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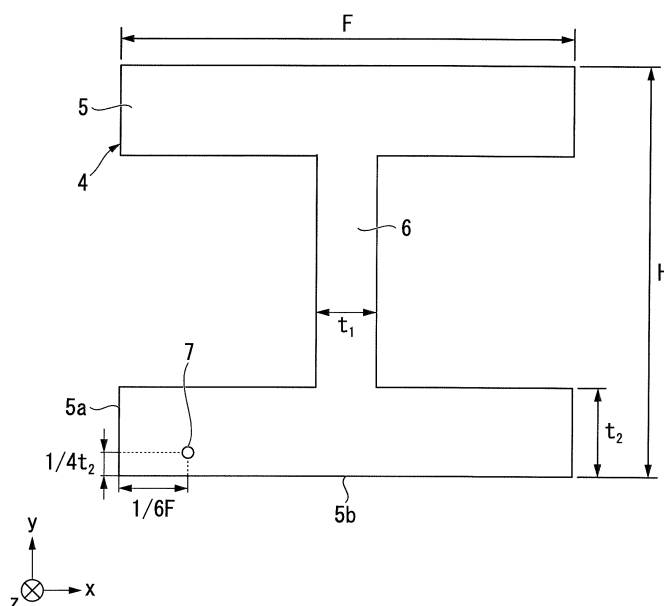
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(54) **H-STEEL AND METHOD FOR MANUFACTURING SAME**

(57) This H section includes, as a chemical composition, C, Si, Mn, Nb, V, Ti, and N; in which the H section includes, as a metallographic structure, ferrite of 60 area% to less than 100 area%, an average grain size of

this ferrite is 1 μm to 30 μm , a thickness of a flange is 20 mm to 140 mm, tensile yield stress is 385 MPa to 530 MPa, and Charpy absorbed energy at -20°C is 100 J or more.

FIG. 1



Description

[Technical Field of the Invention]

[0001] The present invention relates to a thick H section, which has excellent strength and low temperature toughness, and a method for manufacturing the same. Priority is claimed on Japanese Patent Application No. 2016-248181, filed on December 21, 2016, the content of which is incorporated herein by reference.

[Related Art]

[0002] Recently, buildings such as high-rise buildings are becoming large and high, and thick steels have been utilized as strength members required for the structure. However, generally, in ferrous materials, as the thickness of a product increases, it becomes difficult to ensure the strength, and it is also difficult to ensure the toughness.

[0003] In regard to such a problem, in Patent Document 1, a technology of ensuring the toughness by utilizing an effect of refining prior austenite grains due to a Ca-Al-based oxide and obtaining a steel, in which high strength is ensured by applying accelerated cooling, is proposed.

[0004] In addition, in Patent Document 2, a technology of ensuring the toughness by utilizing the effect of refining prior austenite grains due to a Mg-S-based inclusion and obtaining a steel, in which high strength is ensured by applying accelerated cooling, is proposed.

[0005] However, when a thick steel plate is manufactured, if accelerated cooling is applied after hot rolling, the cooling rate becomes slow inside the steel plate compared to its surface, so that a significant difference is caused between the surface and the inside in the temperature history during cooling, and a difference is caused in mechanical properties such as strength, ductility, toughness, depending on a portion of a steel.

[0006] In addition, for large buildings, it is desired to use thick H sections. However, these H sections are unique in shape. Universal rolling and the like are applied to form a steel piece into an H-shape. However, rolling conditions (temperature and rolling reduction) are limited in universal rolling. Therefore, in a case where an H section is manufactured, particularly in a case where a thick H section having a thickness of a flange of 20 mm or more is manufactured, it is not easy to control mechanical properties compared to general thick steel plates (thick steel plates).

[0007] In regard to such a problem, in Patent Documents 3 and 4, methods of ensuring homogeneous mechanical properties of a steel piece by performing natural cooling after hot rolling of the steel piece, in which the amount of C is reduced and B is added, are proposed.

[0008] In addition, in Patent Documents 5 to 8, methods for manufacturing a thick H section or an H section for the purpose of high strength, high toughness, and the like are disclosed.

[Prior Art Document]

[Patent Document]

[0009]

[Patent Document 1] Japanese Patent No. 5655984

[Patent Document 2] Japanese Patent No. 5867651

[Patent Document 3] Japanese Unexamined Patent Application, First Publication No. 2003-328070

[Patent Document 4] Japanese Unexamined Patent Application, First Publication No. 2011-106006

[Patent Document 5] Japanese Unexamined Patent Application, First Publication No. H11-158543

[Patent Document 6] Japanese Unexamined Patent Application, First Publication No. H11-335735

[Patent Document 7] Japanese Unexamined Patent Application, First Publication No. 2016-84524

[Patent Document 8] Japanese Unexamined Patent Application, First Publication No. H10-68016

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0010] In the related art, in thick H sections having a thickness of a flange of 20 mm or more, it has not been easy to control mechanical properties. Therefore, such thick H sections have been required to satisfy toughness no more than at room temperature or at 0°C. However, recently, in consideration of usage in a cold district and the like, thick H sections are required to have excellent toughness at a lower temperature. Furthermore, in consideration of strength per unit weight as structural materials, thick H sections are also required to have yield stress (specifically, yield strength or 0.2% proof stress) of 385 MPa or more.

[0011] The present invention has been made in consideration of such circumstances, and an object thereof is to provide a thick H section, which has excellent strength and low temperature toughness, and a method for manufacturing the same.

[Means for Solving the Problem]

[0012] The gist of the present invention is as follows.

(1) According to an aspect of the present invention, there is provided an H section; in which a steel includes, as a chemical composition, by mass%, C: 0.05% to 0.160%, Si: 0.01% to 0.60%, Mn: 0.80% to 1.70%, Nb: 0.005% to 0.050%, V: 0.05% to 0.120%, Ti: 0.001% to 0.025%, N: 0.0001% to 0.0120%, Cr: 0% to 0.30%, Mo: 0% to 0.20%, Ni: 0% to 0.50%, Cu: 0% to 0.35%, W: 0% to 0.50%, Ca: 0% to 0.0050%, Zr: 0% to 0.0050%, Al: limited to 0.10% or less, B: limited to 0.0003% or less, and a remainder including Fe and impurities; in which C, Mn, Cr, Mo, V, Ni, and Cu in the chemical composition satisfy $0.30 \leq Ceq \leq 0.48$, when $Ceq = C + Mn / 6 + (Cr + Mo + V) / 5 + (Ni + Cu) / 15$ is established; the steel includes, as a metallographic structure, by area fraction, ferrite of 60% to less than 100%, a mixed structure MA of martensite and austenite being limited to 3.0% or less, and a structure other than the ferrite and the MA being limited to 37% or less; an average grain size of the ferrite is 1 μ m to 30 μ m; a shape is an H-shape and a thickness of a flange is 20 mm to 140 mm, when being seen in a cut section orthogonal to a rolling direction; at a position of (1/6)F from an end surface of the flange in the width direction, tensile yield stress is 385 MPa to 530 MPa and maximum tensile strength is 490 MPa to 690 MPa, when a length of the flange in a width direction is F; and at the position of (1/6)F and at a position of (1/4)t₂ from an outer surface of the flange in a thickness direction, absorbed energy in a Charpy test at -20°C is 100 J or more, when the thickness of the flange is t₂.

(2) The H section according to (1) may include, as the chemical composition, by mass%, Nb: more than 0.02% to 0.050%.

(3) The H section according to (1) or (2) may include, as the chemical composition, by mass%, N: more than 0.005% to 0.0120%.

(4) The H section according to any one of (1) to (3) may include, as the chemical composition, by mass%, Cu: limited to less than 0.03%.

(5) The H section according to any one of (1) to (4) may include, as the chemical composition, by mass%, Al: limited to less than 0.003%.

(6) In the H section according to any one of (1) to (5), the thickness of the flange may be 25 mm to 140 mm.

(7) According to another aspect of the present invention, there is provided a method for manufacturing the H section according to any one of (1) to (6), including steelmaking to obtain a molten steel which has the chemical composition according to any one of (1) to (5); casting the molten steel after the steelmaking to obtain a steel piece; heating the steel piece after the casting to 1,100°C to 1,350°C; hot rolling on the steel piece after the heating to form a shape, when being seen in a cut section orthogonal to a rolling direction, into an H-shape under conditions, in which a cumulative rolling reduction at a position of (1/6)F from an end surface of a flange in a width direction is 20% or more within more than 900°C and 1,100°C or less, the cumulative rolling reduction at the position is 15% or more within 730°C to 900°C, and the rolling ends at 730°C or more; and cooling a hot rolled material after the hot rolling by natural cooling.

[Effects of the Invention]

[0013] According to the aspect of the present invention, it is possible to provide a thick H section, which has excellent strength and low temperature toughness, and a method for manufacturing the same.

[Brief Description of the Drawings]

[0014]

FIG. 1 is a schematic cross-sectional view explaining a position at which a test piece of an H section according to an embodiment of the present invention is collected.

FIG. 2 is a flowchart showing a method for manufacturing an H section according to the embodiment of the present invention.

[Embodiment of the Invention]

[0015] Hereinafter, a suitable embodiment of the present invention will be described in detail. However, the present invention is not limited to only the configurations disclosed in the present embodiment, and various changes can be made within a range not departing from the gist of the present invention. In addition, in the following numerical limitation ranges, the lower limit value and the upper limit value are included in the range thereof. In numerical values expressed with "more than" or "less than", the value is not included in the numerical value range thereof. The symbol "%" related to the amount of each element means "mass%".

[0016] As described above, until now, thick H sections having a thickness of a flange of 20 mm or more have been required to satisfy toughness no more than at room temperature or at 0°C. However, currently, in consideration of usage in a cold district and the like, thick H sections are required to have excellent toughness at a lower temperature, such as approximately -20°C. Furthermore, in consideration of strength per unit weight as structural materials, thick H sections are also required to have yield stress (specifically, yield strength or 0.2% proof stress) of 385 MPa or more.

