



(11)

EP 4 008 800 A1

(12)

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

(43) Date of publication:
08.06.2022 Bulletin 2022/23

(21) Application number: **20860644.2**

(22) Date of filing: **01.09.2020**

(51) International Patent Classification (IPC):
C22C 38/34 (2006.01) **C22C 38/26** (2006.01)
C22C 38/38 (2006.01) **C22C 38/00** (2006.01)
C21D 8/02 (2006.01)

(52) Cooperative Patent Classification (CPC):
**C21D 8/02; C22C 38/00; C22C 38/26; C22C 38/34;
C22C 38/38**

(86) International application number:
PCT/KR2020/011684

(87) International publication number:
WO 2021/045476 (11.03.2021 Gazette 2021/10)

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

Designated Extension States:

BA ME

Designated Validation States:

KH MA MD TN

(30) Priority: **03.09.2019 KR 20190108827**

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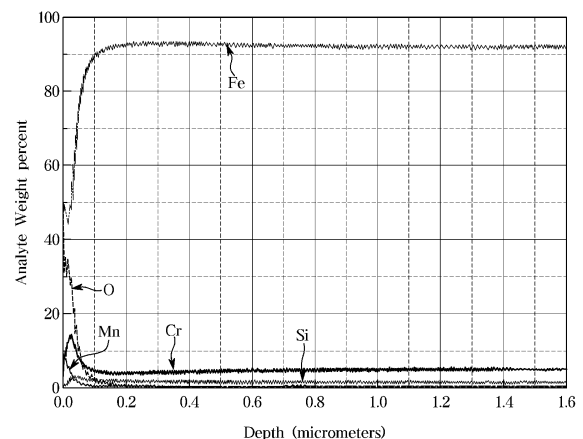
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(54) **STEEL SHEET FOR HOT FORMING, HOT-FORMED MEMBER, AND METHOD FOR MANUFACTURING SAME**

(57) Disclosed are a high-strength and non-plated steel sheet which is for hot forming and may be suitable for use in automotive structural members that require collision resistance characteristics, a hot-formed member, and a method for manufacturing same.

A steel sheet for hot forming and a hot-formed member according to an embodiment of the present disclosure contain, in percent by weight (wt%), 0.05 to 0.3% of carbon (C), 0.5 to 3.0% of silicon (Si), 0.1 to 2.0% of manganese (Mn), 3.0 to 9.0% of chromium (Cr), more than 0% and less than 0.2% of nitrogen (N), and 0.03 to 1.0% of niobium (Nb), with the remainder comprising iron (Fe) and inevitable impurities.

[FIG. 6]



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Description

[Technical Field]

5 **[0001]** The present disclosure relates to a steel sheet for hot forming, a hot-formed member using the same, and a method for manufacturing the same, and more particularly, to a high-strength and non-plated steel sheet which is for hot forming and may be suitable for use in automotive structural members that require collision resistance characteristics, a hot-formed member, and a method for manufacturing the same.

10 [Background Art]

[0002] As various safety regulations for protecting passengers of vehicles have been strengthened and interest in environmental issues has grown recently, regulations on fuel efficiency and CO₂ emission have also been strengthened.

15 **[0003]** Accordingly, thickness of materials used for the vehicles may be reduced to increase fuel efficiency, but a decrease in thickness may cause a stability problem in the vehicles and thus enhancement of strength of the material should be accompanied therewith.

[0004] A process of increasing strength of a material causes a decrease in elongation together with an increase in yield strength, resulting in deterioration of formability in most cases. Therefore, advanced high strength steels (AHSS) such as dual phase (DP) steels and TRIP steels have been developed based on studies on various materials and have
20 been actually applied to automobile parts, and such steel sheets exhibit excellent formability compared to conventional high-strength steels for vehicles.

[0005] However, a higher forming force is required to form automobile parts with an increased strength of a material as described above, and thus capacity and load of a press need to be increased. Also, molding of the high-strength material may cause a decrease in mold life and a decrease in productivity.

25 **[0006]** Although a martensitic steel having an ultra-high strength of 1,000 MPa or more may be effective on reducing a weight of the body of a vehicle when used in the vehicle, commercialization of the martensitic structure is difficult due to poor formability.

[0007] As methods for commercialization using a martensitic steel, a method of preparing a high-strength martensitic structure by cold forming an initial ferritic structure having excellent formability, forming an austenite by heat treatment at a high temperature, and quenching the resultant has been used. However, a problem of poor shape fixability may occur according to the above-described forming method due to phase transformation in a non-constrained state. Particularly, a volume change is accompanied by a change in the crystal structure from FCC to BCC in phase transformation from austenite to martensite occurring during a cooling process, and accordingly dimensional precision deteriorates. Thus, an additional process of performing dimensional correction is required.

35 **[0008]** To solve these problems, a forming method called hot press forming (HPF) or hot forming has recently been proposed. Hot press forming is a forming method to increase a strength of a final product by preparing an austenite single phase by heating a steel sheet at a high temperature higher than Ac₁ at which processing is easily performed, hot forming the steel sheet by press forming, and forming a low-temperature structure such as martensite by quenching. The hot forming is advantageous in that a problem in formability caused during preparation of a high-strength material
40 may be minimized.

[0009] However, because the steel sheet is heated to a high temperature in the case of using the hot press forming method, the surface of the steel sheet is oxidized, and thus a process of removing oxides from the surface of the steel sheet needs to be added after the press forming.

[0010] To solve these problems, a method disclosed in Patent Document 1 has been proposed. In Patent Document 1, although a steel sheet coated with Al-Si is heated at a temperature of 850°C or higher and then hot-pressed to form a martensite structure, the steel sheet is not oxidized during heating due to an Alcoating layer formed on the surface of the steel sheet. When hot press forming is performed using the Al-coated steel sheet, not only a product having an ultra-high strength of 1,000 MPa may be easily obtained but also a product having high dimensional precision may be obtained, and thus the hot press forming has drawn attention and interest as a very effective method for forming automobile parts
50 on a decrease in weight and an increase in rigidity of vehicles.

[0011] However, several problems have recently been raised in the hot press forming method using an Al-coated steel sheet during a forming process and a subsequent bonding/welding process between other members.

[0012] Among them, according to Patent Document 2, because a plating layer includes aluminum as a main phase, aluminum may be liquified at a temperature higher than a melting point of the plating layer to be fused to a roll in a heating furnace when a blank is heated in a heating furnace or partial exfoliation may occur due to stress.

55 **[0013]** Also, according to Patent Document 3, a hot-pressed, formed member may be prepared by bonding two or more members using an adhesive. In this case, a sufficient adhesive strength needs to be maintained to verify adhesive strength. A method of testing whether the bonded portion is easily maintained at a high strength by applying a tensile

stress in a direction perpendicular to the bonded surface is often used. In this case, a plating layer is often detached from the inside of the plating layer or an interface between the plating layer and a steel sheet. In this case, a problem of separation of the two members may occur even under a low stress.

[0014] In addition, according to Patent Document 4, a tailored welded blank (TWB), which is made by pre-bonding different steel sheets having different thicknesses for decreasing a weight of a vehicle, has been used as a major material in hot press forming. The TWB is mainly prepared by laser bonding and it is known that combination of the surface condition of a material and strength of the raw material considerably affects properties. However, in the case of a hot dip Al plated steel sheet, breakage of a welded part was observed when deformed by press forming after heat treatment. This is because Al on the plating layer of the surface penetrates into the welded part during laser welding of a TWB material and thus a ferrite phase remains in the welded part after heat treatment to embrittle the welded part. To overcome this, an additional process of removing a surface film is suggested before laser welding of the hot dip Al plated steel sheet.

[0015] As described above, aluminum plating is essential in order to prevent oxidation during heating for hot press forming of a martensitic steel, but there is a need to develop technologies for solving various problems occurring thereby.

[Patent Document 1] US Patent Publication No. 6,296,805 (October 2, 2001)

[Patent Document 2] Korean Patent Publication No. 10-1696121 (January 6, 2017)

[Patent Document 3] Korean Patent Application Publication No. 10-2018-0131943 (December 11, 2018)

[Patent Document 4] Korean Patent Application Publication No. 10-2015-0075277 (July 3, 2015)

[Disclosure]

[Technical Problem]

[0016] Embodiments of the present disclosure have been proposed to solve problems described above and provided are a steel sheet for hot forming having ultra-high strength while preventing surface oxidation during hot press forming without using a plating layer, a hot-formed member, and a method for manufacturing the same.

