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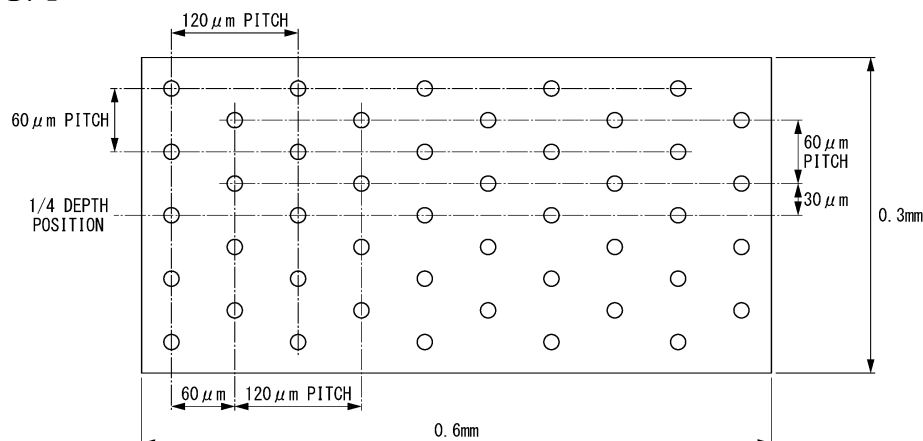
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(54) **HOT STAMP MOLDED ARTICLE**

(57) This hot-stamping formed article includes a steel sheet, all or part of the steel sheet has a predetermined chemical composition, at a 1/4 depth position of a sheet thickness from a surface of the steel sheet, a microstructure contains, by vol%, more than 90.0% of martensite, the average value of Vickers hardness in a region that is

0.3 mm in a sheet thickness direction and 0.6 mm in a direction orthogonal to the sheet thickness direction is 670 or more, the standard deviation of the Vickers hardness in the region is 20 or less, and the tensile strength is 2300 MPa or more.

FIG. 1



Description

[Technical Field]

5 **[0001]** The present invention relates to a hot-stamped product.

[0002] Priority is claimed on Japanese Patent Application No. 2020-022634 and Japanese Patent Application No. 2020-022635, filed in Japan on February 13, 2020, the contents of which are incorporated herein by reference.

[Background Art]

10 **[0003]** At the present time where industrial technology fields have become highly specialized, there is a demand for materials that are used in each technical field to have special and advanced performance. For example, there is a demand for steel sheets for a vehicle to have a high strength in order to improve gas mileage by weight reduction in vehicle bodies in consideration of the global environment. High strength steel sheets are capable of imparting a desired strength to vehicle bodies while reducing the weights of the vehicle bodies by reducing the sheet thicknesses of the steel sheets in the case of being applied to the vehicle bodies of vehicles.

[0004] However, in press forming, which is a step of forming vehicle body members of vehicles, cracks and wrinkles are more likely to be generated as the thicknesses of steel sheets to be used decrease. Therefore, excellent press formability is also required for steel sheets for a vehicle.

20 **[0005]** Securement of press formability and the high-strengthening of steel sheets are conflicting elements, and thus it is difficult to satisfy these characteristics at the same time. In addition, when a high strength steel sheet is pressed and a member is taken out from a die, the shape of the member significantly changes due to spring back, and thus it becomes difficult to secure the dimensional accuracy of the member. As described above, it is not easy to manufacture high-strength vehicle body members by press forming.

25 **[0006]** Hitherto, as a method for manufacturing a vehicle body member having an ultrahigh strength, for example, a technique in which a heated steel sheet is pressed using a low-temperature press die as disclosed in Patent Document 1 has been proposed. This technique is called hot stamping, hot pressing or the like and is capable of manufacturing a member with a complicated shape with a high dimensional accuracy by pressing a soft steel sheet in a state of being heated to a high temperature. In addition, since the steel sheet is rapidly cooled due to the contact with a die, it becomes possible to significantly increase the strength by quenching at the same time as the press forming. For example, Patent Document 1 describes that a member having a tensile strength of 1400 MPa or more can be obtained by hot stamping a steel sheet having a tensile strength of 500 to 600 MPa.

30 **[0007]** Furthermore, as a technique for manufacturing a hot stamping member with a high strength, Patent Document 2 discloses a hot stamping member having a tensile strength of 1770 to 1940 MPa and a manufacturing method thereof, and Patent Document 3 discloses a hot stamping member having a tensile strength of 1960 to 2130 MPa and a manufacturing method thereof. In the methods described in Patent Document 2 and Patent Document 3, a steel sheet for hot stamping is heated to a two phase region of ferrite and austenite and then hot-stamped to form a composite structure of ferrite and martensite having an average grain diameter of 7 μm or less as the microstructure of a hot stamping member, thereby enhancing the ductility of the steel sheet that configures a member.

40 **[0008]** Patent Document 4 discloses a technique for manufacturing a hot stamping member having excellent toughness and a tensile strength of 1800 MPa or more. In a method described in Patent Document 4, a steel sheet for hot stamping is heated to a low-temperature region of austenite, then, hot-stamped and relatively slowly cooled in a temperature range of the Ms point or lower, thereby forming a microstructure formed of tempered martensite having a prior austenite grain size of 10 μm or less and enhancing the toughness of a member. The technique disclosed in Patent Document 4 is capable of obtaining a 1800 MPa-class hot stamping member in which cracking does not occur even in a lot-temperature impact test and is thus excellent.

[Citation List]

[Patent Documents]

[0009]

[Patent Document 1]

Japanese Unexamined Patent Application, First Publication No. 2002-102980

[Patent Document 2]

Japanese Unexamined Patent Application, First Publication No. 2010-65294

[Patent Document 3]

Japanese Unexamined Patent Application, First Publication No. 2010-65295

[Patent Document 4]

Japanese Unexamined Patent Application, First Publication No. 2006-152427

[Summary of the invention]

[Problems to be Solved by the Invention]

[0010] However, according to the present inventors' studies, it was found that, in the hot stamping members composed of a composite structure of ferrite and martensite as described in Patent Documents 2 and 3, when the member distorts upon a collision, there is a case where cracking occurs from ferrite as the starting point in the initial phase of the distortion, and, in particular, when the tensile strength of the member exceeds 2300 MPa, it becomes difficult to secure the collision safety of vehicle bodies.

[0011] In addition, Patent Document 4 describes nothing about a member having a tensile strength of 2300 MPa or more. According to the present inventors' research, it was found that, even in a hot stamping member formed of a single-phase structure of tempered martensite as described in Patent Document 4, if the tensile strength is increased up to 2300 MPa or more, particularly in a case where the forming temperature during the hot stamping of a steel sheet is low, a local fluctuation in hardness is caused in the member, and a strong requirement for crashworthiness of these days cannot be sufficiently met. In addition, it was found that such a local fluctuation in hardness is large particularly in a case where a material steel sheet for hot stamping is a plated steel sheet.

[0012] As described above, in the related art, it was difficult to manufacture a member having a tensile strength of 2300 MPa or more, particularly, a hot stamping member (formed article) having excellent crashworthiness and a tensile strength of 2300 MPa or more by hot stamping.

[0013] An objective of the present invention is to solve the above-described problems and to provide a hot-stamped product having a portion with excellent crashworthiness and a tensile strength of 2300 MPa or more.

[Means for Solving the Problem]

[0014] The present invention has been made to solve the above-described problems, and the gist of the present invention is the following hot-stamped product.

(1) A hot-stamped product according to one aspect of the present invention is a hot-stamped product including a steel sheet, in which all or part of the steel sheet has a chemical composition of, by mass%, C: more than 0.40% and 0.70% or less, Si: less than 2.00%, Mn: 0.01% or more and less than 0.50%, P: 0.200% or less, S: 0.0200% or less, sol. Al: 0.001% to 1.000%, N: 0.0200% or less, Mo: 0.01% or more and less than 0.50%, B: 0.0002% to 0.0200%, Ti: 0% to 0.200%, Nb: 0% to 0.200%, V: 0% to 0.200%, Zr: 0% to 0.200%, Cr: 0% to 2.00%, W: 0% to 2.00%, Cu: 0% to 2.00%, Ni: 0% to 2.00%, Ca: 0% to 0.0100%, Mg: 0% to 0.0100%, REM: 0% to 0.1000% and Bi: 0% to 0.0500% with a remainder of Fe and impurities, at a 1/4 depth position of a sheet thickness from a surface of the steel sheet, a microstructure contains, by vol%, more than 90.0% of martensite, the average value of Vickers hardness in a region that is 0.3 mm in a sheet thickness direction and 0.6 mm in a direction orthogonal to the sheet thickness direction is 670 or more, the standard deviation of the Vickers hardness in the region is 20 or less, and the tensile strength is 2300 MPa or more.

(2) In the hot-stamped product according to (1), the yield ratio may be 0.65 or more.

(3) A hot-stamped product according to another aspect of the present invention including a steel sheet and a plating layer formed on a surface of the steel sheet, in which all or part of the steel sheet has a chemical composition of, by mass%, C: more than 0.40% and 0.70% or less, Si: less than 2.00%, Mn: 0.01% or more and less than 0.50%, P: 0.200% or less, S: 0.0200% or less, sol. Al: 0.001% to 1.000%, N: 0.0200% or less, Mo: 0.01% or more and less than 0.50%, B: 0.0002% to 0.0200%, Ti: 0% to 0.200%, Nb: 0% to 0.200%, V: 0% to 0.200%, Zr: 0% to 0.200%, Cr: 0% to 2.00%, W: 0% to 2.00%, Cu: 0% to 2.00%, Ni: 0% to 2.00%, Ca: 0% to 0.0100%, Mg: 0% to 0.0100%, REM: 0% to 0.1000% and Bi: 0% to 0.0500% with a remainder of Fe and impurities, at a 1/4 depth position of a sheet thickness of the steel sheet from an interface between the steel sheet and the plating layer, a microstructure contains, by vol%, more than 90.0% of martensite, an average value of Vickers hardness in a region that is 0.3 mm in a sheet thickness direction and 0.6 mm in a direction orthogonal to the sheet thickness direction is 670 or more, the standard deviation of the Vickers hardness in the region is 20 or less, the tensile strength is 2300 MPa or more, and the yield ratio is 0.65 or more.

(4) The hot-stamped product according to any one of (1) to (3) may contain, in the chemical composition, by mass%, one or more selected from the group consisting of Ti: 0.001 % to 0.200%, Nb: 0.001% to 0.200%, V: 0.001 % to 0.200% and Zr: 0.001% to 0.200%.

(5) The hot-stamped product according to any one of (1) to (4) may contain, in the chemical composition, by mass%, one or more selected from the group consisting of Cr: 0.001% to 2.00%, W: 0.001% to 2.00%, Cu: 0.001% to 2.00% and Ni: 0.001% to 2.00%.

(6) The hot-stamped product according to any one of (1) to (5) may contain, in the chemical composition, by mass%, one or more selected from the group consisting of Ca: 0.0001% to 0.0100%, Mg: 0.0001% to 0.0100% and REM: 0.0001% to 0.1000%.

(7) The hot-stamped product according to any one of (1) to (6) may contain, in the chemical composition, by mass%, Bi: 0.0001% to 0.0500%.

[Effects of the Invention]

[0015] According to the aspect of the present invention, it is possible to obtain a hot-stamped product excellent in crashworthiness and having a portion in which a tensile strength of 2300 MPa or more.

[Brief Description of Drawings]

[0016]

Fig. 1 is a schematic view showing hardness measurement positions in a hot-stamped product.

Fig. 2 is a schematic view showing an example of a shape of the hot-stamped product.

Fig. 3 is a schematic view showing a shape of a three-point bend test body.

Fig. 4 is a schematic view showing the disposition of a tester and the test body in the three-point bend test.

[Embodiment of the Invention]

[0017] The present inventors intensively studied a method for suppressing the occurrence of cracking when a hot-stamped product having a tensile strength of 2300 MPa or more distorts due to a collision. As a result, the following findings were obtained.

(A) In the hot-stamped product having a tensile strength of 2300 MPa or more, a local fluctuation in hardness is large. The reason therefor is not clear, but is assumed that (a) in a material before hot stamping that is to have a tensile strength of 2300 MPa or more after hot stamping (steel sheet for hot stamping), the local unevenness in the Mn or Mo concentration is large, (b) in a portion with a low Mn or Mo concentration, a microstructure with a high ferrite fraction is exhibited in the steel sheet for hot stamping, austenite coarsens in this portion in a process of heating the steel sheet for hot stamping, and the hardness is likely to become low in a formed article after hot stamping (hot-stamped product), and (c) on the other hand, in a portion with a high Mn or Mo concentration, a microstructure with a high pearlite fraction is exhibited in the steel sheet for hot stamping, austenite is refined in this portion in the process of heating the steel sheet for hot stamping, and the hardness is likely to become high in the formed article after hot stamping.

(B) As the local fluctuation in hardness in the hot-stamped product increases, cracking is more likely to occur in the initial phase of distortion when the formed article distorts. This is considered to be because stress concentrates in a portion with a low hardness.

(C) In a hot-stamped product having a plating layer on the surface, a local fluctuation in hardness is likely to become large compared with a case where the hot-stamped product does not have the plating layer. The reason therefor is not clear, but is assumed that (a) the fluctuation in hardness becomes smaller as the strain energy accumulating in the steel sheet for hot stamping becomes higher and (b) in a plated steel sheet that is manufactured through an annealing step, the strain energy accumulated during hot rolling is released during annealing.

(D) When a steel sheet manufactured without annealing after a cold rolling step (also referred to as a steel sheet as cold rolled or full hard) is used as the steel sheet for hot stamping, the occurrence of cracking upon the distortion of a formed article is suppressed.

The reason therefor is not clear, but is assumed that (a) in the steel sheet as cold rolled, since processing strain during cold rolling accumulates, austenite is refined in a process of heating the steel sheet for hot stamping, and the hardness of a hot-stamped product increases and (b) this effect is strong in a portion with a low Mn or Mo concentration and the use of the steel sheet as cold rolled decreases the local fluctuation in hardness in the hot-stamped product.

(E) In a step of carrying out hot stamping, when a temperature at which the hot stamping is started (forming start temperature) is increased, the occurrence of cracking upon the distortion of the formed article is suppressed.

The reason therefor is not clear, but is assumed that (a) in the steel sheet for hot stamping, in a portion in which the

Mn or Mo concentration is high, strain is more likely to accumulate in austenite during hot stamping, and the hardness becomes higher in the hot-stamped product and (b) when hot stamping is carried out at a high temperature, accumulation of strain in austenite is suppressed, and the hardness of the hot-stamped product becomes low, but this effect is stronger in a portion with a high Mn or Mo concentration than in a portion with a low Mn or Mo concentration, and thus hot stamping at a high temperature decreases the local fluctuation in hardness in the hot-stamped product. (F) When a reheating treatment is carried out on the hot-stamped product at a low temperature after hot stamping, the occurrence of cracking upon the distortion of the formed article is suppressed.

The reason therefor is not clear, but is assumed that (a) the reheating decreases the amount of carbon present in a solid state in martensite and decreases the hardness of the hot-stamped product and (b) this effect is strong in a portion with a high Mn or Mo concentration, and the reheating treatment decreases the local fluctuation in hardness in the hot-stamped product.

[0018] From the above findings (A) to (F), the present inventors found that, when a steel sheet as cold rolled is used as a material steel sheet, and the steel sheet as cold rolled is heated and then hot stamping is started at a high temperature, it is possible to manufacture a hot-stamped product in which the tensile strength is 2300 MPa or more, the local fluctuation in hardness is small and the crashworthiness is excellent.

[0019] Alternatively, it was found that, even in a case where a plated steel sheet is used as a material steel sheet, when a plated steel sheet is heated, then, hot stamping is started at a high temperature, and, after the hot stamping, a reheating treatment is carried out at a low temperature, it is possible to manufacture a hot-stamped product having a plating layer on a surface in which the tensile strength is 2300 MPa or more, a local fluctuation in hardness is small and the crashworthiness is excellent.

[0020] Hereinafter, each requirement of a hot-stamped product according to one embodiment of the present invention (the hot-stamped product according to the present embodiment) and a manufacturing method thereof will be described in detail.