[0017] Therefore, in regard to a thick H section (there may hereinafter be a case where it is disclosed as a steel), particularly in regard to a flange which is an important portion in the structure of an H section, the inventors have found the following knowledge by investigating a steel composition (a chemical composition of a steel) affecting the strength and the low temperature toughness, and the influence of a steel structure (a metallographic structure of a steel). In the present embodiment, strength means tensile yield stress and the maximum tensile strength, and low temperature toughness means absorbed energy in a Charpy test at -20°C.

[0018] First, an excessively increase in hardenability caused by adding an alloying element encourages the generation of a martensite-austenite mixed structure (hereinafter, it will be disclosed as an MA) in a steel, and which leads to deterioration in low temperature toughness. Particularly, since B in an alloying element noticeably tends to encourage the generation of an MA, it is effective that B is not actively added and is limited to the level of impurities or less.

[0019] In addition, in order to realize the high yield stress (yield strength or 0.2% proof stress) and to improve the toughness at -20°C at the same time, it is effective that Nb is added. Since Nb increases the strength of a steel through precipitation strengthening, there is no need to excessively increase the hardenability, and strength of a steel can be increased without encouraging the generation of an MA. In addition, Nb has effects of suppressing recrystallization of austenite during hot rolling, accumulating strain in a steel caused through rolling, and bringing grain refinement of ferrite after transformation.

[0020] In addition, in order to improve the toughness at -20°C, it is effective that V is added. V has effects of being precipitated as carbonitride (VC, VN, or a composite thereof), functioning as a nucleation site of ferrite, and bringing grain refinement of ferrite.

[0021] In addition, when Mn is added, strength and low temperature toughness are further improved. Furthermore, for achieving both the high strength and the low temperature toughness, it is important to control the area fraction of ferrite, the area fraction of MA, the average grain size of ferrite, and the like as the steel structure after the steel composition is controlled.

[0022] In order to stably control a steel structure, when hot rolling a steel piece in which the steel composition is controlled, it is necessary to apply sufficient rolling strain to each of a recrystallization temperature range and a non-recrystallization temperature range of austenite. Specifically, in a temperature range of more than 900°C and 1,100°C or less, hot rolling in which the cumulative rolling reduction is 20% or more is performed. Moreover, in a temperature range of 900°C or less, hot rolling in which the cumulative rolling reduction is 15% or more is performed. Through rolling at a temperature more than 900°C, austenite grains are subjected to grain refinement to deteriorate the hardenability, so that the generation amount of an MA, and the like are kept low. Through rolling at 900°C or less, ferrite is subjected to grain refinement by applying a large amount of strain to the inside of a steel so as to increase the frequency of nucleation of ferrite.

[0023] In addition, in order to stably control a steel structure, when cooling after hot rolling, it is preferable to have a small difference between the cooling rates of a surface of a steel and inside thereof. In a case where a steel is natural cooled without accelerated cooling after hot rolling, the cooling rate is decreased in both a surface and the inside of the steel, so that the difference therebetween is also reduced. For example, in an H section having a thickness of a flange

of 20 mm, if a steel is subjected to natural cooling after hot rolling, both the average cooling rates from 800°C to 500°C of a surface of a steel and inside thereof become 1 °C/sec or less.

[0024] In a case where the cooling rate after hot rolling is slow, generally, it is not easy to ensure the yield stress and the low temperature toughness at the same time. However, both the yield stress and the low temperature toughness can be achieved by optimally controlling the steel composition and manufacturing conditions. For example, as a steel composition, the C content is 0.05% to 0.160%, B is not added and is limited to the level of impurities or less, Nb and V are actively added, the amounts of the alloying elements such as Mn, Ti, and N are appropriately controlled, and a carbon equivalent Ceq is controlled to be a range of 0.30 to 0.48. Furthermore, as the steel structure, the area fraction of ferrite, the area fraction of MA, the average grain size of ferrite, and the like are elaborated by optimally controlling the manufacturing conditions. As a result, a thick H section having excellent strength and low temperature toughness can be obtained.

[0025] Hereinafter, an H section according to the present embodiment will be described. First, the steel composition and reasons for limiting numerical ranges will be described in detail.

[0026] The H section according to the present embodiment includes, as a chemical composition, base elements and includes optional elements as necessary. The remainder includes Fe and impurities.

[0027] In the chemical composition of the H section according to the present embodiment, C, Si, Mn, Nb, V, Ti, and N are the base elements (main alloying elements).

(C: 0.05% to 0.160%)

[0028] C (Carbon) is an element which is effective for strengthening of a steel. Therefore, the lower limit for the C content is set to 0.05%. Preferably, the lower limit for the C content is set to 0.060%, 0.070%, or 0.080%. On the other hand, when the C content exceeds 0.160%, and which leads to deterioration in low temperature toughness. Therefore, the upper limit for the C content is set to 0.160%. In order to further improve the low temperature toughness, the upper limit for the C content is preferably set to 0.140%, 0.130%, or 0.120%.

(Si: 0.01% to 0.60%)

[0029] Si (Silicon) is a deoxidizing element and is an element which also contributes to improvement of strength. Therefore, the lower limit for the Si content is set to 0.01%. Preferably, the lower limit for the Si content is set to 0.05%, 0.10%, or 0.15%. On the other hand, when the Si content exceeds 0.60%, the generation of an MA is encouraged, and which leads to deterioration in low temperature toughness. Therefore, the upper limit for the Si content is set to 0.60%. In order to further improve the low temperature toughness, the upper limit for the Si content is preferably set to 0.40% or 0.30%.

(Mn: 0.80% to 1.70%)

[0030] Mn (Manganese) is an element which contributes to improvement of strength. Therefore, the lower limit for the Mn content is set to 0.80%. In order to further increase the strength, the lower limit for the Mn content is preferably set to 1.0%, 1.1%, or 1.2%. On the other hand, when the Mn content exceeds 1.70%, the hardenability is excessively increased, generation of an MA is encouraged, and the low temperature toughness is impaired. Therefore, the upper limit for the Mn content is set to 1.70%. Preferably, the upper limit for the Mn content is set to 1.60% or 1.50%.

(Nb: 0.005% to 0.050%)

[0031] Nb (Niobium) is an element which suppresses recrystallization of austenite at the time of hot rolling, contributes to grain refinement of ferrite by accumulating work strain in a steel, and contributes to improvement of strength through precipitation strengthening. Therefore, the lower limit for the Nb content is set to 0.005%. Preferably, the lower limit for the Nb content is set to 0.010%, more than 0.020%, 0.025%, or 0.030%. However, when the Nb content exceeds 0.050%, and which may lead to significant deterioration in low temperature toughness. Therefore, the upper limit for the Nb content is set to 0.050%. Preferably, the upper limit for the Nb content is set to 0.045%, 0.043%, or 0.040%. In a case where Nb is not intentionally added, the Nb content included as an impurity is set to less than 0.005%. In order to set the Nb content to 0.005% or more, Nb is intentionally included in a steel.

(V: 0.05% to 0.120%)

[0032] V (Vanadium) is an element which has effects of being precipitated as carbonitride inside grains of austenite, acting as transformation nuclei with respect to ferrite, and refining ferrite grains. Therefore, the lower limit for the V

content is set to 0.05%. Preferably, the lower limit for the V content is set to more than 0.05%, 0.06%, or 0.07%. However, when the V content exceeds 0.120%, the low temperature toughness may be impaired by coarsening precipitates. Therefore, the upper limit for the V content is set to 0.120%. Preferably, the upper limit for the V content is set to 0.110% or 0.100%.

(Ti: 0.001 % to 0.025%)

[0033] Ti (Titanium) is an element which forms TiN and fixes N in a steel. Therefore, the lower limit for the Ti content is set to 0.001%. In order to further refine austenite due to a pinning effect of TiN, the lower limit for the Ti content is preferably set to 0.005%, 0.007%, or 0.010%. On the other hand, when the Ti content exceeds 0.025%, coarse TiN is generated and the low temperature toughness is impaired. Therefore, the upper limit for the Ti content is set to 0.025%. Preferably, the upper limit for the Ti content is set to 0.020%, 0.015%, or 0.012%.

[0034] In addition, in a case where Al is not actively added, Ti serves as a deoxidizing element, thereby remaining N which is not bonded to Ti. However, this N is precipitated as V carbonitride having Ti oxide as nuclei. That is, since Ti serves as a deoxidizing element and Ti oxide is precipitated, precipitation of V carbonitride is promoted, and low temperature toughness can be improved.

(N: 0.0001% to 0.0120%)

[0035] N (Nitrogen) is an element which forms TiN or VN and contributes to grain refinement of a structure or precipitation strengthening. Therefore, the lower limit for the N content is set to 0.0001%. Preferably, the lower limit for the N content is set to 0.0020%, 0.0035%, more than 0.0050%, or 0.0060%. However, when the N content exceeds 0.0120%, the low temperature toughness is deteriorated, and surface cracking at the time of casting or material defect due to strain aging of a manufactured steel is caused. Therefore, the upper limit for the N content is set to 0.0120%. Preferably, the upper limit for the N content is set to 0.0110%, 0.0100%, or 0.0090%.

[0036] The H section according to the present embodiment contains impurities as a chemical composition. "Impurities" indicate elements incorporated from ore or scrap as a raw material, or the manufacturing environment, when a steel is industrially manufactured. For example, impurities mean elements such as Al, B, P, S, and O. In these impurities, it is preferable that Al and B are limited as follows in order to sufficiently exhibit the effects of the present embodiment. In addition, since it is preferable that the amounts of impurities are small, there is no need to limit the lower limit value, and the lower limit value for impurities may be 0%.

