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(54) **ABRASION RESISTANT STEEL HAVING EXCELLENT HARDNESS AND IMPACT TOUGHNESS, AND MANUFACTURING METHOD THEREFOR**

(57) One embodiment of the present invention provides an abrasion resistant steel having excellent hardness and impact toughness, and a manufacturing method therefor, the abrasion resistant steel comprising, by wt%, 0.33-0.42% of carbon (C), 0.1-0.7% of silicon (Si), 0.6-1.6% of manganese (Mn), 0.05% or less of phosphorus (P) (excluding 0), 0.02% or less of sulfur (S) (excluding 0), 0.07% or less of aluminum (Al) (excluding 0), 0.55-5.0% of nickel (Ni), 0.01-1.5% of copper (Cu), 0.01-0.8% of chromium (Cr), 0.01-0.8% of molybdenum (Mo), 50 ppm or less of boron (B) (excluding 0), and 0.02% or less of cobalt (Co) (excluding 0), further comprising one or more selected from the group consisting

of 0.02% or less of titanium (Ti) (excluding 0), 0.05% or less of niobium (Nb) (excluding 0), 0.05% or less of vanadium (V) (excluding 0) and 2-100 ppm of calcium (Ca), and comprising the balance of Fe and other inevitable impurities, wherein C and Ni satisfy the following relation 1, and the microstructure comprises 95 area% or more of martensite and 5% or less of bainite (including 0%) .

$$[\text{Relation 1}] \quad [\text{C}] \times [\text{Ni}] \geq 0.231 \quad 1)$$

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Description

[Technical Field]

[0001] The present disclosure relates to a high hardness abrasion resistant steel and a manufacturing method therefor, and more particularly, to a high hardness abrasion resistant steel which may be used for construction machinery, and the like, and a manufacturing method therefor.

[Background Art]

[0002] As for construction machinery and industrial machinery used in many industrial fields such as construction, civil engineering, mining, and cement industries, since abrasion may occur severely due to friction in operation, it may be necessary to apply a material exhibiting abrasion resistance properties.

[0003] Generally, as abrasion resistance and hardness of a thick steel sheet may be correlated with each other, it may be necessary to increase hardness in the thick steel sheet concerned, to be worn down. To secure stable abrasion resistance, it may be necessary to have uniform hardness from the surface of the thick steel sheet to the inside (around $t/2$, t = thickness) of the sheet thickness (that is, having the same degree of hardness on the surface of the thick steel sheet and inside) .

[0004] Generally, to obtain high hardness in a thick steel sheet, a method of reheating to an Ac3 temperature or higher after rolling and quenching may be widely used. For example, cited references 1 and 2 disclose a method of increasing a content of C and adding a large amount of hardenability enhancing elements such as Cr and Mo, thereby increasing surface hardness. However, to manufacture an extremely thick steel sheet, it may be necessary to add a greater amount of hardenability elements to secure hardenability in the center of the steel sheet, and as C and hardenability alloys are added in large amounts, manufacturing costs may increase, and weldability and low-temperature toughness may degrade, which may be problematic.

[0005] Therefore, while it is inevitable to add hardenability alloys to secure hardenability, it has been necessary to devise a measure for obtaining excellent abrasion resistance by securing high hardness, and securing high strength and high impact toughness.

[Reference]

[0006]

(Reference 1) Japanese Laid-Open Patent Publication No. 1996-041535

(Reference 2) Japanese Laid-Open Patent Publication No. 1986-166954

[Disclosure]

[Technical Problem]

[0007] An aspect of the present disclosure may be to provide a high hardness abrasion resistant steel which may have excellent abrasion resistance and also high strength and high impact toughness, and a manufacturing method therefor.

[Technical Solution]

[0008] An example embodiment of the present disclosure provides an abrasion resistant steel having excellent hardness and impact toughness including, by weight%, 0.33-0.42% of carbon (C), 0.1-0.7% of silicon (Si), 0.6-1.6% of manganese (Mn), 0.05% or less of phosphorus (P) (excluding 0), 0.02% or less of sulfur (S) (excluding 0), 0.07% or less of aluminum (Al) (excluding 0), 0.55-5.0% of nickel (Ni), 0.01-1.5% of copper (Cu), 0.01-0.8% of chromium (Cr), 0.01-0.8% of molybdenum (Mo), 50 ppm or less of boron (B) (excluding 0), and 0.02% or less of cobalt (Co) (excluding 0) and further comprising one or more selected from a group consisting of 0.02% or less of titanium (Ti) (excluding 0), 0.05% or less of niobium (Nb) (excluding 0), 0.05% or less of vanadium (V) (excluding 0) and 2-100 ppm of calcium (Ca), with a balance of Fe and other inevitable impurities, wherein C and Ni satisfy relational expression 1 as below, and wherein a microstructure includes 95 area% or more of martensite and 5% or less of bainite (including 0%).

$$[\text{Relational Expression 1}] \quad [\text{C}] \times [\text{Ni}] \geq 0.231$$

