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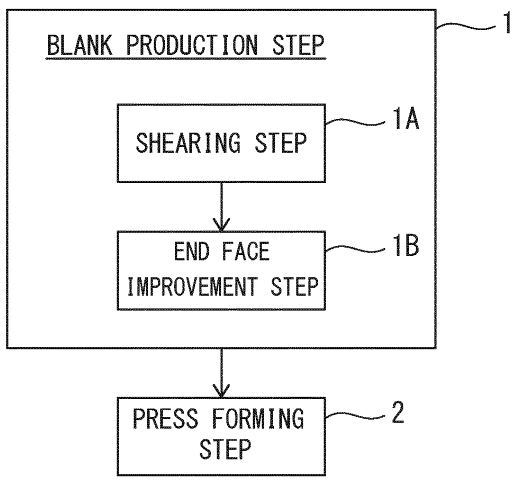
(54) **METHOD FOR IMPROVING DELAYED FRACTURE CHARACTERISTICS OF STEEL SHEET, METHOD FOR PRODUCING BLANK, METHOD FOR PRODUCING PRESS-FORMED ARTICLE, AND PRESS-FORMED ARTICLE**

(57) Provided is a method for improving the delayed fracture characteristics of a metal sheet made of a high-strength steel sheet to suppress delayed fracture from a sheared end face after forming by a simple method. A method for improving delayed fracture characteristics of a metal sheet (10), the metal sheet (10) having a sheared end face (10A) on at least a part of a sheet end portion and being made of a high-strength steel sheet. Plastic deformation is imparted to at least a part of the sheared end face (10A) of the metal sheet (10).

FIG. 1



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Description

Technical Field

[0001] The present invention relates to a technology for improving the delayed fracture characteristics of a metal sheet as a blank, which is used when a formed article is produced by press forming. In particular, the present invention is a technology for improving the delayed fracture characteristics on a sheared end face. In addition, the present invention relates to a technology for producing a formed article having favorable delayed fracture characteristics by press-forming a metal sheet made of a high-strength steel sheet.

[0002] Here, in the present specification, an end face of a metal sheet that has been subjected to shearing is referred to as a sheared end face. In addition, in the present specification, a steel sheet having a tensile strength of 1470 MPa or more is referred to as an ultrahigh-strength steel sheet. The present invention is suitable for a high-strength steel sheet having a tensile strength of 980 MPa or more.

Background Art

[0003] At the moment, for automobiles, there is a demand for fuel efficiency improvement by weight reduction and improvement in collision safety. For vehicle bodies, high-strength steel sheets are used for the purpose of achieving both weight reduction and passenger protection in the event of a collision. Particularly, in recent years, ultrahigh-strength steel sheets having a tensile strength of 1470 MPa or more have been applied to vehicle bodies. One problem at the time of applying high-strength steel sheets, particularly, ultrahigh-strength steel sheets, to vehicle bodies is delayed fracture. In addition, for high-strength steel sheets having a tensile strength of 980 MPa or more, measures against delayed fracture and stretch flange cracking that occur from sheared end faces, which are end faces after shearing, are an important task.

[0004] Here, it is known that large tensile stress remains on sheared end faces. In addition, in pressed components for which a metal sheet having a sheared end face is used, there is a concern of the occurrence of delayed fracture on the sheared end face. This concern becomes significant particularly in ultrahigh-strength steel sheets. Therefore, in order to suppress the fracture on this sheared end face, there is a need to reduce tensile residual stress on the sheared end face.

[0005] Here, as a simple method for reducing the tensile residual stress on the sheared end face, there is, for example, a method in which shearing is performed using a stepped upper blade at the time of drilling (NPL 1). In addition, as another method, there is a method in which a shearing step is performed twice and the cutting allowance of the second shearing is reduced (NPL 2). However, in such methods for shearing, as the material strength becomes higher as in ultrahigh-strength steel sheets, the wear of shearing blades or the management of shearing conditions become more problematic. That is, these methods have a practical difficulty.

[0006] In addition, there is a method described in PTL 1 as a method for reducing tensile residual stress on sheared end faces by plastic processing after shearing. In this method, sheared scrap is pushed up with an opposing punch with respect to a blanking punch and the sheared end face is spread out. However, in such a plastic processing method, a special facility configuration such as an opposing punch is required, and the lead time of a shearing step also increases. Therefore, this method is not always an easy method to apply.

[0007] In addition, in the related art, there is a concern of delayed fracture that occurs from sheared end faces of sheets in formed articles for which a high-strength steel sheet, particularly an ultrahigh-strength steel sheet, is used.

Citation List

Non Patent Literature

[0008]

NPL 1: Yuzo Takahashi et al.: Improvement in Stretch Flange Ability of High-Tensile-Strength Steel Sheets by Piercing under Tension Using Humped Bottom Punch, Journal of the Japan Society for Technology of Plasticity, 54-627 (2013), 343-347

NPL 2: Takeo Nakagawa, Kiyota Yoshida: Scraping method - A new method for recovery of stretchablity of sheared edge -, Journal of the Japan Society for Technology of Plasticity, 10-104 (1969), 665-671

Patent Literature

[0009] PTL 1: JP 6562070 B

Summary of Invention

Technical Problem

[0010] The present invention has been made with attention paid to the above-described points, and an object of the present invention is to suppress delayed fracture from a sheared end face after forming by a simple method. In order for that, an object of the present invention is to make it possible to provide a formed article having favorable delayed fracture characteristics by improving the delayed fracture characteristics of a metal sheet made of a high-strength steel sheet.

Solution to Problem

[0011] The present disclosure is a technology for improving the delayed fracture characteristics of a metal sheet by plastic processing after shearing, which is easy to apply, even when the metal sheet is made of a high-strength steel sheet such as an ultrahigh-strength steel sheet.

[0012] That is, in order to solve the problem, the point of one aspect of the present invention is a method for improving the delayed fracture characteristics of a metal sheet having a sheared end face on at least a part of a sheet end portion and being made of a high-strength steel sheet, in which plastic deformation is imparted to at least a part of the sheared end face of the metal sheet.

[0013] The plastic deformation needs to be imparted to at least the sheared end face, for example, an end portion including the sheared end face.

[0014] In addition, the plastic deformation does not necessarily need to be imparted to all of the sheared end face. In the present disclosure, the plastic deformation needs to be imparted to, for example, in a sheared end face, a place where at least a predetermined degree or more of delayed fracture is assumed to occur.

Advantageous Effects of Invention

[0015] According to the aspect of the present invention, the wear of blades or the management of shearing conditions is not necessarily required even for high-strength steel sheets. In addition, according to the aspect of the present invention, it is possible to reduce tensile residual stress on a sheared end face of a steel sheet, which is generated during shearing, by a simple method. As a result, according to the aspect of the present invention, it is possible to improve the delayed fracture characteristics when high-strength steel sheets are applied to various components such as panel components, structure/frame components, and the like of automobiles.

