius of the fillet at the boundary portion 5 between the top sheet portion 1 and the vertical wall portion 2 as Rp [mm], and the curvature radius of the fillet at the boundary portion 6 between the vertical wall portion 2 and the flange portion 3 as Rd [mm] . Additionally, as illustrated in FIG. 4, the curvature radius of the curved portion 4 at the boundary portion 5 between the top sheet portion 1 and the vertical wall portion 2 in a plan view is defined as r [mm]. These variables are shape parameters that define the shape of the curved portion 4 of the formed component 20. Here, as illustrated in FIG. 3, the inclination angle θ of the vertical wall portion 2 with respect to the top sheet portion 1 is, when assuming that a direction orthogonal to the top sheet portion is 0 degrees, an increase in angle in a direction in which the vertical wall portion 2 is opened with respect to the top sheet portion 1 from 0 degrees. In other words, the inclination angle θ is an angle obtained by subtracting 90 degrees from an obtuse angle formed by the top sheet portion 1 and the vertical wall portion 2 on a back surface side.

[0027] Note that the curvature radius of the curve of the curved portion 4 may not be constant. In that case, for example, an average value of curvature radii of the curved portion 4, a curvature radius of a longitudinal central part of the curved portion 4, a minimum value of the curvature radii of the curved portion 4, or the like may be adopted as the curvature

radius of the curved portion 4.

[0028] The shape of the curved portion 4 in the press formed component 20 of the present embodiment is classified into three kinds of shape conditions as below according to a value of "(1- sinθ)/cosθ".

[0029] First, the shape condition of a first press formed component of the present embodiment is a condition that the inclination angle θ in the curved portion 4 satisfies expression (1) below:

$$(1-\sin\theta)/\cos\theta > 0.95 \ldots (1)$$

[0030] Additionally, the shape condition of a second press formed component of the present embodiment is a condition that the inclination angle θ in the curved portion 4 satisfies expression (2) below and further satisfies condition A or condition B below:

$$0.85 < (1-\sin\theta)/\cos\theta \leq 0.9 \ldots (2)$$

"Condition A"

[0031] Expression (3) below is satisfied:

$$(r-H\cdot\tan\theta)/(r-(H/\cos\theta)) \leq 1.5 \ldots (3)$$

"Condition B"

[0032] Expressions (4) and (5) below are satisfied:

$$1.5 \leq (r-H\cdot\tan\theta)/(r-(H/\cos\theta)) < 5.0 \ldots (4)$$

$$Rd > Rp \ldots (5)$$

[0033] In addition, the shape condition of a third press formed component of the present embodiment is a condition that the inclination angle θ in the curved portion 4 satisfies expression (6) below and further satisfies condition C or condition D below:

$$(1-\sin\theta)/\cos\theta \leq 0.85 \ldots (6)$$

"Condition C"

[0034] Expression (7) below is satisfied:

$$(r-H\cdot\tan\theta)/(r-(H/\cos\theta)) < 1.4 \ldots (7)$$

"Condition D"

[0035] Expressions (8) and (9) below are satisfied:

$$1.4 \leq (r-H\cdot\tan\theta)/(r-(H/\cos\theta)) < 2.0 \ldots (8)$$

$$Rd > Rp \ldots (9)$$

[0036] Next, a description will be given of a reason for limiting a threshold value under the shape condition of the

curved portion 4 described above.

[0037] When a metal sheet is press formed (bent formed) into the curve-containing component shape 10, compressive deformation occurs in a part of the top sheet portion 1 near the vertical wall portion 2 along the longitudinal direction, and shrinkage deformation acts on the flange portion 3 along the longitudinal direction, in the curved portion 4, as illustrated in FIG. 5. Then, due to a difference between deformation states of the top sheet portion 1 and the flange portion 3, wrinkles occur on the vertical wall portion 2. However, depending on the condition of bending, since the top sheet portion 1 is pressed by the pad and the punch, buckling of the top sheet portion 1 due to the compressive deformation hardly occurs, and vertical wall portions 2B adjacent to the vertical wall portion 2A of the curved portion 4 are formed while being shear deformed so as to make the tensile deformation occurring in the flange portion 3 as small as possible, as illustrated in FIG. 6. As a result, the compressive deformation of the top sheet portion 1 and the tensile deformation of the flange portion 3 are reduced, whereby it seems unlikely that wrinkling will occur on the vertical wall portion 2.

[0038] As described above, when press forming the curved portion 4, whether or not shear deformation is likely to occur in the vertical wall portions 2B adjacent to the vertical wall portion 2A of the curved portion 4 is roughly determined by the inclination angle θ formed by the vertical wall portion 2 with respect to the top sheet portion 1 in the curved portion 4. In other words, as illustrated in FIG. 7, a region where shear deformation occurs in the vertical wall portions 2B adjacent to the vertical wall portion 2A of the curved portion 4 is a region in contact with the die 30 in a region to be the vertical wall portion 2 in a metal sheet 11. Thus, it can be said that the smaller the inclination angle θ of the vertical wall portion 2 with respect to the top sheet portion 1, the more easily shear deformation occurs in the vertical wall portions 2B adjacent to the vertical wall portion 2A of the curved portion 4. Note that an inclination angle of the vertical wall portion 2B adjacent to the curved portion 4 is also the same as or approximate to the inclination angle θ of the vertical wall portion 2A.

[0039] In this case, a ratio (shear deformation ratio: SDR) of a length of the region in contact with the die 30 in the region to be formed as the vertical wall portion 2 can be defined as expression (10) below using the inclination angle θ, which is one of the shape parameters.

$$SDR = (1- \sin\theta)/\cos\theta \quad \ldots (10)$$

[0040] In other words, the larger the value of the SDR defined by expression (10), the more easily shear deformation occurs in the vertical wall portion 2 adjacent to the curved portion 4 on the inner side of the L-shape, so that wrinkles occurring on the vertical wall of the curved portion 4 seem to be reduced. Note that an upper limit value of the SDR is 1.

[0041] Additionally, in a process for bending forming a metal sheet formed by unfolding the formed component 20 into the formed component 20, a portion to be the flange portion 3 of the curved portion 4 needs to be elongated, as illustrated in FIG. 8. Considering this, expression (11) below is defined as an index value Elongation index (Eindx) of elongation deformation that acts on the region of the metal sheet 11 to be the flange portion 3 of the curved portion 4.

$$Eindx = (r- H\cdot\tan\theta)/(r- (H/\cos\theta) \quad \ldots \text{expression (11)}$$

[0042] It seems that as the index value Eindx of the elongation deformation shown in expression (11) becomes smaller, the tensile deformation that occurs on the flange portion 3 is more suppressed, which suppresses wrinkling that occurs on the vertical wall portion 2A when press forming the metal sheet 11 into a formed component shape.

[0043] In addition, a magnitude of the tensile deformation that occurs on the flange portion 3 of the curved portion 4 varies depending on a magnitude relationship between the curvature radius Rp of the fillet formed by the boundary portion 5 between the top sheet portion 1 and the vertical wall portion 2A and the curvature radius Rd of the fillet at the boundary portion 6 between the vertical wall portion 2A and the flange portion 3. In other words, as illustrated in FIG. 9A, when Rd > Rp, a resistance of the material passing through the fillet at the boundary portion 6 between the surface of the vertical wall portion 2 and the flange portion 3 becomes relatively smaller, so that the material easily flows in from the flange portion 3 side. Therefore, wrinkles are less likely to occur on the vertical wall portion 2. On the other hand, as illustrated in FIG. 9B, when Rd < Rp, a resistance of the material passing through the fillet at the boundary portion 5 between the top sheet portion 1 and the vertical wall portion 2 becomes relatively smaller, so that the material easily flows in from the top sheet portion 1 side. As a result, the material becomes excessive on the vertical wall portion 2, which is a condition that wrinkles are likely to occur.

