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

(72) Inventors:
• **KIM, Sunmi**
Pohang-si Gyeongsangbuk-do 37859 (KR)
• **KIM, Hakjun**
Pohang-si Gyeongsangbuk-do 37859 (KR)

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

(54) **HIGH-CARBON HOT-ROLLED STEEL SHEET, HIGH CARBON STEEL PRODUCT USING SAME AND METHOD OF MANUFACTURING SAME**

(57) The high-carbon steel product according to the present invention can be manufactured by cold working a high-carbon hot-rolled steel sheet comprising, by weight%, C: 0.70-0.90%, Mn: 0.2-0.6%, Si: 0.1-0.5%, Cr: 0.1-0.5%, Al: 0.007-0.015%, Ni: 0.4-2.0%, V: 0.1%

or less (including 0%), and the balance of Fe and inevitable impurities; subsequently heating and maintaining same at a temperature of 850-950°C for 1-90 minutes; cooling same at an average cooling rate of 7°C/sec or higher; and tempering same.

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Description**[Technical Field]**

- 5 **[0001]** The present invention primarily relates to a technology for manufacturing a high-carbon steel product, such as cutting tools, such as saw blades.
- [0002]** More specifically, the present invention relates to a high-carbon hot-rolled steel sheet suitable for manufacturing a high-carbon steel product with excellent weldability and impact toughness, and a high-carbon steel sheet product using the same.
- 10 **[0003]** In addition, the present invention relates to a method of manufacturing a high-carbon hot-rolled steel sheet and a method of manufacturing a high-carbon steel product.

[Background Art]

- 15 **[0004]** Demand for saw blade materials, necessary for cutting wood, stone, metal, and other materials used in civil engineering, construction, and other fields, is increasing. Saw blades need to rotate at high speeds to cut materials and withstand axial and radial stresses during cutting, and thus materials suitable for the saw blades require high levels of hardness, rigidity, fatigue strength, and impact toughness.
- [0005]** In addition, since a cemented carbide is locally welded to the tooth portion of a saw blade in order to maximize hardness and wear resistance, weldability is required.
- 20 **[0006]** In the manufacture of high-carbon steel products for cutting, techniques for refining tempered martensite grains are known to satisfy both hardness and impact toughness. To this end, a prior austenite grain size needs to be refined during the quenching. Grain refinement is known to improve impact toughness by effectively impeding crack propagation along grain boundaries.
- 25 **[0007]** Methods of refining an austenite grain size are generally classified into a method using precipitates and a method of lowering a quenching temperature. The method using a large amount of precipitates refines the grain size using a phenomenon in which the precipitates are pinned at grain boundaries, and the method of lowering the heat treatment temperature suppresses the growth of austenite grains.
- 30 **[0008]** However, since precipitates formed along the grain boundaries have significantly higher hardness than a base metal, cracks caused by differences in mechanical properties may easily propagate, thereby posing a risk of reduced impact toughness. In addition, when the austenite grain size is reduced, it is difficult to secure sufficient hardness during quenching, and this is because pearlite transformation occurs at the grain boundaries during the quenching, such that not all austenite is transformed into martensite and a portion of pearlite remains formed.

35 **[Disclosure]****[Technical Problem]**

- 40 **[0009]** The present invention is directed to providing a high-carbon hot-rolled steel sheet suitable for manufacturing a high-carbon steel product with superior weldability and impact toughness through alloy composition and microstructure control, and a method of manufacturing the same.
- [0010]** In addition, the present invention is directed to providing a high-carbon steel product with excellent weldability and impact toughness through heat treatment process control along with alloy composition and microstructure control, and a method of manufacturing the same.

45

[Technical Solution]

- [0011]** A high-carbon hot-rolled steel sheet according to an embodiment of the present invention includes 0.70 to 0.90 wt% of C; 0.2 to 0.6 wt% of Mn; 0.1 to 0.5 wt% of Si; 0.1 to 0.5 wt% of Cr; 0.007 to 0.015 wt% of Al; 0.4 to 2.0 wt% of Ni; 0.1 wt% or less (including 0 wt%) of V; and the balance of Fe and inevitable impurities and has a microstructure including 90 area% or more of pearlite.
- 50 **[0012]** The high-carbon hot-rolled steel sheet may preferably satisfy Expression 1 below.

55

[Expression 1]

$$[C]+[Si]/14+[Ni]/24+[V]/10 \leq 0.94$$

([] denotes wt% of corresponding component), and

AlN precipitates may be present and precipitates containing at least one of V, Nb, and Ti may not be present.

[0013] A method of manufacturing a high-carbon hot-rolled steel sheet according to an embodiment of the present invention includes reheating a steel material including 0.70 to 0.90 wt% of C; 0.2 to 0.6 wt% of Mn; 0.1 to 0.5 wt% of Si; 0.1 to 0.5 wt% of Cr; 0.007 to 0.015 wt% of Al; 0.4 to 2.0 wt% of Ni; 0.1 wt% or less (including 0 wt%) of V; and the balance of Fe and inevitable impurities at 1050 to 1300 °C, hot-rolling the steel material at a finishing rolling temperature of 800 to 1150 °C, and cooling the steel material to 550 to 750°C and coiling the cooled steel material.

[0014] The steel material may preferably satisfy Expression 1 below.

[Expression 1]

$$[C]+[Si]/14+[Ni]/24+[V]/10\leq 0.94$$

([] denotes wt% of corresponding component), and

a precipitate containing at least one of V, Nb, and Ti may not be generated during the cooling.

[0015] A high-carbon steel product according to an embodiment of the present invention includes 0.70 to 0.90 wt% of C; 0.2 to 0.6 wt% of Mn; 0.1 to 0.5 wt% of Si; 0.1 to 0.5 wt% of Cr; 0.007 to 0.015 wt% of Al; 0.4 to 2.0 wt% of Ni; 0.1 wt% or less (including 0 wt%) of V; and the balance of Fe and inevitable impurities and having a microstructure including tempered martensite, wherein the tempered martensite has an average grain size of 17 μm or more.