Brief Description of Drawings

[0016]

FIG. 1 is a view illustrating an example of a production process of a formed article according to an embodiment based on the present invention.

FIGS. 2A and 2B are schematic views of a sheared end face. FIG. 2A is a cross-sectional view. FIG. 2B is a plan view seen from an end face direction.

FIG. 3 is a view illustrating an example of a stress distribution in an end portion having the sheared end face.

FIGS. 4A to 4C are views illustrating a relaxation mechanism of stress in the vicinity of the sheared end face by processing.

FIG. 5 is a view illustrating bending and unbending by press forming.

FIG. 6 is a view illustrating bending and unbending by leveling using a leveler.

FIG. 7 is a view illustrating an angle θ (bending angle) formed by a contour line (extending direction of the end face) of the sheared end face and a bending direction of bending and unbending.

FIGS. 8A and 8B are views illustrating an example of residual stress that is generated inside and outside a bend after final bending in the bending and unbending. FIG. 8A is a view illustrating a state after bending. FIG. 8B is a view illustrating a state where a metal sheet is released from a die (springback occurred).

Description of Embodiments

[0017] Next, an aspect of the present invention will be described with reference to drawings.

(Configuration)

[0018] As illustrated in FIG. 1, a method for producing a formed article of the present embodiment includes a blank production step 1 and a press forming step 2.
[0019] The present invention is suitable for a case where a target metal sheet is a high-strength steel sheet, particularly, a high-strength steel sheet having a tensile strength of 980 MPa or more.

(Blank production step 1)

[0020] The blank production step 1 is a step for producing a blank (metal sheet) that is used in the press forming step 2 in which the blank is press-formed in the shape of the formed article. The blank production step 1 includes a shearing step 1A and an end face improvement step 1B.

<Shearing step 1A>

[0021] The shearing step 1A is a step for cutting a metal sheet into a blank shape suitable for producing a formed article.

<End face improvement step 1B>

[0022] The end face improvement step 1B is a step of imparting plastic deformation to at least a part of an end face of the sheared end face in the metal sheet after the shearing step 1A. The plastic deformation is deformation into which distortion is input along the extending direction of the end face.
[0023] At this time, the plastic deformation may be imparted, for example, only to a region including a place in the end face in which preset residual stress is assumed to be generated due to shearing by structural analysis such as CAE.
[0024] In addition, the above-described plastic deformation imparts plastic strain greater than 0 in a direction along the extending direction of the end face. The upper limit of the plastic strain to be imparted is not specified, but the plastic deformation is imparted to an extent that cracking does not occur.
[0025] The plastic deformation is preferably imparted by bending and unbending.
[0026] At this time, it is preferable to set the bending angle at each end face position to which the plastic deformation is imparted to be less than 90 degrees at the time of each bending and unbending. "The bending angle being less than 90 degrees" will be described with reference to FIG. 7. This bending angle indicates an angle formed by a straight line (tangential direction) along the extending direction of the sheared end face and the bending direction of each bending and unbending at the place in the sheared end face to which the plastic deformation is imparted. Here, the premise is that the bending is bending by which plastic strain greater than 0 is imparted in the direction along the extending direction of the end face.
[0027] The bending and unbending is performed by, for example, bending by press forming (refer to FIG. 5). In addition, the bending and unbending is performed by, for example, leveling using a leveler having a plurality of rolls arranged in the conveying direction of the sheet (refer to FIG. 6). The leveling is a processing method that is used at the time of flattening sheets.
[0028] In the bending and unbending, bending and bending by unbending (reverse bending) is executed a plurality of times on the same sheared end face in a sheet thickness direction. At that time, it is preferable to set a final bend such that the outside of the bend is on the burr side of the sheared end face. The burr side is a side where burrs are formed by shearing in the sheet thickness direction.
[0029] Here, the bending and unbending needs to be performed such that the plastic deformation is imparted to the end portion including the target sheared end face (for example, a range including a 1 mm range from the end face) .
[0030] In addition, it is preferable to set the plastic deformation to be imparted such that the sheet end portion to which the plastic deformation has been imparted in the end face improvement step 1B becomes flat.

(Press forming step 2)

[0031] The press forming step 2 is a step of press-forming the blank made of the metal sheet produced in the blank production step 1 into a target component shape. The press forming is executed by one pressing or multi-stage pressing.

(Press-formed article)

[0032] In a press-formed article (product) produced by the producing method of the present embodiment, plastic strain greater than 0 in the direction along the extending direction of the end face is imparted to at least a part of the sheared end face.

[0033] This turns a press-formed article of the present embodiment into a press-formed article having improved delayed fracture characteristics.

(Modification example)

[0034] The above embodiment is an example where the present disclosure is applied to the production of a blank before a step of pressing a metal sheet into a target product shape. That is, the above embodiment exemplified a case where the method for improving the delayed fracture characteristics of a metal sheet of the present disclosure (end face improvement step 1B) is applied as a pretreatment of pressing.

[0035] The end face improvement step 1B of the present disclosure may be applied in the middle of pressing for forming a target product shape or after the pressing. Specifically, the end face improvement step 1B of the present disclosure may be applied to a sheared end face generated by the shearing of an end portion for shaping a sheet outer circumference.

[0036] For example, in a case where a sheet end portion has been sheared to shape a component shape after being formed into a target product shape, the treatment of the above-described end face improvement step 1B may be applied to the sheared end face.

[0037] However, the plastic deformation in the end face improvement step 1B is different from press forming for forming a sheet into a target product shape. When the influence on press forming for forming into a product shape is taken into account, it is preferable to execute the press forming as described below. That is, it is preferable to execute a treatment for imparting the plastic deformation in the end face improvement step 1B only to an end portion having a sheared end face (for example, only to a flange portion).

(Effect)

[0038] In the present embodiment, plastic deformation is imparted to a sheared end face by plastic processing. Preferably, the plastic processing of the present disclosure is performed by bending and unbending. This makes it possible to reduce residual stress in a sheared end face by a simple method even when the metal sheet (blank) is a high-strength steel sheet such as an ultrahigh-strength steel sheet. Furthermore, in the present embodiment, it is possible to obtain the above-described effect while maintaining the shape of the sheet in the same flat state as that after shearing.

[0039] In addition, the reduction of residual stress in the sheared end face suppresses the occurrence of delayed fracture. That is, the delayed fracture characteristics on the sheared end face of the metal sheet are improved.

[0040] Here, when each bending angle at the place of each sheared end face in the bending and unbending is set to less than 90 degrees, it becomes possible to introduce sufficient plastic deformation into the sheared end face.

[0041] When the bending and unbending is performed by bending deformation by press forming or leveling for flattening the sheet, it is possible to easily impart plastic deformation to the end face of the sheet.