[0009] Another example embodiment of the present disclosure provides a method of manufacturing an abrasion resistant steel having excellent hardness and impact toughness including heating a steel slab including, by weight%, 0.33-0.42% of carbon (C), 0.1-0.7% of silicon (Si), 0.6-1.6% of manganese (Mn), 0.05% or less of phosphorus (P) (excluding 0), 0.02% or less of sulfur (S) (excluding 0), 0.07% or less of aluminum (Al) (excluding 0), 0.55-5.0% of nickel (Ni), 0.01-1.5% of copper (Cu), 0.01-0.8% of chromium (Cr), 0.01-0.8% of molybdenum (Mo), 50 ppm or less of boron (B) (excluding 0), and 0.02% or less of cobalt (Co) (excluding 0) and further comprising one or more selected from a group consisting of 0.02% or less of titanium (Ti) (excluding 0), 0.05% or less of niobium (Nb) (excluding 0), 0.05% or less of vanadium (V) (excluding 0) and 2-100 ppm of calcium (Ca), with a balance of Fe and other inevitable impurities, where C and Ni satisfy relational expression 1 as below, in a temperature range of 1050-1250°C; obtaining a rough-rolled bar by rough-rolling the reheated steel slab in a temperature range of 950-1050°C; obtaining a hot-rolled steel sheet by finishing-hot-rolling the rough-rolled bar in a temperature range of 850-950°C; air-cooling the hot-rolled steel sheet to room temperature and reheating the steel sheet for a residence time of 1.3t+10min-1.3t+60min (t: sheet thickness) in a temperature range of 860-950°C; and water-cooling the reheated hot-rolled steel sheet to 150°C or less.

$$[\text{Relational Expression 1}] \quad [\text{C}] \times [\text{Ni}] \geq 0.231$$

[Advantageous Effects]

[0010] According to an aspect of the present disclosure, an effect of providing an abrasion resistant steel having a thickness of 60mm or less and having high hardness and excellent low-temperature toughness may be obtained.

[Best Mode for Invention]

[0011] In the description below, the present disclosure will be described in detail. The alloy composition of the present disclosure will be described first. The content of the alloy composition described below may be represented by weight%.

Carbon (C): 0.33-0.42%

[0012] Carbon (C) may be effective in increasing strength and hardness in a steel having a martensite structure and may be effective for improving hardenability. To sufficiently secure the above-described effect, it may be preferable to add C by 0.33% or more. However, when the content thereof exceeds 0.42%, weldability and toughness may degrade, such that an additional heat treatment such as tempering may be inevitable. Therefore, in the present disclosure, it may be preferable to control the content of C to be 0.33-0.42%. A lower limit of the content of C may more preferably be 0.34%, even more preferably 0.35%, and most preferably 0.36%. An upper limit of the content of C may more preferably be 0.40%, even more preferably 0.39%, and most preferably 0.38%.

Silicon (Si): 0.1-0.7%

[0013] Silicon (Si) may be effective in improving strength according to deoxidation and solid solution strengthening. To obtain the above effect, it may be preferable to add Si by 0.1% or more. However, when the content thereof exceeds 0.7%, weldability may deteriorate, which may not be preferable. Therefore, in the present disclosure, it may be preferable to control the content of Si to be 0.1-0.7%. A lower limit of the content of Si may more preferably be 0.12%, even more preferably 0.15%, and most preferably 0.2%. An upper limit of the Si content may more preferably be 0.5%, even more preferably 0.45%, and most preferably 0.4%.

Manganese (Mn): 0.6-1.6%

[0014] Manganese (Mn) may suppress ferrite formation and may effectively improve hardenability by decreasing Ar₃ temperature, thereby improving strength and toughness of steel. In the present disclosure, to secure hardness of the thick steel material, it may be preferable to include Mn in an amount of 0.6% or more. When the content exceeds 1.6%, weldability may degrade. Therefore, in the present disclosure, it may be preferable to control the content of Mn to be 0.6-1.6%. A lower limit of the content of Mn may more preferably be 0.65%, even more preferably 0.70%, and most preferably 0.75%. An upper limit of the content of Mn may more preferably be 1.55%, even more preferably 1.50%, and most preferably 1.45%.

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Phosphorus (P): 0.05% or less (excluding 0)

[0015] Phosphorus (P) may be inevitably included in steel, and may degrade toughness of steel. Therefore, it may be preferable to control the content of P to be less than 0.05% by lowering the content as much as possible, but 0% may be excluded in consideration of the inevitably included amount. The content of P may more preferably be 0.03% or less, even more preferably 0.02% or less, and most preferably 0.01% or less.

Sulfur (S): 0.02% or less (excluding 0)

[0016] Sulfur (S) may deteriorate toughness of steel by forming an MnS inclusion in steel. Therefore, it may be preferable to control the content of S to be 0.02% or less by lowering the content as much as possible, but 0% may be excluded in consideration of the inevitably included amount. The content of S may more preferably be 0.01% or less, even more preferably 0.005% or less, and most preferably 0.003% or less.

Aluminum (Al): 0.07% or less (excluding 0)

[0017] Aluminum (Al) may be effective in lowering an oxygen content in molten steel as a deoxidizing agent for steel. When the content of Al exceeds 0.07%, cleanliness of the steel may be impaired, which may not be preferable. Therefore, in the present disclosure, it may be preferable to control the content of Al to be 0.07% or less, and 0% may be excluded in consideration of load and an increase in manufacturing costs in the steelmaking process. The content of Al may more preferably be 0.05% or less, even more preferably 0.04% or less, and most preferably 0.03% or less.

Nickel (Ni): 0.55-5.0%

[0018] Nickel (Ni) may be generally effective in improving toughness along with strength of steel. To obtain the above-described effect, it may be preferable to add Ni in an amount of 0.55% or more. However, when the content thereof exceeds 5.0%, the manufacturing costs may increase as Ni is an expensive element. Therefore, in the present disclosure, it may be preferable to control the content of Ni to be 0.55-5.0%. A lower limit of the content of Ni may more preferably be 0.6%, even more preferably 0.7%, and most preferably 0.8%. An upper limit of the content of Ni may more preferably be 4.5%, even more preferably 4.0%, and most preferably 3.5%.

