



(11) **EP 4 541 925 A1**

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

(43) Date of publication:
23.04.2025 Bulletin 2025/17

(21) Application number: **23824112.9**

(22) Date of filing: **22.05.2023**

(51) International Patent Classification (IPC):
C22C 38/58 ^(2006.01) **C22C 38/46** ^(2006.01)
C22C 38/48 ^(2006.01) **C22C 38/50** ^(2006.01)
C22C 38/42 ^(2006.01) **C22C 38/44** ^(2006.01)
B21B 1/02 ^(2006.01) **B21B 1/04** ^(2006.01)

(52) Cooperative Patent Classification (CPC):
B21B 1/02; B21B 1/04; C22C 38/42; C22C 38/44;
C22C 38/46; C22C 38/48; C22C 38/50; C22C 38/58

(86) International application number:
PCT/KR2023/006887

(87) International publication number:
WO 2023/243891 (21.12.2023 Gazette 2023/51)

(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 ME MK MT NL
NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
KH MA MD TN

(30) Priority: **14.06.2022 KR 20220072114**

(71) Applicant: **POSCO Co., Ltd**
Pohang-si, Gyeongsangbuk-do 37859 (KR)

(72) Inventor: **KIM, Dae-Woo**
Pohang-si, Gyeongsangbuk-do 37877 (KR)

(74) Representative: **Meissner Bolte Partnerschaft**
mbB
Patentanwälte Rechtsanwälte
Postfach 86 06 24
81633 München (DE)

(54) **EXTRA HEAVY STEEL MATERIAL FOR FLANGE HAVING EXCELLENT STRENGTH AND LOW TEMPERATURE IMPACT TOUGHNESS, AND MANUFACTURING METHOD FOR SAME**

(57) Provided are an extra heavy steel material for a flange having excellent strength and low temperature impact toughness, and a manufacturing method for same. The steel material of the present invention comprises, in weight%, C: 0.05-0.2%, Si: 0.05-0.5%, Mn: 1.0-2.0%, Al: 0.005-0.1%, P: 0.01% or less, S: 0.015% or less, Nb: 0.001-0.07%, V: 0.001-0.3%, Ti: 0.001-0.03%, Cr: 0.01-0.3%, Mo: 0.01-0.12%, Cu: 0.01-0.6%, Ni: 0.05-1.0%, Ca: 0.0005-0.004%, and the balance being Fe and other inevitable impurities. The steel material has a Ceq, by relational expression 1, satisfying the range of 0.35-0.55, a thickness of

200-500 mm, a steel material microstructure composed of a composite structure of ferrite and pearlite and having a mean grain size of 30 μm or less, wherein: the maximum size of cementite present in ferrite-ferrite and/or ferrite-pearlite crystal grain boundaries is 5 μm or less; the porosity at the center area of a product, which is an area of 3/8t to 5/8t (where t means the steel material thickness (mm)) in the thickness direction from the steel material surface is 0.1 mm³/g or less; and the number of fine NbC or NbCN precipitates with a diameter of 5-15 nm in the precipitates observed in the cross section of the steel material is 5 or more per 1 μm^2 .

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Description

Technical Field

[0001] The present disclosure relates to steel that may be used for wind power generation towers, systems and the like, and a method of manufacturing the same, and more specifically, to an extremely thick steel material for a flange having excellent strength and low-temperature impact toughness, and a method of manufacturing the same.

Background Art

[0002] Wind power generators are gaining attention as an eco-friendly means of generating electricity, and include components such as tower flanges, bearings, main shafts and the like. Thereamong, tower flanges are joint components necessary for connecting towers, and usually 5 to 7 flanges are used for one tower, and are also installed in the sea or in extreme temperature regions, and thus, high durability is required. In particular, in response to the demand for large-scale energy production and high efficiency, wind towers are also increasing in size, and accordingly, the steel used is also continuously required to be high-strength, high-toughness, and thick. As the thickness of the material increases, total deformation decreases, and thus the microstructure becomes larger, and the material tends to deteriorate due to defects in the material such as inclusions, segregation or the like. Therefore, to improve the internal and external soundness of the steel, the trend is to reduce the concentration of impurities such as non-metallic inclusions, segregation or the like, or to control cracks, pores and the like on the surface and inside the material to the extreme.

[0003] In particular, in the case of extremely thick materials exceeding 200 mmt in thickness, since the deformation of the center of the material is not large, if the unsolidified shrinkage pores that occur during continuous casting or casting are not sufficiently compressed during the forging process, they remain in the form of residual pores at the center of the flange.

[0004] These residual pores act as crack initiation points when the structure is subjected to axial stress in the thickness direction, and may eventually cause damage to the entire equipment in the form of lamellar tearing. Therefore, a process is necessary to sufficiently compress the center pores so that there are no residual pores before piercing (hole drilling forging) with small deformation and ring forging (product forming).

[0005] Patent document 1 related thereto is a technology for applying high reduction ratio in a thick plate rough rolling process. In detail, there may be used a technology for determining a thickness-specific limit reduction ratio at which thickness-specific plate bite occurs from a pass-specific reduction ratio set to be close to the design allowance (load and torque) of a rolling mill, a technology for distributing the reduction ratio by adjusting the index of a thickness ratio for each pass to secure the target thickness of a roughing mill, and a technology for modifying the reduction ratio so that plate bite does not occur based on the thickness-specific limit reduction ratio, thereby providing a manufacturing method in which an average reduction ratio of approximately 27.5% in the final three passes of roughing milling based on 80 mmt may be applied. However, in the case of the rolling method above, the average reduction ratio of the entire thickness of a product is measured, and in the case of extremely thick materials with a maximum thickness of 200 mmt or more, it is technically difficult to apply high strain to the center where residual pores exist.

[0006] One of other methods of manufacturing extremely thick materials is to utilize a forging machine with a higher effective strain per pass than a rolling mill. Patent Document 2 provides a method of manufacturing a thick-walled, high-toughness and high-strength material, using a slab comprising, in mass%, C: 0.08 to 0.20%, Si: 0.40% or less, Mn: 0.5 to 5.0%, P: 0.010% or less, S: 0.0050% or less, Cr: 3.0% or less, Ni: 0.1 to 5.0%, Al: 0.010 to 0.080%, N: 0.0070% or less, and O: 0.0025% or less, and satisfying the relationships of Formulas (1) and (2), the remainder being Fe and unavoidable impurities, in which hot forging is performed with a cumulative reduction amount of 25% or more, heating is performed at a temperature of Ac3 point or higher and 1200°C or lower, hot rolling is performed with a cumulative reduction amount of 40% or more, and rapid cooling from a temperature of Ar3 point or higher to a low temperature of 350°C or lower or Ar3 point or lower is performed, and a tempering heat treatment process is performed at a temperature of 450 to 700°C, thereby manufacturing the thick-walled, high-toughness and high-strength material with a plate thickness of 100 mmt or more, a yield strength of 620 MPa or more, and an absorbed energy of 70 J or more when evaluated for low-temperature impact toughness at -40°C.

[0007] However, the manufacturing method may cause surface defects due to localized strain concentration in the case in which the cumulative reduction amount is too high, and in particular, in the case in which a surface or subsurface defect exists in the cast state before forging, the defect may propagate during the forging process, further deteriorating the surface quality in the product state after rolling. In addition, in the case in which the forging reduction amount per pass is insufficient, it is difficult to sufficiently pressurize the pores remaining in the center even if the cumulative reduction amount is high, and the rolling process is also not suitable for controlling the central pores and structure of extremely thick materials because the effective deformation amount in the center is small compared to the surface deformation.

[0008] Meanwhile, Patent Document 3 discloses that a thick-walled high-strength steel plate having 100 mmt or more and a yield strength of 620 MPa or more may be manufactured through a process of heating a material provided with a

predetermined alloy composition to 1200-1350°C, performing hot forging with a cumulative reduction amount of 25% or more, heating to a temperature of Ac3 point or higher and 1200°C or lower, performing hot rolling with a cumulative reduction amount of 40% or more, reheating to a temperature of Ac3 point or higher and 1050°C or lower, rapidly cooling from a temperature of Ac3 point or higher to a low temperature of 350°C or lower or Ar3 point or lower, and performing tempering at a temperature of 450°C to 700°C.

[0009] However, in the case of the ultra-high strength steel plate described above, the carbon equivalent (Ceq) and hardenability index (DI) are high, and thus in addition to being vulnerable to surface cracks during casting, in the case of flange steel manufactured by normalizing heat treatment, the corresponding process conditions cannot be easily applied. In addition, in the case in which the carbon equivalent (Ceq) and hardenability index (DI) are high, cracks easily occur on the surface layer of the cast due to the formation of surface hard tissue during the second cooling process of steelmaking, and the cracks may propagate during the forging process, which may deteriorate the surface quality of the final product.

[0010] Therefore, a method of performing forging to improve the internal soundness of the final product by compressing the central pore has been proposed, but no practical method has been presented to secure both the appropriate material and excellent surface quality of the steel for a flange.

[Prior art literature]

[Patent literature]

[0011]

(Patent literature 1) Republic of Korea Patent Publication No. 10-2012-0075246 (published on July 6, 2012)

(Patent literature 2) Republic of Korea Patent Publication No. 10-2017-0095307 (published on August 22, 2017)

(Patent literature 3) Republic of Korea Patent Publication No. 10-2017-0095307 (published on August 22, 2017)

Summary of Invention

Technical Problem

[0012] An aspect of the present disclosure is to provide an extremely thick steel material for a flange having excellent strength and low-temperature impact toughness and a method of manufacturing the same.

[0013] The subject matter of the present disclosure is not limited to the above-described contents. Those skilled in the art will have no difficulty in understanding the additional subjects of the present disclosure from the overall content of this specification.

