



(11)

EP 3 199 257 A1

(12)

EUROPEAN PATENT APPLICATION
published in accordance with Art. 153(4) EPC

(43) Date of publication:
02.08.2017 Bulletin 2017/31

(51) Int Cl.:
B21D 22/20 (2006.01) **B21D 24/00** (2006.01)
C23C 30/00 (2006.01) **C25D 5/26** (2006.01)

(21) Application number: **15843885.3**

(86) International application number:
PCT/JP2015/004533

(22) Date of filing: **07.09.2015**

(87) International publication number:
WO 2016/047058 (31.03.2016 Gazette 2016/13)

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

(72) Inventors:
• **NAKAGAITO, Tatsuya**
Tokyo 100-0011 (JP)
• **TOKITA, Yuichi**
Tokyo 100-0011 (JP)
• **MINOTE, Toru**
Tokyo 100-0011 (JP)
• **TAMAI, Yoshikiyo**
Tokyo 100-0011 (JP)

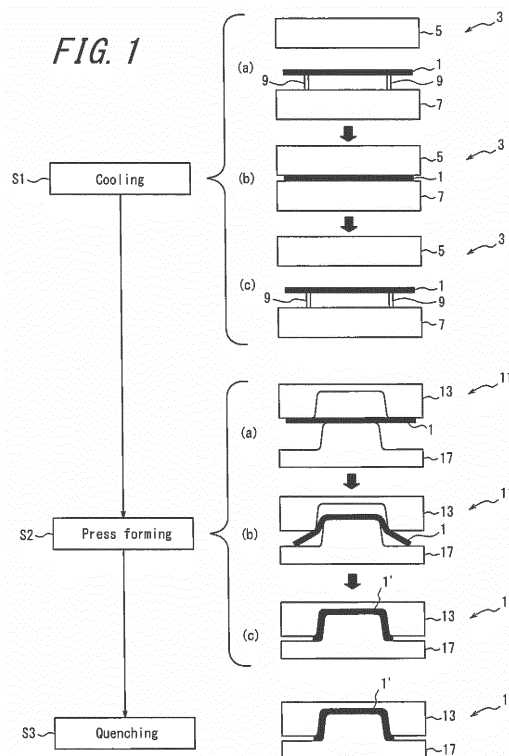
(30) Priority: **25.09.2014 JP 2014195530**

(74) Representative: **Grünecker Patent- und Rechtsanwälte**
PartG mbB
Leopoldstraße 4
80802 München (DE)

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

(54) **METHOD OF MANUFACTURING HOT PRESS-FORMED PART, AND HOT PRESS-FORMED PART**

(57) A method of manufacturing a hot press-formed part by hot pressing a coated steel sheet formed with a Zn-Ni plating layer on a surface of a steel sheet includes: heating the coated steel sheet to a temperature range of A_{c3} transformation temperature to 1000°C; cooling the coated steel sheet to 550-410°C at a cooling rate of 100°C/s or higher by squeezing the coated steel sheet with a press tool for cooling having flat surfaces configured to contact the coated steel sheet; press forming the coated steel sheet with a tool of press forming to obtain a formed body, the press forming being initiated within 5 seconds after the cooling while the temperature of the coated steel sheet is 550-400°C; and quenching the formed body, while squeezing the formed body with the tool of press forming and holding at its press bottom dead center, to obtain a hot press-formed part.



Description

TECHNICAL FIELD

[0001] This disclosure relates to a hot press-formed part and a method of manufacturing the same, and particularly, to a method of manufacturing a hot press-formed part from a coated steel sheet that enables press forming of the coated steel sheet which is heated beforehand, whereby the coated steel sheet can be quenched to attain a predetermined strength (tensile strength: 1180 MPa or higher) while being formed into a predetermined shape.

This disclosure also relates to a hot press-formed part produced by the method of manufacturing a hot press-formed part.

BACKGROUND

[0002] In recent years, strengthening and sheet metal thinning of automotive parts have been required. As the steel sheets used have higher strength, press formability decreases, and it becomes more difficult to form the steel sheets into the desired part shape.

To solve this problem, some conventional techniques propose performing hot press forming of a blank sheet heated to high temperature to have a desired shape using a tool of press forming, while quenching the blank sheet in the tool of press forming by utilizing heat extraction, to achieve high-strengthening of the hot press-formed part.

For example, GB1490535A (PTL 1) proposes a technique in which, when manufacturing a part of a predetermined shape by hot press forming a blank sheet (steel sheet) heated to an austenite single phase region at around 900 °C, the blank sheet is quenched in a tool of press forming simultaneously with the hot press forming, thus providing high-strengthening of the part.

[0003] However, the technique proposed in PTL 1 has a problem in that if the steel sheet is heated to a temperature as high as around 900 °C before subjection to the press forming, oxidized scale (iron oxide) forms on the surface of the steel sheet, and the oxidized scale peels during the hot press forming and damages the tool of press forming or the surface of the press formed part. Besides, the oxidized scale remaining on the surface of the part causes poor appearance and degraded coating adhesion properties. Accordingly, the oxidized scale on the surface of the part is typically removed by a process such as pickling or shot blasting. Such a process, however, causes lower productivity. Moreover, although suspension parts of vehicles, structural parts of automotive bodies, and the like are also required to have excellent corrosion resistance, a rust preventive film such as a plating layer is not provided on the blank sheet with the technique proposed in PTL 1. Accordingly, this technique does not provide sufficient corrosion resistance to the hot press-formed part.

[0004] For these reasons, there is demand for a hot press forming technique that can suppress the generation of oxidized scale during heating before hot press forming, and improve the corrosion resistance of the hot press-formed part. To meet this demand, other conventional techniques propose coated steel sheets having films such as plating layers on their surfaces, hot press forming methods using coated steel sheets, and the like.

For example, JP3663145B (PTL 2) proposes a technique in which a steel sheet coated with Zn or a zinc-based alloy is heated to 700 °C to 1200 °C and then hot press formed to obtain a hot press-formed part having a Zn-Fe-based compound or a Zn-Fe-Al-based compound on its surface. PTL 2 describes that the use of the steel sheet coated with Zn or a zinc-based alloy can suppress the oxidation of the surface of the steel sheet during heating before hot press forming, and provide a hot press-formed part having excellent corrosion resistance.

[0005] With the technique proposed in PTL 2, the generation of oxidized scale on the surface of the hot press-formed part is suppressed to some extent. However, Zn in the plating layer may induce liquid metal embrittlement cracking, causing cracks of about 100 μm in depth in the surface layer part of the hot press-formed part. Such cracks pose various problems, such as a decrease in the fatigue resistance of the hot press-formed part.

[0006] To address these issues, JP201391099A (PTL 3) proposes a method that includes heating a coated steel sheet having a Zn-Fe-based plating layer formed on the steel sheet surface to a temperature from the A_c1 transformation temperature of the steel sheet to 950 °C, and cooling the coated steel sheet to a temperature at or below the freezing point of the plating layer before starting press forming. PTL 3 describes that liquid metal embrittlement cracking can be suppressed by starting the press forming after the coated steel sheet is cooled to a temperature at or below the freezing point of the plating layer.

CITATION LIST

Patent Literature

[0007]

PTL 1 : GB1490535A
 PTL 2:JP3663145B
 PTL 3:JP201391099A

5 SUMMARY

(Technical Problem)

10 **[0008]** It is believed that the technique proposed in PTL 3 can suppress liquid metal embrittlement cracking, i.e., cracks in the surface of the hot press-formed part, which are about 100 μm in depth from the interface between the plating layer and the steel sheet (steel) toward the inside of the steel sheet, and in which Zn is detected at its interface (such cracks referred to hereinafter as "macro-cracks").

For suppressing macro-cracks, we studied the use of Zn-Ni alloy coating obtained by blending Zn with about 9 % to 25 % of Ni as a plating layer with high melting point. To ensure the corrosion resistance of a Zn-Ni alloy, the Zn-Ni alloy
 15 needs to be γ -phase. The γ -phase in the phase equilibrium diagram of Zn-Ni alloy has a melting point of 860 °C or higher, which is very high as compared to that of a normal Zn or Zn alloy plating layer, making it possible to suppress macro-cracks under normal press conditions.

However, in addition to the macro-cracks, microfissures which are about 30 μm or less in depth from the interface between the plating layer and the steel sheet toward the inside of the steel sheet, and in which Zn is not detected at its
 20 interface, may also occur in the surface of the hot press formed-part. Such microfissures are called "micro-cracks", which pass through the interface between the plating layer and the steel sheet and reach the inside of the steel sheet, adversely affecting the characteristics (fatigue resistance, etc.) of the hot press-formed part.

Macro-cracks also occur in, for example, a round portion of the die shoulder on the punch-contacting side which is subjected to only tensile strain while press forming of a hat-shaped section part. On the other hand, micro-cracks do not
 25 occur in such area, but on the die-contacting side of wall portions, which are subjected to compression (due to bending) followed by tensile strain (due to bend restoration). It is thus estimated that macro-cracks and micro-cracks are produced by different mechanisms.

[0009] In this regard, PTL 3 may suppress the occurrence of macro-cracks in a coated steel sheet having a Zn-Fe-based plating layer formed thereon, but is not necessarily effective for suppressing the occurrence of micro-cracks, because it does not consider potential micro-cracks occurring in a coated steel sheet having a Zn-Ni plating layer formed
 30 thereon.

With the technique proposed in PTL 3, the coated steel sheet is press formed in a state where the entire coated steel sheet has been cooled to a temperature at or below the freezing point of the plating layer, without specifying the lowest
 35 temperature at which the press forming can be started. This leads to the problem of a lower press forming temperature resulting in an increase in the strength of the steel sheet during press forming, deteriorating the shape fixability (which is a characteristic that maintains the shape at its press bottom dead center with little springback and the like), and making the steel sheet prone to springback.

[0010] It could thus be helpful by this disclosure to provide a method of manufacturing a hot press-formed part that can suppress a reduction in the shape fixability during hot press forming while preventing micro-cracks, when producing
 40 a hot press-formed part by hot press forming of a coated steel sheet having a Zn-Ni-based plating layer formed thereon. It could also be helpful to provide a hot press-formed part produced with the method.

(Solution to Problem)

45 **[0011]** Firstly, we investigated how to suppress micro-cracks (microfissures) which would otherwise occur during hot press forming of a steel sheet coated with Zn or a zinc-based alloy.

[0012] Although the micro-crack occurrence mechanism is still unclear, press forming of a steel sheet coated with Zn or a zinc-based alloy at high temperature at or below the freezing point of the plating layer may cause microfissures in the surface of the steel sheet. Similar microfissures also occur in a Zn-Ni coated steel sheet during press forming. Such
 50 microfissures are about 30 μm in depth from the interface between the plating layer and the steel sheet, and pass through the interface between the plating layer and the steel sheet and reach the inside of the steel sheet.

