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(54) **HIGH-HARDNESS STEEL SHEET, AND MANUFACTURING METHOD THEREFOR**

(57) The objective of one aspect of the present invention is to provide a high-hardness steel sheet and a manufacturing method, the high-hardness steel sheet having Brinell hardness of 500 HB or more by setting a steel composition according to a minimum carbon content relation (1). Another aspect of the present invention relates to, as a high-hardness steel sheet having Brinell hardness of 500 HB or more and to be manufactured by comprising a process of cooling a hot rolled steel sheet, a high-hardness steel sheet having a minimum carbon (C) content which meets the following relation (1), having a microstructure comprising 95 vol% or more of martensite phase, and having Brinell hardness of 500 HB or more; and a manufacturing method therefor.

[Relation 1] C (minimum carbon (c) content)  $\geq$

$0.481 - 0.104\text{Mn} - 0.035\text{Si} - 0.088\text{Cr} - 0.054\text{Ni} - 0.035\text{Mo} - 0.0003\text{C.R.}$

(wherein Mn, Si, Cr, Ni and Mo are a value representing the content of each element by wt%, and C.R. is a value represent cooling rate during cooling a hot rolled steel sheet and the unit thereof is °C /sec)

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**Description**

[Technical Field]

5 **[0001]** The present disclosure relates to a high-hardness steel sheet used in various fields and a manufacturing method thereof.

[Background Art]

10 **[0002]** A steel sheet having high hardness is excellent in terms of wear resistance and load supporting ability, thus guaranteeing long service life as well as durability, and is used in various components.

**[0003]** In detail, in the case of wear-resistant steel, a steel grade is defined on the basis of Brinell hardness, and steel is manufactured to have various levels of hardness, from a Brinell hardness (HB) grade of 350 to a HB grade of 600, according to the related art.

15 **[0004]** Moreover, a steel sheet having high hardness also has high strength, and thus may even be used in a field requiring a structure having high strength, such as a collision member or a reinforcing member. In addition, the steel sheet described above may have good economic value in terms of lightweightness and efficiency.

**[0005]** In the case of the high-hardness steel sheet described above, a steel sheet is phase-transformed to a martensite or bainite structure in a cooling process from an austenite temperature range to room temperature, so high hardness and strength, which a low temperature transformation structure has, are generally provided.

20 **[0006]** However, in the prior art, various components and process control methods are used to obtain the required hardness according to a component, but a criteria for unified hardness acquisition is not provided.

[Disclosure]

25

[Technical Problem]

**[0007]** An aspect of the present disclosure may provide a high-hardness steel sheet having a Brinell hardness of 500 HB or more in which a steel composition is set using a minimum carbon content relation for obtaining a Brinell hardness of 500 HB or more.

30 **[0008]** Another aspect of the present disclosure may provide a method of manufacturing a high-hardness steel sheet having a Brinell hardness of 500 HB or more by setting a steel composition according to a minimum carbon content relation for obtaining a Brinell hardness of 500 HB or more.

35 [Technical Solution]

**[0009]** According to an aspect of the present disclosure, a high-hardness steel sheet having a Brinell hardness of 500 HB or more, the steel sheet manufactured by including cooling of a hot rolled steel sheet, includes carbon (C) : 0.05 wt% to 0.3 wt%, silicon (Si) : 0.5 wt% or less (excluding 0%), manganese (Mn) : 2.5 wt% or less (excluding 0%), chrome (Cr) : 1.5 wt% or less (excluding 0%), molybdenum (Mo) : 1.0 wt% or less (excluding 0%), nickel (Ni) : 1.0 wt% or less (excluding 0%), niobium (Nb) : 0.1wt% or less (excluding 0%), titanium (Ti) : 0.1 wt% or less (excluding 0%), vanadium (V) : 0.1 wt% or less (excluding 0%), boron (B) : 0.01 wt% or less (excluding 0%), aluminum (Al) : 0.1 wt% or less (excluding 0%), a balance of iron (Fe) and other unavoidable impurities; has a minimum content of carbon (C) satisfying Relation(1); and has a microstructure including 95 vol.% or more of a martensite phase.

45

[Relation 1]

C (a minimum content of carbon (C))  $\geq$

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$$0.481-0.104\text{Mn}-0.035\text{Si}-0.088\text{Cr}-0.054\text{Ni}-0.035\text{Mo}-0.0003\text{C.R.}$$

**[0010]** Here, Mn, Si, Cr, Ni, and Mo are values representing the content of each element by wt%, C.R. is a value representing a cooling rate during cooling of a hot-rolled steel sheet, and the unit thereof is °C/sec.

55 **[0011]** According to another aspect of the present disclosure, a method of manufacturing a high-hardness steel sheet, the method of manufacturing a steel sheet, having a microstructure including 95 vol.% or more of a martensite phase and a Brinell hardness of 500 HB or more, includes hot-rolling and cooling a steel slab including carbon (C) : 0.05 wt% to 0.3 wt%, silicon (Si) : 0.5 wt% or less (excluding 0%), manganese (Mn) : 2.5 wt% or less (excluding 0%), chrome (Cr) :

1.5 wt% or less (excluding 0%), molybdenum (Mo): 1.0 wt% or less (excluding 0%), nickel (Ni) : 1.0 wt% or less (excluding 0%), niobium (Nb) : 0.1 wt% or less (excluding 0%), titanium (Ti) : 0.1 wt% or less (excluding 0%), vanadium (V): 0.1 wt% or less (excluding 0%), boron (B) : 0.01 wt% or less (excluding 0%), aluminum (Al) : 0.1 wt% or less (excluding 0%), a balance of iron (Fe) and other unavoidable impurities, as a hot-rolled steel sheet, wherein a minimum content of carbon (C) satisfies Relation(1).