[0042] At this time, it is desirable that the outside of a bend formed by the final bending is on the burr side of the sheared end face. Here, the burr side in the sheet thickness direction is a portion where delayed fracture is likely to occur due to the influence of burrs or rough surface texture. In this case, it becomes possible to further suppress delayed fracture occurring from the burrs as a starting point.

(Regarding action (mechanism) and others)

<Regarding relaxation of stress caused by plastic deformation>

[0043] Hereinafter, relaxation of stress caused by the plastic deformation of the sheared end face, which is generated by the application of the present disclosure, will be described.

[0044] FIGS. 2A and 2B are views illustrating a state of a sheet end portion in a case where the end portion of a sheet is cut by moving a shearing blade from the upper side toward the lower side. In the case of FIGS. 2A and 2B, the burr side is on the lower side.

[0045] In this case, residual stress in a direction along the extending direction of the sheared end face 10A becomes as illustrated in FIG. 3 in a sheared end face 10A and the end portion including the sheared end face 10A. At this time, the direction along the extending direction of the sheared end face 10A is a sheet width direction (refer to FIG. 2B). FIG. 3 illustrates an example of a stress distribution in a direction away from the sheared end face 10A (a direction orthogonal to the end face 10A) as indicated by an arrow in FIG. 2A.

[0046] As is clear from FIG. 3, there are first to third regions ARA1, ARA2, and ARA3 from the sheared end face 10A toward the inside. The first region ARA1 is a region where strong tensile residual stress is present on the surface of the sheared end face. The second region ARA2 is a region where compressive residual stress is present to counterbalance the tensile residual stress. The third region ARA3 is a region inside the second region ARA2 where there is no residual stress.

[0047] Plastic deformation attributed to uniform tensile strain caused by bending generating the burr side on the bend outside or tensile processing is introduced mainly into the first and second regions ARA1 and ARA2 among these three regions ARA1 to ARA3. After that, when uniform springback of the sheet into which the plastic deformation has been introduced is performed, the stress distribution changes from FIG. 4A to FIG. 4C. That is, in the first region ARA1, the initial tensile residual stress is relaxed by the stress-strain history. In addition, the difference between stress in the first region ARA1 on the front surface side and stress in the second region ARA2 inside the first region ARA1 reduces. This is also true even in a case where plastic strain that is introduced by shearing is compressive strain.

[0048] From the above-described fact, it is found that, if sufficient tensile or compressive plastic strain can be introduced into the sheared end face 10A, it is possible to relax residual stress on the surface of the sheared end face 10A.

[0049] Particularly, when bending and unbending is adopted as a method for introducing plastic strain, it is possible to relax stress while maintaining various sheet shapes in the same flat state as that after shearing.

[0050] Here, the sheared end face 10A, which is intended to be dealt with in the present disclosure, is, for example, a sheared end face of a metal sheet 10 having an arbitrary shape fabricated by shearing. In addition, in the present disclosure, what is intended as the sheared end face 10A is an end face 10A of a drilled portion or an end face 10A configuring the contour line that specifies the outer form of a blank.

[0051] Here, FIG. 3 is a case where a specimen piece made of a high-strength steel sheet having a tensile strength of 980 MPa is used. In this case, a depth d from the end face 10A to the boundary between the second region ARA2 and the third region ARA3 is 1 mm. Therefore, the region to which plastic deformation is imparted needs to be a region within a depth d = 1 mm or less from the surface of the end face 10A fabricated by shearing in which strain and stress caused by shearing are present. That is, bending and unbending needs to be performed such that shear deformation is imparted to at least an end portion in a region of 1 mm from the sheared end face 10A. The depth d of the first region ARA1 is, for example, 100 um.

<Regarding method for imparting plastic deformation>

[0052] Here, a case where plastic strain is introduced by uniaxial tension or uniaxial compression is considered.

[0053] In this case, the thickness of a sheet changes due to the introduction of the plastic strain. Furthermore, in a blank having a complicated shape, since strain concentrates in a portion having a narrow width in a direction perpendicular to the tensile axis, it is not possible to uniformly deform the blank. In addition, in a case where plastic strain is introduced by simple bend forming, a blank bends significantly as a whole after the forming. Therefore, it is impossible for the metal sheet 10 to maintain the same flat state as that after shearing.

[0054] From such a fact, it is found that the plastic deformation is preferably imparted by bending and unbending. In a case where the contour shape of the end face 10A in the extending direction is a curved shape that changes in a direction orthogonal to the end face 10A, the plastic deformation needs to be imparted as described below. That is, bending and unbending needs to be performed such that a depth of 1 mm or less from the surface of the end face 10A can be secured in the end portion of the sheared end face 10A at the most recessed place.

[0055] One simple bending may be adopted, but bending and unbending is adopted in consideration of the shape returning to the original flat shape or the like.

[0056] The bending and unbending is performed by bending by press forming as illustrated in FIG. 5 or by leveling as illustrated in FIG. 6. In this case, bending and unbending deformation is caused on the surface of the sheared end face 10A, residual stress on the sheared end face 10A is relaxed, and delayed fracture is suppressed.

[0057] A die 20 and a punch 21 for bending and a die 22 and a punch 23 for reverse bending that are used to perform unbending, which are illustrated in FIG. 5, may be in the same die, or different dies may be used.

[0058] In addition, each diameter of a roll 30 for a leveler may not be the same as each other.

[0059] Here, the bending and unbending can also be performed by bend deforming by press forming. However, there is a need to add at least two steps of pressing and a forming die between a blanking step and a subsequent forming step.

[0060] On the other hand, when the bending and unbending is performed by leveling, it is possible to relatively easily perform the bending and unbending using only a leveler between the blanking step by shearing and the subsequent forming step. However, in the present disclosure, it is necessary to use a strong leveler enough to introduce plastic strain even into a steel sheet having a tensile strength of 980 MPa class or more.

<Regarding bending angle θ>

[0061] In order to improve delayed fracture characteristics by relaxing residual stress in the sheared end face 10A, bending and unbending deformation large enough to introduce plastic deformation is preferable. In order to obtain the effect, the tensile or compressive plastic strain with respect to the sheared end face 10A needs to be 0.003 or more. Preferably, when the plastic strain is 0.005 or more, it is possible to significantly relax residual stress in the sheared end face 10A.

[0062] As long as sufficient plastic strain is introduced even once by this processing step by which plastic strain is introduced, residual stress is relaxed regardless of whether the bending and unbending deformation is any of bending deformation and unbending deformation.

[0063] Here, a bending angle θ that is formed by the contour line of the sheared end face 10A (the extending direction of the end face 10A) and a bending direction of the bending and unbending as illustrated in FIG. 7 is set in a range of, for example, 0 degrees or more and 75 degrees or less. It is desirable that the bending angle θ is preferably in a range of 0 degrees or more and 45 degrees or less. This is because, in a case where the angle θ between the bending direction and the contour line of the sheared end face 10A is close to 90 degrees, it becomes difficult to introduce strain into the surface of the sheared end face 10A. The reason therefor is that the surface of the sheared end face 10A is open with respect to the tensile/compressive deformation direction in the direction along the end face 10A by bending.