As a result of making various researches on this problem, we discovered that micro-cracks are suppressed by keeping the steel sheet at low temperature during hot press forming. Further, by keeping the steel sheet at low temperature during press forming as mentioned above, the effect of significantly reducing the coating weight attached to the tool of
 55 press forming, which would be quite large to cause problems with conventional coated steel sheets for hot press forming, was obtained.

[0013] However, lowering the temperature of the steel sheet during press forming leads to an increase in the strength of the steel sheet and thus causes lower shape fixability, which could cancel the advantage of hot press forming. We

thus conceived cooling, before performing hot press forming, only those portions of the steel sheet that are subjected to forming that would cause micro-cracks during the press forming. We then studied what forming would cause micro-cracks and which part would be subjected to such forming. Firstly, in our studies on forming that could cause micro-cracks, we investigated the influences of forming strain upon the occurrence of micro-cracks. As a result, it was discovered that micro-cracks are not caused by compressive deformation or bending deformation alone, but are caused at those portions that are subjected to deformation resulting from bending and subsequent bend restoration.

[0014] To this extent, forming as described above may be limited to a particular range, but in some cases the portions of the steel sheet subjected to forming that would cause micro-cracks may be extensive depending on the shape of the formed part.

[0015] Accordingly, we investigated how to suppress the occurrence of micro-cracks throughout, rather than in a limited range of, a steel sheet as a press forming sheet. As a result, it was discovered that by cooling the heated coated steel sheet to a temperature of 550 °C or lower and 410 °C or higher, at a cooling rate of 100 °C/s or higher, by squeezing the heated coated steel sheet with a press tool for cooling having flat surfaces configured to contact the coated steel sheet, and by starting press forming of the coated steel sheet with a tool of press forming within 5 seconds after the cooling while the temperature of the coated steel sheet is 550 °C or lower and 400 °C or higher, it becomes possible to suppress the occurrence of micro-cracks throughout both front and back surfaces of the resulting press formed part, while preventing loss of shape accuracy.

[0016] The reason why such cooling using the press tool for cooling prevented loss of shape accuracy is thought to be as follows.

For hat-shaped section parts, typical defects in shape accuracy include angle change such that the angle formed by two faces across the bending ridgeline becomes large relative to the angle of the tool of press forming, and wall camber such that the planes of the wall portions have curvature. Both of these defects occur due to the difference of any stress distribution in the sheet thickness direction, and the higher the flow stress of the steel sheet during forming, the difference becomes more significant and the shape accuracy decreases. In other words, in hot press forming, as the press forming temperature becomes lower, flow stress in the steel sheet during the press forming increases and shape accuracy decreases. As a result of cooling, the temperature of the steel sheet would become lower at the time of press forming and shape accuracy would degrade. However, when the steel sheet was cooled to a temperature of 550 °C or lower and 410 °C or higher at a cooling rate of 100 °C/s or higher, and when press forming of the steel sheet was started within 5 seconds after the cooling while the temperature of the steel sheet was 550 °C or lower and 400 °C or higher, there was almost no loss of shape accuracy.

The reason is considered to be that when the heated steel sheet is quenched with the press tool for cooling and subjected to press forming while the steel sheet temperature is 550 °C or lower and 400 °C or higher, the steel sheet has a microstructure of austenite during the press forming, and austenite transforms to martensite after the press forming, thereby relieving the stress accumulating during the press forming.

In contrast, if the press forming start temperature is decreased without quenching the heated steel sheet, ferrite and bainite are formed before the start of press forming, which is believed to cause a decrease in strength and the above-described angle change.

In addition, if press forming is started while the steel sheet temperature is below 400 °C, martensitic transformation would already begin before the start of press forming, and the above-described wall camber would be caused by the stress accumulating during the press forming in combination with increased steel sheet strength.

This disclosure is based on the aforementioned discoveries. We thus provide the following.

[1] A method of manufacturing a hot press-formed part by hot pressing a coated steel sheet formed with a Zn-Ni plating layer on a surface of a steel sheet, the method comprising: heating the coated steel sheet to a temperature range of A_{c3} transformation temperature to 1000°C; cooling the heated coated steel sheet to a temperature of 550 °C or lower and 410 °C or higher, at a cooling rate of 100 °C/s or higher, by squeezing the coated steel sheet with a press tool for cooling having flat surfaces configured to contact the coated steel sheet; press forming the coated steel sheet with a tool of press forming to obtain a formed body, the press forming being initiated within 5 seconds after the cooling while the temperature of the coated steel sheet is 550 °C or lower and 400 °C or higher; and quenching the formed body, while squeezing the formed body with the tool of press forming and holding at its press bottom dead center, to obtain a hot press-formed part.

[2] The method of manufacturing a hot press-formed part according to [1], wherein the Zn-Ni plating layer of the coated steel sheet contains 9 mass% or more and 25 mass% or less of Ni.

[3] A hot press-formed part manufactured by the method as recited in [1] or [2].

(Advantageous Effect)

[0017] According to the disclosure, it becomes possible to provide hot press-formed parts, using coated steel sheets

as steel sheets, that are free from micro-cracks throughout both front and back surfaces and that have sufficient hardness and satisfactory shape fixability without a significant increase in press forming load, and thus to manufacture automotive parts and the like in a variety of product shapes using coated steel sheets with high strength.

BRIEF DESCRIPTION OF THE DRAWING

[0018] In the accompanying drawings:

FIG. 1 illustrates a method for manufacturing a hot press-formed part according to one of the disclosed embodiments;
FIGS. 2A and 2B are first schematic diagrams, each illustrating the relationship between metallographic structure, temperature, and cooling time;

FIG. 3 is a second schematic diagram illustrating the relationship between metallographic structure, temperature, and cooling time;

FIG. 4 illustrates a test piece used in experiments according to one of the disclosed embodiments;

FIG. 5 is a graph illustrating experimental results according to one of the disclosed embodiments, showing the change in temperature of the test piece;

FIG. 6 is a partial enlarged view of FIG. 5, with emphasis on the horizontal axis;

FIGS. 7A-7C show SEM images of wall portions of press formed parts, demonstrating experimental results according to embodiments of the disclosure;

FIG. 8 is a graph illustrating experimental results according to one of the disclosed embodiments, showing the relationship between press forming start temperature and press forming load;

FIG. 9 is a graph illustrating experimental results according to one of the disclosed embodiments, showing the relationship between press forming start temperature and amount of mouth opening deformation;

FIGS. 10A and 10B illustrate forming methods according to embodiments of the disclosure;

FIG. 11 illustrates a press formed part to be press formed in examples;

FIG. 12 is a diagram for explaining a micro-crack examined in examples; and

FIG. 13 illustrates the amount of mouth opening deformation examined in examples.

DETAILED DESCRIPTION

[0019] In one of the disclosed embodiment, a method of manufacturing a hot press-formed part by hot pressing a coated steel sheet 1 formed with a Zn-Ni plating layer on a surface of a steel sheet as illustrated in FIG. 1, comprises: heating (not shown) the coated steel sheet 1 to a temperature range of A_{c3} transformation temperature to 1000 °C; cooling (S1) the heated coated steel sheet 1 to a temperature of 550 °C or lower and 410 °C or higher, at a cooling rate of 100 °C/s or higher, by squeezing the coated steel sheet 1 with a press tool for cooling 3 having flat surfaces configured to contact the coated steel sheet 1; starting (S2) press forming of the coated steel sheet 1 with a tool of press forming 11 within 5 seconds after the cooling while the temperature of the coated steel sheet 1 is 550 °C or lower and 400 °C or higher, to obtain a formed body 1'; and quenching (S3) the formed body 1', while squeezing the formed body with the tool of press forming 11 and holding at its press bottom dead center, to obtain a hot press-formed part.

The following provides details of the material of a hot press-formed part, and the steps of heating, cooling (S1), press forming (S2), and quenching (S3) performed thereon.

<Material of hot press-formed part>

[0020] As the material of a hot press-formed part, a coated steel sheet formed with a Zn-Ni plating layer on a surface of a steel sheet is used. The provision of a Zn-Ni plating layer on a surface of the steel sheet ensures the corrosion resistance of the part after subjection to hot press forming.

[0021] The method of forming a Zn-Ni plating layer on a surface of the steel sheet is not particularly limited, and any methods such as hot-dip galvanizing and electrogalvanizing may be used. The coating weight per side is preferably 10 g/m² or more and 90 g/m² or less.

[0022] The Ni content in the plating layer is preferably 9 mass% or more and 25 mass% or less. In the case of forming a Zn-Ni plating layer on a surface of the steel sheet by electrogalvanizing, a γ phase having any of the crystal structures of Ni_2Zn_{11} , $NiZn_3$, or Ni_5Zn_{21} is formed when the Ni content in the plating layer is 9 mass% or more and 25 mass% or less. The γ phase has a high melting point, and thus is advantageous in preventing the plating layer from evaporating when heating the coated steel sheet before subjection to hot press forming. The γ phase is also advantageous in suppressing liquid metal embrittlement cracking during high-temperature hot press forming.

<Heating>

[0023] The coated steel sheet 1 is heated to a temperature range of A_{c3} transformation temperature to 1000 °C. If the heating temperature of the coated steel sheet 1 is below A_{c3} transformation temperature, a sufficient amount of austenite cannot be obtained during heating, leading to the presence of ferrite during press forming. As a result, it becomes difficult to obtain sufficient strength or good shape fixability through hot press forming. When the heating temperature of the coated steel sheet 1 exceeds 1000 °C, on the other hand, the plating layer evaporates or excessive oxide generation occurs in the surface layer part, as a result of which the oxidation resistance or the corrosion resistance of the hot press-formed part decreases. Therefore, the heating temperature is from A_{c3} transformation temperature to 1000 °C. More preferably, the heating temperature is from A_{c3} transformation temperature + 30 °C to 950 °C. The method of heating the coated steel sheet 1 is not particularly limited, and any methods may be used, such as heating in an electric furnace, induction heating furnace, or direct current furnace.

<Cooling>

[0024] In the cooling (S1), the coated steel sheet 1 thus heated is cooled to a temperature of 550 °C or lower and 410 °C or higher at a cooling rate of 100 °C/s or higher, by being squeezed with the press tool for cooling 3.

[0025] As illustrated in FIG. 1, the press tool for cooling 3 comprises an upper cooling tool 5 and a lower cooling tool 7, each having a flat surface configured to contact the coated steel sheet 1. An extendable lifter pin 9 is provided on the lower cooling tool 7. The heated coated steel sheet 1 is placed on the lifter pin 9, and cooled by being squeezed between the upper cooling tool 5 and the lower cooling tool 7.

