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(54) **STEEL MATERIAL HAVING EXCELLENT WEAR RESISTANCE AND MANUFACTURING METHOD FOR SAME**

(57) The purpose of the present invention is to provide a steel material and a manufacturing method for the same, wherein the steel material has excellent strength, elongation, and impact toughness as well as excellent inside quality and wear resistance. According to the present invention, provided are a steel material having excellent wear resistance and a manufacturing method for the same, wherein the steel material contains, in

weight, 0.55-1.4% carbon (C), 12-23% manganese (Mn), 5% or less (excluding 0%) chromium (Cr), 5% or less (excluding 0%) copper (Cu), 0.5% or less (excluding 0%) Al, 1.0% or less (excluding 0%) Si, 0.02% or less (including 0%) S, 0.04% or less (including 0%) phosphor (P), and the balance Fe and unavoidable impurities, and has a microstructure comprising, in area, 10% or less (including 0%) carbide and the balance austenite.

【FIG. 1】



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Description

[Technical Field]

5 **[0001]** The present disclosure relates to an austenitic steel material, used for steels in the fields of mining, transportation, storage, and the like, in the oil and gas industries, as steels for industrial machinery, structural materials and slurry pipes, and as sour-resistant steel and the like, and a method of manufacturing the same, and more particularly, to an austenitic steel material having excellent internal quality and wear resistance, and a method of manufacturing the same.

10 [Background Art]

15 **[0002]** Austenitic steels are used for a variety of applications due to their excellent work hardenability, low-temperature toughness, and non-magnetic properties. In detail, as carbon steel composed of ferrite or martensite as a main structure, which has been mainly used, has limitations in its properties, the austenitic steel application has recently been increasing as a substitute for overcoming the disadvantages.

20 **[0003]** In particular, according to the growth of the mining industry, oil and gas industries, wear of steel used in mining, transportation, refining and storage processes has emerged as a major problem. Furthermore, as the development of oil sands as fossil fuels to replace petroleum has recently started, wear of steel by slurry containing oil, rock, gravel, sand, and the like, is pointed out as an important cause of increasing production costs. Accordingly, demand for the development and application of steel materials having excellent wear resistance is greatly increasing.

25 **[0004]** In the existing parts industry for the mining and machinery industry, Hadfield steel having excellent wear resistance have been mainly used. To increase the wear resistance of steel materials, efforts to generate the austenite structure by including a high content of carbon and a large amount of manganese to increase wear resistance have been made steadily. However, in the case of Hadfield steel, a high carbon content sharply degrades the properties of steel, especially ductility, by forming network-type carbide at high temperature along the austenite grain boundary.

30 **[0005]** To suppress the precipitation of carbides in the form of a network, a method of manufacturing a high-manganese steel has been proposed by performing a solution heat treatment at a high temperature or quenching to room temperature after hot working. However, it may be difficult to suppress the precipitation of carbides in the form of this network when the change in manufacturing conditions is not easy, such as when the thickness of the steel material is thick or when welding is essential, and thus, it causes a problem that the mechanical properties of the steel material deteriorate rapidly.

35 **[0006]** In addition, ingots or steel slabs of high-manganese steel inevitably cause segregation by impurity elements such as P, S and the like in addition to alloying elements such as manganese and carbon during solidification. Eventually, coarse carbide is formed along the deep segregation zone in the final product, which eventually causes non-uniformity of the microstructure and deterioration of properties.

40 **[0007]** In addition, it may result in generating a central portion crack due to heat or stress generated during processing.

45 **[0008]** To improve wear resistance, it is essential to increase the carbon content, and increasing the manganese content to prevent deterioration of mechanical properties due to carbide precipitation may be a general method, but this leads to an increase in the alloy amount and manufacturing cost.

50 **[0009]** To solve this, studies on the addition of elements effective for suppressing carbide formation, compared to manganese, are also required. In addition, research on brittleness problems due to segregation, which is common in high-alloy products, is continuously required.

(Prior Art Document)

55 **[0010]** (Patent Document 1) Korean Patent Application Publication No. 2016-0077558

[Disclosure]

[Technical Problem]

60 **[0011]** An aspect of the present disclosure is to provide a steel material having excellent internal quality and wear resistance as well as excellent strength, elongation and impact toughness.

65 **[0012]** Another aspect of the present disclosure is to provide a method of manufacturing a steel material having excellent internal quality and wear resistance as well as excellent strength, elongation and impact toughness.