[0044] Considering the above, the present inventors conducted intensive and extensive studies through simulation analysis and experiments, as a result of which it was found that regarding the formed component 20 manufactured from the metal sheet 11 into the curve-containing component shape 10, geometric conditions of the shape of the formed component 20 in which no wrinkles occur on the vertical wall portion 2A of the curved portion 4 during bending are as follows:

1) When SDR > 0.95, no wrinkles occur on the vertical wall portion 2 of the curved portion 4 in all geometric shapes.
2) When 0.85 < SDR ≤ 0.95, if Eindx < 1.5, or if 1.5 ≤ Eindx < 5.0 and Rd > Rp, no wrinkles occur on the vertical wall portion 2 of the curved portion 4.
3) When SDR ≤ 0.85, if Eindx < 1.4, or if 1.4 ≤ Eindx < 2.0 and Rd > Rb, no wrinkles occur on the vertical wall portion 2 of the curved portion 4.

[0045] Here, threshold values for determining the shape of the press formed component 20 in each expression under the geometric conditions of the shape of the formed component 20 described above were determined from forming results as to whether or not wrinkles occurred on the vertical wall portion 2 of the curved portion 4 in a plurality of kinds of curve-containing component shapes 10 obtained by bending forming. FIG. 10 illustrates the forming results. FIG. 10 summarizes each of the cases of Rd > Rp and Rd < Rp by using the SDR and the Eindx as two parameters. Note that in FIG. 10, conditions with the occurrence of wrinkles were plotted as "X", and conditions without the occurrence of wrinkles were plotted as "O".

[0046] In FIG. 10, the conditions without the occurrence of wrinkles are indicated by hatching. As long as the shape is within the hatched region, there are no wrinkles occurring on the vertical wall portion 2 of the curved portion 4. Each threshold value in the above expressions was calculated so as to satisfy the hatched region.

[0047] Here, the above description has been given assuming that bending has been applied as press forming. However, in drawing forming compared to bending forming, shape conditions for whether or not wrinkles occur on the vertical wall portion 2 of the curved portion 4 are looser, so that the above shape conditions without the occurrence of wrinkles are applicable even in drawing forming (drawing).

<Metal Sheet 11>

[0048] Here, when considering the yield of the sheet, it is preferable that the metal sheet 11 to be used as material has a shape of the formed component shape unfolded. However, as long as the yield is within a permissible range, the metal sheet 11 having an area larger than an area required for the component shape may be used as the material for press forming.

[0049] The metal sheet 11 suitable as the material is a steel sheet having a tensile strength of from 4400 MPa to 1800 MPa.

[0050] Note that when determining the threshold values of each of the above expressions, a steel sheet having a tensile strength of 980 MPa was appropriately used as the metal sheet 11 as the material.

<Die and Press Forming Method>

[0051] As described above, the shape of the curved portion 4 is defined by using, as the shape parameters, the height H [mm] of the vertical wall portion 2, the inclination angle θ [deg] of the vertical wall portion 2 with respect to the top sheet portion 1, the curvature radius Rp [mm] of the fillet at the boundary portion 5 between the top sheet portion 1 and the vertical wall portion 2, the curvature radius Rd [mm] of the fillet at the boundary portion 6 between the vertical wall portion 2 and the flange portion 3, and the curvature radius r [mm] of the curved portion 4 at the boundary portion 5 between the top sheet portion 1 and the vertical wall portion 2 in the plan view.

[0052] In the curve-containing component shape 10, other constraint conditions, such as constraints of shapes other than the curved portion 4, are considered, and the shape of the formed component 20 is specified so as to satisfy any of the shape conditions of the first to third press formed components of the present embodiment, thereby manufacturing the formed component by press processing.

[0053] For example, according to the value of the SDR defined by the inclination angle θ of the vertical wall portion 2 with respect to the top sheet portion 1, one shape condition is selected from the shape conditions of the first to third press formed components of the present embodiment. Then, the shape of the curved portion 4 is selected to satisfy the selected shape, and thereby the shape of the press formed component 20 is determined.

[0054] Press forming into the curve-containing component shape 10 as described above is performed by bending forming using a die, for example, illustrated in FIG. 11. The die illustrated in FIG. 11 is composed of an upper die including the die 30 and the pad 31 and a lower die including the punch 32. Then, a portion of the metal sheet 11 to be the top sheet portion 1 is sandwiched by the pad 31 and the punch 32, and in this state, the die 30 is lowered to perform bending forming of the vertical wall portion 2 and the flange portion 3. In FIG. 11, the pad 31 is arranged to cover the entire top sheet portion 1 so that the entire top sheet portion 1 is pressed. However, the pad 31 may be configured to press a part of the top sheet portion 1.

[0055] Additionally, press forming into the curve-containing component shape 10 may be performed by manufacturing by drawing forming. Specifically, a die composed of a die, a punch, and a blank holder (wrinkle presser) may be used for forming. In this case, manufacturing may be performed by drawing forming in which the metal sheet 11 is subjected

to drawing by reducing a distance between the punch and the die while pressing a periphery of the metal sheet 11 by the die and the blank holder.

[0056] Here, the metal sheet 11 to be press formed may be a metal sheet that is pre-formed in a previous step. In addition, the component formed into the curve-containing component shape 10 by the above-described press forming may be an intermediate component before a final product shape is obtained.

<Effects and Others>

[0057] In the present embodiment, simply specifying the shape condition of the press formed component 20 enables suppression of the occurrence of wrinkles on the vertical wall portion 2 of the curved portion 4 in a component shape having an L-shape, a T-shape, or the like when viewed in a plan view.

Example

[0058] An Example based on the present embodiment will be described.

[0059] A 980 MPa-class cold-rolled steel sheet (sheet thickness: 1.4 mm) was used as the material metal sheet, and a component shape having a T-shape as illustrated in FIG. 12 was set as the curve-containing component shape 10. The component shape includes the curved portion 4 on each widthwise side of the top sheet portion 1 on the left side on the paper in FIG. 12.

[0060] The following conditions were adopted as forming analysis conditions for the geometric shape of the above component.

<Component Shape Parameters>

[0061]

Height H of vertical wall portion: 60 mm
Inclination angle θ: 2 deg, 7 deg, and 12 deg
Length f at an outer edge of the flange portion 3 in the curved portion 4: 30 mm
Punch shoulder R (curvature radius Rp at boundary portion 5): 10 mm
Die shoulder R (curvature radius Rd at boundary portion 6): 8 mm, 12 mm, and 16 mm
Curved portion R (curvature radius r of curved portion) : 100 mm, 150 mm, and 200 mm

[0062] Then, the formed component 20 was subjected to press forming analysis under a condition that bending was performed by a die composed of the die 30, the pad 31, and the punch 32, as illustrated in FIG. 13.

[0063] During the forming analysis, pad pressure was 40 tons, and stroke of the pad 31 was 75 mm. In addition, a coefficient of friction between the die and the metal sheet 11 was set constant at 0.12.

[0064] Then, a forming analysis result on the metal sheet 11 at a point 15 mm before a forming bottom dead center during the bending was visually observed to investigate the presence or absence of wrinkles occurring on the vertical wall portion 2 of the curved portion 4.

[0065] Under the above conditions, there were obtained geometric shape parameters SDR and Eindx, the magnitude relationship between Rd and Rp, and the presence or absence of occurrence of wrinkles on the vertical wall portion 2 of the curved portion 4 in each formed component 20. Tables 1 to 3 show the obtained results.