<Chemical composition of steel sheet included in hot-stamped product>

[0021] All or part of a steel sheet included in the hot-stamped product according to the present embodiment has a chemical composition shown below (in a case where the hot-stamped product is consisting of a steel sheet, all or part of the hot-stamped product can be said to have a chemical composition shown below). The reason for limiting each element is as described below. "%" regarding contents in the following description means "mass%". In addition, numerical value ranges shown using "to" include numerical values at both ends in the ranges. On the other hand, numerical values shown using "less than" or "more than" do not include the numerical values in the ranges.

[0022] In a case where the hot-stamped product includes a portion having a tensile strength of 2300 MPa or more and a portion having a tensile strength of less than 2300 MPa (in a case where the steel sheet included in the hot-stamped product according to the present embodiment includes a portion having a tensile strength of 2300 MPa or more and a portion having a tensile strength of less than 2300 MPa), at least the portion where the tensile strength becomes 2300 MPa or more needs to have the following chemical composition.

[0023] In a case where the hot-stamped product includes a steel sheet and a plating layer formed on a surface of the steel sheet, the chemical composition to be described below means the chemical composition of the steel sheet excluding the plating layer.

C: More than 0.40% and 0.70% or less

[0024] C is an element having an effect on an increase in the tensile strength of the steel sheet after hot-stamping (the steel sheet included in the hot-stamped product). When the C content is 0.40% or less, the tensile strength of the hot-stamped product sheet becomes less than 2300 MPa, and the strength of the formed article becomes insufficient. Therefore, the C content is set to more than 0.40%. The preferable C content is more than 0.42%, more than 0.43%, more than 0.44% or more than 0.45%.

[0025] On the other hand, when the C content exceeds 0.70%, the strength of the hot-stamped product becomes too high, and it becomes impossible to secure the crashworthiness. Therefore, the C content is set to 0.70% or less. The preferable C content is 0.65% or less, 0.60% or less, 0.55% or less or 0.50% or less.

Si: Less than 2.00%

[0026] Si is an element that is contained in steel as an impurity and embrittles steel. When the Si content becomes 2.00% or more, the adverse influence of Si becomes particularly large. Therefore, the Si content is set to less than 2.00%. The preferable Si content is less than 1.50%, less than 1.00%, less than 0.75% or less than 0.50%. From the

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viewpoint of securing the plateability, the Si content is preferably set to 0.40% or less, 0.30% or less or 0.20% or less.

[0027] The lower limit of the Si content is not particularly limited, but an excessive decrease in the Si content increases the steelmaking cost. Therefore, the Si content is preferably set to 0.001% or more. In addition, Si has an action of enhancing the hardenability of steel and thus may be actively incorporated. From the viewpoint of improving the hardenability, the Si content is preferably 0.10% or more, 0.20% or more or 0.30% or more.

Mn: 0.01% or more and less than 0.50%

[0028] Mn is an element that degrades the crashworthiness of the hot-stamped product. When the Mn content is 0.50% or more, the crashworthiness significantly deteriorates, and it becomes impossible to secure the crashworthiness of the formed article even in the case of applying a manufacturing method of the hot-stamped product to be described below. Therefore, the Mn content is set to less than 0.50%. The Mn content is preferably less than 0.45%, less than 0.40%, less than 0.35% or less than 0.30%.

[0029] On the other hand, Mn is an element that bonds to S, which is an impurity, to form MnS and has an action of suppressing the harmful effect of S. In order to obtain this effect, the Mn content is set to 0.01% or more. The Mn content is preferably 0.05% or more or 0.10% or more. In addition, Mn is an element that improves the hardenability of steel. From the viewpoint of improving the hardenability, the Mn content is preferably 0.15% or more, 0.20% or more or 0.25% or more.

P: 0.200% or less

[0030] P is an element that is contained in steel as an impurity and embrittles steel. When the P content exceeds 0.200%, the adverse influence of P becomes particularly large, and furthermore, the weldability significantly deteriorates. Therefore, the P content is set to 0.200% or less. The preferable P content is less than 0.100%, less than 0.050% or less than 0.020%. From the viewpoint of securing the plateability, the P content is preferably less than 0.020%, less than 0.015% or less than 0.010%.

[0031] The lower limit of the P content is not particularly limited, but an excessive decrease in the P content increase the steelmaking cost. Therefore, the P content may be set to 0.001% or more.

S: 0.0200% or less

[0032] S is an element that is contained in steel as an impurity and embrittles steel. When the S content exceeds 0.0200%, the adverse influence of S becomes particularly large. Therefore, the S content is set to 0.0200% or less. The preferable S content is less than 0.0050%, less than 0.0020% or less than 0.0010%.

[0033] The lower limit of the S content is not particularly limited, but an excessive decrease in the S content increase the steelmaking cost. Therefore, the S content may be set to 0.0001% or more.

sol. Al: 0.001% to 1.000%

[0034] Al is an element having an action of deoxidizing molten steel. When the sol. Al content (acid-soluble Al content) is less than 0.001%, deoxidation becomes insufficient. Therefore, the sol. Al content is set to 0.001% or more. The sol. Al content is preferably 0.005% or more, 0.010% or more or 0.020% or more.

[0035] On the other hand, when the sol. Al content is too high, the transformation point increases, and it becomes difficult to heat the steel sheet to a temperature exceeding the Ac_3 point in a heating step of hot stamping. Therefore, the sol. Al content is set to 1.000% or less. The sol. Al content is preferably less than 0.500%, less than 0.100%, less than 0.060% or less than 0.040%.

N: 0.0200% or less

[0036] N is an element that is contained in steel as an impurity and forms a nitride during the continuous casting of steel. Since this nitride degrades the ductility of the hot-stamped product sheet, the N content is preferably as low as possible. When the N content becomes more than 0.0200%, the adverse influence of Si becomes particularly large. Therefore, the N content is set to 0.0200% or less. The N content is preferably less than 0.0100%, less than 0.0080% or less than 0.0050%.

[0037] The lower limit of the N content is not particularly limited, but an excessive decrease in the N content increase the steelmaking cost. Therefore, the N content may be set to 0.0010% or more.

Mo: 0.01% or more and less than 0.50%

[0038] Mo is an element that improves the hardenability of steel and an effective element for securing the strength of the hot-stamped product by forming a microstructure mainly containing martensite. In order to obtain this effect, the Mo, content is set to 0.01% or more. The preferable Mo content is 0.05% or more, 0.10% or more or 0.15% or more.

[0039] On the other hand, Mo is an element that degrades the crashworthiness of the hot-stamped product. When the Mo content is 0.50% or more, the crashworthiness significantly deteriorates, and it becomes impossible to secure the crashworthiness of the formed article even in the case of applying the manufacturing method of the hot-stamped product to be described below. Therefore, the Mo content is set to less than 0.50%. The Mo content is preferably less than 0.40%, less than 0.35% or less than 0.30%.

B: 0.0002% to 0.0200%

[0040] B is an element that improves the hardenability of steel and an effective element for forming a microstructure mainly containing martensite and securing the strength of the hot-stamped product. In order to obtain this effect, the B content is set to 0.0002% or more. The preferable B content is 0.0006% or more, 0.0010% or more or 0.0015% or more.

[0041] On the other hand, in a case where the B content exceeds 0.0200%, a carboboride is formed, and the effect of B contained on the improvement in the hardenability is impaired. Therefore, the B content is set to 0.0200% or less. The preferable B content is less than 0.0050%, less than 0.0040% or less than 0.0030%.

[0042] The hot-stamped product according to the present embodiment may have a chemical composition including the above-described chemical components with a remainder of Fe and impurities; however, in order to improve characteristics or the like, the hot-stamped product according to the present embodiment may further contain one or more selected from the group consisting of Ti, Nb, V, Zr, Cr, W, Cu, Ni, Ca, Mg, REM and Bi. These elements (optional elements) do not need to be contained at all times, and thus the lower limits are 0%.

[0043] Here, the "impurity" means a component that is mixed in from a raw material such as ore or a scrap or due to a variety of factors in manufacturing steps at the time of industrially manufacturing the steel sheet and is allowed to an extent that the hot-stamped product according to the present embodiment is not adversely affected.

Ti: 0% to 0.200%

Nb: 0% to 0.200%

V: 0% to 0.200%

Zr: 0% to 0.200%

[0044] Ti, Nb, V and Zr are elements having an action of improving the crashworthiness of the hot-stamped product by the refinement of the microstructure. In order to obtain this effect, one or more selected from the group consisting of Ti, Nb, V and Zr may be contained as necessary.

[0045] In the case of hoping to obtain the above-described effect, the amount of each of one or more selected from the group consisting of Ti, Nb, V and Zr contained is preferably 0.001% or more, more preferably 0.005% or more and still more preferably 0.010% or more.

[0046] On the other hand, in a case where the amount of each of Ti, Nb, V and Zr exceeds 0.200%, the above-described effect is saturated, and thus the manufacturing cost of the steel sheet increases. Therefore, in the case of being contained, the amount of each of Ti, Nb, V and Zr is set to 0.200% or less.

[0047] In a case where the amount of Ti, Nb, V and Zr is large, a large amount of carbides of these elements are precipitated, and the ductility of the hot-stamped product sheet is impaired. From the viewpoint of securing the ductility, the preferable Ti content is less than 0.050% or less than 0.030%, the preferable Nb content is less than 0.050%, less than 0.030% or less than 0.020%, the preferable V content is less than 0.100% or less than 0.050% and the preferable Zr content is less than 0.100% or less than 0.050%.

Cr: 0% to 2.00%

W: 0% to 2.00%

Cu: 0% to 2.00%

Ni: 0% to 2.00%

[0048] Cr, W, Cu and Ni are elements having an action of enhancing the hardenability of steel. Therefore, one or more selected from the group consisting of Cr, W, Cu and Ni may be contained as necessary.

[0049] In the case of hoping to obtain the above-described effect, the amount of each of one or more selected from the group consisting of Cr, W, Cu and Ni contained is preferably 0.001% or more. A more preferable Cr content is 0.05% or more or 0.10% or more, a more preferable W content is 0.05% or more or 0.10% or more, a more preferable Cu content is 0.10% or more and a more preferable Ni content is 0.10% or more.

[0050] On the other hand, when the amount of each of Cr, W, Cu and Ni exceeds 2.00%, the crashworthiness of the hot-stamped product deteriorates. Therefore, in the case of being contained, the amount of each of Cr, W, Cu and Ni is set to 2.00% or less. The preferable Cr content is less than 0.50%, less than 0.40% or less than 0.30%, the preferable W content is less than 0.50%, less than 0.40% or less than 0.30%, the preferable Cu content is less than 1.00% or less than 0.50% and the preferable Ni content is less than 1.00% or less than 0.50%.

Ca: 0% to 0.0100%
Mg: 0% to 0.0100%
REM: 0% to 0.1000%

[0051] Ca, Mg and REM are elements having an action of improving the ductility of the steel sheet after hot-stamping by adjusting the shape of an inclusion. Therefore, Ca, Mg and REM may be contained as necessary. In the case of hoping to obtain the above-described effect, the amount of each of one or more selected from the group consisting of Ca, Mg and REM contained is preferably 0.0001% or more.

[0052] On the other hand, in a case where the Ca or Mg content is more than 0.0100% or the REM content is more than 0.1000%, not only is the above-described effect saturated, but an excessive cost is also caused. Therefore, in the case of being contained, the amount of each of Ca and Mg is set to 0.0100% or less, and the REM content is set to 0.1000% or less.

[0053] In the present embodiment, REM refers to a total of 17 elements of Sc, Y, and lanthanoids, and the REM content means the total amount of these elements. Industrially, lanthanoids are added in a mischmetal form.

Bi: 0% to 0.0500%

[0054] Bi is an element having an action of improving the crashworthiness of the hot-stamped product by refining a solidification structure. Therefore, Bi may be contained as necessary. In the case of hoping to obtain the above-described effect, the Bi content is preferably 0.0001% or more. A more preferable Bi content is 0.0003% or more or 0.0005% or more.

[0055] On the other hand, in a case where the Bi content exceeds 0.0500%, the above-described effect is saturated, and an excessive cost is caused. Therefore, in the case of being contained, the Bi content is set to 0.0500% or less. A more preferable Bi content is 0.0100% or less or 0.0050% or less.

[0056] As described above, in the chemical composition of the hot-stamped product according to the present embodiment, the essential elements are contained and the remainder may be Fe and impurities or the essential elements are contained, and, furthermore, one or more of the optional elements are contained, and the remainder may be Fe and impurities.

<Microstructure of steel sheet included in the hot-stamped product>

[0057] The microstructure of the steel sheet included in the hot-stamped product according to the present embodiment will be described. All or part of the steel sheet included in the hot-stamped product according to the present embodiment has a microstructure containing martensite in the amount shown below (in a case where the hot-stamped product is consisting of a steel sheet, all or part of the hot-stamped product can be said to have a microstructure containing martensite in an amount shown below). "%" in the following description regarding the microstructure means "vol%". In a case where the hot-stamped product includes a portion having a tensile strength of 2300 MPa or more and a portion having a tensile strength of less than 2300 MPa, at least the portion where the tensile strength becomes 2300 MPa or more needs to have the following microstructure.

[0058] In a case where the hot-stamped product includes a steel sheet and a plating layer formed on a surface of the steel sheet, the microstructure to be described below means the microstructure of the steel sheet.

[0059] In the hot-stamped product according to the present embodiment, a microstructure at a 1/4 depth position of the sheet thickness from the surface of the steel sheet (the interface between the steel sheet and the plating layer in the case of having the plating layer) is specified.

Martensite: More than 90.0% by vol%

[0060] Martensite is an important structure for increasing the tensile strength of the hot-stamped product sheet. When the volume percentage of martensite is 90.0% or less, the tensile strength of the steel sheet after hot-stamping (the

tensile strength of the steel sheet included in the hot-stamped product) becomes less than 2300 MPa, and the strength becomes insufficient. Therefore, the volume percentage of martensite is set to more than 90.0%. The preferable volume percentage of martensite is more than 91.0%, more than 93.0% or more than 95.0%.

[0061] The upper limit of the volume percentage of martensite does not need to be particularly determined; however, in order to significantly increase the volume percentage of martensite, it is necessary to excessively increase the heating temperature of the steel sheet or excessively increase the cooling rate in a hot stamping step, which significantly impairs the productivity of the hot-stamped product. Therefore, the volume percentage of martensite is preferably set to 99.0% or less or 98.0% or less.

[0062] In the martensite, in addition to fresh martensite that is not tempered, tempered martensite that has been tempered and contains an iron carbide is contained.

[0063] The remainder of the microstructure may contain ferrite, pearlite, bainite or residual austenite and may further contain a precipitate such as cementite. Since there is no need to contain ferrite, pearlite, bainite, residual austenite and the precipitate, the lower limits of the volume percentages of ferrite, pearlite, bainite, residual austenite and the precipitate are all 0%.

[0064] Since ferrite, pearlite and bainite have an action of improving the ductility of the hot-stamped product sheet, in the case of obtaining this effect, one or more selected from the group consisting of ferrite, pearlite and bainite are preferably contained. The volume percentage of ferrite is preferably set to 0.5% or more or 1.0% or more, and the volume percentages of pearlite and bainite are each preferably set to 1.0% or more and each more preferably set to 2.0% or more.

[0065] On the other hand, when ferrite, pearlite and bainite are excessively contained, the crashworthiness of the hot-stamped product deteriorates. Therefore, the volume percentage of ferrite is preferably set to less than 3.0% or less than 2.0%, and the volume percentages of pearlite and bainite are each preferably set to less than 10.0% and each more preferably set to less than 5.0%.

[0066] Residual austenite has an action of improving the ductility of the hot-stamped product sheet. In the case of obtaining this effect, the volume percentage of residual austenite is preferably set to 0.5% or more, 1.0% or more or 2.0% or more.

[0067] On the other hand, in order to excessively increase the volume percentage of residual austenite, it is necessary to carry out an austempering treatment at a high temperature after hot stamping, which significantly degrades the productivity of the hot-stamped product. In addition, when residual austenite is excessively contained, there is a case where the crashworthiness of the hot-stamped product deteriorates. Therefore, the volume percentage of residual austenite is preferably set to less than 9.0%, less than 7.0%, less than 5.0% or less than 4.0%.

[0068] In the present embodiment, the volume percentage of each structure is obtained as described below.