Copper (Cu): 0.01-1.5%

[0019] Copper (Cu) may simultaneously increase strength and toughness of steel along with Ni. To obtain the above effect, it may be preferable to add Cu in an amount of 0.01% or more. However, when the content of Cu exceeds 1.5%, possibility of surface defects may increase, and hot workability may be deteriorated. Therefore, in the present disclosure, it may be preferable to control the content of Cu to be 0.01-1.5%. A lower limit of the content of Cu may more preferably be 0.05%, even more preferably 0.10%, and most preferably 0.15%. An upper limit of the Cu content may more preferably be 1.2%, even more preferably 1.0%, and most preferably 0.8%.

Chrome (Cr): 0.01-0.8%

[0020] Chromium (Cr) may increase strength of steel by increasing hardenability, and may be advantageous in securing hardness. To obtain the above-described effect, it may be preferable to add Cr in an amount of 0.01% or more, but when the content thereof exceeds 0.8%, weldability may be deteriorated and the manufacturing costs may increase. Therefore, in the present disclosure, it may be preferable to control the content of Cr to be 0.01-0.8%. A lower limit of the Cr content may more preferably be 0.1%, even more preferably 0.15%, and most preferably 0.2%. An upper limit of the content of Cr may more preferably be 0.75%, even more preferably 0.70%, and most preferably 0.65%.

Molybdenum (Mo): 0.01-0.8%

[0021] Molybdenum (Mo) may increase hardenability of steel, and may be effective in improving hardness of a thick steel material. To sufficiently obtain the above-described effect, it may be preferable to add Mo in an amount of 0.01% or more. However, as Mo is also an expensive element, when the content thereof exceeds 0.8%, the manufacturing costs may increase, and weldability may degrade. Therefore, in the present disclosure, it may be preferable to control the content of Mo to be 0.01-0.8%. A lower limit of the content of Mo may more preferably be 0.1%, even more preferably 0.12%, and most preferably 0.15%. An upper limit of the Mo content may more preferably be 0.75%, even more preferably 0.72%, and most preferably 0.70%.

Boron (B): 50ppm or less (excluding 0)

[0022] Boron (B) may be effective in improving strength by effectively increasing hardenability of steel even by adding a small amount of B. When the content thereof is excessive, however, toughness and weldability of steel may be deteriorated, and thus, it may be preferable to control the content to be 50 ppm or less. A lower limit of the content of B may more preferably be 2 ppm, even more preferably 3 ppm, and most preferably 5 ppm. An upper limit of the content of B may more preferably be 40 ppm, even more preferably 35 ppm, and most preferably 30 ppm.

Cobalt (Co): 0.02% or less (excluding 0)

[0023] Cobalt (Co) may be advantageous in securing hardness as well as strength of steel by increasing hardenability of steel. When the content thereof exceeds 0.02%, hardenability of the steel may decrease, and may increase the manufacturing costs as Co is an expensive element. Therefore, in the present disclosure, it may be preferable to add Co by 0.02% or less. A lower limit of the Co content may more preferably be 0.001%, even more preferably 0.002% or less, and most preferably 0.003% or less. An upper limit of the Co content may more preferably be 0.018%, even more preferably 0.015%, and most preferably 0.013%.

[0024] In addition to the above-described alloy composition, the abrasion-resistant steel in the present disclosure may further include elements advantageous for securing physical properties aimed in the present disclosure. For example, the abrasion-resistant steel may further include one or more selected from a group consisting of 0.02% or less of titanium (Ti) (excluding 0), 0.05% or less of niobium (Nb) (excluding 0), 0.05% or less of vanadium (V) (excluding 0) and 2-100 ppm of calcium (Ca).

Titanium (Ti): 0.02% or less (excluding 0)

[0025] Titanium (Ti) may maximize the effect of B, an element effective in improving hardenability of steel. Specifically, Ti may form a TiN precipitate by being combined with nitrogen (N), such that formation of BN may be prevented. Accordingly, solid solute B may increase, such that improvement of hardenability may be maximized. When the content of Ti exceeds 0.02%, a coarse TiN precipitate may be formed, such that toughness of the steel may deteriorate. Therefore, in the present disclosure, it may be preferable to add Ti by 0.02% or less. A lower limit of the content of Ti may more preferably be 0.005%, even more preferably 0.007%, and most preferably 0.010%. An upper limit of the content of Ti may more preferably be 0.019%, even more preferably 0.017%, and most preferably 0.015%.

Niobium (Nb): 0.05% or less (excluding 0)

[0026] Niobium (Nb) may be solid-solute in austenite and may increase hardenability of austenite, and may form carbonitride such as Nb (C,N) such that Nb may be effective for increasing strength of steel and inhibiting austenite grain growth. When the content of Nb exceeds 0.05%, a coarse precipitate may be formed, which becomes a starting point of brittle fracture, such that toughness may degrade. Therefore, in the present disclosure, it may be preferable to add Nb by 0.05% or less. A lower limit of the content of Nb may more preferably be 0.002%, even more preferably 0.003%, and most preferably 0.005%. An upper limit of the content of Nb may more preferably be 0.040%, even more preferably 0.035%, and most preferably 0.030%.