Solution to Problem

[0014] According to an aspect of the present disclosure, an extremely thick steel material for a flange includes,

in wt%, C: 0.05 to 0.2%, Si: 0.05 to 0.5%, Mn: 1.0 to 2.0%, Al: 0.005 to 0.1%, P: 0.01% or less, S: 0.015% or less, Nb: 0.001 to 0.07%, V: 0.001 to 0.3%, Ti: 0.001 to 0.03%, Cr: 0.01 to 0.3%, Mo: 0.01 to 0.12%, Cu: 0.01 to 0.6%, Ni: 0.05 to 1.0%, Ca: 0.0005 to 0.004%, and a remainder of Fe and other unavoidable impurities, and Ceq thereof according to the following relational expression 1 satisfying a range of 0.35 to 0.55,

the extremely thick steel material for a flange,

having a thickness of 200 to 500 mm,

having a steel microstructure composed of a composite structure of pearlite and ferrite with an average grain size of 30 μm or less,

having a maximum size of cementite existing in ferrite-ferrite and/or ferrite-pearlite grain boundary, being 5 μm or less,

having a porosity of 0.1 mm^3/g or less in a central portion of a product, a region of 3/8t to 5/8t (where t means a steel thickness (mm)) in a thickness direction from a steel surface, and

having 5 or more fine NbC or NbCN precipitates with a diameter of 5 to 15 nm, per 1 μm^2 , among precipitates observed in a cross section of steel.

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

[Relational expression 1]

[0015] In the relational expression 1, [C], [Mn], [Cr], [Mo], [V], [Ni], and [Cu] represent contents (in weight%) of C, Mn, Cr, Mo, V, Ni, and Cu contained in the steel, respectively, and 0 is substituted if these components are not added intentionally.

[0016] In addition, the steel may have a tensile strength of 510 to 690 MPa, a yield strength of 370 MPa or more, and an absorbed energy value of -50°C Charpy impact test of 50 J or more.

[0017] A maximum surface crack depth of the steel may be 0.1 mm or less (including 0).

[0018] According to an aspect of the present disclosure, a method of manufacturing an extremely thick steel material for a flange includes,

an operation of manufacturing a slab containing, in wt%, C: 0.05 to 0.2%, Si: 0.05 to 0.5%, Mn: 1.0 to 2.0%, Al: 0.005 to 0.1%, P: 0.01% or less, S: 0.015% or less, Nb: 0.001 to 0.07%, V: 0.001 to 0.3%, Ti: 0.001 to 0.03%, Cr: 0.01 to 0.3%, Mo: 0.01 to 0.12%, Cu: 0.01 to 0.6%, Ni: 0.05 to 1.0%, Ca: 0.0005 to 0.004%, and a remainder of Fe and other inevitable impurities, the slab satisfying, C_{eq} according to the following relational expression 1 being in a range of 0.35 to 0.55, and having a thickness of 500 mm or more;

an operation of heating the manufactured slab to a temperature within a range of 1100 to 1300°C, and then performing a first upsetting with a forging ratio of 1.3 to 2.4;

an operation of bloom forging with a forging ratio of 1.5 to 2.0 after the first upsetting;

an operation of reheating the bloom forged material to a temperature within a range of 1100 to 1300°C, and then performing round forging with a forging ratio of 1.65 to 2.25, and then performing a second upsetting with a forging ratio of 1.3 to 2.3;

an operation of performing a third upsetting with a forging ratio of 2.0 to 2.8 on the second upsetting material, and then performing hole processing;

an operation of reheating the hole-processed material to a temperature within a range of 1100 to 1300°C, and then ring-forging with a forging ratio of 1.0 to 1.6; and

an operation of performing a normalizing heat treatment by heating the ring-forged material to a temperature within a range of 820 to 930°C based on a temperature measurement standard of a central portion thereof and maintaining the temperature for 5 to 600 minutes and then performing air cooling to room temperature.

$$C_{eq} = [C] + [Mn]/6 + ([Cr] + [Mo] + [V])/5 + ([Ni] + [Cu])/15 \quad [\text{Relational expression 1}]$$

[0019] In the relational expression 1, [C], [Mn], [Cr], [Mo], [V], [Ni], and [Cu] represent contents (weight%) of C, Mn, Cr, Mo, V, Ni, and Cu contained in steel, respectively, and 0 is substituted if these components are not intentionally added.

[0020] The slab may be manufactured using one of a continuous casting process, a semi-continuous casting process, and an ingot casting process.

[0021] It is preferable that after manufacturing the slab, a prior austenite grain size of a surface layer of the slab before forging is 1000 μm or less, and a microstructure of the surface layer of the slab before forging is composed of a composite structure of polygonal ferrite of 15% or more and residual bainite.

[0022] A size of a forging surface punched during the first upsetting may be 1000-1200 mm $\times$ 1800-2000 mm when being initially 700 mm $\times$ 1800 mm.

[0023] In the case of the bloom forging, when forging is completed, a size of a forging surface may be 1450-1850mm $\times$ 2100-2500mm when being initially 1000-1200mm $\times$ 1800-2000mm.

[0024] When the round forging and the second upsetting are completed, a size of a product may be 1450-18500 $\times$ 1300-1700mm.

[0025] When the third upsetting is completed, a size of a product may be 2300-2800 $\varnothing$ $\times$ 400-800mm.

[0026] The flange made of the steel may have a maximum thickness of 200 to 500 mm, an inner diameter of 4000 to 7000 mm, and an outer diameter of 5000 to 8000 mm.

[0027] It is preferable that during the normalizing heat treatment, a heat treatment is performed such that an LMP defined by the following relational expression 2 satisfies 20 to 33.

$$[\text{Relational expression 2}] \text{ LMP} = T (\text{Log}t + 20) \times (1/1000)$$

[0028] In the relational expression 2, T is Kelvin reference temperature, t is time, and an exponent of log is 10.

[0029] The method may further include an operation of performing a post-weld heat treatment, a stress relieving heat treatment, or a tempering heat treatment, when welding is performed on the steel after the normalizing heat treatment.

[0030] It is preferable that the post-weld heat treatment is performed in a range where a value defined by the following relational expression 2 is LMP 19.3 or less.

$$[\text{Relational expression 2}] \text{ LMP} = T (\text{Log}t + 20) \times (1/1000)$$

[0031] In the relational expression 2, T is Kelvin reference temperature, t is time, and an exponent of log is 10.

[0032] According to an aspect of the present disclosure, a method of manufacturing an extremely thick steel material for a flange includes,

an operation of manufacturing a slab by second-cooling a cast iron discharged from a mold to a temperature within a range of 800 to 850°C at a cooling rate of 0.01 to 3°C/s, when manufacturing the slab using molten steel containing, in wt%, C: 0.05 to 0.2%, Si: 0.05 to 0.5%, Mn: 1.0 to 2.0%, Al: 0.005 to 0.1%, P: 0.01% or less, S: 0.015% or less, Nb: 0.001 to 0.07%, V: 0.001 to 0.3%, Ti: 0.001 to 0.03%, Cr: 0.01 to 0.3%, Mo: 0.01 to 0.12%, Cu: 0.01 to 0.6%, Ni: 0.05 to 1.0%, Ca: 0.0005 to 0.004%, and a remainder of Fe and other inevitable impurities, Ceq thereof according to the following relational expression 1 satisfying a range of 0.35 to 0.55;

an operation of heating the manufactured slab to a temperature within a range of 1100 to 1300°C, and then performing a first upsetting with a forging ratio of 1.3 to 2.4;

an operation of bloom-forging with a forging ratio of 1.5 to 2.0 after the first upsetting;

an operation of reheating the bloom-forged material to a temperature within a range of 1100 to 1300°C, and then performing round forging with a forging ratio of 1.65 to 2.25, and then performing a second upsetting with a forging ratio of 1.3 to 2.3;

an operation of performing a third upsetting of the second-upsetting material with a forging ratio of 2.0 to 2.8, and then performing hole processing;

an operation of reheating the hole-processed material to a temperature within a range of 1100 to 1300°C, and then performing ring forging with a forging ratio of 1.0 to 1.6; and

an operation of performing a normalizing heat treatment by heating the ring-forged material to a temperature within a range of 820 to 930°C based on a temperature measurement standard of a central portion thereof and maintaining the temperature for 5 to 600 minutes and then air-cooling to room temperature.

$$Ceq = [C] + [Mn]/6 + ([Cr] + [Mo] + [V])/5 + ([Ni] + [Cu])/15 \quad [\text{Relational expression 1}]$$

[0033] In the relational expression 1, [C], [Mn], [Cr], [Mo], [V], [Ni], and [Cu] represent contents (weight%) of C, Mn, Cr, Mo, V, Ni, and Cu contained in steel, respectively, and 0 is substituted if these components are not intentionally added.

[0034] In the normalizing heat treatment, it is preferable that a heat treatment is performed so that an LMP defined by the following relational expression 2 satisfies 20 to 33.

$$[\text{Relational expression 2}] \quad LMP = T (\text{Log} t +$$

$$20) \times (1/1000),$$

[0035] In the relational expression 2, T is Kelvin reference temperature, t is time, and an exponent of log is 10.

Advantageous Effects of Invention

[0036] The present disclosure having the above-described configuration may effectively provide an extremely thick steel material that may be used for flanges, having excellent low-temperature impact toughness as well as strength, by compressing the central pore of the steel material by optimizing a forging process and thereby improving the internal soundness of a final product.

Best Mode for Invention

[0037] The present disclosure relates to an extremely thick steel for flanges having excellent strength and low-temperature impact toughness and a method of manufacturing a product. Hereinafter, preferred embodiments of the present disclosure will be described. The embodiments of the present disclosure may be modified in various forms, and the scope of the present disclosure should not be construed as being limited to the embodiments described below. These implementation examples are provided to further detail the present disclosure to a person having ordinary knowledge in the technical field to which the present disclosure belongs.