[Technical Solution]

[0017] In accordance with an aspect of the present disclosure, a steel sheet for hot forming includes, in percent by weight (wt%), 0.05 to 0.3% of carbon (C), 0.5 to 3.0% of silicon (Si), 0.1 to 2.0% of manganese (Mn), 3.0 to 9.0% of chromium (Cr), more than 0% and less than 0.2% of nitrogen (N), 0.03 to 1.0% of niobium (Nb), and the remainder of iron (Fe) and inevitable impurities, wherein a microstructure comprises a ferrite phase and 20 vol% or less of a carbonitride.

[0018] Also, according to an embodiment of the present disclosure, the ferrite phase may have an average grain size of 100 μm or less.

[0019] Also, according to an embodiment of the present disclosure, the steel sheet may satisfy Expression (1) below:

$$0.80 \cdot \text{Si} + 0.57 \cdot \text{Cr} - 3.53 \cdot \text{C} - 1.45 \cdot \text{Mn} - 1.9 > 0$$

[0020] Also, according to an embodiment of the present disclosure, a content of Cr may be from 3.5 to 5.5%.

[0021] Also, according to an embodiment of the present disclosure, the steel sheet may further include less than 3.0% of nickel (Ni).

[0022] Also, according to an embodiment of the present disclosure, the steel sheet may further include less than 0.1% of phosphorus (P) and less than 0.01% of sulfur (S).

[0023] In accordance with another aspect of the present disclosure, a hot-formed member includes, in percent by weight (wt%), 0.05 to 0.3% of carbon (C), 0.5 to 3.0% of silicon (Si), 0.1 to 2.0% of manganese (Mn), 3.0 to 9.0% of chromium (Cr), more than 0% and less than 0.2% of nitrogen (N), 0.03 to 1.0% of niobium (Nb), and the remainder of iron (Fe) and inevitable impurities.

[0024] Also, according to an embodiment of the present disclosure, the hot-formed member may satisfy Expression (1) below:

$$0.80 \cdot \text{Si} + 0.57 \cdot \text{Cr} - 3.53 \cdot \text{C} - 1.45 \cdot \text{Mn} - 1.9 > 0$$

[0025] Also, according to an embodiment of the present disclosure, an average oxygen content may be 20 wt% or less at a point of 0.1 μm depth from the surface.

[0026] Also, according to an embodiment of the present disclosure, the hot-formed member may have a yield strength

of 1,100 MPa or more and a tensile strength of 1,500 MPa or more.

[0027] Also, according to an embodiment of the present disclosure, a content of Cr may be from 3.5 to 5.5%.

[0028] Also, according to an embodiment of the present disclosure, the hot-formed member may further include less than 3.0% of nickel (Ni).

[0029] Also, according to an embodiment of the present disclosure, the hot-formed member may further include less than 0.1% of phosphorus (P) and less than 0.01% of sulfur (S).

[0030] In accordance with another aspect of the present disclosure, a method for manufacturing a hot-formed member includes: preparing a steel sheet for hot forming comprising, in percent by weight (wt%), 0.05 to 0.3% of carbon (C), 0.5 to 3.0% of silicon (Si), 0.1 to 2.0% of manganese (Mn), 3.0 to 9.0% of chromium (Cr), more than 0% and less than 0.2% of nitrogen (N), 0.03 to 1.0% of niobium (Nb), and the remainder of iron (Fe) and inevitable impurities; heating the steel sheet at a rate of 1 to 1,000 °C/sec to a temperature range of Ac3+50°C to Ac3+200°C and maintaining for 1 to 1,000 seconds; and hot-forming the heated and maintained steel sheet and cooling the steel sheet at a rate of 1 to 1000°C/sec to a temperature below Mf.

[0031] Also, according to an embodiment of the present disclosure, the steel sheet for hot forming may satisfy Expression (1) below.

$$(1) 0.80 \cdot Si + 0.57 \cdot Cr - 3.53 \cdot C - 1.45 \cdot Mn - 1.9 > 0$$

[0032] Also, according to an embodiment of the present disclosure, the steel sheet for hot forming may include a microstructure comprising a ferrite phase and 20 vol% or less of a carbonitride, wherein an average grain size of the ferrite phase is 100 μm or less.

[0033] Also, according to an embodiment of the present disclosure, a content of Cr in the steel sheet for hot forming may be from 3.5 to 5.5%.

[0034] Also, according to an embodiment of the present disclosure, the steel sheet for hot forming may further include less than 3.0% of nickel (Ni).

[0035] Also, according to an embodiment of the present disclosure, the steel sheet for hot forming may further include less than 0.1% of phosphorus (P) and less than 0.01% of sulfur (S).

[0036] Also, according to an embodiment of the present disclosure, the preparing of the steel sheet for hot forming may include: reheating a slab in a temperature range of 1,000 to 1,300°C; preparing a hot-rolled steel sheet by finish-rolling the reheated slab in a temperature range higher than Ar3 and equal to or lower than 1,000°C; coiling the hot-rolled steel sheet in a temperature range higher than Ms and equal to or lower than 850°C; and acid-pickling the coiled, hot-rolled steel sheet.

[0037] Also, according to an embodiment of the present disclosure, the method may further include: preparing a cold-rolled steel sheet by rolling the acid pickled, hot-rolled steel sheet with a reduction ratio of 30 to 80%; and continuously annealing the cold-rolled steel sheet in a temperature range of 700 to 900°C.

[0038] Also, according to an embodiment of the present disclosure, the method may further include batch-annealing the coiled, hot-rolled or acid-pickled steel sheet in a temperature range of 500 to 850°C for 1 to 100 hours.

[Advantageous Effects]

[0039] In the steel sheet for hot forming and the hot-formed member according to an embodiment of the present disclosure, surface oxidation is prevented during hot press forming by improving oxidation resistance by controlling alloying elements, and thus conventional aluminum plating may be omitted.

[0040] In addition, problems, which may occur during a hot press forming process and a bonding/welding process performed between different members when an Al-coated steel sheet is used, may be solved.

[0041] In addition, high strength at an equivalent level to that of conventional Al-plated steel materials may be obtained.

[Description of Drawings]

[0042]

FIG. 1 is an electron microscope image showing a microstructure of a steel sheet for hot forming according to an embodiment of the present disclosure.

FIG. 2 is a photograph exemplarily illustrating good formability (a) and poor formability (b) obtained when hot forming is performed using a mini-bumper mold.

FIG. 3 is a graph illustrating tensile test results of samples of examples and comparative examples which are hot-formed using a plate-shaped mold.

FIGS. 4 and 5 are electron microscope images of microstructures of steel sheets for hot forming according to an example and a comparative example prior to formation, respectively.

FIGS. 6 and 7 are graphs illustrating GDS analysis results of hot-formed members obtained using a mini-bumper mold according to an example exhibiting good oxidation resistance and a comparative example exhibiting inferior oxidation resistance with respect to depth from the surface.

[Best Mode]

[0043] A steel sheet for hot forming according to an embodiment of the present disclosure may include, in percent by weight (wt%), 0.05 to 0.3% of carbon (C), 0.5 to 3.0% of silicon (Si), 0.1 to 2.0% of manganese (Mn), 3.0 to 9.0% of chromium (Cr), more than 0% and less than 0.2% of nitrogen (N), 0.03 to 1.0% of niobium (Nb), and the remainder of iron (Fe) and inevitable impurities, wherein a microstructure includes a ferrite phase and 20 vol% or less of a carbonitride.

[Modes of the Invention]

[0044] Hereinafter, embodiments of the present disclosure will be described in detail with reference to the accompanying drawings. The following embodiments are provided to fully convey the spirit of the present disclosure to a person having ordinary skill in the art to which the present disclosure belongs. The present disclosure is not limited to the embodiments shown herein but may be embodied in other forms. In the drawings, parts unrelated to the descriptions are omitted for clear description of the disclosure and sizes of elements may be exaggerated for clarity.

[0045] All of the above-described problems occurring during the hot forming process and the bonding/welding process are caused by presence of a plating layer. The present inventors have designed optimum alloying elements such as Cr, Si, and Mn to obtain high strength at an equivalent level to that of conventional plated-steel sheet, to inhibit surface oxidation without using a plated layer, and to have excellent formability suitable for preparation of a formed member.