[0069] First, a test piece is collected from the hot-stamped product, the longitudinal section of the steel sheet is polished with a buffer, and then the structure is observed at a 1/4 depth position of the sheet thickness of the steel sheet in the sheet thickness direction of the steel sheet from the surface of the steel sheet (the interface between the steel sheet, which is a substrate, and a plating layer in the case of having the plating layer). In a case where the hot-stamped product includes a portion having a tensile strength of 2300 MPa or more and a portion having a tensile strength of less than 2300 MPa, the test piece is collected from the portion where the tensile strength becomes 2300 MPa or more, and the structure is observed.

[0070] Specifically, the polished surface is Nital-etched or electrolytically polished, the structure is observed using an optical microscope and a scanning electron microscope (SEM), and image analysis is carried out on an obtained structural photograph based on a luminance difference or a difference in form among iron carbides present in the phase, thereby obtaining the area ratio of each of ferrite, pearlite, bainite and tempered martensite. After that, the same observation position is LePera-etched, the structure is observed using the optical microscope and the scanning electron microscope (SEM), and image analysis is carried out on an obtained structural photograph, thereby calculating the total area ratio of residual austenite and martensite.

[0071] In addition, at the same observation position, the longitudinal section is electrolytically polished, and then the area ratio of residual austenite is measured using a SEM including an electron backscatter diffraction pattern analyzer (EBSP).

[0072] Based on these results, the area ratio of each of ferrite, pearlite, bainite, tempered martensite, martensite and residual austenite is obtained. In addition, with an assumption that the area ratio is equal to the volume percentage, the measured area ratio is regarded as the volume percentage of each structure.

[0073] In the structural observation, tempered martensite can be differentiated from martensite due to the fact that iron carbides are present in tempered martensite and can be differentiated from bainite due to the fact that the iron carbides present in tempered martensite elongate in a plurality of directions.

<Strength of hot-stamped product>

[0074] All or part of the hot-stamped product according to the present embodiment has a tensile strength of 2300 MPa

or more. In order for that, the tensile strength of all or part of the steel sheet included in the hot-stamped product according to the present embodiment is 2300 MPa or more. When the tensile strength is not 2300 MPa or more in at least a part, it becomes impossible to secure the impact absorption amount of the hot-stamped product. Therefore, the tensile strength of all or part of the hot-stamped product is set to 2300 MPa or more. In all or part of the hot-stamped product, the tensile strength is preferably 2400 MPa or more or 2500 MPa or more. On the other hand, since an excessive increase in the strength of the hot-stamped product degrades the crashworthiness, the tensile strength of the hot-stamped product is preferably set to less than 3000 MPa or less than 2800 MPa.

[0075] In all or part of the hot-stamped product according to the present embodiment, it is preferable that the tensile strength is 2300 MPa or more and the yield ratio is 0.65 or more. When the yield ratio is set to 0.65 or more, it becomes possible to further improve the crashworthiness. In all or part of the hot-stamped product according to the present embodiment, the yield ratio is more preferably 0.68 or more or 0.70 or more. On the other hand, the upper limit of the yield ratio is not particularly limited; however, in order to significantly increase the yield ratio, it is necessary to excessively increase the reheating temperature in the reheating step to be described below, which decreases the strength of the formed article. Therefore, the yield ratio is preferably set to less than 0.90, less than 0.85 or less than 0.80.

[0076] In the hot-stamped product according to the present embodiment, the tensile strength may be 2300 MPa or more in all of the hot-stamped product (the entire formed article), but a portion having a tensile strength of 2300 MPa or more and a portion having a tensile strength of less than 2300 MPa may be present in a mixed form in the hot-stamped product. When portions with different strengths are provided, it becomes possible to control the distortion state of the hot-stamped product upon a collision. A hot-stamped product having portions with different strengths can be manufactured by a method in which two or more steel sheets having different chemical compositions are joined together and then hot-stamped, a method in which the heating temperature or cooling rate after hot stamping of a steel sheet is partially changed in a hot stamping step, a method in which a reheating treatment is partially carried out on a hot-stamped product or the like.

[0077] The tensile strength and the yield ratio are obtained by collecting a JIS No. 13B tensile test piece along the longitudinal direction of a member and carrying out a tensile test at a tension rate of 10 mm/minute.

[0078] The yield ratio is obtained by dividing the yield stress of the steel sheet by the tensile strength. As the yield stress, the 0.2% proof stress is used in a case where the steel sheet yields continuously, and a stress at an upper yield point is used in a case where the steel sheet yields discontinuously.

[0079] The plating layer has a small influence on the tensile strength or the yield ratio, and thus the plating layer may be present on the surface of the test piece.

<Hardness distribution of hot-stamped product>

[0080] In the hot-stamped product according to the present embodiment, the average value of Vickers hardness is 670 (Hv) or more and the standard deviation of the Vickers hardness is 20 (Hv) or less in a 0.18 mm² region, that is, a region that is 0.3 mm long in the sheet thickness direction and 0.6 mm long in a direction orthogonal to the sheet thickness direction, in which the 1/4 depth position of the sheet thickness of the steel sheet in the sheet thickness direction of the steel sheet from the surface of the steel sheet (the interface between the steel sheet, which is a substrate, and the plating layer in the case of having the plating layer) is centered, in the portion where the tensile strength is 2300 MPa or more.

[0081] The fact that the average value of the Vickers hardness is 670 (Hv) or more means that the tensile strength is 2300 MPa or more in the hardness measurement region, and, when the average value of the Vickers hardness is less than 670 (Hv), the strength of the formed article becomes insufficient. Therefore, the average value of the Vickers hardness in the above-described region is set to 670 (Hv) or more. The average value of the Vickers hardness is preferably 695 (Hv) or more or 720 (Hv) or more.

[0082] In addition, when the standard deviation of the Vickers hardness in the above-described region is more than 20 (Hv), cracking occurs in the initial phase of distortion when the formed article distorts, and the crashworthiness significantly deteriorates. Therefore, the standard deviation of the hardness in the above-described region is set to 20 (Hv) or less. The standard deviation of the hardness is preferably 15 (Hv) or less, 12 (Hv) or less or 10 (Hv) or less.

[0083] In the present embodiment, the Vickers hardness of the hot-stamped product is obtained as described below.

[0084] First, a test piece is collected from the hot-stamped product, the longitudinal section of the steel sheet is polished with waterproof abrasive paper and further polished with a buffer using a diamond suspension, and then the Vickers hardness is measured at a 1/4 depth position of the sheet thickness of the steel sheet in the sheet thickness direction of the steel sheet from the surface of the steel sheet (the interface between the steel sheet and the plating layer in the case of having the plating layer). In a case where the hot-stamped product includes a portion having a tensile strength of 2300 MPa or more and a portion having a tensile strength of less than 2300 MPa, the test piece is collected from the portion where the tensile strength is 2300 MPa or more, and the Vickers hardness is measured.

[0085] Specifically, as shown in Fig. 1, in a range that is 0.3 mm long in the sheet thickness direction and 0.6 mm long in a direction orthogonal to the sheet thickness direction, in which the 1/4 depth position is centered, the Vickers hardness

is measured at 45 points at predetermined intervals according to JIS Z 2244: 2009, and the arithmetic average value and the standard deviation are obtained from the obtained measurement values. In the measurement of the hardness, a micro Vickers hardness tester is used, and, as the measurement conditions, the applied load is set to 0.49 N, and the load retention time is set to 10 seconds. When the applied load is high, the dimensions of an indentation become large, and it is not possible to evaluate the distribution of local hardness that is closely related to the crashworthiness. Therefore, the applied load is determined to be 0.49 N.

[0086] Regarding the relationship between the distribution of hardness and the crashworthiness of a hot-stamped product, for example, PCT International Publication No. WO 2018/151325 describes that it is important in terms of securing the crashworthiness that a variation in hardness in a cross section of the compact perpendicular to the longitudinal direction is small. However, in PCT International Publication No. WO 2018/151325, a variation in microhardness in the entire cross-sectional region of the compact is obtained by measuring the Vickers hardness in the central part in the sheet thickness direction at 1 mm intervals with an applied load set to 1 kgf, and it can be said that the distribution of the hardness is different from that of the hot-stamped product according to the present embodiment.

[Plating layer]

[0087] The hot-stamped product according to the present embodiment may have a plating layer on a surface of the steel sheet. When the plating layer is provided on the surface, it becomes possible to prevent the generation of scale during hot stamping and, furthermore, to improve the corrosion resistance of the hot-stamped product. The type of plating needs to be suitable for the objective and is not particularly limited. The plating layer in the hot-stamped product can be formed by carrying out hot stamping using a plated steel sheet as described below. An example of the type of the plating layer includes a zinc-based plating layer or aluminum-based plating layer hot-stamped using a zinc-based plated steel sheet or an aluminum-based plated steel sheet. The plating layer may be formed on one surface or may be formed on both surfaces.

[0088] Next, a steel sheet for hot stamping suitable for manufacturing the hot-stamped product (hereinafter, the steel sheet for hot stamping according to the present embodiment) will be described.

<Chemical composition of steel sheet for hot stamping>

[0089] Since chemical compositions substantially do not change due to hot stamping, the chemical composition of the steel sheet for hot stamping is set to be the same as the chemical composition of the hot-stamped product.

<Microstructure of steel sheet for hot stamping>

[0090] The steel sheet for hot stamping according to the present embodiment is a steel sheet that is manufactured without annealing after a cold rolling step and has a microstructure expanded in a rolling direction in which strain energy is high (also referred to as the steel sheet as cold rolled or full hard) or a plated steel sheet.

[0091] The reason for forming such a microstructure is to decrease a local fluctuation in the hardness of the hot-stamped product and to improve the crashworthiness of the formed article. The steel sheet as cold rolled in which accumulated strain energy is high is preferably used since it is possible to decrease the local fluctuation in hardness by a small number of manufacturing steps. On the other hand, from the viewpoint of preventing the generation of scale in the manufacturing steps and, furthermore, improving the corrosion resistance of the hot-stamped product, the plated steel sheet is preferably used.

[0092] In any case of the steel sheet as cold rolled or the plated steel sheet, when martensite is contained in the microstructure, the steel sheet becomes significantly hard, and it becomes difficult to cut the steel sheet. Therefore, in the case of the steel sheet as cold rolled, the microstructure of the steel sheet for hot stamping preferably mainly contains ferrite, pearlite and/or bainite expanded in the rolling direction. The total volume percentage of ferrite expanded in the rolling direction, pearlite expanded in the rolling direction and bainite expanded in the rolling direction is more preferably more than 90.0% or more than 95.0%. In the case of the plated steel sheet, the microstructure preferably mainly contains ferrite, pearlite and/or bainite.

[0093] The volume percentage in the microstructure of the steel sheet for hot stamping can be obtained by collecting a test piece from the steel sheet for hot stamping, polishing a longitudinal section of the steel sheet parallel to the rolling direction with a buff and then observing the structure by the same method as that in the case of the hot-stamped product at the 1/4 depth position of the sheet thickness of the steel sheet in the sheet thickness direction of the steel sheet from the surface of the steel sheet (the interface between the steel sheet and the plating layer in the case of the plated steel sheet).

[0094] The type of the plated steel sheet is not particularly limited, and examples thereof include a hot-dip galvanized steel sheet, a galvannealed steel sheet, a hot-dip aluminum-plated steel sheet, a hot-dip Zn-Al alloy-plated steel sheet,

a hot-dip Zn-Al-Mg alloy-plated steel sheet, a hot-dip Zn-Al-Mg-Si alloy-plated steel sheet and the like. The plating layer may be provided on one surface of the steel sheet or may be provided on both surfaces.

<Strength of steel sheet for hot stamping>

[0095] In a case where the steel sheet for hot stamping according to the present embodiment is the steel sheet as cold rolled, in order to decrease the local fluctuation in the hardness of the hot-stamped product and enhance the crashworthiness of the hot-stamped product, the tensile strength is preferably more than 900 MPa. The tensile strength is more preferably more than 950 MPa or more than 1000 MPa.

<Manufacturing method>

[0096] A manufacturing method of the hot-stamped product according to the present embodiment and the preferable manufacturing method of the steel sheet for hot stamping according to the present embodiment will be described.

[Manufacturing method of hot-stamped product]

[0097] The hot-stamped product according to the present embodiment can be manufactured by a manufacturing method including the following steps (I) and (II) or a manufacturing method including the following steps (i), (ii) and (iii).

(I) A heating step of heating a steel sheet for hot stamping as cold rolled having the above-described chemical composition

(II) A hot stamping step of carrying out hot stamping on the heated steel sheet for hot stamping to obtain a hot-stamped product

(i) A heating step of heating a steel sheet for hot stamping having the above-described chemical composition and having a plating layer on a surface

(ii) A hot stamping step of carrying out hot stamping on the heated steel sheet for hot stamping to obtain a hot-stamped product

(iii) A reheating step of reheating the formed article after the hot stamping step

[0098] In the hot stamping steps (II) and (ii), forming using a die and cooling are carried out.

[0099] Regarding each step, preferable conditions will be described.

[Heating step] (I) and (i)

[0100] In the heating step, prior to the hot stamping step, a steel sheet for hot stamping as cold rolled or a plated steel sheet for hot stamping, which have a predetermined chemical composition, such as the steel sheet for hot stamping according to the present embodiment, is heated. In the heating step of heating the steel sheet for hot stamping, the heating temperature is preferably set to higher than 1050°C and higher than the Ac_3 point. When the heating temperature is higher than 1050°C, in the hot stamping step to be described below, the hot stamping start temperature can be set to higher than 1050°C, and it becomes easy to secure the crashworthiness of the hot-stamped product. In addition, when the heating temperature is higher than the Ac_3 point, the volume percentage of martensite is secured in the microstructure of the hot-stamped product, the strength of the formed article increases, and it becomes easy to secure the crashworthiness. The Ac_3 point is a temperature at which ferrite in the microstructure disappears when the material steel sheet has been heated and can be obtained from a change in the thermal expansion of the steel sheet in the heating step. The heating temperature is preferably higher than 1100°C and higher than the Ac_3 point.

[0101] The upper limit of the heating temperature is not particularly limited; however, when the heating temperature is too high, in a case where the steel sheet for hot stamping is the steel sheet as cold rolled, scale is excessively generated on the hot-stamped product, and the productivity of the formed article deteriorates due to the deposition of the scale in a die. In a case where the steel sheet for hot stamping is a plated steel sheet, the amount of a plating attached decreases, and the corrosion resistance of the hot-stamped product deteriorates. Therefore, the heating temperature is preferably set to 1200°C or lower or 1150°C or lower.

[0102] The heating rate of the steel sheet does not need to be particularly limited; however, as the heating rate is faster, the local fluctuation in hardness in the hot-stamped product decreases, and the crashworthiness improves. Therefore, the average heating rate up to 700°C is preferably set to faster than 10 °C/second, faster than 20°C/second, faster than 30 °C/second or faster than 50 °C/second. On the other hand, when the heating rate is suppressed, it is possible to suppress the formation of a coarse iron carbide in microstructure of the hot-stamped product, and the ductility of the hot-stamped product sheet can be enhanced. Therefore, the average heating rate is preferably set to slower than

150 °C/second, slower than 120°C/second or slower than 90 °C/second.

[Hot stamping step] (II) and (ii)

[0103] In the step of carrying out hot stamping on the heated steel sheet for hot stamping, the heated steel sheet is taken out from a heating furnace and cooled in the atmosphere, and hot stamping is started. The hot stamping start temperature is preferably higher than 1050°C. When the hot stamping start temperature is higher than 1050°C, the excessive accumulation of strain in austenite during hot stamping is suppressed, the local fluctuation in hardness in the hot-stamped product decreases, and the crashworthiness can be enhanced. The hot stamping start temperature is preferably higher than 1100°C.

[0104] The upper limit of the hot stamping start temperature is not particularly limited; however, in order to increase the start temperature, it is necessary to increase the heating temperature of the steel sheet in the above-described heating step. In this case, scale is excessively generated on the hot-stamped product, and the productivity of the formed article deteriorates or the corrosion resistance of the hot-stamped product deteriorates. Therefore, the start temperature is preferably set to 1200°C or lower or 1150°C or lower.