[Technical Solution]

70 **[0013]** According to an aspect of the present disclosure, a steel material having excellent wear resistance, includes,

in weight percent, 0.55 to 1.4% of carbon (C), 12 to 23% of manganese (Mn), 5% or less (excluding 0%) of chromium (Cr), 5% or less (excluding 0%) of copper (Cu), 0.5% or less (excluding 0%) of Al, 1.0% or less (excluding 0%) of Si, 0.02% or less (including 0%) of S, 0.04% or less (including 0%) of phosphorus (P), and a balance of Fe and unavoidable impurities, wherein the steel material includes, in area%, 10% or less (including 0%) of carbide and balance austenite, as a microstructure.

[0014] The steel material may have a component segregation index (S) of 3.0 or less, represented by relational expression 1.

[Relational Expression 1]

$$\begin{aligned} \text{Component segregation index (S)} = & (\text{C component in central} \\ & \text{portion of rolled material/C component in molten steel})/1.25 \\ & + (\text{Mn component in central portion of rolled material/Mn} \\ & \text{component in molten steel})/1.15 + (\text{P component in central} \\ & \text{portion of rolled material/P component in molten steel})/3.0, \end{aligned}$$

where a component in the central portion indicates a component in a range of 50 μm or less in upper and lower portions of a part in which a highest component is measured in microstructure analysis at a position equal to half of a thickness of the rolled material.

[0015] The steel material may have a yield strength of 350 MPa or more, a uniform elongation of 20% or more, and an impact toughness of 40 J or more.

[0016] According to another aspect of the present disclosure, a method of manufacturing a steel material having excellent wear resistance, includes:

preparing a molten steel containing, in weight percent, 0.55 to 1.4% of carbon (C), 12 to 23% of manganese (Mn), 5% or less (excluding 0%) of chromium (Cr), 5% or less (excluding 0%) of copper (Cu), 0.5% or less (excluding 0%) of Al, 1.0% or less (excluding 0%) of Si, 0.02% or less (including 0%) of S, 0.04% or less (including 0%) of phosphorus (P), and a balance of Fe and unavoidable impurities;
continuous casting operating of obtaining a slab by continuously casting the molten steel under conditions of a molten steel temperature (T_c) satisfying the following relational expression 2 and a casting speed (V) satisfying the following relational expression 3,

[Relational Expression 2]

$$K \leq T_c \leq K + 60$$

where in relational expression 2, a K value represents a value determined by the following relational expression 4,

[Relational Expression 3]

$$V \text{ (m/min)} \geq 0.025 [T_c - K]$$

where in relational expression 3, a K value represents a value determined by the following relational expression 4,

[Relational Expression 4]

$$K \text{ (}^\circ\text{C)} = 1536 - (69[C] + 4.2[Mn] + 39[P])$$

where [C], [Mn] and [P] each indicate a content (weight%) of an element;
reheating the slab at a reheating temperature (T_R) or lower obtained by the following relational expression 5,

[Relational Expression 5]

$$T_R = 1453 - 165[C] - 4.5[Mn] - 414[P]$$

where T_R indicates a reheating temperature (°C), and [C] and [Mn] each indicate a content (weight%) of an element; hot rolling the slab reheated in the reheating to a finish rolling temperature of 850 to 1050°C to obtain a hot rolled steel; and cooling the hot rolled steel to 600°C or less at 5°C/sec or more.

[Advantageous Effects]

[0017] According to an exemplary embodiment of the present disclosure, a steel material may have excellent wear resistance, and may thus be applied to fields requiring wear resistance, across the mining, transportation, storage or industrial machinery fields in the oil and gas industries in which a relatively large amount of wear occurs. In detail, since internal defects that may occur during the production process, may be significantly reduced, the steel material may be expandably applied to fields requiring relatively high internal quality.

[Description of Drawings]

[0018] FIG. 1 is an image illustrating a defect in a central portion of a steel sheet thickness of comparative steel 4.

[Best Mode for Invention]

[0019] The present inventors have studied steels having superior strength and wear resistance, as compared to existing steels used in technical fields in which wear resistance is required, and have recognized that, in the case of high manganese steels, excellent strength and elongation, unique to austenitic steels, may be secured, and furthermore, excellent wear resistance may be secured as the hardness of the material may be increased due to work hardening of the material itself in an abrasive environment when improving a work hardening rate, thereby completing the present disclosure.

[0020] An exemplary embodiment of the present disclosure provides an austenitic steel material having excellent strength as well as superior strength and elongation characteristics unique to austenite-based steel materials, as the hardness of the material was increased due to work hardening of the material itself in an abrasive environment.