[0038] Hereinafter, extremely thick steel for a flange of the present disclosure will be described in more detail.

[0039] An extra heavy steel material for a flange of the present disclosure includes, in wt%, C: 0.05 to 0.2%, Si: 0.05 to 0.5%, Mn: 1.0 to 2.0%, Al: 0.005 to 0.1%, P: 0.01% or less, S: 0.015% or less, Nb: 0.001 to 0.07%, V: 0.001 to 0.3%, Ti: 0.001 to 0.03%, Cr: 0.01 to 0.3%, Mo: 0.01 to 0.12%, Cu: 0.01 to 0.6%, Ni: 0.05 to 1.0%, Ca: 0.0005 to 0.004%, the remainder of Fe and other unavoidable impurities, the extremely thick steel material for a flange having a Ceq according to

the relational expression 1 satisfying a range of 0.35 to 0.55, having a thickness of 200 to 500 μm, having a steel microstructure composed of a composite structure of ferrite and pearlite with an average grain size of 30 μm or less, having a maximum size of cementite existing in a ferrite-ferrite and/or ferrite-pearlite grain boundary, being 5 μm or less, having a porosity of 0.1 mm³/g or less in a central portion of a product, which is a region of 3/8t to 5/8t (where t represents the steel thickness (mm)) in the thickness direction from the steel surface, and having five or more fine NbC or NbCN precipitates with a diameter of 5 to 15 nm per 1 μm² among the precipitates observed in the cross section of the steel.

[0040] Hereinafter, the alloy composition of the present disclosure will be described in more detail, and unless otherwise specifically indicated, the % and ppm described in relation to the alloy composition are based on weight.

Carbon (C): 0.05-0.20%

[0041] Carbon (C) is the most important element for securing basic strength, and thus it needs to be contained in steel within an appropriate range, and to obtain this addition effect, 0.05% or more of carbon (C) may be added. Preferably, 0.10% or more of carbon (C) may be added. On the other hand, if the content of carbon (C) exceeds a certain level, the fraction of pearlite increases during normalizing heat treatment, which may excessively exceed the strength and hardness of the base material, resulting in surface cracks during a forging process and deterioration of the low-temperature impact toughness and lamellar tearing resistance characteristics in the final product. Therefore, the present disclosure may limit the carbon (C) content to 0.20%, and the upper limit of the more desirable carbon (C) content may be 0.18%.

Silicon (Si): 0.05-0.50%

[0042] Silicon (Si) is a substitutional element that improves the strength of steel through solid solution strengthening and has a strong deoxidation effect, and thus is an essential element for manufacturing clean steel. Therefore, silicon (Si) may be added at 0.05% or more, and more preferably, may be added at 0.20% or more. On the other hand, if silicon (Si) is added in a large amount, a Martensite-Austenite (MA) phase is generated and the strength of the ferrite matrix excessively increases, which may deteriorate the surface quality of the ultra-thick product, and thus the upper limit of the content may be limited to 0.50%. A more preferable upper limit of the silicon (Si) content may be 0.40%.

Manganese (Mn): 1.0-2.0%

[0043] Manganese (Mn) is a useful element that improves strength by solid solution strengthening and enhances hardenability to generate a low-temperature transformation phase. Therefore, to secure a tensile strength of 550 MPa or more, it is preferable to add 1.0% or more of manganese (Mn). A more preferable manganese (Mn) content may be 1.1% or more. On the other hand, manganese (Mn) forms MnS, a non-metallic inclusion that is elongated with sulfur (S), and reduces toughness and may act as an impact initiation point, and may thus be a factor that rapidly reduces the low-temperature impact toughness of the product. Therefore, it is preferable to manage the manganese (Mn) content to 2.0% or less, and a more desirable manganese (Mn) content may be 1.5% or less.

Aluminum (Al): 0.005-0.1%

[0044] Aluminum (Al) is one of the powerful deoxidizers in the steelmaking process along with silicon (Si), and it is preferable to add 0.005% or more to obtain this effect. The lower limit of the more desirable aluminum (Al) content may be 0.01%. On the other hand, if the aluminum (Al) content is excessive, the fraction of Al₂O₃ among the oxidizing inclusions generated as a result of deoxidation increases excessively, and the size thereof becomes coarse, causing a problem in which it is difficult to remove the inclusions during refining, which may be a factor that reduces the low-temperature impact toughness. Therefore, it is preferable to manage the aluminum (Al) content to 0.1% or less. A more desirable aluminum (Al) content may be 0.07% or less.

Phosphorus (P): 0.010% or less (including 0%), Sulfur (S): 0.0015% or less (including 0%)

[0045] Phosphorus (P) and sulfur (S) are elements that cause brittleness at grain boundaries or form coarse inclusions to cause brittleness. Therefore, to improve brittle crack propagation resistance, it is preferable to limit phosphorus (P) to 0.010% or less and sulfur (S) to 0.0015% or less.

Niobium (Nb): 0.001-0.07%

[0046] Niobium (Nb) is an element that improves the strength of the base material by precipitating in the form of NbC or NbCN. In addition, niobium (Nb) dissolved during high-temperature reheating is significantly finely precipitated in the form

of NbC during rolling, which inhibits recrystallization of austenite, thus having the effect of refining the structure. Therefore, it is preferable that niobium (Nb) be added in an amount of 0.001% or more, and a more preferable niobium (Nb) content may be 0.005% or more. On the other hand, if niobium (Nb) is added excessively, undissolved niobium (Nb) is generated in the form of TiNb (C,N), which becomes a factor that inhibits low-temperature impact toughness, and thus it is preferable that the upper limit of the niobium (Nb) content be limited to 0.07%. A more desirable niobium (Nb) content may be 0.065% or less.

Vanadium (V): 0.001-0.3%

[0047] Since vanadium (V) is almost completely reused during reheating, the strengthening effect by precipitation or solid solution during subsequent rolling is minimal, but in the case of extremely thick forged products, since the air cooling speed is very slow, it has the effect of improving the strength by precipitating as very fine carbonitrides during the cooling process or additional heat treatment process. To sufficiently obtain this effect, it is necessary to add vanadium (V) of 0.001% or more. The lower limit of the more desirable vanadium (V) content may be 0.01%. On the other hand, if the content is excessive, the slab surface hardness may be excessively increased due to the high hardenability, which may act as a factor such as surface cracks or the like during flange processing, and the manufacturing cost may also increase rapidly, which is not commercially advantageous. Therefore, the vanadium (V) content may be limited to 0.3% or less. The more desirable vanadium (V) content may be 0.25% or less.

Titanium (Ti): 0.001-0.03%

[0048] Titanium (Ti) is a component that significantly improves low-temperature toughness by precipitating as TiN during reheating and inhibiting the growth of prior austenite grains at high temperatures. To obtain this effect, it is preferable to add 0.001% or more of titanium (Ti). On the other hand, if titanium (Ti) is added excessively, low-temperature toughness may decrease due to clogging of the casting nozzle may occur or low-temperature toughness may decrease due to central crystallization. In addition, titanium (Ti) combines with nitrogen (N) to form coarse TiN precipitates at the thickness center, which reduces the elongation of the product, thereby reducing the uniform elongation during the forging process and causing surface cracks. Therefore, the titanium (Ti) content may be 0.03% or less. The preferred titanium (Ti) content may be 0.025% or less, and the more preferred titanium (Ti) content may be 0.018% or less.

Chromium (Cr): 0.01-0.30%

[0049] Chromium (Cr) is a component that increases the yield strength and tensile strength by increasing the hardenability and forming a low-temperature transformation structure. It is also a component that has the effect of preventing the decrease in strength by slowing down the spheroidization rate of cementite. For this effect, 0.01% or more of chromium (Cr) may be added. On the other hand, if the chromium (Cr) content is excessive, the size and fraction of Cr-rich coarse carbides such as $M_{23}C_6$ or the like increase, which reduces the impact toughness of the product, and the solubility of niobium (Nb) in the product and the fraction of fine precipitates such as NbC decrease, which may cause a decrease in the strength of the product. Therefore, the upper limit of the chromium (Cr) content in the present disclosure may be limited to 0.30%. The preferable upper limit of the chromium (Cr) content may be 0.25%.

Molybdenum (Mo): 0.01-0.12%

[0050] Molybdenum (Mo) is an element that increases grain boundary strength and has a large effect of solid solution strengthening in ferrite, and is an element that effectively contributes to increasing the strength and ductility of the product. In addition, molybdenum (Mo) has the effect of preventing the deterioration of toughness due to grain boundary segregation of impurity elements such as phosphorus (P) or the like. For this effect, 0.10% or more of molybdenum (Mo) may be added. However, molybdenum (Mo) is an expensive element, and if added excessively, the manufacturing cost may increase significantly, and thus the upper limit of the molybdenum (Mo) content may be limited to 0.12%.

Copper (Cu): 0.01-0.60%

[0051] Copper (Cu) may significantly improve the strength of the matrix phase by solid solution strengthening in ferrite, and also has the effect of suppressing corrosion in a wet hydrogen sulfide atmosphere, and thus is an advantageous element in the present disclosure. For this effect, 0.01% or more of copper (Cu) may be included. A more preferable copper (Cu) content may be 0.03% or more. However, if the copper (Cu) content is excessive, the possibility of causing star cracks on the surface of the steel plate increases, and since copper (Cu) is an expensive element, there may be a problem of significantly increasing the manufacturing cost. Therefore, the present disclosure may limit the upper limit of the copper

(Cu) content to 0.60%. The upper limit of the desirable copper (Cu) content may be 0.35%.