[Relation 1]

$$C(a \text{ minimum content of carbon } (C)) \geq 0.481 - 0.104Mn - 0.035Si - 0.088Cr - 0.054Ni - 0.035Mo - 0.0003C.R.$$

**[0012]** Here, Mn, Si, Cr, Ni, and Mo are values representing the content of each element by wt%, C.R. is a value representing a cooling rate during cooling of a hot-rolled steel sheet, and the unit thereof is °C/sec.

[Advantageous Effects]

**[0013]** According to an exemplary embodiment in the present disclosure, in order to manufacture a steel sheet including a microstructure having 95 vol.% or more of a martensite phase and Brinell hardness of 500 HB or more, a component of a more economical and unified steel sheet may be designed.

[Best Mode for Invention]

**[0014]** The prior art related to a high-hardness steel sheet has proposed various components and process control methods in order to obtain a level of hardness required, according to the components, but fails to provide a component criteria for unified hardness acquisition.

**[0015]** Therefore, the present inventors have conducted studies and experiments on the conditions of component design for securing a required level of hardness, when a microstructure of a steel sheet is formed to have 95 vol. % or more of a martensite structure in order to secure a high level of hardness and strength, and the present invention has been completed on the basis of the results thereof.

**[0016]** In other words, one of the main technical features of the present invention is to provide the conditions of a component design for securing a required level of hardness when a microstructure of a steel sheet is formed as 95 vol.% or more of a martensite structure in order to secure high hardness and strength, and thus, more economically manufacturing a microstructure including 95 vol.% or more of a martensite phase and a steel sheet having a Brinell hardness of 500 HB or more, and obtaining unified hardness.

**[0017]** Hereinafter, a steel sheet according to a preferred aspect of the present invention will be described.

Carbon (C): 0.05 wt% to 0.3 wt% (hereinafter, referred to as "%")

**[0018]** The content of carbon (C) may be 0.05% to 0.3%.

**[0019]** When the content of carbon is less than 0.05%, it may be difficult for martensitic transformation from an austenite region to occur during cooling. When the content of carbon exceeds 0.3%, it may be difficult to ensure stability of a component due to increased brittleness of steel.

**[0020]** The content of carbon (C) may be 0.19 wt% to 0.3%.

Silicon (Si): 0.5% or less (excluding 0%)

**[0021]** The content of silicon (Si) may be 0.5% or less (excluding 0%).

**[0022]** Silicon is a preferred alloying element in applications in which hardness is used, because silicon increases the wear resistance of steel. However, when an amount of Si is excessive, surface properties and plating properties of the steel become poor, and a complete austenitization may not be performed during reheating.

**[0023]** The content of silicon (Si) may be 0.21% to 0.5%. The content of silicon (Si) may be 0.253% to 0.34%.

Manganese (Mn): 2.5% or less (excluding 0%) and Chrome (Cr): 1.5% or less (excluding 0%)

**[0024]** Manganese (Mn) and chrome (Cr) are elements significantly lowering martensite transformation temperatures, and manganese and chrome are elements, which may be used economically as low-cost elements, since manganese

and chrome have an effect of reducing a transformation temperature less than that of carbon, among elements generally added to steel.

**[0025]** An upper limit of the manganese content is preferably limited to 2.5%, and an upper limit of the chromium content is preferably limited to 1.5%.

**[0026]** When the contents of manganese and chrome are excessively high, austenite may remain at room temperature, so 95 vol.% or more of a martensitic structure, a targeted amount, may not be obtained.

**[0027]** The content of manganese may be 1.4% to 2.5%. The content of manganese may be 2.1% to 2.5%.

Molybdenum (Mo): 1.0% or less (excluding 0%) and Nickel (Ni): 1.0% or less (excluding 0%)

**[0028]** Molybdenum (Mo) and nickel (Ni) are elements lowering a martensite transformation start temperature.

**[0029]** However, a degree of lowering a martensite transformation start temperature is smaller than those of Mn and Cr. Due to being relatively expensive elements, an upper limit of an addition amount of each of these elements is preferably limited to 1.0%.

Niobium (Nb): 0.1% or less (excluding 0%) and Titanium (Ti): 0.1% or less (excluding 0%),

**[0030]** Each of niobium (Nb) and titanium (Ti) may be added in an amount of 0.1% or less (excluding 0%), and may have an effect of improving the impact characteristics of a steel sheet through austenite grain refinement. However, the excessive addition of Nb and Ti may cause coarsening of Nb carbonitride, fixing grain boundaries, so a crystal grain refinement effect may be lost. Thus, an upper limit of each of Nb and Ti is preferably limited to 0.1%.

**[0031]** On the other hand, when B is added, Ti may be essentially added to protect B from N. Titanium (Ti) first reacts with carbon or nitrogen in steel, so TiC or TiN is formed. Thus, an addition effect of boron (B) may be increased. In this case, the content of titanium (Ti) may satisfy Relation 2 depending on stoichiometry, with respect to an amount of nitrogen in steel.

[Relation 2]

$$\text{Ti (wt\%)} > \text{N (wt\%)} \times 3.42$$

Vanadium (V): 0.1% or less (excluding 0%)

**[0032]** Vanadium (V) may be added in an amount of 0.1% or less (excluding 0%), and may serve to prevent precipitation hardening through the formation of fine V carbides and the deterioration of physical properties of a welded portion.