Table 1

H (mm)	θ (deg)	f (mm)	Rd (mm)	Rp (mm)	r (mm)	Shear Deformation ratio	Elongation index	Rd>Rp or Rd<Rp	Condition of Good product	Wrinkle
60	2	30	8	10	100	0.966	2.45	Rd<Rp	○	None
					150		1.64		○	None
					200		1.41		○	None
			12		100		2.45	Rd>Rp	○	None
					150		1.64		○	None
					200		1.41		○	None
			16		100		2.45		○	None
					150		1.64		○	None
					200		1.41		○	None

Table 2

H (mm)	θ (deg)	f (mm)	Rd (mm)	Rp (mm)	r (mm)	Shear Deformation ratio	Elongation index	Rd>Rp or Rd<Rp	Condition of Good product	Wrinkle
60	7	30	8	10	100	0.885	2.34	Rd<Rp		Observed
					150		1. 59			Observed
					200		1.38		○	None
			12		100		2.34	Rd>Rp	○	None
					150		1. 59		○	None
					200		1.38		○	None
			16		100		2.34		○	None
					150		1. 59		○	None
					200		1.38		○	None

Table 3

H (mm)	θ (deg)	f (mm)	Rd (mm)	Rp (mm)	r (mm)	Shear Deformation ratio	Elongation index	Rd>Rp or Rd<Rp	Condition of Good product	Wrinkle
60	12	30	8	10	100	0.810	2.26	Rd<Rp		Observed
60	12	30	8	10	150	0.810	1.55	Rd<Rp		Observed
60	12	30	8	10	200	0.810	1.35	Rd<Rp	○	None
60	12	30	12	10	100	0.810	2.26	Rd>Rp		Observed
60	12	30	12	10	150	0.810	1.55	Rd>Rp	○	None
60	12	30	12	10	200	0.810	1.35	Rd>Rp	○	None
60	12	30	16	10	100	0.810	2.26	Rd>Rp		Observed
60	12	30	16	10	150	0.810	1.55	Rd>Rp	○	None
60	12	30	16	10	200	0.810	1.35	Rd>Rp	○	None

[0066] According to the results in Table 1, under the condition that the inclination angle θ is 2 deg, the SDR value is 0.966, and when the SDR value is larger than 0.95, it is judged to be a condition of good product regardless of the Eindx value and the magnitude relationship between Rd and Rp, i.e., in all geometric shapes. Additionally, even in the analysis results, no wrinkles were observed under all the conditions. Therefore, designing under the condition that the SDR value is larger than 0.95 was shown to enable the formed component 20 to be manufactured without the occurrence of any wrinkles on the vertical wall portion 2A of the curved portion 4. It was thus confirmed that when the shape condition of the first press formed component is satisfied, no wrinkles occur on the vertical wall portion 2A.

[0067] According to the results in Table 2, under the condition that the inclination angle θ is 7 deg, the SDR value is 0.855, and it was predicted that depending on the shape of the formed component 20, wrinkles will occur on the vertical wall portion 2A. Additionally, under the condition that the curvature radius r of the curved portion 4 on the curved inner side is 200 mm, the Eindx value is 1.38, which is below 1.5, so that it is judged to be a condition of good product regardless of the magnitude relationship between Rd and Rp. Even in the analysis results under the condition, there were observed no wrinkles. On the other hand, when the curvature radius of the curved portion 4 was 100 mm and 150 mm, the Eindx values were 2.34 and 1.59, respectively. When the Eindx value is from 1.5 to below 5.0, if the curvature radius of the fillet at the boundary portion 6 between the vertical wall portion 2 and the flange portion 3 is 8 mm, the condition of Rd > Rp is not satisfied, so that it was judged not to be a condition of good product. The other cases of 12 mm and 16 mm satisfied the condition of Rd > Rp, and therefore were judged to be conditions of good product. Even in analysis results under the conditions, no wrinkles were observed. Thus, it was confirmed that when the shape condition of the second press formed component is satisfied, no wrinkles occur on the vertical wall portion 2A.

[0068] According to the results in Table 3, under the condition that the inclination angle θ is 12 deg, the SDR value is 0.810, and, for example, when SDR = 0.81, wrinkling was predicted to occur on the vertical wall portion 2 depending on the formed component shape. When the curvature radius of the curved portion 4 was 200 mm, the Eindx value was 1.35, which was below 1.4, so that it was judged to be a condition of good product regardless of the magnitude relationship between Rd and Rb. The analysis results also confirmed that there were no wrinkles. Additionally, when the curvature radius of the curved portion 4 is 150 mm, the Eindx value is 1.55, which is not less than 1.4. However, when the value of Eindx is below 2.0, if the curvature radius of the fillet at the boundary portion 6 between the vertical wall portion 2 and the flange portion 3 is 8 mm, the condition of Rd > Rp is not satisfied, so that it is judged not to be a condition of good product. Since the other cases of 12 mm and 16 mm satisfy the condition of Rd > Rp, they are judged to be conditions of good product. In addition, when the curvature radius of the curved portion 4 is 100 mm, the Eindx value is 2.26, which exceeds 2.0, so that it was judged not to be a condition of good product in all the other geometric shapes. The analysis results under the condition also confirmed that wrinkles occurred on the vertical wall portion 2A. Thus, it was confirmed that when the shape condition of the third press formed component is satisfied, no wrinkles occur on the vertical wall portion 2A.

[0069] The results described above indicate that when the component including the top sheet portion 1, the vertical wall portion 2 continuous thereto, and the flange portion 3 and being curved in the L-shape when viewed in a plan view has a shape within the range of the conditions of good product, which is a geometric shape illustrated in FIG. 11, i.e., a shape that satisfies the present invention, no wrinkles occur on the vertical wall portion 2 in the formed component 20, whereas when the shape deviates from the range, wrinkles occur.

[0070] This application claims priority to Japanese Patent Application No. 2018-205495 (filed on Oct. 31, 2018), the entire contents of which form a part of the present disclosure by reference. Although the present invention has been described with reference to the limited number of embodiments, the scope of the invention is not limited thereto, and modifications of each embodiment based on the above disclosure are obvious to those skilled in the art. Reference Signs List

[0071]

1: Top sheet portion
2: Vertical wall portion
3: Flange portion
4: Curved portion
5: Boundary portion
6: Boundary portion
10: Curve-containing component shape
11: Metal sheet
20: Press formed component

Claims

1. A press formed component comprising a top sheet portion, a vertical wall portion continuous to the top sheet portion, and a flange portion and also comprising a curved portion in which when viewed in a plan view, at least a part of a boundary portion between the top sheet portion and the vertical wall portion is displaced to the vertical wall portion side and curved concavely toward a longitudinal direction,
wherein, in a cross-sectional shape of the curved portion, an inclination angle θ [deg] of the vertical wall portion with respect to the top sheet portion satisfies expression (1) below:

$$(1-\sin\theta)/\cos\theta > 0.95 \ldots (1)$$

2. A press formed component comprising a top sheet portion, a vertical wall portion continuous to the top sheet portion, and a flange portion and also comprising a curved portion in which when viewed in a plan view, at least a part of a boundary portion between the top sheet portion and the vertical wall portion is displaced to the vertical wall portion side and curved concavely toward a longitudinal direction,
wherein when, in a cross-sectional shape, a height of the vertical wall portion is defined as H [mm], an inclination angle of the vertical wall portion with respect to the top sheet portion as θ [deg], a curvature radius at the boundary portion between the top sheet portion and the vertical wall portion as Rp [mm], a curvature radius at a boundary portion between the vertical wall portion and the flange portion as Rd [mm], and a curvature radius of the curved portion in the plan view as r [mm], the inclination angle θ of the vertical wall portion in the curved portion satisfies expression (2) below, and further, the curved portion satisfies expression (3) below or satisfies expressions (4) and (5) below:

$$0.85 < (1-\sin\theta)/\cos\theta \leq 0.95 \ldots (2)$$

$$(r-H\cdot\tan\theta)/(r-(H/\cos\theta)) < 1.5 \ldots (3)$$

$$1.5 \leq (r-H\cdot\tan\theta)/(r-(H/\cos\theta)) < 5.0 \ldots (4)$$

$$Rd > Rp \ldots (5)$$

3. A press formed component comprising a top sheet portion, a vertical wall portion continuous to the top sheet portion, and a flange portion and also comprising a curved portion in which when viewed in a plan view, at least a part of a boundary portion between the top sheet portion and the vertical wall portion is displaced to the vertical wall portion side and curved concavely toward a longitudinal direction,
wherein when, in a cross-sectional shape, a height of the vertical wall portion is defined as H [mm], an inclination angle of the vertical wall portion with respect to the top sheet portion as θ [deg], a curvature radius at the boundary portion between the top sheet portion and the vertical wall portion as Rp [mm], a curvature radius at a boundary portion between the vertical wall portion and the flange portion as Rd [mm], and a curvature radius of the curved portion at the boundary portion between the top sheet portion and the vertical wall portion in the plan view as r [mm], the inclination angle θ of the vertical wall portion in the curved portion satisfies expression (6) below, and further, the curved portion satisfies expression (7) below or satisfies expressions (8) and (9) below:

$$(1-\sin\theta)/\cos\theta \leq 0.85 \ldots (6)$$

$$(r-H\cdot\tan\theta)/(r-(H/\cos\theta)) < 1.4 \ldots (7)$$

$$1.4 \leq (r-H\cdot\tan\theta)/(r-(H/\cos\theta)) < 2.00 \ldots (8)$$

$$Rd > Rp \ldots (9)$$

4. The press formed component according to any one of claims 1 to 3, wherein a metal sheet forming the press formed component is a steel sheet having a tensile strength of from 440 MPa to 1800 MPa.