[0026] In general, when squeezing the heated coated steel sheet 1 with the press tool for cooling 3, both front and back surfaces of the coated steel sheet 1 may be squeezed entirely with the press tool for cooling 3 as illustrated in FIG. 1. However, the coated steel sheet 1 may be placed with some portions, such as portions to be trimmed afterwards before finishing operations to form a final product, extending beyond the edges of the press tool for cooling 3. In this way, if portions subjected to forming that would cause micro-cracks, i.e., bending-bend restoration deformation, cover a large area of the coated steel sheet 1 as the working material, it is possible to suppress the occurrence of micro-cracks throughout both front and back surfaces of the resulting press formed part.

The temperature at start of squeezing the heated coated steel sheet 1 with the press tool for cooling 3 is preferably 800 °C or lower from the perspective of preventing the risk of the Zn-Ni plating layer being adhered to the press tool for cooling, and preferably 670 °C or higher from the perspective of guaranteeing the strength after hot press forming. In addition, the coated steel sheet 1 may be cooled with one surface pressed against the press tool for cooling 3.

[0027] In this case, the cooling rate is set to be 100 °C/s or higher because this cooling rate enables the press formed part to have a martensite single phase structure, and thus allows for strengthening, without increasing cost.

In the following, this will be described in detail.

FIG. 2 schematically illustrates the relationship between a typical metallographic structure, temperature, and cooling time when a steel sheet is subjected to hot press forming using a tool of press forming. FIG. 2A shows a case where the press forming start temperature is high and, after the start of press forming, the coated steel sheet is rapidly cooled by heat extraction to the tool of press forming, so as to have a martensite single phase structure.

On the other hand, if the press forming start temperature is low as shown in FIG. 2B, ferrite and bainite are formed before the start of press forming, leading to a decrease in the strength of the press formed part after subjection to the press forming.

In this way, simply lowering the press forming start temperature ends up in a state as shown in FIG. 2B.

In contrast, according to the disclosure, by utilizing a cooling process that enables quenching before the start of press forming, a martensite single phase structure can be obtained while lowering the forming start temperature, as indicated by a dashed curve in FIG. 3.

The upper limit of the cooling rate is normally around 500 °C/s.

[0028] In the cooling, the cooling stop temperature is set to be 550 °C or lower because, above 550 °C, cooling becomes insufficient, causing micro-cracks after the hot press forming. The cooling stop temperature is preferably 500 °C or lower. In addition, the lower limit of the cooling stop temperature is 410 °C because, below 410 °C, the coated steel sheet 1 is excessively cooled before subjection to the press forming, leading to deterioration in shape fixability after subjection to the press forming. The cooling stop temperature is preferably 430 °C or higher.

[0029] In the cooling, the cooling rate and the cooling stop temperature may be controlled by, for example, varying the time to hold the coated steel sheet 1 with the press tool for cooling 3 (see FIG. 1). Changes in the temperature of the coated steel sheet 1 when squeezed with the press tool for cooling 3 may be determined by measuring the temperature of the coated steel sheet 1 using a sheath type thermocouple 19 of 0.5 mmφ inserted into the steel sheet in a manner as illustrated in FIG. 4. FIG. 5 is a graph showing some of the results, where the vertical axis is temperature (°C) and the horizontal axis is time (s). FIG. 6 is a graph representing a partial enlarged view of FIG. 5, with emphasis on the

horizontal axis, and focusing on an area enclosed by a dashed line in FIG. 5. It can be seen from FIG. 6 that the change in temperature during the cooling process with the press tool for cooling was about 160 °C/s, proving the ability to perform quenching.

[0030] As an experiment in one embodiment, press formed parts were formed at different conditions by varying the holding time during which the press formed part was being held in the press tool for cooling (in particular, the cooling stop temperature set for the press tool for cooling), and the press forming start temperature, which will be described below, and evaluation was made of the following parameters. For evaluation, observations were made to: (i) verify whether micro-cracks occurred by observing cross sections of wall portions of the press formed parts; (ii) determine the hardness of the press formed parts; (iii) determine the press forming load; and (iv) determine the shape fixability by measuring the amount of mouth opening deformation of hat openings of the press formed parts (the difference between the width of each opening after die release following the press forming and the width of the corresponding press formed part conformed to the tool of press forming).

[0031] FIG. 7 shows SEM (Scanning Electron Microscope) images of cross sections of surface layers, on the side contacting a die 13, of wall portions of press formed parts that were formed at different conditions by varying the time to cool the press formed part in the press tool for cooling (the cooling stop temperature set for the press tool for cooling) and the press forming start temperature. It can be seen from FIGS. 7A-7C that no micro-cracks were observed in the steel sheets with a cooling time in the press tool for cooling of 0.9 s or more (and a press forming start temperature of 550 °C or lower). Under all conditions, Hv > 450, proving that quench hardenability does not deteriorate.

[0032] FIG. 8 shows the relationship between press forming start temperature and press forming load, where the vertical axis is the press forming load (kN) and the horizontal axis is the press forming start temperature (°C). It can be seen from FIG. 8 that a reduction in the press forming start temperature caused by the process of cooling in the press tool for cooling prior to press forming caused an increased press forming load, which was, however, equivalent to that on mild steel (270D, cold deep forming) at temperatures around 550 °C at which micro-cracks do not occur, and thus posed no problem.

[0033] FIG. 9 shows the relationship between press forming start temperature and amount of mouth opening deformation, where the vertical axis is the amount of mouth opening deformation (mm) of a formed part and the horizontal axis is the press forming start temperature (°C). As shown in FIG. 9, the amount of mouth opening deformation increases due to a decrease in the forming start temperature caused by the process of cooling in the press tool for cooling prior to the press forming process, which shows a tendency such that shape fixability deteriorates accordingly. However, up to the point where the press forming start temperature is 400 °C or higher, almost no deterioration of shape fixability is observed.

[0034] As described above, by cooling the coated steel sheet by means of a predetermined press tool for cooling to a temperature of 550 °C or lower to 410 °C or higher at a cooling rate of 100 °C/s or higher, and, as described below, by starting press forming of the coated steel sheet within 5 seconds after the cooling while the temperature of the coated steel sheet is 550 °C or lower to 400 °C or higher, it becomes possible to provide a press formed part that is free from micro-cracks and has sufficient hardness and shape fixability without increasing the press forming load.

<Press forming

[0035] In the press forming (S2), the coated steel sheet 1 is press formed into the shape of a product. The press forming is performed with the tool of press forming 11 after the cooling. The tool of press forming 11 comprises a die 13 and a punch 17 as illustrated in FIG. 1. The coated steel sheet 1 is press formed by being squeezed between the die 13 and the punch 17, to obtain a formed body 1'.

[0036] As described above, it is possible to manufacture a press formed part that is free from micro-cracks and has sufficient hardness and shape fixability, without increasing the press forming load, by, in the cooling, cooling the coated steel sheet 1 in the press tool for cooling 3 to a temperature of 550 °C, or lower and 410 °C or higher at a cooling rate of 100 °C/s or higher, then removing the coated steel sheet 1 from the press tool for cooling 3, and starting press forming while the temperature of the coated steel sheet 1 is 550 °C or lower and 400 °C or higher.

The press forming is started within 5 seconds after the cooling because, if press forming is started after expiry of the time limit of 5 seconds after the cooling, for example, ferrite and bainite are formed before the start of press forming, preventing formation of a martensite single phase structure. As a result, the press formed part has insufficient hardness. Press forming is preferably started within 3 seconds after the cooling. No lower limit is particularly placed on the time limit, yet a preferred time limit is normally 1 second or more.

[0037] The present disclosure is not limited to a particular press forming method. However, available methods include, for example, draw forming whereby the coated steel sheet 1 is subjected to forming while being squeezed between the die 13 and the blank holder 15 as illustrated in FIG. 10A, and crash forming whereby the coated steel sheet 1 is subjected to forming while lowering the blank holder 15, or alternatively, without using the blank holder 15, as illustrated in FIG. 10B. From the perspective of suppressing micro-cracks, crash forming is preferred because of less excessive forming

of wall portions of the press formed part.

<Quenching>

5 [0038] In the quenching (S3), which follows the press forming, the formed body 1' is quenched while being squeezed and held in the tool of press forming 11, to obtain a hot press-formed part. In order for the formed body 1' to be quenched with the tool of press forming 11 after the press forming, the press slide of the formed body 1' is stopped at its press bottom dead center after subjection to the press forming. The sliding stop time is preferably 3 seconds or more, although it varies with the amount of heat released by the tool of press forming. No upper limit is particularly placed on the sliding stop time, yet it is preferably 20 seconds or less from the perspective of productivity.

10 [0039] In order for a steel sheet to be held in the tool of press forming for a predetermined period of time to have a quenched microstructure, it is possible to use a hot-rolled or cold-rolled steel sheet having a chemical composition containing (consisting of), for example, in mass%, C: 0.15 % or more and 0.50 % or less, Si: 0.05 % or more and 2.00 % or less, Mn: 0.50 % or more and 3.00 % or less, P: 0.10 % or less, S: 0.050 % or less, Al: 0.10 % or less, and N: 0.010 % or less, and the balance consisting of Fe and unavoidable impurities. The following provides a description of the chemical composition. When the composition is expressed in "%", this refers to "mass%" unless otherwise specified.

<<C: 0.15 % or more and 0.50 % or less>>

20 [0040] C is an element that improves the strength of steel. To increase the strength of the hot pressed part, the C content is preferably 0.15 % or more. When the C content exceeds 0.50 %, on the other hand, the weldability of the hot press-formed part and the fine blanking workability of the material (steel sheet) decrease significantly. Accordingly, the C content is preferably 0.15 % or more and 0.50 % or less, and more preferably 0.20 % or more and 0.40 % or less.

<<Si: 0.05 % or more and 2.00 % or less>>

25 [0041] Si is an element that improves the strength of steel, as with C. To increase the strength of the hot pressed part, the Si content is preferably 0.05 % or more. When the Si content exceeds 2.00 %, on the other hand, a surface defect, called red scale, increases significantly during hot rolling for manufacturing a steel sheet. Accordingly, the Si content is preferably 0.05 % or more and 2.00 % or less, and more preferably 0.10 % or more and 1.50 % or less.

<<Mn: 0.50 % or more and 3.00 % or less>>

35 [0042] Mn is an element that enhances the quench hardenability of steel, and is effective in suppressing the ferrite transformation of the steel sheet and improving quench hardenability in the cooling process after the hot press forming. Mn also has a function of lowering the Ac_3 transformation temperature, and thus is an element effective in lowering the heating temperature of the coated steel sheet 1 before subjection to hot press forming. To achieve these effects, the Mn content is preferably 0.50 % or more. When the Mn content exceeds 3.00 %, on the other hand, Mn segregation occurs, reducing the uniformity of characteristics of the steel sheet and of the hot press-formed part. Accordingly, the Mn content is preferably 0.50 % or more and 3.00 % or less, and more preferably 0.75 % or more and 2.50 % or less.