**[0033]** When an addition amount of V is excessive, the effect described above may be reduced due to the coarsening of a carbide, so that an upper limit of the content of V is preferably limited to 0.1%.

Boron (B): 0.01% or less (excluding 0%)

**[0034]** Boron (B) may be added in an amount of 0.01% or less (excluding 0%), and B is an element significantly increasing hardenability of steel by inhibiting nucleation of ferrite and pearlite. Even when a thickness of steel is great, utilization thereof is significant.

**[0035]** In the present invention, a final microstructure may be provided as 95 vol.% or more of martensite. A manufacturing method thereof is not particularly limited, so B may be added to secure hardenability as required. However, when the content of B is excessively added, B may rather act as a nucleation site on ferrite or pearlite to deteriorate hardenability, so an upper limit of the content of B is preferably limited to 0.01%.

Aluminum (Al): 0.1% or less (excluding 0%)

**[0036]** Aluminum (Al) is added for deoxidization and grain refinement, and the content of Al is preferably limited to 0.1% or less (excluding 0%).

**[0037]** The remainder excluding elements described above include iron (Fe) and other unavoidable impurities.

**[0038]** In the present invention, a minimum content of carbon (C) may satisfy Relation (1).

[Relation 1]

$C(\text{a minimum content of carbon (C)}) \geq$

$0.481 - 0.104\text{Mn} - 0.035\text{Si} - 0.088\text{Cr} - 0.054\text{Ni} - 0.035\text{Mo} - 0.0003\text{C.R.}$

**[0039]** Here, Mn, Si, Cr, Ni, and Mo are values representing the content of each element by wt%, C.R. is a value representing a cooling rate during cooling of a hot-rolled steel sheet, and the unit thereof is °C/sec.

**[0040]** Relation (1) represents a minimum content of a carbon (C) for obtaining a Brinell hardness of 500 HB or more from a composition of silicon (Si), manganese (Mn), chrome (Cr), molybdenum (Mo), nickel (Ni), and chrome (Cr).

**[0041]** Even when the content of carbon (C) satisfies 0.05 wt% to 0.3 wt%, in a case in which Relation (1) is not satisfied, a Brinell hardness of 500 HB or more may not be obtained.

**[0042]** Relation (1) may be designed using, for example, Relation (3).

[Relation 3]

$\text{HB (Brinell hardness)} = 100.4 + 830.5 \cdot C + 86.5 \cdot \text{Mn} + 28.8 \cdot \text{Si}$

$+ 73.4 \cdot \text{Cr} + 44.5 \cdot \text{Ni} + 28.8 \cdot \text{Mo} + 0.252 \cdot \text{C.R.}$

**[0043]** Here, C, Mn, Si, Cr, Ni, and Mo are values representing the content of each element by wt%, C.R. is a value representing a cooling rate during cooling of a hot-rolled steel sheet, and the unit thereof is °C/sec.

**[0044]** Relation (1) with respect to a minimum carbon content for HB  $\geq 500$  may be derived from Relation (3).

**[0045]** Moreover, by using Relation (3) within a steel sheet component range of the present invention, proper alloying element design conditions to obtain any required level of hardness of 350 HB or more may be derived.

**[0046]** A microstructure of a steel sheet according to the present invention may include 95 vol.% or more of a martensite phase.

**[0047]** When a fraction of the martensite phase is less than 95 vol.%, it may be difficult to secure targeted strength and hardness.

**[0048]** The microstructure of a steel sheet according to the present invention may include one or two of ferrite and bainite, in an amount of less than 5.0 vol.%, as a second phase structure, other than martensite.

**[0049]** The steel sheet according to the present invention may have Brinell hardness of 500 HB or more.

**[0050]** Hereinafter, a method of manufacturing a steel sheet according to another preferred aspect of the present invention will be described.

**[0051]** In a method of manufacturing a steel sheet according to another preferred aspect of the present invention, after a steel slab including carbon (C) : 0.05 wt% to 0.3 wt%, silicon (Si) : 0.5 wt% or less (excluding 0%), manganese (Mn) : 2.5 wt% or less (excluding 0%), chrome (Cr) : 1.5 wt% or less (excluding 0%), molybdenum (Mo) : 1.0 wt% or less (excluding 0%), nickel (Ni) : 1.0 wt% or less (excluding 0%), niobium (Nb) : 0.1 wt% or less (excluding 0%), titanium (Ti) : 0.1 wt% or less (excluding 0%), vanadium (V) : 0.1 wt% or less (excluding 0%), boron (B) : 0.01 wt% or less (excluding 0%), aluminum (Al) : 0.1 wt% or less (excluding 0%), a balance of iron (Fe) and other unavoidable impurities is hot-rolled as a hot-rolled steel sheet, the hot-rolled steel sheet is cooled, so a steel sheet having a martensite phase including 95 vol.% or more of a microstructure and 500 HB or more of Brinell hardness is manufactured.

**[0052]** A minimum content of carbon (C) in the steel slab satisfies Relation (1).

[Relation 1]

$C(\text{a minimum content of carbon (C)}) \geq$

$0.481 - 0.104\text{Mn} - 0.035\text{Si} - 0.088\text{Cr} - 0.054\text{Ni} - 0.035\text{Mo} - 0.0003\text{C.R.}$

**[0053]** Here, Mn, Si, Cr, Ni, and Mo are values representing the content of each element by wt%, C.R. is a value representing a cooling rate during cooling of a hot-rolled steel sheet, and the unit thereof is °C/sec.