[0016] The tempered martensite may have an average grain size of 30 to 40 μm.

[0017] The microstructure may consist of a single phase of tempered martensite.

[0018] The high-carbon steel product may satisfy Expression 1 below.

[Expression 1]

$$[C]+[Si]/14+[Ni]/24+[V]/10\leq 0.94$$

([] denotes wt% of corresponding component), and

AlN precipitates may be present and precipitates containing at least one of V, Nb, and Ti may not be present.

[0019] A method of manufacturing a high-carbon hot-rolled steel sheet according to an embodiment of the present invention includes cold-working a high-carbon hot-rolled steel sheet including 0.70 to 0.90 wt% of C; 0.2 to 0.6 wt% of Mn; 0.1 to 0.5 wt% of Si; 0.1 to 0.5 wt% of Cr; 0.007 to 0.015 wt% of Al; 0.4 to 2.0 wt% of Ni; 0.1 wt% or less (including 0 wt%) of V; and the balance of Fe and inevitable impurities, heating and maintaining the cold-worked product at a temperature of 850 to 950 °C for 1 to 90 minutes and then cooling the product at an average cooling rate of 7 °C/sec or more, and tempering the quenched product.

[0020] The method may further include, prior to the cold working, spheroidizing annealing the high-carbon hot-rolled steel sheet.

[0021] The high-carbon hot-rolled steel sheet may satisfy Expression 1 below.

[Expression 1]

$$[C]+[Si]/14+[Ni]/24+[V]/10\leq 0.94$$

([] denotes wt% of corresponding component).

[0022] The average grain size of the austenite produced by the heating and maintaining process may be 17 μm or more. The average grain size of the austenite produced by the heating and maintaining process may range from 30 to 40 μm.

[Advantageous Effects]

[0023] According to the present invention, the steel product with excellent weldability and impact toughness can be manufactured by controlling alloying elements such as C, Al, and Ni, preventing refinement of austenite grain size by precipitates, and controlling a quenching temperature.

[0024] Specifically, according to the present invention, the steel product manufactured through the alloy composition, microstructure, and heat treatment control can exhibit high hardness of 650 Hv or more together with excellent

impact toughness, and thus is suitable for use as a cutting material such as a saw blade.

[0025] Specific effects together with the above effects are described together with a description of the following detailed matters for carrying out the invention.

[Mode for Invention]

[0026] Advantages and features of the present invention and methods for achieving them will become clear with reference to various embodiments, which will be described in detail below. However, the present disclosure is not limited to the embodiments disclosed below but can be implemented in various different forms, the embodiments are merely provided to make the disclosure of the present disclosure complete and fully inform those skilled in the art to which the present disclosure pertains of the scope of the present disclosure, and the present disclosure is only defined by the scope of the appended claims.

[0027] Hereinafter, a high-carbon hot-rolled steel sheet, a high-carbon steel product using the same, and a method of manufacturing the same according to a preferred embodiment of the present invention will be described in detail.

[0028] The present invention primarily relates to a high-carbon hot-rolled steel sheet suitable for manufacturing steel products such as saw blades for wood cutting, stone cutting, and circular saws, a high-carbon steel product using the same, and a method of manufacturing the same.

[0029] For example, saw blades need to rotate at high speeds to cut materials and withstand axial and radial stresses during cutting, and thus materials suitable for the saw blades require high levels of hardness, rigidity, fatigue strength, and impact toughness. In addition, since a cemented carbide is locally welded to the tooth portion of a saw blade in order to maximize hardness and wear resistance, weldability is required. In summary, cutting materials such as saw blades need to satisfy high hardness, excellent impact toughness, and weldability.

[0030] Hardness and weldability are largely determined by the alloy composition of the material. As the content of alloying elements, such as carbon (C), silicon (Si), nickel (Ni), etc., increases, hardness improves due to the solid solution strengthening effect, and adding vanadium (V) also enhances hardness by forming hard carbides. On the other hand, these elements affect the structure of a heat-affected zone when exposed to high temperatures, promoting property differences between a melt zone and a base metal, resulting in poor weldability.

[0031] In manufacturing materials with superior hardness and impact toughness, not only the alloy composition but also the microstructure significantly influences these properties. It is known that refining a prior austenite grain size and increasing the grain boundary area effectively impedes crack propagation, thereby improving impact toughness.

[0032] The most representative method is to use a large amount of precipitates. However, this method can actually reduce impact toughness. Generally, since precipitates formed along the grain boundaries have significantly higher hardness than a base metal, cracks caused by differences in mechanical properties may easily propagate, thereby posing a risk of reduced impact toughness.

[0033] In addition, when the austenite grain size is reduced, it is difficult to secure sufficient hardness during quenching, and this is because pearlite transformation occurs at the grain boundaries during the quenching, such that not all austenite is transformed into martensite and a portion of pearlite remains formed. During the cooling process, the number of grain boundaries capable of forming pearlite, rather than martensite, increases, reducing hardenability, which increases a critical cooling rate required to secure martensite by cooling within an austenite single-phase temperature range during the quenching, thereby deteriorating heat treatment characteristics.

[0034] Accordingly, a high alloying element content is required to secure high hardness characteristics, and weldability requires a low alloying element content. While fine austenite grain size is essential for improving impact toughness, excessive use of precipitates to refine grain size can actually reduce impact toughness. In addition, small grain sizes can prevent uniform martensite formation during the quenching.

[0035] The present invention provides a high-carbon hot-rolled steel sheet that simultaneously considers alloying elements and microstructure to secure both weldability and impact toughness, a high-carbon steel product using the same, and a method of manufacturing the same.