[0105] After forming by hot stamping, the formed article is cooled while held in the die and/or the formed article is removed from the die and cooled by an arbitrary method. When the cooling rate is increased, since the volume percentage of martensite is secured in the microstructure of the hot-stamped product, and the strength of the formed article increases, the average cooling rate from the hot stamping start temperature to 400°C is preferably set to 30 °C/second or faster, 60 °C/second or faster or 90 °C/second or faster. In addition, when the cooling stop temperature is low, similarly, the volume percentage of martensite is secured in the microstructure of the hot-stamped product, and the strength of the formed article increases. In addition, the formation of ferrite, pearlite or bainite after the reheating step to be described below is suppressed, and the crashworthiness improves. Therefore, the cooling stop temperature of the cooling is preferably set to lower than 90°C or lower than 50°C.

[Reheating step] (iii)

[0106] In a case where a plated steel sheet is used as the steel sheet for hot stamping, the steel sheet after hot-stamping (hot-stamped product) is reheated. When the reheating temperature is 90°C or higher, the local fluctuation in hardness in the hot-stamped product decreases, and the crashworthiness can be enhanced. On the other hand, when the reheating temperature is lower than 150°C, the softening of the steel sheet is suppressed, and the strength of the formed article is secured. In addition, the precipitation of a coarse iron carbide is suppressed, and the crashworthiness improves. Therefore, the reheating temperature is preferably set to 90°C or higher and lower than 150°C. The reheating temperature is more preferably set to 100°C or higher, 110°C or higher or 120°C or higher. In addition, the reheating temperature is more preferably set to lower than 140°C or lower than 130°C.

[0107] When the retention time is extended at the reheating temperature, the above-described effect on the suppression of the local fluctuation in hardness can be sufficiently obtained. Therefore, the retention time is preferably set to five minutes or longer or 10 minutes or longer. On the other hand, when the retention time is short, it is possible to secure the strength of the formed article. Therefore, the retention time is preferably set to shorter than 20 minutes or shorter than 15 minutes.

[0108] In addition, when the hot-stamped product sheet is reheated under the above-described conditions, it is possible to increase the yield ratio.

[0109] In a case where the steel sheet as cold rolled is used as the steel sheet for hot stamping, the reheating step may not be carried out. As described above, the fluctuation in hardness decreases when the strain energy accumulated in the steel sheet for hot stamping is high. This is because, in the steel sheet as cold rolled, processing strain accumulates during hot rolling, and thus a target standard deviation of Vickers hardness can be achieved even without reheating. However, even in a case where the steel sheet as cold rolled is used as the steel sheet for hot stamping, when the steel sheet as cold rolled is reheated, it is possible to increase the yield ratio. Therefore, reheating may be carried out on a hot-stamped product not including any plating layer on a surface. In order to sufficiently obtain the effect on an increase in the yield ratio, reheating is preferably carried out under the same conditions as those in a case where a plated steel sheet is used as the steel sheet for hot stamping.

[Manufacturing method of steel sheet for hot stamping]

[0110] The steel sheet for hot stamping according to the present embodiment that is to be subjected to the manufacturing of the hot-stamped product is preferably manufactured by the following manufacturing method.

[0111] A manufacturing method of a slab that is subjected to the manufacturing method of the steel sheet for hot stamping according to the present embodiment is not particularly limited. In a preferable manufacturing method of a slab

to be exemplified, steel having the above-described composition (chemical composition) is melted by well-known means, then, made into a steel ingot by a continuous casting method or made into a steel ingot by an arbitrary casting method and made into a steel piece by a blooming method or the like. In a continuous casting step, in order to suppress the generation of a surface defect attributed to an inclusion, it is preferable to cause an externally-added viscous flow such as electromagnetic stirring in molten steel in a mold. The steel ingot or the steel piece may be once cooled, reheated and hot-rolled or the steel ingot in a high-temperature state after continuous casting or the steel piece in a high-temperature state after blooming may be hot-rolled as it is or after thermally insulated or supplementarily heated. In the present embodiment, such a steel ingot and a steel piece will be collectively referred to as "slab" as a material for hot rolling.

[0112] At the time of hot rolling, the slab is heated. The temperature of the slab that is subjected to hot rolling (slab heating temperature) is preferably set to lower than 1250°C or more preferably set to lower than 1200°C in order to prevent the coarsening of austenite. When the slab heating temperature is low, since rolling becomes difficult, the slab heating temperature may be set to 1050°C or higher.

[0113] The heated slab is hot-rolled, thereby obtaining a hot-rolled steel sheet. The hot rolling is preferably completed in a temperature range of the A_{r3} point or higher in order to refine the microstructure of the hot-rolled steel sheet by the transformation of austenite after the completion of the rolling. The A_{r3} point is a temperature at which ferritic transformation from austenite starts in the microstructure when the steel sheet has been cooled and can be obtained from a change in the thermal expansion of the steel sheet during cooling.

[0114] In a case where the hot rolling includes rough rolling and finish rolling, in order to complete the finish rolling at the above-described temperature, a rough rolling material may be heated between the rough rolling and the finish rolling. At this time, it is desirable to suppress fluctuations in temperature throughout the entire length of the rough rolling material at the time of the start of the finish rolling to 140°C or less by heating the rough rolling material such that the temperature becomes higher at the rear end than the front end. In such a case, the uniformity of product characteristics in a coil after a coiling step improves.

[0115] The rough rolling material may be heated using well-known means. For example, a solenoid-type induction heating device may be provided between a roughing mill and a finishing mill, and the amount of the temperature increased by heating may be controlled based on the temperature distribution or the like of the rough rolling material in the longitudinal direction on the upstream side of this induction heating device.

[0116] In the case of coiling the hot-rolled steel sheet after the hot rolling, the coiling temperature is preferably set to higher than 600°C. When the coiling temperature is 600°C or lower, the hot-rolled steel sheet becomes excessively hard, it becomes difficult to carry out hot rolling, and there is a case where the crashworthiness of the hot-stamped product deteriorates. A more preferable coiling temperature is higher than 620°C or higher than 650°C.

[0117] On the other hand, when the coiling temperature becomes too high, the amount of a coarse iron carbide generated in the microstructure of the hot-stamped product becomes excessive, and the ductility of the hot-stamped product sheet deteriorates. Therefore, the coiling temperature is preferably set to 750°C or lower or 700°C or lower. The hot-rolled steel sheet may be annealed before a cold rolling step.

[0118] In a case where the steel sheet as cold rolled is used as the steel sheet for hot stamping, a steel sheet that has been hot-rolled and coiled is cold-rolled according to a normal method, thereby producing a cold-rolled steel sheet. In the cold rolling, the cold rolling reduction (cumulative rolling reduction in the cold rolling) is preferably set to 10% or larger. When the cold rolling reduction is smaller than 10%, the local fluctuation in hardness in the hot-stamped product increases, and the crashworthiness of the formed article deteriorates. A more preferably cold rolling reduction is 20% or larger, 30% or larger or 40% or larger. The upper limit of the cold rolling reduction does not need to be particularly limited; however, an excessive increase in the cold rolling reduction increases the load on a rolling facility and degrades the productivity, and thus the cold rolling reduction is preferably set to smaller than 70%, smaller than 60% or smaller than 50%.

[0119] In order for weight reduction in the hot-stamped product, the sheet thickness of the cold-rolled steel sheet is preferably 2.0 mm or less, more preferably 1.8 mm or less and still more preferably 1.6 mm or less. Before the cold rolling, flatness correction by skin pass rolling or the like or descaling by pickling or the like may be carried out according to a well-known method. On the cold-rolled steel sheet obtained as described above, a treatment such as degreasing may be carried out according to a normal method.

[0120] In a case where the steel sheet as cold rolled is used as the steel sheet for hot stamping, the cold-rolled steel sheet is not annealed. By annealing is not carried out, due to the strain energy accumulated during the cold rolling, the local fluctuation in hardness in the hot-stamped product can be decreased, and the crashworthiness of the formed article improves.

[0121] On the other hand, in a case where a plated steel sheet is used as the steel sheet for hot stamping, cold rolling may not be carried out or may be carried out under the above-described conditions. When the steel sheet for hot stamping is cold-rolled, the microstructure is refined, and the crashworthiness of the hot-stamped product improves.

[0122] In a case where a plated steel sheet is used as the steel sheet for hot stamping, plating is carried out according to a normal method on the hot-rolled steel sheet or cold-rolled steel sheet manufactured by the above-described method.

In a case where plating is carried out on the cold-rolled steel sheet, in order to refine the microstructure of the plated steel sheet, the lower limit of the soaking temperature in an annealing process of continuous hot-dip plating is preferably set to 600°C, 650°C or 700°C. On the other hand, when the heating rate is too slow, the soaking temperature is too high or the soaking time is too long, the microstructure of the plated steel sheet coarsens due to grain growth, and the crashworthiness of the hot-stamped product deteriorates. In addition, there is a case where the iron carbide becomes spheroidal and coarse and the ductility of the hot-stamped product sheet deteriorates. Therefore, the average heating rate up to the soaking temperature is preferably set to 1 °C/second or faster, the soaking temperature is preferably set to 800°C or lower or 760°C or lower, and the soaking time (the retention time at the soaking temperature) is preferably set to shorter than 300 seconds or shorter than 120 seconds.

[0123] After continuous annealing is carried out on the cold-rolled steel sheet to produce an annealed steel sheet, plating may be carried out on the annealed steel sheet. However, when the heating rate in the continuous annealing is too slow, the microstructure of the annealed steel sheet coarsens due to grain growth, and the crashworthiness of the hot-stamped product deteriorates. In addition, the iron carbide becomes spheroidal and coarse and the ductility of the hot-stamped product sheet deteriorates. Therefore, the average heating rate up to the soaking temperature in the continuous annealing is preferably set to 1 °C/second or faster.

[0124] On the plated steel sheet obtained as described above, temper rolling may be carried out according to a normal method.

[0125] Hereinafter, the present invention will be more specifically described with examples, but the present invention is not limited to these examples.

[Examples]

(Example 1)

[0126] Molten steel was cast using a vacuum melting furnace to manufacture steels A to V having chemical compositions shown in Table 1. The Ac_3 points in Table 1 were obtained from changes in thermal expansion when cold-rolled steel sheets having the chemical compositions of the steels A to V were heated at 8 °C/second. After the steels A to V were heated to 1200°C and retained for 60 minutes, hot rolling was carried out under hot rolling conditions shown in Table 2.

[Table 1]

Steel	Chemical composition (mass%) (remdnder: Fe and impurity)													Ac ₃ point (°C)
	C	Si	Mn	P	S	sol. Al	N	Mo	B	Cr	Ti	Nb	Others	
A	0.43	0.39	0.39	0.011	0.0003	0.027	0.0019	0.20	0.0020	-	0.021	0.049	-	815
B	0.47	0.42	0.38	0.010	0.0017	0.049	0.0029	0.20	0.0018	-	0.020	0.051	-	813
C	0.46	0.004	0.48	0.010	0.0010	0.034	0.0022	0.05	0.0019	0.15	0.029	0.078	-	799
D	0.38	0.005	0.40	0.008	0.0004	0.045	0.0011	0.30	0.0018	-	0.020	0.050	-	811
E	0.72	0.005	0.45	0.008	0.0007	0.043	0.0018	0.05	0.0020	-	-	-	-	753
F	0.45	0.004	0.54	0.010	0.0018	0.045	0.0039	0.20	0.0018	0.62	0.020	0.047	-	790
G	0.45	0.21	1.27	0.010	0.0009	0.052	0.0030	0.02	0.0018	0.20	0.020	-	-	779
H	0.43	0.004	0.09	0.012	0.0003	0.055	0.0011	0.51	0.0018	-	0.021	0.049	-	819
I	0.43	0.03	0.38	0.011	0.0007	0.050	0.0019	-	-	-	0.020	0.050	-	811
J	0.44	0.03	0.39	0.010	0.0005	0.043	0.0025	-	0.0019	0.20	0.021	0.052	-	806
K	0.44	0.22	0.41	0.009	0.0007	1.050	0.0032	0.18	0.0020	0.19	0.022	0.053	-	1173
L	0.46	0.40	0.39	0.009	0.0006	0.047	0.0029	0.19	0.0018	0.33	0.021	0.019	-	808
M	0.46	0.60	0.39	0.010	0.0005	0.047	0.0034	0.19	0.0022	0.21	0.020	0.018	-	829
N	0.46	0.43	0.38	0.008	0.0008	0.049	0.0031	0.10	0.0018	0.33	0.021	0.019	-	806
O	0.46	0.42	0.39	0.010	0.0018	0.050	0.0031	0.19	0.0017	-	0.020	-	-	814
P	0.46	0.42	0.39	0.009	0.0017	0.048	0.0029	0.20	0.0018	-	-	-	-	804
Q	0.46	0.40	0.39	0.008	0.0004	0.038	0.0020	0.19	0.0024	-	-	-	V: 0.041, Zr: 0.017	798
R	0.46	0.41	0.38	0.008	0.0006	0.038	0.0019	0.20	0.0019	-	0.022	0.028	Cu: 0.30, Ni:0.14	805
S	0.47	0.38	0.28	0.010	0.0006	0.039	0.0027	0.20	0.0020	0.28	0.021	0.028	Ca: 0.0004, Mg: 0.0004, REM: 0.0005	810
T	0.47	0.39	0.18	0.010	0.0005	0.038	0.0030	0.19	0.0021	0.29	0.022	0.027	Bi: 0.0021	816
U	0.46	0.41	0.38	0.010	0.0005	0.046	0.0030	0.10	0.0019	0.31	0.022	0.018	W:0.11	805
V	0.51	0.38	0.29	0.008	0.0002	0.048	0.0021	0.20	0.0018	0.10	0.021	-	-	816

Note) 1. The "-" marks indicate that the corresponding element is not added intentionally.

2. The Ac₃ point was obtained from a change in thermal expansion when the cold rolled steel sheet was heated at 8 °C/s within a temperature range of 700°C or higher.

[Table 2]

Test No.	Steel	Hot rolling conditions		Cold rolling conditions		Presence or absence of annealing	Microstructure of steel sheet for hot stamping	Mechanical properties of steel sheet for hot stamping
		Sheet thickness after rolling (mm)	Coiling temperature (°C)	Sheet thickness after rolling (mm)	Cold rolling reduction (%)			
1	A	3.2	640	1.4	56	Absent	97.5	1008
2	A	3.2	640	1.4	56	Present	0	848
3	A	3.2	640	1.4	56	Absent	97.5	1008
4	A	3.2	640	1.4	56	Absent	97.5	1008
5	A	3.2	640	-	-	Absent	0	698
6	A	3.2	640	1.4	56	Absent	97.5	1008
7	B	2.6	660	1.4	46	Absent	97.2	1051
8	B	2.6	660	1.4	46	Present	0	864
9	B	2.6	660	1.4	46	Absent	97.2	1051
10	B	2.6	660	1.4	46	Absent	97.2	1051
11	B	2.6	660	-	-	Absent	0	701
12	B	2.6	660	1.4	46	Absent	97.2	1051
13	C	2.6	660	1.4	46	Absent	95.8	1029
14	C	2.6	660	1.4	46	Present	0	879
15	D	2.6	640	1.4	46	Absent	94.0	946
16	E	2.2	660	1.4	36	Absent	95.6	1302
17	F	2.6	640	1.4	46	Absent	94.1	1014
18	G	2.6	640	1.4	46	Absent	94.7	1011
19	H	2.6	640	1.4	46	Absent	96.4	1101
20	I	2.6	640	1.4	46	Absent	96.0	868
21	J	2.6	640	1.4	46	Absent	95.0	899

(continued)

Test No.	Steel	Hot rolling conditions		Cold rolling conditions		Presence or absence of annealing	Microstructure of steel sheet for hot stamping	Mechanical properties of steel sheet for hot stamping
		Sheet thickness after rolling (mm)	Coiling temperature (°C)	Sheet thickness after rolling (mm)	Cold rolling reduction (%)			
22	K	2.6	640	1.4	46	Absent	Total volume percentage of expanded ferrite, expanded pearlite and expanded bainite (%) 94.3	Tensile strength (MPa) 998
23	L	2.6	660	1.4	46	Absent	97.4	1042
24	L	2.6	660	1.4	46	Absent	97.4	1042
25	L	2.6	660	1.4	46	Absent	97.4	1042
26	M	2.2	660	1.4	36	Absent	98.1	992
27	M	2.2	660	1.4	36	Present	0	854
28	N	2.6	660	1.4	46	Absent	96.6	1026
29	N	2.6	660	-	-	Absent	0	704
30	O	2.6	660	1.4	46	Absent	97.6	1004
31	O	2.6	660	1.4	46	Absent	97.6	1004
32	P	2.6	660	1.4	46	Absent	97.8	1001
33	P	2.6	660	1.4	46	Absent	97.8	1001
34	P	2.6	660	1.4	46	Absent	97.8	1001
35	Q	2.6	660	1.4	46	Absent	97.4	1014
36	R	2.6	660	1.4	46	Absent	97.6	1023
37	S	2.6	660	1.4	46	Absent	97.2	1039
38	T	2.6	660	1.4	46	Absent	96.8	1042
39	U	2.6	660	1.4	46	Absent	97.6	1036

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(continued)

Test No.	Steel	Hot rolling conditions		Cold rolling conditions		Presence or absence of annealing	Microstructure of steel sheet for hot stamping	Mechanical properties of steel sheet for hot stamping
		Sheet thickness after rolling (mm)	Coiling temperature (°C)	Sheet thickness after rolling (mm)	Cold rolling reduction (%)			
40	V	2.6	660	1.4	46	Absent	Total volume percentage of expanded ferrite, expanded pearlite and expanded bainite (%) 95.3	Tensile strength (MPa) 1074
Note) 1. The column of the sheet thickness after rolling as a hot rolling condition indicates the sheet thickness of the hot-rolled steel sheet. 2. The column of the sheet thickness after rolling as a cold rolling condition indicates the sheet thickness of the cold-rolled steel sheet. The "-" marks indicate that the cold rolling was not carried out. 3. In the column of the presence or absence of annealing, the "Present" marks indicate that annealing was carried out, and the "Absent" marks indicate that annealing was not carried out.								