[0021] Furthermore, in an exemplary embodiment of the present disclosure, casting conditions and reheating conditions may be relatively optimized to provide an improved austenitic wear-resistant steel material having improved internal quality (central portion quality) and a method of manufacturing the same, by controlling the embrittlement of the core due to impurities such as P or the like, and large amounts of carbon and manganese, which are problems with existing austenitic wear-resistant steels.

[0022] Hereinafter, a steel material having excellent wear resistance according to an exemplary embodiment of the present disclosure will be described.

[0023] A steel material having excellent wear resistance according to an exemplary embodiment of the present disclosure includes, in weight percent, 0.55 to 1.4% of carbon (C), 12 to 23% of manganese (Mn), 5% or less (excluding 0%) of chromium (Cr), 5% or less (excluding 0%) of copper (Cu), 0.5% or less (excluding 0%) of Al, 1.0% or less (excluding 0%) of Si, 0.02% or less (including 0%) of S, 0.04% or less (including 0%) of phosphorus (P), and a balance of Fe and unavoidable impurities. The steel material includes 10 area% or less (including 0%) of carbide and balance austenite, as a microstructure.

[0024] Hereinafter, components and component ranges will be described.

C: 0.55 to 1.4% by weight (hereinafter, also referred to as "%")

[0025] Carbon (C) is an austenite stabilizing element, which not only serves to improve the uniform elongation, but also is a significantly advantageous element for improving strength and increasing a work hardening rate. If the carbon content is less than 0.55%, it may be difficult to form stable austenite at room temperature, and there is a problem that it may be difficult to secure sufficient strength and work hardening rate. On the other hand, if the content exceeds 1.4%, a large amount of carbide is precipitated to reduce the uniform elongation, and thus, it may be difficult to secure excellent elongation, causing wear resistance deterioration and premature fracture.

[0026] Therefore, the content of C may be preferably limited to 0.55 to 1.4%, and in detail, limited to 0.8 to 1.3%.

Mn: 12 to 23%

[0027] Manganese (Mn) is a significantly important element that plays a role in stabilizing austenite and improves uniform elongation. To obtain austenite as a main structure in an exemplary embodiment of the present disclosure, it may be preferable that Mn is included in 12% or more.

[0028] If the Mn content is lower than 12%, the austenite stability may decrease, and thus, a martensite structure may be formed. Therefore, if the austenite structure is not sufficiently secured, it may be difficult to secure a sufficient uniform elongation. On the other hand, if the Mn content exceeds 23%, not only does the manufacturing cost increase, but also there are problems such as corrosion resistance deterioration due to manganese addition, difficulty in a manufacturing process, and the like.

[0029] Therefore, the Mn content may be preferably limited to 12 to 23%, and in detail, 15 to 21%.

Cr: 5% or less (excluding 0%)

[0030] Chromium (Cr) stabilizes austenite up to a range of an appropriate addition amount, thereby improving impact toughness at low temperatures, and is solidified in austenite to increase the strength of steel. In addition, chromium is also an element that improves the corrosion resistance of steel materials. However, if the content of Cr exceeds 5%, it may not be preferable because excessively formed carbides at the austenite grain boundary may significantly reduce toughness of steel. Also, in some cases, the content may be limited to 3.5% or less.

Cu: 5% or less (excluding 0%)

[0031] Copper (Cu) has a significantly low solid solubility in carbide and has slow diffusion in austenite, to be concentrated at an austenite and nucleated carbide interface, thereby hindering diffusion of carbon, such that the growth of carbide effectively slows. Therefore, eventually, there is an effect of suppressing generation of carbide. However, if the content of Cu exceeds 5%, there is a problem of deteriorating hot workability of the steel, and thus, it may be preferable to limit the upper limit of the content to 5%.

Al: 0.5% or less (excluding 0%), Si: 1.0% or less (excluding 0%)

[0032] Aluminum (Al) and silicon (Si) are components added as a deoxidizer during the steelmaking process, and the upper limit of the aluminum (Al) content is limited to 0.5%, and the upper limit of the silicon (Si) content may be preferably limited to 1.0%..

S: 0.02% or less (including 0%)

[0033] S is an impurity and may be preferably suppressed as much as possible, and the upper limit thereof may be preferably managed to be 0.02%.

P: 0.04% or less (including 0%)

[0034] In general, P is well known as an element that causes hot brittleness by segregation at the grain boundary. In detail, high alloy steels containing a large amount of C and Mn, such as in the steel according to an exemplary embodiment of the present disclosure, may cause serious brittleness for slabs and products in a case in which P segregation is added. Moreover, if P exceeds a certain content, the segregation degree rises rapidly, and thus, it may be preferable to limit the content to 0.04% or less.