[0036] A high-carbon hot-rolled steel sheet according to an embodiment of the present invention contains 0.70 to 0.90 wt% of carbon (C), 0.2 to 0.6 wt% of manganese (Mn), 0.1 to 0.5 wt% of silicon (Si), 0.1 to 0.5 wt% of chromium (Cr), 0.007 to 0.015 wt% of aluminum (Al), 0.4 to 2.0 wt% of nickel (Ni), 0.1 wt% or less (including 0 wt%) of vanadium (V), the balance of Fe, and inevitable impurities.

[0037] Hereinafter, the roles and contents of each component included in a high-carbon hot-rolled steel sheet according to the present invention will be described.

Carbon (C): 0.7 to 0.9 wt%

[0038] Carbon stably forms austenite and is an alloying element that most significantly influences the enhancement of the strength and hardness of steel. Carbon is also the most important element that enhances hardenability and

determines the hardness of martensite after quenching.

[0039] As the carbon content increases, brittleness increases and toughness decreases, and thus, it is preferable to adjust the carbon content according to the application and required level.

[0040] From the perspective of manufacturing high-hardness steel products suitable for cutting materials such as saw blades, when the carbon content is less than 0.7 wt%, it is difficult to form hard carbides in addition to the martensitic matrix after quenching or quenching and tempering, which can reduce wear resistance.

[0041] When the carbon content exceeds 0.9 wt%, a large amount of carbides precipitate at grain boundaries, drastically reducing toughness, making it difficult to maintain the required level of impact toughness even after heat treatment.

[0042] From this perspective, the appropriate carbon content ranges from 0.7 to 0.9 wt%, more preferably from 0.75 to 0.85 wt%.

Manganese (Mn): 0.2 to 0.6 wt%

[0043] Manganese combines with the impurity sulfur to improve the cleanliness of steel. In addition, manganese has an effect of slightly increasing strength and hardness through solid solution strengthening and improve the hardenability of steel to facilitate the formation of martensite even at a slow cooling rate. For this effect, manganese needs to be added in an amount of 0.2 wt% or more. On the other hand, when the manganese content exceeds 0.6 wt%, segregation layers may be formed, which may deteriorate the workability of the steel.

[0044] From this perspective, the appropriate manganese content ranges from 0.2 to 0.6 wt%, more preferably from 0.3 to 0.5 wt%.

Silicon (Si): 0.1 to 0.5 wt%

[0045] Silicon has a high affinity for oxygen and is used for deoxidation. Silicon is an element that stably forms ferrite and, when dissolved in ferrite, can improve strength. For this effect, silicon needs to be added in an amount of 0.1 wt% or more. On the other hand, excessive silicon additions exceeding 0.5 wt% can deteriorate hot workability and toughness and hinder scale exfoliation at high temperatures, deteriorating the surface quality of hot-rolled steel.

[0046] From this perspective, the appropriate silicon content ranges from 0.1 to 0.5 wt%, more preferably from 0.2 to 0.4 wt%.

Chromium (Cr): 0.1 to 0.5 wt%

[0047] Chromium is a ferrite-stabilizing element that secures hardenability. For this effect, chromium needs to be added in an amount of 0.1 wt% or more.

[0048] Conversely, excessive chromium content exceeding 0.5 wt% can lead to the formation of chromium oxide during the welding process, leading to weld embrittlement.

[0049] From this perspective, the appropriate chromium content ranges from 0.1 to 0.5 wt%, more preferably from 0.2 to 0.4 wt%.

Aluminum (Al): 0.007 to 0.015 wt%

[0050] Aluminum has a high affinity for oxygen and is used for deoxidation. In addition, when precipitate-forming elements such as Nb, Ti, and V are not substantially included, nitrogen may combine with aluminum to form AlN during a hot-rolled steel sheet manufacturing process, thereby suppressing excessive grain growth, and to this end, aluminum needs to be added in an amount of 0.007 wt% or more.

[0051] On the other hand, when the aluminum content exceeds 0.015 wt%, the amount of alumina-based inclusions increases, which may cause undesirable grain refinement and consequently deterioration of toughness.

[0052] From this perspective, the appropriate aluminum content ranges from 0.007 to 0.015 wt%, more preferably from 0.008 to 0.012 wt%.

Nickel (Ni): 0.4 to 2.0 wt%

[0053] Nickel is an element that stably forms austenite. Although nickel does not significantly affect the strength and hardness of steel, it does not form high-hardness precipitates, and thus even with large additions, toughness is not significantly reduced. In particular, nickel enhances hardenability, ensuring the stable formation of martensite even at slow cooling rates after quenching. For this effect, nickel needs to be added in an amount of 0.4 wt% or more.

[0054] On the other hand, adding nickel in excess of 2.0 wt% can increase the fraction of retained austenite after

heat treatment, thereby reducing hardness.

[0055] From this perspective, the appropriate nickel content ranges from 0.4 to 2.0 wt%, more preferably from 0.8 to 1.85 wt%.

5 Vanadium (V): 0.1 wt% or less (including 0 wt%)

[0056] Vanadium combines with carbon to form hard carbides, thereby improving strength, hardness, and wear resistance and in particular, compensates for the hardness loss caused by precipitates formed during tempering.

[0057] However, when vanadium is added excessively, precipitates can significantly promote austenite grain refinement, thereby degrading impact toughness.

[0058] From this perspective, vanadium is omitted, or, if added, its content is preferably 0.1 wt% or less.

[0059] In addition to the above composition, the steel of the present invention may contain the balance of iron (Fe) and inevitable impurities. The inevitable impurities may be unintentionally incorporated during typical manufacturing processes and thus cannot be excluded.