[0127] Specifically, 10 passes of rolling were carried out on the steels A to V in a temperature range of the Ar_3 point or higher to produce hot-rolled steel sheets having a thickness of 2.2 to 3.2 mm. After the hot rolling, the hot-rolled steel sheets were cooled to 640°C to 660°C by a water spray, the cooling stop temperature was regarded as the coiling temperature, the hot-rolled steel sheets were charged into an electric heating furnace retained at this coiling temperature and retained for 60 minutes, after that, the hot-rolled steel sheets were cooled in the furnace to room temperature at an average cooling rate of 20 °C/hour, and slow cooling after the coiling was simulated.

[0128] Some of the hot-rolled steel sheets were picked to produce base materials for cold rolling, and cold rolling was carried out under cold rolling conditions shown in Table 2 to produce cold-rolled steel sheets having a thickness of 1.4 mm. In addition, some of the hot-rolled steel sheets were mechanically ground to produce hot-rolled and ground steel sheets having a thickness of 1.4 mm.

[0129] In addition, some of the cold-rolled steel sheets were heated up to 780°C at an average heating rate of 5 °C/second and soaked for 120 seconds using a continuous annealing simulator. Subsequently, the cold-rolled steel sheets were cooled to room temperature at an average cooling rate of 5 °C/second to produce annealed steel sheets.

[0130] From the cold-rolled steel sheets, hot-rolled and ground steel sheets and annealed steel sheets obtained as described (these steel sheets will be collectively referred to as the steel sheets for hot stamping), test pieces for structural observation were collected, longitudinal sections of the steel sheets in these test pieces parallel to a rolling direction were polished, then, structures were observed by the above-described method at 1/4 depth positions of the sheet thicknesses of the steel sheets from the surfaces of the steel sheets, and the total volume percentages of ferrite expanded in the rolling direction, pearlite expanded in the rolling direction and bainite expanded in the rolling direction was obtained.

[0131] In addition, JIS No. 13B tensile test pieces were collected from the steel sheets for hot stamping along a direction orthogonal to the rolling direction, a tensile test was carried out at a tension rate of 10 mm/minute, and the tensile strengths were obtained. Table 2 shows the observation results of the microstructures of the steel sheets for hot stamping and the investigation results of the mechanical properties of the steel sheets for hot stamping.

[0132] Raw sheets for hot stamping that were 240 mm in width and 800 mm in length were collected from the steel sheets for hot stamping, and hat members having a shape shown in Fig. 2 were manufactured by hot stamping. In a hot stamping step, the raw sheets (steel sheets for hot stamping) were heated using a gas heating furnace up to the heating temperatures shown in Table 3-1 at an average heating rate up to 700°C set to 22 °C/second and retained at the temperatures for one minute. After that, the raw sheets were taken out from the heating furnace, cooled in the air, inserted into a die including a cooling apparatus to be formed into a hat shape at start temperatures shown in Table 3-1 and subsequently cooled in the die to cooling stop temperatures shown in Table 3-1. In addition, some of the hat members were reheated using an electrical heating furnace under conditions shown in Table 3-1. The "-" marks in Table 3-1 regarding the hot stamping conditions indicate that the reheating step was not carried out.

[0133] Test pieces for structural observation were collected from the vertical wall portions of the obtained hat members (hot-stamped products), the longitudinal sections of these test pieces were polished, and then the microstructures at the 1/4 depth positions of the sheet thicknesses of the steel sheets from the surfaces of the steel sheets were observed by the above-described method.

[0134] In addition, JIS No. 13B tensile test pieces were collected from the vertical wall portions of the hat members along the longitudinal directions of the members, a tensile test was carried out at a tension rate of 10 mm/minute, and the tensile strengths, the yield stresses and the yield ratios were obtained.

[0135] In addition, test pieces for hardness measurement were collected from the vertical wall portions of the hat members, the longitudinal sections of these test pieces were polished, then, Vickers hardness were measured according to JIS Z 2244: 2009 at the 1/4 depth positions of the sheet thicknesses of the steel sheets from the surfaces of the steel sheets by the above-described method at an applied load of 0.49 N, and the average values and standard deviations of the Vickers hardness were obtained.

[0136] In addition, as shown in Fig. 3, closing plates that were 1.4 mm in thickness, 130 mm in width and 800 mm in length were welded to the hat members to manufacture test bodies for a three-point bend test. As the closing plate, a steel sheet having a tensile strength of 1553 MPa was used.

[0137] As shown in Fig. 4, the 800 mm-long test body was placed on two support rolls disposed at a roll interval of 700 mm such that the closing plate faced downward, a three-point bend test was carried out at a testing rate of 2 m/second, and the maximum load, the displacement caused while the test body and an impactor came into contact with each other and then cracking began to occur in the test body and the absorbed energy until cracking began to occur were obtained. When the maximum load was 23.0 kN or more, the cracking occurrence displacement was 35 mm or more, and the absorbed energy was 0.80 kJ or more, the crashworthiness was determined to be favorable.

[0138] Table 3-1 and Table 3-2 show the observation results of the microstructures of the hat members, the evaluation results of the mechanical properties of the hat members and the evaluation results of the crashworthiness of the hat members. In Table 3-1 and Table 3-2, underlined numerical values mean that the corresponding values are outside the ranges of the present invention.

[Table 3-1]

Test No.	Steel	Hot stamping conditions						Microstructure of hot-stamped product		
		Heating temperature (°C)	Start temperature (°C)	Cooling stop temperature (°C)	Reheating temperature (°C)	Retention time (minutes)	Volume percentage of martensite (%)	Volume percentage of residual austenite (%)	Other volume percentage (%)	
1	A	1150	1060	40	-	-	96.0	2.8	1.2	
2	A	1150	1060	40	-	-	96.2	2.9	0.9	
3	A	1150	1010	40	-	-	95.8	3.1	1.1	
4	A	980	910	30	-	-	95.7	2.8	1.5	
5	A	1150	1060	40	-	-	95.9	2.7	1.4	
6	A	1150	1060	40	110	12	95.8	2.9	1.3	
7	B	1150	1060	40	-	-	95.1	3.5	1.4	
8	B	1150	1060	40	-	-	95.0	3.7	1.3	
9	B	1150	1010	40	-	-	94.9	3.6	1.5	
10	B	980	910	30	-	-	94.8	3.3	1.9	
11	B	1150	1060	40	-	-	95.0	3.3	1.7	
12	B	1150	1060	40	120	14	95.1	3.6	1.3	
13	C	1150	1060	40	-	-	94.8	3.0	2.2	
14	C	980	910	30	-	-	94.7	3.1	2.2	
15	D	1150	1060	40	-	-	95.9	2.1	2.0	
16	E	1150	1060	40	-	-	92.5	6.8	0.7	
17	F	1150	1060	40	-	-	96.0	2.9	1.1	
18	G	1150	1060	40	-	-	95.1	4.5	0.4	
19	H	1150	1060	40	-	-	96.1	3.1	0.8	
20	I	1150	1060	40	-	-	65.5	2.5	32.0	
21	J	1150	1060	40	-	-	86.3	2.6	11.1	
22	K	1150	1060	40	-	-	82.2	5.2	12.6	
23	L	1150	1060	40	-	-	95.9	3.3	0.8	

(continued)

Test No.	Steel	Hot stamping conditions					Microstructure of hot-stamped product		
		Heating temperature (°C)	Start temperature (°C)	Cooling stop temperature (°C)	Reheating temperature (°C)	Retention time (minutes)	Volume percentage of martensite (%)	Volume percentage of residual austenite (%)	Other volume percentage (%)
24	L	1150	1010	40	-	-	95.8	3.5	0.7
25	L	1150	1060	40	120	14	95.6	3.5	0.9
26	M	1150	1060	40	-	-	95.1	4.1	0.8
27	M	1150	1060	40	-	-	95.2	4.3	0.5
28	N	1150	1060	40	-	-	95.9	2.9	1.2
29	N	1150	1060	40	-	-	95.8	2.6	1.6
30	O	1150	1060	40	-	-	95.9	3.4	0.7
31	O	1150	1060	40	120	14	95.9	3.5	0.6
32	P	1150	1060	40	-	-	95.8	3.6	0.6
33	P	980	910	30	-	-	95.6	3.5	0.9
34	P	1150	1060	40	120	14	95.6	3.8	0.6
35	Q	1150	1060	40	-	-	95.8	3.4	0.8
36	R	1150	1060	40	-	-	95.8	3.5	0.7
37	S	1150	1060	40	-	-	96.0	3.1	0.9
38	T	1150	1060	40	-	-	95.9	3.0	1.1
39	U	1150	1060	40	-	-	95.7	3.5	0.8
40	V	1150	1060	40	140	18	94.1	3.9	2.0
Note) 1. The column of the start temperature as a hot stamping condition indicates the forming start temperature.									
2. The "-" marks in the column of the reheating temperature and the column of the retention time as hot stamping conditions indicate that the reheating treatment was not carried out.									
3. The "-" marks in the column of the tensile strength, the column of the yield stress and the column of the yield ratio as the mechanical properties of the hot-stamped product indicate that the tensile strength, the yield stress and the yield ratio were not measurable.									
4. The column of the absorbed energy as the crashworthiness of the hot-stamped product indicates the absorbed energy until the occurrence of cracking.									

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[Table 3-2]

Test No.	Mechanical properties of hot-stamped product					Crashworthiness of hot-stamped product		
	Tensile strength (MPa)	Yield stress (MPa)	Yield ratio	Average value of Vickers hardness	Standard deviation of Vickers hardness	Maximum load (kN)	Cracking occurrence displacement (mm)	Absorbed energy (kJ)
1	2353	1413	0.60	682	13	23.7	44	0.92
2	2330	1417	0.61	679	21	20.8	12	0.22
3	2388	1426	0.60	691	<u>21</u>	23.8	33	0.62
4	2445	1457	0.60	709	24	23.9	27	0.49
5	2332	1431	0.61	675	22	21.2	13	0.24
6	2334	1545	0.66	680	8	24.1	53	1.03
7	2615	1559	0.60	748	15	25.4	40	0.87
8	2594	1572	0.61	742	23	22.4	17	0.29
9	2642	1582	0.60	758	22	25.2	31	0.64
10	2701	1610	0.60	765	25	25.4	26	0.52
11	2588	1597	0.62	742	<u>22</u>	22.8	18	0.31
12	2562	1743	0.68	737	9	25.6	46	0.98
13	2536	1486	0.59	730	16	24.9	41	0.89
14	2615	1530	0.59	744	<u>27</u>	22.3	14	0.25
15	<u>2140</u>	1320	0.62	<u>631</u>	15	21.4	61	0.97
16	-	-	-	1043	27	19.2	10	0.19
17	2457	1449	0.59	705	22	22.7	19	0.33
18	2494	1439	0.58	719	<u>28</u>	21.3	12	0.21
19	2436	1434	0.59	705	21	22.2	17	0.28
20	<u>1710</u>	989	0.58	<u>522</u>	33	20.2	11	0.20
21	<u>2285</u>	1366	0.60	<u>661</u>	<u>26</u>	20.8	11	0.20
22	<u>2268</u>	1350	0.60	<u>660</u>	<u>30</u>	21.9	15	0.26
23	2551	1556	0.61	730	12	25.2	42	0.91
24	2579	1565	0.61	740	22	25.3	32	0.67
25	2513	1716	0.68	725	7	25.5	47	1.01
26	2560	1562	0.61	736	13	25.3	42	0.90
27	2536	1564	0.62	730	22	22.6	18	0.31
28	2532	1543	0.61	725	14	25.2	43	0.91
29	2509	1561	0.62	723	23	22.2	17	0.29
30	2546	1581	0.62	731	15	25.3	39	0.88
31	2515	1720	0.68	726	9	25.6	45	0.96
32	2539	1584	0.62	728	14	25.2	39	0.87
33	2621	1596	0.61	748	22	25.2	25	0.51
34	2507	1710	0.68	724	9	25.5	45	0.95

(continued)

Test No.	Mechanical properties of hot-stamped product					Crashworthiness of hot-stamped product		
	Tensile strength (MPa)	Yield stress (MPa)	Yield ratio	Average value of Vickers hardness	Standard deviation of Vickers hardness	Maximum load (kN)	Cracking occurrence displacement (mm)	Absorbed energy (kJ)
35	2544	1587	0.62	731	15	25.2	39	0.88
36	2548	1559	0.61	733	15	25.3	43	0.91
37	2603	1580	0.61	742	12	25.4	42	0.90
38	2608	1581	0.61	744	13	25.4	42	0.91
39	2548	1549	0.61	733	13	25.2	41	0.89
40	2633	1877	0.71	751	5	25.7	45	1.02
Note) 1. The column of the start temperature as a hot stamping condition indicates the forming start temperature. 2. The "-" marks in the column of the reheating temperature and the column of the retention time as hot stamping conditions indicate that the reheating treatment was not carried out. 3. The "-" marks in the column of the tensile strength, the column of the yield stress and the column of the yield ratio as the mechanical properties of the hot-stamped product indicate that the tensile strength, the yield stress and the yield ratio were not measurable. 4. The column of the absorbed energy as the crashworthiness of the hot-stamped product indicates the absorbed energy until the occurrence of cracking.								

[0139] In all of Test Nos. 1, 6, 7, 12, 13, 23, 25, 26, 28, 30 to 32 and 34 to 40 where the specification of the present invention was satisfied, the tensile strengths of the hot-stamped products were 2300 MPa or more, the average values of the Vickers hardness were 670 or more and the standard deviations of the Vickers hardness were 20 or less. In addition, in the three-point bend tests of the formed articles, the maximum loads were 23.0 kN or more, the cracking occurrence displacements were 35 mm or more, the absorbed energies were 0.80 kJ or more, and favorable crashworthiness was exhibited.

[0140] In addition, in Test Nos. 6, 12, 25, 31, 34 and 40 where the reheating treatment was carried out in the manufacturing steps of the hot-stamped products, the tensile strengths of the hot-stamped products were 2300 MPa or more, the average values of the Vickers hardness were 670 or more and the standard deviations of the Vickers hardness were 10 or less. In addition, the yield ratios were 0.65 or more, in the three-point bend tests of the formed articles, the maximum loads were 23.0 kN or more, the cracking occurrence displacements were 45 mm or more, the absorbed energies were 0.95 kJ or more, and the crashworthiness was particularly favorable.