Vanadium (V): 0.05% or less (excluding 0)

[0027] Vanadium (V) may form a VC carbide during reheating after hot-rolling, such that growth of austenite grains may be inhibited, and V may be advantageous to securing strength and toughness by improving hardenability of steel. As V is an expensive element, when the content thereof exceeds 0.05%, V may become a factor increasing the manufacturing costs. Therefore, in the present disclosure, it may be preferable to control the content thereof to be 0.05% or less. A lower limit of the content of V may more preferably be 0.002%, even more preferably 0.003%, and most preferably 0.005%. An upper limit of the content of V may more preferably be 0.045%, even more preferably 0.042%, and most preferably 0.040%.

Calcium (Ca): 2-100ppm

[0028] Calcium (Ca) may have good bonding strength with S such that Ca may have an effect of inhibiting formation of MnS segregated in a center of a thickness of a steel material by generating CaS. Also, CaS created by adding Ca may have an effect of increasing corrosion resistance in a humid external environment. To obtain the above-described effect, it may be preferable to add Ca in an amount of 2 ppm or more. However, when the content thereof exceeds 100

ppm, it may not be preferable as Ca may cause clogging of a nozzle in steelmaking. Therefore, in the present disclosure, it may be preferable to control the content of Ca to be 2-100 ppm. A lower limit of the content of Ca may more preferably be 3 ppm, even more preferably 4 ppm, and most preferably 5 ppm. An upper limit of the content of Ca may more preferably be 80 ppm, even more preferably 60 ppm, and most preferably 40 ppm.

[0029] Also, the abrasion resistant steel in the present disclosure may further include one or more selected from a group consisting of 0.05% or less of arsenic (As) (excluding 0), 0.05% or less of tin (Sn) (excluding 0), and 0.05% or less of tungsten (W) (excluding 0).

[0030] As may be effective in improving toughness of steel, and Sn may be effective in improving strength and corrosion resistance of steel. Also, W may increase hardenability such that W may be effective in improving strength and also improving hardness at high temperature. When each content of As, Sn, and W exceeds 0.05%, the manufacturing costs may increase, and physical properties of steel may rather be deteriorated. Therefore, in the present disclosure, when As, Sn and W are additionally included, it may be preferable to control each content thereof to be 0.05% or less. A lower limit of each content of As, Sn, and W may more preferably be 0.001%, even more preferably 0.002%, and most preferably 0.003%. An upper limit of each content of As, Sn and W may more preferably be 0.04%, even more preferably 0.03%, and most preferably 0.02%.

[0031] A remainder of the present disclosure may be iron (Fe). However, in a general manufacturing process, inevitable impurities may be inevitably added from raw materials or an ambient environment, and thus, impurities may not be excluded. A person skilled in the art of a general manufacturing process may be aware of the impurities, and thus, the descriptions of the impurities may not be provided in the present disclosure.

[0032] In the abrasion resistant steel in the present disclosure, it may be preferable for C and Ni of the above-described alloy composition to satisfy relational expression 1 as below. In the present disclosure, ultra-high hardness and also excellent low-temperature toughness may be secured, and to this end, relational expression 1 should be satisfied preferably. When relational expression 1 is not satisfied, it may be difficult to improve both hardness and low temperature toughness to an excellent level. Therefore, a value of $[C] \times [Ni]$ may preferably be 0.231 or more. A value of $[C] \times [Ni]$ may more preferably be 0.396 or more, even more preferably 0.792 or more, and most preferably 1 or more. The higher the value of $[C] \times [Ni]$, the more advantageous the effect may be implemented, and thus, an upper limit of the value of $[C] \times [Ni]$ may not be particularly limited in the present disclosure.

$$[\text{Relational Expression 1}] \quad [C] \times [Ni] \geq 0.231$$

[0033] It may be preferable for a microstructure of the abrasion resistant steel in the present disclosure to include martensite as a matrix structure. More specifically, the abrasion resistant steel in the present disclosure may include 95% or more (including 100%) of martensite by an area fraction. When the fraction of martensite is less than 95%, it may be difficult to secure a target level of strength and hardness. The microstructure of the abrasion resistant steel in the present disclosure may further include bainite by 5 area% or less, and accordingly, low-temperature impact toughness may further improve. A fraction of martensite may more preferably be 96% or more, and even more preferably 97% or more. A fraction of bainite may more preferably be 4% or less, and even more preferably 3% or less.

[0034] The abrasion resistant steel in the present disclosure provided as above may have an effect of securing surface hardness of 550-650HB and also having an impact absorption energy of 21J or more at a low temperature of -40°C. HB indicates surface hardness of the steel measured by the Brinell hardness tester.

[0035] Also, it may be preferable that hardness (HB) and impact absorption energy (J) of the abrasion resistant steel in the present disclosure satisfy relational expression 2 as below. In the present disclosure, low-temperature toughness properties may improve in addition to high hardness, and to this end, it may be preferable to satisfy relational expression 2 as below. In other words, when only surface hardness is high and impact toughness is degraded such that relational expression 2 is not satisfied, or when impact toughness is excellent but surface hardness does not reach a target value such that relational expression 2 is not satisfied, final target high hardness and low temperature toughness properties may not be guaranteed.

[0036] [Relational Expression 2] $HB \div J \leq 31.0$ (HB indicates surface hardness of the steel measured by the Brinell hardness tester, and J indicates an impact absorption energy value at -40°C)

[0037] Hereinafter, a method of manufacturing the abrasion resistant steel will be described in detail.