15 **[0060]** The high-carbon hot-rolled steel sheet according to the present invention preferably satisfies Expression 1 below:

20 [Expression 1]

$$[C]+[Si]/14+[Ni]/24+[V]/10 \leq 0.94$$

25 ([] denotes wt% of corresponding component)

[0061] Expression 1 represents a type of carbon equivalent (Ceq), and a lower value thereof indicates improved weldability. When the value of Equation 1 exceeds 0.94, the carbon equivalent may be impaired due to excessive alloying elements. That is, when the elements included in Expression 1 are excessive, it affects the structure of a heat-affected zone when exposed to high temperatures during welding and promotes property differences between a melt zone and a base metal, thereby deteriorating welding characteristics.

30 **[0062]** To easily achieve Expression 1, the C content is more preferably added in an amount of 0.85 wt% or less.

[0063] Meanwhile, the lower limit of Expression 1 is preferably 0.80 or more, more preferably 0.84 or more, to secure sufficient hardness.

35 **[0064]** The high-carbon hot-rolled steel sheet according to the present invention may have a microstructure containing 90 area% or more of pearlite through the hot rolling process to be described below, in addition to the alloying composition. In addition to pearlite, cementite, austenite, bainite, etc. may be added in an amount of 10 area% or less. Meanwhile, the high-carbon hot-rolled steel sheet according to the present invention may contain AlN precipitates, but may not contain precipitates containing at least one of the representative precipitate-forming elements, Nb and Ti. Furthermore, in some embodiments in which V is not included, precipitates containing V may also be absent.

40 **[0065]** The high-carbon hot-rolled steel sheet according to the present invention may be manufactured by a method including the following operations of reheating, hot rolling, and coiling a steel material having the above alloy composition.

Reheating and hot rolling

45 **[0066]** A steel material, such as a slab, having the above alloy composition is manufactured using a converter or electric furnace, and then reheated at a temperature of 1050 °C or higher and 1300 °C or lower for 270 minutes or less. Reheating can promote homogenization of the steel.

50 **[0067]** The homogenized steel slab is hot-rolled at 800 °C or higher. The finishing rolling temperature preferably ranges from 800 to 1150 °C, preferably from 800 to 1000 °C, and more preferably from 820 to 920 °C. When the finishing rolling temperature is 800 °C or lower, hot rolling may be performed in an austenite-ferrite coexistence region or an austenite-cementite coexistence region, which may lead to plate fracture due to deformation imbalance at a phase interface. On the other hand, when the finishing rolling temperature is 1150 °C or higher, excessive scale formation may deteriorate surface quality.

Coiling

55 **[0068]** Coiling within an appropriate temperature range determines the shape of a material. Immediately after hot

rolling, a hot-rolled steel sheet is preferably cooled to a temperature of 550 to 750 °C, preferably 600 to 700 °C, and then coiled. When coiling is performed at a temperature lower than 550 °C, low-temperature microstructures such as bainite, martensite, etc. may be locally formed in a width or length direction, distorting the shape of the material, thereby leading to property differences or edge cracking. When coiling is performed at a temperature higher than 750 °C, excessive scale formation may deteriorate surface quality.

[0069] In the present invention, since the alloy composition does not include Nb and Ti, precipitates containing at least one of Nb and Ti are not formed during cooling. Furthermore, when V is not included, precipitates containing V may not be formed either.

[0070] Through the above process, a microstructure containing pearlite of 90 area% or more can be obtained, and other elements such as cementite, austenite, bainite, etc. may be added in an amount of 10 area% or less.

[0071] Hereinafter, a high-carbon steel product using the high-carbon hot-rolled steel sheet and a method of manufacturing the same according to the present invention will be described.

Spheroidizing annealing

[0072] Materials having a microstructure primarily composed of pearlite cannot be easily processed due to high strength and hardness thereof. Spheroidizing annealing softens the material into a ferrite and spherical cementite microstructure, significantly reducing strength and hardness, making room-temperature processing, such as rolling, forging, pressing, punching, etc., much easier.

[0073] The spheroidizing annealing may be performed within a temperature range of 650 to 750 °C. When maintained at a temperature lower than 650 °C, spheroidization becomes difficult, requiring a prolonged time and resulting in a very low spheroidization ratio. At temperatures of 750 °C or higher, a portion of the austenite phase may be stably formed, which may cause pearlite transformation.

[0074] Depending on the circumstances, the spheroidizing annealing may be omitted.

Cold working

[0075] Cold working may be performed at room temperature using known methods, such as rolling, forging, pressing, punching, etc. to obtain the desired shape of a product.

Quenching and tempering

[0076] The method of manufacturing a steel product according to the present invention performs quenching and tempering to impart hardness and toughness to the steel product. For example, in the case of steel products for cutting purposes, such as blades and saw blades, high hardness and high toughness are required, and thus quenching and tempering are performed to simultaneously satisfy these properties.

[0077] In the present invention, the quenching is performed by heating and maintaining the material at a temperature of 850 °C or higher to secure an austenite microstructure, and then cooling the material at a rate of 7 °C/s or more to transform it into a martensite structure.

[0078] The heating and maintaining process is specifically performed at 850 to 950 °C, preferably 860 to 920 °C, and more preferably 870 to 900 °C, for 1 to 90 minutes, preferably 10 to 60 minutes, and more preferably 20 to 50 minutes. When a heating and maintaining temperature is lower than 850 °C or a heating and maintaining time is less than 1 minute, sufficient austenite cannot be secured, making it difficult to secure a martensite microstructure after cooling, and in addition, it is difficult to obtain the desired coarse austenite grain size. On the other hand, when the heating and maintaining temperature exceeds 950 °C or the heating and maintaining time exceeds 90 minutes, there is a risk of excessive austenite grain growth, for example, exceeding 40 μm.