[0046] A steel sheet for hot forming and a hot-formed member according to an embodiment of the present disclosure may include, in percent by weight (wt%), 0.05 to 0.3% of carbon (C), 0.5 to 3.0% of silicon (Si), 0.1 to 2.0% of manganese (Mn), 3.0 to 9.0% of chromium (Cr), more than 0% and less than 0.2% of nitrogen (N), 0.03 to 1.0% of niobium (Nb), and the remainder of iron (Fe) and inevitable impurities.

[0047] Hereinafter, reasons for numerical limitations on the contents of alloying elements in the embodiment of the present disclosure will be described. Hereinafter, the unit is wt% unless otherwise stated.

[0048] The content of C is from 0.05 to 0.3%.

[0049] C is an element not only effective on stabilization of an austenite phase but also effective on obtaining high strength by solid solution strengthening effects. However, an excess of C may not only deteriorate processibility due to an increase in a carbide in a microstructure but also deteriorate physical and mechanical properties (e.g., ductility, toughness, and corrosion resistance) of a welded part and a heat-affected portion. Therefore, an upper limit thereof is set to 0.3%. In addition, as described above, C needs to be added in an amount of 0.05% or more to obtain stability of the austenite stability and target mechanical properties. Preferably, C may be added in an amount of 0.15% or more to obtain high strength. However, because high strength may be complemented by adding N and formation of a Cr carbide deteriorates oxidation resistance, the C content is not necessarily 0.15% or more.

[0050] The content of Si is from 0.5 to 3.0%.

[0051] Si, serving as a deoxidizer during a steelmaking process, is effective on enhancing corrosion resistance and oxidation resistance, and these properties are effective when the Si content is 0.5% or more. However, because Si is an element effective on stabilizing a ferrite phase, an excess of Si may promote formation of delta (δ) ferrite in a cast slab, thereby not only deteriorating hot processibility but also deteriorating ductility and toughness of a steel material due to solid solution strengthening effects. Therefore, an upper limit thereof is set to 0.7%. Preferably, Si may be added in an amount of 1.0 to 2.0%.

[0052] The content of Mn is from 0.1 to 2.0%.

[0053] Mn, as an element effective on stabilizing an austenite phase, is essential to obtain the austenite phase at a high temperature during heat treatment and is added in an amount of 0.1% or more. However, an excess of Mn not only causes an increase in S-based inclusions (MnS) leading to deterioration of ductility, toughness, and corrosion resistance of a steel material but also deteriorates oxidation resistance due to an increase in MnO on the surface of the steel material during heat treatment at a high temperature in an oxidizing atmosphere for forming an austenite structure. Therefore, an upper limit thereof is set to 2.0%.

[0054] The content of Cr is from 3.0 to 9.0%.

[0055] Cr, as a ferrite-stabilizing element, is effective on improving corrosion resistance and oxidation resistance, and these properties are effective when the Cr content is 3.0% or more. However, an excess of Cr may cause an increase in Ac1 due to enhancement of stability of ferrite making it difficult to obtain an austenite phase during heat treatment of a steel material. Therefore, an upper limit thereof is set to 9.0%. In consideration of hot formability and economic efficiency,

the Cr content may be from 3.5 to 7.0%, preferably, from 3.5 to 5.5%.

[0056] The content of N is more than 0% and less than 0.2%.

[0057] N, as not only an austenite phase-stabilizing element but also an element effective on obtaining high strength by solid solution strengthening effects, may decrease the amounts of Ni and Mn, thereby preventing an increase in costs of materials. However, an excess of N may cause formation of a large amount of a nitride in a microstructure, thereby deteriorating processibility. Also, when more than a certain level of N is added, delta (δ) ferrite formed during a cooling process after casting may cause local formation of nitrogen pin holes, thereby deteriorating quality. Therefore, an upper limit thereof is set to 0.2%.

[0058] The content of Nb is from 0.03 to 1.0%.

[0059] Nb, forming a carbonitride of Nb(C,N) at a high temperature, is effective on preventing coarsening of grains during heat treatment and this property is effective when the Nb content is 0.03% or more. Such grain refinement is effective not only on improving processibility of a steel material at a high temperature but also on enhancing impact resistance. However, an excess of Nb may cause formation of a large amount of the Nb(C,N) carbonitride, thereby decreasing amounts of solute C and N, making it difficult to obtain target mechanical properties. Therefore, an upper limit thereof is set to 1.0%, preferably 0.3%.

[0060] The content of Ni is less than 3.0%.

[0061] Although used as a strong austenite phase-stabilizing element, Ni is not an essential element in the present disclosure because manufacturing costs are increased thereby. However, when Ni is added within an upper limit of 3.0%, an austenite phase may be easily formed at a high temperature. However, when the Ni content is 3.0% or more, residual austenite is excessively formed in a cooled structure after heat treatment and thus strength may deteriorate. Therefore, an upper limit thereof is set to 3.0%.

[0062] The content of P is less than 0.1%.

[0063] Because P deteriorates corrosion resistance or hot processibility, an upper limit thereof is set to 0.1%.

[0064] The content of S is less than 0.01%.

[0065] Because S deteriorates corrosion resistance or hot processibility, an upper limit thereof is set to 0.01%.

[0066] The remaining component of the composition of the present disclosure is iron (Fe). However, the composition may include unintended impurities inevitably incorporated from raw materials or surrounding environments, and thus addition of other alloy components is not excluded. The impurities are not specifically mentioned in the present disclosure, as they are known to any person skilled in the art of manufacturing.

[0067] The steel sheet for hot forming of the present disclosure has a microstructure including a ferrite phase and 20 vol% or less of a carbonitride. Because good hot formability is required to prevent cracks or bursts on the surface during hot forming, e.g., hot press forming (HPF), grain refinement is required in a ferrite phase.

[0068] The steel sheet for hot forming according to an embodiment of the present disclosure may include a ferrite phase having an average grain size of 100 μm or less. In the present disclosure, the average grain size of the ferrite phase is controlled by the chemical composition of alloying elements. By adding Nb as described above, a carbonitride is formed to reduce in size of grains and coarsening of grains may be prevented at a high temperature, and thus addition of Nb is essential. The ranges of contents of C and N which form the carbonitride with Nb are also important to control the average grain size. When the content of Cr is too low, e.g., less than 3.0%, grains are coarsened, thereby deteriorating formability. As will be described below, the steel sheet for hot forming may be a hot-rolled steel sheet obtained by batch annealing, a cold-rolled steel sheet obtained by continuous annealing, or a hot-rolled steel sheet obtained by acid pickling without performing annealing. Although the grain size of steel sheets provided to hot forming may generally be controlled by annealing, excellent formability may be obtained during hot forming regardless of performing annealing when the range of the chemical composition of alloying elements of the present disclosure is satisfied.

[0069] In addition, according to an embodiment of the present disclosure, the steel sheet for hot forming may satisfy Expression (1) below.

$$(1) \quad 0.80 \cdot \text{Si} + 0.57 \cdot \text{Cr} - 3.53 \cdot \text{C} - 1.45 \cdot \text{Mn} - 1.9 > 0$$

[0070] According to the present disclosure, excellent oxidation resistance may be obtained by adjusting the contents of Si, Cr, C, and Mn to satisfy Expression (1) although a plating layer is not formed. Although the contents of oxidation-inhibiting elements such as Cr and Si have the greatest influence on oxidation resistance of a hot-formed member, the oxidation resistance is also sensitive to the contents of C and Mn that promote formation of precipitates and oxides as well thereby deriving Expression (1) above. When the contents of Cr and Si are low, dense formation of Cr and Si oxides

is inhibited and a thick Fe oxide is formed on the surface layer. In addition, when a large amount of C is added, formation of a Cr carbide increases to reduce the Cr content in a matrix, thereby causing formation of an Fe oxide. In addition, when a large amount of Mn is locally added, a Mn oxide is formed thereby deteriorating oxidation resistance on the surface.

[0071] Oxidation behavior of the surface layer sensitively changes during hot forming due to influence of various alloying elements as described above. It is important to define the quality of oxidation resistance of the surface layer, and the hot-formed member according to an embodiment of the present disclosure may have an average oxygen content of 20 wt% or less at a point of 0.1 μm depth from the surface.

[0072] Then, a method of preparing a steel sheet for hot forming and a hot-formed member will be described.

[0073] First, a steel sheet for hot forming may be manufactured according to a well-known manufacturing process as a cold-rolled steel sheet or an acid-pickled, hot-rolled steel sheet, but manufacturing conditions are not particularly limited. An example of the method for manufacturing the steel sheet for hot forming is as follows.