[0064] The contour line of the sheared end face 10A before bending is illustrated as a straight line in FIG. 7, but the contour line of this end face 10A may be a curved line or a partially discontinuous line.

<Final bending direction>

[0065] Due to final bending, tensile strain is imparted to a tensile portion as illustrated in FIGS. 8A and 8B. FIGS. 8A and 8Bare a case where a final bend is present on the lower side. Therefore, after springback caused by the release of the restraint of the press, compressive residual stress as large as the tensile strain remains. Therefore, it is desirable that the outside (the lower side in FIG. 8) of the bend formed by the final bending is on the burr side of the sheared end face 10A.

[0066] The burr side is a portion where delayed fracture is likely to occur due to the influence of burrs or rough surface texture. When the outside of the bend is made to be the burr side, residual stress on the burr side of the sheared end face 10A is reduced by the compressive residual stress caused by forming.

(Other)

[0067] The present disclosure may also have the following configurations.

(1) A method for improving the delayed fracture characteristics of a metal sheet, the metal sheet having a sheared end face on at least a part of a sheet end portion and being made of a high-strength steel sheet, in which plastic deformation is imparted to at least a part of the sheared end face of the metal sheet.
(2) The plastic deformation imparts plastic strain greater than 0 in a direction along an extending direction of the end face to at least a part of the sheared end face.
(3) The plastic deformation is imparted by bending and unbending.
(4) Each bending angle in the bending and unbending is set to less than 90 degrees.
(5) The bending and unbending is performed by bending by press forming.
(6) The bending and unbending is performed by leveling using a plurality of rolls.
(7) A final bend in the bending and unbending is set such that an outside of the bend is on a burr side of the sheared end face.
(8) The metal sheet is a high-strength steel sheet having a tensile strength of 980 MPa or more.
(9) A method for producing a blank for press forming, including a step of performing shearing on a metal sheet made of a high-strength steel sheet and a step of imparting plastic deformation to a sheared end face by the above-described delayed fracture characteristics improvement method of the present disclosure, which is a step after the step of performing shearing.
(10) A method for producing a press-formed article by press-forming a metal sheet made of a high-strength steel sheet, including a step of performing shearing on the metal sheet made of a high-strength steel sheet and a step of imparting plastic deformation to a sheared end face by the above-described delayed fracture characteristics improvement method of the present disclosure, which is a step after the step of performing shearing.
(11) A press-formed article having a sheared end face on at least a part of a sheet end portion and being obtained by processing a metal sheet made of a high-strength steel sheet, in which plastic strain greater than 0 in a direction along an extending direction of the end face is imparted to at least a part of the sheared end face.

[Examples]

[0068] Next, examples based on the present embodiment will be described.

[0069] Here, examples will be described using a test material A for which a steel sheet having a sheet thickness of 1.4 mm and a tensile strength of 1470 MPa was used. The present disclosure is not limited to the steel sheet having a tensile strength of 1470 MPa. The present disclosure is applicable to metal materials including steel sheets having a tensile strength of 980 MPa or more, in which delayed fracture occurs on a sheared end face.

(Regarding shearing)

[0070] In the present example, first, the test material A was sheared to fabricate a linear sheared end face having a length of 500 mm, which was to be an evaluation object. The clearance during the shearing was set to 12% with respect to the sheet thickness.

(Bending and unbending)

[0071] On the fabricated sheared end face, unbending was performed by press forming as illustrated in FIG. 5 or leveling as illustrated in FIG. 6 such that the maximum plastic strain in each step changed.

[0072] Here, the unbending was executed with a different angle that was formed by the contour line of the sheared end face and the bending direction of bending and unbending, which is defined in FIG. 7, to fabricate each sample after the bending and unbending.

[0073] In the leveling, large strain was imparted with a first roll as is normally performed. At this time, the amount of each roll compressed was adjusted such that strain that was imparted to rolls gradually reduced toward the final roll.

(Evaluation)

[0074] After the fabrication of the sample, residual stress in the sheared end face after cutting was measured with X-rays. Furthermore, each sample was immersed in a bath of hydrochloric acid with a PH of 1 for 96 hours, and the presence or absence of a crack in the sample and the occurrence time of cracking were confirmed. At this time, the occurrence of delayed fracture was determined from the sheet thickness penetration of a surface crack caused by the delayed fracture of the sheared end face. In addition, the measurement with X-rays was performed within a measurement range with a diameter of 500 um. In addition, in the central portion of the sheet thickness, stress at the center of the sheet thickness was measured in a direction parallel to the sheared end face after the shearing.

(Example 1)

[0075] Sample forming conditions and evaluation results in Example 1 are shown in Tables 1 and 2, respectively. In the examples shown in Table 1, the bending and unbending was performed by press forming.

[0076] Table 1 shows results when the angle formed by the contour line of the sheared end face and the bending direction of the bending and unbending was set to 0 degrees in the press forming. Specifically, Table 1 shows the relationship among the maximum amount of plastic strain introduced by the bending and unbending, the presence or absence of the occurrence of delayed fracture, the time taken for the occurrence of delayed fracture, and the residual stress.

[Table 1]

Processing method	Maximum amount of plastic strain introduced	Angle formed by bending direction and sheared end face (°)	Outside of final bend	Time taken for occurrence of delayed fracture/h	Residual stress/MPa
Press forming	0.000	0	Rollover burr side	23	1213
	0.002			58	684
	0.003			80	315
	0.005			(No occurrence)	105
	0.010				23
	0.030				12
	0.050				9

[0077] In addition, in Table 2, the bending and unbending was performed by press forming.

[0078] Table 2 shows results when the angle formed by the contour line of the sheared end face and the bending direction of the bending and unbending was set to 0 degrees in the leveling. Specifically, Table 2 shows the relationship among the maximum amount of plastic strain introduced by the bending and unbending, the presence or absence of the occurrence of delayed fracture, the time taken for the occurrence of delayed fracture, and the residual stress.

[Table 2]

Processing method	Maximum amount of plastic strain introduced	Angle formed by bending direction and sheared end face (°)	Outside of final bend	Time taken for occurrence of delayed fracture/h	Residual stress/M Pa
Leveler	0.000	0	Rollover burr side	23	1205
	0.002			74	691
	0.003			87	308
	0.005			(No occurrence)	95
	0.010				24
	0.030				19
	0.050				7

[0079] Here, in both examples of Table 1 and Table 2, the outside of the final bend in the bending and unbending was made to be on the rollover burr side of the sheared end face.