**[0054]** Before the steel slab is hot-rolled as a hot-rolled steel sheet, a steel slab may be reheated.

**[0055]** Conditions for reheating a slab are not particularly limited, and the conditions are sufficient as long as homog-

enization is allowed.

**[0056]** A slab reheating temperature is preferably 1100°C to 1300°C.

**[0057]** The hot-rolling conditions are preferably not limited, and a hot finish rolling temperature is sufficient as long as austenitization is allowed.

**[0058]** The hot finish rolling temperature may be, for example, 870°C to 930°C, and whole hot-rolling may be performed within a temperature range of 1150°C to a hot finish rolling temperature, after extraction from a heating furnace.

**[0059]** A cooling rate during cooling the hot-rolled steel sheet is not preferably limited while a cooling rate allows 95 vol.% or more of a martensite phase to be obtained. For example, the cooling rate is 20°C/sec or more, and preferably, 20°C/sec to 150°C/sec.

**[0060]** A cooling end temperature during cooling the hot-rolled steel sheet is the Ms point (a martensite transformation start temperature) or below, and is not particularly limited as long as a cooling end temperature allows 95 vol.% or more of a martensite phase to be obtained.

[Mode for Invention]

**[0061]** Hereinafter, the present disclosure will be described in greater detail with reference to examples. The examples are only for illustrating the present invention, and the present invention is not limited thereto.

(Example)

**[0062]** An experiment was conducted using 17 types of steel A to Q having the compositions (unit: wt%) illustrated in Table 1.

**[0063]** The compositions of steels of Table 1 satisfy a composition range of the present invention.

**[0064]** After a steel sheet having the steel composition of Table 1 while having a thickness of 30 mm and a width of 200 mm was manufactured, the steel sheet was reheated for 180 minutes at 1200°C. Next, the steel sheet, having been reheated, was hot-rolled in a hot finish temperature range of 900°C, and a hot-rolled steel sheet having a thickness of 3.0 mm was manufactured. Thereafter, the steel sheet was cooled to 200°C at a cooling rate of Table 2.

**[0065]** Brinell hardness (HB) and a microstructure of the hot-rolled steel sheet manufactured as described above were measured, and results thereof are illustrated in Table 2.

**[0066]** A second phase structure of Table 2 indicates a second phase structure, other than martensite. Moreover, a structure other than a second phase structure is martensite, and 100% martensite is referred to as 100%M.

**[0067]** In the second phase structure described above, F indicates ferrite, B indicates bainite, and M indicates martensite.

**[0068]** Moreover, in Table 2, a required carbon content obtained by Relation (1), an actual carbon content, and a difference between the actual content and the required carbon content are illustrated.

[Table 1]

| Steel | C     | Si    | Mn   | Cr    | Mo    | Ni    | Al    | Ti    | Nb    | V     | B      |
|-------|-------|-------|------|-------|-------|-------|-------|-------|-------|-------|--------|
| A     | 0.081 | 0.298 | 1.85 | 0.498 | 0.101 | 0.008 | 0.03  | 0.006 | 0.032 | 0.006 | 0.0002 |
| B     | 0.121 | 0.351 | 2.11 | 0.313 | 0.798 | 0.012 | 0.032 | 0.025 | 0.023 | 0.005 | 0.0017 |
| C     | 0.195 | 0.354 | 2.01 | 0.297 | 0.006 | 0.812 | 0.031 | 0.029 | 0.025 | 0.003 | 0.0016 |
| D     | 0.152 | 0.248 | 1.49 | 0.296 | 0.008 | 0.011 | 0.033 | 0.03  | 0.056 | 0.005 | 0.003  |
| E     | 0.242 | 0.432 | 1.72 | 0.411 | 0.312 | 0.013 | 0.036 | 0.03  | 0.003 | 0.006 | 0.0033 |
| F     | 0.148 | 0.243 | 1.48 | 0.607 | 0.012 | 0.005 | 0.034 | 0.029 | 0.004 | 0.004 | 0.0032 |
| G     | 0.148 | 0.24  | 1.48 | 0.3   | 0.007 | 0.007 | 0.035 | 0.098 | 0.005 | 0.005 | 0.0033 |
| H     | 0.297 | 0.253 | 1.51 | 0.3   | 0.211 | 0.006 | 0.035 | 0.03  | 0.007 | 0.002 | 0.0016 |
| I     | 0.212 | 0.25  | 1.49 | 1.1   | 0.203 | 0.008 | 0.035 | 0.03  | 0.022 | 0.098 | 0.0029 |
| J     | 0.2   | 0.249 | 1.47 | 0.3   | 0.011 | 0.021 | 0.03  | 0.029 | 0.005 | 0.003 | 0.0029 |
| K     | 0.252 | 0.254 | 2.31 | 0.125 | 0.012 | 0.015 | 0.033 | 0.03  | 0.032 | 0.005 | 0.0028 |
| L     | 0.198 | 0.243 | 1.49 | 0.297 | 0.015 | 0.023 | 0.034 | 0.03  | 0.008 | 0.004 | 0.0031 |
| M     | 0.199 | 0.254 | 1.47 | 1.12  | 0.012 | 0.015 | 0.033 | 0.03  | 0.032 | 0.005 | 0.0028 |