Nickel (Ni): 0.05-1.00%

[0052] Nickel (Ni) is an element that effectively contributes to improving impact toughness and improving strength by easily providing cross-slip of dislocations by increasing stacking faults at low temperatures and improving hardenability. For this effect, 0.05% or more of nickel (Ni) may be added. The desirable nickel (Ni) content may be 0.10% or more. On the other hand, if nickel (Ni) is added excessively, it may increase the manufacturing cost due to its high cost, so the upper limit of the nickel (Ni) content may be limited to 1.00%. The upper limit of the desirable nickel (Ni) content may be 0.80%.

Calcium (Ca): 0.0005-0.0040%

[0053] When calcium (Ca) is added after deoxidation by aluminum (Al), it combines with sulfur (S) forming MnS inclusions to suppress the formation of MnS, and at the same time, it forms spherical CaS to suppress the occurrence of cracks due to hydrogen-induced cracking. To sufficiently form sulfur (S) contained as an impurity into CaS, it is preferable to add 0.0005% or more of calcium (Ca). However, if the amount added is excessive, the calcium (Ca) remaining after forming CaS combines with oxygen (O) to generate coarse oxidized inclusions, which may be elongated and destroyed during rolling, thereby deteriorating the lamellar tearing characteristics. Therefore, the upper limit of the calcium (Ca) content may be limited to 0.0040%.

Relational expression 1

[0054] In the present disclosure, it is required that Ceq by the following relational expression 1 satisfies the range of 0.35 to 0.55. If Ceq by the following relational expression 1 is less than 0.35, the pearlite fraction decreases, so that the tensile strength value of 510 to 690 MPa required by the present disclosure cannot be secured, and if it exceeds 0.55, the pearlite fraction exceeds 30%, so that it is not easy to secure the -50°C low-temperature impact energy value. Therefore, in the present disclosure, it is preferable to limit Ceq to the range of 0.35 to 0.55.

$$Ceq = [C] + [Mn]/6 + ([Cr] + [Mo] + [V])/5 + ([Ni] + [Cu])/15$$
 [Relational expression 1]

[0055] In the relational expression 1, [C], [Mn], [Cr], [Mo], [V], [Ni] and [Cu] represent the contents (weight%) of C, Mn, Cr, Mo, V, Ni and Cu contained in the steel, respectively, and if these components are not intentionally added, 0 is substituted.

[0056] An extremely thick steel material for a flange of the present disclosure, having excellent strength and low-temperature impact toughness, and a product thereof may contain the remaining Fe and other unavoidable impurities in addition to the aforementioned components. However, since unintended impurities may inevitably be mixed in during a normal manufacturing process from raw materials or the surrounding environment, they cannot be completely excluded. Since these impurities are known to anyone with ordinary knowledge in the art, not all of their contents are specifically mentioned in this specification. In addition, the addition of additional effective components other than the aforementioned components is not completely excluded.

[0057] Meanwhile, the extremely thick steel material of the present disclosure has a steel microstructure composed of a composite structure of pearlite and ferrite with an average grain size of 30 μm or less. If the average grain size of the ferrite exceeds 30 μm, the length of the crack path during impact fracture becomes shorter and the Ductile Brittle Transition Temperature (DBTT) increases, thereby deteriorating the low-temperature impact toughness. Therefore, it is appropriate that the grain size of the ferrite is 30 μm or less.

[0058] In addition, it is preferable that a maximum size of the cementite existing at the grain boundary of the microstructure (the grain boundary between ferrite-ferrite and/or ferrite-pearlite) is 5 μm or less. If the maximum size of the cementite exceeds 5 μm, the coarse cementite may act as an impact initiation point, so the impact toughness deteriorates and the grain boundary strength decreases, and accordingly, intergranular fracture easily occurs, thereby deteriorating the impact toughness. Therefore, it is preferable that the maximum size of cementite be 5 μm or less.

[0059] More preferably, the fraction of cementite existing in the grain boundary is controlled to 3 area% or less.

[0060] And the extremely thick steel material of the present disclosure has a porosity of 0.1 mm³/g or less in the central portion of the product, which is a region of 3/8t to 5/8t (where t means the steel thickness (mm)) in the thickness direction from the steel surface.

[0061] In addition, it is preferable that the extremely thick steel material of the present disclosure has 5 or more fine NbC or NbCN precipitates with a diameter of 5 to 15 nm among the precipitates observed in the cross section of the steel, per 1 μm². If the number of the fine precipitates is less than 5, the precipitation strengthening effect is weakened, and there may be a problem in securing the properties required in the present disclosure.

[0062] In addition, the extremely thick heavy steel material of the present disclosure may have a thickness of 200 to 500 mm.

[0063] In addition, the extremely thick steel material of the present disclosure may have a tensile strength of 510 to 690 MPa, a yield strength of 370 MPa or more, and an absorption energy value of 50 J or more in -50°C Charpy impact test.

[0064] And a maximum surface crack depth of the steel material may be 0.1 mm or less (including 0).

[0065] Next, a method of manufacturing an extremely thick steel material for a flange according to another aspect of the present disclosure will be described in detail.

[0066] A method of manufacturing an extremely thick steel material of the present disclosure includes, in manufacturing a slab by using molten steel having the composition as described above, an operation of manufacturing a slab by second cooling the cast iron discharged from a mold to a temperature within a range of 800 to 850°C at a cooling rate of 0.01 to 3°C/s; an operation of heating the manufactured slab to a temperature within a range of 1100 to 1300°C, and then performing a first upsetting with a forging ratio of 1.3 to 2.4; an operation of bloom forging with a forging ratio of 1.5 to 2.0 after the first upsetting; an operation of reheating the bloom-forged material to a temperature within a range of 1100 to 1300°C, and then performing round forging with a forging ratio of 1.65 to 2.25, and then performing a second upsetting with a forging ratio of 1.3 to 2.3; an operation of performing a third upsetting of the second-upset material with a forging ratio of 2.0 to 2.8, and then performing hole processing; an operation of reheating the hole-processed material to a temperature within a range of 1100 to 1300°C, and then performing ring forging with a forging ratio of 1.0 to 1.6; and an operation of performing a normalizing heat treatment by heating the ring-forged material to a temperature within a range of 820 to 930°C based on the temperature measurement standard of a central portion thereof, maintaining the temperature for 5 to 600 minutes, and then air cooling the same to room temperature.

Slab Preparation

[0067] First, in the present disclosure, a slab is manufactured.

[0068] Preferably, when manufacturing a slab using molten steel having the composition as described above, the cast iron discharged from the mold is secondarily cooled at a cooling rate of 0.01 to 3°C/s to a temperature within a range of 800 to 850°C, thereby manufacturing the slab.

[0069] The inventor of the present disclosure has conducted in-depth research on a method of manufacturing an extremely thick steel material having properties suitable for flanges while also having excellent strength, impact toughness, and surface quality, and in particular, to secure the strength, toughness, and surface quality of the final flange product in a slab manufactured with a thickness of 500 mm or more, it was recognized that it is necessary to control the carbon equivalent (Ceq) of the slab within a certain range, and the grain size and microstructure fraction of the prior austenite of the slab surface layer are also effective conditions, which led to the derivation of the present invention.

[0070] Since the casting speed of a large-section casting machine that manufactures slabs with a thickness of 650 mm or more is 0.06 to 0.1 m/min, the casting process is performed at a significantly slower speed than that of a general casting machine (casting speed: 0.4 to 1.5 m/min) that manufactures slabs with a thickness of 250 to 400 mm. Therefore, when manufacturing slabs with a thickness of 500 mm or more, the time maintained in the mold is relatively long, and thus an environment is created where austenite may grow more coarsely.

[0071] As the initial austenite grain size increases, the manganese (Mn) segregation index of the austenite grain boundary increases, and the grain boundary strength decreases while the hardenability increases at the same time, so the fraction of hard bainite and martensite, rather than soft ferrite and pearlite, increases in the surface layer of the slab. Since the hard structure has low uniform elongation, intergranular cracking may easily occur when thermal deformation, external deformation, or stress is applied. Therefore, when the prior austenite grain size of the slab surface layer is large, intergranular cracking on the slab surface may occur more actively, and the depth of crack intrusion may further increase during subsequent high-strain processes such as forging, rolling and the like. Therefore, to suppress surface cracking of the final product, it is very important to control the prior austenite grain size to an appropriate level or less and secure the ratio of the soft intergranular polygonal ferrite to an appropriate level or more.

[0072] For example, in the present disclosure, it is preferable that the prior austenite grain size of the slab surface layer is 1000 μm or less, and its microstructure is composed of a composite structure of polygonal ferrite of 15 area% or more and the remainder bainite.

[0073] To reduce the prior austenite grain size and secure a polygonal ferrite fraction of 15 area% or more, there is a method of designing the components of carbon (C), nickel (Ni), chromium (Cr), and molybdenum (Mo), which have a solute dragging effect or a pinning effect, to be high. However, when the components of carbon (C), nickel (Ni), chromium (Cr), and molybdenum (Mo) are high, the carbon equivalent (Ceq) also increases, which may cause low-temperature transformation structure to be generated during the cooling process of the slab. Therefore, the present disclosure may limit the carbon equivalent (Ceq) of a steel slab to 0.55 or less according to the following relational expression 1. The preferred carbon equivalent (Ceq) may be 0.4 to 0.53.

$$C_{eq} = [C] + [Mn]/6 + ([Cr] + [Mo] + [V])/5 + ([Ni] + [Cu])/15$$

[Relational expression 1]

[0074] In the relational expression 1, [C], [Mn], [Cr], [Mo], [V], [Ni] and [Cu] represent the contents (in weight%) of C, Mn, Cr, Mo, V, Ni and Cu contained in the steel, respectively, and 0 is substituted if these components are not intentionally added.