5. A method for manufacturing a press formed component, wherein in manufacturing the press formed component by press forming into a component shape including a top sheet portion, a vertical wall portion continuous to the top sheet portion, and a flange portion and also including a curved portion in which when viewed in a plan view, at least a part of a boundary portion between the top sheet portion and the vertical wall portion is displaced to the vertical wall portion side and curved concavely toward a longitudinal direction, the curved portion is formed by press forming by bending or drawing in such a manner that an inclination angle θ of the vertical wall portion with respect to the top sheet portion in a cross-sectional shape satisfies expression (10) below:

$$(1- \sin\theta)/\cos\theta > 0.95 \ldots (10)$$

6. A method for manufacturing a press formed component, wherein, in manufacturing the press formed component by press forming into a component shape including a top sheet portion, a vertical wall portion continuous to the top sheet portion, and a flange portion and also including a curved portion in which when viewed in a plan view, at least a part of a boundary portion between the top sheet portion and the vertical wall portion is displaced to the vertical wall portion side and curved concavely toward a longitudinal direction, when, in a cross-sectional shape, a height of the vertical wall portion is defined as H [mm], an inclination angle of the vertical wall portion with respect to the top sheet portion as θ [deg], a curvature radius at the boundary portion between the top sheet portion and the vertical wall portion as Rp [mm], a curvature radius at a boundary portion between the vertical wall portion and the flange portion as Rd [mm], and a curvature radius of the curved portion at the boundary portion between the top sheet portion and the vertical wall portion in the plan view as r [mm], if forming into a shape in which the inclination angle θ of the vertical wall portion with respect to the top sheet portion in a cross-sectional shape of the curved portion satisfies expression (12) below, the press formed component is manufactured by press forming the curved portion by bending or drawing in such a manner as to satisfy expression (13) below or satisfy expressions (14) and (15) below, or if forming into a shape in which the inclination angle θ of the vertical wall portion with respect to the top sheet portion in the cross-sectional shape of the curved portion satisfies expression (16) below, the press formed component is manufactured by press forming the curved portion by bending or drawing in such a manner as to satisfy expression (17) below or satisfy expressions (18) and (15) below:

$$0.85 < (1- \sin\theta)/\cos\theta \leq 0.95 \ldots (12)$$

$$(r- H\cdot\tan\theta)/(r- (H/\cos\theta)) < 1.5 \ldots (13)$$

$$1.5 \leq (r- H\cdot\tan\theta)/(r- (H/\cos\theta)) < 5.0 \ldots (14)$$

$$Rd > Rp \ldots (15)$$

$$(1- \sin\theta)/\cos\theta \leq 0.85 \ldots (16)$$

$$(r- H\cdot\tan\theta)/(r- (H/\cos\theta)) < 1.4 \ldots (17)$$

$$1.4 \leq (r- H\cdot\tan\theta)/(r- (H/\cos\theta)) < 2.00 \ldots (18)$$

7. The method for manufacturing a press formed component according to claim 5 or 6, wherein a metal sheet used as a material to be press formed is a steel sheet having a tensile strength of from 440 MPa to 1800 MPa.