<<P: 0.10 % or less>>

45 [0043] When the P content exceeds 0.10 %, P segregates to grain boundaries, reducing the low-temperature toughness of the steel sheet and of the hot press-formed part. Accordingly, the P content is preferably 0.10 % or less, and more preferably 0.01 % or less. Excessively reducing the P content, however, leads to increased cost in the steelmaking process. Therefore, the P content is preferably 0.003 % or more.

<<S: 0.050 % or less>>

50 [0044] S is an element that forms a coarse sulfide by combining with Mn and causes a decrease in ductility of steel. The S content is preferably reduced as much as possible, though up to 0.050 % is allowable. Accordingly, the S content is preferably 0.050 % or less, and more preferably 0.010 % or less. Excessively reducing the S content, however, leads to increased cost of desulfurization in the steelmaking process. Therefore, the S content is preferably 0.0005 % or more.

<<A1: 0.10 % or less>>

55 [0045] When the A1 content exceeds 0.10 %, oxide inclusions in steel increase, and the ductility of steel decreases.

Accordingly, the A1 content is preferably 0.10 % or less, and more preferably 0.07 % or less. A1 functions as a deoxidation material, however, and from the perspective of improving the cleanliness factor of steel, the A1 content is preferably 0.01 % or more.

<<N: 0.010 % or less>>

[0046] When the N content exceeds 0.010 %, nitrides such as AlN form in the steel sheet, which causes lower formability during hot press forming. Accordingly, the N content is preferably 0.010 % or less, and more preferably 0.005 % or less. Excessively reducing the N content, however, leads to increased cost in the steelmaking process. Therefore, the N content is preferably 0.001 % or more.

[0047] While preferable basic components of the steel sheet used in the method according to the disclosure have been described, the steel sheet may further contain one or more of the following elements as necessary:

Cr: 0.01 % or more and 0.50 % or less, V: 0.01 % or more and 0.50 % or less, Mo: 0.01 % or more and 0.50 % or less, and Ni: 0.01 % or more and 0.50 % or less

Cr, V, Mo, and Ni are each an element effective in enhancing the quench hardenability of steel. This effect is achieved when the content of any of these elements contained is 0.01 % or more. However, adding any of Cr, V, Mo, or Ni beyond 0.50 % fails to further increase this effect, but instead increases cost. Accordingly, in the case where one or more of Cr, V, Mo, and Ni is included, the content is preferably 0.01 % or more and 0.50 % or less, and more preferably 0.10 % or more and 0.40 % or less.

Ti: 0.01 % or more and 0.20 % or less

[0048] Ti is effective for strengthening steel. The strengthening effect of Ti is achieved when the content is 0.01 % or more. Ti can be used to strengthen steel without any problem as long as the content is within the range specified herein. However, adding Ti beyond 0.20 % fails to increase this effect, but instead increases cost. Accordingly, in the case where Ti is included, the content is preferably 0.01 % or more and 0.20 % or less, and more preferably 0.01 % or more and 0.05 % or less.

Nb: 0.01 % or more and 0.10 % or less

[0049] Nb is also effective for strengthening steel. The strengthening effect of Nb is achieved when the content is 0.01 % or more. Nb can be used to strengthen steel without any problem as long as the content is within the range specified herein. However, adding Nb beyond 0.10 % fails to increase this effect, but instead increases cost. Accordingly, in the case where Nb is included, the content is preferably 0.01 % or more and 0.10 % or less, and more preferably 0.01 % or more and 0.05 % or less.

B: 0.0002 % or more and 0.0050 % or less

[0050] B is an element that enhances the quench hardenability of steel, and is effective in suppressing the generation of ferrite from austenite grain boundaries and obtaining a quenched microstructure when cooling the steel sheet after subjection to the hot press forming. This effect is achieved when the B content is 0.0002 % or more. However, adding B beyond 0.0050 % fails to increase this effect, but instead increases cost. Accordingly, in the case where B is included, the content is preferably 0.0002 % or more and 0.0050 % or less, and more preferably 0.0005 % or more and 0.0030 % or less.

Sb: 0.003 % or more and 0.030 % or less

[0051] Sb has the effect of suppressing generation of a decarburized layer in the surface layer part of the steel sheet during the period from when a steel sheet is heated before subjection to hot press forming to when the steel sheet is cooled through a series of hot press forming processes. To obtain this effect, the Sb content is preferably 0.003 % or more. When the Sb content exceeds 0.030 %, however, the rolling load increases during steel sheet manufacture, which may cause lower productivity. Accordingly, in the case where Sb is included, the content is preferably 0.003 % or more and 0.030 % or less, and more preferably 0.005 % or more and 0.010 % or less.

[0052] The components (balance) other than the above are Fe and unavoidable impurities.

[0053] The manufacturing conditions of the coated steel sheet 1 used as the material of the hot press-formed part are

not particularly limited. For example, the steel sheet may be a hot-rolled steel sheet (pickled steel sheet) having a predetermined chemical composition or a cold-rolled steel sheet obtained by subjecting the hot-rolled steel sheet to cold rolling.

[0054] The formation of a Zn-Ni plating layer on a surface of the steel sheet for obtaining the coated steel sheet 1 is not limited to particular conditions. In the case where a hot-rolled steel sheet (pickled steel sheet) is used as the steel sheet, the coated steel sheet 1 may be obtained by subjecting the hot-rolled steel sheet (pickled steel sheet) to Zn-Ni coating treatment.

[0055] In the case where a cold-rolled steel sheet is used as the steel sheet, the coated steel sheet 1 may be obtained by subjecting the cold-rolled steel sheet to Zn-Ni coating treatment either directly after subsection to the cold rolling, or after subsection to annealing treatment following the cold rolling.

[0056] In the case of forming a Zn-Ni plating layer on a surface of the steel sheet, for example, the Zn-Ni plating layer may be formed by degreasing and pickling the steel sheet, and then subjecting the steel sheet to electrogalvanizing treatment with a current density of 10 A/dm² or more and 150 A/dm² or less, in a plating bath which has a pH of 1.0 or more and 3.0 or less and a bath temperature of 30 °C or higher and 70 °C or lower, and which contains 100 g/L or more and 400 g/L or less nickel sulfate hexahydrate and 10 g/L or more and 400 g/L or less zinc sulfate heptahydrate.

In the case where a cold-rolled steel sheet is used as the steel sheet, the cold-rolled steel sheet may be subjected to annealing treatment before subsection to the degreasing and pickling. The Ni content in the plating layer may be set within the desired range (for example, 9 mass% to 25 mass%) by appropriately adjusting the concentration of zinc sulfate heptahydrate or the current density within the above-mentioned range. The coating weight of the Zn-Ni plating layer may be set within the desired range (for example, 10 g/m² to 90 g/m² per side) by adjusting the energizing time.

EXAMPLES

[0057] The following provides a description of experiments, which were conducted to confirm the effect of the method of manufacturing a hot press-formed part disclosed herein.

[0058] Steels having the compositions shown in Table 1 were each smelted into a cast slab, and the cast slab was heated to 1200 °C, hot rolled with a finish rolling completion temperature of 870 °C, and coiled at 600 °C to obtain a hot-rolled steel sheet.

[Table 1]

Table 1

Steel	Chemical Composition (mass%)									Ac ₁ transformation temperature (°C)
	C	Si	Mn	P	S	Al	N	B	Sb	
A	0.23	0.32	1.75	0.01	0.005	0.02	0.003	-	-	789
B	0.31	0.15	1.32	0.01	0.005	0.03	0.003	-	-	783
C	0.19	0.95	2.35	0.03	0.007	0.02	0.004	-	-	822
D	0.21	0.20	1.80	0.01	0.003	0.03	0.004	0.0020	0.010	791

[0059] The hot-rolled steel sheet was then pickled and cold rolled with a reduction of 50 %, to obtain a cold-rolled steel sheet with a thickness of 1.6 mm. The Ac₃ transformation temperature in Table 1 was calculated by Formula (1) below (see William C. Leslie, "The Physical Metallurgy of Steels", translation supervised by Nariyasu Kouda, translated by Hiroshi Kumai and Talsuhiko Noda, Maruzen Co., Ltd., 1985, p. 273).

$$Ac_3 (°C) = 910 - 203[C]^{0.5} + 44.7 \times [Si] - 30 \times [Mn] + 700 \times [P] + 400 \times [Al] \quad \dots (1)$$

Where [C], [Si], [Mn], [P], and [Al] are the contents (in mass%) of the elements enclosed in brackets (C, Si, Mn, P, and Al) in steel.

Using each cold-rolled steel sheet thus obtained as a steel sheet, a pure Zn plating layer, a Zn-Fe plating layer, or a Zn-Ni plating layer was formed on a surface of the steel sheet to obtain a coated steel sheet I. Each plating layer was formed under the following conditions.

<Pure Zn plating layer>

[0060] A cold-rolled steel sheet was passed through a continuous hot-dip galvanizing line, heated to a temperature range of 800 °C to 900 °C at a heating rate of 10 °C/s, and held in this temperature range for 10 s or more and 120 s or less. Subsequently, the cold-rolled steel sheet was cooled to a temperature range of 460 °C to 500 °C at a cooling rate of 15 °C/s, and dipped into a galvanizing bath at 450 °C to form a Zn plating layer. The coating weight of the Zn plating layer was adjusted to a predetermined coating weight using a gas wiping method.

<Zn-Fe plating layer>

[0061] A cold-rolled steel sheet was passed through a continuous hot-dip galvanizing line, heated to a temperature range of 800 °C to 900 °C at a heating rate of 10 °C/s, and held in this temperature range for 10 s or more and 120 s or less. Subsequently, the cold-rolled steel sheet was cooled to a temperature range of 460 °C to 500 °C at a cooling rate of 15 °C/s, and dipped into a galvanizing bath at 450 °C to form a Zn plating layer. The coating weight of the Zn plating layer was adjusted to a predetermined coating weight using a gas wiping method. As soon as the Zn plating layer was adjusted to the predetermined coating weight using the gas wiping method, the cold rolled steel sheet was heated to a temperature range of 500 °C to 550 °C and held for 5 s to 60 s in an alloying furnace, thereby forming a Zn-Fe plating layer. The Fe content in the plating layer was set to a predetermined content by changing the heating temperature in the alloying furnace and the holding time at the heating temperature within the above-mentioned ranges.