[0075] Meanwhile, when manufacturing a slab from molten steel using a continuous casting process or a semi-continuous casting process, water cooling and then air cooling performed from immediately after coming out of the mold at a casting speed of 0.06 to 0.1 m/min until the slab surface layer temperature of 800 to 850°C at a cooling rate of 0.01 to 3°C/s during second cooling. If the surface layer cooling speed is too slow, the austenite grain growth continues, so AGS of the surface layer cannot be finely controlled, and if it exceeds 3°C/s, surface layer hard phase formation and surface layer-interior temperature gradient increase may cause surface cracks during the cooling process. If the target temperature is also less than 800°C, a local low-temperature transformation structure may be formed, and if it exceeds 850°C, it is also difficult to control the AGS to 1000 μm or less as required in the present disclosure, and thus appropriate surface quality cannot be secured.

Heating and First Upsetting

[0076] Next, in the present disclosure, the manufactured slab is heated to a temperature within a range of 1100-1300°C, and then first upsetting is performed at a forging ratio of 1.3-2.4.

[0077] The manufactured slab may be heated in a temperature within a range of 1100-1300°C. As described above, the thickness of the slab may be 500mm or more, and the preferred thickness may be 700mm or more.

[0078] It is necessary to heat the slab within a certain temperature range or more to re-dissolve the composite carbonitride of titanium (Ti) or niobium (Nb), the coarse crystallites of TiNb(C,N) formed during casting, or the like. In addition, it is preferable to homogenize the structure by heating the slab before the first upsetting forging to the recrystallization temperature or more and maintaining the same, and to heat the slab within a certain temperature range or more to secure a sufficiently high forging end temperature to minimize surface cracks that may occur during the forging process. Therefore, it is preferable that the slab heating of the present disclosure is performed in a temperature within a range of 1100°C or higher.

[0079] On the other hand, if the slab heating temperature is excessively high, high-temperature oxide scale may occur excessively, and the manufacturing cost may increase excessively due to high-temperature heating and maintenance. Therefore, it is preferable that the slab heating of the present disclosure is performed in a range of 1300°C or lower.

[0080] Meanwhile, upsetting is a method of performing strong plastic deformation vertically with the longitudinal axis as the axis, and the forging ratio at the time of the first upsetting is appropriately 1.3 to 2.4, and preferably 1.5 to 2.0. In this case, the forging ratio refers to the ratio of the cross-sectional area changed by forging. At the time of this first upsetting, if the size of the forging surface to be punched is initially 700 mm × 1800 mm, it may be 1000 to 1200 mm × 1800 to 2000 mm.

[0081] If the forging ratio is less than 1.3 during the first upsetting, it is difficult to sufficiently pressurize the porosity remaining in the center of the slab. Therefore, it is difficult to control the porosity required in the final product of the present disclosure to an appropriate level of 0.1 mm³/g or less, so it is not easy to secure the low-temperature impact toughness in the center. On the other hand, if the forging ratio exceeds 2.4 during the first upsetting, buckling occurs during the forging process, so it is not easy to obtain the surface quality and appropriate shape control required in the flange product. Therefore, the forging ratio is appropriately 1.3 to 2.4 during the first upsetting.

Bloom Forging (upper and lower two-sided forging)

[0082] And in the present disclosure, bloom forging is performed on the first upsetting material with a forging ratio of 1.5 to 2.0.

[0083] Bloom forging is a method of further compressing the first upsetting material into a bloom shape, and is a method of expanding the area while processing both the upper and lower surfaces in a certain direction of width or length. In the case of the bloom forging, the size of the forged surface when forging is completed may be 1450 to 1850 mm × 2100 to 2500 mm if it is initially 1000 to 1200 mm × 1800 to 2000 mm. In the case of bloom forging, the forging ratio is appropriately 1.5 to 2.0. If the forging ratio is less than 1.5, it is difficult to secure the appropriate pore quality required in the present disclosure, like in upsetting forging, and if it exceeds 2.0, surface cracks may occur.

[0084] Forging may be performed in both the longitudinal and transverse directions, but in the longitudinal direction, since the casting structure is more densely structured, the elongation of the surface layer structure is high, which may lead to excellent workability. Therefore, longitudinal bloom forging may be more appropriate than transverse bloom forging in terms of surface cracks.

Reheating and Round Forging - Second upsetting

[0085] In the present disclosure, the bloom-forged material is reheated to a temperature within a range of 1100 to 1300°C, then round forged at a forging ratio of 1.65 to 2.25, and then second upsetting is performed at a forging ratio of 1.3 to 2.3.

[0086] When the bloom forging is completed, the bloom surface layer temperature is 950°C or lower, and if processing continues, surface cracks or material fracture may occur. Therefore, the material may be heated again to a temperature within a range of 1100 to 1300°C after bloom forging. As mentioned above, it is preferable to heat to 1100°C or higher for reasons such as re-dissolution of the crystallized material, homogenization of the structure, prevention of surface cracks and the like, and it is preferable to control to 1300°C or lower due to problems such as excessive scale, grain coarsening, and the like.

[0087] In the case of a bloom after heating is completed, round forging is performed to process the flange edge into a circular shape, and then second upsetting is applied again. When the round forging and second upsetting are completed, the size of the product may be 1450-1850 $\varnothing$ × 1300-1700mm. The forging ratio for round forging and second upsetting may be 1.65-2.25 and 1.3-2.3, respectively. If the forging ratio is lower than the level required in the present disclosure during round forging and second upsetting, it is difficult to control the center porosity in the final product to 0.1 mm³/g or less, so it is not easy to secure the center low-temperature impact toughness, and if the forging ratio standard is exceeded, the desired processed shape of the flange product may not be obtained due to problems such as buckling and surface cracks, shape defects and the like.

[0088] After the second upsetting is completed, round forging may be applied again for shape control, and then heating may be performed under the same conditions as the aforementioned reheating temperature.

Third Upsetting and Hole Processing

[0089] And in the present disclosure, the material that has been second upset is upset 3rd with a forging ratio of 2.0 to 2.8, and then a hole is processed.

[0090] The material processed into the cylindrical shape may be processed to an appropriate flange thickness through third upsetting before hole processing (piercing). When the third upsetting is completed, the size of the product may be 2300-2800 $\varnothing$ × 400-800mm. The forging ratio of the third upsetting may be 2.0-2.8, and if the forging ratio is insufficient or exceeded, problems such as residual gap pore control, surface cracks/shape control failure and the like as mentioned above may occur. After the third upsetting is completed, a hole may be made in the center of the material using a 500-10000 punch.

Reheating and Ring Forging

[0091] Subsequently, in the present disclosure, the material with the hole processed is reheated to a temperature within a range of 1100 to 1300°C, and then ring forged with a forging ratio of 1.0 to 1.6.

[0092] The material with the hole processed is reheated to the temperature within a range of 1100 to 1300°C mentioned above, and may then be processed into a final flange ring shape. A maximum thickness of the flange made of the steel may be 200 to 500mm, the inner diameter may be 4000 to 7000mm, and the outer diameter may be 5000 to 8000mm. Since ring forging is a process in which final shape and dimension control are more important than pore compression, strong plastic processing is not applied. Therefore, the forging ratio may be 1.0 to 1.6, and more preferably, may be 1.2 to 1.4.

[0093] Meanwhile, the strain rate in all the forging processes presented in the present disclosure may be 1/s to 4/s. At a strain rate of less than 1/s, the temperature of the finishing forging may decrease, which may cause possibility of surface cracks. On the other hand, when a high strain rate exceeding 4/s is applied in the non-recrystallized region, surface cracks may be induced due to a decrease in elongation caused by excessive local work hardening.

Normalizing Heat Treatment

[0094] Lastly, in the present disclosure, a normalizing heat treatment may be performed by heating the flange product, which has completed the forging, to a temperature within a range of 820 to 930°C based on the temperature measurement standard of the central portion of the product, maintaining the temperature for 5 to 600 minutes, and then air cooling to room temperature.

[0095] During the normalizing heat treatment, if the heating temperature is lower than 820°C or the maintaining time is lower than 5 minutes, the carbides generated during cooling after forging or the impurity elements segregated at the grain boundaries do not re-dissolve smoothly, so that the low-temperature toughness of the steel after the heat treatment may be significantly reduced. On the other hand, when the heating temperature exceeds 930°C or the holding time exceeds 600 minutes during the normalizing heat treatment, the ferrite matrix phase grain size of the ferrite-pearlite composite structure

may exceed 30 μm required in the present disclosure or the strength and low-temperature impact toughness may deteriorate due to the coarsening of precipitated phases such as Nb (C,N), V(C,N) and the like.

[0096] Meanwhile, in the present disclosure, it is preferable to perform normalizing heat treatment on the ring-forged flange material under the condition that LMP defined by the following relational expression 2 satisfies 20 to 33.

[0097] The normalizing heat treatment and holding time may be expressed by the Larson-Miller Parameter Equation 2 (Literature: F.R. Larson and J. Miller: Trans. ASME, 1952, vol. 74, pp. 765-75) as follows, and the LMP for the normalizing temperature and time conditions may be 20 to 23 to satisfy the impact toughness required in the present disclosure by refining the size of pearlite colonies.

$$\text{[Relational expression 2]} \quad \text{LMP} = T (\text{Log} t + 20) \times (1/1000)$$

[0098] In the relational expression 2, T is the normalizing heat treatment temperature in Kelvin, t is the heat treatment time, and the log exponent is 10

[0099] If the LMP is less than 20, there is a disadvantage that the material may not be sufficiently heated to the austenite single-phase region or the diffusion of the solute does not occur uniformly, resulting in material deviation, and if the LMP exceeds 23, the ferrite and pearlite colonies are formed too coarsely, and thus it is difficult to secure the low-temperature impact toughness required by the present disclosure.