[0141] In contrast, in Test Nos. 15 to 22 of comparative examples where steel sheets having a chemical composition that was not within the range of the present invention were used, the tensile strengths of the hot-stamped products were less than 2300 MPa, the average values of the Vickers hardness were less than 670, in the three-point bend tests of the formed articles, the maximum loads were low or the standard deviations of the Vickers hardness were more than 20, the maximum loads, the cracking occurrence displacements and the absorbed energies in the three-point bend tests of the formed articles were low, and the crashworthiness was poor.

[0142] Specifically, in Test No. 15 where the steel D was used, since the C content of the steel was too low, the tensile strength of the hot-stamped product was less than 2300 MPa, the average value of the Vickers hardness was less than 670, and the maximum load of the formed article was low.

[0143] In Test No. 16 where the steel E was used, since the C content of the steel was too high, the average value of the Vickers hardness was high, and, in the tensile test, fracture occurred in an early phase, and it was not possible to obtain the tensile strength, the yield stress and the yield ratio. The standard deviation of the Vickers hardness was more than 20, and the maximum load, cracking occurrence displacement and absorbed energy of the formed article were low.

[0144] In Test Nos. 17 and 18 where the steels F and G were used, respectively, the Mn contents of the steels were too high, and, in Test No. 19 where the steel H was used, the Mo content of the steel was too high, and thus, in all of the test numbers, the standard deviations of the Vickers hardness were more than 20, and the maximum loads, cracking occurrence displacements and absorbed energies of the formed articles were low.

[0145] In Test No. 20 where the steel I was used, the Mo and B contents of the steel were too low, in Test No. 21 where the steel J was used, the Mo content of the steel was too low, and, in Test No. 22 where the steel K was used, the sol. Al content of the steel was too high, and thus the volume percentages of martensite in the microstructures of

the hot-stamped products were insufficient, the tensile strengths were less than 2300 MPa, the average values of the Vickers hardness were less than 670, the standard deviations of the Vickers hardness were more than 20, and the maximum loads, cracking occurrence displacements and absorbed energies of the formed articles were low.

[0146] In Test Nos. 2 to 5, 8 to 11, 14, 24, 27, 29 and 33 of comparative examples where the chemical compositions were within the ranges of the present invention, but the manufacturing conditions of the hot-stamped products were not within the above-described ranges, the standard deviations of the Vickers hardness of the hot-stamped products were more than 20, the maximum loads, cracking occurrence displacements and absorbed energies of the formed articles were low or the cracking occurrence displacements and the absorbed energies were low, and the crashworthiness was poor.

[0147] Specifically, in Test No. 2 where the steel A was used, Test No. 8 where the steel B was used, and Test No. 27 where the steel M was used, in the manufacturing steps of the steel sheets for hot stamping, since annealing was carried out after hot rolling (the steel sheets that were subjected to the hot stamping were not as cold-rolled), the standard deviations of the Vickers hardness of the formed articles were more than 20, and the maximum loads, the cracking occurrence displacements and the absorbed energies were low.

[0148] In Test No. 5 where the steel A was used, Test No. 11 where the steel B was used, and Test No. 29 where the steel N was used, in the manufacturing steps of the steel sheets for hot stamping, since hot rolling was not carried out (the steel sheets that were subjected to the hot stamping were not as cold-rolled), the standard deviations of the Vickers hardness of the formed articles were more than 20, and the maximum loads, the cracking occurrence displacements and the absorbed energies were low.

[0149] In Test Nos. 3 and 4 where the steel A was used, Test Nos. 9 and 10 where the steel B was used, Test No. 24 where the steel L was used, and Test No. 33 where the steel P was used, since the forming start temperatures in the hot stamping steps were too low, the standard deviations of the Vickers hardness of the formed articles were more than 20, and the cracking occurrence displacements and the absorbed energies were low.

[0150] In Test No. 14 where the steel C was used, since the annealed steel sheet was used as the steel sheet for hot stamping, and the forming start temperature in the hot stamping step was too low, the standard deviations of the Vickers hardness of the formed articles were more than 20, and the maximum load, the cracking occurrence displacements and the absorbed energies were low.

(Example 2)

[0151] Molten steel was cast using a vacuum melting furnace to manufacture steels a to w having chemical compositions shown in Table 4. The Ac_3 points in Table 4 were obtained from changes in thermal expansion when plated steel sheets having the chemical compositions of the steels a to w were heated at 8 °C/second. After the steels a to w were heated to 1200°C and retained for 60 minutes, hot rolling was carried out under hot rolling conditions shown in Table 5.

[0152] Specifically, 10 passes of rolling was carried out on the steels a to w in a temperature range of the Ar_3 point or higher to produce hot-rolled steel sheets having a thickness of 2.2 to 3.2 mm. After the hot rolling, the hot-rolled steel sheets were cooled to 640°C to 660°C by a water spray, the cooling stop temperature was regarded as the coiling temperature, the hot-rolled steel sheets were charged into an electric heating furnace retained at this coiling temperature and retained for 60 minutes, after that, the hot-rolled steel sheets were cooled in the furnace to room temperature at an average cooling rate of 20 °C/hour, and slow cooling after the coiling was simulated.

[0153] Some of the hot-rolled steel sheets were picked to produce base materials for cold rolling, and cold rolling was carried out under cold rolling conditions shown in Table 5 to produce cold-rolled steel sheets having a thickness of 1.4 mm. In addition, some of the hot-rolled steel sheets (examples where hot rolling was not carried out) were mechanically ground to produce hot-rolled and ground steel sheets having a thickness of 1.4 mm.

[0154] In addition, the obtained steel sheets (cold-rolled steel sheets and hot-rolled and ground steel sheets) were heated up to the soaking temperatures of annealing shown in Table 5 at an average heating rate of 5 °C/second and soaked for 120 seconds using a hot-dip plating simulator. Subsequently, the steel sheets were cooled and immersed in a hot-dip galvanizing bath or hot-dip aluminum plating bath, and hot-dip galvanizing or hot-dip aluminum plating was carried out. After the hot-dip galvanizing, some of the material steel sheets were heated up to 520°C to carry out an alloying treatment.

[Table 4]

Steel	Chemical composition (mass%) (remainder: Fe and impurity)												Ac ₃ point (°C)	
	C	Si	Mn	P	S	sol. Al	N Mo B		Cr	Ti	Nb	Others		
a	0.43	0.003	0.39	0.010	0.0004	0.024	0.0028	0.20	0.0020	0.21	0.020	0.049	-	804
b	0.46	0.005	0.38	0.009	0.0018	0.048	0.0031	0.20	0.0019	0.21	0.020	0.051	-	815
c	0.46	0.21	0.39	0.009	0.0004	0.046	0.0034	0.19	0.0021	0.21	0.002	0.018	-	808
d	0.47	0.42	0.38	0.010	0.0017	0.049	0.0029	0.20	0.0018	-	0.020	0.051	-	820
e	0.46	0.004	0.48	0.010	0.0010	0.034	0.0022	0.05	0.0019	0.15	0.029	0.078	-	803
f	0.38	0.005	0.40	0.008	0.0004	0.045	0.0011	0.30	0.0018	-	0.020	0.050	-	817
g	0.72	0.005	0.45	0.008	0.0007	0.043	0.0018	0.05	0.0020	-	-	-	-	764
h	0.45	0.004	0.54	0.010	0.0018	0.045	0.0039	0.20	0.0018	0.62	0.020	0.047	-	803
i	0.45	0.21	1.27	0.010	0.0009	0.052	0.0030	0.02	0.0018	0.20	0.020	-	-	793
i	0.43	0.004	0.09	0.012	0.0003	0.055	0.0011	0.51	0.0018	-	0.021	0.049	-	828
k	0.43	0.03	0.38	0.011	0.0007	0.050	0.0019	-	-	-	0.020	0.050	-	813
l	0.44	0.03	0.39	0.010	0.0005	0.043	0.0025	-	0.0019	0.20	0.021	0.052	-	809
m	0.44	0.22	0.41	0.009	0.0007	1.050	0.0032	0.18	0.0020	0.19	0.022	0.053	-	1177
n	0.46	0.40	0.39	0.009	0.0006	0.047	0.0029	0.19	0.0018	0.33	0.021	0.019	-	819
o	0.46	0.60	0.39	0.010	0.0005	0.047	0.0034	0.19	0.0022	0.21	0.020	0.018	-	839
p	0.46	0.21	0.39	0.009	0.0008	0.048	0.0032	0.10	0.0017	0.41	0.020	0.019	-	806
q	0.46	0.005	0.39	0.009	0.0019	0.048	0.0033	0.19	0.0017	0.21	0.020	-	-	803
r	0.46	0.004	0.38	0.009	0.0018	0.046	0.0037	0.19	0.0018	0.21	-	-	-	797
s	0.46	0.40	0.39	0.008	0.0004	0.038	0.0020	0.19	0.0024	-	-	-	V: 0.041, Zr: 0.017	805
t	0.46	0.41	0.38	0.008	0.0006	0.038	0.0019	0.20	0.0019	-	0.022	0.028	Cu: 0.30, Ni: 0.14	815
u	0.47	0.38	0.28	0.010	0.0006	0.039	0.0027	0.20	0.0020	0.28	0.021	0.028	Ca: 0.0004, Mg: 0.0004, REM: 0.0005	820
v	0.47	0.39	0.18	0.010	0.0005	0.038	0.0030	0.19	0.0021	0.29	0.022	0.027	Bi: 0.0021	824
w	0.51	0.005	0.36	0.008	0.0003	0.046	0.0025	0.20	0.0024	0.22	0.019	-	-	794

Note) 1. The "-" marks indicate that the corresponding element is not added intentionally.

2. The Ac₃ point was obtained from a change in thermal expansion when the plated steel sheet was heated at 8 °C/s within a temperature range of 700°C or higher.

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[Table 5]

5	Test No.	Steel	Hot rolling conditions		Cold rolling conditions		Annealing condition	Plating type
			Sheet thickness after rolling (mm)	Coiling temperature (°C)	Sheet thickness after rolling Cold rolling reduction (mm) (%)		Soaking temperature (°C)	
10	101	a	3.2	640	1.4	56	730	GA
	102	a	3.2	640	1.4	56	730	GI
	103	a	3.2	640	1.4	56	740	AL
15	104	a	3.2	640	1.4	56	730	GA
	105	a	3.2	640	1.4	56	730	GA
	106	a	3.2	640	1.4	56	730	GA
20	107	b	2.6	660	1.4	46	740	AL
	108	b	2.6	660	-	-	730	GA
	109	b	2.6	660	1.4	46	730	GI
25	110	b	2.6	660	1.4	46	740	AL
	111	b	2.6	660	1.4	46	740	AL
	112	b	2.6	660	1.4	46	740	AL
30	113	c	2.6	660	1.4	46	730	GA
	114	c	2.6	660	1.4	46	730	GA
	115	d	2.6	660	1.4	46	730	GA
35	116	d	2.6	660	1.4	46	740	AL
	117	d	2.6	660	1.4	46	740	AL
	118	e	2.6	660	1.4	46	740	AL
40	119	e	2.6	660	1.4	46	740	AL
	120	f	2.6	640	1.4	46	730	GA
	121	g	2.2	640	1.4	36	730	GA
45	122	h	2.6	640	1.4	46	730	GA
	123	i	2.6	640	1.4	46	740	AL
	124	j	2.6	640	1.4	46	740	AL
50	125	k	2.6	640	1.4	46	740	AL
	126	l	2.6	640	1.4	46	730	GA
	127	m	2.6	640	1.4	46	730	GA
55	128	n	2.6	660	1.4	46	730	GA
	129	n	2.6	660	1.4	46	740	AL
	130	n	2.6	660	1.4	46	730	GA
	131	o	2.2	660	1.4	36	740	AL
	132	o	2.2	660	1.4	36	740	AL
	133	o	2.2	660	1.4	36	740	AL
	134	o	2.2	660	1.4	36	740	AL

(continued)

Test No.	Steel	Hot rolling conditions		Cold rolling conditions		Annealing condition	Plating type
		Sheet thickness after rolling (mm)	Coiling temperature (°C)	Sheet thickness after rolling Cold rolling reduction (mm) (%)		Soaking temperature (°C)	
135	p	2.6	660	1.4	46	740	AL
136	p	2.6	660	1.4	46	740	AL
137	q	2.6	660	1.4	46	730	GA
138	r	2.6	660	1.4	46	730	GI
139	s	2.6	660	1.4	46	740	AL
140	t	2.6	660	1.4	46	740	AL
141	u	2.6	660	1.4	46	730	GA
142	v	2.6	660	1.4	46	730	GI
143	w	2.6	660	1.4	46	730	GA
Note) 1. The column of the sheet thickness after rolling as a hot rolling condition indicates the sheet thickness of the hot-rolled steel sheet. 2. The column of the sheet thickness after rolling as a cold rolling condition indicates the sheet thickness of the cold-rolled steel sheet. The "-" marks indicate that the cold rolling was not carried out. 3. In the column of the plating type, the "GI" marks indicate hot-dip galvanized steel sheets, the "GA" marks indicate galvanized steel sheets and the "AL" marks indicate hot-dip aluminum-plated steel sheets.							

[0155] From the hot-dip galvanized steel sheets, galvanized steel sheets and hot-dip aluminum-plated steel sheets obtained as described (these steel sheets will be collectively referred to as the steel sheets for hot stamping), raw sheets for hot stamping that were 240 mm in width and 800 mm in length were collected, and hat members having a shape shown in Fig. 2 were manufactured by hot stamping. In a hot stamping step, the raw sheets were heated using a gas heating furnace up to the heating temperatures shown in Table 6-1 at an average heating rate up to 700°C set to 11 °C/second or faster and retained at the temperatures for one minute. After that, the raw sheets were taken out from the heating furnace, cooled in the air, inserted into a die including a cooling apparatus to be formed into a hat shape at start temperatures shown in Table 6-1 and subsequently cooled in the die to cooling stop temperatures shown in Table 6-1. In addition, some of the hat members were reheated using an electrical heating furnace under conditions shown in Table 6-1. The "-" marks in Table 6-1 regarding the hot stamping conditions indicate that the reheating step was not carried out.

[0156] Test pieces for structural observation were collected from the vertical wall portions of the obtained hat members (hot-stamped products), the longitudinal sections of these test pieces were polished, and then the microstructures at the 1/4 depth positions of the sheet thicknesses of the steel sheets, which were substrates, from the interfaces between the steel sheets, which were substrates, and the plated layers were observed by the above-described method.

[0157] In addition, JIS No. 13B tensile test pieces were collected from the vertical wall portions of the hat members along the longitudinal directions of the members, a tensile test was carried out at a tension rate of 10 mm/minute, and the tensile strengths, the yield stresses and the yield ratios were obtained.

[0158] In addition, test pieces for hardness measurement were collected from the vertical wall portions of the hat members, the longitudinal sections of these test pieces were polished, then, Vickers hardness were measured at the 1/4 depth positions of the sheet thicknesses of the steel sheets from the interfaces between the steel sheets and the plated layers by the above-described method at an applied load of 0.49 N, and the average values and standard deviations of the Vickers hardness were obtained.

[0159] In addition, as shown in Fig. 3, closing plates that were 1.4 mm in thickness, 130 mm in width and 800 mm in length were welded to the hat members to manufacture test bodies for a three-point bend test. As the closing plate, a steel sheet having a tensile strength of 1553 MPa was used.

[0160] As shown in Fig. 4, the 800 mm-long test body was placed on two support rolls disposed at a roll interval of 700 mm such that the closing plate faced downward, a three-point bend test was carried out at a testing rate of 2 m/second, and the maximum load, the displacement caused while the test body and an impactor came into contact with each other and then cracking began to occur in the test body and the absorbed energy until cracking began to occur

were obtained. When the maximum load was 23.0 kN or more, the cracking occurrence displacement was 35 mm or more, and the absorbed energy was 0.80 kJ or more, the crashworthiness was determined to be favorable.

[0161] Table 6-1 and Table 6-2 show the observation results of the microstructures of the hat members, the evaluation results of the mechanical properties of the hat members and the evaluation results of the crashworthiness of the hat members. In Table 6-1 and Table 6-2, underlined numerical values mean that the corresponding values are outside the ranges of the present invention.