(Al: 0.10% or less)

[0037] Al (Aluminum) is an element used as a deoxidizing element. However, when the Al content exceeds 0.10%, oxide is coarsened and becomes origins of brittle fracture, so that low temperature toughness is deteriorated. Therefore, the upper limit for the Al content is limited to 0.10%. In addition, in a case where Al is not actively used as a deoxidizing element, Ti serves as the deoxidizing element, and Ti oxide is precipitated in a steel. This Ti oxide functions as a nucleation site of V carbonitride, refines the grain size of ferrite, and contributes to improvement of low temperature toughness. Therefore, the upper limit for the Al content may be limited to less than 0.003%, 0.002%, or 0.001% in a case of including Al as impurities, instead of using Al as a deoxidizing element. Generally, in order to set the Al content to 0.003% or more, Al is intentionally included in a steel.

(B: 0.0003% or less)

[0038] B (Boron) increases the hardenability, encourages the generation of an MA, and deteriorates the low temperature toughness. Therefore, in the present embodiment, B is not actively added and is limited to the level of impurities or less. The upper limit for the B content is limited to 0.0003%. Preferably, the upper limit for the B content is limited to less than 0.0003%, 0.0002%, or 0.0001%. Generally, in order to set the B content to more than 0.0003%, B is intentionally included in a steel.

(P: 0.03% or less, S: 0.02% or less, and O: 0.005% or less)

[0039] P (Phosphorus), S (Sulfur), and O (Oxygen) are impurities. P and S encourage the weld cracking through solidifying segregation and deteriorates the low temperature toughness. Preferably, the upper limit for the P content is limited to 0.03%, 0.02%, or 0.01%. In addition, preferably, the upper limit for the S content is limited to 0.02% or 0.01%. O deteriorates the low temperature toughness by being solid-solubilized in a steel, and deteriorates the low temperature toughness through coarsening of oxide particles. Preferably, the upper limit for the O content is limited to 0.005%,

0.004%, or 0.003%.

[0040] In addition to the base elements and the impurities described above, the H section according to the present embodiment may contain optional elements. For example, instead of a part of Fe which is the remainder as described above, Cr, Mo, Ni, Cu, W, Ca, Zr, Mg, and/or REM may be contained as optional elements. These optional elements may be contained in accordance with their purpose. Thus, there is no need to limit the lower limit values for these optional elements, and the lower limit values may be 0%. In addition, even if these optional elements are contained as impurities, the foregoing effects are not impaired.

(Cr: 0% to 0.30%)

[0041] Cr (Chromium) is an element which contributes to improvement of strength. As necessary, the Cr content may be 0% to 0.30%. In order to further improve the strength, the lower limit for the Cr content is preferably set to 0.01%, 0.05%, or 0.10%. On the other hand, when the Cr content exceeds 0.30%, the generation of an MA may be encouraged and the low temperature toughness may be deteriorated. Therefore, preferably, the upper limit for the Cr content is set to 0.30%, 0.25%, or 0.20%.

(Mo: 0% to 0.20%)

[0042] Mo (Molybdenum) is an element which is solid-solubilized in a steel and contributes to improvement of strength. As necessary, the Mo content may be 0% to 0.20%. In order to further improve the strength, the lower limit for the Mo content is preferably set to 0.01%, 0.05%, or 0.10%. However, when the Mo content exceeds 0.20%, the generation of an MA may be encouraged, and which may lead to deterioration in low temperature toughness. Therefore, the upper limit for the Mo content is preferably set to 0.20%, 0.17%, or 0.15%.

(Ni: 0% to 0.50%)

[0043] Ni (Nickel) is an element which is solid-solubilized in a steel and contributes to improvement of strength. As necessary, the Ni content may be 0% to 0.50%. In order to further improve the strength, the lower limit for the Ni content is preferably set to 0.01%, 0.05%, or 0.10%. However, when the Ni content exceeds 0.50%, the hardenability may be increased, the generation of an MA may be encouraged, and the low temperature toughness may be deteriorated. Therefore, the upper limit for the Ni content is preferably set to 0.50%, 0.30%, or 0.20%.

(Cu: 0% to 0.35%)

[0044] Cu (Copper) is an element which contributes to improvement of strength. As necessary, the Cu content may be 0% to 0.35%. However, addition of Cu may encourage the generation of an MA and may deteriorate the low temperature toughness. Therefore, preferably, the Cu content is limited to 0.30% or less, 0.20% or less, or 0.10% or less. Alternatively, the Cu content may be limited to less than 0.03% or less than 0.01% which is the level of impurities.

(W: 0% to 0.50%)

[0045] W (Tungsten) is an element which is solid-solubilized in a steel and contributes to improvement of strength. As necessary, the W content may be 0% to 0.50%. Preferably, the lower limit for the W content is set to 0.001%, 0.01%, or 0.10%. However, when the W content exceeds 0.50%, the generation of an MA may be encouraged and the low temperature toughness may be deteriorated. Therefore, preferably, the upper limit for the W content is set to 0.50%, 0.40%, or 0.30%. In a case where W is not intentionally added, the W content included as an impurity is set to less than 0.001%. In order to set the W content to 0.001% or more, W is intentionally included in a steel.

(Ca: 0% to 0.0050%)

[0046] Ca (Calcium) is an element which is effective for controlling the form of sulfide, suppresses generation of coarse MnS, and contributes to improvement of low temperature toughness. As necessary, the Ca content may be set 0% to 0.0050%. Preferably, the lower limit for the Ca content is set to 0.0001%, 0.0005%, or 0.0010%. On the other hand, when the Ca content exceeds 0.0050%, the low temperature toughness may be deteriorated. Therefore, preferably, the upper limit for the Ca content is set to 0.0050%, 0.0040%, or 0.0030%.

(Zr: 0% to 0.0050%)

[0047] Zr (Zirconium) is an element which is precipitated as carbide, nitride, or a composite thereof and contributes to precipitation strengthening. As necessary, the Zr content may be set 0% to 0.0050%. Preferably, the lower limit for the Zr content is set to 0.0001%, 0.0005%, or 0.0010%. On the other hand, when the Zr content exceeds 0.0050%, carbide or nitride of Zr may be coarsened and the low temperature toughness may be deteriorated. Therefore, preferably, the upper limit for the Zr content is set to 0.0050%, 0.0040%, or 0.0030%. In a case where Zr is not intentionally added, the Zr content included as an impurity is set to less than 0.0001%. In order to set the Zr content to 0.0001% or more, Zr is intentionally included in a steel.

(Mg: 0% to 0.0050%, and REM: 0% to 0.0050%)

[0048] Mg (Magnesium) and REM (rare earth metal) are elements which contribute to improvement of toughness of a base material or toughness of a welded heat-affected zone (HAZ). As necessary, the Mg content may be 0% to 0.0050%, and the REM content may be 0% to 0.0050%. Preferably, the lower limit for the Mg content is set to 0.0005%, 0.0010%, or 0.0020%, and the lower limit for the REM content is set to 0.0005%, 0.0010%, or 0.0020%. On the other hand, preferably, the upper limit for the Mg content is set to 0.0040%, 0.0030%, or 0.0025%, and the upper limit for the REM content is set to 0.0040%, 0.0030%, or 0.0025%.

(Ceq: 0.30 to 0.48)

[0049] In the H section according to the present embodiment, from the view of ensuring the strength, the carbon equivalent Ceq is controlled. Specifically, when the Ceq is set as the following Expression 1, C, Mn, Cr, Mo, V, Ni, and Cu, by mass%, in the chemical composition of an H section satisfy $0.30 \leq \text{Ceq} \leq 0.48$. If the Ceq is less than 0.30, strength becomes insufficient. Therefore, the lower limit for Ceq is set to 0.30. Preferably, the lower limit for Ceq is set to 0.32%, 0.34%, or 0.35%. On the other hand, when Ceq exceeds 0.48, the low temperature toughness is deteriorated. Therefore, the upper limit for Ceq is set to 0.48. Preferably, the upper limit for Ceq is set to 0.45%, 0.43%, or 0.40%. When the Ceq is calculated by the following Expression 1, the Ceq may be calculated by substituting 0 for the value in Expression 1, for an element in which the amount in a steel is equal to or less than a detection limit.

$$\text{Ceq} = \text{C} + \text{Mn}/6 + (\text{Cr} + \text{Mo} + \text{V})/5 + (\text{Ni} + \text{Cu})/15 \dots (\text{Expression 1})$$

[0050] The steel composition described above may be measured by a general analysis method for a steel. For example, the steel composition may be measured by using ICP-AES (inductively coupled plasma-atomic emission spectrometry). C and S may be measured by using a combustion-infrared absorption method, N may be measured by using an inert gas fusion-thermal conductivity method, and O may be measured by using an inert gas fusion-non dispersive infrared absorption method.

[0051] Next, the steel structure and reasons for limiting numerical ranges of the H section according to the present embodiment will be described in detail.

[0052] In the H section according to the present embodiment, the steel structure includes ferrite of 60% to less than 100% by area fraction, a mixed structure MA of martensite and austenite being limited to 3.0% or less, and a structure other than ferrite and the MA being limited to 37% or less. In addition, the average grain size of ferrite is set to 1 μm or more and 30 μm or less.

(Area fraction of ferrite: 60% to less than 100%)

[0053] Ferrite is a main constituent phase in the steel structure of the H section according to the present embodiment. If the area fraction of ferrite is less than 60%, low temperature toughness is deteriorated. Therefore, the lower limit for the ferrite fraction is set to 60%. Preferably, the lower limit for the ferrite fraction is set to 65%, 70%, or 75%. On the other hand, controlling the area fraction of ferrite to 100% is physically difficult because it involves formation of pearlite or bainite. Therefore, the upper limit for the ferrite fraction is set to less than 100%. In order to preferably control the strength and the low temperature toughness, the upper limit for the ferrite fraction is preferably set to 90%, 85%, or 80%.

(Area fraction of MA: 3.0% or less)

[0054] If generation of an MA is encouraged, low temperature toughness is deteriorated. In the H section according to the present embodiment, strength of a steel is increased without encouraging the generation of an MA. Therefore,

the MA fraction is limited to 3.0% or less. Preferably, the upper limit for the MA fraction is set to 2.5%, 2.0%, or 1.5%. The smaller the MA fraction, the more preferable. Therefore, the lower limit for the MA fraction may be 0%.