<Zn-Ni plating layer>

[0062] The cold-rolled steel sheet was passed through a continuous annealing line, heated to a temperature range of 800 °C to 900 °C at a heating rate of 10 °C/s, and held in this temperature range for 10 s or more and 120 s or less. Subsequently, the cold-rolled steel sheet was cooled to a temperature range of 500 °C or lower at a cooling rate of 15 °C/s. Then, the cold-rolled steel sheet was subjected to degreasing and pickling, followed by electrogalvanizing treatment whereby the cold-rolled steel sheet was energized for 10 s to 100 s with a current density of 30 A/dm² to 100 A/dm², in a plating bath containing 200 g/L nickel sulfate hexahydrate and 10 g/L to 300 g/L zinc sulfate heptahydrate and having a pH of 1.3 and a bath temperature 50 °C, thereby forming a Zn-Ni plating layer. The Ni content in the plating layer was set to a predetermined content by appropriately adjusting the concentration of zinc sulfate heptahydrate and the current density within the above-mentioned ranges. The coating weight of the Zn-Ni plating layer was set to a predetermined coating weight by appropriately adjusting the energizing time within the above-mentioned range.

[0063] A blank sheet of 200 mm × 400 mm was blanked from each coated steel sheet thus obtained, and heated in an electric furnace in air atmosphere. The blank sheet was then placed and cooled in a press tool for cooling (material: SKD61), and subjected to press forming and quenching using a tool of press forming under the conditions presented in Table 2. After being quenched, the blank sheet was released from the tool of press forming to manufacture a press formed part with a hat-shaped section as illustrated in FIG. 11. Regarding the size of the tool of press forming, the round portion of punch shoulder was 6 mm and the round portion of die shoulder was 6 mm. The press forming was performed with a punch-die clearance of 1.6 mm. Cooling prior to press forming was performed by bringing the blank sheet into contact with the press tool for cooling. Press forming was performed either by draw forming under a blank holder force of 98 kN, or crash forming without using a blank holder.

[0064] Table 2 shows the blank sheet heating temperature, type of steel sheet, type of plating layer, heating conditions, cooling conditions, and press forming conditions.

[0065] A sample was collected from a wall portion of each press formed part having a hat-shaped section, and a cross section of the surface was observed under a scanning electron microscope (SEM) at 1000 times magnification over ten fields per sample to examine the presence or absence of micro-cracks (microfissures in the surface of the sample, which pass through the interface between the plating layer and the steel sheet and reach the inside of the steel sheet) and the average depth of any micro-cracks. The average depth of micro-cracks was determined by averaging the micro-crack depths of arbitrarily selected 20 micro-cracks. As used herein, a "micro-crack depth" refers to, as illustrated in FIG. 12, the length of a micro-crack 21 measured from the interface between a plating layer 23 and a steel sheet 25 toward the center in the thickness direction (as indicated by length h in FIG. 12). In the case where the number of microcracks observed was less than 20, the average of the depths of all the observed micro-cracks was used.

The shape accuracy of each press formed part was evaluated based on the amount of mouth opening deformation, which was determined by the difference ($W - W_0$) between the width (W) of each press formed part with a hat-shaped section after die release and the width (W_0) of the corresponding formed part when conformed to the shape of the tool of press forming illustrated in FIG. 13.

Table 2 also lists these results.

[0066] Additionally, a sample for hardness measurement was collected from a wall portion of each press formed part

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with a hat-shaped section. The hardness of the cross section of each sample was measured using a micro-Vickers hardness meter. A test was conducted with a test load of 9.8 N, and hardness measurement was made at five central positions in the thickness direction for each sample, and the average was used as the hardness of the sample. In this case, the targeted hardness was 400 Hv or more.

Additionally, a JIS No. 13 B tensile test piece was collected from a wall portion of each press formed part with a hat-shaped section. A tensile test was conducted on each test piece thus collected according to JIS G 0567 (1998), and measurement was made of the tensile strength at room temperature (22 ± 5 °C). Note that all of the tensile tests were conducted with a cross-head speed of 10 mm/min. In this case, the targeted tensile strength was 1180 MPa or more. Table 2 also lists these results.

[Table 2]

Table 2																			
Steel	Plating layer		Heating Conditions		Cooling conditions						Press forming conditions				Evaluation results				Remarks
	Type	Coating weight (g/m ²)	Heating temp. (°C)	Holding time (s)	Cooling method	Cooling start temp. (°C)	Cooling time (s)	Cooling rate (°C/s)	Cooling stop temp. (°C)	Forming method	Time limit to start press forming after cooling (s)	Press forming start temp. (°C)	Holding time at press bottom dead center (s)	Steel sheet surface		Amount of mouth opening deformation (mm)	Hardness (Hv)	Tensile strength (MPa)	
														Cracks	Average depth of cracks (μm)				
A	Zn-10Ni%	60	880	10	Cooling in press tool for cooling	700	0.9	189	530	Crash forming	2	525	10	Not occurred	-	0	478	1514	Example 1
	Zn-12Ni%	45	900	30	Cooling in press tool for cooling	740	1.1	218	500	Draw forming	2	495	12	Not occurred	-	0	470	1493	Example 2
	Zn-21Ni%	30	920	5	Cooling in press tool for cooling	720	1.7	159	450	Draw forming	3	442	15	Not occurred	-	0	485	1528	Example 3
	Zn-15Ni%	55	900	120	Cooling in press tool for cooling	650	1.1	155	480	Crash forming	3	472	8	Not occurred	-	0	487	1545	Example 4
	Zn-15%Ni	55	920	15	Cooling in press tool for cooling	700	1.0	180	520	Draw forming	3	512	12	Not occurred	-	0	480	1520	Example 5
	Zn-12Ni%	45	850	20	Cooling in press tool for cooling	770	1.2	225	500	Crash forming	5	487	15	Not occurred	-	0	498	1573	Example 6
	Zn-12Ni%	45	880	5	Cooling in press tool for cooling	640	0.6	167	540	Crash forming	3	532	10	Not occurred	-	0	473	1499	Example 7
	Zn-12Ni%	45	920	60	-	-	-	-	-	Crash forming	-	720	15	Occurred	8	0	481	1520	Comparative Example 1
	Zn-10Ni%	60	900	90	Cooling in press tool for cooling	680	0.4	200	600	Draw forming	3	592	15	Occurred	12	0	471	1491	Comparative Example 2
	Zn-21Ni%	45	880	20	Cooling in press tool for cooling	700	3.5	103	340	Draw forming	2	335	12	Not occurred	-	8	502	1581	Comparative Example 3
	Zn-15Ni%	55	900	30	Cooling in press tool for cooling	740	4.9	92	290	Crash forming	2	285	10	Not occurred	-	9	500	1580	Comparative Example 4

Table 2 (cont'd)																			
Steel	Plating layer		Heating Conditions		Cooling conditions					Press forming conditions				Evaluation results					Remarks
	Type	Coating weight (g/m ²)	Heating temp. (°C)	Holding time (s)	Cooling method	Cooling start temp. (°C)	Cooling time (s)	Cooling rate (°C/s)	Cooling stop temp. (°C)	Forming method	Time limit to start press forming after cooling (s)	Press forming start temp. (°C)	Holding time at press bottom dead center (s)	Steel sheet surface		Amount of mouth opening deformation (mm)	Hardness (Hv)	Tensile strength (MPa)	
														Cracks	Average depth of cracks (μm)				
A	Zn-12Ni%	45	900	10	Gas cooling	700	1.8	22	660	Draw forming	2	655	15	Occurred	13	0	467	1473	Comparative Example 5
	Zn-12Ni%	45	880	20	Gas cooling	720	4.8	27	590	Crash forming	2	585	10	Occurred	7	2	376	1171	Comparative Example 6
	Zn-10%Ni	60	910	10	Gas cooling	680	10.5	16	510	Crash forming	3	502	10	Not occurred	-	3	345	1104	Comparative Example 7
	Zn-12%Ni	45	900	10	Cooling in press tool for cooling	710	1.0	180	530	Draw forming	10	505	15	Not occurred	-	2	365	1155	Comparative Example 8
	Zn-15%Ni	55	890	20	Cooling in press tool for cooling	670	1.5	153	440	Crash forming	8	420	15	Not occurred	-	2	382	1162	Comparative Example 9
	Zn	50	900	20	Cooling in press tool for cooling	700	1.2	167	500	Crash forming	2	495	15	Occurred	31	0	480	1510	Comparative Example 10
	Zn-10Fe%	40	880	10	Cooling in press tool for cooling	720	1.0	190	530	Draw forming	2	525	15	Occurred	5	0	488	1545	Comparative Example 11
B	Zn-12Ni%	60	900	60	Cooling in press tool for cooling	700	1.2	167	500	Crash forming	2	495	12	Not occurred	-	0	543	1620	Example 8
C	Zn-10Ni%	50	890	30	Cooling in press tool for cooling	680	1.0	160	520	Draw forming	3	512	3	Not occurred	-	0	436	1420	Example 9
D	Zn-12Ni%	50	900	20	Cooling in press tool for cooling	700	1.0	180	520	Draw forming	3	520	15	Not occurred	-	0	475	1505	Example 10

[0067] In examples 1 to 10, the type of plating layer (Zn-Ni plating layer), cooling process (cooling in the press tool for cooling), cooling time (0.6 s to 1.7 s), cooling rate (appropriate range: 100 °C/s or higher), cooling stop temperature (appropriate range: 410 °C to 550 °C), time limit to start press forming after cooling (appropriate range: within 5 seconds), and press forming start temperature (appropriate range: 400 °C to 550 °C) are all within the appropriate ranges specified in this disclosure. The pressed samples according to our examples were free from micro-cracks, and the amount of mouth opening deformation was determined to be 0 mm for these samples. From these results, it can be seen that, with the press forming process disclosed herein, it is possible to suppress the occurrence of micro-cracks while ensuring good shape fixability.

[0068] In contrast, Comparative Example 1 was subjected to a forming process without being cooled with the press tool for cooling. Comparative Examples 2 to 4 were outside the appropriate range (410 °C to 550 °C) in terms of cooling stop temperature. Specifically, the cooling stop temperature was 600 °C in Comparative Example 2, 340 °C in Comparative Example 3, and 290 °C in Comparative Example 4.

[0069] In Comparative Examples 1 and 2, micro-cracks occurred, although the amount of mouth opening deformation was 0 mm. From this follows that micro-cracks will occur in a steel sheet when the forming start temperature of the steel sheet is higher than 550 °C.

In Comparative Examples 3 and 4, micro-cracks did not occur, yet the amount of mouth opening deformation was 8 mm to 10 mm. From these results, it can be seen that if the cooling time is excessively long and the cooling stop temperature of the steel sheet is below 410 °C, then the press forming start temperature is below 400 °C, which causes an increase in the strength of the steel sheet and thus a reduction in the shape fixability.