[0035] In addition, the balance of Fe and unavoidable impurities are included. However, in the normal manufacturing process, impurities not intended, from the raw material or the surrounding environment, may be inevitably mixed, and therefore may not be excluded. These impurities are known to anyone skilled in the art and thus, are not specifically mentioned in this specification. In addition, addition of effective ingredients, in addition to the above composition, is not excluded.

[0036] A steel material having excellent wear resistance according to an exemplary embodiment of the present disclosure includes, in area%, 10% or less (including 0%) of carbide and residual austenite, as a microstructure.

[0037] If the fraction of the carbide exceeds 10% by area, rapid impact toughness deterioration may be caused. The austenite improves ductility and toughness.

[0038] The steel material may preferably have a component segregation index (S) of 3.0 or less.

[Relational Expression 1]

Component segregation index (S) = (C component in central
 portion of rolled material/C component in molten steel)/1.25
 + (Mn component in central portion of rolled material/Mn
 component in molten steel)/1.15 + (P component in central
 portion of rolled material/P component in molten steel)/3.0,

(where a component in the central portion indicates a component in a range of 50 μm or less in upper and lower portions of a part in which a highest component is measured in microstructure analysis at a position equal to half of a thickness of the rolled material).

[0039] If the component segregation index (S) represented by relational expression 1 exceeds 3.0, the probability of occurrence of cracks along the segregation zone at a position of $1/2t$ (t : a steel thickness) during processing, for example, during cutting, may increase rapidly.

[0040] The steel material may have a yield strength of 350 MPa or more, a uniform elongation of 20% or more, and an impact toughness of 40 J or more.

[0041] Hereinafter, a method of manufacturing a steel material having excellent wear resistance according to another exemplary embodiment of the present disclosure will be described in detail.

[0042] A method of manufacturing a steel material having excellent wear resistance according to another exemplary embodiment of the present disclosure, includes:

preparing a molten steel containing, in weight percent, 0.55 to 1.4% of carbon (C), 12 to 23% of manganese (Mn), 5% or less (excluding 0%) of chromium (Cr), 5% or less (excluding 0%) of copper (Cu), 0.5% or less (excluding 0%) of Al, 1.0% or less (excluding 0%) of Si, 0.02% or less (including 0%) of S, 0.04% or less (including 0%) of phosphorus (P), and a balance of Fe and unavoidable impurities;
 continuous casting operating of obtaining a slab by continuously casting the molten steel under conditions of a molten steel temperature (T_c) satisfying the following relational expression 2 and a casting speed (V) satisfying the following relational expression 3,

[Relational Expression 2]

$$K \leq T_c \leq K + 60$$

where in relational expression 2, a K value represents a value determined by the following relational expression 4,

[Relational Expression 3]

$$V \text{ (m/min)} \geq 0.025 [T_c - K]$$

where in relational expression 3, a K value represents a value determined by the following relational expression 4,

[Relational Expression 4]

$$K \text{ (}^\circ\text{C)} = 1536 - (69[C] + 4.2[Mn] + 39[P])$$

where [C], [Mn] and [P] each indicate a content (weight%) of an element;

reheating the slab at a reheating temperature (T_R) or lower obtained by the following relational expression 5,

[Relational Expression 5]

$$T_R = 1453 - 165[C] - 4.5[Mn] - 414[P]$$

where T_R indicates a reheating temperature ($^{\circ}\text{C}$), and $[C]$ and $[Mn]$ each indicate a content (weight%) of an element; hot rolling the slab reheated in the reheating to a finish rolling temperature of 850 to 1050 $^{\circ}\text{C}$ to obtain a hot rolled steel; and cooling the hot rolled steel to 600 $^{\circ}\text{C}$ or less at 5 $^{\circ}\text{C}/\text{sec}$ or more.

Continuous casting

[0043] A steel slab is obtained by continuously casting the molten steel formed as described above under the conditions of a molten steel temperature (T_c) satisfying the following relational expression 2 and of a casting speed (V) satisfying the following relational expression 3.

[Relational Expression 2]

$$K \leq T_c \leq K + 60$$

[0044] (In relational expression 2, a K value represents a value determined by the following relational expression 4.)

[Relational Expression 3]

$$V \text{ (m/min)} \geq 0.025[T_c - K]$$

[0045] (In relational expression 3, a K value represents a value determined by the following relational expression 4.)

[Relational Expression 4]

$$K \text{ (}^{\circ}\text{C)} = 1536 - (69[C] + 4.2[Mn] + 39[P])$$

(where $[C]$, $[Mn]$ and $[P]$ each indicate a content (weight%) of an element.)