[0100] And in the present disclosure, if welding is performed after the normalizing heat treatment, post-weld heat treatment or stress-relieving heat treatment or tempering heat treatment may be performed. This post-weld heat treatment may be performed in a range where the value defined by the relational expression 2 is LMP 19.3 or less. If LMP exceeds 19.3, the grain boundary cementite size increases and exceeds 5 μm required in the present disclosure, and thus the impact toughness may deteriorate. Therefore, when welding is performed, it is preferable that the LMP of the subsequent heat treatment be 19.3 or less.

Mode for Invention

[0101] The present disclosure will be described in detail through examples below. However, it should be noted that the following examples are only intended to illustrate the present disclosure in more detail and are not intended to limit the scope of the rights of the present disclosure.

(Example)

[0102]

[Table 1]

Classification	C	Si	Mn	Al	P	S	Nb	V	Ti	Cr	Mo	Cu	Ni	Ca	Ce q
Invention steel 1	0.14	0.35	1.39	0.03	68	8	0.025	0.023	0.003	0.21	0.08	0.23	0.4	15	0.48
Invention steel 2	0.17	0.27	1.43	0.02	55	10	0.011	0.031	0.02	0.08	0.05	0.21	0.28	21	0.47
Invention steel 3	0.15	0.31	1.38	0.01	80	13	0.023	0.021	0.005	0.12	0.09	0.08	0.15	18	0.45
Invention steel 4	0.13	0.29	1.34	0.03	81	11	0.017	0.08	0.013	0.19	0.1	0.12	0.19	22	0.45
Invention steel 5	0.18	0.3	1.18	0.02	69	14	0.007	0.031	0.01	0.27	0.04	0.19	0.25	17	0.47
Comparison steel 1	0.03	0.33	1.11	0.03	71	6	0.015	0.043	0.009	0.05	0.06	0.12	0.23	19	0.27
Comparison steel 2	0.14	0.32	0.8	0.05	94	11	0.012	0.023	0.019	0.17	0.08	0.27	0.3	17	0.37

(continued)

Classification	C	Si	Mn	Al	P	S	Nb	V	Ti	Cr	Mo	Cu	Ni	Ca	Ce q
Comparison steel 3	0.11	0.36	3.54	0.01	49	8	0.031	0.025	0.007	0.12	0.05	0.15	0.3	20	0.77
Comparison steel 4	0.25	0.29	1.45	0.03	89	13	0.007	0.03	0.012	0.25	0.11	0.43	0.89	18	0.66
Comparison steel 5	0.17	0.35	1.29	0.05	85	17	0.0008	0.025	0.02	0.2	0.08	0.21	0.39	18	0.49
* In Table 1 above, the unit of content of the constituent elements is weight%, but the unit of P, S, and Ca is ppm. And the remaining components are Fe and unavoidable impurities.															

[0103] A 700mm thick cast steel having the alloy composition of Table 1 above was manufactured. Using this cast steel, a slab was prepared by cooling according to the process conditions of Table 2 below, and then a final 320mmt flange was manufactured through a forging process (reheating and 1st upsetting, bloom forging, reheating-2nd upsetting, 3rd upsetting, reheating and ring forging) and normalizing heat treatment. Process conditions satisfying the range of the present disclosure were applied to all processes other than the processes described in Table 2.

[0104] Thereafter, the values of physical properties of the manufactured respective specimens were measured and are illustrated in Table 3 below. In this case, the prior austenite grain size and polygonal ferrite (PF) fraction of the slab surface layer were measured using an image auto-analyzer by collecting a specimen from the surface layer structure after casting.

[0105] And the ferrite grain size of the steel was also measured using an image auto-analyzer by collecting a specimen from the final steel structure. Meanwhile, in both the invention examples and comparative examples, the product microstructure was a mixed structure of ferrite and pearlite.

[0106] In addition, the yield/tensile strength was evaluated through a room temperature tensile test, and a 0.2% offset was applied for the yield strength. In addition, the impact toughness for each specimen used the average of the absorbed energy values measured three times at each temperature by the Charpy V-Notch Test was used.

[0107] In addition, the number and the like of NbC precipitates in the cross section of the steel was measured using TEM. The NbC precipitates were confirmed through the diffraction pattern of NbC and EDX mapping, and the number of NbC precipitates located at 1 μm^2 was counted.

[0108] The porosity at the central portion of the product was measured by measuring the density (g/mm^3) and taking the reciprocal (mm^3/g).

[0109] In addition, after visually observing the surface of each specimen, grinding was performed at the point where the surface crack was formed, and the grinding length until the crack disappeared was measured as the surface crack length. In the case of a penetrating crack, the crack is not limited to the surface layer portion, but penetrates deep into the interior, and the total length of the crack introduced was measured by cutting the cross-section.

[Table 2]

Classif ication	Steel grade	Slab manufacturing		Heating and 1 st upsetting		Bloom forging	Reheating and 2nd upsetting		3rd upsetting	Reheating and ring forging		Normal izing LMP	Post-weld heat treatment LMP
		2nd cooling temper ature (°C)	Cooling speed (°C/s)	Heating temper ature (°C)	Forging ratio		Reheating temper ature (°C)	Forging ratio		Rehea ting temper ature (°C)	Forging ratio		
Inventive Ex- ample 1	Invention steel 1	823	1.3	1237	1.83	1.8	1159	2.01	2.54	1259	1.35	21.15	Not con- ducted
Inventive Ex- ample 2	Invention steel 2	815	1.5	1257	1.75	1.69	1233	198	2.46	1253	1.5	21.09	Not con- ducted
Inventive Ex- ample 3	Invention steel 3	833	1.7	1233	1.92	1.59	1259	2.21	2.61	1240	1.41	22.01	Not con- ducted
Inventive Ex- ample 4	Invention steel 4	841	2.3	1195	1.86	1.83	1260	2.07	2.33	1239	1.39	21.07	Not con- ducted
Inventive Ex- ample 5	Invention steel 5	807	2.8	1291	1.69	1.75	1283	2.15	2.75	1255	1.25	20.58	Not con- ducted
Comparative Example 1	Invention steel 1	631	1.6	1286	1.83	1.91	1245	1.88	2.65	1243	1.41	21.14	Not con- ducted
Comparative Example 2	Invention steel 1	894	1.8	1256	1.81	1.69	1234	1.59	2.56	1254	1.44	21.05	Not con- ducted
Comparative Example 3	Invention steel 1	825	5.9	1244	1.76	1.88	1193	1.59	2.45	1195	1.09	20.73	Not con- ducted
Comparative Example 4	Invention steel 2	823	2.1	1012	1.75	1.75	1208	1. 68	2.44	1208	1.17	21.65	Not con- ducted
Comparative Example 5	Invention steel 2	840	1.8	1255	2.95	1.68	1211	2.07	2.3	1244	1.23	21.53	Not con- ducted
Comparative Example 6	Invention steel 2	841	2.5	1263	1.06	1.95	1246	2.16	2.53	1254	1.34	21.09	Not con- ducted
Comparative Example 7	Invention steel 3	832	0.9	1237	1.91	1.13	1259	2.15	2.19	1238	1.35	21.68	Not con- ducted

(continued)

Classif ication	Steel grade	Slab manufacturing		Heating and 1 st upsetting		Bloom forging	Reheating and 2nd upsetting		3rd upsetting	Reheating and ring forging		Normal izing LMP	Post-weld heat treatment LMP
		2nd cooling temper ature (°C)	Cooling speed (°C/s)	Heating temper ature (°C)	Forging ratio	Forg ing ratio	Reheating temper ature (°C)	Forging ratio	Rehea ting temper ature (°C)	Forging ratio			
Comparative Example 8	Invention steel 3	809	1.5	1229	1.93	1.89	1026	1.89	2.28	1198	1.29	22.54	Not con- ducted
Comparative Example 9	Invention steel 3	843	1.6	1253	1.69	1.93	1253	1.12	2.54	1259	1.43	20.99	Not con- ducted
Comparative Example 10	Invention steel 4	815	2.7	1218	1.59	1.88	1283	2.66	2.63	1186	1.51	20.38	Not con- ducted
Comparative Example 11	Invention steel 4	814	1.3	1200	1.62	1.86	1259	1.9	1.32	1206	1.47	21.33	Not con- ducted
Comparative Example 12	Invention steel 4	841	2.5	1209	1.83	1.94	1250	2.07	3.05	1255	1.54	22.54	Not con- ducted
Comparative Example 13	Invention steel 5	829	2.5	1209	1.84	1.91	1264	1.85	2.75	1336	1.38	20.69	Not con- ducted
Comparative Example 14	Invention steel 5	840	1.4	1255	1.66	1.69	1257	1.9	2.55	1249	2.05	21.47	Not con- ducted
Comparative Example 15	Invention steel 5	832	2.3	1289	1.73	1.69	1233	2.01	2.53	1256	1.34	27	Not con- ducted
Comparative Example 16	Comparison steel 1	808	2.3	1283	1.69	1.63	1255	1.89	2.5	1210	1.44	20.76	Not con- ducted
Comparative Example 17	Comparison steel 2	817	1.9	1272	1.65	1.58	1235	1.94	2.54	1199	1.54	21.57	Not con- ducted
Comparative Example 18	Comparison steel 3	808	2.3	1283	1.69	1.63	1255	1.89	2.5	1210	1.44	20.76	Not con- ducted
Comparative Example 19	Comparison steel 4	817	1.9	1272	1.65	1.58	1235	1.94	2.54	1199	1.54	21.57	Not con- ducted

(continued)