[0079] The average grain size of the austenite produced by the heating and maintaining process may be 17 μm or more. This contrasts with conventional techniques aimed at minimizing austenite grain size. In addition, in some embodiments, vanadium (V) may not be included, and in this case, the average grain size of the austenite formed by the heating and maintaining process may range from 30 to 40 μm.

[0080] Cooling may be performed using water cooling, oil cooling, etc., more preferably water cooling. The key to the present invention is to secure the highest possible fraction of martensite during cooling. Hardenability, which refers to the ability to secure martensite, is influenced by factors such as microstructure, alloy composition, etc. In the present invention, cooling is preferably performed at an average cooling rate of 7 °C/s or more. When the average cooling rate is less than 7 °C/s, structures such as bainite, pearlite, etc. may be formed. When the average cooling rate is 7 °C/s or more, 100 area% of martensite can be secured. Meanwhile, in the present invention, the addition of 0.1 to 0.5 wt% of Cr and 0.4 to 2.0 wt% of Ni enhances hardenability without impairing toughness, enabling complete quenching even at an average cooling rate of 20 °C/s or less. Accordingly, the quenching applied to the method of manufacturing a steel

product according to the present invention is preferably performed at an average cooling rate of 7 °C/s or more, more preferably 7 to 20 °C/s, and even more preferably 10 to 20 °C/s.

[0081] Through the quenching, a high-hardness martensitic structure with a hardness of 650 Hv or higher can be obtained. However, materials subjected to the quenching have poor room-temperature impact toughness of less than 2 J and thus secure impact toughness through sufficient tempering.

[0082] Tempering may be performed by maintaining the quenched material within a temperature range of 150 to 600 °C, more preferably 300 to 500 °C, for 1 to 180 minutes, preferably 10 to 90 minutes, and more preferably 20 to 60 minutes and then cooling the quenched material to secure a tempered martensite microstructure. A temperature region less than 150 °C has little effect on eliminating dislocations, whereas a temperature region of 600 °C or higher causes excessive reduction in hardness, making it difficult to secure desired mechanical properties. A heat treatment time of less than 1 minute is insufficient for even heating of the material, and a heat treatment time exceeding 180 minutes results in convergence and ineffectiveness.

[0083] Cooling after the tempering may be performed, for example, by exposing the material to air at room temperature.

[0084] The high-carbon steel product according to the embodiment of the present invention contains 0.70 to 0.90 wt% of C, 0.2 to 0.6 wt% of Mn, 0.1 to 0.5 wt% of Si, 0.1 to 0.5 wt% of Cr, 0.007 to 0.015 wt% of Al, 0.4 to 2.0 wt% of Ni, 0.1 wt% or less (including 0 wt%) of V, the balance of iron (Fe), and inevitable impurities and has a microstructure containing tempered martensite through quenching and tempering. Preferably, the high-carbon steel product according to the present invention has a microstructure composed of a single phase of tempered martensite.

[0085] In the present invention, the average austenite grain size is 17 μm or more during quenching, which may directly lead to the grain size of tempered martensite. Accordingly, for the high-carbon steel product according to the present invention, the average grain size of tempered martensite may be 17 μm or more. In some embodiments in which V is not included, the average grain size of tempered martensite may range from 30 to 40 μm.

Examples

[0086] Hereinafter, the present invention will be described in more detail through an example. However, it should be noted that the examples to be described below are intended only to illustrate and describe the present invention in more detail and are not intended to limit the scope of the present invention.

[0087] Table 1 shows chemical compositions of steel specimens prepared for the present invention, with the balance of Fe and inevitable impurities.

[Table 1]

	C	Mn	Si	Ni	Cr	V	Al	A
Steel in Example 1	0.79	0.38	0.19	1.82	0.25	0	0.012	0.88
Steel in Example 2	0.8	0.4	0.3	1.34	0.25	0	0.01	0.88
Steel in Example 3	0.82	0.4	0.21	0.9	0.25	0	0.007	0.87
Steel in Example 4	0.81	0.41	0.21	0.46	0.25	0	0.010	0.84
Steel in Example 5	0.8	0.41	0.41	1.79	0.25	0	0.010	0.90
Steel in Example 6	0.79	0.41	0.42	1.35	0.25	0	0.008	0.88
Steel in Example 7	0.8	0.39	0.2	1.81	0.25	0.095	0.010	0.90
Steel in Example 8	0.79	0.41	0.31	1.36	0.25	0.1	0.008	0.88
Steel in Example 9	0.8	0.42	0.4	1.81	0.25	0.098	0.010	0.91
Steel in Example 10	0.8	0.41	0.4	1.36	0.25	0.1	0.011	0.90
Steel in Comparative example 1	0.79	0.39	0.45	1.83	0.25	0.49	0.011	0.95
Steel in Comparative example 2	0.81	0.41	0.46	1.33	0.25	0.51	0.009	0.95
Steel in Comparative example 3	0.79	0.38	0.19	1.82	0.25	0	0.003	0.88
Steel in Comparative example 4	0.79	0.38	0.19	1.82	0.25	0	0.020	0.88

$$\text{Expression 1 (A): } [C] + [Si]/14 + [Ni]/24 + [V]/10 \leq 0.94$$

([] denotes wt% of corresponding component)

[0088] The steel specimens listed in Table 1 were each reheated at 1250 °C for 2 hours, hot-rolled to a thickness of 6 mm under finishing rolling conditions at 850 °C, and then coiled at 620 °C to manufacture hot-rolled steel sheets.

[0089] The hot-rolled steel sheets were quenched at 880 °C for 30 minutes and then cooled in water at room temperature. After quenching, the steel sheets were tempered at 300 °C, 400 °C, and 500 °C for 40 minutes, and then cooling in air at room temperature.

[0090] The fraction of tempered martensite and the average grain size of the tempered martensite in the final tempered steel specimens were measured under a microscope, and the average grain size of the austenite was derived from the observed tempered martensite.