[0070] In Comparative Examples 5 to 7, the cooling process was gas cooling, in which the cooling rate was outside the appropriate range (100 °C/s or higher), and thus rapid cooling could not be performed. Accordingly, in Comparative Examples 5 and 6, the cooling stop temperature and the press forming start temperature of the steel sheets were outside the appropriate ranges (cooling stop temperature: 410 °C to 550 °C, press forming start temperature: 400 °C to 550 °C), and micro-cracks occurred. Further, in Comparative Example 7, the cooling stop temperature was 510 °C, which is within the appropriate range. However, the amount of mouth opening deformation was 3 mm, which shows a reduction in the shape fixability. The reason is believed to be that due to a low cooling rate of gas cooling, the angle formed by two faces of the press formed part across a bend ridgeline was larger than the angle of the tool of press forming.

Moreover, in Comparative Examples 6 and 7, the steel sheets were quenched after being mild cooled to some extent by gas cooling and subjected to press forming, and thus showed a reduction in the hardness and tensile strength after subjection to the press forming.

[0071] In Comparative Examples 8 and 9, press forming was started in 10 seconds and 8 seconds respectively after the cooling, exceeding the appropriate time limit of 5 seconds. Accordingly, in Comparative Examples 8 and 9, the amount of mouth opening deformation was 2 mm, and the steel sheets showed a reduction in the hardness and tensile strength after subjection to the press forming.

[0072] Comparative Examples 10 and 11 were different from the examples and other comparative examples in the type of plating layer. Specifically, Comparative Example 10 used a pure Zn plating layer and Comparative Example 11 used a Zn-Fe plating layer. The press forming start temperature at which micro-cracks will not occur in the pure Zn plating layer or in the Zn-Fe plating layer is even lower than the press forming start temperature at which micro-cracks will not occur in a Zn-Ni plating layer. Thus, micro-cracks occurred in Comparative Examples 10 and 11.

REFERENCE SIGNS LIST

[0073]

- 1 Coated steel sheet
- 1' Formed body
- 3 Press tool for cooling
- 5 Upper cooling tool
- 7 Lower cooling tool
- 9 Lifter pin
- 11 Tool of press forming
- 13 Die
- 15 Blank holder
- 17 Punch
- 19 Thermocouple
- 21 Micro-crack
- 23 Plating layer
- 25 Steel sheet

Claims

1. A method of manufacturing a hot press-formed part by hot pressing a coated steel sheet formed with a Zn-Ni plating layer on a surface of a steel sheet, the method comprising:

heating the coated steel sheet to a temperature range of A_{c3} transformation temperature to 1000 °C;
cooling the heated coated steel sheet to a temperature of 550 °C or lower and 410 °C or higher, at a cooling rate of 100 °C/s or higher, by squeezing the coated steel sheet with a press tool for cooling having flat surfaces configured to contact the coated steel sheet;
press forming the coated steel sheet with a tool of press forming to obtain a formed body, the press forming being initiated within 5 seconds after the cooling while the temperature of the coated steel sheet is 550 °C or lower and 400 °C or higher; and
quenching the formed body, while squeezing the formed body with the tool of press forming and holding at its press bottom dead center, to obtain a hot press-formed part.

2. The method of manufacturing a hot press-formed part according to claim 1, wherein the Zn-Ni plating layer of the coated steel sheet contains 9 mass% or more and 25 mass% or less of Ni.