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(continued)

| Steel | C     | Si    | Mn   | Cr    | Mo    | Ni    | Al    | Ti    | Nb    | V     | B      |
|-------|-------|-------|------|-------|-------|-------|-------|-------|-------|-------|--------|
| N     | 0.2   | 0.207 | 1.47 | 0.3   | 0.011 | 0.014 | 0.034 | 0.098 | 0.045 | 0.002 | 0.0025 |
| O     | 0.26  | 0.297 | 2.11 | 0.02  | 0.101 | 0.005 | 0.027 | 0.007 | 0.022 | 0.011 | 0.0003 |
| P     | 0.27  | 0.212 | 1.51 | 0.52  | 0.112 | 0.012 | 0.021 | 0.005 | 0.023 | 0.012 | 0.0020 |
| Q     | 0.232 | 0.491 | 1.78 | 0.298 | 0.005 | 0.003 | 0.026 | 0.021 | 0.015 | 0.055 | 0.0018 |

[Table 2]

| Classification        | Steel | Ms (°C) | Cooling rate (°C/sec) | Required carbon content (wt.%, Relation 1) ① | Actual carbon content (wt.%) ② | ②-①    | Brinell hardness (HB) | Second phase structure |
|-----------------------|-------|---------|-----------------------|----------------------------------------------|--------------------------------|--------|-----------------------|------------------------|
| Comparative Example 1 | A     | 432     | 100                   | 0.200                                        | 0.081                          | -0.119 | 395                   | F8%, B11%              |
| Comparative Example 2 | B     | 401     | 50                    | 0.178                                        | 0.121                          | -0.057 | 445                   | F2%, B3%               |
| Inventive Example 1   | C     | 381     | 50                    | 0.174                                        | 0.195                          | 0.021  | 519                   | B3%                    |
| Comparative Example 3 | D     | 433     | 50                    | 0.275                                        | 0.152                          | -0.123 | 404                   | F1%, B4%               |
| Inventive Example 2   | E     | 387     | 35                    | 0.229                                        | 0.242                          | 0.013  | 505                   | F1%, B3%               |
| Inventive Example 3   | E     | 379     | 70                    | 0.218                                        | 0.242                          | 0.024  | 523                   | 100%M                  |
| Comparative Example 4 | F     | 425     | 50                    | 0.249                                        | 0.148                          | -0.101 | 405                   | B4%                    |
| Comparative Example 5 | G     | 434     | 20                    | 0.286                                        | 0.148                          | -0.138 | 364                   | F6%, B7%               |
| Inventive Example 4   | H     | 380     | 50                    | 0.266                                        | 0.297                          | 0.031  | 531                   | B3%                    |
| Inventive Example 5   | I     | 379     | 35                    | 0.202                                        | 0.212                          | 0.010  | 511                   | 100%M                  |
| Comparative Example 6 | J     | 411     | 35                    | 0.281                                        | 0.2                            | -0.081 | 437                   | F2%, B2%               |
| Inventive Example 6   | K     | 372     | 100                   | 0.190                                        | 0.252                          | 0.062  | 551                   | 100%M                  |
| Comparative Example 7 | L     | 417     | 35                    | 0.279                                        | 0.198                          | -0.081 | 440                   | F2%, B2%               |

(continued)

| Classification        | Steel | Ms (°C) | Cooling rate (°C/sec) | Required carbon content (wt.%, Relation 1) ① | Actual carbon content (wt.%) ② | ②-①    | Brinell hardness (HB) | Second phase structure |
|-----------------------|-------|---------|-----------------------|----------------------------------------------|--------------------------------|--------|-----------------------|------------------------|
| Comparative Example 8 | M     | 394     | 20                    | 0.213                                        | 0.199                          | -0.014 | 491                   | F1%, B3%               |
| Comparative Example 9 | N     | 417     | 70                    | 0.272                                        | 0.2                            | -0.072 | 448                   | B4%                    |
| Inventive Example 7   | O     | 377     | 80                    | 0.222                                        | 0.26                           | 0.038  | 527                   | B3%                    |
| Inventive Example 8   | P     | 386     | 50                    | 0.251                                        | 0.27                           | 0.019  | 510                   | B2%                    |
| Inventive Example 9   | Q     | 396     | 100                   | 0.222                                        | 0.232                          | 0.010  | 502                   | B3%                    |

**[0069]** As illustrated in Table 2, according to the present invention, in the case of Inventive Examples 1 through 9, in which an actual carbon content is larger than a required carbon content, it is confirmed that a Brinell hardness (HB) value is 500 HB or more.

**[0070]** On the other hand, in the case of Comparative Examples 1 through 9, in which an actual carbon content is smaller than a required carbon content, it is confirmed that a value of Brinell hardness is less than 500 HB.

**[0071]** While exemplary embodiments have been shown and described above, it will be apparent to those skilled in the art that modifications and variations could be made without departing from the scope of the present invention as defined by the appended claims.

## Claims

1. A high-hardness steel sheet, the steel sheet provided by cooling a hot rolled steel sheet, comprising:

carbon (C): 0.05 wt% to 0.3 wt%, silicon (Si): 0.5 wt% or less (excluding 0%), manganese (Mn): 2.5 wt% or less (excluding 0%), chrome (Cr): 1.5 wt% or less (excluding 0%), molybdenum (Mo): 1.0 wt% or less (excluding 0%), nickel (Ni): 1.0 wt% or less (excluding 0%), niobium (Nb): 0.1 wt% or less (excluding 0%), titanium (Ti): 0.1 wt% or less (excluding 0%), vanadium (V): 0.1 wt% or less (excluding 0%), boron (B): 0.01 wt% or less (excluding 0%), aluminum (Al): 0.1 wt% or less (excluding 0%), a balance of iron (Fe) and other unavoidable impurities;

having a minimum content of carbon (C) satisfying Relation (1);

having a microstructure comprising 95 vol.% or more of a martensite phase; and

having a Brinell hardness of 500 HB or more,

[Relation 1]

$$C \text{ (a minimum content of carbon (C))} \geq$$

$$0.481 - 0.104Mn - 0.035Si - 0.088Cr - 0.054Ni - 0.035Mo - 0.0003C.R.$$

where Mn, Si, Cr, Ni, and Mo are values representing the content of each element by wt%, C.R. is a value representing a cooling rate during the cooling a hot-rolled steel sheet, and the unit thereof is °C/sec.