[Table 2]

Expression 1 (A)		Hot-rolled steel sheet Microstructure	Austenite Average grain size (μm) (B)	B/A	Tempered martensite	
		Pearlite fraction (%)			Fraction (%)	Average grain size (μm)
Steel in Example 1	0.88	97.3	30.0	34.1	100%	30.0
Steel in Example 2	0.88	98.7	31.7	36.0	100%	31.7
Steel in Example 3	0.87	99.1	30.1	34.6	100%	30.1
Steel in Example 4	0.84	99	30.0	35.7	100%	30.0
Steel in Example 5	0.90	97.9	36.3	40.3	100%	36.3
Steel in Example 6	0.88	98.8	32.3	36.7	100%	32.3
Steel in Example 7	0.90	96.9	25.2	28.0	100%	25.2
Steel in Example 8	0.88	98.7	23.5	26.7	100%	23.5
Steel in Example 9	0.91	97.7	19.5	21.4	100%	19.5
Steel in Example 10	0.90	98.3	17.0	18.9	100%	17.0
Steel in Comparative example 1	0.95	96.8	5.4	5.7	100%	5.4
Steel in Comparative example 2	0.95	96.1	6.3	6.6	100%	6.3
Steel in Comparative example 3	0.88	99.3	51.7	58.8	100%	51.7
Steel in Comparative example 4	0.88	96.3	4.6	5.2	100%	4.6
Steel in Comparative example 5	0.88	97.5	21.0	23.9	99.4	21.0
Steel in Comparative example 6	0.88	97.2	25.4	28.9	99.7	25.4

$$\text{Expression 1: } [C] + [Si]/14 + [Ni]/24 + [V]/10 \leq 0.94$$

([] denotes wt% of corresponding component)

[0091] The steel in Comparative example 3 has the same steel composition and manufacturing process as the steel in Example 1, but the result was obtained from a specimen containing only 0.005 wt% of Al in the steel composition, and the steel in Comparative example 4 has the same steel composition and manufacturing process as the steel in Example 1, but the result was obtained from a specimen containing an excessive 0.02 wt% of Al in the steel composition.

[0092] The steel in Comparative example 5 has the same steel composition and manufacturing process as the steel in Example 1, but when a quenching temperature is 820 °C, the steel in Comparative example 6 has the same steel composition and manufacturing process as the steel in Example 1, but the result was obtained from a specimen having the quenching temperature of 840 °C.

[0093] Referring to Table 2, all of the steels in Examples 1 to 10 and the steels in Comparative examples 1 to 6 exhibited 90% or more of pearlite in the hot-rolled material. However, the steels in Examples 1 to 10 exhibited an

average austenite grain size of 17 μm or more after quenching, whereas the steels in Comparative examples 1 and 2 exhibited an average austenite grain size of only 5 to 7 μm . In addition, when comparing the steels in Examples 1 to 10 with the steels in Examples 1 to 6, the specimens according to the steels in Examples 1 to 6, which do not contain V, exhibited the average austenite grain size of 30 to 40 μm . Meanwhile, the steel in Comparative example 3 containing only 0.005 wt% of Al exhibited an average austenite grain size exceeding 50 μm , whereas the steel in Comparative example having an excessive 0.02 wt% of Al exhibited an average austenite grain size of less than 5 μm .

[0094] Furthermore, as a result of dividing the average austenite grain size (B) by the value (A) obtained from Expression 1, the specimens according to the steels in Examples 1 to 10 exhibited a B/A of 18 or more, whereas the steels in Comparative examples 1 and 2 exhibited a B/A of 5 to 7. In addition, when comparing the steels in Examples 1 to 10 with the steels in Examples 1 to 6, which do not contain V, the B/A exceeded 30. This B/A indicates that the austenite grain size may be coarsened to a target size using alloying compositions, such as aluminum, that do not significantly change the carbon equivalent.

[0095] In addition, the steels in Examples 1 to 10, which satisfy the alloying compositions and quenching temperatures proposed in the present invention, exhibited the target tempered martensite single-phase microstructure. However, for the steels in Comparative examples 5 and 6, which have the same steel composition and manufacturing process as the steel in Example 1 but were quenched at 820 °C and 840 °C, respectively, the target tempered martensite single phase could not be achieved.

[0096] Table 3 shows the room-temperature impact toughness and hardness values of steels subjected to quenching and tempering.

[0097] The room-temperature impact toughness was measured using V-notched specimens machined according to ISO 148-1, and the test was repeated three times, and the impact toughness values were converted into values at 10 mm thickness in consideration of the thickness of the material.

[0098] The hardness was measured using a Vickers hardness test with a load of 10 kgf, and the results were obtained from 10 repeated tests.

[Table 3]

	Impact toughness (J, cm)				Vickers hardness (Hv, 10 kgf)			
	Quenching	Tempering at 300 °C	Tempering at 400 °C	Tempering at 500 °C	Quenching	Tempering at 300 °C	Tempering at 400 °C	Tempering at 500 °C
Steel in Example 1	0.2	2.0	8.9	21.1	697.6	613.6	456.1	366.8
Steel in Example 2	0.2	1.1	8.9	24.5	725.6	627.0	470.4	364.7
Steel in Example 3	0.0	1.4	8.4	22.8	770.7	617.2	485.7	368.5
Steel in Example 4	0.0	1.6	8.1	21.9	777.2	628.7	474.0	379.4
Steel in Example 5	0.2	1.1	7.9	19.4	752.9	639.4	460.9	387.6
Steel in Example 6	0.0	1.1	8.6	20.6	723.0	652.7	474.4	383.6
Steel in Example 7	0.6	2.7	8.7	17.7	736.4	635.2	486.8	402.2
Steel in Example 8	0.2	1.8	8.7	20.4	786.9	643.2	496.9	397.0
Steel in Example 9	1.8	1.4	8.1	11.9	748.9	635.0	492.3	420.0
Steel in Example 10	1.6	1.4	8.1	12.4	784.1	650.6	508.3	420.2
Steel in Comparative example 1	1.9	1.7	3.4	6.7	792.8	665.8	511.3	431.5