[0038] First, a steel slab may be heated in the temperature range of 1050-1250°C. When the slab heating temperature is less than 1050°C, re-solid solution of Nb may not be sufficient, whereas when the temperature exceeds 1250°C, austenite crystal grains may be coarsen such that a non-uniform structure may be formed. Therefore, in the present disclosure, the heating temperature of the steel slab may have a range of 1050-1250°C preferably. A lower limit of the heating temperature of the steel slab may more preferably be 1060°C, even more preferably 1070°C, and most preferably 1080°C. An upper limit of the heating temperature of the steel slab may more preferably be 1230°C, even more preferably 1200°C, and most preferably 1180°C.

[0039] The reheated steel slab may be roughly rolled in a temperature range of 950-1050°C to obtain a rough-rolled bar. When the temperature is less than 950°C during the rough-rolling, a rolling load may increase and the pressure may be relatively weakened, such that deformation may not be sufficiently transmitted to a center of the slab in a thickness direction, and defects such as voids may not be removed. When the temperature exceeds 1050°C, recrystallization may simultaneously occur while rolling, and grains may grow, such that initial austenite grains may become excessively coarse. Therefore, in the present disclosure, the rough-rolling temperature may preferably be 950-1050°C. A lower limit of the rough-rolling temperature may more preferably be 960°C, even more preferably 970°C, and most preferably 980°C. An upper limit of the rough-rolling temperature may more preferably be 1040°C, even more preferably 1020°C, and most preferably 1000°C.

[0040] The rough-rolled bar may be finishing hot-rolled in a temperature range of 850-950°C to obtain a hot-rolled steel sheet. When the finishing hot-rolling temperature is less than 850°C, the rolling may become two-phase rolling, such that ferrite may be formed in the microstructure. When the temperature exceeds 950°C, a grain size of the final structure may become coarse such that low-temperature toughness may be deteriorated. Therefore, in the present disclosure, the finishing hot-rolling temperature may be 850-950°C preferably. A lower limit of the finishing hot-rolling temperature may more preferably be 860°C, even more preferably 870°C, and most preferably 880°C. An upper limit of the finish hot-rolling temperature may more preferably be 940°C, even more preferably 930°C, and most preferably 920°C.

[0041] Thereafter, the hot-rolled steel sheet may be air-cooled to room temperature, and may be reheated in a temperature range of 860-950°C for a residence time of 1.3t+10min-1.3t+60min (t: sheet thickness). The reheating may be performed for reverse transformation of the hot-rolled steel sheet including ferrite and pearlite into austenite single phase. When the reheating temperature is less than 860°C, austenitization may not be sufficiently performed and coarse soft ferrites may be mixed, such that hardness of the final product may degrade. When the temperature exceeds 950°C, austenite grains may become coarse, such that hardenability may increase, but low temperature toughness of the steel may be deteriorated. Therefore, in the present disclosure, the reheating temperature may preferably be 860-950°C. A lower limit of the reheating temperature may more preferably be 870°C, even more preferably 880°C, and most preferably 890°C. An upper limit of the reheating temperature may more preferably be 940°C, even more preferably 930°C, and most preferably 920°C.

[0042] When the residence time during the reheating is less than 1.3t+10 minutes (t: sheet thickness), austenitization may not occur sufficiently, such that a phase transformation by rapid cooling subsequently performed, a martensitic structure, may not be sufficiently obtained. When the residence time during the reheating exceeds 1.3t+60 minutes (t: sheet thickness), austenite crystal grains may become coarse such that hardenability may increase, but low temperature toughness may deteriorate. Therefore, in the present disclosure, the residence time during the reheating may preferably be 1.3t+10min-1.3t+60min (t: sheet thickness). A lower limit of the residence time during reheating may more preferably be 1.3t+12 minutes, even more preferably 1.3t+15 minutes, and most preferably 1.3t+20 minutes. An upper limit of the residence time during reheating may more preferably be 1.3t+50min, even more preferably 1.3t+45min, and most preferably 1.3t+40min.

[0043] Thereafter, the reheated hot-rolled steel sheet may be water-cooled to 150°C or less with reference to a surface layer portion (e.g., the area from the surface to 1/8t (t: sheet thickness (mm)) of the sheet. The water-cooling stop temperature exceeds 150°C, a ferrite phase may be formed during cooling or a bainite phase may be excessively formed. Therefore, the water-cooling stop temperature may preferably be 150°C or less. The water-cooling stop temperature may more preferably be 100°C or less, even more preferably 70°C or less, and most preferably 40°C or less.

[0044] The water-cooling rate may preferably be 10°C/s or more. When the cooling rate is less than 10°C/s, a ferrite phase may be formed during cooling or a bainite phase may be excessively formed. A cooling rate during the water-cooling may more preferably be 15°C/s or more, and even more preferably 20°C/s or more. In the present disclosure, the higher the cooling rate, the more advantageous it may be, and thus, an upper limit of the cooling rate may not be particularly limited, and may be determined in consideration of facility limitations by a person skilled in the art.

[0045] The hot-rolled steel sheet in the present disclosure having gone through the above process conditions may be a thick steel sheet having a thickness of 60mm or less, and may have a thickness of 8-50mm more preferably, and 12-40mm even more preferably. In the present disclosure, it may be preferable to not perform a tempering process on the thick steel sheet.

[Mode for Invention]

[0046] Hereinafter, the present disclosure will be described in greater detail with reference to an embodiment. However, it should be noted that the following embodiment are provided to describe the present disclosure in greater detail, and to not limit the scope of the present disclosure. The scope of the present disclosure may be determined by matters described in the claims and matters reasonably inferred therefrom.