(Area fraction of structure other than ferrite and MA: 37% or less)

[0055] The steel structure of the H section according to the present embodiment includes bainite, pearlite, and the like as structures other than the ferrite and the MA, as described above. If a structure other than ferrite and an MA is excessively included, low temperature toughness is deteriorated. Therefore, the area fraction of a structure other than ferrite and an MA (the remainder of ferrite and an MA, as described above) is limited to 37% or less. Preferably, the fraction of a structure other than ferrite and an MA is set to 35% or less, 30% or less, or 25% or less. The smaller the fraction of a structure other than ferrite and an MA, the more preferable. Therefore, the lower limit therefor may be 0%.

(Average grain size of ferrite: 1 μm to 30 μm)

[0056] It is preferable that an average grain size of ferrite is refined. When the grain size of ferrite exceeds 30 μm , the low temperature toughness is deteriorated. Therefore, the upper limit for the grain size of ferrite is set to 30 μm . Preferably, the upper limit for the grain size of ferrite is set to 25 μm , 22 μm , or 18 μm . On the other hand, it is industrially difficult to control the grain size of ferrite to be less than 1 μm . Therefore, the lower limit for the grain size of ferrite is set to 1 μm . Preferably, the lower limit for the grain size of ferrite is set to 3 μm , 5 μm , or 10 μm .

[0057] The steel structure described above may be discriminated through observation using an optical microscope. For example, FIG. 1 is a schematic cross-sectional view orthogonal to a rolling direction of an H section. However, the steel structure is observed by setting a portion in the vicinity of an evaluation portion 7 illustrated in FIG. 1 as an observed section. Specifically, in FIG. 1, the steel structure is observed by setting a portion in the vicinity of the evaluation portion 7 at a position of $(1/6)F$ from an end surface 5a of a flange in a width direction and a position of $(1/4)t_2$ from an outer surface 5b of the flange in a thickness direction, as the observed section. This observed section is a section parallel to the end surface 5a of the flange in the width direction.

[0058] The steel structure is observed by polishing and etching the observed section described above. Polishing is performed until the observed section becomes a specular section, and etching is performed by using an etching solution suitable for identifying the constituent phase. For example, if the observed section finished to be a specular section is etched with a nital solution such that the steel structure is manifested, pearlite or bainite is colored. Therefore, ferrite, martensite, and austenite can be identified. In addition, if the observed section finished to be a specular section is etched with a Le Pera solution such that the steel structure is manifested, the constituent phases other than martensite and austenite are colored black. Therefore, the mixed structure MA of martensite and austenite can be identified.

[0059] In the H section according to the present embodiment, the fractions of ferrite and an MA are obtained from the nital-etched observed section, and the remainder is regarded as the fractions of the structures of pearlite and bainite. The MA fraction is obtained from the Le Pera-etched observed section. Specifically, on a photograph of an optical microscope of 200 magnifications (as necessary, a plurality of visual fields) captured in the nital-etched observed section, measurement points are disposed in a lattice shape having one side of 25 μm , and it is discriminated whether or not the structure is ferrite or an MA at not less than 1,000 measurement points. The value obtained by dividing the number of measurement points determined to be ferrite or an MA by the number of all of the measurement points is regarded as the fraction of ferrite or an MA.

[0060] Similarly, on a photograph of an optical microscope of 200 magnifications (as necessary, a plurality of visual fields) captured in the Le Pera-etched observed section, measurement points are disposed in a lattice shape having one side of 25 μm , and it is discriminated whether or not the structure is an MA at not less than 1,000 measurement points. The value obtained by dividing the number of measurement points determined to be an MA by the number of all of the measurement points is regarded as the MA fraction. Then, the fraction of ferrite is obtained by subtracting the total fraction of pearlite, bainite, and the MA fraction obtained as above from 100%.

[0061] In addition, in the H section according to the present embodiment, the average grain size of ferrite is obtained by an intercept method in conformity with JIS G 0551 (2013) using the photograph of an optical microscope of 200 magnifications captured in the nital-etched observed section described above.

[0062] Next, mechanical properties of the H section according to the present embodiment will be described in detail.

[0063] In the H section according to the present embodiment, test pieces are collected from a region including the evaluation portion 7 illustrated in FIG. 1, as a position at which the average mechanical properties (strength and low temperature toughness) can be obtained, and mechanical properties are evaluated.

[0064] First, the evaluation portion 7 in FIG. 1 will be described. FIG. 1 is a schematic cross-sectional view orthogonal to the rolling direction of an H section. In FIG. 1, an X-axis direction is defined as the width direction of the flange, a Y-axis is defined as the thickness direction of the flange, and a Z-axis direction is defined as the rolling direction.

[0065] As illustrated in FIG. 1, when the length of the flange in the width direction is F and the thickness of the flange

is t_2 , the center of the evaluation portion 7 is at the position of $(1/6)F$ from the end surface of the flange in the width direction and the position of $(1/4)t_2$ from the outer surface of the flange in the thickness direction. The outer surface of the flange in the thickness direction is a surface on one side in the thickness direction of the flange, is a surface on a side which does not come into contact with a web 6, and is the surface 5b illustrated in FIG. 1. In addition, the end surface of the flange in the width direction is the end surface 5a illustrated in FIG. 1.

[0066] A test piece used when low temperature toughness is evaluated through the Charpy test is collected at the position of the evaluation portion 7 such that the longitudinal direction of the test piece becomes parallel to the rolling direction. In addition, a surface on which a notch is formed in the test piece is any of surfaces parallel to the end surface 5a of the flange in the width direction. In addition, the test piece may be collected at any position as long as it is the position of $(1/6)F$ from the end surface 5a of the flange in the width direction and the position of $(1/4)t_2$ from the outer surface 5b of the flange in the thickness direction.

[0067] A test piece used when yield stress (yield strength or 0.2% proof stress) and tensile strength (maximum tensile strength) are evaluated through a tension test is collected such that the position of $(1/6)F$ from the end surface 5a of the flange in the width direction becomes the center of the test piece in the thickness direction, in FIG. 1. In a test piece, the longitudinal direction of the test piece may be parallel to the rolling direction such that the entirety of the flange in the thickness direction is cut out. The test piece may be collected at any position as long as it is the position of $(1/6)F$ from the end surface 5a of the flange in the width direction.

[0068] In the H section according to the present embodiment, as mechanical properties, the yield stress at a normal temperature becomes 385 MPa or more, the tensile strength becomes 490 MPa or more, and the Charpy absorbed energy at -20°C becomes 100 J or greater. When the strength is excessively high, the low temperature toughness may be impaired. Therefore, the upper limit for the yield stress is preferably set to 530 MPa and the upper limit for the tensile strength is preferably set to 690 MPa. In addition, since it is industrially difficult that the Charpy absorbed energy at -20°C exceeds 500 J, the upper limit for the Charpy absorbed energy at -20°C may be set to 500 J. A normal temperature indicates 20°C .

[0069] When mechanical properties of the H section according to the present embodiment are evaluated, the tension test is performed in conformity with JIS Z 2241 (2011), and the Charpy test is performed in conformity with JIS Z 2242 (2005). When a yielding phenomenon is recognized in a stress-strain curve obtained from the tension test, yield strength is obtained as the yield stress. When no yielding phenomenon is recognized in the stress-strain curve, 0.2% proof stress is obtained as the yield stress.

[0070] Next, the shape of the H section according to the present embodiment will be described in detail.

[0071] In the H section according to the present embodiment, the thickness t_2 of the flange is 20 mm to 140 mm. For example, in a high-rise building structure, thick H sections are demanded as strength members. Therefore, the lower limit for the thickness of the flange is set to 20 mm. Preferably, the lower limit for the thickness of the flange is set to 25 mm, 40 mm, or 56 mm. On the other hand, if the thickness t_2 of the flange exceeds 140 mm, the working amount at the time of hot working becomes insufficient, so that it is difficult to achieve both the strength and the low temperature toughness. Therefore, the upper limit for the thickness of the flange is set to 140 mm. Preferably, the upper limit for the thickness of the flange is set to 125 mm, 89 mm, or 77 mm. For example, it is preferable that the thickness t_2 of the flange is 25 mm to 140 mm. The thickness t_1 of the web of an H section is not particularly regulated. However, it is preferable that the thickness t_1 of the web of an H section is 20 mm to 140 mm, and it is more preferable that the thickness t_1 of the web of an H section is 25 mm to 140 mm.

[0072] In addition, in a case where an H section is manufactured through hot rolling, it is preferable that the ratio (t_2/t_1) of thickness of flange / thickness of web is 0.5 to 2.0. If the ratio (t_2/t_1) of thickness of flange / thickness of web exceeds 2.0, the web may be deformed into a wavy shape. On the other hand, in a case where the ratio (t_2/t_1) of thickness of flange / thickness of web is less than 0.5, the flange may be deformed into a wavy shape.

[0073] In technologies in the related art, in thick H sections having a thickness of a flange of 20 mm or more, it has been difficult to achieve both the strength and the toughness. However, even though the H section according to the present embodiment is a thick H section having a thickness of a flange of 20 mm or more, the steel composition and the steel structure are optimally controlled. Therefore, it is possible to achieve both the strength and the low temperature toughness.

[0074] Next, a preferable method for manufacturing the H section according to the present embodiment will be described in detail.

[0075] The method for manufacturing an H section according to the present embodiment includes steelmaking, casting, heating, hot rolling, and cooling.

[0076] In the steelmaking, the chemical composition of a molten steel is adjusted to obtain the steel composition described above. In the steelmaking, a molten steel manufactured by performing converter refining or secondary refining may be used, or a molten steel melted in an electric furnace may be used as a raw material. In the steelmaking, as necessary, deoxidation processing or vacuum degassing may be performed.