[0046] In an exemplary embodiment of the present disclosure, to suppress excessive segregation in the slab structure, which may easily occur in high-carbon high-manganese wear-resistant steel, the casting conditions depending on the component changes, as in relational expressions 2 to 4, are derived. Therefore, internal quality (core quality) defects frequently occurring in the final steel may be suppressed.

[0047] If the slab is not manufactured under the above casting conditions, an excessive segregation zone may be formed in the slab, resulting in slab brittleness, and the excessive segregation zone may remain even after reheating and rolling, leading to quality defects.

Slab Reheating

[0048] The slab obtained by continuous casting as above is reheated.

[0049] It may be preferable that the slab reheating is performed at the reheating temperature (T_R) or lower obtained by the following relational expression 5.

[Relational Expression 5]

$$T_R = 1453 - 165[C] - 4.5[Mn] - 414[P]$$

[0050] [T_R indicates a reheating temperature ($^{\circ}\text{C}$), and $[C]$ and $[Mn]$ each indicate the content (weight%) of the corresponding element]

[0051] In an exemplary embodiment of the present disclosure, to suppress the embrittlement of the central portion

due to partial melting of a segregation zone during reheating, which may easily occur in high-carbon high-manganese wear-resistant steel, the conditions for limiting the reheating temperature depending on the component change as in relational expression 5 above is derived. Therefore, internal quality (core quality) defects frequently occurring in the final steel may be suppressed.

[0052] If the slab reheating temperature exceeds the T_R temperature, partial melting may occur in the segregation zone in the slab, and the resulting embrittlement of the core affects a product, causing a component segregation index of the rolled material to exceed 3.0 to cause defects in the core.

obtaining a hot rolled steel

[0053] Hot rolled steel is obtained by hot rolling the reheated slab as described above to a finish rolling temperature of 850 to 1050°C.

[0054] If the finish rolling temperature is less than 850°C, carbides may precipitate so that uniform elongation may decrease, and microstructures may become pancakes, resulting in uneven elongation due to anisotropy of the structure. If the finish rolling temperature exceeds 1050°C, grain growth may be active, which may easily cause coarsening of the grain, resulting in a decrease in strength.

Cooling hot rolled steel

[0055] The hot-rolled steel is cooled to 600°C or less at 5°C/sec or more.

[0056] If the cooling rate is less than 5°C/sec, or if the cooling stop temperature exceeds 600°C, carbides may be precipitated, resulting in a problem that the elongation decreases. The rapid cooling process helps ensure high solid-solubility of C and N elements in the matrix. Therefore, the cooling may be preferably carried out to 600°C or less at 5°C/sec or more. The cooling rate may be, in detail, 10°C/sec or more, and in more detail, 15°C/sec or more.

[0057] The upper limit of the cooling rate is not particularly limited, and may be limited in consideration of the cooling capability of the equipment. The hot rolled steel may also be cooled to room temperature.

[0058] In a method of manufacturing a steel material having excellent wear resistance according to another exemplary embodiment of the present disclosure, for example, a steel material having a yield strength of 350 MPa or more, a uniform elongation of 20% or more, and an impact toughness of 40 J or more may be manufactured.

[Mode for Invention]

[0059] Hereinafter, an exemplary embodiment of the present disclosure will be described in more detail through examples. However, it should be noted that the embodiments described below are only intended to exemplify the present disclosure and are not intended to limit the scope of the present disclosure. This is because the scope of the present disclosure is determined by the items described in the claims and items able to be reasonably inferred therefrom.

(Example)

[0060] Slabs were prepared by continuously casting molten steel satisfying the components and component ranges illustrated in Table 1 under the conditions in Table 2, and then, hot-rolled steels were prepared by reheating, hot rolling and cooling the slabs under the conditions in Table 3.

[0061] The microstructure, component segregation index, cut-crack incidence rate (%), wear resistance (g), yield strength (MPa), and uniform elongation (%) of the hot-rolled steel prepared as described above were measured, and the results are illustrated in Table 4 below. In this case, the wear resistance is evaluated by measuring the reduced weight after contacting the specimen to a rotating roll while spraying a predetermined amount of sand with a sand abrasion test according to the ASTM 65 test method.

[0062] In addition, the -29°C impact toughness (impact energy (J)) for the hot-rolled steel was measured, and the results are illustrated in Table 4 below.

[0063] On the other hand, for comparative steel 4, to observe the occurrence of defects in a central portion of a thickness of the steel sheet, an image was observed, and the result is illustrated in FIG. 1.