[0074] An ingot or slab having the above-described chemical composition of alloying elements is heated in a temperature range of 1,000 to 1,300°C and hot-rolled. At a heating temperature below 1,000°C, it is difficult to homogenize the slab structure, and at a heating temperature exceeding 1,300°C, an oxide layer may be excessively formed and manufacturing costs may increase.

[0075] Subsequently, hot finish rolling is performed in a temperature range higher than A_{r3} and equal to or lower than 1,000°C. At a finish rolling temperature of A_{r3} or less, recrystallization rolling may be easily induced making it difficult to control formation of a surface mixed structure and a steel sheet. When the finish rolling temperature exceeds 1,000°C, hot-rolled grains may be easily coarsened.

[0076] The hot-rolled steel sheet may be coiled in a temperature range higher than M_s and equal to or lower than 850°C. When a coiling temperature is M_s or below, it is difficult to perform a subsequent cold rolling due to too high strength of the hot-rolled steel. When the coiling temperature is higher than 850°C, a thickness of an oxide layer excessively increases making it difficult to perform acid pickling on the surface.

[0077] The hot-rolled steel sheet may be hot-formed immediately after acid pickling. Meanwhile, the acid pickling and cold rolling may be performed to control the thickness of the steel sheet more precisely. Although a cold rolling reduction ratio after acid pickling is not particularly limited, the cold rolling may be performed with a reduction ratio of 30 to 80% to obtain a target thickness. In this regard, to reduce a rolling load of the cold rolling, if required, the hot-rolled steel sheet or the previously acid-pickled, hot-rolled steel sheet may be batch-annealed. In this regard, although batch annealing conditions are not particularly limited, the batch annealing may be performed at a temperature of 500 to 850°C for 1 to 100 hours to reduce strength of the hot-rolled steel sheet.

[0078] The cold-annealed, cold-rolled steel sheet may be continuously annealed. Although a continuous annealing heat treatment process is not particularly limited, the heat treatment may be performed in a temperature range of 700 to 900°C.

[0079] Subsequently, the hot-rolled steel sheet or cold-rolled, annealed steel sheet prepared as described above may be hot-formed to prepare a hot-formed member.

[0080] The prepared steel sheet for hot forming is heated to a temperature range of $A_{c3}+50^\circ\text{C}$ to $A_{c3}+200^\circ\text{C}$ at a heating rate of 1 to 1,000°C/sec. At a heating rate below 1°C/sec, it is difficult to obtain sufficient productivity. Also, a too long heating time not only excessively increases a grain size to deteriorate impact toughness but also excessively forms oxides on the surface of the formed member to deteriorate spot weldability. To increase the heating rate to exceed 1,000°C/sec, expensive equipment is required.

[0081] Subsequently, the heat treatment may be maintained in the temperature range of $A_{c3}+50^\circ\text{C}$ to $A_{c3}+200^\circ\text{C}$ for 1 to 1,000 seconds. At a heating temperature below $A_{c3}+50^\circ\text{C}$, there is a high possibility that ferrite is formed while a blank is transferred from a heating furnace to a mold, thereby failing to obtain a target strength. When the heating temperature exceeds $A_{c3}+200^\circ\text{C}$, an excess of oxides on the surface of the formed member makes it difficult to obtain spot weldability and coating property during a subsequent process.

[0082] The hot-formed member is cooled to a temperature below M_f simultaneously with the hot forming and a cooling rate may be controlled in a range of 1 to 1000°C/sec. At a cooling rate below 1°C/sec, undesirable ferrite is formed making it difficult to obtain a tensile strength 1,500 MPa or more. On the contrary, to obtain a cooling rate exceeding 1,000°C/sec, expensive, specified equipment is required.

[0083] Hereinafter, the present disclosure will be described in more detail with reference to the following examples.

Examples

[0084] Ingot materials having chemical compositions of alloying elements shown in Table 1 were below melted, heated in a furnace at a temperature of 1,180°C for 2 hours, and hot-rolled to obtain hot-rolled steel sheets having a final thickness of 3 mm. Subsequently, the hot-rolled steel sheets were acid-pickled for cold rolling, cold-rolled with a reduction ratio of 60%, and annealed at 760°C to obtain steel sheets for hot forming.

Table 1

Steel type (wt%)	C	Si	Mn	P	S	Cr	Ni	N	Nb	Others
Comparative Example 1	0.219	1.47	0.5	0.012	0.002	5.0	0.2	0.019	0	
Comparative Example 2	0.222	1.51	0.5	0.014	0.004	3.97	0.196	0.016	0	
Comparative Example 3	0.22	1.51	1.48	0.018	0.002	4.0	0.198	0.02	0	
Comparative Example 4	0.215	1.99	1.5	0.016	0.003	4.0	0.201	0.016	0	
Comparative Example 5	0.217	2.45	1.48	0.012	0.002	3.98	0.197	0.016	0	
Comparative Example 6	0.223	1.55	1.51	0.012	0.003	3.93	0.203	0.018	0	Al:0.51
Comparative Example 7	0.225	1.49	1.48	0.014	0.004	3.93	201	0.02	0	Al:1.02
Comparative Example 8	0.223	1.49	0.5	0.016	0.002	7.05	0.198	0.021	0	
Comparative Example 9	0.225	1.48	1.47	0.017	0.002	6.93	0.2	0.027	0	
Comparative Example 10	0.14	0.4	0.48	0.016	0.003	11.3	0.39	0.05	0.16	B:0.0038
Comparative Example 11	0.179	1.5	0.52	0.013	0.002	3.98	0.2	0.027	0	
Comparative Example 12	0.182	1.5	0.5	0.014	0.004	4.0	0.2	0.028	0	B:0.0054
Comparative Example 13	0.135	1.47	0.49	0.012	0.003	3.87	0.2	0.027	0	
Comparative Example 14	0.14	1.5	0.49	0.018	0.003	4.04	0.2	0.03	0	B:0.0038
Comparative Example 15	0.139	1.51	0.51	0.014	0.002	4.0	0.2	0.029	0	B:0.0083
Comparative Example 16	0.265	1.49	0.498	0.016	0.002	3.97	0.203	0.031	0	
Comparative Example 17	0.295	1.49	0.492	0.018	0.002	4.05	0.206	0.033	0	
Comparative Example 18	0.216	1.5	0.512	0.014	0.002	4.0	0.2	0.031	0.096	Sb:0.043
Comparative Example 19	0.202	1.49	0.495	0.013	0.002	3.88	0.196	0.026	0.103	Sb:0.046
Comparative Example 20	0.25	1.53	0.512	0.014	0.002	4.99	0.201	0.026	0.101	Sb:0.055
Comparative Example 21	0.225	1.5	0.506	0.016	0.004	2.97	0.212	0.028	0.098	Sb:0.048
Comparative Example 22	0.216	1.51	0.495	0.012	0.004	1.92	0.204	0.028	0.101	Sb:0.05
Comparative Example 23	0.258	1.5	0.496	0.012	0.003	2.94	0.204	0.03	0.047	Sb:0.045
Example 1	0.215	1.49	0.495	0.013	0.002	3.96	0.203	0.032	0.095	
Example 2	0.217	1.49	0.496	0.016	0.004	4.99	0.196	0.031	0.1	
Example 3	0.215	1.49	0.493	0.012	0.002	4.49	0.197	0.035	0.07	
Example 4	0.238	1.5	0.505	0.016	0.004	5.0	0.2	0.028	0.102	
Example 5	0.242	1.52	0.497	0.011	0.003	5.02	0.201	0.027	0.105	Sn:0.052
Example 6	0.234	1.64	0.61	0.016	0.004	4.61	0.28	0.021	0.096	Al:1.12
Example 7	0.217	1.5	0.496	0.012	0.003	4.0	0.206	0.031	0.052	

[0085] FIG. 1 is an electron microscope image illustrating a microstructure of a steel sheet for hot forming according to an embodiment of the present disclosure. Referring to FIG. 1, it may be confirmed that a microstructure of a cold-rolled, annealed steel sheet for hot forming includes 20 vol% of a carbonitride in a ferrite matrix structure.

[0086] The steel sheets for hot forming prepared as described above were hot-formed and heat treatment conditions therefor are shown in Table 2 below. The steel sheets were put into a furnace pre-heated to 950°C, maintained for 5.5 minutes, air-cooled for 12 seconds, hot-formed in a mold, and quenched to room temperature at a cooling rate of 30°C/sec or more.