[0077] In the casting, a steel piece is obtained by casting a molten steel after the steelmaking. Casting is performed

by a continuous casting method, an ingot method, or the like. From the viewpoint of productivity, it is preferable to adopt continuous casting. It is preferable that the shape of a steel piece is a beam blank having a shape close to that of an H section to be manufactured, but the shape thereof is not particularly limited. In addition, from the viewpoint of productivity, it is preferable that the thickness of a steel piece is 200 mm or more. In consideration of reduction of segregation or homogeneity in the heating temperature before hot rolling is performed, it is preferable that the thickness thereof is 350 mm or less.

[0078] In the heating, a steel piece after the casting is heated to 1,100°C to 1,350°C. If the heating temperature of a steel piece is less than 1,100°C, deformation resistance at the time of finish rolling is increased. Therefore, the lower limit for the heating temperature is set to 1,100°C. In order to sufficiently solid-solubilize elements which forms carbide or nitride, such as Nb, the lower limit for the heating temperature is preferably set to 1,150°C. On the other hand, if the heating temperature exceeds 1,350°C, scale on a steel piece surface is liquefied, so that manufacturing is hindered. Therefore, the upper limit for the heating temperature is set to 1,350°C. In the heating, a steel piece which is not cooled to the room temperature after the casting may be used.

[0079] In the hot rolling, rough rolling, intermediate rolling, and finish rolling are performed with respect to a steel piece after the heating. In rough rolling, forming is performed such that the shape seen in a cut section orthogonal to the rolling direction becomes a substantial H-shape. With respect to this steel piece having a substantial H-shape, hot rolling, in which the surface temperature of the steel is a temperature range of more than 900°C and 1,100°C or less and the cumulative rolling reduction is 20% or more, is performed. Moreover, hot rolling, in which the surface temperature of the steel is a temperature range of 730°C to 900°C and the cumulative rolling reduction is 15% or more, is performed. In this hot rolling, forming is performed such that the shape seen in the foregoing cut section ultimately becomes an H-shape.

[0080] In the temperature range of more than 900°C and 1,100°C or less, in order to reduce the generation amount of bainite or an MA through grain refinement of austenite grains, the cumulative rolling reduction is set to 20% or more. Preferably, the lower limit for the cumulative rolling reduction in the temperature range of more than 900°C and 1,100°C or less is set to 25%, 30%, or 35%. As necessary, the upper limit for the cumulative rolling reduction in the temperature range of more than 900°C and 1,100°C or less may be set to 60%.

[0081] In the temperature range of 730°C to 900°C, in order to refine ferrite, the cumulative rolling reduction is set to 15% or more. Preferably, the lower limit for the cumulative rolling reduction in the temperature range of 730°C to 900°C is set to 20%, 25%, or 30%. As necessary, the upper limit for the cumulative rolling reduction in the temperature range of 730°C to 900°C may be set to 50%.

[0082] When rolling is performed at a temperature below 730°C, and which may lead to deterioration in low temperature toughness. Therefore, a finish temperature of rolling (finish rolling temperature) is set to 730°C or more on the surface temperature of a steel. Preferably, the upper limit for the finish rolling temperature is set to 750°C.

[0083] In the hot rolling, rough rolling, intermediate rolling, and finish rolling are performed. However, for example, rolling at the temperature range of more than 900°C to 1,100°C may be performed by any of rough rolling, intermediate rolling, and finish rolling. Similarly, rolling at the temperature range of 730°C to 900°C may be performed by any of rough rolling, intermediate rolling, and finish rolling. In the method for manufacturing an H section according to the present embodiment, the cumulative rolling reduction in the foregoing temperature range may be controlled.

[0084] In addition, the cumulative rolling reduction in the foregoing temperature range is obtained with reference to the thickness of the flange at a position corresponding to $(1/6)F$ from the end surface 5a of the flange in the width direction illustrated in FIG. 1. For example, the cumulative rolling reduction in the temperature range of more than 900°C and 1,100°C or less is set to the rolling reduction calculated from the difference between the thickness of the flange at the time when the surface temperature of a steel is 1,100°C and the thickness of the flange immediately before the temperature reaches 900°C. Similarly, the cumulative rolling reduction in the temperature range of 730°C to 900°C is set to the rolling reduction calculated from the difference between the thickness of the flange at the time when the surface temperature of a steel is 900°C and the thickness of the flange at the time when the surface temperature of a steel is 730°C.

[0085] In the hot rolling, the methods for rough rolling, intermediate rolling, and finish rolling are not particularly limited. For example, breakdown rolling is performed as the rough rolling, universal rolling or edging rolling is performed as the intermediate rolling, universal rolling is performed as the finish rolling, so that the shape seen in a cut section orthogonal to the rolling direction may be formed into an H-shape.

[0086] In the hot rolling, water cooling may be performed between rolling passes. Water cooling performed between the rolling passes is cooling performed for the purpose of controlling temperature in a temperature range which is more than the temperature at which austenite is phase-transformed. Bainite or an MA is not generated in a steel due to water cooling performed between the rolling passes.

[0087] In addition, in the hot rolling, dual heat rolling may be performed. Dual heat rolling means a rolling method in which a steel piece is cooled to a temperature of 500°C or less after primary rolling, and then, the steel piece is heated to 1,100°C to 1,350°C and secondary rolling is performed again. In dual heat rolling, the plastic deformation amount is reduced in hot rolling, and the decrease in temperature in the rolling also becomes small. Therefore, a second heating temperature can be lowered.

[0088] In the cooling, a hot rolled material after the hot rolling is cooled. In the method for manufacturing an H section according to the present embodiment, a hot rolled material is subjected to natural cooling in the atmosphere as it is after ending of the hot rolling. In a case where a hot rolled material is subjected to natural cooling in the atmosphere, the average cooling rates of a surface of a steel and inside thereof from 800°C to 500°C become 1 °C/sec or less. Since the cooling rates of a surface of a steel and inside thereof are uniform by performing natural cooling on a hot rolled material in the atmosphere, unevenness in mechanical properties depending on the portions of a steel is suppressed. In the method for manufacturing an H section according to the present embodiment, natural cooling means that cooling is performed in the atmosphere without forcibly performing cooling until the temperature of a steel reaches to 400°C or less from immediately after hot rolling.

[0089] In technologies in the related art, a hot rolled material has been subjected to accelerated cooling in order to achieve both the strength and the toughness. Accordingly, unevenness in mechanical properties has been caused between a surface of a steel and inside thereof. On the other hand, in the method for manufacturing an H section according to the present embodiment, although a hot rolled material is subjected to natural cooling in the atmosphere, the steel composition and the steel structure are optimally controlled. Therefore, it is possible to achieve both the strength and the low temperature toughness without causing unevenness in mechanical properties between a surface of a steel and inside thereof.

[0090] Since the method for manufacturing an H section according to the present embodiment does not require an advanced steelmaking technology or accelerated cooling, it is possible to reduce a manufacturing load and to shorten a construction period. Therefore, the H section according to the present embodiment can improve reliability of a large building without impairing economic feasibility.

[Example 1]

[0091] Next, the effects of the aspect of the present invention will be specifically described in more detail using Examples. However, the conditions in Examples are merely examples of conditions employed to check the feasibility and the effects of the present invention, and the present invention is not limited to these examples of conditions. The present invention can employ various conditions as long as the conditions do not depart from the gist of the present invention and the object of the present invention is achieved.

[0092] Steels respectively having the chemical compositions shown in Table 1 to Table 3 were smelted, and steel pieces having a thickness of 240 mm to 300 mm were manufactured through continuous casting. The steels were smelted by using a converter, and their compositions were adjusted by performing primary deoxidation and adding an alloying element. As necessary, vacuum degassing was performed. H sections were manufactured by heating the obtained steel pieces and performing hot rolling. The steel compositions indicated as compositions No. 1 to No. 48 were obtained by chemically analyzing samples respectively collected from the manufactured H sections. Although it is not shown in Tables, P was 0.03% or less, S was 0.02% or less, and O was 0.005% or less in all of the Examples. The blank for the chemical composition in Tables indicates that it was not actively added to the steel, or its amount was equal to or less than the detection limit.

[0093] FIG. 2 illustrates processes for manufacturing an H section. Hot rolling of a steel piece heated by a heating furnace 1 was performed in a universal rolling apparatus array including a rough rolling mill 2a, an intermediate rolling mill 2b, and a finish rolling mill 2c. A hot rolled material was subjected to natural cooling as it is until the temperature reached to 400°C or less after ending of hot rolling. Both the average cooling rates of a surface of the hot rolled material and inside thereof from an ending temperature of hot rolling to 500°C were 1 °C/sec or less. In the case where water cooling was performed between passes of hot rolling, spray cooling of an outer surface of the flange was performed by using water cooling apparatuses 3 provided in the front and the rear of the intermediate universal rolling mill (intermediate rolling mill) 2b. In this case, reverse rolling was performed.

[0094] Table 4 to Table 6 show the manufacturing conditions and the manufactured results. The rolling reductions at the time of hot rolling shown in Table 4 to Table 6 are cumulative rolling reductions in the temperature ranges at a position corresponding to (1/6)F from the end surface 5a of the flange in the width direction illustrated in FIG. 1.

[0095] In regard to the manufactured H sections, as described above, the Charpy test was performed at -20°C by using the test piece collected from the evaluation portion 7 illustrated in FIG. 1, and the low temperature toughness was evaluated. In addition, the tension test was performed at a normal temperature (20°C) by using the test piece in which the position of (1/6)F from the end surface 5a of the flange in the width direction became the center in the thickness direction, and the tensile properties were evaluated. In addition, the structure was observed by using the sample having a portion in the vicinity of the evaluation portion 7 illustrated in FIG. 1 as the observed section, and the steel structure was evaluated.

[0096] The tension test was performed in conformity with JIS Z 2241 (2005). In the case where the stress-strain curve of the tension test indicated yielding behavior, a yield point was regarded as the yield stress. In the case where no yielding behavior was indicated, 0.2% proof stress was regarded as the yield stress. A Charpy impact test was performed

in conformity with JIS Z 2242 (2005). The Charpy impact test was performed at -20°C.