[Table 1]

Steel Grade	Steel Composition (weight%)							
	c	Mn	P	Cr	Cu	Al	Si	S
Inventive Steel 1	0.58	22.1	0.031	4.3	2.1	0.035	0.43	0.006

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(continued)

Steel Grade	Steel Composition (weight%)							
	c	Mn	P	Cr	Cu	Al	Si	S
Inventive Steel 2	0.65	16.6	0.022	3.4	3.9	0.078	0.017	0.011
Inventive Steel 3	0.83	14.9	0.019	1.2	0.33	0.044	0.21	0.007
Inventive Steel 4	1.11	18.4	0.015	2.1	0.06	0.121	0.015	0.005
Inventive Steel 5	1.32	12.6	0.011	0.08	1.2	0.264	0.085	0.012
Comparative Steel 1	<u>0.36</u>	16.1	0.018	3.1	0.02	0.055	0.07	0.01
Comparative Steel 2	<u>1.44</u>	17.2	0.012	2.3	0.3	0.049	0.12	0.007
Comparative Steel3	0.59	<u>11.6</u>	0.015	0.8	1.2	0.078	0.15	0.005
Comparative Steel4	1.17	17.1	<u>0.045</u>	0.4	0.2	0.043	0.11	0.008
Comparative Steel5	1.21	18.9	0.016	1.0	0.9	0.039	0.21	0.007
Comparative Steel6	0.98	15.8	0.015	3.3	2.3	0.046	0.098	0.004
Comparative Steel7	0.89	18.3	0.015	2.1	1.3	0.039	0.046	0.006
Comparative Steel8	1.09	21.3	0.022	0.01	1.2	0.063	0.15	0.011
Comparative Steel9	0.99	17.8	0.018	0.05	0.044	<u>1.2</u>	0.8	0.009

[Table 2]

Steel Grade	Continuous Casting Condition			
	Temperature of molten steel in Relational Expression 2 (T_c) (°C)	Casting speed in Relational Expression 3 (V) (m/min)	Actual Molten Steel Temperature (°C)	Actual Casting Speed (m/min)
Inventive Steel 1	1425	0.2	1434	0.5
Inventive Steel 2	1447	0.3	1459	0.4
Inventive Steel3	1445	0.6	1467	1
Inventive Steel4	1415	0.5	1433	1
Inventive Steel8	1430	0.8	1462	0.9
Comparative Steel 1	1465	0.5	1486	0.7
Comparative Steel 2	1403	0.8	1435	1
Comparative Steel 3	1473	1.1	1517	1.2
Comparative Steel 4	1416	0.2	1425	0.5
Comparative Steel 5	1407	1.0	1446	1.2

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(continued)

Steel Grade	Continuous Casting Condition			
	Temperature of molten steel in Relational Expression 2 (T_c) (°C)	Casting speed in Relational Expression 3 (V) (m/min)	Actual Molten Steel Temperature (°C)	Actual Casting Speed (m/min)
Comparative Steel 6	1433	1.4	1489	1.5
Comparative Steel 7	1427	0.8	1460	1
Comparative Steel 8	1402	0.7	1431	1
Comparative Steel 9	1424	0.7	1453	0.2

In Table 2, the casting speed V is $V \text{ (m/min)} = 0.025 [T_c - K]$.

[Table 3]

Steel Grade	Reheating, hot rolling and cooling conditions				
	Reheating temperature in Relational Expression 5 (T_R) (°C)	Reheating Temperature (°C)	Finish Rolling Temperature (°C)	Cooling Rate (°C/sec)	Cooling Stop Temperature (°C)
Inventive Steel 1	1245	1212	870	11	510
Inventive Steel 2	1262	1205	875	25	390
Inventive Steel 3	1241	1185	903	19	320
Inventive Steel 4	1181	1170	980	61	250
Inventive Steel 5	1174	1162	990	41	270
Comparative Steel 1	1314	1220	1020	21	560
Comparative Steel 2	1133	1130	905	19	440
Comparative Steel 3	1297	1196	898	28	280
Comparative Steel 4	1164	1152	885	30	370
Comparative Steel 5	1162	<u>1187</u>	913	29	380
Comparative Steel 6	1214	1195	<u>829</u>	25	385
Comparative Steel 7	1218	1207	908	<u>3</u>	420

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(continued)

Steel Grade	Reheating, hot rolling and cooling conditions				
	Reheating temperature in Relational Expression 5 (T_R)(°C)	Reheating Temperature (°C)	Finish Rolling Temperature (°C)	Cooling Rate (°C/sec)	Cooling Stop Temperature (°C)
Comparative Steel 8	1168	<u>1179</u>	950	16	<u>690</u>
Comparative Steel 9	1202	1156	945	22	420