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[Table 6-1]

Test No.	Steel	Hot stamping conditions						Microstructure of hot-stamped product		
		Heating temperature (°C)	Start temperature (°C)	Cooling stop temperature (°C)	Reheating temperature (°C)	Retention time (minutes)	Volume percentage of martensite (%)	Volume percentage of residual austenite (%)	Other volume percentage (%)	
101	a	1150	1060	40	110	12	96.8	1.7	1.5	
102	a	1150	1060	40	110	12	96.7	1.8	1.5	
103	a	1150	1060	40	110	12	97.0	1.7	1.3	
104	a	1150	1010	40	110	12	96.6	2.0	1.4	
105	a	980	910	30	110	12	96.7	1.7	1.6	
106	a	1150	1060	40	170	20	96.7	1.8	1.5	
107	b	1150	1060	40	120	14	95.7	2.5	1.8	
108	b	1150	1060	40	120	14	96.3	2.1	1.6	
109	b	1150	1060	40	120	14	95.9	2.4	1.7	
110	b	1150	1010	40	120	14	95.7	2.6	1.7	
111	b	980	910	30	120	14	95.6	2.4	2.0	
112	b	1150	1060	40	70	20	95.8	2.5	1.7	
113	c	1150	1060	40	130	14	95.6	2.8	1.6	
114	c	1150	1010	40	130	14	95.5	2.9	1.6	
115	d	1150	1060	40	120	14	95.0	3.6	1.4	
116	d	1150	1060	40	120	14	94.9	3.7	1.4	
117	d	1150	1060	40	-	-	95.1	3.6	1.3	
118	e	1150	1060	40	140	14	94.6	3.1	2.3	
119	e	980	910	30	140	14	94.6	3.2	2.2	
120	f	1150	1060	40	110	12	95.8	2.3	1.9	
121	g	1150	1060	40	110	12	92.6	6.8	0.6	
122	h	1150	1060	40	110	12	96.0	2.8	1.2	
123	i	1150	1060	40	110	12	94.9	4.5	0.6	

(continued)

Test No.	Steel	Hot stamping conditions					Microstructure of hot-stamped product		
		Heating temperature (°C)	Start temperature (°C)	Cooling stop temperature (°C)	Reheating temperature (°C)	Retention time (minutes)	Volume percentage of martensite (%)	Volume percentage of residual austenite (%)	Other volume percentage (%)
124 j		1150	1060	40	110	12	95.9	3.3	0.8
125	k	1150	1060	40	110	12	67.8	2.1	30.1
126	l	1150	1060	40	110	12	87.9	2.1	10.0
127	m	1150	1060	40	110	12	82.7	5.1	12.2
128	n	1150	1060	40	120	14	95.5	3.6	0.9
129	n	1150	1060	40	120	14	95.3	3.7	1.0
130	n	1150	1010	40	120	14	95.7	3.7	0.6
131	o	1150	1060	40	120	14	95.2	4.1	0.7
132	o	1150	1060	40	-	-	95.4	4.2	0.4
133	o	1150	1060	120	270	20	88.6	5.2	6.2
134	o	1150	1010	40	-	-	95.2	4.3	0.5
135	p	1150	1060	40	120	14	96.7	2.3	1.0
136	p	1150	1060	40	270	20	94.5	2.0	3.5
137	q	1150	1060	40	110	12	97.0	2.2	0.8
138	r	1150	1060	40	110	12	97.0	2.0	1.0
139	s	1150	1060	40	120	14	96.1	3.2	0.7
140	t	1150	1060	40	130	14	95.7	3.6	0.7
141	u	1150	1060	40	130	14	95.8	3.4	0.8
142	v	1150	1060	40	130	14	96.1	3.1	0.8

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(continued)

Test No.	Steel	Hot stamping conditions					Microstructure of hot-stamped product		
		Heating temperature (°C)	Start temperature (°C)	Cooling stop temperature (°C)	Reheating temperature (°C)	Retention time (minutes)	Volume percentage of martensite (%)	Volume percentage of residual austenite (%)	Other volume percentage (%)
143	w	1150	1060	40	140	18	93.6	2.6	3.8
Note) 1. The column of the start temperature as a hot stamping condition indicates the forming start temperature. 2. The "-" marks in the column of the reheating temperature and the column of the retention time as hot stamping conditions indicate that the reheating treatment was not carried out. 3. The "-" marks in the column of the tensile strength, the column of the yield stress and the column of the yield ratio as the mechanical properties of the hot-stamped product indicate that the tensile strength, the yield stress and the yield ratio were not measurable. 4. The column of the absorbed energy as the crashworthiness of the hot-stamped product indicates the absorbed energy until the occurrence of cracking.									

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[Table 6-2]

5	Test No.	Mechanical properties of hot-stamped product					Crashworthiness of hot-stamped product		
		Tensile strength (MPa)	Yield stress (MPa)	Yield ratio	Average value of Vickers hardness	Standard deviation of Vickers hardness	Maximum load (kN)	Cracking occurrence displacement (mm)	Absorbed energy (kJ)
10	101	2326	1555	0.67	674	18	24.1	40	0.84
	102	2324	1550	0.67	672	18	24.0	40	0.84
	103	2349	1577	0.67	684	19	24.2	37	0.82
	104	2355	1585	0.67	685	25	24.1	28	0.50
15	105	2412	1633	0.68	694	28	24.0	22	0.33
	106	<u>2160</u>	1510	0.70	635	14	21.5	54	0.92
	107	2595	1766	0.68	740	15	25.5	36	0.84
	108	2593	1763	0.68	740	18	25.6	36	0.84
20	109	2571	1744	0.68	735	14	25.5	39	0.86
	110	2602	1775	0.68	748	22	25.4	29	0.59
	111	2665	1833	0.69	762	26	25.5	23	0.46
	112	2622	1681	<u>0.64</u>	751	22	22.5	16	0.24
25	113	2568	1799	0.70	733	12	25.7	43	0.92
	114	2597	1814	0.70	746	21	25.6	32	0.61
	115	2554	1738	0.68	732	13	25.6	42	0.89
	116	2571	1759	0.68	735	13	25.6	39	0.85
30	117	2615	1592	<u>0.61</u>	748	23	22.6	15	0.22
	118	2506	1781	0.71	718	11	25.8	40	0.88
	119	2573	1844	0.72	739	22	25.9	27	0.54
	120	<u>2122</u>	1400	0.66	624	16	21.3	56	0.93
35	121	-	-	-	1030	27	20.3	12	0.21
	122	2440	1608	0.66	701	21	24.6	33	0.64
	123	2474	1609	0.65	715	26	24.8	22	0.44
	124	2398	1585	0.66	697	21	24.1	30	0.60
40	125	<u>1751</u>	1068	<u>0.61</u>	<u>530</u>	31	20.3	11	0.18
	126	<u>2282</u>	1434	0.63	<u>663</u>	25	21.0	12	0.25
	127	<u>2285</u>	1436	<u>0.63</u>	667	28	22.3	18	0.30
	128	2502	1726	0.69	716	13	25.5	42	0.92
45	129	2515	1736	0.69	720	14	25.6	40	0.89
	130	2529	1745	0.69	728	22	25.4	31	0.64
	131	2524	1713	0.68	726	14	25.6	39	0.86
	132	2557	1531	<u>0.60</u>	733	23	22.2	14	0.28
50	133	<u>2146</u>	1630	0.76	<u>628</u>	25	21.6	34	0.71
	134	2581	1551	<u>0.60</u>	743	27	20.6	13	0.18

(continued)

Test No.	Mechanical properties of hot-stamped product					Crashworthiness of hot-stamped product		
	Tensile strength (MPa)	Yield stress (MPa)	Yield ratio	Average value of Vickers hardness	Standard deviation of Vickers hardness	Maximum load (kN)	Cracking occurrence displacement (mm)	Absorbed energy (kJ)
135	2533	1749	0.69	731	15	25.6	37	0.85
136	2117	1717	0.81	625	11	21.3	55	0.89
137	2519	1662	0.66	724	16	25.5	40	0.87
138	2523	1641	0.65	728	17	25.5	39	0.85
139	2518	1716	0.68	725	13	25.6	40	0.86
140	2522	1766	0.70	728	12	25.7	41	0.88
141	2511	1758	0.70	720	12	25.6	43	0.90
142	2517	1788	0.71	721	12	25.8	44	0.92
143	2620	1874	0.72	750	11	26.0	35	0.83
Note) 1. The column of the start temperature as a hot stamping condition indicates the forming start temperature. 2. The "-" marks in the column of the reheating temperature and the column of the retention time as hot stamping conditions indicate that the reheating treatment was not carried out. 3. The "-" marks in the column of the tensile strength, the column of the yield stress and the column of the yield ratio as the mechanical properties of the hot-stamped product indicate that the tensile strength, the yield stress and the yield ratio were not measurable. 4. The column of the absorbed energy as the crashworthiness of the hot-stamped product indicates the absorbed energy until the occurrence of cracking.								

[0162] In all of Test Nos. 101 to 103, 107 to 109, 113, 115, 116, 118, 128, 129, 131, 135 and 137 to 143 where the specification of the present invention was satisfied, the tensile strengths of the hot-stamped products were 2300 MPa or more, the average values of the Vickers hardness were 670 or more and the standard deviations of the Vickers hardness were 20 or less. In addition, the yield ratios were 0.65 or more, in the three-point bend tests of the formed articles, the maximum loads were 23.0 kN or more, the cracking occurrence displacements were 35 mm or more, the absorbed energies were 0.80 kJ or more, and favorable crashworthiness was exhibited.

[0163] In contrast, in Test Nos. 120 to 127 of comparative examples where steel sheets having a chemical composition that was not within the range of the present invention were used, any or all of the maximum loads, cracking occurrence displacements and absorbed energies of the formed articles were low, and the crashworthiness was poor.

[0164] Specifically, in Test No. 120 where the steel f was used, since the C content of the steel was too low, the tensile strength of the hot-stamped product was less than 2300 MPa, the average value of the Vickers hardness was less than 670, and the maximum load of the formed article was low.

[0165] In Test No. 121 where the steel g was used, since the C content of the steel was too high, the average value of the Vickers hardness was high, and, in the tensile test, fracture occurred in an early phase, and it was not possible to obtain the tensile strength, the yield stress and the yield ratio. The standard deviation of the Vickers hardness was more than 20, and the maximum load, cracking occurrence displacement and absorbed energy of the formed article were low.

[0166] In Test Nos. 122 and 123 where the steels h and i were used, respectively, the Mn contents of the steels were too high, and, in Test No. 124 where the steel j was used, the Mo content of the steel was too high, and thus, in all of the test numbers, the standard deviations of the Vickers hardness were more than 20, and the cracking occurrence displacements and the absorbed energies were low.

[0167] In Test No. 125 where the steel k was used, the Mo and B contents of the steel were too low, in Test No. 126 where the steel l was used, the Mo content of the steel was too low, and, in Test No. 127 where the steel m was used, the sol. Al content of the steel was too high, and thus the volume percentages of martensite in the microstructures of the hot-stamped products were insufficient, the tensile strengths were less than 2300 MPa, the average values of the Vickers hardness were less than 670, the standard deviations of the Vickers hardness were more than 20, and the maximum loads, cracking occurrence displacements and absorbed energies of the formed articles were low.

[0168] In Test Nos. 104 to 106, 110 to 112, 114, 117, 119, 130, 132 to 134 and 136 of comparative examples where the chemical compositions were within the ranges of the present invention, but the manufacturing conditions of the hot-stamped products were not within the above-described ranges, in the three-point bend tests of the formed articles, any or all of the maximum loads, the cracking occurrence displacements and the absorbed energies were low, and the crashworthiness was poor.

[0169] Specifically, in Test Nos. 104 and 105 where the steel a was used, Test Nos. 110 and 111 where the steel b was used, Test No. 114 where the steel c was used, Test No. 119 where the steel e was used and Test No. 130 where the steel n was used, since the forming start temperatures in the hot stamping steps were too low, the standard deviations of the Vickers hardness of the formed articles were more than 20, and the cracking occurrence displacements and the absorbed energies were low.

[0170] In Test No. 106 where the steel a was used and Test No. 136 where the steel p was used, since the reheating temperatures in the reheating steps were too high, the tensile strengths of the hot-stamped products were less than 2300 MPa, the average values of the Vickers hardness were less than 670, and the maximum loads were low.

[0171] In Test No. 112 where the steel b was used, Test No. 117 where the steel d was used and Test No. 132 where the steel o was used, since the reheating temperatures in the reheating steps were too low or the reheating treatments were not carried out, the standard deviations of the Vickers hardness were more than 20, the yield ratios were less than 0.65 and the maximum loads, the cracking occurrence displacements and the absorbed energies were low.

[0172] In Test No. 133 where the steel o was used, since the cooling stop temperature in the hot stamping step was high and the reheating temperature in the reheating step was too high, the volume percentage of martensite was insufficient, the tensile strength was less than 2300 MPa, the average value of the Vickers hardness was less than 670, the standard deviation of the Vickers hardness was more than 20 and the maximum load, cracking occurrence displacement and absorbed energy of the formed article were low.

[0173] In Test No. 134 where the steel o was used, since the forming start temperature in the hot stamping step was low and the reheating treatments were not carried out, the standard deviation of the Vickers hardness was more than 20, the yield ratio was less than 0.65, and the maximum load, the cracking occurrence displacements and the absorbed energies were low.

[Industrial Applicability]

[0174] According to the present invention, it becomes possible to obtain a hot-stamped product having a portion with a tensile strength of 2300 MPa or more and excellent crashworthiness.

Claims

1. A hot-stamped product comprising:

a steel sheet,
wherein all or part of the steel sheet has a chemical composition of,
by mass%,
C: more than 0.40% and 0.70% or less;
Si: less than 2.00%;
Mn: 0.01% or more and less than 0.50%;
P: 0.200% or less;
S: 0.0200% or less;
sol. Al: 0.001% to 1.000%;
N: 0.0200% or less;
Mo: 0.01% or more and less than 0.50%;
B: 0.0002% to 0.0200%;
Ti: 0% to 0.200%;
Nb: 0% to 0.200%;
V: 0% to 0.200%;
Zr: 0% to 0.200%;
Cr: 0% to 2.00%;
W: 0% to 2.00%;
Cu: 0% to 2.00%;
Ni: 0% to 2.00%;
Ca: 0% to 0.0100%;

Mg: 0% to 0.0100%;

REM: 0% to 0.1000%; and

Bi: 0% to 0.0500%

with a remainder of Fe and impurities,

at a 1/4 depth position of a sheet thickness from a surface of the steel sheet, a microstructure contains, by vol%, more than 90.0% of martensite,

an average value of Vickers hardness in a region that is 0.3 mm in a sheet thickness direction and 0.6 mm in a direction orthogonal to the sheet thickness direction is 670 or more, a standard deviation of the Vickers hardness in the region is 20 or less, and

a tensile strength is 2300 MPa or more.

2. The hot-stamped product according to claim 1, wherein a yield ratio is 0.65 or more.

3. A hot-stamped product comprising:

a steel sheet; and

a plating layer formed on a surface of the steel sheet,

wherein all or part of the steel sheet has a chemical composition of,

by mass%,

C: more than 0.40% and 0.70% or less;

Si: less than 2.00%;

Mn: 0.01% or more and less than 0.50%;

P: 0.200% or less;

S: 0.0200% or less;

sol. Al: 0.001% to 1.000%;

N: 0.0200% or less;

Mo: 0.01% or more and less than 0.50%;

B: 0.0002% to 0.0200%;

Ti: 0% to 0.200%;

Nb: 0% to 0.200%;

V: 0% to 0.200%;

Zr: 0% to 0.200%;

Cr: 0% to 2.00%;

W: 0% to 2.00%;

Cu: 0% to 2.00%;

Ni: 0% to 2.00%;

Ca: 0% to 0.0100%;

Mg: 0% to 0.0100%;

REM: 0% to 0.1000%; and

Bi: 0% to 0.0500%

with a remainder of Fe and impurities,

at a 1/4 depth position of a sheet thickness of the steel sheet from an interface between the steel sheet and the plating layer,

a microstructure contains, by vol%, more than 90.0% of martensite,

an average value of Vickers hardness in a region that is 0.3 mm in a sheet thickness direction and 0.6 mm in a direction orthogonal to the sheet thickness direction is 670 or more, a standard deviation of the Vickers hardness in the region is 20 or less, and

a tensile strength is 2300 MPa or more, and a yield ratio is 0.65 or more.