FIG. 1

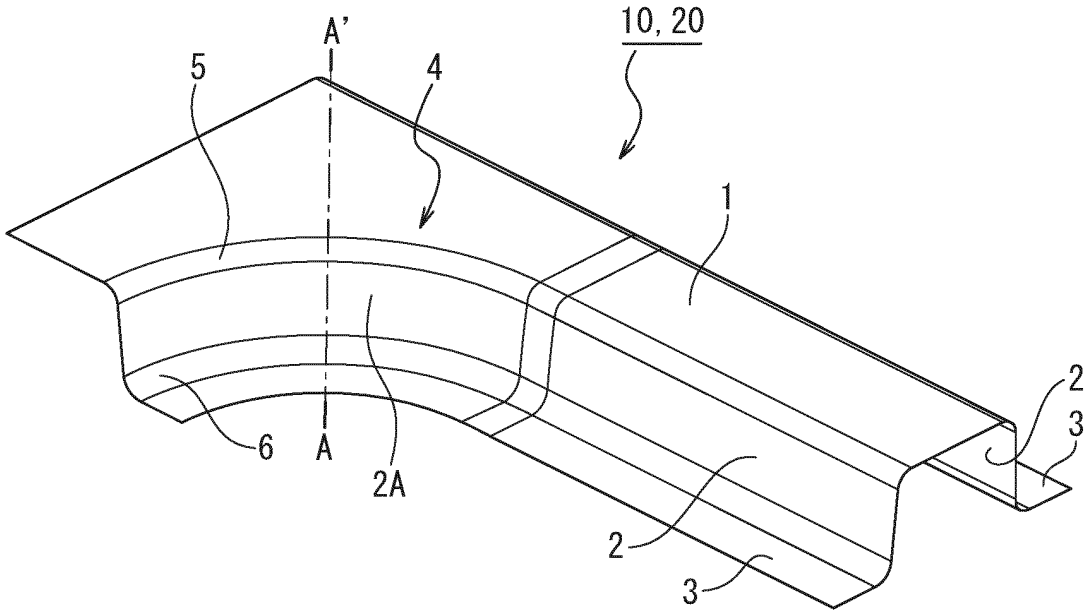


FIG. 2

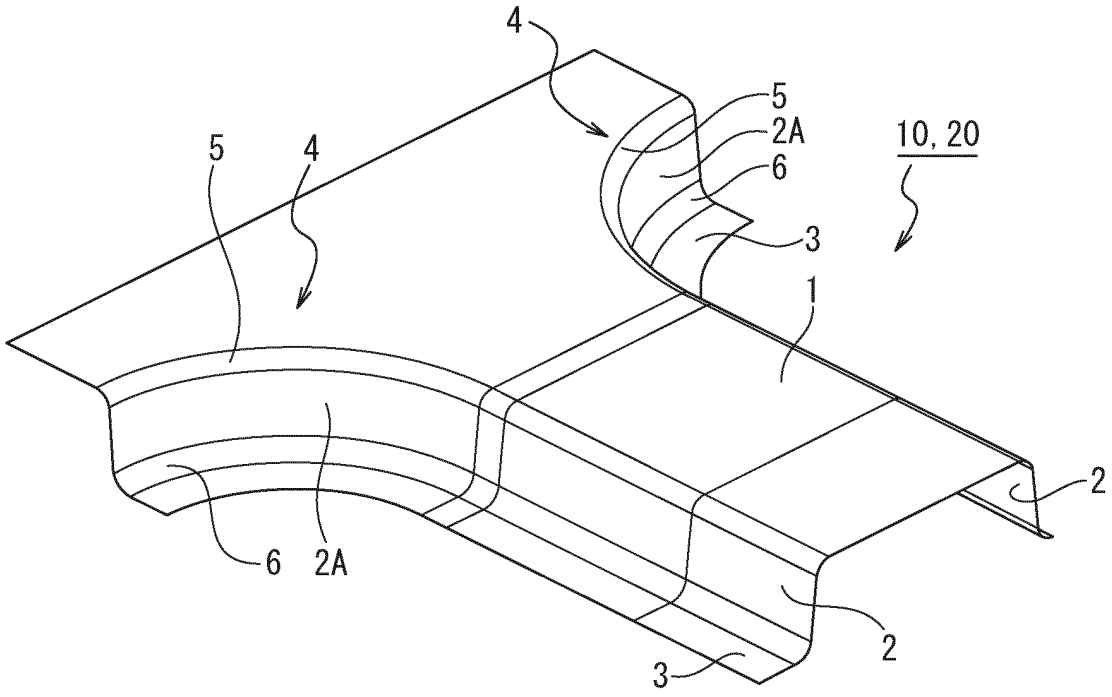


FIG. 3

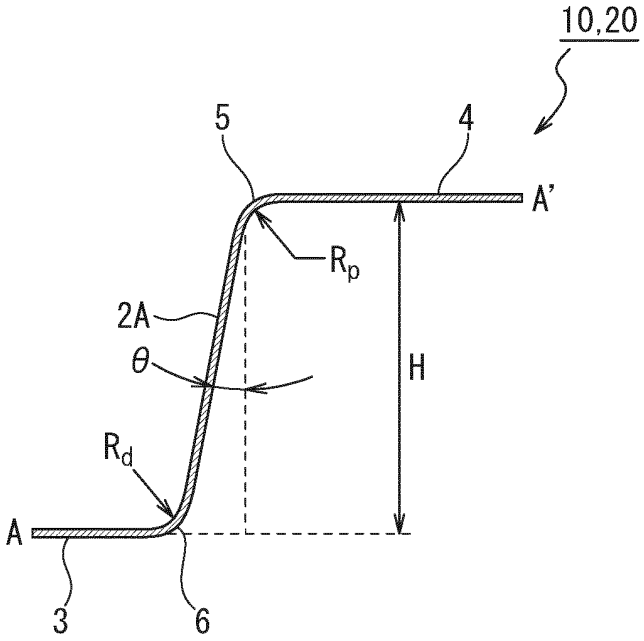


FIG. 4

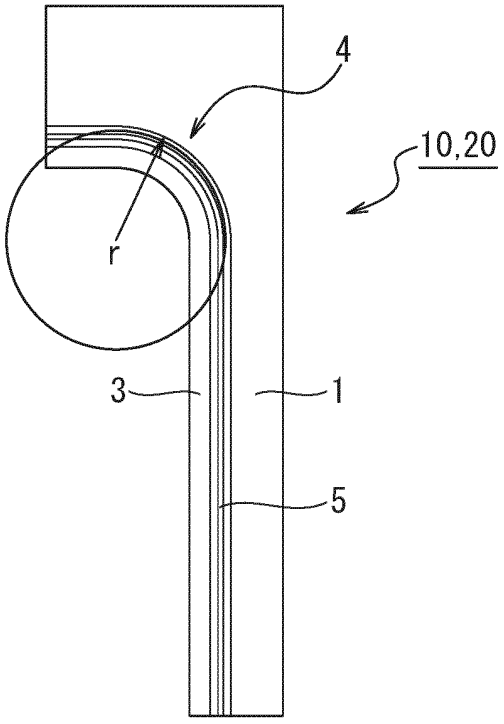


FIG. 5

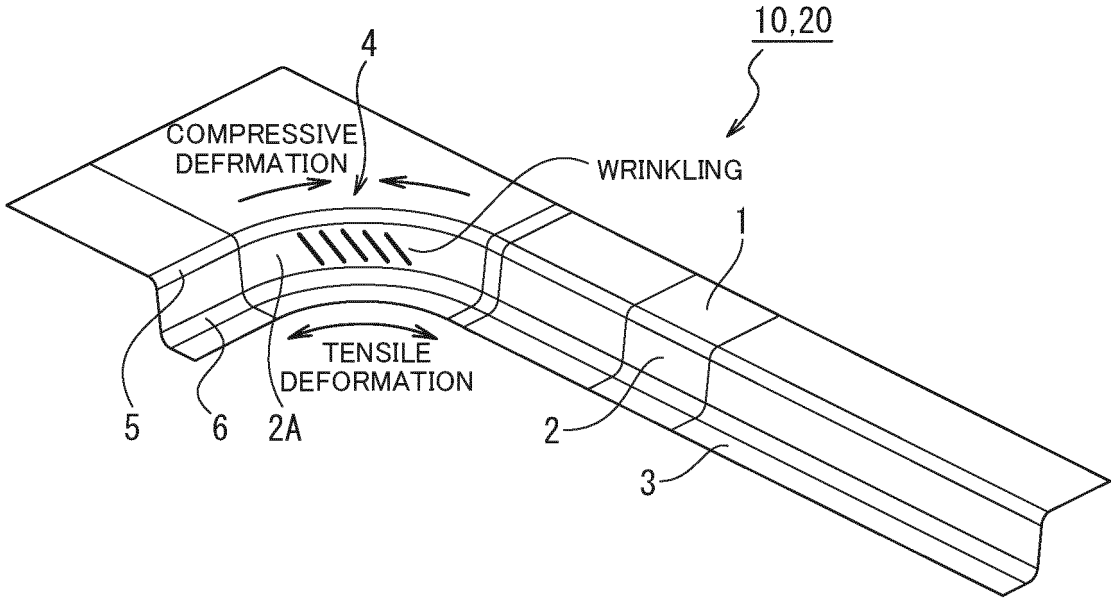

10,20
4
COMPRESSIVE
DEFRMATION
WRINKLING
1
TENSILE
DEFORMATION
5
6
2A
2
3

FIG. 6

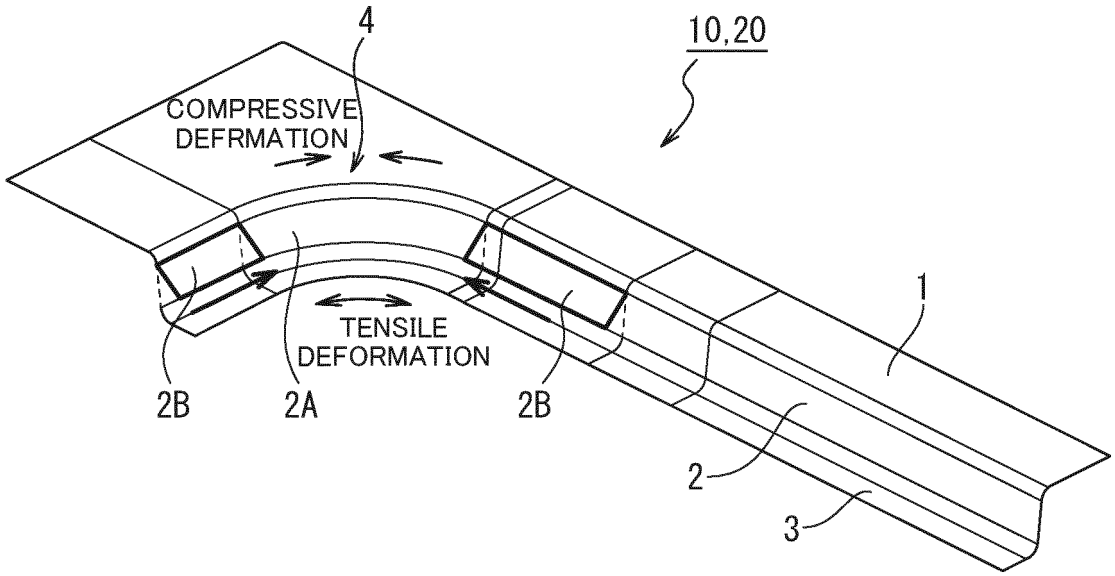

4
10,20
COMPRESSIVE
DEFRMATION
1
TENSILE
DEFORMATION
2B
2A
2B
2
3

FIG. 7

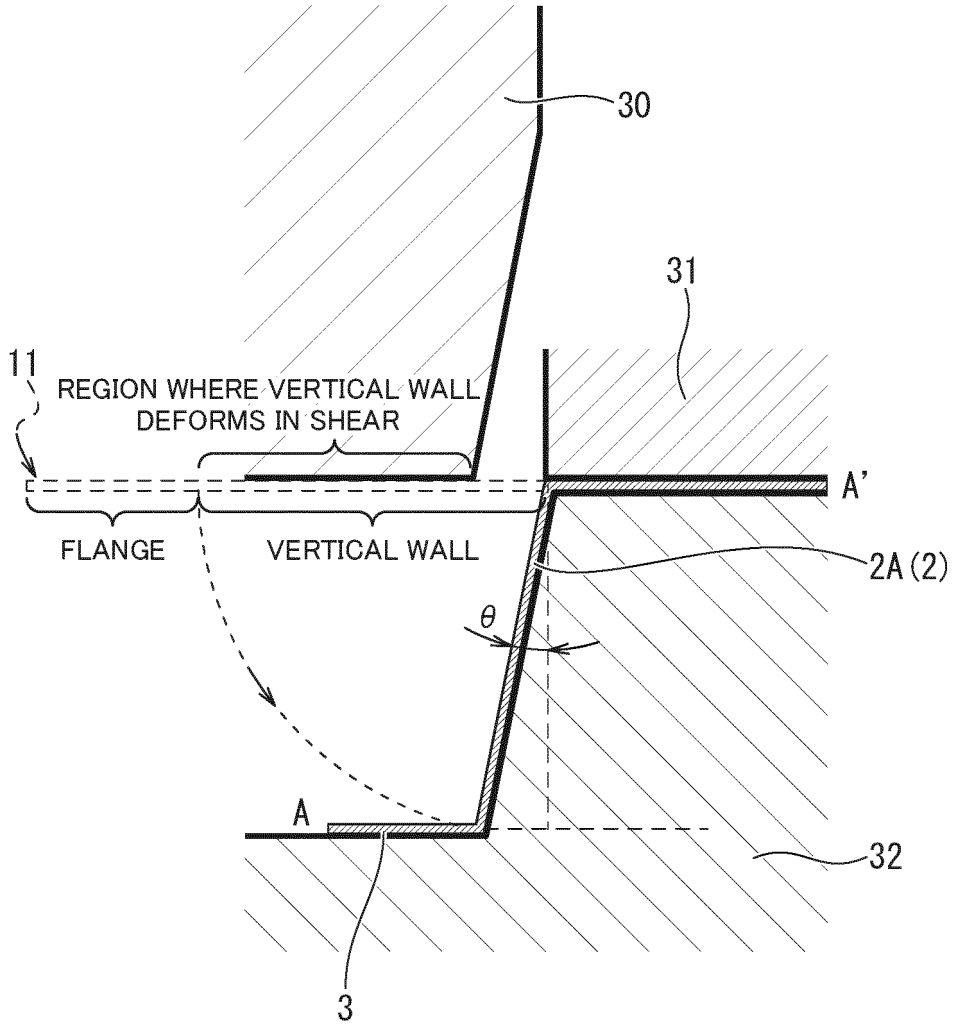

30
31
11
REGION WHERE VERTICAL WALL
DEFORMS IN SHEAR