[Table 4]

Classification	Microstructure	Component Segregation Index 1)	Cutting crack incidence rate (%) ²⁾	Wear Resistance (g)	Yield Strength (MPa)	Uniform Elongation (%)	Impact Toughness (-29°C)(J)
Inventive Steel1	γ + Carbide 10% or less	2.85	0	1.88	363	51	193
Inventive Steel2	γ + Carbide 10% or less	2.58	0	1.74	451	53	233
Inventive Steel3	γ + Carbide 10% or less	2.51	0	1.54	412	60	265
Inventive Steel1	γ + Carbide 10% or less	2.45	0	1.43	499	53	217
Inventive Steel8	γ + Carbide 10% or less	2.27	0	1.41	522	49	122
Comparative Steel1	γ + Carbide 10% or less	2.45	0	2.69	270	49	99
Comparative Steel 2	γ + Carbide 15.8%	2.31	0	1.56	581	18	33
Comparative Steel3	$\gamma + a$	-	12	2.98	378	36	20
Comparative Steel4	γ + Carbide 10% or less	3.56	83	-	505	22	60
Comparative Steel8	γ + Carbide 10% or less	3.59	68	-	514	27	69
Comparative Steel6	γ + Carbide 12.1%	2.39	0	2.11	418	28	33
Comparative Steel7	γ + Carbide 13.2%	2.31	0	2.17	432	25	29
Comparative Steels	γ + Carbide 14.2%	2.55	0	2.31	519	33	35
Comparative Steel9	γ + Carbide 10% or less	3.9	85	-	508	29	55

1) Component segregation index (S) = (C component in
 central portion of rolled material/C component in molten
 steel)/1.25 + (Mn component in central portion of rolled
 material/Mn component in molten steel)/1.15 + (P component in
 central portion of rolled material/P component in molten
 steel)/3.0

[0064] * Component in the central portion: refers to a component in a range of 50 μm or less in upper and lower portions of a part in which a highest component is measured in microstructure analysis at a position equal to half of a thickness of the rolled material.

2) Cut-crack incidence rate: (length of crack in central
 portion/total cutting length) $\times$ 100

[0065] As illustrated in Tables 1 to 4, in the case of inventive steels 1 to 5 that satisfy all of the steel composition and manufacturing conditions of the present disclosure, it can be seen that not only excellent wear resistance, yield strength, impact toughness and uniform elongation, but also the low cutting crack rate may be exhibited.

[0066] On the other hand, in the case of the comparative steels 1 to 9 that do not satisfy the condition of at least one of the steel composition and manufacturing conditions of the present disclosure, it can be seen that at least one property of wear resistance, yield strength, impact toughness and uniform elongation is insufficient or the cutting crack rate is high.

[0067] In the case of the comparative steel 4 having a central-portion component segregation index of more than 3.0, it was found that the cracking incidence rate was high, and as illustrated in FIG. 1, a defect in the central portion of the steel thickness was generated. It can be seen that the crack occurred in the central portion most vulnerable to thermal stress generated during the cutting process, and the crack propagated along the central portion.

Claims

1. A steel material having excellent wear resistance, comprising:

in weight percent, 0.55 to 1.4% of carbon (C), 12 to 23% of manganese (Mn), 5% or less (excluding 0%) of chromium (Cr), 5% or less (excluding 0%) of copper (Cu), 0.5% or less (excluding 0%) of Al, 1.0% or less (excluding 0%) of Si, 0.02% or less (including 0%) of S, 0.04% or less (including 0%) of phosphorus (P), and a balance of Fe and unavoidable impurities,
 wherein the steel material includes, in area%, 10% or less (including 0%) of carbide and balance austenite, as a microstructure.

2. The steel material having excellent wear resistance of claim 1, wherein the steel material has a component segregation index of 3.0 or less, represented by relational expression 1,

[Relational Expression 1]

Component segregation index (S) = (C component in central
portion of rolled material/C component in molten steel)/1.25
+ (Mn component in central portion of rolled material/Mn
component in molten steel)/1.15 + (P component in central
portion of rolled material/P component in molten steel)/3.0,

where a component in the central portion indicates a component in a range of 50 μm or less in upper and lower portions of a part in which a highest component is measured in microstructure analysis at a position equal to half of a thickness of the rolled material.

3. The steel material having excellent wear resistance of claim 1, wherein the steel material has a yield strength of 350 MPa or more, a uniform elongation of 20% or more, and an impact toughness of 40 J or more.