(Embodiment)

[0047] A steel slab having alloy compositions as in Tables 1 and 2 below was prepared, and the steel slab heating-rough-rolling-hot-rolling-cooling (room temperature)-reheating-water cooling was performed on the steel slab under the conditions as in Table 3 below to manufacture a hot-rolled steel sheet. A microstructure and mechanical properties of the hot-rolled steel sheet were measured, and results thereof are listed in Table 4 below.

[0048] In this case, as for the microstructure, the sample was cut out in an arbitrary size to manufacture a mirror surface, the surface was corroded using a nital etching solution, and a 1/2t position, a center of the thickness, was observed using an optical microscope and an electron scanning microscope.

[0049] Hardness and toughness were measured using the Brinell hardness tester (load 3000kgf, 10mm tungsten indentation) and the Charpy impact tester, respectively. As for surface hardness, an average value of values obtained by milling the sheet surface by 2 mm and measuring surface hardness three times therefrom was used. As for the Charpy impact test result, an average value of values obtained by taking a sample from a 1/4t position and measuring toughness three times therefrom at -40°C was used.

[Table 1]

CLASSIFICATION	ALLOY COMPOSITION (WEIGHT%)										
	C	Si	Mn	P	S	Al	Cr	Ni	Mo	B	Co
COMPARATIVE STEEL 1	0.346	0.35	3.07	0.013	0.0031	0.031	0.05	0.05	0.01	0.0011	-
COMPARATIVE STEEL 2	0.287	0.38	0.85	0.009	0.0018	0.025	0.12	1.21	0.13	0.0002	-
COMPARATIVE STEEL 3	0.440	0.31	1.51	0.015	0.0016	0.036	0.45	0.09	0.19	0.0015	0.01
COMPARATIVE STEEL 4	0.385	0.25	0.85	0.007	0.0021	0.036	0.78	0.37	0.56	0.0017	0.01
INVENTIVE STEEP	0.370	0.34	1.36	0.007	0.0010	0.023	0.58	0.92	0.25	0.0022	0.01
INVENTIVE STEEP 2	0.401	0.31	1.23	0.008	0.0021	0.022	0.31	2.91	0.56	0.0020	0.01
INVENTIVE STEEP3	0.383	0.21	1.47	0.008	0.0009	0.031	0.31	1.74	0.33	0.0020	0.01

[Table 2]

CLASSIFICATION	ALLOY COMPOSITION (WEIGHT%)								
	Cu	Ti	Nb	V	Ca	As	Sn	W	RELATIONAL EXPRESSION 1
COMPARATIVE STEEL	0.05	0.013	0.021	0.03	0.0002	-	-	-	0.017
COMPARATIVE STEEL 2	0.45	0.018	0.037	0.01	0.0004	-	-	-	0.347
COMPARATIVE STEEL 3	0.02	0.017	0.026	0.02	0.0009	0.003	0.003	-	0.040
COMPARATIVE STEEL 4	0.21	0.002	0.023	0.03	0.0005	0.003	0.004	0.01	0.142
INVENTIVE STEEP 1	0.31	0.016	0.035	0.04	0.0012	-	-	0.01	0.340
INVENTIVE STEEP 2	0.15	0.012	0.024	-	0.0006	0.003	0.003	0.01	1.167
INVENTIVE STEEP 3	0.22	0.013	-	0.04	0.0004	0.003	0.003	-	0.666
[RELATIONAL EXPRESSION 1] [C] × [Ni]									

[Table 3]

CLASSIFICATION	STEEL TYPE No.	SLAB HEATING TEMPERATURE (°C)	ROUGH-ROLLING TEMPERATURE (°C)	FINISHING-ROLLING TEMPERATURE (°C)	REHEATING TEMPERATURE (°C)	REHEATING RESIDENCE TIME (MIN)	COOLING RATE (°C/s)	COOLING TERMINATION TEMPERATURE (°C)	THICKNESS (mm)
COMPARATIVE EXAMPLE 1	COMPARATIVE STEEL 1	1121	1048	901	908	32	52	42	12
COMPARATIVE EXAMPLE 2		1137	1050	923	915	75	41	126	40
COMPARATIVE EXAMPLE 3		1117	1023	940	912	90	38	23	60
COMPARATIVE EXAMPLE 4	COMPARATIVE STEEL 2	1133	1045	903	921	45	49	176	20
COMPARATIVE EXAMPLE 5		1125	1021	911	921	52	48	52	30
COMPARATIVE EXAMPLE 6		1140	1030	920	909	100	31	25	50
COMPARATIVE EXAMPLE 7 COMPARATIVE EXAMPLE 8	COMPARATIVE STEEL 3	1123	1049	882	911	32	65	24	8
		1097	1038	901	917	71	47	40	25
COMPARATIVE EXAMPLE 9	COMPARATIVE STEEL 4	1145	1019	934	915	93	40	123	50
COMPARATIVE EXAMPLE 10		1130	1028	922	931	60	51	36	15
COMPARATIVE EXAMPLE 11		1112	1039	930	927	77	47	135	30
COMPARATIVE EXAMPLE 12		1127	1044	947	928	113	25	27	60

(continued)