[0080] As is clear from Table 1 and Table 2, the time taken until the occurrence of delayed fracture was extended by plastic strain of 0.003 or less. Furthermore, delayed fracture did not occur by plastic strain of 0.005 or more. In addition, the time taken for the occurrence of delayed fracture or the presence or absence of the occurrence of delayed fracture was observed to correlate with residual stress.

(Example 2)

[0081] Example 2 is an example where the relationship between the maximum amount of plastic strain introduced by bending and unbending and the presence or absence of the occurrence of delayed fracture and the time taken for the occurrence of delayed fracture in a case where each bending angle of the bending and unbending was changed was examined.

[0082] Table 3 is an example in a case where the bending and unbending was performed by leveling.

[0083] Here, the outside of the final bend in the bending and unbending was made to be on the rollover burr side of the sheared end face. In addition, the maximum amount of plastic strain was set to 0.005.

[Table 3]

Processing method	Maximum amount of plastic strain introduced	Angle formed by bending direction and sheared end face (°)	Outside of final bend	Time taken for occurrence of delayed fracture/h	Residual stress/M Pa
Leveler	0.005	0	Rollover burr side	(No occurrence)	105
		15			138
		30			148
		45			249
		60		87	367
		75		82	318
		80		71	519
		85		54	749
		90		21	1213

[0084] As is clear from Table 3, it was confirmed that the occurrence of delayed fracture was suppressed in a case where the angle formed by the contour line of the sheared end face and the bending direction of the bending and unbending was 0 degrees to 85 degrees compared with the case of 90 degrees. That is, it was confirmed that the occurrence of delayed fracture was suppressed in a case where the bending angle was smaller than 90 degrees compared with the case of 90 degrees. Particularly, in a case where the bending angle formed by the contour line of the sheared end face and the bending direction of the bending and unbending was 0 degrees to 75 degrees, a significant effect was obtained.

[0085] In the examples shown in Table 3, the influence of the angle formed by the contour line of the sheared end face and the bending direction of the bending and unbending in the case of leveling was described.

[0086] However, the present disclosure is not limited thereto. Even by bending and unbending by press forming or even in a case where the amount of plastic strain is different from 0.005, a favorable result can be obtained in the above-described angle range.

(Example 3)

[0087] In Example 3, the time taken for the occurrence of delayed fracture or the presence or absence of the occurrence of delayed fracture and residual stress are shown in a case where the bending and unbending was performed by each of press forming and leveling. In Example 3, a case where the outside of the final bend formed by bending and unbending was on the burr side and a case where the outside of the final bend was on the rollover burr side were described. Here, the maximum amount of plastic strain was set to 0.003. In addition, the angle formed by the bending direction and the sheared end face 10A was set to 0 degrees.

[0088] The results are shown in Table 4.

[0089] Here, in Table 4, measurement with X-rays was performed within a measurement range with a diameter of 250 um, and residual stress was measured at a position of 0.25 mm from the sheet surface on each of the burr side and the rollover burr side of the sheet thickness. The measurement was performed in a direction parallel to the sheared end face 10A after shearing. The former was regarded as burr-side residual stress, and the latter was regarded as rollover burr-side residual stress.

[Table 4]

Processing method	Maximum amount of plastic strain introduced	Angle formed by bending direction and sheared end face (°)	Outside of final bend	Time taken for occurrence of delayed fracture/h	Burr-side residual stress/MPa	Rollover burr-side residual stress/MPa
Press forming	0.003	0	Rollover burr side	80	515	106
			Burr side	(No occurrence)	214	306
Leveler			Rollover burr side	87	409	237
			Burr side	(No occurrence)	301	249

[0090] As is clear from Table 4, on the inside of the final bend formed by the bending and unbending, there is a tendency that residual stress increases and turns into tensile stress. On the other hand, as is clear from Table 4, on the outside of the final bend, there is a tendency that residual stress decreases and turns into compressive stress.

[0091] The difference was larger in the case of the bending and unbending by pressing than by leveling. The reason therefor is that, in the leveling, the amount of deformation by bending and unbending gradually decreased from the start to the end of the processing, and thus the difference in stress in the sheet thickness direction was leveled.

[0092] In addition, the time taken until the occurrence of delayed fracture became longer as the residual stress on the burr side became lower. This is because the original residual stress is high on the burr side and the burr side is also a portion where delayed fracture is likely to occur due to the influence of burrs or rough surface texture.

[0093] Therefore, it was found that delayed fracture can be further suppressed by making the outside of the final bend by bending and unbending to be on the burr side of the sheared end face.

[0094] Here, the entire contents of Japanese Patent Application No. 2021-146245 (filed on September 08, 2021), based on which the present application claims priority, form a part of the present disclosure by reference. Here, the present invention has been described with reference to the definite number of embodiments, but the scope of the present invention is not limited thereto and modifications of each embodiment based on the above-described disclosure are obvious to those skilled in the art.

Reference Signs List

[0095]

1	blank production step
1A	shearing step
1B	end face improvement step (delayed fracture characteristics improvement method)
2	press forming step
10	metal sheet
10A	sheared end face
θ	bending angle

Claims

1. A method for improving delayed fracture characteristics of a metal sheet, the metal sheet having a sheared end face on at least a part of a sheet end portion and being made of a high-strength steel sheet,
wherein plastic deformation is imparted to at least a part of the sheared end face of the metal sheet.

2. The method for improving delayed fracture characteristics of a metal sheet according to claim 1,
wherein the plastic deformation imparts plastic strain greater than 0 in a direction along an extending direction of the end face to at least a part of the sheared end face.

3. The method for improving delayed fracture characteristics of a metal sheet according to claim 1 or 2,
wherein the plastic deformation is imparted by bending and unbending.

4. The method for improving delayed fracture characteristics of a metal sheet according to claim 3,
wherein each bending angle in the bending and unbending is set to less than 90 degrees.

5. The method for improving delayed fracture characteristics of a metal sheet according to claim 3 or 4,
wherein the bending and unbending is performed by bending by press forming.

6. The method for improving delayed fracture characteristics of a metal sheet according to claim 3 or 4,
wherein the bending and unbending is performed by leveling using a plurality of rolls.

7. The method for improving delayed fracture characteristics of a metal sheet according to any one of claims 3 to 6,
wherein a final bend in the bending and unbending is set such that an outside of the bend is on a burr side of the sheared end face.

8. The method for improving delayed fracture characteristics of a metal sheet according to any one of claims 1 to 6,
wherein the metal sheet is a steel sheet having a tensile strength of 980 MPa or more.

9. A method for producing a blank for press forming, comprising:

    performing shearing on a metal sheet; and
    imparting plastic deformation to a sheared end face by the method for improving delayed fracture characteristics according to any one of claims 1 to 8, which is a step after the performing of shearing.