[0097] The structure was observed by using the method described above, and the ferrite fraction, the MA fraction, and the fraction of a structure other than the ferrite and the MA was measured by using a photograph of an optical microscope. In addition, the structure other than the ferrite and the MA was bainite or pearlite. In addition, the average grain size of ferrite was obtained by an intercept method in conformity with JIS G 0551 (2013) using a photograph of an optical microscope.

[0098] In regard to the tensile properties, a steel having yield stress (YS) at a normal temperature of 385 MPa or more and tensile strength (TS) of 490 MPa or more was determined as PASSED. In addition, in regard to the low temperature toughness, a steel having Charpy absorbed energy at -20°C (vE-20) of 100 J or greater was determined as PASSED.

[0099] As shown in Tables 1 to 6, in Serial No. 1 to No. 8, Serial No. 11 to No. 18, and Serial No. 34 to No. 43, which were the examples in the present invention, all of the steel composition, the steel structure, and mechanical properties satisfied the range of the present invention.

[0100] On the other hand, in Serial No. 9 to No. 10, Serial No. 19 to No. 33, and Serial No. 44 to No. 50, which were comparative examples, any of the steel composition, the steel structure, and mechanical properties did not satisfy the range of the present invention.

[0101] Serial No. 9 was an example in which rolling reduction within more than 900°C and 1,100°C or less was insufficient. Therefore, the ferrite fraction in the steel structure became insufficient and the fraction of the structure other than the ferrite and the MA became excessive, so that the Charpy absorbed energy at -20°C became insufficient.

[0102] Serial No. 10 was an example in which rolling reduction within 730°C to 900°C was insufficient. Therefore, grain size of ferrite was coarsened, so that the Charpy absorbed energy at -20°C became insufficient.

[0103] Serial No. 19 was an example in which rolling reduction within more than 900°C and 1,100°C or less was insufficient. Therefore, the fraction ferrite became insufficient, the MA fraction became excessive, and the fraction of the structure other than the ferrite and the MA became excessive, so that the Charpy absorbed energy at -20°C became insufficient.

[0104] Serial No. 20 was an example in which the C content was large. Serial No. 25 was an example in which the Nb content was large. Serial No. 26 was an example in which the V content was large. Serial No. 28 was an example in which the Al content was large. Serial No. 29 was an example in which the Ti content was large. Serial No. 30 was an example in which the N content was large. Serial No. 31 was an example in which Ceq was excessive. Therefore, the Charpy absorbed energy at -20°C became insufficient in these examples.

[0105] Serial No. 21 was an example in which the C content was small. Serial No. 24 was an example in which the Mn content was small. Serial No. 32 was an example in which Ceq was insufficient. Serial No. 46 was an example in which the Si content was small. Therefore, YS and TS became insufficient in these examples.

[0106] Serial No. 22 was an example in which the Si content was large. Serial No. 23 was an example in which the Mn content was large and MA fraction was excessive. Therefore, the Charpy absorbed energy at -20°C became insufficient in these examples.

[0107] Serial No. 27 was an example in which the V content was small, so that grain size of ferrite is coarsened. Therefore, the Charpy absorbed energy at -20°C became insufficient.

[0108] Serial No. 33 was an example in which the B content was excessive and Ceq was excessive. Serial No. 49 was an example in which the B was large, so that the MA fraction became excessive. Therefore, the Charpy absorbed energy at -20°C became insufficient in these examples.

[0109] Serial No. 44 and Serial No. 45 were examples in which the V content was small, so that grain size of ferrite was coarsened. Therefore, the Charpy absorbed energy at -20°C became insufficient in these examples.

[0110] Serial No. 47 was an example in which the Nb content was small, so that grain size of ferrite was coarsened. Therefore, YS and TS became insufficient and the Charpy absorbed energy at -20°C became insufficient.

[0111] Serial No. 48 was an example in which the Ti content was small, so that grain size of ferrite was coarsened. Therefore, the Charpy absorbed energy at -20°C became insufficient.

[0112] Serial No. 50 was an example in which the finish rolling temperature was low. Therefore, the Charpy absorbed energy at -20°C became insufficient.

[Table 1]

Serial No.	Composition No.	Chemical composition [mass%] (remainder of Fe and impurities)																Ceq
		C	Si	Mn	Nb	V	Al	Ti	N	Cr	Mo	Ni	Cu	W	B	Ca	Zr	
1	1	0.158	0.55	0.82	0.045	0.098	0.095	0.024	0.0005									0.314
2	2	0.157	0.54	0.84	0.046	0.051	0.091	0.022	0.0007									0.307
3	3	0.131	0.38	1.55	0.047	0.099	0.032	0.012	0.0023					0.40			0.0018	0.409
4	4	0.130	0.09	1.59	0.041	0.102	0.028	0.010	0.0030									0.415
5	5	0.121	0.40	1.40	0.045	0.110	0.037	0.011	0.0070			0.20	0.20					0.403
6	6	0.119	0.44	0.95	0.040	0.115	0.031	0.012	0.0042		0.18							0.336
7	7	0.110	0.29	1.20	0.033	0.099	0.030	0.008	0.0019	0.20					0.0036			0.370
8	8	0.109	0.05	1.60	0.045	0.111	0.030	0.011	0.0071									0.398
9	8	0.109	0.05	1.60	0.045	0.111	0.030	0.011	0.0071									0.398
10	8	0.109	0.05	1.60	0.045	0.111	0.030	0.011	0.0071									0.398
11	9	0.100	0.41	1.22	0.049	0.089	0.012	0.002	0.0022	0.28								0.377
12	10	0.099	0.28	1.01	0.020	0.098	0.030	0.007	0.0080		0.19				0.0020			0.325
13	11	0.090	0.15	1.40	0.005	0.070	0.051	0.019	0.0114									0.337
14	12	0.090	0.12	1.35	0.035	0.090	0.040	0.009	0.0056			0.31				0.0025		0.354
15	13	0.080	0.56	1.55	0.030	0.099	0.019	0.012	0.0095									0.358
16	14	0.071	0.33	1.59	0.044	0.102	0.025	0.009	0.0072		0.18							0.392
17	15	0.060	0.07	1.30	0.033	0.088	0.032	0.010	0.0029	0.20	0.19	0.20	0.20					0.399
The blank means that an element is not intentionally added or is equal to or less than a detection limit. The underline means that the value is beyond the range of the present invention.																		

[Table 2]

Serial No	Composition No	Chemical composition [mass%] (remainder of Fe and impurities)															Ceq	
		C	Si	Mn	Nb	V	Al	Ti	N	Cr	Mo	Ni	Cu	W	B	Ca		Zr
18	16	0.051	0.20	1.66	0.040	0.109	0.030	0.012	0.0030		0.18	0.25						0.402
19	16	0.051	0.20	1.66	0.040	0.109	0.030	0.012	0.0030		0.18	0.25						0.402
20	17	<u>0.174</u>	0.30	1.50	0.041	0.098	0.032	0.011	0.0034		0.10							0.464
21	18	<u>0.040</u>	0.10	1.42	0.020	0.101	0.028	0.011	0.0052			0.20	0.20					0.324
22	19	0.140	0.65	1.59	0.039	0.110	0.044	0.009	0.0070		0.10							0.447
23	20	0.139	0.39	<u>1.80</u>	0.038	0.111	0.031	0.010	0.0055									0.461
24	21	0.101	0.21	<u>0.73</u>	0.045	0.099	0.029	0.011	0.0039		0.19	0.21	0.21					0.308
25	22	0.130	0.38	1.60	<u>0.061</u>	0.113	0.040	0.012	0.0040			0.11	0.10					0.433
26	23	0.141	0.35	1.55	0.045	<u>0.130</u>	0.030	0.008	0.0051									0.425
27	24	0.099	0.35	1.54	0.039	<u>0.044</u>	0.021	0.008	0.0029									0.364
28	25	0.121	0.37	1.58	0.044	0.080	<u>0.110</u>	0.010	0.0027									0.400
29	26	0.120	0.38	1.55	0.047	0.090	0.052	<u>0.028</u>	0.0031									0.396
30	27	0.119	0.39	1.54	0.038	0.102	0.030	0.011	<u>0.0131</u>									0.396
31	28	0.150	0.45	1.61	0.045	0.112	0.030	0.012	0.0050	0.11	0.10	0.20						<u>0.496</u>
32	29	0.065	0.30	0.89	0.010	0.061	0.029	0.009	0.0044	0.20								<u>0.266</u>
33	30	0.070	0.35	1.10	0.035	0.051	0.030	0.012	0.0020						<u>0.0005</u>			<u>0.264</u>
The blank means that an element is not intentionally added or is equal to or less than a detection limit. The underline means that the value is beyond the range of the present invention.																		

[Table 3]

Serial No	Composition No	Chemical composition [mass%] (remainder of Fe and impurities)															Ceq	
		C	Si	Mn	Nb	V	Al	Ti	N	Cr	Mo	Ni	Cu	W	B	Ca		Zr
34	31	0.150	0.03	1.01	0.020	0.099		0.008	0.0006									0.338
35	32	0.139	0.51	1.20	0.015	0.078		0.009	0.0050	0.09						0.0022	0.0021	0.373
36	33	0.129	0.40	1.32	0.032	0.101	0.002	0.020	0.0033									0.369
37	34	0.121	0.10	0.99	0.045	0.089		0.015	0.0101		0.20		0.20					0.317
38	35	0.110	0.35	1.59	0.044	0.101	0.001	0.011	0.0077									0.395
39	36	0.100	0.34	1.62	0.042	0.051		0.012	0.0029									0.380
40	37	0.092	0.25	1.44	0.039	0.062		0.010	0.0020									0.344
41	38	0.082	0.41	1.00	0.019	0.110	0.001	0.025	0.0061	0.20	0.20	0.22						0.339
42	39	0.073	0.50	1.40	0.039	0.098		0.010	0.0080		0.11						0.0015	0.348
43	40	0.062	0.42	1.62	0.045	0.080		0.012	0.0073	0.20								0.388
44	41	0.099	0.35	1.50	0.020	0.040		0.012	0.0025		0.20				0.0019			0.370
45	42	0.102	0.36	1.48	0.031	0.031	0.001	0.008	0.0029									0.355
46	43	0.099	0.004	1.49	0.042	0.099	0.001	0.011	0.0061									0.367
47	44	0.111	0.35	1.35	0.004	0.109	0.001	0.009	0.0039									0.358
48	45	0.119	0.35	1.48	0.045	0.089	0.002	0.0004	0.0029									0.383
49	46	0.065	0.35	1.01	0.039	0.051	0.001	0.011	0.0033		0.20	0.20	0.22		0.0004			0.312
50	47	0.092	0.36	1.59	0.044	0.070		0.022	0.0025									0.371
The blank means that an element is not intentionally added or is equal to or less than a detection limit. The underline means that the value is beyond the range of the present invention.																		