A'
FLANGE
VERTICAL WALL
2A (2)
θ
A
32
3

FIG. 8A

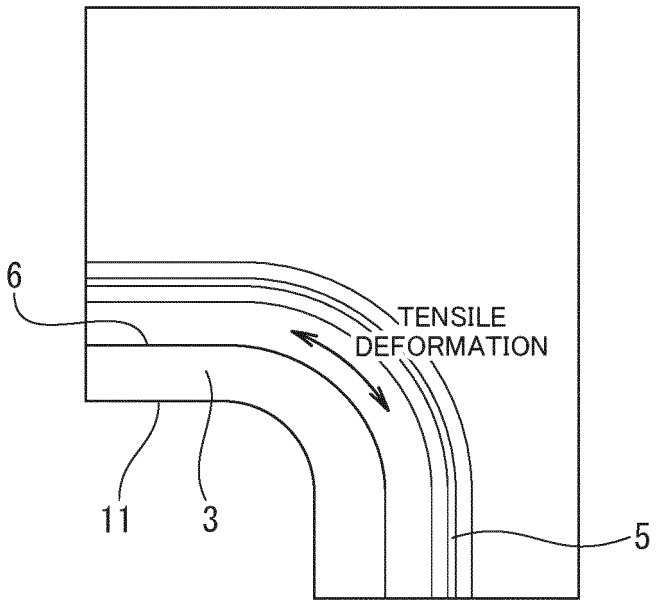

6
TENSILE
DEFORMATION
11
3
5

FIG. 8B

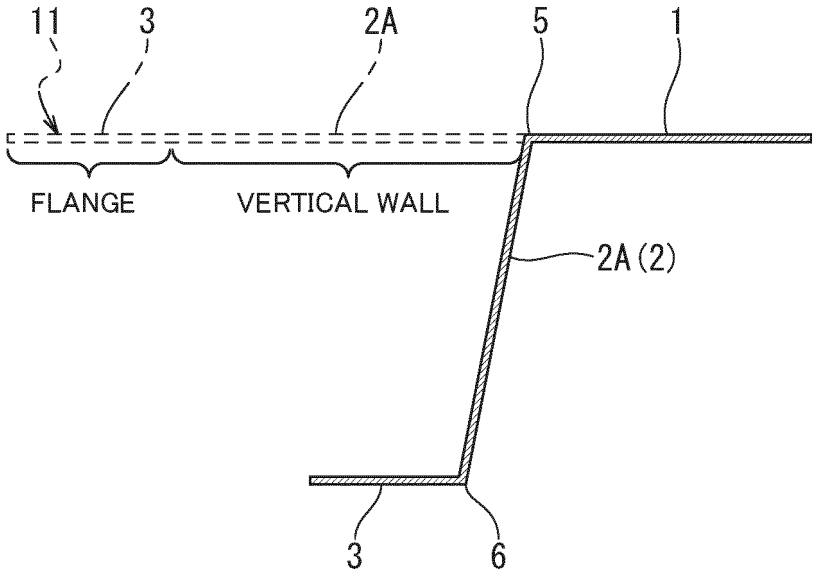

11
3
2A
5
1
FLANGE
VERTICAL WALL
2A (2)
3
6

FIG. 9A

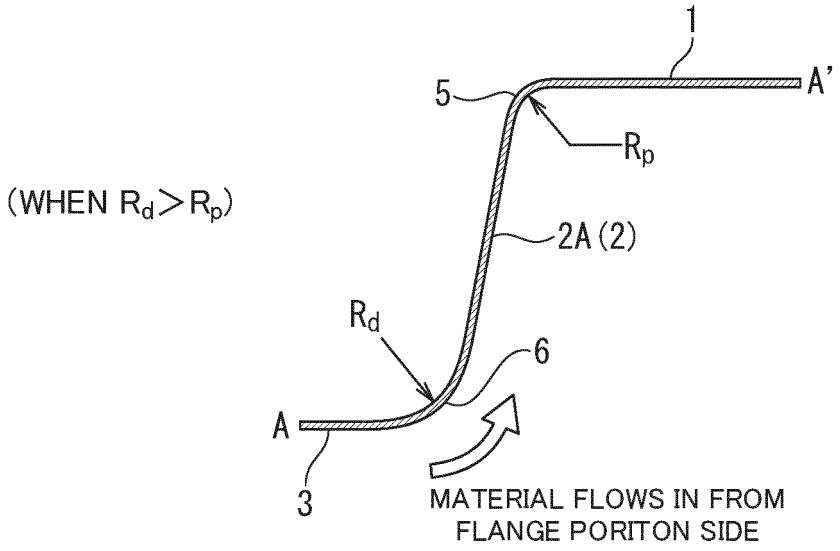

(WHEN $R_d > R_p$)
1
A'
5
R_p
2A (2)
R_d
6
A
3
MATERIAL FLOWS IN FROM FLANGE PORITON SIDE

FIG. 9B

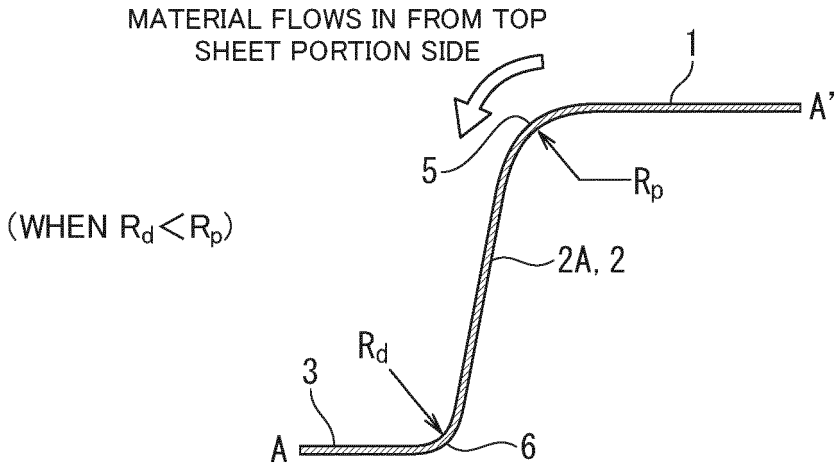

MATERIAL FLOWS IN FROM TOP SHEET PORTION SIDE
(WHEN $R_d < R_p$)
1
A'
5
R_p
2A, 2
R_d
3
A
6

FIG. 10A

(WHEN $R_d > R_p$)