Classification	Steel grade	Slab manufacturing		Heating and 1 st upsetting		Bloom forging	Reheating and 2 nd upsetting		3 rd upsetting	Reheating and ring forging		Normalizing LMP	Post-weld heat treatment LMP
		2 nd cooling temperature (°C)	Cooling speed (°C/s)	Heating temperature (°C)	Forging ratio		Reheating temperature (°C)	Forging ratio		Reheating temperature (°C)	Forging ratio		
Comparative Example 20	Comparison steel 5	835	1.8	1243	1.82	1.54	1249	2.11	2.51	1244	1.51	21.07	Not conducted
Inventive Example 6	Invention steel 1	822	1.6	1233	1.82	1.9	1154	2.03	2.52	1254	1.32	21.13	18.1
Inventive Example 7	Invention steel 1	840	2.1	1254	1.05	1.90	1245	2.10	2.51	1253	1.32	21.05	19.0
Comparative Example 21	Invention steel 1	832	2.3	1256	1.69	1.83	1239	2.01	2.40	1233	1.45	20.58	23.7
Comparative Example 22	Invention steel 2	839	2.0	1280	1.83	1.92	1233	1.94	2.39	1219	1.40	21.02	22.5

[Table 3]

Classification	Steel grade	Slab		Product			Porosity (mm ³ /g)	Yield strength (MPa)	Tensile strength (MPa)	-50°C impact absorbed energy (J)	Surface crack depth (mm)
		Prior austenite grain size (μm)	PF fraction (%)	Ferrite grain size (μm)	Grain boundary cementite size (μm)	Number of precipitates					
Inventive Example 1	Invention steel1	853	16.7	26.5	1.2	24	0.033	435	576	108	Not observed
Inventive Example 2	Invention steel2	694	17.5	24.3	3.1	31	0.016	424	554	153	Not observed
Inventive Example 3	Invention steel3	738	18.1	22.4	2.2	25	0.031	439	535	182	Not observed
Inventive Example 4	Invention steel4	766	15.9	25.6	1.5	41	0.023	429	541	175	Not observed
Inventive Example 5	Invention steel5	594	16.4	26.1	2.7	29	0.015	440	529	169	Not observed
Comparative Example 1	Invention steel1	695	18.3	27.3	3.3	13	0.073	419	543	172	3.6 (Surface crack)
Comparative Example 2	Invention steel1	1273	18.2	40.7	2.2	18	0.065	428	564	21	Not observed
Comparative Example 3	Invention steel1	659	4.7	25	2.2	22	0.043	431	535	199	3.7 (Surface crack)
Comparative Example 4	Invention steel2	707	15.9	23.9	3.1	18	0.039	452	564	182	2.8 (Surface crack)
Comparative Example 5	Invention steel2	810	16.3	21.9	1.5	33	0.025	414	535	176	21.6 (Penetrating crack)
Comparative Example 6	Invention steel2	905	17.4	22.4	2.0	25	0.237	440	544	11	Not observed
Comparative Example 7	Invention steel3	865	18.1	23.4	1.0	41	0.196	419	531	33	Not observed
Comparative Example 8	Invention steel3	889	19	26.9	1.5	38	0.029	428	581	188	2.9 (Surface crack)

(continued)

Classification	Steel grade	Slab		Product			Porosity (mm ³ /g)	Yield strength (MPa)	Tensile strength (MPa)	-50°C impact absorbed energy (J)	Surface crack depth (mm)
		Prior austenite grain size (μm)	PF fraction (%)	Ferrite grain size (μm)	Grain boundary cementite size (μm)	Number of precipitates					
Comparative Example9	Invention steel3	808	16.9	28.4	1.3	27	0.209	430	601	15	Not observed
Comparative Example10	Invention steel4	891	20.1	29.5	2.1	30	0.007	429	583	168	19.8 (Surface crack)
Comparative Example11	Invention steel4	885	18.7	28.4	2.5	41	0.259	428	587	14	Not observed
Comparative Example12	Invention steel4	843	18.3	28.1	2.1	35	0.005	441	532	159	30.7 (Penetrating crack)
Comparative Example13	Invention steel5	817	17.8	51.9	1.1	29	0.036	439	522	8	Not observed
Comparative Example14	Invention steel5	826	18.1	26.4	1.9	41	0.061	434	584	159	16.9 (Penetrating crack)
Comparative Example 15	Invention steel5	841	18.9	50.7	2.3	40	0.054	409	513	10	Not observed
Comparative Example16	Comparison steel1	839	17.6	26.5	1.2	19	0.033	258	342	389	Not observed
Comparative Example17	Comparison steel2	840	15.4	26.4	1.7	22	0.038	375	486	158	Not observed
Comparative Example18	Comparison steel3	868	16.9	28.1	1.8	31	0.045	605	725	7	Not observed
Comparative Example 19	Comparison steel4	887	16.6	29	1.2	25	0.068	495	587	13	Not observed
Comparative Example20	Comparison steel5	870	16.3	28.3	2.4	1	0.043	369	488	253	Not observed
Inventive Example6	Invention steel1	901	17.2	24.5	1.5	33	0.037	392	543	255	Not observed

(continued)

Classification	Steel grade	Slab		Product			Porosity (mm ³ /g)	Yield strength (MPa)	Tensile strength (MPa)	-50°C impact absorbed energy (J)	Surface crack depth (mm)
		Prior austenite grain size (μm)	PF fraction (%)	Ferrite grain size (μm)	Grain boundary cementite size (μm)	Number of precipitates					
Inventive Example7	Invention steel1	694	18.0	25.3	2.3	25	0.019	412	551	198	Not observed
Comparative Example21	Invention steel1	705	17.6	21.4	8.9	33	0.037	382	513	12	Not observed
Comparative Example22	Invention steel2	773	15.9	25.2	10.5	25	0.019	402	521	3	Not observed

*In Table 3 above, the number of precipitates refers to the number of fine NbC or NbCN precipitates per 1 μm², with a diameter of 5 to 15 nm, among the precipitates observed in the cross-section of the steel, and the porosity refers to the porosity in the central portion of the product, which is a region of 3/8t to 5/8t (where t refers to the steel thickness (mm)) in the thickness direction from the surface of the steel.

[0110] As can be seen from Tables 1-3, in the case of all Invention Examples 1-7, which satisfy the alloy composition and manufacturing conditions proposed by the present disclosure, it can be seen that in addition to excellent strength and excellent low-temperature impact toughness at -50°C, good surface quality may be secured in the flange product state.

[0111] In contrast, Comparative Examples 1-15 and 21-22 satisfy the alloy composition proposed by the present disclosure but do not satisfy the manufacturing conditions, and thus it can be seen that the strength and low-temperature impact toughness values are low because they do not satisfy the characteristics of the slab's prior austenite grain size, polygonal ferrite fraction, or center porosity, and ferrite grain size and the like in the flange product state proposed by the present disclosure. In addition, even if the material is good, if the forging ratio conditions are not satisfied at each stage of forging, poor surface quality characteristics may also be confirmed in the product state due to the occurrence of surface cracks or penetrating cracks.

[0112] Meanwhile, Comparative Examples 16-20 satisfy the manufacturing conditions proposed by the present disclosure, but do not satisfy the alloy composition, so it can be seen that the quality level is low, such as exceeding the strength (not meeting the impact toughness) or not meeting the strength.

[0113] As described above, in the detailed description of the present disclosure, preferred embodiments of the present disclosure have been described, but it is obvious that various modifications are possible within the scope of the present disclosure by those skilled in the art. Therefore, the scope of the rights of the present disclosure should not be limited to the described embodiments, but should be defined by the claims described below as well as equivalents thereof.

Claims

1. An extremely thick steel material for a flange comprising:

in wt%, C: 0.05 to 0.2%, Si: 0.05 to 0.5%, Mn: 1.0 to 2.0%, Al: 0.005 to 0.1%, P: 0.01% or less, S: 0.015% or less, Nb: 0.001 to 0.07%, V: 0.001 to 0.3%, Ti: 0.001 to 0.03%, Cr: 0.01 to 0.3%, Mo: 0.01 to 0.12%, Cu: 0.01 to 0.6%, Ni: 0.05 to 1.0%, Ca: 0.0005 to 0.004%, and a remainder of Fe and other unavoidable impurities, and Ceq thereof according to the following relational expression 1 satisfying a range of 0.35 to 0.55,

the extremely thick steel material for a flange,

having a thickness of 200 to 500 mm,

having a steel microstructure composed of a composite structure of pearlite and ferrite with an average grain size of 30 μm or less,

having a maximum size of cementite existing in ferrite-ferrite and/or ferrite-pearlite grain boundary, being 5 μm or less,

having a porosity of 0.1 mm³/g or less in a central portion of a product, a region of 3/8t to 5/8t (where t means a steel thickness (mm)) in a thickness direction from a steel surface, and

having 5 or more fine NbC or NbCN precipitates with a diameter of 5 to 15 nm, per 1 μm², among precipitates observed in a cross section of steel,

$$Ceq = [C] + [Mn]/6 + ([Cr] + [Mo] + [V])/5 + ([Ni] + [Cu])/15, \quad [\text{Relational expression 1}]$$

wherein in the relational expression 1, [C], [Mn], [Cr], [Mo], [V], [Ni], and [Cu] represent contents (in weight%) of C, Mn, Cr, Mo, V, Ni, and Cu contained in the steel, respectively, and 0 is substituted if these components are not added intentionally.

2. The extremely thick steel material for a flange of claim 1, wherein the steel has a tensile strength of 510 to 690 MPa, a yield strength of 370 MPa or more, and an absorbed energy value of -50°C Charpy impact test of 50 J or more.

3. The extremely thick steel material for a flange of claim 1, wherein a maximum surface crack depth of the steel is 0.1 mm or less (including 0).

4. The extremely thick steel material for a flange of claim 1, wherein a fraction of the cementite existing in the ferrite-ferrite or ferrite-pearlite grain boundary is 3 area% or less.