(continued)

	Impact toughness (J, cm)				Vickers hardness (Hv, 10 kgf)			
	Quenching	Tempering at 300 °C	Tempering at 400 °C	Tempering at 500 °C	Quenching	Tempering at 300 °C	Tempering at 400 °C	Tempering at 500 °C
Steel in Comparative example 2	1.9	1.2	3.7	7.4	798.1	658.7	509.4	428.9
Steel in Comparative example 3	0.0	0.2	1.7	6.3	767.8	654.1	534.2	452.9
Steel in Comparative example 4	0.1	0.9	2.4	5.7	734.5	631.2	487.5	418.7
Steel in Comparative example 5	0.0	0.2	0.9	2.1	657.7	572.7	424.1	354.1
Steel in Comparative example 6	0.0	0.4	1.1	3.4	674.3	589.4	413.5	364.5

[0099] Referring to Table 3, the hardness of specimens according to the steels in Examples 1 to 10 and the steels in Comparative examples 1 to 4, which were subjected to quenching, were 697 Hv or more. Subsequently, it can be seen that the hardness decreased after tempering. In particular, it can be seen that hardness gradually decreased as the tempering temperature increased.

[0100] Regarding Vickers hardness, the steels in Examples 1 to 10 and the steels in Comparative examples 1 and 2 exhibited high hardness characteristics of 697 Hv or more after quenching. As the tempering temperature increased, dislocations disappeared, gradually decreasing the hardness, and after tempering at 500 °C, the hardness decreased to 360 Hv. The measured hardness values were similar regardless of the steels in Examples 1 to 11 and the steels in Comparative examples 1 to 4, which can be attributed to the fact that the carbon content, the most dominant factor affecting the hardness of the tempered martensite microstructure, was at a similar level.

[0101] The room temperature impact toughness of the quenched materials was significantly inferior at less than 2 J for all of the steels in Examples 1 to 10 and the steels in Comparative examples 1 to 6. However, it can be seen that, when tempering was performed, impact toughness was improved, and it can be seen that the impact toughness gradually increased as the tempering temperature increased. Specifically, the steels in Examples 1 to 10 exhibited room-temperature impact toughness of 1.8 J or less in the quenched materials, and as the tempering temperature increased, the impact toughness increased, and thus an impact toughness of 10 J or more is observed after tempering at 500 °C.

[0102] However, the steels in Comparative examples 1 and 2 exhibited relatively high impact toughness compared to other steel specimens, with a room-temperature impact toughness of 1.9 J in the quenched materials. This is attributable to the high retained austenite phase fraction, and when tempering is performed, the retained austenite decomposes into tempered martensite and the effect disappears, and thus, after the final tempering, inferior impact toughness values are observed compared to the steels in Examples 1 to 10.

[0103] Meanwhile, the steels in Comparative examples 1 and 2 contain 0.4 wt% of vanadium (V), and the steel in Comparative example 4 contains 0.02 wt% of Al. It is generally known that, as the austenite grain size decreases, the number of grain boundaries that can hinder crack propagation increases, thereby improving impact toughness. That is, V precipitates and Al precipitates are highly effective in reducing grain size. As shown in Table 2, the steels in Comparative examples 1 and 2 containing 0.4 wt% of V and the steel in Comparative example 4 containing 0.02 wt% of Al exhibited the smallest average austenite grain sizes of 4 to 6 μm .

[0104] However, in the case of the steels in Comparative examples 1, 2, and 4, in which V and Al were excessively added, the impact toughness was rather inferior to that of the steels in Examples 1 to 10, which can be attributed to the excessive vanadium precipitates, which increased the likelihood of crack initiation due to the mismatch in mechanical properties between the matrix and the precipitates. In particular, the material tempered at 500 °C, at which vanadium carbide precipitation readily occurs, exhibited a significant decrease in impact toughness.

[0105] In the case of the steel in Comparative example 3, the Al content was only 0.005 wt%, and thus the average austenite grain size exceeded 50 μm , and as a result of the excessively coarse austenite grains, the impact toughness was poor.

[0106] In the steels in Comparative examples 5 and 6, the quenching temperature was relatively low, and in this case, carbides are not readily redissolved, and thus cementite partially remains even after quenching. As a result, the steels in Comparative examples 5 and 6 exhibited low impact toughness due to the retained cementite. In addition, in the steels in Comparative examples 5 and 6, carbon that should have been dissolved in martensite to contribute to hardness improvement was consumed in forming cementite, and thus the concentration of dissolved carbon in the martensitic matrix was relatively reduced, resulting in an overall decrease in hardness.

[0107] Although the present invention has been described above, the present invention is not limited by the embodiments disclosed herein, and it is apparent that various modifications can be made by those skilled in the art within the scope of the technical spirit of the present invention. In addition, even when the operational effects according to the configuration of the present invention have not been explicitly described in the description of the embodiments of the present invention, it goes without saying that the effects predictable by the corresponding configuration should also be recognized.

Claims

1. A high-carbon hot-rolled steel sheet comprising: 0.70 to 0.90 wt% of C; 0.2 to 0.6 wt% of Mn; 0.1 to 0.5 wt% of Si; 0.1 to 0.5 wt% of Cr; 0.007 to 0.015 wt% of Al; 0.4 to 2.0 wt% of Ni; 0.1 wt% or less (including 0 wt%) of V; and the balance of Fe and inevitable impurities, which has a microstructure including 90 area% or more of pearlite.