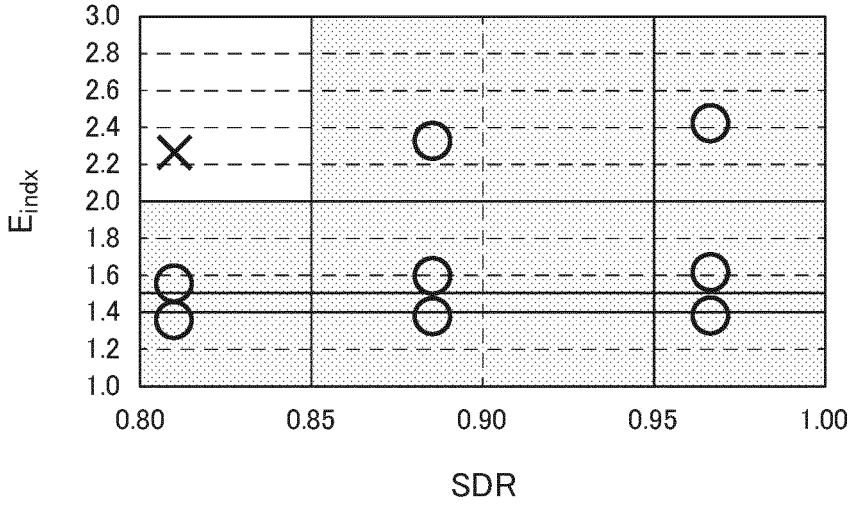


FIG. 10B

(WHEN $R_d < R_p$)