3. A hot press-formed part manufactured by the method as recited in claim 1 or 2.

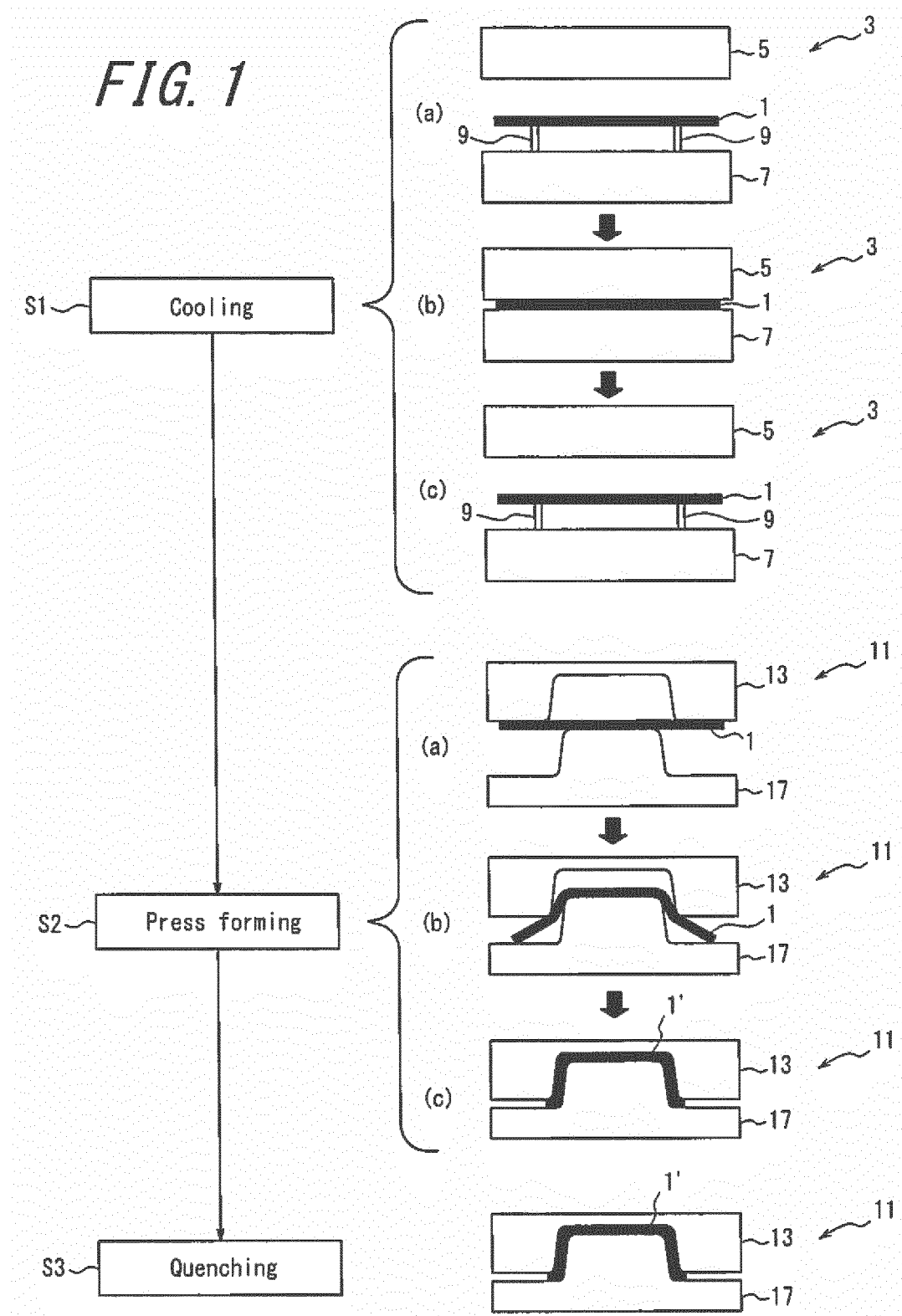


FIG. 2A

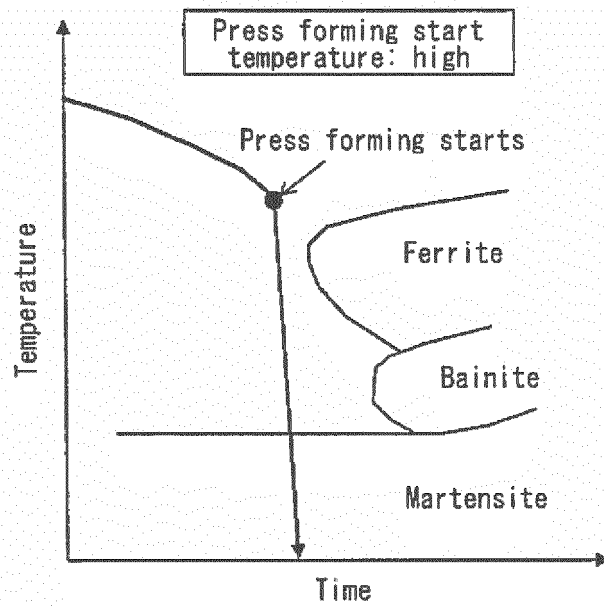


FIG. 2B

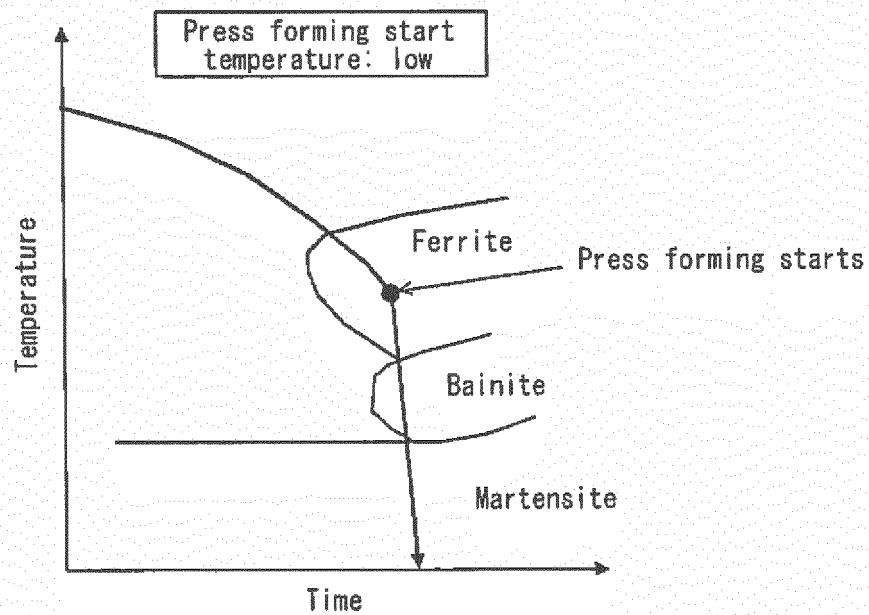


FIG. 3

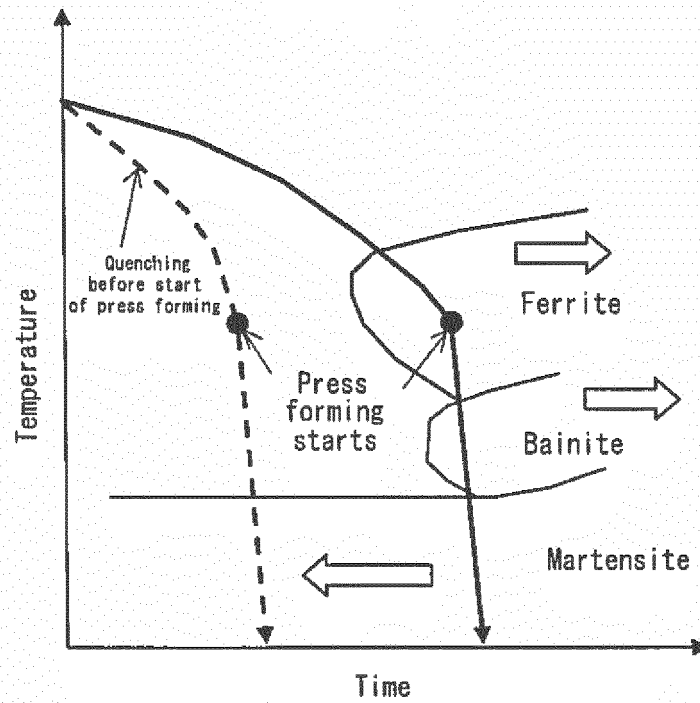


FIG. 4

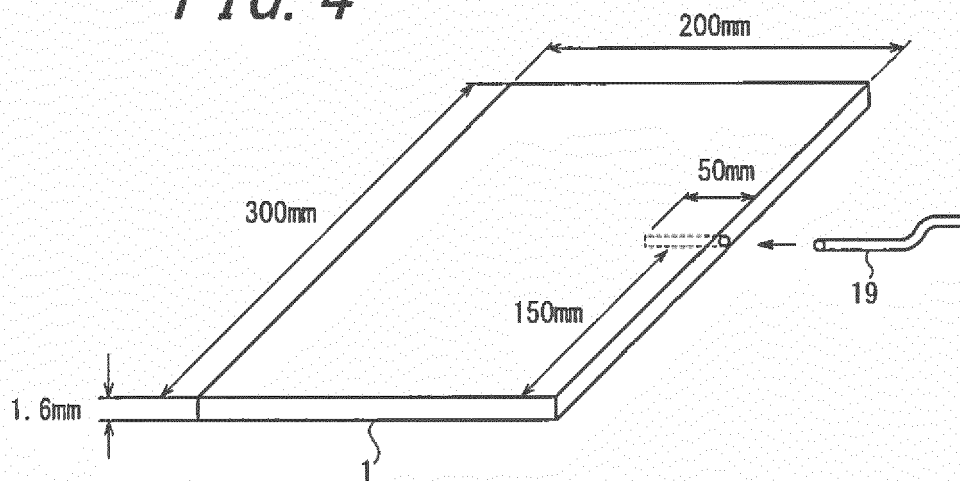


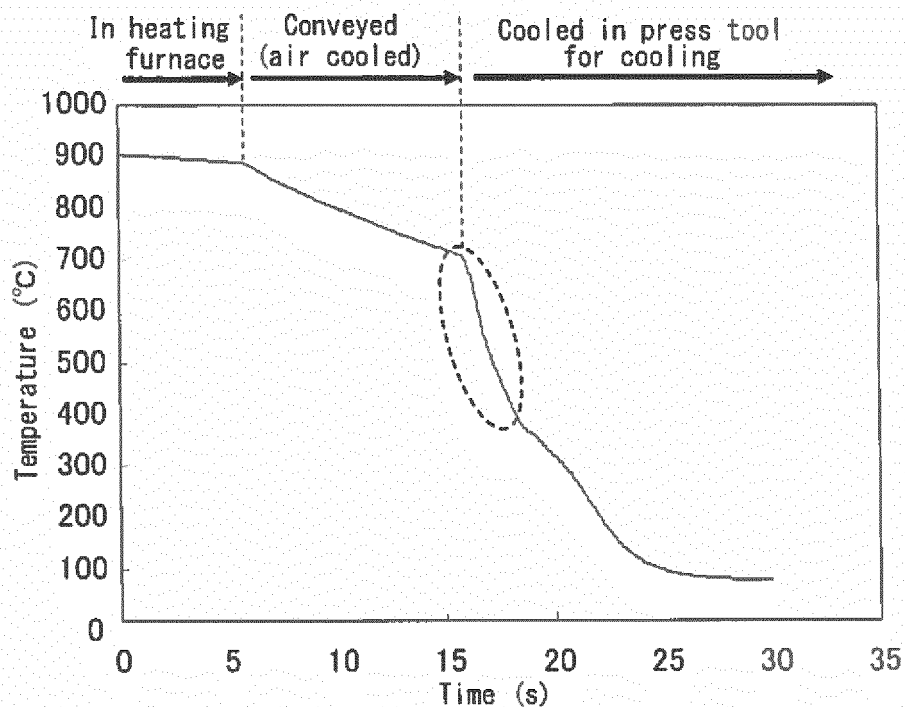
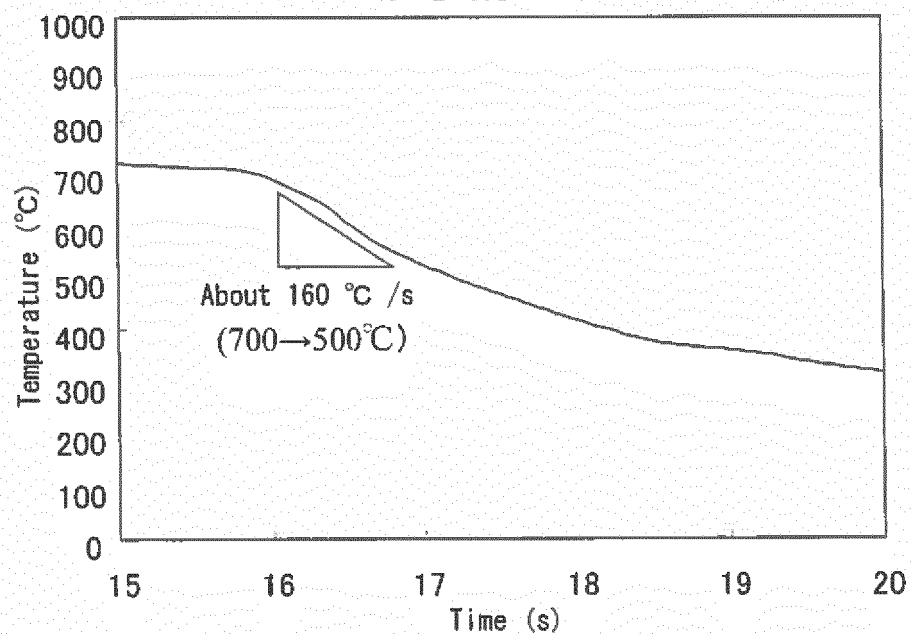
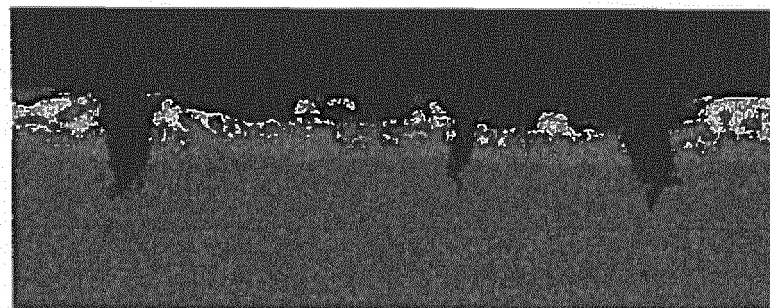
FIG. 5*FIG. 6*

FIG. 7A

Cooling time 0.6 s (600 °C)



Micro-cracks

Plating layer
Steel sheet

FIG. 7B

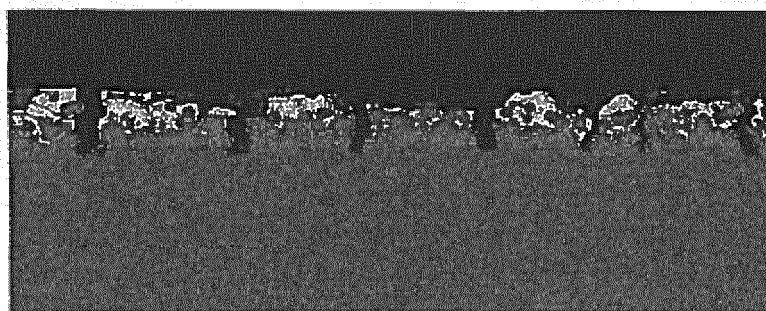
Cooling time 0.9 s (550 °C)



Plating layer
Steel sheet

FIG. 7C

Cooling time 1.3 s (500 °C)