10. A method for producing a press-formed article by press-forming a metal sheet made of a high-strength steel sheet, comprising:

    performing shearing on the metal sheet; and
    imparting plastic deformation to a sheared end face by the method for improving delayed fracture characteristics according to any one of claims 1 to 8, which is a step after the performing of shearing.

11. A press-formed article having a sheared end face on at least a part of a sheet end portion and being obtained by processing a metal sheet made of a high-strength steel sheet,
wherein plastic strain greater than 0 in a direction along an extending direction of the end face is imparted to at least

a part of the sheared end face.

FIG. 1

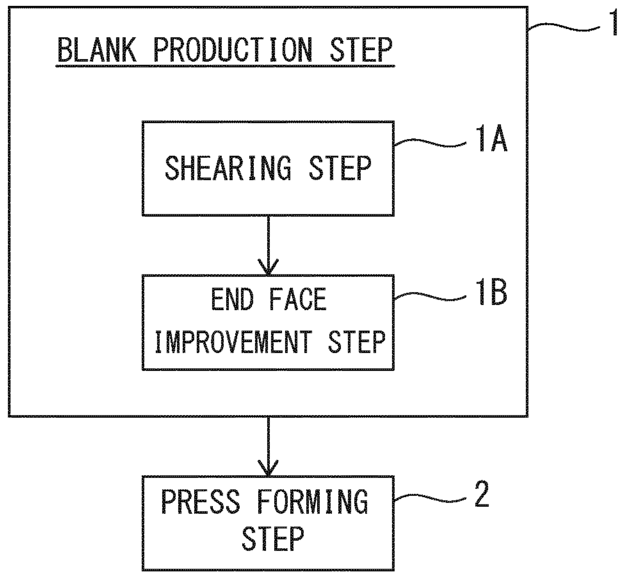


FIG. 2A

FIG. 2B

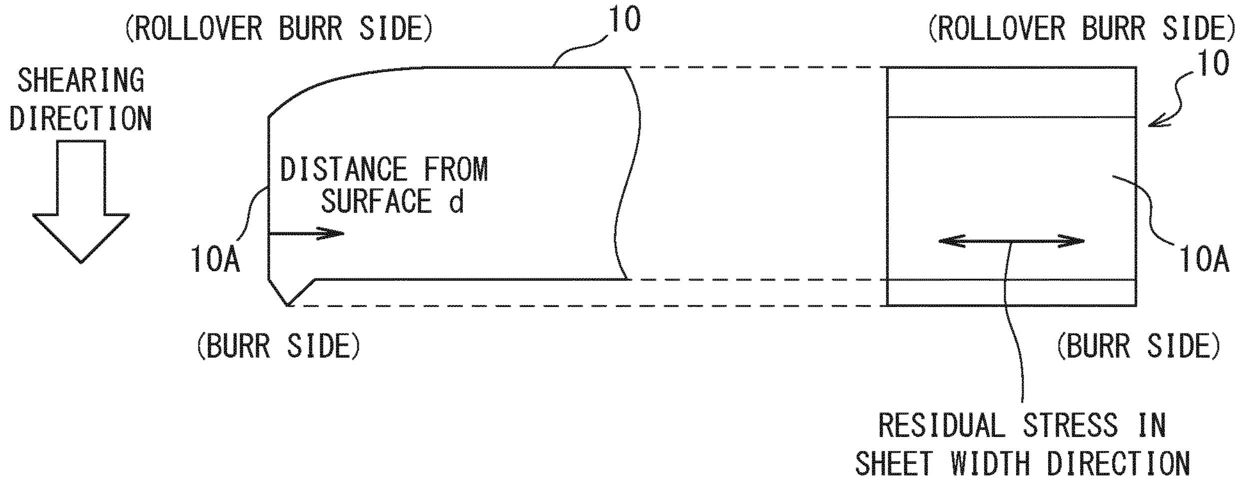
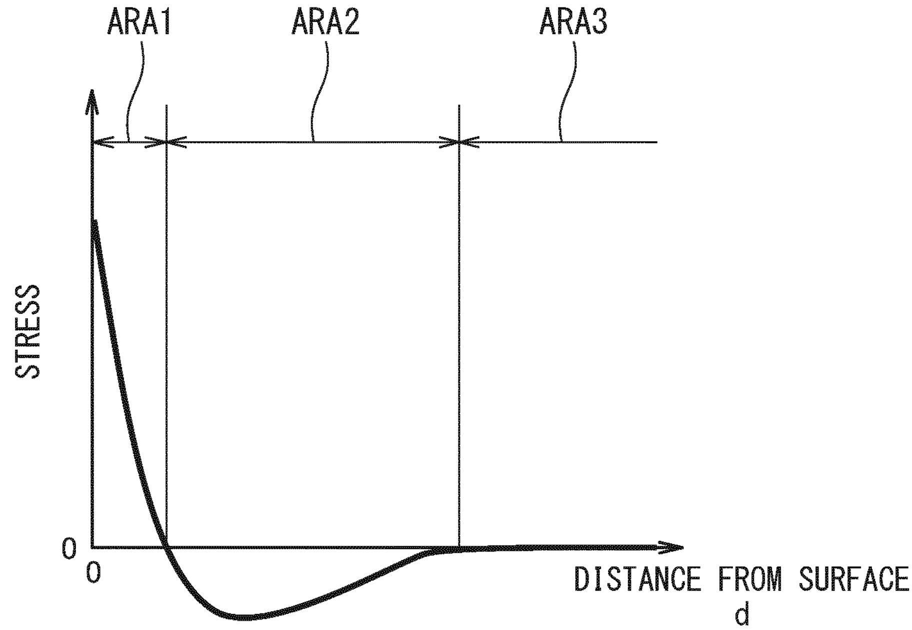
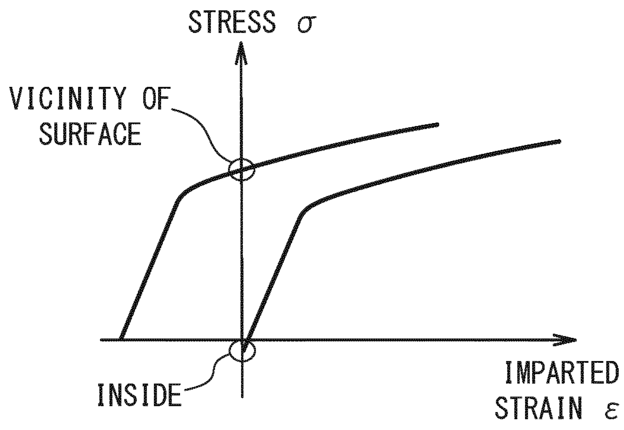