2. The high-hardness steel sheet of claim 1, wherein the microstructure includes one or two of ferrite and bainite, in an amount of less than 5.0 vol.%, as a second phase structure, other than martensite.

3. The high-hardness steel sheet of claim 1, wherein Relation (1) is derived from Relation (3),

[Relation 3]

$$\text{HB (Brinell hardness)} = 100.4 + 830.5 \cdot C + 86.5 \cdot \text{Mn} + 28.8 \cdot \text{Si} \\ + 73.4 \cdot \text{Cr} + 44.5 \cdot \text{Ni} + 28.8 \cdot \text{Mo} + 0.252 \cdot \text{C.R.}$$

where C, Mn, Si, Cr, Ni, and Mo are values representing the content of each element by wt%, C.R. is a value representing a cooling rate during the cooling of a hot-rolled steel sheet, and the unit thereof is °C/sec.

4. The high-hardness steel sheet of any one of claims 1 to 3, wherein the content of carbon (C) is 0.19 wt% to 0.3 wt%.

5. The high-hardness steel sheet of any one of claims 1 to 3, wherein the content of silicon (Si) is 0.21 wt% to 0.5 wt%.

6. The high-hardness steel sheet of any one of claims 1 to 3, wherein the content of manganese is 1.4 wt% to 2.5 wt%.

7. A method of manufacturing a high-hardness steel sheet, the method of manufacturing a steel sheet, having a microstructure comprising 95 vol. % or more of a martensite phase and a Brinell hardness of 500 HB or more, comprising: hot-rolling and cooling a steel slab including carbon (C) : 0.05 wt% to 0.3 wt%, silicon (Si): 0.5 wt% or less (excluding 0%), manganese (Mn): 2.5 wt% or less (excluding 0%), chrome (Cr): 1.5 wt% or less (excluding 0%), molybdenum (Mo) : 1.0 wt% or less (excluding 0%), nickel (Ni): 1.0 wt% or less (excluding 0%), niobium (Nb): 0.1 wt% or less (excluding 0%), titanium (Ti): 0.1 wt% or less (excluding 0%), vanadium (V): 0.1 wt% or less (excluding 0%), boron (B): 0.01 wt% or less (excluding 0%), aluminum (Al) : 0.1 wt% or less (excluding 0%), a balance of iron (Fe) and other unavoidable impurities, as a hot-rolled steel sheet, wherein a minimum content of carbon (C) satisfies Relation (1),

[Relation 1]

$$C \text{ (a minimum content of carbon (C))} \geq \\ 0.481 - 0.104\text{Mn} - 0.035\text{Si} - 0.088\text{Cr} - 0.054\text{Ni} - 0.035\text{Mo} - 0.0003\text{C.R.}$$

where Mn, Si, Cr, Ni, and Mo are values representing the content of each element by wt%, C.R. is a value representing a cooling rate during cooling of a hot-rolled steel sheet, and the unit thereof is °C/sec.

8. The method of manufacturing a high-hardness steel sheet of claim 7, wherein a cooling rate during the cooling of the hot-rolled steel sheet is 20°C/sec to 150°C/sec.

9. The method of manufacturing a high-hardness steel sheet of claim 7 or 8, wherein a cooling end temperature during the cooling of the hot-rolled steel sheet is the Ms point (a martensite transformation start temperature) or below.

10. The method of manufacturing a high-hardness steel sheet of claim 7 or 8, wherein the content of carbon (C) is 0.19% to 0.3%.

11. The method of manufacturing a high-hardness steel sheet of claim 7 or 8, wherein the content of silicon (Si) is 0.21% to 0.5%.

12. The method of manufacturing a high-hardness steel sheet of claim 7 or 8, wherein the content of manganese is 1.4% to 2.5%.