Plating layer
Steel sheet

20μm

Temperature in parentheses: press forming start temperature

FIG. 8

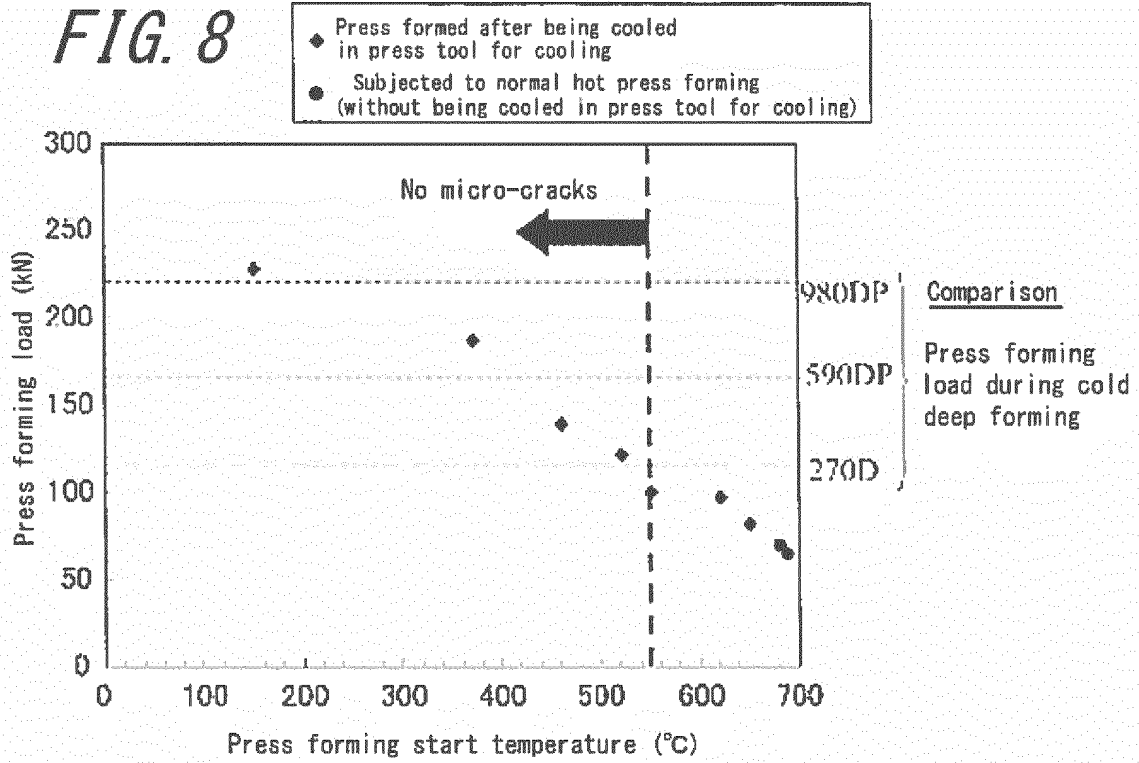


FIG. 9

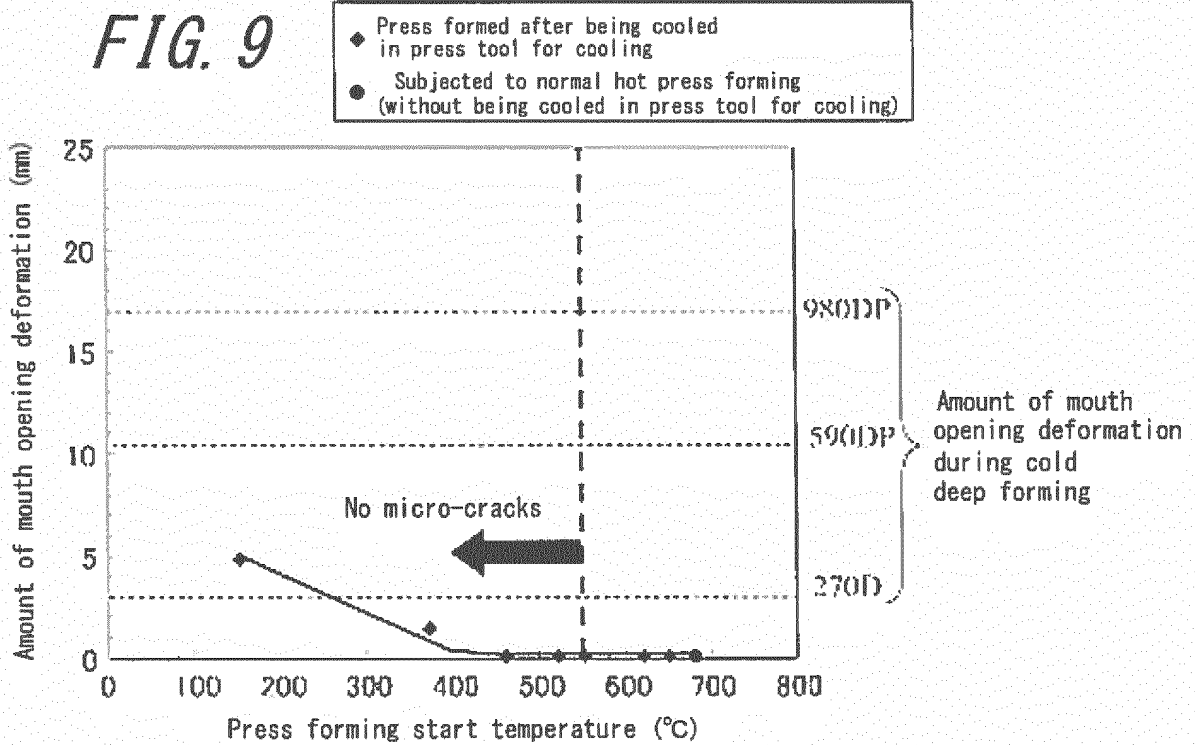


FIG. 10A

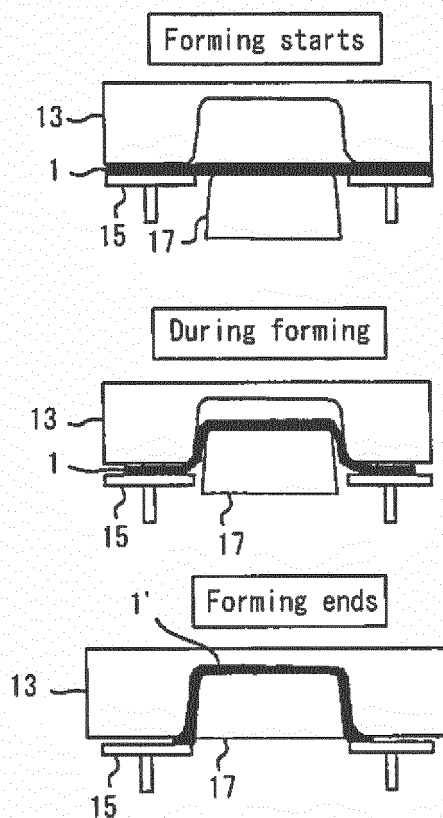


FIG. 10B

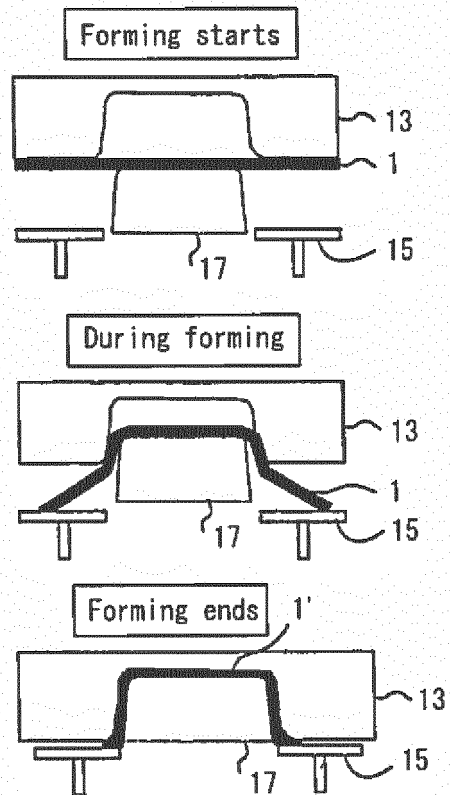


FIG. 11

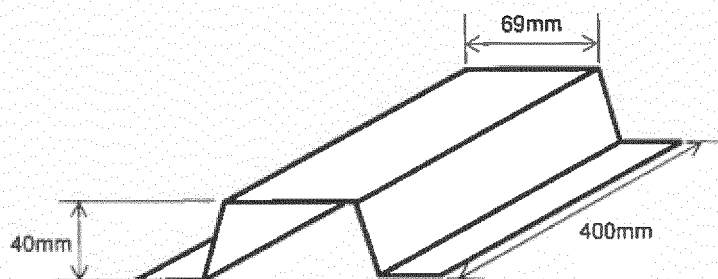


FIG. 12

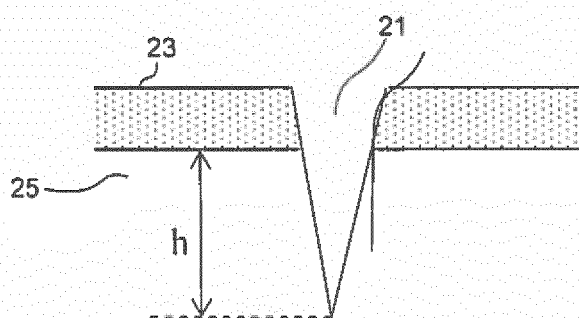
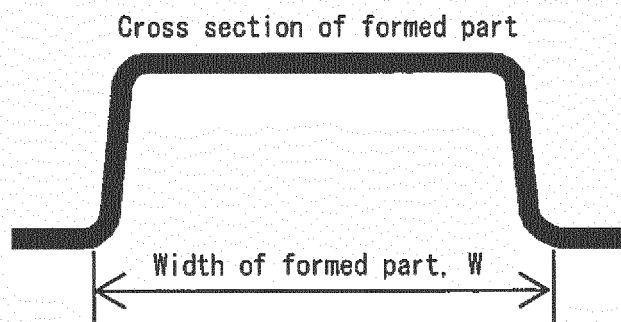


FIG. 13



Amount of mouth opening deformation = $W - W_0$

* W_0 is the width of the formed part when conformed to the shape of the tool of press forming

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2015/004533

A. CLASSIFICATION OF SUBJECT MATTER

B21D22/20(2006.01)i, B21D24/00(2006.01)i, C23C30/00(2006.01)i, C25D5/26(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)

B21D22/20, B21D24/00, C23C30/00, C25D5/26, B21D5/01

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

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2015

Kokai Jitsuyo Shinan Koho 1971-2015 Toroku Jitsuyo Shinan Koho 1994-2015

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 2007-275937 A (Nippon Steel Corp.), 25 October 2007 (25.10.2007), paragraphs [0020] to [0049] (Family: none)	1-3
Y	WO 2013/047526 A1 (Kobe Steel, Ltd.), 04 April 2013 (04.04.2013), paragraphs [0022] to [0058]; fig. 4 to 5, 8 & JP 2013-75329 A & US 2014/0338802 A1 paragraphs [0030] to [0077]; fig. 4 to 5, 8 & EP 2762243 A1 & CN 103826771 A & KR 10-2014-0056374 A	1-3

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

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Date of the actual completion of the international search
17 November 2015 (17.11.15)

Date of mailing of the international search report
01 December 2015 (01.12.15)

Name and mailing address of the ISA/
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INTERNATIONAL SEARCH REPORT

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2012-197505 A (JFE Steel Corp.), 18 October 2012 (18.10.2012), paragraphs [0016] to [0043] & WO 2012/121399 A1 & EP 2684985 A1 page 3, line 41 to page 12 & TW 201243106 A & MX 2013010352 A & AR 86804 A1	1-3
A	GB 1490535 A (NORRBOTTENS JAERNVERK AB), 02 November 1977 (02.11.1977), entire text; all drawings & DE 2452486 A1 & NO 743986 A & SE 7315058 A & FI 321874 A & DK 306581 A	1-3
A	JP 3663145 B2 (USINOR), 22 June 2005 (22.06.2005), entire text; all drawings & US 2001/0042393 A1 entire text; all drawings & EP 1143029 A1 & DE 1400861 T1 & FR 2807447 A1 & BR 102747 A & CA 2343340 A1 & AT 327353 T & DK 1143029 T3 & PT 1143029 E & ES 2263567 T3 & AR 28319 A1	1-3
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E, A	WO 2015/163016 A1 (JFE Steel Corp.), 29 October 2015 (29.10.2015), entire text; all drawings (Family: none)	1-3

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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- JP 3663145 B [0004] [0007]
- JP 201391099 A [0006] [0007]

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- **WILLIAM C. LESLIE.** The Physical Metallurgy of Steels. Maruzen Co., Ltd, 1985, 273 [0059]