FIG. 3



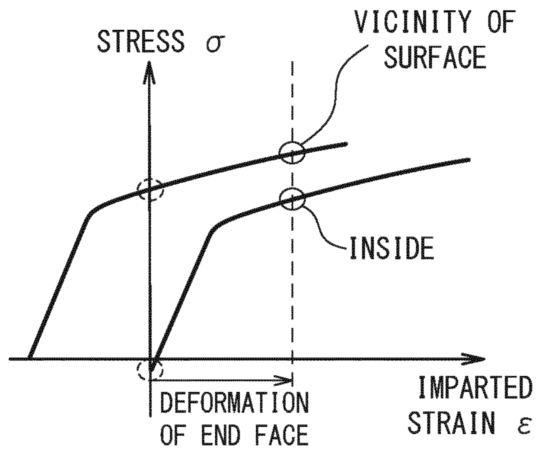
STRESS DISTRIBUTION

FIG. 4A



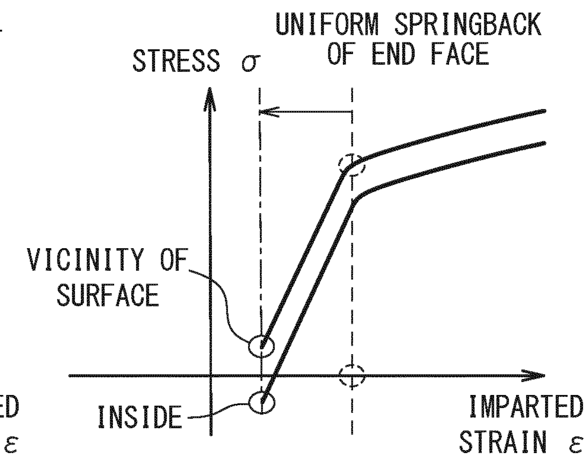
(INITIAL STATE)

FIG. 4B



(DURING IMPARTING OF STRAIN)

FIG. 4C



(DURING SPRINGBACK)