2. The high-carbon hot-rolled steel sheet of claim 1, which satisfies Expression 1 below:

[Expression 1]

$$[\text{C}] + [\text{Si}]/14 + [\text{Ni}]/24 + [\text{V}]/10 \leq 0.94$$

([] denotes wt% of corresponding component).

3. The high-carbon hot-rolled steel sheet of claim 1, wherein AlN precipitates are present and precipitates containing at least one of V, Nb, and Ti are not present.

4. A method of manufacturing a high-carbon hot-rolled steel sheet, the method comprising:

reheating a steel material including 0.70 to 0.90 wt% of C; 0.2 to 0.6 wt% of Mn; 0.1 to 0.5 wt% of Si; 0.1 to 0.5 wt% of Cr; 0.007 to 0.015 wt% of Al; 0.4 to 2.0 wt% of Ni; 0.1 wt% or less (including 0 wt%) of V; and the balance of Fe and inevitable impurities at 1050 to 1300 °C;
hot-rolling the steel material at a finishing rolling temperature of 800 to 1150 °C; and
cooling the steel material to 550 to 750 °C and coiling the cooled steel material.

5. The method of claim 4, wherein the steel material satisfies Expression 1 below:

[Expression 1]

$$[\text{C}] + [\text{Si}]/14 + [\text{Ni}]/24 + [\text{V}]/10 \leq 0.94$$

([] denotes wt% of corresponding component).

6. The method of claim 4, wherein a precipitate containing at least one of V, Nb, and Ti is not generated during the cooling.

7. A high-carbon steel product comprising: 0.70 to 0.90 wt% of C; 0.2 to 0.6 wt% of Mn; 0.1 to 0.5 wt% of Si; 0.1 to 0.5 wt% of Cr; 0.007 to 0.015 wt% of Al; 0.4 to 2.0 wt% of Ni; 0.1 wt% or less (including 0 wt%) of V; and the balance of Fe and inevitable impurities and having a microstructure including tempered martensite, wherein the

tempered martensite has an average grain size of 17 μm or more.

8. The high-carbon steel product of claim 7, wherein the tempered martensite has an average grain size of 30 to 40 μm .

9. The high-carbon steel product of claim 7, wherein the microstructure consists of a single phase of tempered martensite.

10. The high-carbon steel product of claim 7, which satisfies Expression 1 below:

[Expression 1]

$$[\text{C}]+[\text{Si}]/14+[\text{Ni}]/24+[\text{V}]/10\leq 0.94$$

([] denotes wt% of corresponding component).

11. The high-carbon steel product of claim 8, wherein AlN precipitates are present and precipitates containing at least one of V, Nb, and Ti are not present.

12. A method of manufacturing a high-carbon steel product, the method comprising:

cold-working a high-carbon hot-rolled steel sheet including 0.70 to 0.90 wt% of C; 0.2 to 0.6 wt% of Mn; 0.1 to 0.5 wt% of Si; 0.1 to 0.5 wt% of Cr; 0.007 to 0.015 wt% of Al; 0.4 to 2.0 wt% of Ni; 0.1 wt% or less (including 0 wt%) of V; and the balance of Fe and inevitable impurities;
heating and maintaining the cold-worked product at a temperature of 850 to 950 °C for 1 to 90 minutes and then cooling the product at an average cooling rate of 7 °C/sec or more; and
tempering the quenched product.

13. The method of claim 12, further comprising, prior to the cold working, spheroidizing annealing the high-carbon hot-rolled steel sheet.

14. The method of claim 12, wherein the high-carbon hot-rolled steel sheet satisfies Expression 1 below:

[Expression 1]

$$[\text{C}]+[\text{Si}]/14+[\text{Ni}]/24+[\text{V}]/10\leq 0.94$$

([] denotes wt% of corresponding component).

15. The method of claim 12, wherein an average grain size of austenite formed by the heating and maintaining is 17 μm or more.

16. The method of claim 15, wherein the average grain size of austenite formed by the heating and maintaining ranges from 30 to 40 μm .

INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/017987

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/46(2006.01)i; C21D 8/02(2006.01)i; C21D 1/18(2006.01)i; C21D 1/32(2006.01)i; C21D 9/46(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C 38/46(2006.01); B21C 47/02(2006.01); C21D 8/02(2006.01); C21D 9/46(2006.01); C22C 38/00(2006.01);
C22C 38/06(2006.01); C22C 38/32(2006.01); C22C 38/58(2006.01)

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

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

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

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

eKOMPASS (KIPO internal) & keywords: 고탄소강(high carbon steel), 니켈(nickel), 바나듐(vanadium), 펄라이트(pearlite), 템퍼드 마르텐사이트(tempered martensite), 가열(heating), 냉각(cooling), 냉간압연(cold rolled), 결정립(grain), 오스테나이트(austenite)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KR 10-2021-0120087 A (NIPPON STEEL CORPORATION) 06 October 2021 (2021-10-06) See paragraphs [0126]-[0127] and claims 1 and 6.	1-6
X	JP 2023-116799 A (JFE STEEL CORP. et al.) 22 August 2023 (2023-08-22) See paragraphs [0044] and [0088]-[0089] and claims 1-2 and 5.	7-16
A	KR 10-2014-0044925 A (NIPPON STEEL & SUMITOMO METAL CORPORATION) 15 April 2014 (2014-04-15) See paragraph [0137] and claims 1 and 4.	1-16
A	JP 2011-012316 A (NIPPON STEEL CORP.) 20 January 2011 (2011-01-20) See paragraph [0063] and claims 1-4.	1-16

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

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“P” document published prior to the international filing date but later than the priority date claimed

“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

“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

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

“&” document member of the same patent family

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Name and mailing address of the ISA/KR

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

Facsimile No. +82-42-481-8578

Authorized officer

Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Information on patent family members

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