CLASSIFICATION	STEEL TYPE No.	SLAB HEATING TEMPERATURE (°C)	ROUGH-ROLLING TEMPERATURE (°C)	FINISHING-HOT-ROLLING TEMPERATURE (°C)	REHEATING TEMPERATURE (°C)	REHEATING RESIDENCE TIME (MIN)	COOLING RATE (°C/s)	COOLING TERMINATION TEMPERATURE (°C)	THICKNESS (mm)
INVENTIVE EX-AMPLE 1	INVENTIVE STEEL 1	1124	1031	888	918	52	53	126	12
INVENTIVE EX-AMPLE 2		1131	1039	915	915	61	50	53	20
COMPARATIVE EXAMPLE 13		1126	1042	939	850	110	32	29	60
COMPARATIVE EXAMPLE 14	INVENTIVE STEEL 2	1129	1045	920	910	78	50	200	25
INVENTIVE EX-AMPLE 3		1137	1042	931	913	93	44	25	40
INVENTIVE EX-AMPLE 4		1102	1041	946	920	88	33	36	50
INVENTIVE EX-AMPLE 5	INVENTIVE STEEL 3	1126	1040	890	914	59	46	22	20
COMPARATIVE EXAMPLE 15		1120	1053	913	925	104	6	29	40
INVENTIVE EX-AMPLE 6		1105	1044	932	916	116	28	141	60

[Table 4]

CLASSIFICATION	MICROSTRUCTURE (AREA%)		SURFACE HARDNESS (HB)	IMPACT TOUGHNESS (J, @-40°C)	RELATIONAL EXPRESSION 2
	M	THE OTHERS			
COMPARATIVE EXAMPLE 1	100	-	589	7	84.1
COMPARATIVE EXAMPLE 2	95	B:5%	592	5	118.4
COMPARATIVE EXAMPLE 3	100	-	574	8	71.8
COMPARATIVE EXAMPLE 4	94	B:6%	541	34	15.9
COMPARATIVE EXAMPLE 5	97	B:3%	529	38	13.9
COMPARATIVE EXAMPLE 6	98	B:2%	545	31	17.6
COMPARATIVE EXAMPLE 7	100	-	670	6	111.7
COMPARATIVE EXAMPLE 8	100	-	667	5	133.4
COMPARATIVE EXAMPLE 9	99	B:1%	662	5	132.4
COMPARATIVE EXAMPLE 10	100	-	619	11	56.3
COMPARATIVE EXAMPLE 11	96	B:4%	609	19	32.1
COMPARATIVE EXAMPLE 12	100	-	623	12	51.9
INVENTIVE EXAMPLE 1	99	B:1%	608	25	24.3
INVENTIVE EXAMPLE 2	100	-	605	27	22.4
COMPARATIVE EXAMPLE 3	85	B:10%, PF: 5%	516	48	10.8
COMPARATIVE EXAMPLE 14	90	B:6%, RA: 4%	531	75	7.1
INVENTIVE EXAMPLE 3	100	-	625	35	17.9
INVENTIVE EXAMPLE 4	100	-	630	33	19.1
INVENTIVE EXAMPLE 5	98	B:2%	618	42	14.7
COMPARATIVE EXAMPLE 15	75	B: 25%	411	63	6.5

(continued)

CLASSIFICATION	MICROSTRUCTURE (AREA%)		SURFACE HARDNESS (HB)	IMPACT TOUGHNESS (J, @-40°C)	RELATIONAL EXPRESSION 2
	M	THE OTHERS			
INVENTIVE EXAMPLE 6	96	B:4%	604	45	13.4
[RELATIONAL EXPRESSION 2] $HB \div J$ (HB INDICATES SURFACE HARDNESS OF THE STEEL MEASURED BY THE BRINELL HARDNESS TESTER, AND J INDICATES AN IMPACT ABSORPTION ENERGY VALUE AT -40°C.) M: MARTENSITE, B: BAINITE, PF: POLYGONAL FERRITE, RA: RETAINED AUSTENITE					

[0050] As indicated in Tables 1 to 4, inventive examples 1 to 6 satisfying the alloy composition, relational expression 1, and the manufacturing conditions suggested in the present disclosure satisfied the microstructure fraction of the present disclosure, and secured excellent hardness and low-temperature impact toughness.

[0051] It is indicated that comparative examples 1 to 12, which satisfied the manufacturing conditions suggested in the present disclosure but did not satisfy the alloy composition or relational expression 1, did not satisfy hardness and low-temperature impact toughness aimed in the present disclosure.

[0052] It is indicated that comparative example 13 satisfying the alloy composition and relational expression 1 suggested in the present disclosure but not satisfying the reheating temperature among the manufacturing conditions did not secure the microstructure type and fraction suggested in the present disclosure, and surface hardness was low.

[0053] It is indicated that comparative example 14 satisfying the alloy composition and relational expression 1 suggested in the present disclosure but not satisfying the cooling termination temperature among the manufacturing conditions secured the martensite fraction suggested in the present disclosure, but retained austenite was formed, and accordingly, surface hardness was low.

[0054] It is indicated that comparative example 15 satisfying the alloy composition and relational expression 1 suggested in the present disclosure but not satisfying the cooling rate among the manufacturing conditions did not secure the martensite fraction suggested in the present disclosure, and accordingly, surface hardness was low.