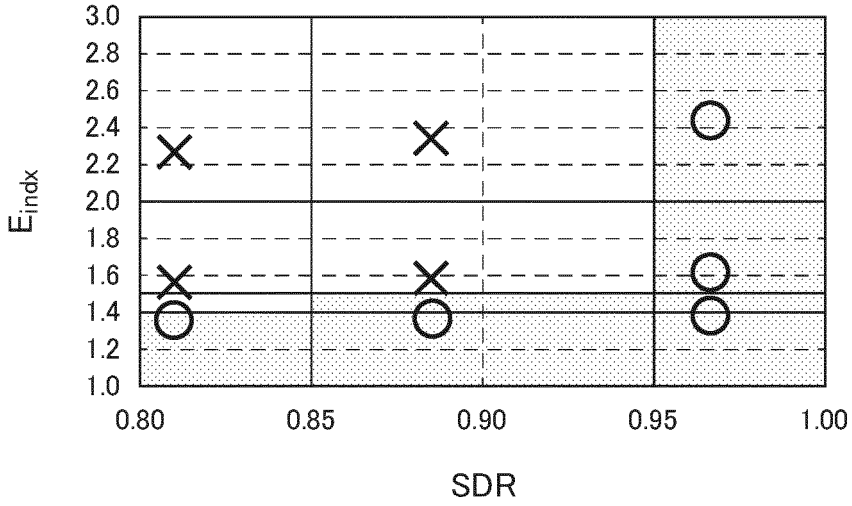


FIG. 11

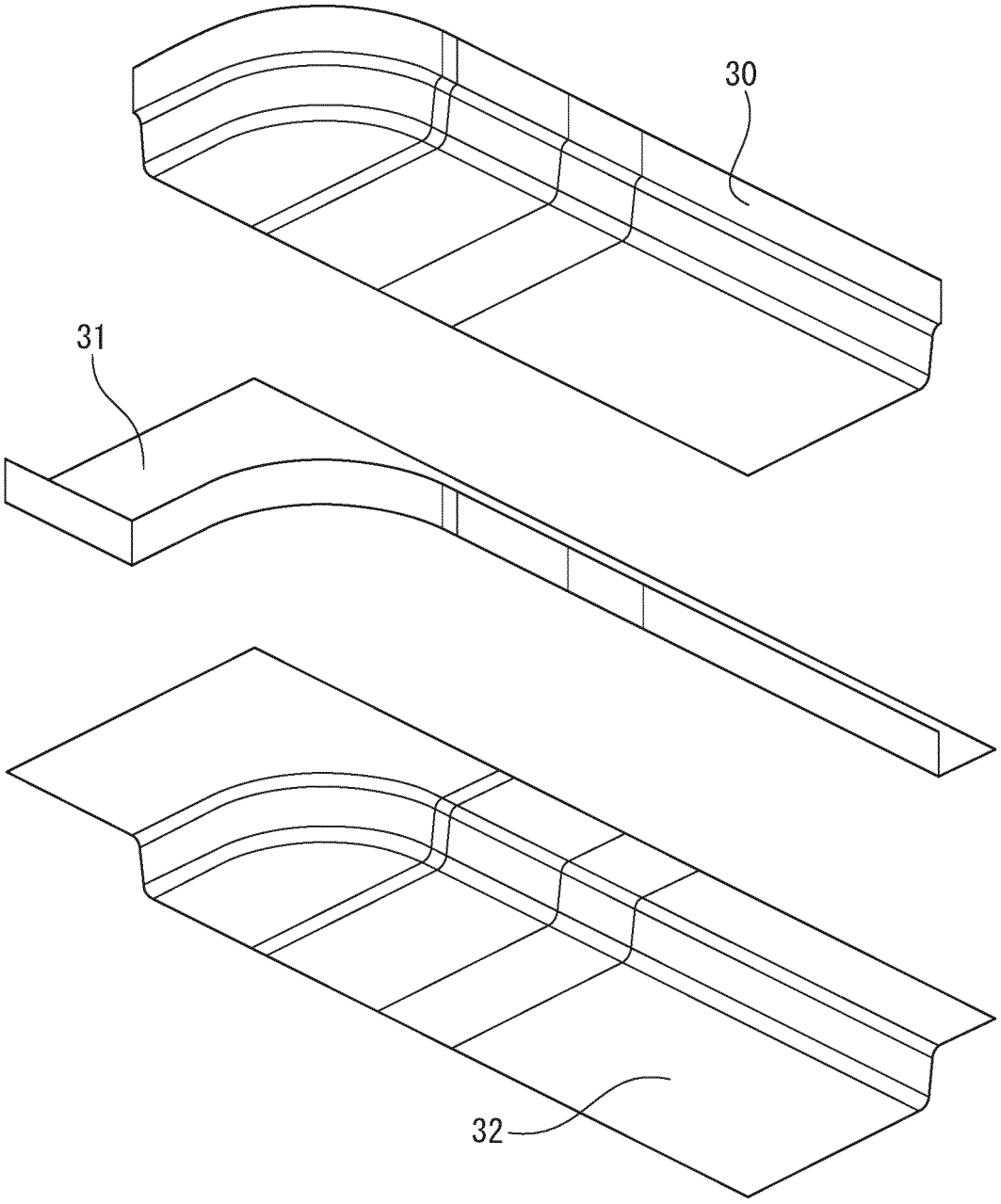


FIG. 12

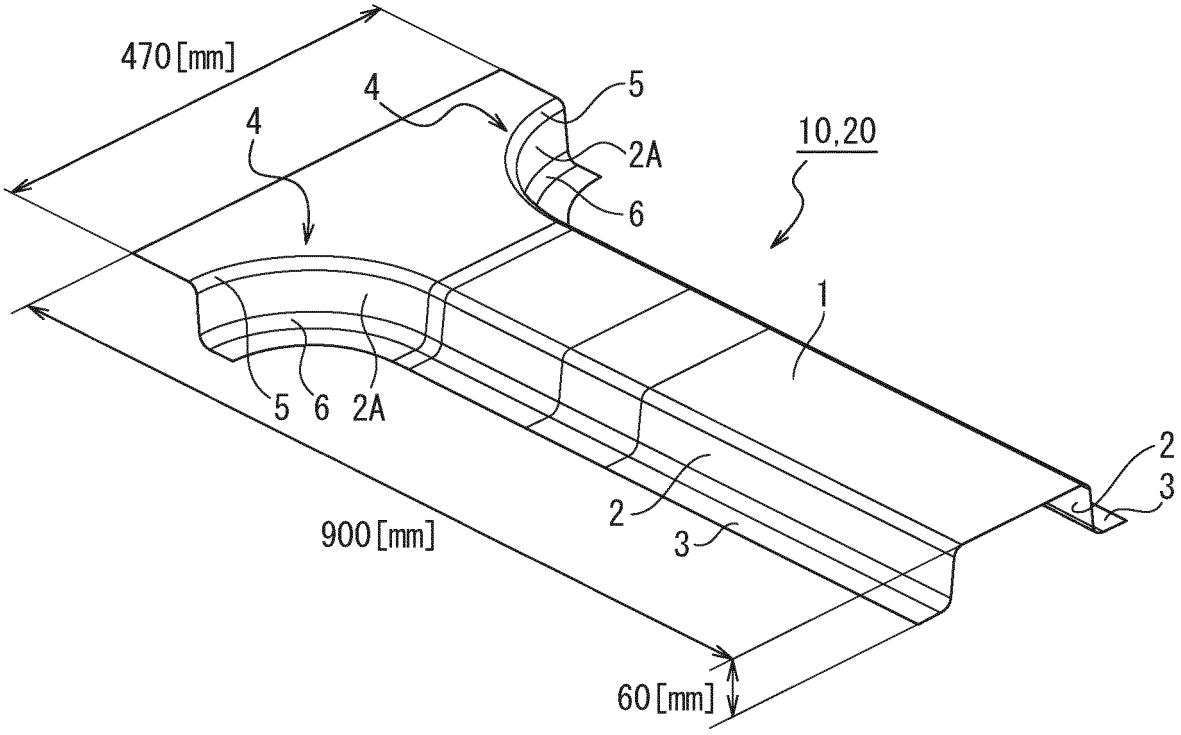
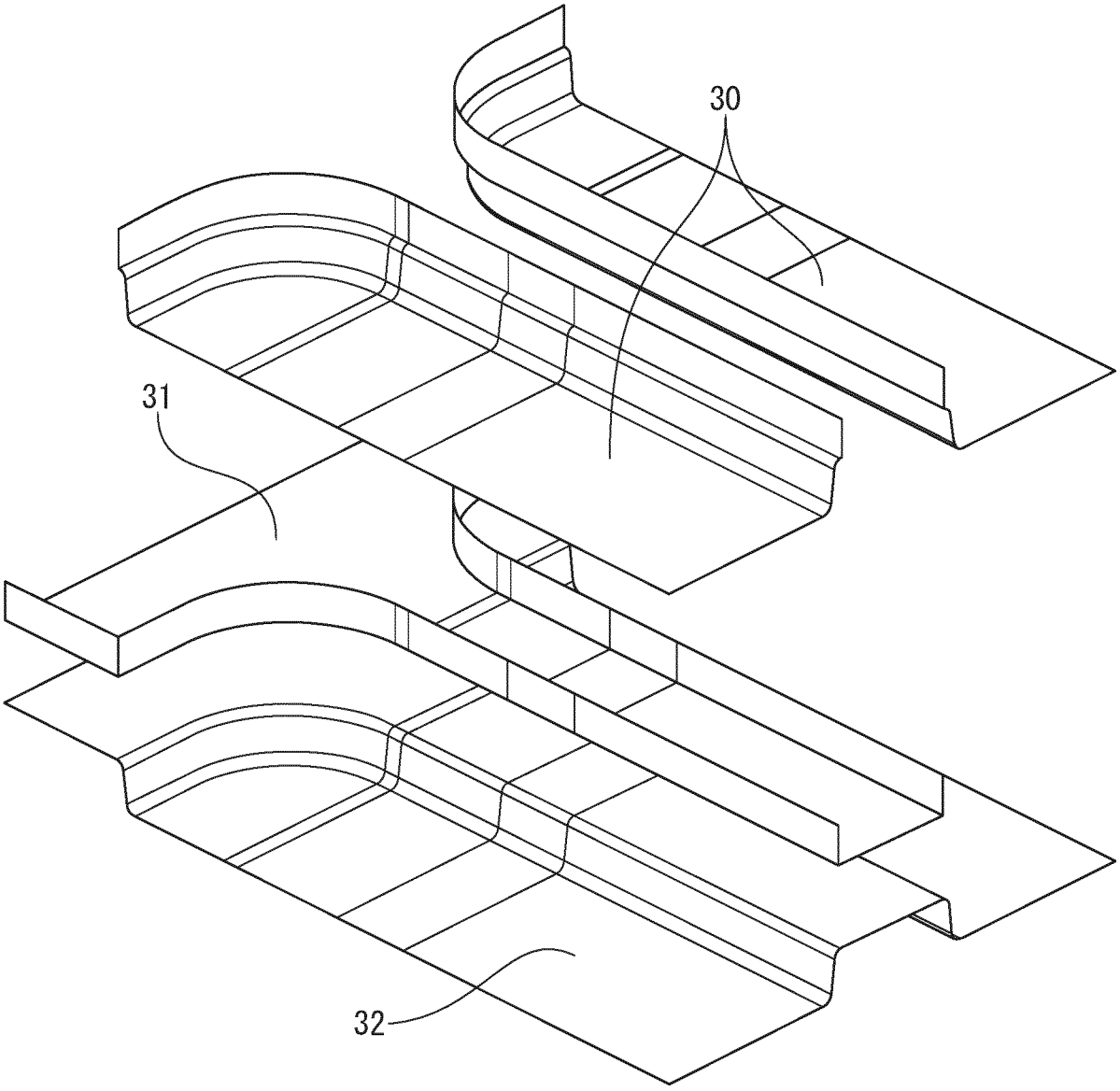


FIG. 13



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2019/025968

A. CLASSIFICATION OF SUBJECT MATTER
Int. Cl. B21D22/26(2006.01)i, B21D22/20(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. B21D22/26, B21D22/20

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 1971-2019
Registered utility model specifications of Japan 1996-2019
Published registered utility model applications of Japan 1994-2019

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 2018-164919 A (JFE STEEL CORP.) 25 October 2018, paragraphs [0015]-[0034], fig. 2 & WO 2018/180712 A1	1, 4-5 2-3, 6-7
A	JP 2016-131984 A (JFE STEEL CORP.) 25 July 2016, entire text, all drawings (Family: none)	1-7
A	WO 2016/157976 A1 (JFE STEEL CORP.) 06 October 2016, entire text, all drawings & US 2018/0085811 A1 & EP 3278897 A1 & KR 10-2017-0120156 A & CN 107405668 A & MX 2017012499 A	1-7

☒ 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
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"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
"T" 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	Date of mailing of the international search report
12.09.2019	24.09.2019
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)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2019/025968

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 5796560 B2 (NIPPON STEEL & SUMITOMO METAL CORP.) 21 October 2015, entire text, all drawings & US 2012/0297853 A1 & WO 2011/145679 A1 & EP 2572811 A1 & AU 2011255898 A1 & TW 201206585 A & CA 2788845 A1 & CN 102791396 A & MX 2012009036 A & KR 10-2012-0140236 A & RU 2012133251 A & ZA 201205651 B & AR 86415 A1	1-7
A	JP 9-66320 A (FURUKAWA ELECTRIC CO., LTD, KAWASAKI STEEL CO., TOYOTA MOTOR CORP.) 11 March 1997, entire text, all drawings (Family: none)	1-7

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

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 5796560 B **[0009]**
- JP H0966320 A **[0009]**
- JP 2018205495 A **[0070]**