[0087] Two types of molds were used to form the hot-formed member. A first mold was a plate-shaped mold for forming the hot-formed member and performing a tensile test to evaluate physical properties after hot forming, and a second

mold was prepared as a mini-bumper mold to evaluate formability and oxidation resistance.

[0088] Samples of the formed members obtained using the plate-shaped mold were evaluated by the tensile test according to the JIS 13 B standards and the results are shown in Table 2. In addition, formability and oxidation resistance of the formed members obtained by using the mini-bumper mold were evaluated by applying the same hot forming heat treatment conditions and the results are shown in Table 2.

[0089] FIG. 2 is a photograph exemplarily illustrating good formability (a) and poor formability (b) obtained when hot forming is performed using a mini-bumper mold after hot forming. As shown in (b) of FIG. 2, cracks or bursts occurred on the surfaces during hot forming in some of the comparative examples and they were indicated as "poor" in Table 2. On the contrary, good formability as shown in (a) of FIG. 2 was indicated as "good".

[0090] Oxidation resistance of the hot-formed members obtained using the mini-bumper mold was evaluated based on whether excessive oxide scales were locally formed on the surface. A case in which surface oxidation was inhibited was indicated as "good" and a case in which excessive oxide scales were locally formed was indicated as "inferior".

Table 2

Example	Heat treatment conditions for hot forming			Tensile test properties			Properties of hot-formed member		
	Atmosphere	Temperature (°C)	Time (min)	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Formability	Expression (1)	Oxidation resistance
Comparative Example 1	air	950	5.5	1,075	1,564	7.7	poor	0.628	good
Comparative Example 2	air	950	5.5	1,029	1,517	8.2	poor	0.062	good
Comparative Example 3	air	950	5.5	1,107	1,643	7.6	poor	-1.335	inferior
Comparative Example 4	air	950	5.5	1,176	1,744	7.1	poor	-0.962	inferior
Comparative Example 5	air	950	5.5	1,202	1,814	7.5	poor	-0.583	inferior
Comparative Example 6	air	950	5.5	1,108	1,605	6.8	poor	-1.397	good
Comparative Example 7	air	950	5.5	969	1,491	8.9	poor	-1.408	good
Comparative Example 8	air	950	5.5	1,141	1,644	6.8	poor	1.798	good
Comparative Example 9	air	950	5.5	1,180	1,731	7.2	poor	0.308	good
Comparative Example 10	air	950	5.5	1,086	1,411	8.5	poor	3.671	good
Comparative Example 11	air	950	5.5	995	1,411	8.1	poor	0.183	good
Comparative Example 12	air	950	5.5	979	1,405	9.2	poor	0.213	good
Comparative Example 13	air	950	5.5	905	1,304	9.9	poor	0.295	good
Comparative Example 14	air	950	5.5	920	1,303	9	poor	0.398	good
Comparative Example 15	air	950	5.5	897	1,286	8.8	poor	0.358	good

(continued)

Example	Heat treatment conditions for hot forming			Tensile test properties			Properties of hot-formed member		
	Atmosphere	Temperature (°C)	Time (min)	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Formability	Expression (1)	Oxidation resistance
Comparative Example 16	air	950	5.5	1,206	1,723	7.2	good	-0.103	inferior
Comparative Example 17	air	950	5.5	1,256	1,804	7.3	good	-0.154	inferior
Comparative Example 18	air	950	5.5	1,180	1,657	8.2	good	0.075	inferior
Comparative Example 19	air	950	5.5	1,411	1,796	10.2	good	0.073	inferior
Comparative Example 20	air	950	5.5	1,189	1,704	7.4	good	0.543	inferior
Comparative Example 21	air	950	5.5	1,150	1,645	9.1	poor	-0.535	inferior
Comparative Example 22	air	950	5.5	1,089	1,599	9.3	poor	-1.078	inferior
Comparative Example 23	air	950	5.5	1,187	1,701	8.6	poor	-0.654	inferior
Example 1	air	950	5.5	1,140	1,596	8.8	good	0.073	good
Example 2	air	950	5.5	1,127	1,597	7.6	good	0.651	good
Example 3	air	950	5.5	1,135	1,597	8.2	good	0.378	good
Example 4	air	950	5.5	1,165	1,662	7.6	good	0.578	good
Example 5	air	950	5.5	1,174	1,679	7.6	good	0.602	good
Example 6	air	950	5.5	1,203	1,735	7.8	good	0.329	good
Example 7	air	950	5.5	1,110	1,553	8.5	good	0.095	good

[0091] FIG. 3 is a graph illustrating tensile test results of the hot-formed samples of examples and comparative examples using a plate-shaped mold, and the tensile test was performed according to JIS 13 B standards. Upon comparison among all of the tensile test curves of the examples and comparative examples, it was confirmed that fracture did not occur before exhibiting a maximum strength but occurred after the maximum tensile strength was obtained as shown in FIG. 3.

[0092] With regard the results, to evaluate hydrogen delayed fracture resistance of an Al-plated hot-formed member, a method of measuring the H content in a steel sheet has been known. According to Patent Document 2 (Korean Patent Publication No. 10-1696121), occurrence of a fracture was observed before a maximum strength was obtained in a tensile curve, and a normal fracture was not observed in the tensile test due to the high H content in the steel sheet. That is, this indicates that hydrogen delayed fracture resistance may be judged based on the results of the tensile curve obtained from the tensile test. In the case of the hot-formed member prepared using the chemical composition of the alloying elements according to the present disclosure, a tensile behavior, in which fracture occurred after a tensile strength reached a maximum level, was observed and thus excellent hydrogen delayed fracture resistance was confirmed.

[0093] Upon evaluation of formability of the hot-formed members shown in Table 2, grain size of the steel sheets for hot forming was confirmed as a factor the most significantly affecting the formability. That is, in most cases in which formability of steel types indicated as "poor" in Table 2, the C content was low or the grain refining element such as Nb was not added, and this result was more clearly identified by observing a microstructure thereof. FIGS. 4 and 5 are electron microscope images of microstructures of steel sheets for hot forming according to an example and a comparative

example prior to formation, respectively. FIG. 4 is a photograph of the microstructure of Example 2 before hot forming, and FIG. 5 is a photograph of the microstructure of Comparative Example 1 before hot forming. It was confirmed that the steel types having formability indicated by "poor" had a coarse ferrite grain size of 100 μm or more before hot forming as shown in FIG. 5. Based on these results, it was confirmed that the average grain size of ferrite in the microstructure

needs to be controlled to 100 μm or less to obtain good formability in the final hot-formed member.

[0094] Meanwhile, it was confirmed that excellent oxidation resistance of the hot-formed member was obtained when the contents of Cr and Si which are oxidation-suppressing elements and the contents of C and Mn which are elements forming precipitates and oxides satisfy Expression (1) as described above based on Table 2.

[0095] Oxidation resistance quality of surface layers during hot forming were classified into good and inferior by visual observation based on glow discharge spectrometer (GDS) analysis results, and representative results are shown in FIGS. 6 and 7. FIGS. 6 and 7 are graphs illustrating GDS analysis results of hot-formed members using a mini-bumper mold according to an example exhibiting good oxidation resistance and a comparative example exhibiting inferior oxidation resistance with respect to depth from the surface. As a result of analyzing contents of the alloying elements with respect to depth in the thickness direction from the surface by the GDS, a difference of oxygen contents between the hot-formed member having good oxidation resistance and that having inferior oxidation resistance was clearly observed. While the average oxygen content exceeds 20 wt% at a point of 0.1 μm depth from the surface in the comparative example exhibiting inferior oxidation resistance of FIG. 7, it was confirmed that the average oxygen content was about 2 to 3 wt% at a point of 0.1 μm depth from the surface in the example exhibiting good oxidation resistance of FIG. 6. Based on these results, it was confirmed that the average oxygen content needs to be controlled to 20 wt% or less at a point of 0.1 μm depth from the surface to obtain good oxidation resistance of a final hot-formed member.

[0096] The comparative examples and examples of Table 2 will be described in more detail below.

[0097] In Comparative Examples 1 to 9 to which Nb was not added, grain refinement did not occur before hot forming, and thus poor formability was obtained. Among them, inferior oxidation resistance was observed in Comparative Examples 3 to 5 due to negative values of Expression (1). However, in the cases of Comparative Examples 6 and 7, good oxidation resistance was obtained despite negative values of Expression (1) because Al, effective on oxidation resistance, was added in an amount of 0.5% or more.