Claims

1. An abrasion resistant steel having excellent hardness and impact toughness, comprising:

by weight%, 0.33-0.42% of carbon (C), 0.1-0.7% of silicon (Si), 0.6-1.6% of manganese (Mn), 0.05% or less of phosphorus (P) (excluding 0), 0.02% or less of sulfur (S) (excluding 0), 0.07% or less of aluminum (Al) (excluding 0), 0.55-5.0% of nickel (Ni), 0.01-1.5% of copper (Cu), 0.01-0.8% of chromium (Cr), 0.01-0.8% of molybdenum (Mo), 50 ppm or less of boron (B) (excluding 0), and 0.02% or less of cobalt (Co) (excluding 0) and further comprising one or more selected from a group consisting of 0.02% or less of titanium (Ti) (excluding 0), 0.05% or less of niobium (Nb) (excluding 0), 0.05% or less of vanadium (V) (excluding 0) and 2-100 ppm of calcium (Ca), with a balance of Fe and other inevitable impurities, wherein C and Ni satisfy relational expression 1 as below, and wherein a microstructure includes 95 area% or more of martensite and 5% or less of bainite (including 0%),

$$[\text{Relational Expression 1}] \quad [C] \times [Ni] \geq 0.231.$$

2. The abrasion resistant steel of claim 1, wherein the abrasion resistant steel further includes one or more selected from a group consisting of 0.05% or less of arsenic (As) (excluding 0), 0.05% or less of tin (Sn) (excluding 0), and 0.05% or less of tungsten (W) (excluding 0).

3. The abrasion resistant steel of claim 1, wherein the abrasion resistant steel secures hardness of 550-650HB, and has 21J or more at a low temperature of -40°C, where HB is surface hardness of the steel measured by the Brinell hardness tester.

4. The abrasion resistant steel of claim 1, wherein the abrasion resistant steel has hardness (HB) and impact absorption

energy (J) satisfying relational expression 2 as below,

$$[\text{Relational Expression 2}] \quad \text{HB} \div \text{J} \leq 31.0,$$

where HB is surface hardness of the steel measured by the Brinell hardness tester, and J is an impact absorption energy value at -40°C.

5. The abrasion resistant steel of claim 1, wherein the abrasion resistant steel has a thickness of 60mm or less.

6. A method of manufacturing an abrasion resistant steel having excellent hardness and impact toughness, the method comprising:

heating a steel slab including, by weight%, 0.33-0.42% of carbon (C), 0.1-0.7% of silicon (Si), 0.6-1.6% of manganese (Mn), 0.05% or less of phosphorus (P) (excluding 0), 0.02% or less of sulfur (S) (excluding 0), 0.07% or less of aluminum (Al) (excluding 0), 0.55-5.0% of nickel (Ni), 0.01-1.5% of copper (Cu), 0.01-0.8% of chromium (Cr), 0.01-0.8% of molybdenum (Mo), 50 ppm or less of boron (B) (excluding 0), and 0.02% or less of cobalt (Co) (excluding 0) and further comprising one or more selected from a group consisting of 0.02% or less of titanium (Ti) (excluding 0), 0.05% or less of niobium (Nb) (excluding 0), 0.05% or less of vanadium (V) (excluding 0) and 2-100 ppm of calcium (Ca), with a balance of Fe and other inevitable impurities, where C and Ni satisfy relational expression 1 as below, in a temperature range of 1050-1250°C;

obtaining a rough-rolled bar by rough-rolling the reheated steel slab in a temperature range of 950-1050°C;

obtaining a hot-rolled steel sheet by finishing-hot-rolling the rough-rolled bar in a temperature range of 850-950°C;

air-cooling the hot-rolled steel sheet to room temperature and reheating the steel sheet for a residence time of $1.3t+10\text{min}$ - $1.3t+60\text{min}$ (t: sheet thickness) in a temperature range of 860-950°C; and

water-cooling the reheated hot-rolled steel sheet to 150°C or less.

$$[\text{Relational Expression 1}] \quad [\text{C}] \times [\text{Ni}] \geq 0.231$$

7. The method of claim 6, wherein the steel slab further includes one or more selected from a group consisting of 0.05% or less of arsenic (As) (excluding 0), 0.05% or less of tin (Sn) (excluding 0), and 0.05% or less of tungsten (W) (excluding 0).

8. The method of claim 6, wherein a cooling rate is 10°C/s or more in the water-cooling.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2019/012325

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/58(2006.01)i, C22C 38/42(2006.01)i, C22C 38/44(2006.01)i, C22C 38/54(2006.01)i, C22C 38/52(2006.01)i,
C22C 38/04(2006.01)i, C22C 38/02(2006.01)i, C22C 38/06(2006.01)i, C21D 8/02(2006.01)i
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C 38/58; C21D 8/02; C22C 38/00; C22C 38/06; C22C 38/32; C22C 38/38; C22C 38/44; C22C 38/54; C22C 38/42; C22C 38/52;
C22C 38/04; C22C 38/02

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: steel, carbon, silicone, manganese, nickel, copper, martensite, bainite, coil, rolling

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2011-214120 A (JFE STEEL CORP.) 27 October 2011 See paragraphs [0009], [0014], [0037], [0040]-[0042] and claims 1-2.	1-8
A	KR 10-2015-0038590 A (JFE STEEL CORPORATION) 08 April 2015 See paragraphs [0085]-[0089], [0120] and claims 1-6.	1-8
A	KR 10-2018-0073368 A (POSCO) 02 July 2018 See paragraph [0009] and claims 1, 3-4.	1-8
A	KR 10-1271792 B1 (POSCO) 07 June 2013 See claims 1-11.	1-8
A	US 2014-0193667 A1 (SHUTO et al.) 10 July 2014 See paragraphs [0195]-[0197] and claims 1-15.	1-8

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

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

27 DECEMBER 2019 (27.12.2019)

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

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