[Table 4]

Serial No.	Composition No.	Thickness of flange [mm]	Heating temperature of slab [°C]	Rolling reduction within more than 900°C and 1,100°C or less [%]	Rolling reduction within 730°C to 900°C [%]	Finish rolling temperature [°C]	Area fraction of ferrite [%]	Area fraction of MA [%]	Area fraction other than ferrite and MA [%]	Average grain size of ferrite [μm]	YS [MPa]	TS [MPa]	$vE_{-20^\circ\text{C}}$ [J]	Remarks
1	1	20	1310	50	35	740	75	0.5	24.5	13.5	498	602	260	Present invention
2	2	20	1310	35	35	750	64	2.8	33.2	27.5	457	590	108	Present invention
3	3	40	1310	35	30	762	68	2.5	29.5	16.0	464	570	248	Present invention
4	4	40	1310	35	30	760	70	0.8	29.2	15.5	454	575	239	Present invention
5	5	140	1310	25	22	801	75	1.3	23.7	18.9	414	521	208	Present invention
6	6	140	1310	25	22	795	73	1.3	25.7	17.8	394	517	202	Present invention
7	7	56	1310	33	30	752	77	0.8	22.2	12.6	425	555	255	Present invention
8	8	77	1250	33	28	789	78	0.8	21.2	17.7	458	550	241	Present invention
9	8	77	1250	<u>13</u>	28	796	<u>55</u>	2.8	<u>42.2</u>	24.5	461	553	<u>77</u>	Comparative Example
10	8	77	1250	33	<u>13</u>	800	76	1.0	23.0	<u>38.2</u>	469	563	<u>36</u>	Comparative Example
11	9	125	1310	28	25	822	79	0.5	20.5	18.8	413	532	199	Present invention
12	10	125	1310	28	25	825	80	0.3	19.7	20.1	414	529	189	Present invention

(continued)

Serial No.	Composition No.	Thickness of flange [mm]	Heating temperature of slab [°C]	Rolling reduction within more than 900°C and 1,100°C or less [%]	Rolling reduction within 730°C to 900°C [%]	Finish rolling temperature [°C]	Area fraction of ferrite [%]	Area fraction of MA [%]	Area fraction other than ferrite and MA [%]	Average grain size of ferrite [μm]	YS [MPa]	TS [MPa]	vE-20°C [J]	Remarks
13	11	89	1200	30	27	848	83	0.0	17.0	24.0	451	539	180	Present invention
14	12	89	1200	30	27	841	82	2.3	15.7	26.6	425	544	177	Present invention
15	13	40	1150	35	30	790	84	0.3	15.7	18.6	460	590	202	Present invention
16	14	40	1150	35	30	796	83	0.5	16.5	18.8	500	601	231	Present invention
17	15	77	1310	33	28	849	86	1.0	13.0	27.8	423	552	169	Present invention
The underline means that the value is beyond the range of the present invention.														

[Table 5]

Serial No.	Composition No.	Thickness of flange [mm]	Heating temperature of slab [°C]	Rolling reduction within more than 900°C and 1,100°C or less [%]	Rolling reduction within 730°C to 900°C [%]	Finish rolling temperature [°C]	Area fraction of ferrite [%]	Area fraction of MA [%]	Area fraction other than ferrite and MA [%]	Average grain size of ferrite [μm]	YS [MPa]	TS [MPa]	$vE_{-20^\circ\text{C}}$ [J]	Remarks
18	16	77	1310	33	28	840	88	1.0	11.0	24.5	418	548	135	Present invention
19	16	77	1310	<u>13</u>	35	835	<u>54</u>	<u>3.5</u>	<u>42.5</u>	26.0	423	554	<u>67</u>	Comparative Example
20	17	89	1310	30	27	821	62	0.8	<u>37.2</u>	18.2	434	543	88	Comparative Example
21	18	89	1310	30	27	827	90	1.5	8.5	17.7	<u>380</u>	<u>485</u>	215	Comparative Example
22	19	89	1310	30	27	833	65	<u>3.5</u>	31.5	18.4	446	551	<u>54</u>	Comparative Example
23	20	56	1310	40	30	787	70	<u>3.3</u>	26.7	14.4	443	575	<u>69</u>	Comparative Example
24	21	56	1310	40	30	777	75	0.3	24.7	14.3	<u>383</u>	<u>484</u>	275	Comparative Example
25	22	56	1310	40	30	775	69	1.5	29.5	13.9	463	574	<u>70</u>	Comparative Example
26	23	77	1310	33	28	780	68	1.3	30.7	15.0	462	555	<u>92</u>	Comparative Example
27	24	77	1310	33	28	792	79	0.8	20.2	<u>30.5</u>	421	549	<u>96</u>	Comparative Example
28	25	77	1310	33	28	799	75	0.5	24.5	16.1	448	556	<u>48</u>	Comparative Example
29	26	77	1310	33	28	805	77	0.0	23.0	16.0	441	564	<u>39</u>	Comparative Example

(continued)

Serial No.	Composition No.	Thickness of flange [mm]	Heating temperature of slab [°C]	Rolling reduction within more than 900°C and 1,100°C or less [%]	Rolling reduction within 730°C to 900°C [%]	Finish rolling temperature [°C]	Area fraction of ferrite [%]	Area fraction of MA [%]	Area fraction other than ferrite and MA [%]	Average grain size of ferrite [μm]	YS [MPa]	TS [MPa]	vE _{-20°C} [J]	Remarks
30	27	77	1310	33	32	783	79	0.5	20.5	15.2	452	561	<u>88</u>	Comparative Example
31	28	77	1310	33	32	800	65	2.8	32.2	15.5	486	632	<u>74</u>	Comparative Example
32	29	77	1310	33	32	774	85	0.3	14.7	14.8	<u>369</u>	<u>481</u>	236	Comparative Example
33	30	77	1310	33	32	795	66	<u>5.0</u>	29.0	27.9	438	598	<u>44</u>	Comparative Example
The underline means that the value is beyond the range of the present invention.														

[Table 6]

Serial No.	Composition No.	Thickness of flange [mm]	Heating temperature of slab [°C]	Rolling reduction within more than 900°C and 1,100°C or less [%]	Rolling reduction within 730°C to 900°C [%]	Finish rolling temperature [°C]	Area fraction of ferrite [%]	Area fraction of MA [%]	Area fraction other than ferrite and MA [%]	Average grain size of ferrite [μm]	YS [MPa]	TS [MPa]	$vE_{-20^\circ\text{C}}$ [J]	Remarks
34	31	56	1250	40	30	820	77	0.3	22.7	16.8	456	562	334	Present invention
35	32	56	1250	40	30	827	74	0.9	25.1	16.4	440	567	307	Present invention
36	33	125	1310	28	25	830	69	1.3	29.7	18.5	415	519	280	Present invention
37	34	125	1310	28	25	821	69	1.4	29.6	18.0	418	505	300	Present invention
38	35	77	1310	33	28	812	72	0.8	27.2	13.2	468	581	355	Present invention
39	36	77	1310	33	28	802	70	1.2	28.8	27.9	444	561	114	Present invention
40	37	77	1310	33	28	798	72	1.0	27.0	27.5	456	549	128	Present invention
41	38	89	1310	30	27	845	75	2.5	22.5	14.4	438	539	332	Present invention
42	39	89	1310	30	27	856	76	1.6	22.4	13.9	447	544	318	Present invention
43	40	89	1310	30	27	863	79	0.6	20.4	15.0	458	560	299	Present invention
44	41	77	1310	33	28	790	73	1.5	25.5	33.6	450	570	77	Comparative Example
45	42	77	1310	33	28	788	74	1.3	24.7	35.9	447	558	45	Comparative Example

(continued)

Serial No.	Composition No.	Thickness of flange [mm]	Heating temperature of slab [°C]	Rolling re-duction within more than 900°C and 1,100°C or less [%]	Rolling re-duction within 730°C to 900°C [%]	Finish rolling temperature [°C]	Area fraction of ferrite [%]	Area fraction of MA [%]	Area fraction other than ferrite and MA [%]	Average grain size of ferrite [μm]	YS [MPa]	TS [MPa]	vE _{-20°C} [J]	Remarks
46	43	89	1310	30	27	833	65	2.5	32.5	18.0	<u>375</u>	<u>487</u>	115	Comparative Example
47	44	56	1310	40	30	760	70	1.3	28.7	<u>31.2</u>	<u>379</u>	<u>479</u>	<u>92</u>	Comparative Example
48	45	77	1310	33	30	792	75	0.5	24.5	<u>31.8</u>	447	561	<u>85</u>	Comparative Example
49	46	77	1310	33	32	774	70	<u>4.6</u>	25.4	27.9	492	602	<u>54</u>	Comparative Example
50	47	77	1310	25	35	<u>720</u>	69	0.6	30.4	28.5	498	592	<u>88</u>	Comparative Example
The underline means that the value is beyond the range of the present invention.														