4. The hot-stamped product according to any one of claims 1 to 3, comprising, in the chemical composition, by mass%, one or more selected from the group consisting of:

Ti: 0.001% to 0.200%;

Nb: 0.001% to 0.200%;

V: 0.001% to 0.200%; and

Zr: 0.001% to 0.200%.

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5. The hot-stamped product according to any one of claims 1 to 4, comprising, in the chemical composition, by mass%, one or more selected from the group consisting of:

Cr: 0.001% to 2.00%;
W: 0.001% to 2.00%;
Cu: 0.001% to 2.00%; and
Ni: 0.001% to 2.00%.

6. The hot-stamped product according to any one of claims 1 to 5, comprising, in the chemical composition, by mass%, one or more selected from the group consisting of:

Ca: 0.0001% to 0.0100%;
Mg: 0.0001% to 0.0100%; and
REM: 0.0001% to 0.1000%.

7. The hot-stamped product according to any one of claims 1 to 6, comprising, in the chemical composition, by mass%:
Bi: 0.0001% to 0.0500%.

FIG. 1

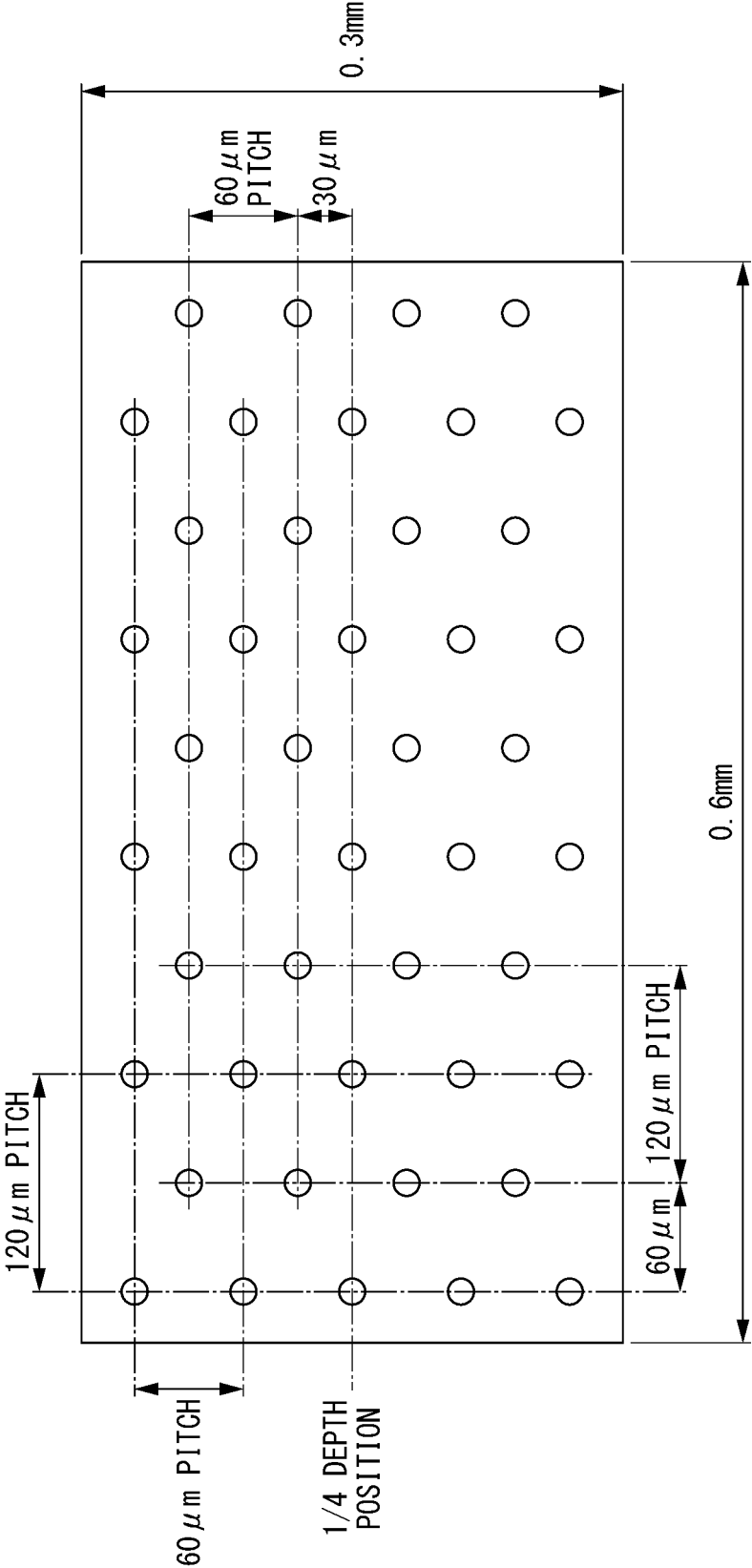


FIG. 2

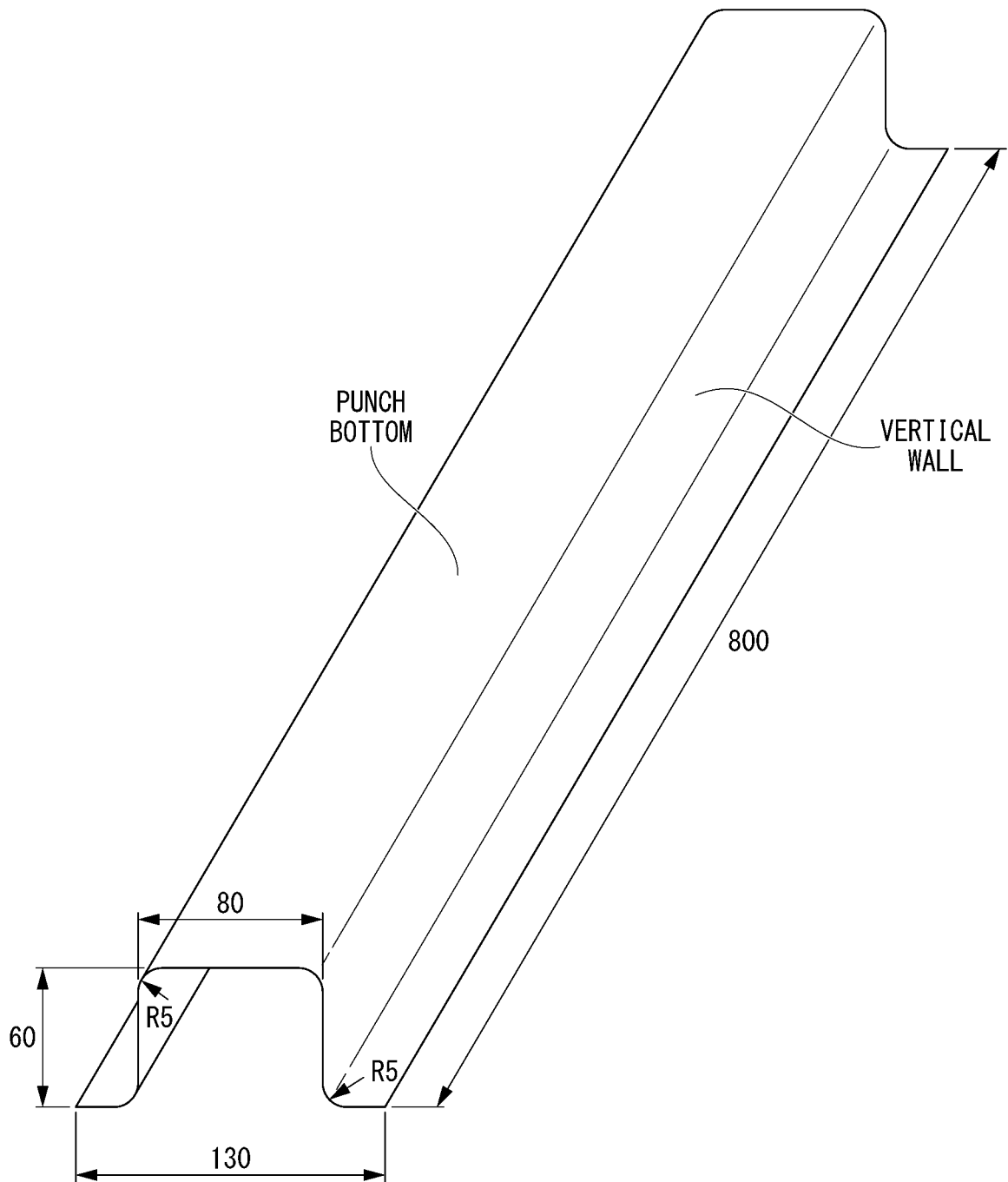


FIG. 3

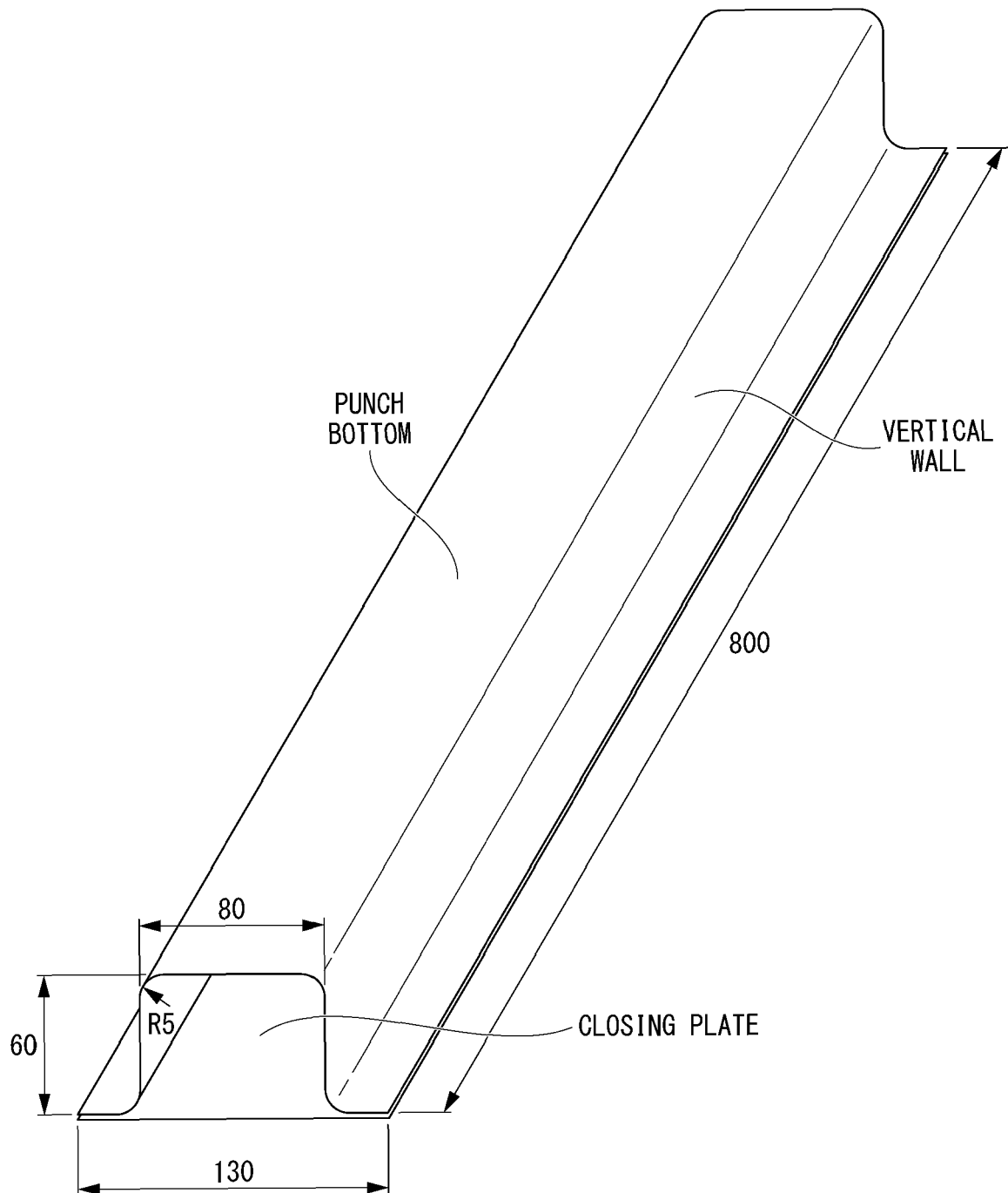
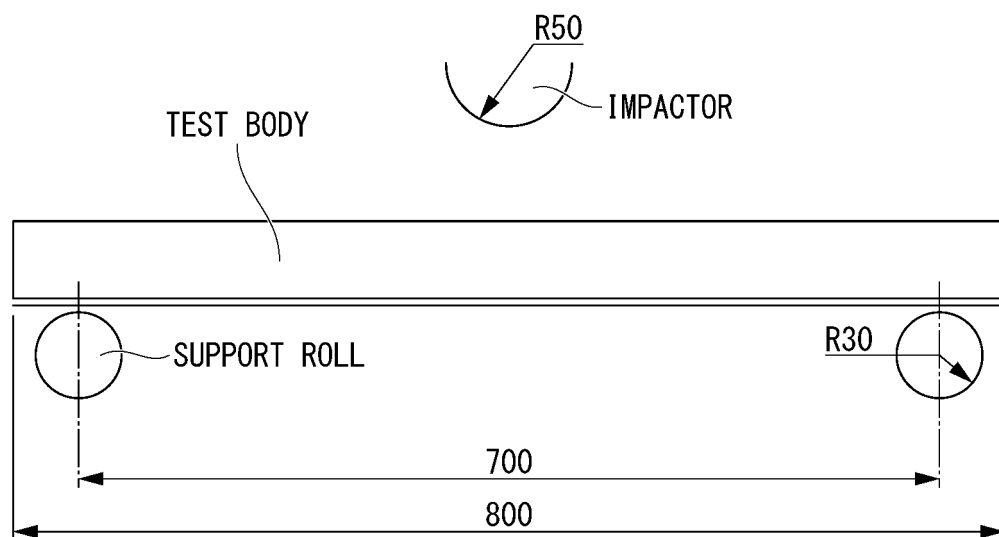


FIG. 4



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2021/005226

A. CLASSIFICATION OF SUBJECT MATTER

C21D 9/00(2006.01)i; C21D 9/46(2006.01)i; C22C 38/00(2006.01)i; C22C 38/54(2006.01)i; C21D 1/18(2006.01)i; C23C 2/06(2006.01)i

FI: C22C38/00 301Z; C21D9/00 A; C21D1/18 C; C22C38/54; C21D9/46 G; C21D9/46 J; C21D9/46 U; C23C2/06

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)

C21D9/00; C21D9/46; C22C38/00-38/60; C21D1/18; C23C2/06

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 1971-2021

Registered utility model specifications of Japan 1996-2021

Published registered utility model applications of Japan 1994-2021

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2019/208556 A1 (NIPPON STEEL CORPORATION) 31 October 2019 (2019-10-31) entire text	1-7
A	WO 2018/151322 A1 (NIPPON STEEL & SUMITOMO METAL CORPORATION) 23 August 2018 (2018-08-23) entire text	1-7
A	WO 2019/003451 A1 (JFE STEEL CORPORATION) 03 January 2019 (2019-01-03) entire text	1-7
P, A	WO 2020/189767 A1 (NIPPON STEEL CORPORATION) 24 September 2020 (2020-09-24) entire text	1-7



Further documents are listed in the continuation of Box C.



See patent family annex.

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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

09 April 2021 (09.04.2021)

Date of mailing of the international search report

20 April 2021 (20.04.2021)

Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

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

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application no.

PCT/JP2021/005226

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
WO 2019/208556 A1	31 Oct. 2019	TW 201945554 A entire text	
WO 2018/151322 A1	23 Aug. 2018	US 2020/0010919 A1 entire text EP 3584348 A1 CN 110177894 A KR 10-2019-0108129 A MX 2019009701 A BR 112019016852 A TW 201834846 A	
WO 2019/003451 A1	03 Jan. 2019	US 2020/0131596 A1 entire text EP 3647445 A1 KR 10-2020-0004364 A CN 110799660 A	
WO 2020/189767 A1	24 Sep. 2020	(Family: none)	

REFERENCES CITED IN THE DESCRIPTION

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