[0098] In Comparative Example 10, poor formability was obtained despite addition of Nb due to the high Cr content and good oxidation resistance was obtained despite the low Si content because Expression (1) was satisfied by the high Cr content.

[0099] In Comparative Examples 10 to 15 where the C content was slightly low even within the range proposed by the present disclosure, and thus it was confirmed that the yield strength and the tensile strength did not reach 1,100 MPa and 1,500 Mpa, respectively. However, in Comparative Example 10 where the N content was high as 0.05%, a result close to the target strength was obtained and thus it was confirmed that high strength property may be complemented by adding N.

[0100] Good formability was obtained in Comparative Examples 16 and 17 although Nb was not added and this was because oxidation resistance more deteriorated by formation of a large amount of a carbide due to a slightly high C content but formability was improved due to oxide scales.

[0101] Sb was further added to the steel types of Comparative Examples 18 to 23. Sb was oxidized at a hot forming temperature of 950°C to be present as scales in the form of ash resulting in inferior oxidation resistance although Expression (1) was satisfied in Comparative Examples 18 to 20.

[0102] In Comparative Examples 21 to 23, poor formability was obtained despite addition of Nb, and it was confirmed that this is because the grains coarsened due to the low Cr content to deteriorate formability.

[0103] While the present disclosure has been particularly described with reference to exemplary embodiments, it should be understood by those of skilled in the art that various changes in form and details may be made without departing from the spirit and scope of the present disclosure.

[Industrial Applicability]

[0104] The steel sheet for hot forming according to the present disclosure may be applied to automotive structural members because ultra-high strength may be obtained simultaneously inhibiting surface oxidation during hot press forming without using a plating layer.

Claims

1. A steel sheet for hot forming comprising, in percent by weight (wt%), 0.05 to 0.3% of carbon (C), 0.5 to 3.0% of silicon (Si), 0.1 to 2.0% of manganese (Mn), 3.0 to 9.0% of chromium (Cr), more than 0% and less than 0.2% of nitrogen (N), 0.03 to 1.0% of niobium (Nb), and the remainder of iron (Fe) and inevitable impurities,

wherein a microstructure comprises a ferrite phase and 20 vol% or less of a carbonitride.

2. The steel sheet according to claim 1, wherein the ferrite phase has an average grain size of 100 μm or less.

5 3. The steel sheet according to claim 1, wherein the steel sheet satisfies Expression (1) below:

$$(1) 0.80 \cdot \text{Si} + 0.57 \cdot \text{Cr} - 3.53 \cdot \text{C} - 1.45 \cdot \text{Mn} - 1.9 > 0$$

10 (wherein Si, Cr, C, and Mn denote contents (wt%) of the elements, respectively).

4. The steel sheet according to claim 1, wherein a content of Cr is from 3.5 to 5.5%.

15 5. The steel sheet according to claim 1, further comprising less than 3.0% of nickel (Ni).

6. The steel sheet according to claim 1, further comprising less than 0.1% of phosphorus (P) and less than 0.01% of sulfur (S).

20 7. A hot-formed member comprising, in percent by weight (wt%), 0.05 to 0.3% of carbon (C), 0.5 to 3.0% of silicon (Si), 0.1 to 2.0% of manganese (Mn), 3.0 to 9.0% of chromium (Cr), more than 0% and less than 0.2% of nitrogen (N), 0.03 to 1.0% of niobium (Nb), and the remainder of iron (Fe) and inevitable impurities.

8. The hot-formed member according to claim 7, wherein the hot-formed member satisfies Expression (1) below:

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$$(1) 0.80 \cdot \text{Si} + 0.57 \cdot \text{Cr} - 3.53 \cdot \text{C} - 1.45 \cdot \text{Mn} - 1.9 > 0$$

(wherein Si, Cr, C, and Mn denote contents (wt%) of the elements, respectively).

30 9. The hot-formed member according to claim 7, wherein an average oxygen content is 20 wt% or less at a point of 0.1 μm depth from the surface.

10. The hot-formed member according to claim 7, wherein the hot-formed member has a yield strength of 1,100 MPa or more and a tensile strength of 1,500 MPa or more.

35 11. The hot-formed member according to claim 7, wherein a content of Cr is from 3.5 to 5.5%.

12. The hot-formed member according to claim 7, further comprising less than 3.0% of nickel (Ni).

40 13. The hot-formed member according to claim 7, further comprising less than 0.1% of phosphorus (P) and less than 0.01% of sulfur (S).

14. A method for manufacturing a hot-formed member, the method comprising:

45 preparing a steel sheet for hot forming comprising, in percent by weight (wt%), 0.05 to 0.3% of carbon (C), 0.5 to 3.0% of silicon (Si), 0.1 to 2.0% of manganese (Mn), 3.0 to 9.0% of chromium (Cr), more than 0% and less than 0.2% of nitrogen (N), 0.03 to 1.0% of niobium (Nb), and the remainder of iron (Fe) and inevitable impurities; heating the steel sheet at a rate of 1 to 1,000 °C/sec to a temperature range of Ac3+50°C to Ac3+200°C and maintaining for 1 to 1,000 seconds; and

50 hot-forming the heated and maintained steel sheet and cooling the steel sheet at a rate of 1 to 1000°C/sec to a temperature below Mf.

15. The method according to claim 14, wherein the steel sheet for hot forming satisfies Expression (1) below.

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$$(1) 0.80 \cdot \text{Si} + 0.57 \cdot \text{Cr} - 3.53 \cdot \text{C} - 1.45 \cdot \text{Mn} - 1.9 > 0$$

(wherein Si, Cr, C, and Mn denote contents (wt%) of the elements, respectively).

16. The method according to claim 14, wherein the steel sheet for hot forming comprises a microstructure comprising a ferrite phase and 20 vol% or less of a carbonitride, wherein an average grain size of the ferrite phase is 100 μm or less.

5 17. The method according to claim 14, wherein a content of Cr in the steel sheet for hot forming is from 3.5 to 5.5%.

18. The method according to claim 14, wherein the steel sheet for hot forming further comprises less than 3.0% of nickel (Ni).

10 19. The method according to claim 14, wherein the steel sheet for hot forming further comprises less than 0.1% of phosphorus (P) and less than 0.01% of sulfur (S).

20. The method according to claim 14, wherein the preparing of the steel sheet for hot forming comprises:

15 reheating a slab in a temperature range of 1,000 to 1,300°C;
preparing a hot-rolled steel sheet by finish-rolling the reheated slab in a temperature range higher than Ar3 and equal to or lower than 1,000°C;
coiling the hot-rolled steel sheet in a temperature range higher than Ms and equal to or lower than 850°C; and
acid-pickling the coiled, hot-rolled steel sheet.

20 21. The method according to claim 20, further comprising:

preparing a cold-rolled steel sheet by rolling the acid pickled, hot-rolled steel sheet with a reduction ratio of 30 to 80%; and
25 continuously annealing the cold-rolled steel sheet in a temperature range of 700 to 900°C.

22. The method according to claim 20, further comprising batch-annealing the coiled, hot-rolled or acid-pickled steel sheet in a temperature range of 500 to 850°C for 1 to 100 hours.