4. A method of manufacturing a steel material having excellent wear resistance, comprising:

preparing a molten steel containing, in weight percent, 0.55 to 1.4% of carbon (C), 12 to 23% of manganese (Mn), 5% or less (excluding 0%) of chromium (Cr), 5% or less (excluding 0%) of copper (Cu), 0.5% or less (excluding 0%) of Al, 1.0% or less (excluding 0%) of Si, 0.02% or less (including 0%) of S, 0.04% or less (including 0%) of phosphorus (P), and a balance of Fe and unavoidable impurities;
continuous casting operating of obtaining a slab by continuously casting the molten steel under conditions of a molten steel temperature (T_c) satisfying the following relational expression 2 and a casting speed (V) satisfying the following relational expression 3,

[Relational Expression 2]

$$K \leq T_c \leq K + 60$$

where in relational expression 2, a K value represents a value determined by the following relational expression 4,

[Relational Expression 3]

$$V \text{ (m/min)} \geq 0.025 [T_c - K]$$

where in relational expression 3, a K value represents a value determined by the following relational expression 4,

[Relational Expression 4]

$$K \text{ (}^\circ\text{C)} = 1536 - (69[C] + 4.2[Mn] + 39[P])$$

where [C], [Mn] and [P] each indicate a content (weight%) of an element;
reheating the slab at a reheating temperature (T_R) or lower obtained by the following relational expression 5,

[Relational Expression 5]

$$T_R = 1453 - 165[C] - 4.5[Mn] - 414[P]$$

where T_R indicates a reheating temperature ($^\circ\text{C}$), and [C] and [Mn] each indicate a content (weight%) of an

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element;

hot rolling the slab reheated in the reheating to a finish rolling temperature of 850 to 1050°C to obtain a hot rolled steel; and

cooling the hot rolled steel to 600°C or less at 5°C/sec or more.

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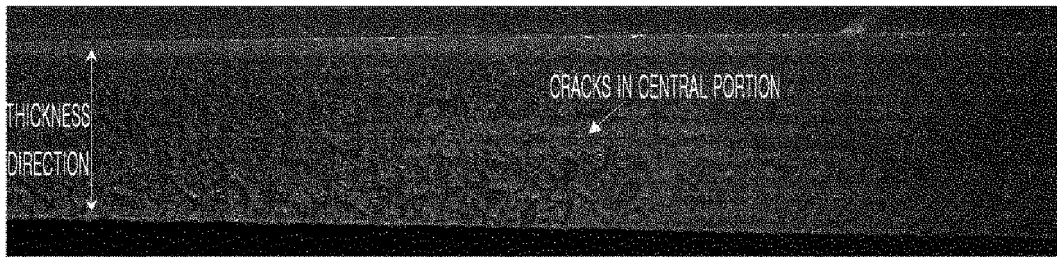
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【FIG. 1】



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2018/016384

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/38(2006.01)i, C22C 38/20(2006.01)i, C22C 38/02(2006.01)i, C22C 38/06(2006.01)i, C21D 9/00(2006.01)i, C21D 8/00(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 38/38; B21B 1/22; B21B 3/00; B22D 11/00; B22D 11/20; C21D 6/00; C21D 8/02; C21D 9/46; C22C 38/04; C22C 38/20; C22C 38/02; C22C 38/06; C21D 9/00; C21D 8/00

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

Korean Utility models and applications for Utility models: IPC as above
Japanese Utility models and applications for Utility models: IPC as above

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

eKOMPASS (KIPO internal) & Keywords: steel plate, abrasion resistance, austenite, high manganese, continuous casting, re-heating, elongation percentage, impact toughness, casting speed, molten steel temperature

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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Y		4
Y	KR 10-2007-0091300 A (ARCELORMITTAL FRANCE) 10 September 2007 See paragraphs [0040]-[0045], [0064]-[0071] and claim 9.	4
Y	KR 10-1714922 B1 (POSCO) 10 March 2017 See claims 1-6 and figure 1.	4
A	KR 10-2006-0040718 A (USINOR SA.) 10 May 2006 See paragraphs [0059]-[0063] and claim 3.	1-4
A	KR 10-2000-0041265 A (POHANG IRON & STEEL CO., LTD.) 15 July 2000 See abstract and claims 5-8.	1-4
A	KR 10-1998-0058369 A (KIA SPECIAL STEEL CO., LTD.) 25 September 1998 See abstract and claims 7-9.	1-4

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

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"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

"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

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

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Date of the actual completion of the international search

03 APRIL 2019 (03.04.2019)

Date of mailing of the international search report

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Name and mailing address of the ISA/KR


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