FIG. 5

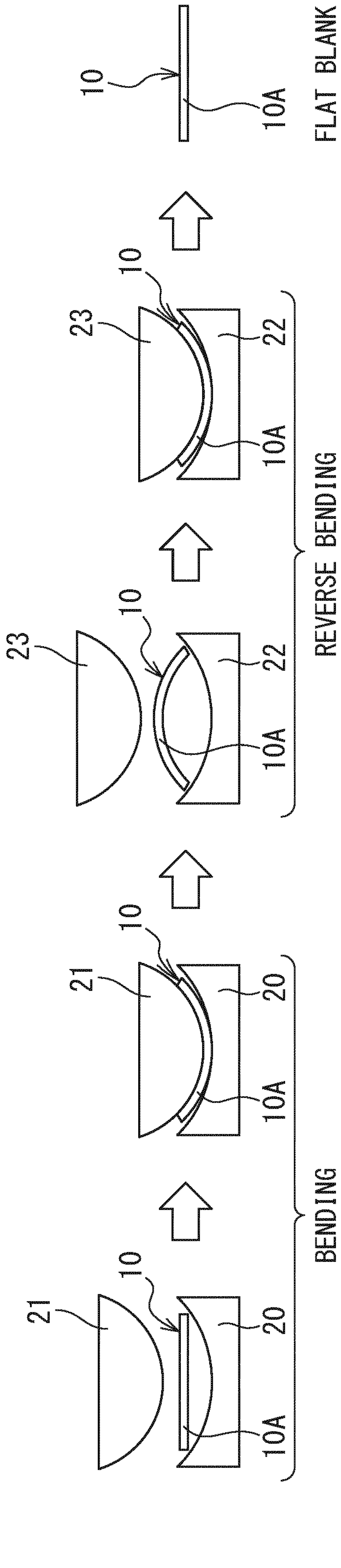

21
10
20
10A
BENDING
21
10
20
10A
23
10
22
10A
REVERSE BENDING
23
10
22
10A
10
10A
FLAT BLANK

FIG. 6

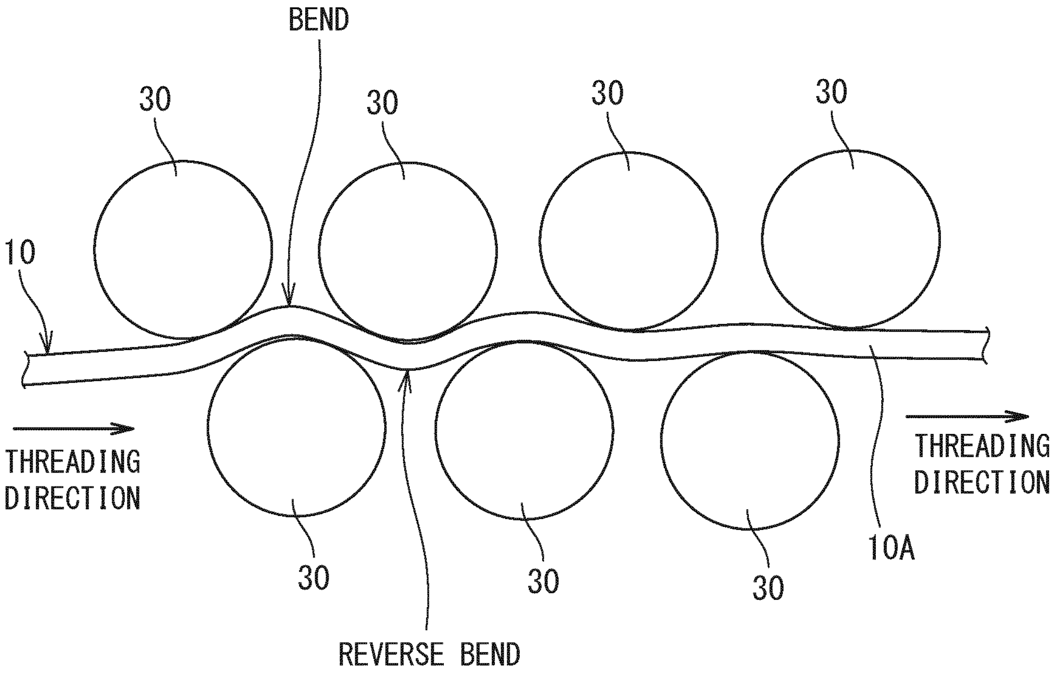

BEND
30
30
30
30
10
THREADING DIRECTION
THREADING DIRECTION
10A
30
30
30
REVERSE BEND

FIG. 7

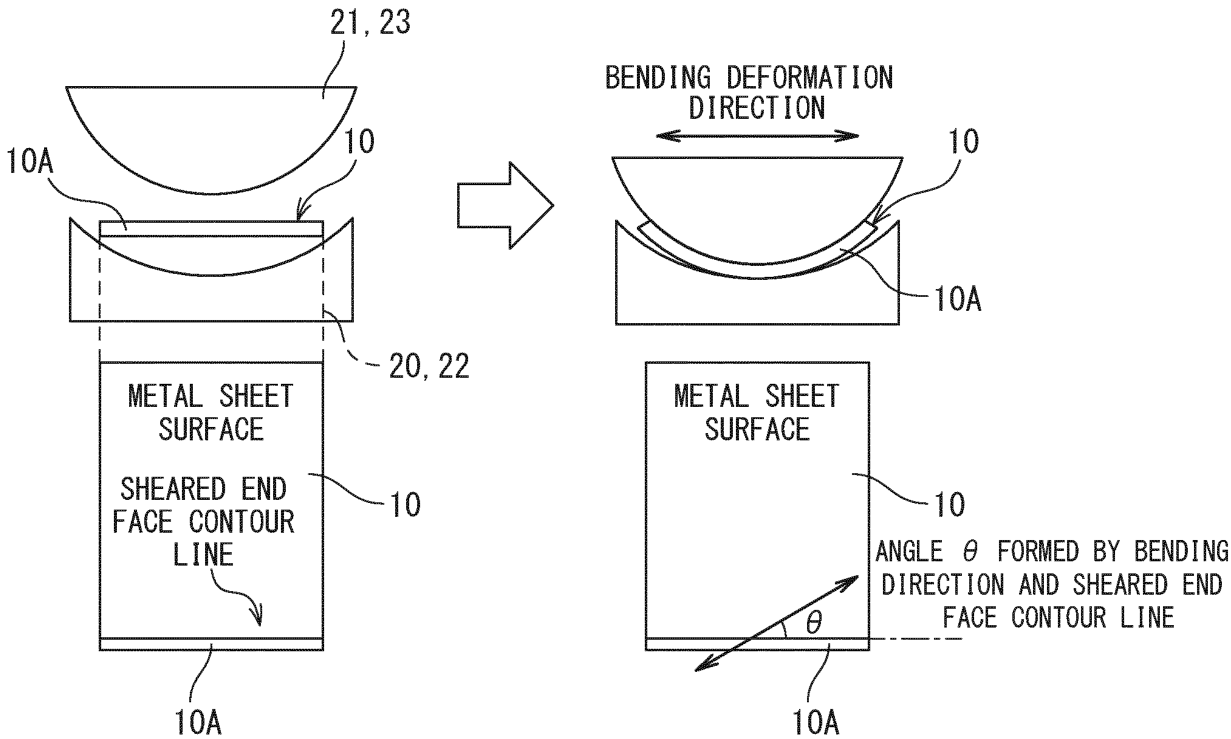

21, 23
10A
10
20, 22
METAL SHEET SURFACE
SHEARED END FACE CONTOUR LINE
10
10A
BENDING DEFORMATION DIRECTION
10
10A
METAL SHEET SURFACE
10
ANGLE θ FORMED BY BENDING DIRECTION AND SHEARED END FACE CONTOUR LINE
θ
10A

FIG. 8A

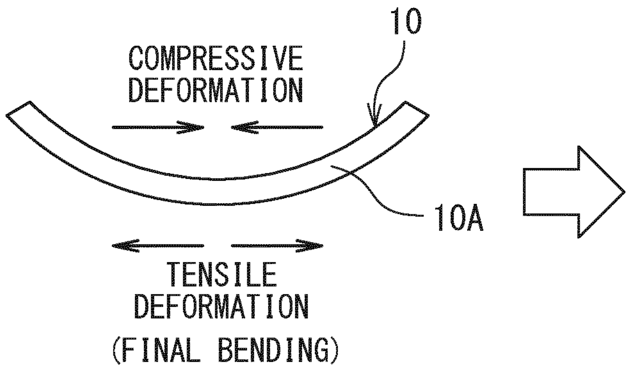
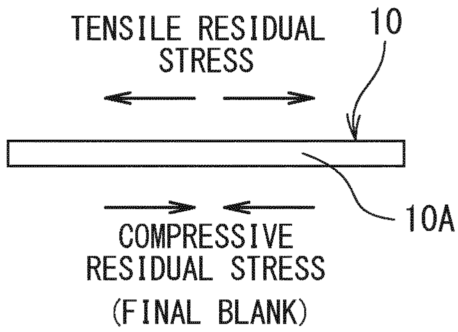

10
COMPRESSIVE
DEFORMATION
10A
TENSILE
DEFORMATION
(FINAL BENDING)

FIG. 8B


TENSILE RESIDUAL
STRESS
10
10A
COMPRESSIVE
RESIDUAL STRESS
(FINAL BLANK)

INTERNATIONAL SEARCH REPORT

International application No. **PCT/JP2022/032988**

A. CLASSIFICATION OF SUBJECT MATTER

B21D 1/06(2006.01)i
FI: B21D1/06 Z

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)

B21D1/06

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 1971-2022
Registered utility model specifications of Japan 1996-2022
Published registered utility model applications of Japan 1994-2022

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.
Y	JP 2006-224151 A (NIPPON STEEL CORP.) 31 August 2006 (2006-08-31) paragraphs [0014]-[0033], fig. 1-8	1-11
Y	JP 58-55128 A (NIPPON STEEL & SUMIKIN METAL PRODUCTS CO., LTD.) 01 April 1983 (1983-04-01) p. 3, upper left column, line 14 to lower left column, line 4	1-11
Y	JP 2017-125228 A (JFE STEEL CORP.) 20 July 2017 (2017-07-20) paragraph [0028]	1-11
Y	JP 9-122756 A (KAWASAKI STEEL CORP.) 13 May 1997 (1997-05-13) paragraphs [0010]-[0018], fig. 1-5	4-8
A	JP 2019-89076 A (NIPPON STEEL & SUMITOMO METAL CORP.) 13 June 2019 (2019-06-13) entire text, all drawings	1-11

☐ 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
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"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
17 October 2022	**08 November 2022**

Name and mailing address of the ISA/JP	Authorized officer
Japan Patent Office (ISA/JP) **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Telephone No.

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

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2022/032988

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2006-224151 A	31 August 2006	(Family: none)	
JP 58-55128 A	01 April 1983	(Family: none)	
JP 2017-125228 A	20 July 2017	(Family: none)	
JP 9-122756 A	13 May 1997	(Family: none)	
JP 2019-89076 A	13 June 2019	(Family: none)	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 6562070 B **[0009]**
- JP 2021146245 A **[0094]**

Non-patent literature cited in the description

- **YUZO TAKAHASHI et al.** Improvement in Stretch Flange Ability of High-Tensile-Strength Steel Sheets by Piercing under Tension Using Humped Bottom Punch. *Journal of the Japan Society for Technology of Plasticity,* 2013, vol. 54-627, 343-347 **[0008]**
- **TAKEO NAKAGAWA ; KIYOTA YOSHIDA.** Scraping method - A new method for recovery of stretchablity of sheared edge. *Journal of the Japan Society for Technology of Plasticity,* 1969, vol. 10-104, 665-671 **[0008]**