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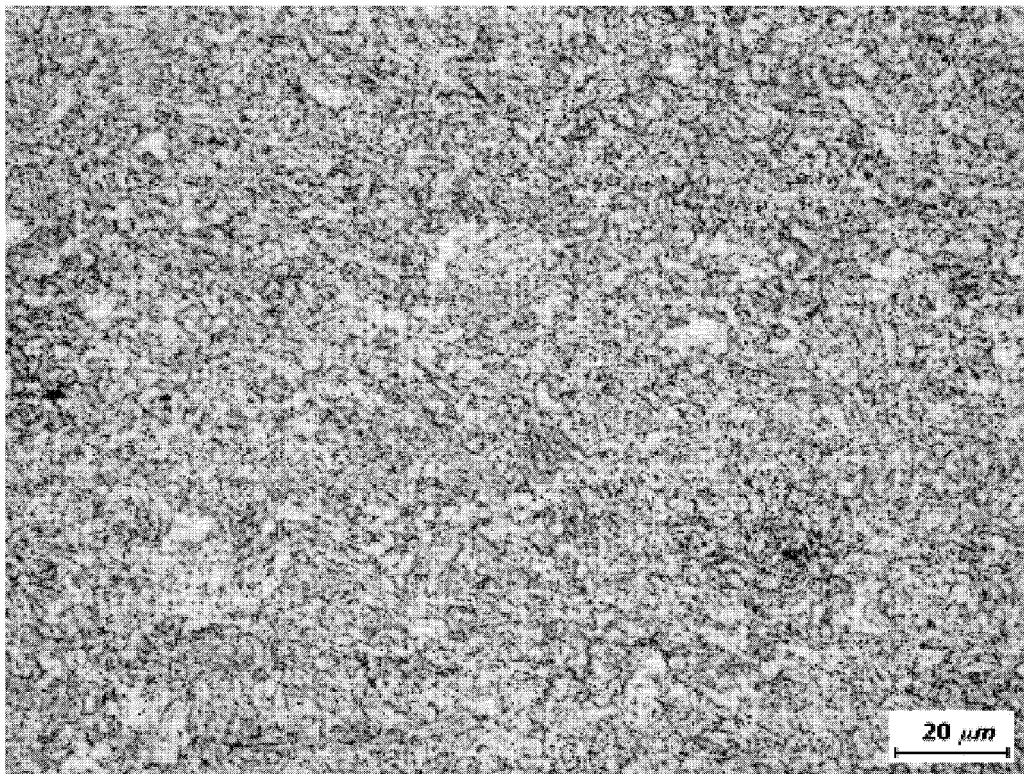
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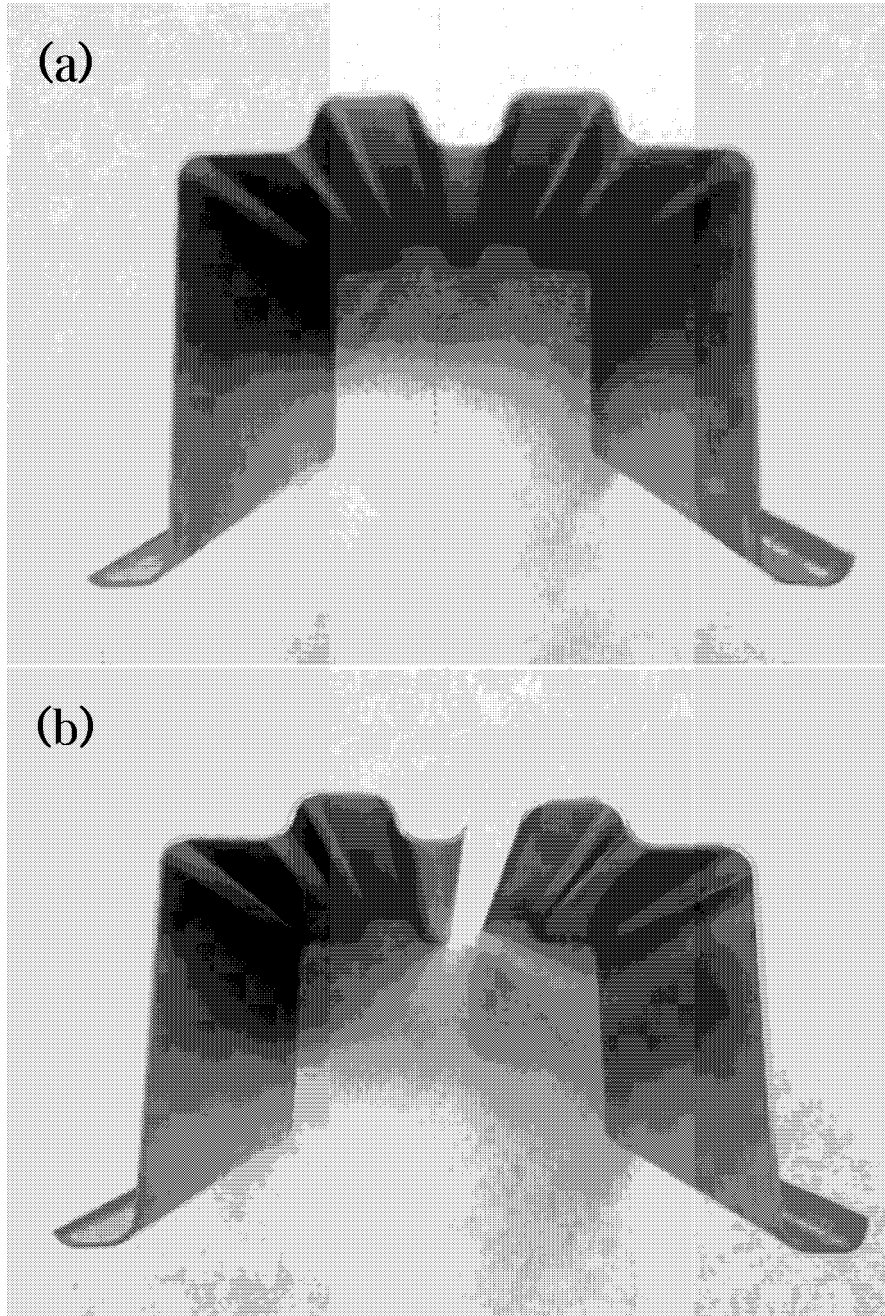
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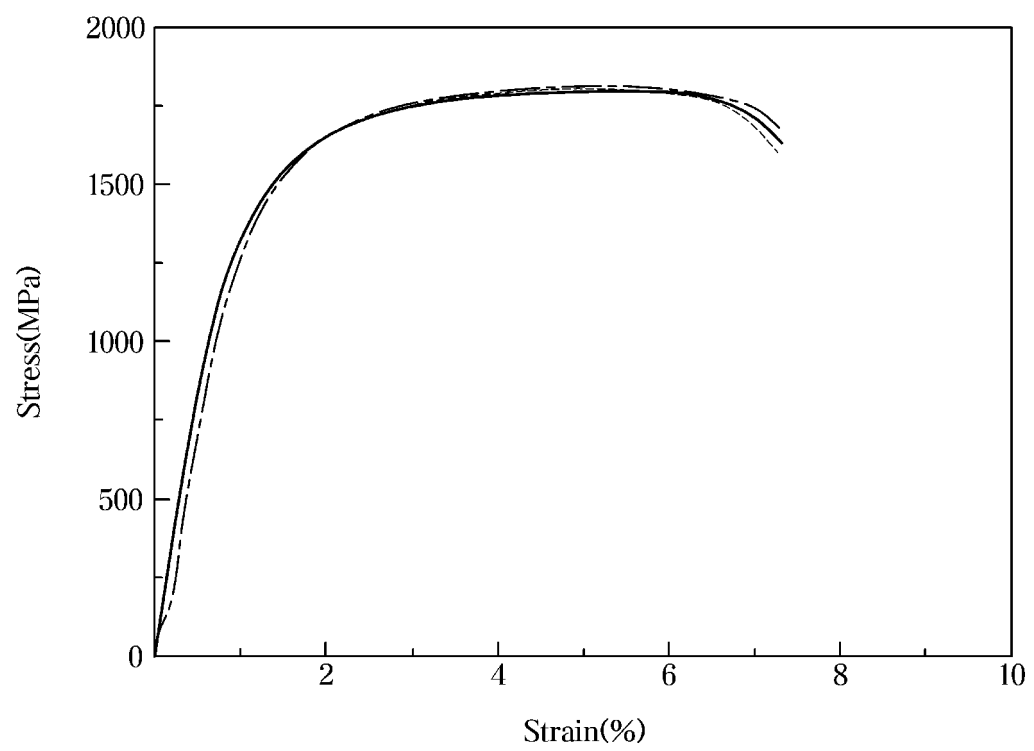
【FIG. 1】