[Industrial Applicability]

[0113] According to the aspect of the present invention, it is possible to provide a thick H section, which has excellent strength and low temperature toughness, and a method for manufacturing the same. Therefore, industrial applicability is high.

[Brief Description of the Reference Symbols]

[0114]

1: heating furnace
 2a: rough rolling mill
 2b: intermediate rolling mill
 2c: finish rolling mill
 3: water cooling apparatuses before and after intermediate rolling mill
 4: H section
 5: flange
 5a: end surface of flange in width direction
 5b: outer surface of flange in thickness direction
 6: web
 7: tensile properties, low temperature toughness, and evaluation portion of steel structure
 F: length of flange in width direction
 H: height
 t_1 : thickness of web
 t_2 : thickness of flange

Claims

1. An H section, wherein
 a steel comprises, as a chemical composition, by mass%,
 C: 0.05% to 0.160%,
 Si: 0.01% to 0.60%,
 Mn: 0.80% to 1.70%,
 Nb: 0.005% to 0.050%,
 V: 0.05% to 0.120%,
 Ti: 0.001% to 0.025%,
 N: 0.0001% to 0.0120%,
 Cr: 0% to 0.30%,
 Mo: 0% to 0.20%,
 Ni: 0% to 0.50%,
 Cu: 0% to 0.35%,
 W: 0% to 0.50%,
 Ca: 0% to 0.0050%,
 Zr: 0% to 0.0050%,
 Al: limited to 0.10% or less,
 B: limited to 0.0003% or less, and
 a remainder including Fe and impurities, wherein
 $C, Mn, Cr, Mo, V, Ni, \text{ and } Cu$ in the chemical composition satisfy $0.30 \leq C_{eq} \leq 0.48$, when
 $C_{eq} = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15$,
 the steel includes, as a metallographic structure, by area fraction, ferrite of 60% to less than 100%, a mixed structure MA of martensite and austenite being limited to 3.0% or less, and a structure other than the ferrite and the MA being limited to 37% or less,
 an average grain size of the ferrite is 1 μm to 30 μm ,
 a shape is an H-shape and a thickness of a flange is 20 mm to 140 mm, when being seen in a cut section orthogonal to a rolling direction,
 at a position of $(1/6)F$ from an end surface of the flange in the width direction, tensile yield stress is 385 MPa to 530 MPa and maximum tensile strength is 490 MPa to 690 MPa, when a length of the flange in a width direction is F, and

at the position of $(1/6)F$ and at a position of $(1/4)t_2$ from an outer surface of the flange in a thickness direction, absorbed energy in a Charpy test at -20°C is 100 J or more, when the thickness of the flange is t_2 .

2. The H section according to claim 1, comprising, as the chemical composition, by mass%,
Nb: more than 0.02% to 0.050%.

3. The H section according to claim 1, comprising, as the chemical composition, by mass%,
N: more than 0.005% to 0.0120%.

4. The H section according to claim 1, comprising, as the chemical composition, by mass%,
Cu: limited to less than 0.03%.

5. The H section according to claim 1, comprising, as the chemical composition, by mass%,
Al: limited to less than 0.003%.

6. The H section according to claim 1,
wherein the thickness of the flange is 25 mm to 140 mm.

7. A method for manufacturing the H section according to any one of claims 1 to 6, comprising:

steelmaking to obtain a molten steel which has the chemical composition according to any one of claims 1 to 5;
casting the molten steel after the steelmaking to obtain a steel piece;
heating the steel piece after the casting to $1,100^{\circ}\text{C}$ to $1,350^{\circ}\text{C}$;
hot rolling on the steel piece after the heating to form a shape, when being seen in a cut section orthogonal to
a rolling direction, into an H-shape under conditions, wherein

a cumulative rolling reduction at a position of $(1/6)F$ from an end surface of a flange in a width direction
within more than 900°C and $1,100^{\circ}\text{C}$ or less is 20% or more,
the cumulative rolling reduction at the position within 730°C to 900°C is 15% or more, and
the rolling ends at 730°C or more; and

cooling a hot rolled material after the hot rolling by natural cooling.

FIG. 1

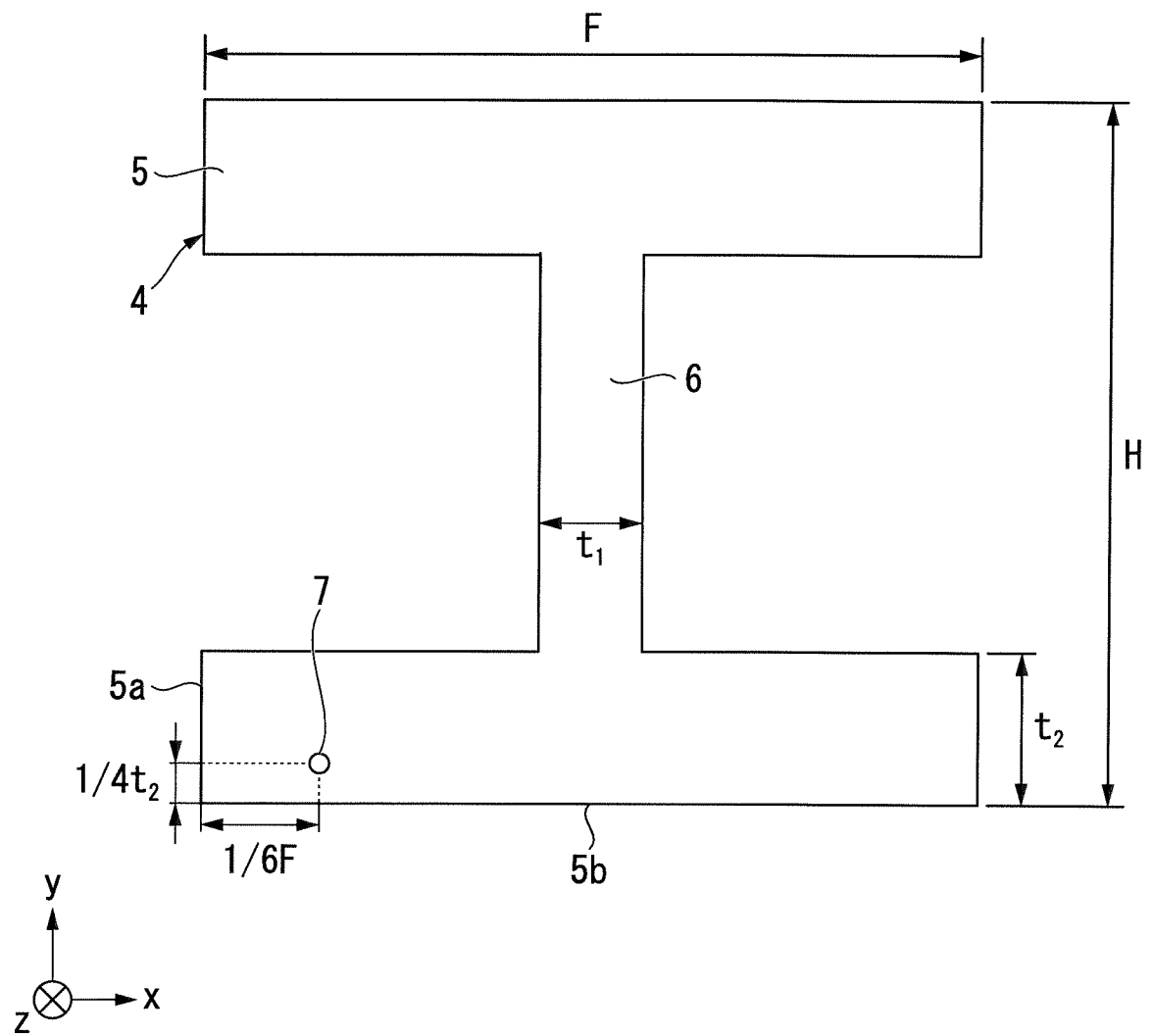
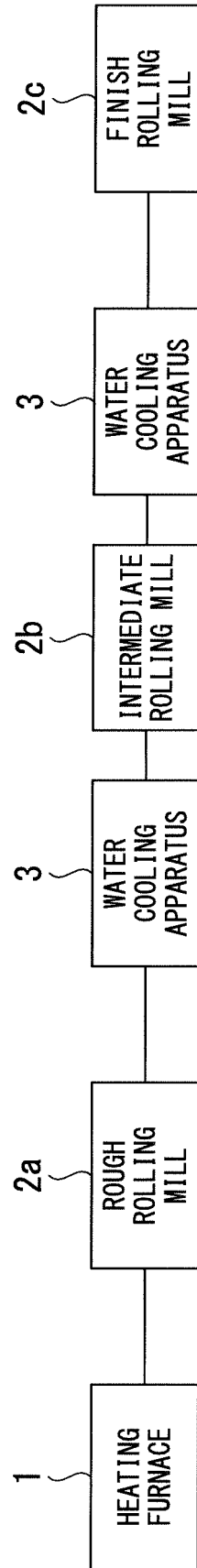


FIG. 2



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2017/045965

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. C22C38/00 (2006.01) i, C21D8/00 (2006.01) i, C22C38/14 (2006.01) i,
C22C38/58 (2006.01) i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl. C22C38/00-38/60, C21D8/00

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 1971-2018

Registered utility model specifications of Japan 1996-2018

Published registered utility model applications of Japan 1994-2018

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	JP 2016-141834 A (NIPPON STEEL & SUMITOMO METAL CORP.) 08 August 2016 (Family: none)	1-7
A	JP 2016-079443 A (NIPPON STEEL & SUMITOMO METAL CORP.) 16 May 2016 (Family: none)	1-7
A	JP 2016-117945 A (NIPPON STEEL & SUMITOMO METAL CORP.) 30 June 2016 (Family: none)	1-7



Further documents are listed in the continuation of Box C.



See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search
13 March 2018 (13.03.2018)Date of mailing of the international search report
27 March 2018 (27.03.2018)Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

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

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2017/045965

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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REFERENCES CITED IN THE DESCRIPTION

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