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2016/009079

| <p>A. CLASSIFICATION OF SUBJECT MATTER<br/> <i>C22C 38/58(2006.01)i, C22C 38/54(2006.01)i, C22C 38/50(2006.01)i, C22C 38/48(2006.01)i, C22C 38/46(2006.01)i, C22C 38/44(2006.01)i, C21D 8/02(2006.01)i</i><br/>           According to International Patent Classification (IPC) or to both national classification and IPC</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                     |                                                                                                          |                                                                                                                                                                              |                                                                                                                                           |                                                                                                                                                                                                                                                  |                                                                                                                                                                         |                                                                                       |                                                                              |   |                                                                                                        |      |   |                                                                                        |      |   |                                                                                                  |      |
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| <p>B. FIELDS SEARCHED</p> <p>Minimum documentation searched (classification system followed by classification symbols)<br/>           C22C 38/58; C21D 8/02; C22C 38/00; C21D 9/30; C21D 8/00; C22C 38/54; C22C 38/50; C22C 38/48; C22C 38/46; C22C 38/44</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                     |                                                                                                          |                                                                                                                                                                              |                                                                                                                                           |                                                                                                                                                                                                                                                  |                                                                                                                                                                         |                                                                                       |                                                                              |   |                                                                                                        |      |   |                                                                                        |      |   |                                                                                                  |      |
| <p>Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched<br/>           Korean Utility models and applications for Utility models: IPC as above<br/>           Japanese Utility models and applications for Utility models: IPC as above</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                     |                                                                                                          |                                                                                                                                                                              |                                                                                                                                           |                                                                                                                                                                                                                                                  |                                                                                                                                                                         |                                                                                       |                                                                              |   |                                                                                                        |      |   |                                                                                        |      |   |                                                                                                  |      |
| <p>Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)<br/>           eKOMPASS (KIPO internal) &amp; Keywords: high hardened, toughened, cooling, hot rolled steel sheets, martensite, microstructure</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                     |                                                                                                          |                                                                                                                                                                              |                                                                                                                                           |                                                                                                                                                                                                                                                  |                                                                                                                                                                         |                                                                                       |                                                                              |   |                                                                                                        |      |   |                                                                                        |      |   |                                                                                                  |      |
| <p>C. DOCUMENTS CONSIDERED TO BE RELEVANT</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                     |                                                                                                          |                                                                                                                                                                              |                                                                                                                                           |                                                                                                                                                                                                                                                  |                                                                                                                                                                         |                                                                                       |                                                                              |   |                                                                                                        |      |   |                                                                                        |      |   |                                                                                                  |      |
| <table border="1"> <thead> <tr> <th>Category*</th> <th>Citation of document, with indication, where appropriate, of the relevant passages</th> <th>Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td>X</td> <td>KR 10-2012-0071614 A (POSCO) 03 July 2012<br/>See abstract; paragraphs [0017], [0058], [0071], [0072], [0086], [0087]; and claims 1, 2, 4.</td> <td>1-12</td> </tr> <tr> <td>X</td> <td>KR 10-2012-0070603 A (SUMITOMO METAL INDUSTRIES LTD.) 29 June 2012<br/>See claims 1-5.</td> <td>1-12</td> </tr> <tr> <td>A</td> <td>JP 2002-080930 A (NKK CORP.) 22 March 2002<br/>See abstract; paragraphs [0067]-[0069]; and claims 1-5.</td> <td>1-12</td> </tr> <tr> <td>A</td> <td>KR 10-2007-0004055 A (JFE STEEL CORPORATION) 05 January 2007<br/>See claims 2, 5 and 8.</td> <td>1-12</td> </tr> <tr> <td>A</td> <td>KR 10-0536828 B1 (NATIONAL RESEARCH INSTITUTE FOR METALS)<br/>28 February 2006<br/>See claims 1-3.</td> <td>1-12</td> </tr> </tbody> </table>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Category*                                                                                                                                                                                                                                                                                | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                  | Relevant to claim No.                                                                                    | X                                                                                                                                                                            | KR 10-2012-0071614 A (POSCO) 03 July 2012<br>See abstract; paragraphs [0017], [0058], [0071], [0072], [0086], [0087]; and claims 1, 2, 4. | 1-12                                                                                                                                                                                                                                             | X                                                                                                                                                                       | KR 10-2012-0070603 A (SUMITOMO METAL INDUSTRIES LTD.) 29 June 2012<br>See claims 1-5. | 1-12                                                                         | A | JP 2002-080930 A (NKK CORP.) 22 March 2002<br>See abstract; paragraphs [0067]-[0069]; and claims 1-5.  | 1-12 | A | KR 10-2007-0004055 A (JFE STEEL CORPORATION) 05 January 2007<br>See claims 2, 5 and 8. | 1-12 | A | KR 10-0536828 B1 (NATIONAL RESEARCH INSTITUTE FOR METALS)<br>28 February 2006<br>See claims 1-3. | 1-12 |
| Category*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                                                                       | Relevant to claim No.                                                                                                                                                                               |                                                                                                          |                                                                                                                                                                              |                                                                                                                                           |                                                                                                                                                                                                                                                  |                                                                                                                                                                         |                                                                                       |                                                                              |   |                                                                                                        |      |   |                                                                                        |      |   |                                                                                                  |      |
| X                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | KR 10-2012-0071614 A (POSCO) 03 July 2012<br>See abstract; paragraphs [0017], [0058], [0071], [0072], [0086], [0087]; and claims 1, 2, 4.                                                                                                                                                | 1-12                                                                                                                                                                                                |                                                                                                          |                                                                                                                                                                              |                                                                                                                                           |                                                                                                                                                                                                                                                  |                                                                                                                                                                         |                                                                                       |                                                                              |   |                                                                                                        |      |   |                                                                                        |      |   |                                                                                                  |      |
| X                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | KR 10-2012-0070603 A (SUMITOMO METAL INDUSTRIES LTD.) 29 June 2012<br>See claims 1-5.                                                                                                                                                                                                    | 1-12                                                                                                                                                                                                |                                                                                                          |                                                                                                                                                                              |                                                                                                                                           |                                                                                                                                                                                                                                                  |                                                                                                                                                                         |                                                                                       |                                                                              |   |                                                                                                        |      |   |                                                                                        |      |   |                                                                                                  |      |
| A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | JP 2002-080930 A (NKK CORP.) 22 March 2002<br>See abstract; paragraphs [0067]-[0069]; and claims 1-5.                                                                                                                                                                                    | 1-12                                                                                                                                                                                                |                                                                                                          |                                                                                                                                                                              |                                                                                                                                           |                                                                                                                                                                                                                                                  |                                                                                                                                                                         |                                                                                       |                                                                              |   |                                                                                                        |      |   |                                                                                        |      |   |                                                                                                  |      |