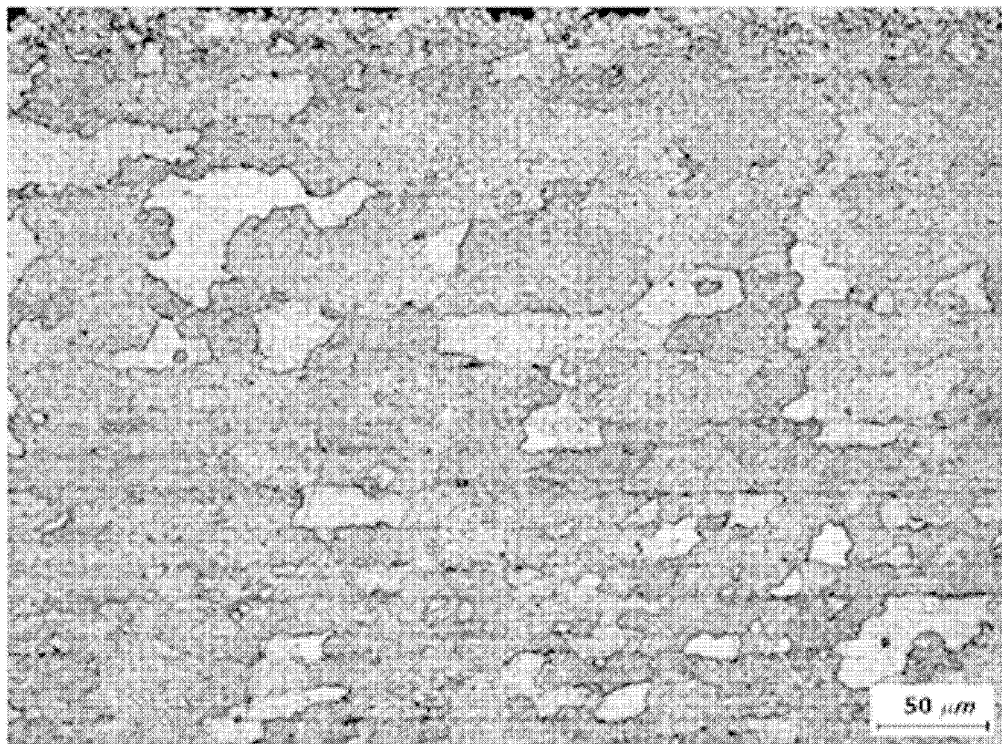
【FIG. 2】



【FIG. 3】



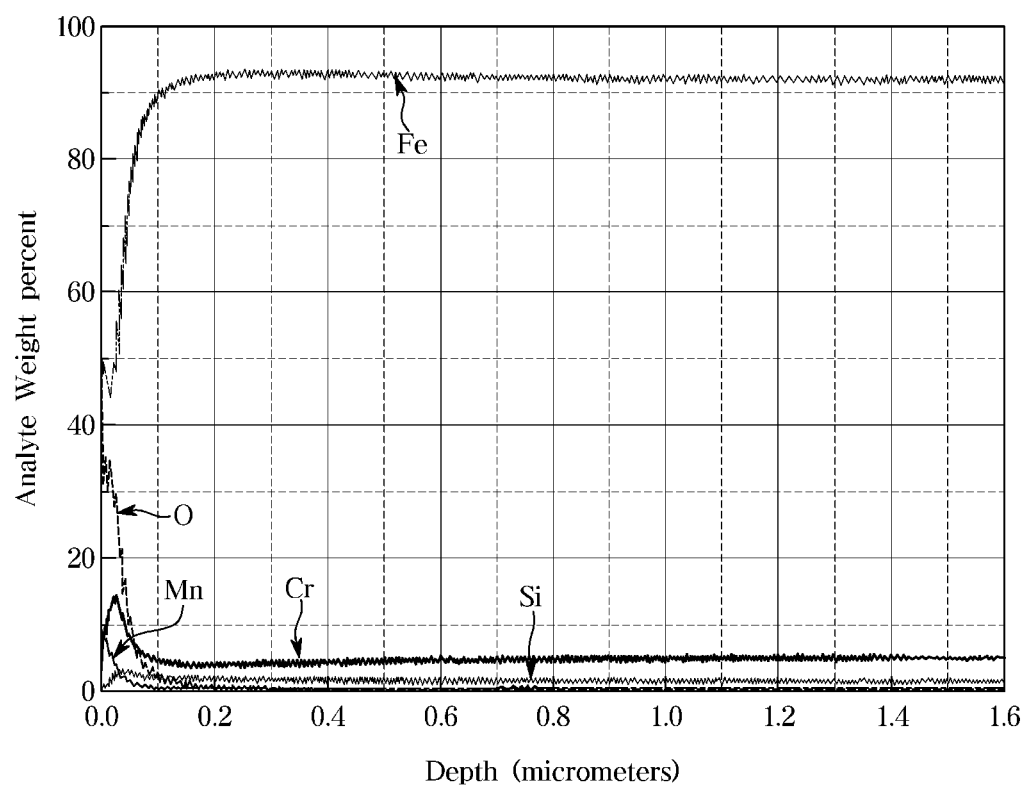
【FIG. 4】



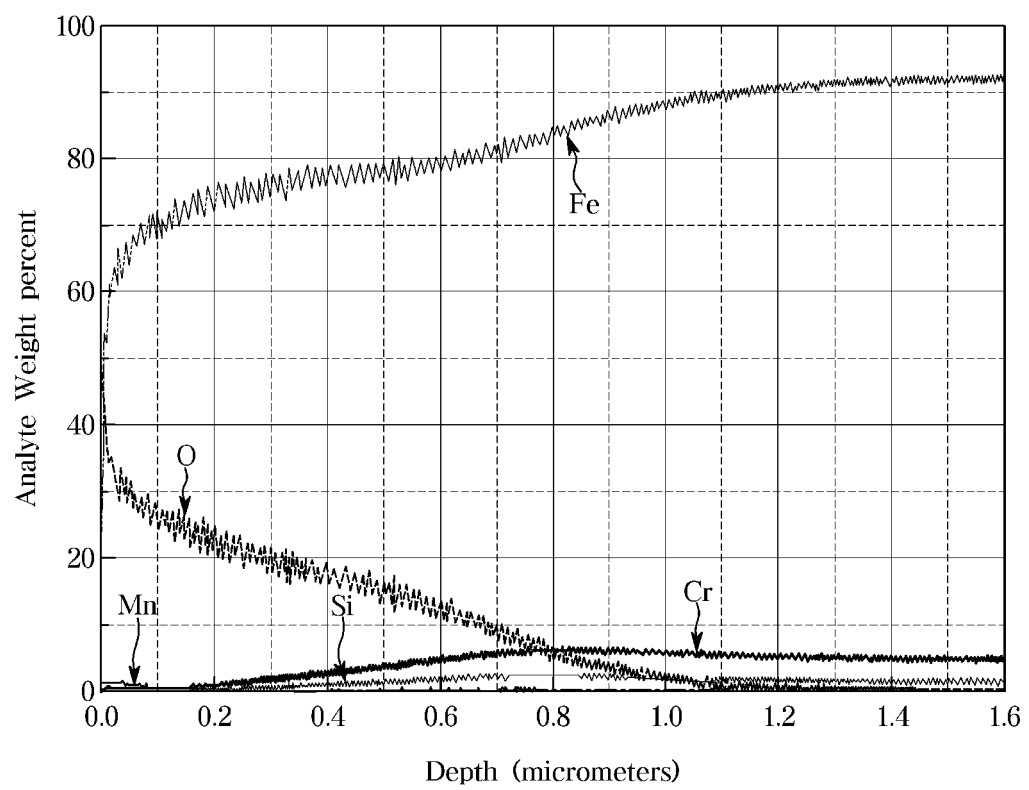
【FIG. 5】



【FIG. 6】



【FIG. 7】



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2020/011684

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/34(2006.01)i; C22C 38/26(2006.01)i; C22C 38/38(2006.01)i; C22C 38/00(2006.01)i; C21D 8/02(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C 38/34(2006.01); C21D 1/18(2006.01); C21D 8/02(2006.01); C21D 9/56(2006.01); C22C 38/00(2006.01);
C22C 38/06(2006.01); C22C 38/38(2006.01); C22C 38/60(2006.01)

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

Korean utility models and applications for utility models: IPC as above
Japanese utility models and applications for utility models: IPC as above

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

eKOMPASS (KIPO internal) & keywords: 열간성형(hot stamping), 도금(plating), 열간프레스(hot press), 크롬(chrome)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	KR 10-2016-0078851 A (POSCO) 05 July 2016 (2016-07-05) See paragraph [0064] and claims 1 and 5-8.	1-22
Y	JP 2010-065293 A (JFE STEEL CORP.) 25 March 2010 (2010-03-25) See paragraph [0032], claims 1-2 and table 2.	1-22
A	JP 2011-063877 A (JFE STEEL CORP.) 31 March 2011 (2011-03-31) See claims 1-3 and 13.	1-22
A	WO 2018-179839 A1 (JFE STEEL CORPORATION) 04 October 2018 (2018-10-04) See claims 1-2.	1-22
A	KR 10-1830527 B1 (POSCO) 21 February 2018 (2018-02-21) See claims 1 and 6.	1-22

☐ 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

07 December 2020

Date of mailing of the international search report

08 December 2020

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/KR2020/011684

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REFERENCES CITED IN THE DESCRIPTION

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