5. A method of manufacturing an extremely thick steel material for a flange, comprising:

an operation of manufacturing a slab containing, in wt%, C: 0.05 to 0.2%, Si: 0.05 to 0.5%, Mn: 1.0 to 2.0%, Al: 0.005 to 0.1%, P: 0.01% or less, S: 0.015% or less, Nb: 0.001 to 0.07%, V: 0.001 to 0.3%, Ti: 0.001 to 0.03%, Cr:

0.01 to 0.3%, Mo: 0.01 to 0.12%, Cu: 0.01 to 0.6%, Ni: 0.05 to 1.0%, Ca: 0.0005 to 0.004%, and a remainder of Fe and other inevitable impurities, the slab satisfying, C_{eq} according to the following relational expression 1 being in a range of 0.35 to 0.55, and having a thickness of 500 mm or more;

an operation of heating the manufactured slab to a temperature within a range of 1100 to 1300°C, and then performing a first upsetting with a forging ratio of 1.3 to 2.4;

an operation of bloom forging with a forging ratio of 1.5 to 2.0 after the first upsetting;

an operation of reheating the bloom forged material to a temperature within a range of 1100 to 1300°C, and then performing round forging with a forging ratio of 1.65 to 2.25, and then performing a second upsetting with a forging ratio of 1.3 to 2.3;

an operation of performing a third upsetting with a forging ratio of 2.0 to 2.8 on the second upsetting material, and then performing hole processing;

an operation of reheating the hole-processed material to a temperature within a range of 1100 to 1300°C, and then ring-forging with a forging ratio of 1.0 to 1.6; and

an operation of performing a normalizing heat treatment by heating the ring-forged material to a temperature within a range of 820 to 930°C based on a temperature measurement standard of a central portion thereof and maintaining the temperature for 5 to 600 minutes and then performing air cooling to room temperature,

$$C_{eq} = [C] + [Mn]/6 + ([Cr] + [Mo] + [V])/5 + ([Ni] + [Cu])/15, \quad [\text{Relational expression 1}]$$

wherein in the relational expression 1, [C], [Mn], [Cr], [Mo], [V], [Ni], and [Cu] represent contents (weight%) of C, Mn, Cr, Mo, V, Ni, and Cu contained in steel, respectively, and 0 is substituted if these components are not intentionally added.

6. The method of manufacturing an extremely thick steel material for a flange of claim 5, wherein the slab is manufactured using a continuous casting process or a semi-continuous casting process.

7. The method of manufacturing an extremely thick steel material for a flange of claim 5, wherein after manufacturing the slab, a prior austenite grain size of a surface layer of the slab before forging is 1000 μm or less, and a microstructure of the surface layer of the slab before forging is composed of a composite structure of polygonal ferrite of 15% or more and residual bainite.

8. The method of manufacturing an extremely thick steel material for a flange of claim 5, wherein a size of a forging surface punched during the first upsetting is 1000-1200 mm $\times$ 1800-2000 mm when being initially 700 mm $\times$ 1800 mm.

9. The method of manufacturing an extremely thick steel material for a flange of claim 5, wherein in the case of the bloom forging, when forging is completed, a size of a forging surface is 1450-1850mm $\times$ 2100-2500mm when being initially 1000-1200mm $\times$ 1800-2000mm.

10. The method of manufacturing an extremely thick steel material for a flange of claim 5, wherein when the round forging and the second upsetting are completed, a size of a product is 1450-18500 $\times$ 1300-1700mm.

11. The method of manufacturing an extremely thick steel material for a flange of claim 5, wherein when the third upsetting is completed, a size of a product is 2300-2800 $\varnothing$ $\times$ 400-800mm.

12. The method of manufacturing an extremely thick steel material for a flange of claim 5, wherein the flange made of the steel has a maximum thickness of 200 to 500 mm, an inner diameter of 4000 to 7000 mm, and an outer diameter of 5000 to 8000 mm.

13. The method of manufacturing an extremely thick steel material for a flange of claim 5, wherein during the normalizing heat treatment, a heat treatment is performed such that an LMP defined by the following relational expression 2 satisfies 20 to 33,

$$[\text{Relational expression 2}] \quad \text{LMP} = T (\text{Log} t + 20) \times (1/1000)$$

wherein in the relational expression 2, T is Kelvin reference temperature, t is time, and an exponent of log is 10.

14. The method of manufacturing an extremely thick steel material for a flange of claim 5, further comprising an operation of performing a post-weld heat treatment, a stress relieving heat treatment, or a tempering heat treatment, when welding is performed on the steel after the normalizing heat treatment.

15. The method of manufacturing an extremely thick steel material for a flange of claim 14, wherein the post-weld heat treatment is performed in a range where a value defined by the following relational expression 2 is LMP 19.3 or less,

$$[\text{Relational expression 2}] \text{ LMP} = T (\text{Log} t + 20) \times (1/1000),$$

wherein in the relational expression 2, T is Kelvin reference temperature, t is time, and an exponent of log is 10.

16. A method of manufacturing an extremely thick steel material for a flange, comprising:

an operation of manufacturing a slab by second-cooling a cast iron discharged from a mold to a temperature within a range of 800 to 850°C at a cooling rate of 0.01 to 3°C/s, when manufacturing the slab using molten steel containing, in wt%, C: 0.05 to 0.2%, Si: 0.05 to 0.5%, Mn: 1.0 to 2.0%, Al: 0.005 to 0.1%, P: 0.01% or less, S: 0.015% or less, Nb: 0.001 to 0.07%, V: 0.001 to 0.3%, Ti: 0.001 to 0.03%, Cr: 0.01 to 0.3%, Mo: 0.01 to 0.12%, Cu: 0.01 to 0.6%, Ni: 0.05 to 1.0%, Ca: 0.0005 to 0.004%, and a remainder of Fe and other inevitable impurities, Ceq thereof according to the following relational expression 1 satisfying a range of 0.35 to 0.55;

an operation of heating the manufactured slab to a temperature within a range of 1100 to 1300°C, and then performing a first upsetting with a forging ratio of 1.3 to 2.4;

an operation of bloom-forging with a forging ratio of 1.5 to 2.0 after the first upsetting;

an operation of reheating the bloom-forged material to a temperature within a range of 1100 to 1300°C, and then performing round forging with a forging ratio of 1.65 to 2.25, and then performing a second upsetting with a forging ratio of 1.3 to 2.3;

an operation of performing a third upsetting of the second-upsetting material with a forging ratio of 2.0 to 2.8, and then performing hole processing;

an operation of reheating the hole-processed material to a temperature within a range of 1100 to 1300°C, and then performing ring forging with a forging ratio of 1.0 to 1.6; and

an operation of performing a normalizing heat treatment by heating the ring-forged material to a temperature within a range of 820 to 930°C based on a temperature measurement standard of a central portion thereof and maintaining the temperature for 5 to 600 minutes and then air-cooling to room temperature,

$$\text{Ceq} = [\text{C}] + [\text{Mn}]/6 + ([\text{Cr}] + [\text{Mo}] + [\text{V}])/5 + ([\text{Ni}] + [\text{Cu}])/15, \quad [\text{Relational expression 1}]$$

wherein in the relational expression 1, [C], [Mn], [Cr], [Mo], [V], [Ni], and [Cu] represent contents (weight%) of C, Mn, Cr, Mo, V, Ni, and Cu contained in steel, respectively, and 0 is substituted if these components are not intentionally added.

17. The method of manufacturing an extremely thick steel material having excellent strength and low-temperature impact toughness for a flange of claim 16, wherein in the normalizing heat treatment, a heat treatment is performed so that an LMP defined by the following relational expression 2 satisfies 20 to 33,

$$[\text{Relational expression 2}] \text{ LMP} = T (\text{Log} t + 20) \times (1/1000),$$

wherein in the relational expression 2, T is Kelvin reference temperature, t is time, and a exponent of log is 10.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2023/006887

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/58(2006.01)i; C22C 38/46(2006.01)i; C22C 38/48(2006.01)i; C22C 38/50(2006.01)i; C22C 38/42(2006.01)i;
C22C 38/44(2006.01)i; B21B 1/02(2006.01)i; B21B 1/04(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 38/58(2006.01); B21J 5/00(2006.01); B21J 5/08(2006.01); C21D 8/06(2006.01); C22C 38/00(2006.01);
C22C 38/02(2006.01); C22C 38/04(2006.01); C22C 38/48(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: 플랜지(flange), 후물강재(thick steel sheet), 저온인성(low temperature toughness), 펄라이트(pearlite), 페라이트(ferrite), 단조(forging), 업세팅(upsetting), 공극(porosity)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	KR 10-2021-0079847 A (POSCO) 30 June 2021 (2021-06-30) See paragraphs [0060] and [0087], claims 1, 4 and 6 and tables 1 and 3.	1-17
A	CN 109338219 B (ANGANG STEEL CO., LTD.) 07 January 2020 (2020-01-07) See paragraphs [0020]-[0021] and claim 1.	1-17
A	JP 2008-127595 A (KOBE STEEL LTD.) 05 June 2008 (2008-06-05) See paragraph [0031] and claims 1-4.	1-17
A	KR 10-1051241 B1 (UNISON CO., LTD. et al.) 21 July 2011 (2011-07-21) See paragraphs [0053]-[0057] and claims 1 and 4.	1-17
A	KR 10-2014-0052094 A (HYUNDAI STEEL COMPANY et al.) 07 May 2014 (2014-05-07) See paragraphs [0067]-[0085].	1-17

☐ 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

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Date of the actual completion of the international search

29 August 2023

Date of mailing of the international search report

29 August 2023

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**Korean Intellectual Property Office
Government Complex-Daejeon Building 4, 189 Cheongsaro, Seo-gu, Daejeon 35208**

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2023/006887

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KR 10-2021-0079847 A	30 June 2021	None	
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KR 10-1051241 B1	21 July 2011	None	
KR 10-2014-0052094 A	07 May 2014	KR 10-1455462 B1	28 October 2014

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REFERENCES CITED IN THE DESCRIPTION

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- **F.R. LARSON ; J. MILLER.** *Trans. ASME*, 1952, vol. 74, 765-75 [0097]