| A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | KR 10-2007-0004055 A (JFE STEEL CORPORATION) 05 January 2007<br>See claims 2, 5 and 8.                                                                                                                                                                                                   | 1-12                                                                                                                                                                                                |                                                                                                          |                                                                                                                                                                              |                                                                                                                                           |                                                                                                                                                                                                                                                  |                                                                                                                                                                         |                                                                                       |                                                                              |   |                                                                                                        |      |   |                                                                                        |      |   |                                                                                                  |      |
| A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | KR 10-0536828 B1 (NATIONAL RESEARCH INSTITUTE FOR METALS)<br>28 February 2006<br>See claims 1-3.                                                                                                                                                                                         | 1-12                                                                                                                                                                                                |                                                                                                          |                                                                                                                                                                              |                                                                                                                                           |                                                                                                                                                                                                                                                  |                                                                                                                                                                         |                                                                                       |                                                                              |   |                                                                                                        |      |   |                                                                                        |      |   |                                                                                                  |      |
| <p><input type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                     |                                                                                                          |                                                                                                                                                                              |                                                                                                                                           |                                                                                                                                                                                                                                                  |                                                                                                                                                                         |                                                                                       |                                                                              |   |                                                                                                        |      |   |                                                                                        |      |   |                                                                                                  |      |
| <table border="1"> <tr> <td>* Special categories of cited documents:</td> <td>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</td> </tr> <tr> <td>"A" document defining the general state of the art which is not considered to be of particular relevance</td> <td>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</td> </tr> <tr> <td>"E" earlier application or patent but published on or after the international filing date</td> <td>"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</td> </tr> <tr> <td>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</td> <td>"&amp;" document member of the same patent family</td> </tr> <tr> <td>"O" document referring to an oral disclosure, use, exhibition or other means</td> <td></td> </tr> <tr> <td>"P" document published prior to the international filing date but later than the priority date claimed</td> <td></td> </tr> </table> | * Special categories of cited documents:                                                                                                                                                                                                                                                 | "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention | "A" document defining the general state of the art which is not considered to be of particular relevance | "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone | "E" earlier application or patent but published on or after the international filing date                                                 | "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 | "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) | "&" document member of the same patent family                                         | "O" document referring to an oral disclosure, use, exhibition or other means |   | "P" document published prior to the international filing date but later than the priority date claimed |      |   |                                                                                        |      |   |                                                                                                  |      |
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| "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | "&" document member of the same patent family                                                                                                                                                                                                                                            |                                                                                                                                                                                                     |                                                                                                          |                                                                                                                                                                              |                                                                                                                                           |                                                                                                                                                                                                                                                  |                                                                                                                                                                         |                                                                                       |                                                                              |   |                                                                                                        |      |   |                                                                                        |      |   |                                                                                                  |      |
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| "P" document published prior to the international filing date but later than the priority date claimed                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                     |                                                                                                          |                                                                                                                                                                              |                                                                                                                                           |                                                                                                                                                                                                                                                  |                                                                                                                                                                         |                                                                                       |                                                                              |   |                                                                                                        |      |   |                                                                                        |      |   |                                                                                                  |      |
| <table border="1"> <tr> <td>Date of the actual completion of the international search<br/><b>26 OCTOBER 2016 (26.10.2016)</b></td> <td>Date of mailing of the international search report<br/><b>01 NOVEMBER 2016 (01.11.2016)</b></td> </tr> </table>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Date of the actual completion of the international search<br><b>26 OCTOBER 2016 (26.10.2016)</b>                                                                                                                                                                                         | Date of mailing of the international search report<br><b>01 NOVEMBER 2016 (01.11.2016)</b>                                                                                                          |                                                                                                          |                                                                                                                                                                              |                                                                                                                                           |                                                                                                                                                                                                                                                  |                                                                                                                                                                         |                                                                                       |                                                                              |   |                                                                                                        |      |   |                                                                                        |      |   |                                                                                                  |      |
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| <table border="1"> <tr> <td>Name and mailing address of the ISA/KR<br/> <br/>           Korean Intellectual Property Office<br/>           Government Complex-Daejeon, 189 Seonsa-ro, Daejeon 302-701,<br/>           Republic of Korea<br/>           Facsimile No. 82-42-472-7140</td> <td>Authorized officer<br/><br/>Telephone No.</td> </tr> </table>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Name and mailing address of the ISA/KR<br><br>Korean Intellectual Property Office<br>Government Complex-Daejeon, 189 Seonsa-ro, Daejeon 302-701,<br>Republic of Korea<br>Facsimile No. 82-42-472-7140 | Authorized officer<br><br>Telephone No.                                                                                                                                                             |                                                                                                          |                                                                                                                                                                              |                                                                                                                                           |                                                                                                                                                                                                                                                  |                                                                                                                                                                         |                                                                                       |                                                                              |   |                                                                                                        |      |   |                                                                                        |      |   |                                                                                                  |      |
| Name and mailing address of the ISA/KR<br><br>Korean Intellectual Property Office<br>Government Complex-Daejeon, 189 Seonsa-ro, Daejeon 302-701,<br>Republic of Korea<br>Facsimile No. 82-42-472-7140                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Authorized officer<br><br>Telephone No.                                                                                                                                                                                                                                                  |                                                                                                                                                                                                     |                                                                                                          |                                                                                                                                                                              |                                                                                                                                           |                                                                                                                                                                                                                                                  |                                                                                                                                                                         |                                                                                       |                                                                              |   |                                                                                                        |      |   |                                                                                        |      |   |                                                                                                  |      |

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INTERNATIONAL SEARCH REPORT  
Information on patent family members

International application No.

PCT/KR2016/009079

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member | Publication<br>date |
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