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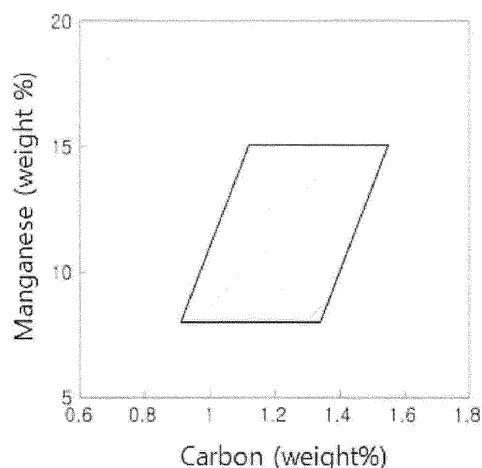
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(54) **WEAR RESISTANT AUSTENITIC STEEL HAVING SUPERIOR MACHINABILITY AND DUCTILITY METHOD FOR PRODUCING SAME**

(57) Provided are a wear resistant austenitic steel having superior machinability and ductility and a method for producing same, the austenitic steel comprising, in weight %, 8 to 15% of manganese (Mn), carbon (C) that satisfies the relationship of $23\% < 33.5C - Mn \leq 37\%$, copper (Cu) that satisfies $1.6C - 1.4(\%) \leq Cu \leq 5\%$, 0.03 to 0.1% of sulfur (S), 0.001 to 0.01% of calcium (Ca), the remainder being Fe and other inevitable impurities. According to the present invention, austenitic steel having superior machinability is provided in which the generation of carbide in the steel is inhibited in order to prevent degradation of the steel, and corrosion resistance is sufficiently ensured to enable the steel to be used with a long service life in a corrosive environment.

[Figure 1]



Description

[Technical Field]

- 5 **[0001]** The present disclosure relates to wear resistant austenitic steel having superior machinability and ductility, and a method for producing the wear resistant austenitic steel.

[Background Art]

- 10 **[0002]** Along with the development of the mining, oil, and gas industries, the wear on steel used for mining, transportation, and refining applications has become problematic. Particularly, as oil sands have been recently developed in earnest as an unconventional source of petroleum, the wear on steel members caused by slurry containing oil, gravel, and sand is one of the main factors increasing the production cost of oil from oil sands, and thus, the development and practical implementation of steel having a high degree of resistance to wear are increasingly required.

- 15 **[0003]** In the mining industry, Hadfield steel having high wear resistance has been mainly been used. Hadfield steel is high-strength steel having a high manganese content, and there have been steady efforts to improve the wear resistance of such steel by adding large amounts of carbon and manganese thereto to increase the formation of austenite and wear resistance therein. However, due to a high carbon content in Hadfield steel, carbides may be formed at high temperature in a network manner along austenite grain boundaries of the Hadfield steel, and thus the physical properties of the
20 Hadfield steel (particularly, ductility) are markedly worsened.

- [0004]** To prevent the formation of such network-shaped precipitates of carbides, a method for manufacturing high-manganese steel by rapidly cooling the high-manganese steel to room temperature after a solution heat treatment or a hot working process is performed on the high-manganese steel at a high temperature has been proposed. However, if a relatively thick steel sheet is formed by the proposed method, the effect of preventing the precipitation of carbides may
25 not be sufficiently obtained by rapid cooling. In addition, if a welding process is performed, it is difficult to control the rate of cooling after the welding process and thus difficult to suppress the formation of network-shaped precipitates of carbides. Therefore, physical properties of steel may be markedly worsened. In addition, alloying elements such as manganese or carbon inevitably segregate in a high-manganese ingot or slab during solidification, and such segregation is facilitated in a post processing process such as a hot rolling process. As a result, carbides may partially precipitate in the form of
30 a network along intensive segregation zones of a final product, and thus the microstructure of the final product may be inhomogeneous, resulting in poor physical properties.

- [0005]** Generally, the content of carbon in steel may be increased to improve the wear resistance of steel, and the content of manganese in the steel may be increased to prevent the deterioration of physical properties of the steel caused by the precipitation of carbides. However, this method increases the amounts of alloying elements and thus the
35 manufacturing cost of steel. Furthermore, the addition of manganese to steel decreases the corrosion resistance of the steel as compared with general carbon steel. Thus, such steel may not be used in fields requiring corrosion resistant steel.

- [0006]** Furthermore, since the machinability of austenitic high-manganese steel is poor due to a high degree of work hardenability, the lifespans of cutting tools may be decreased, and thus costs for cutting tools may be increased. In addition, process suspension times may be increased due to the need for the frequent replacement of cutting tools.
40 Eventually, manufacturing costs may be increased.

[Disclosure]

[Technical Problem]

- 45 **[0007]** Aspects of the present disclosure may provide austenitic steel having improved machinability, ductility, and wear resistance through suppressing the formation of carbides, and a method for producing the austenitic steel.

- [0008]** However, aspects of the present disclosure are not limited thereto. Additional aspects will be set forth in part in the description which follows, and will be apparent from the description to those having ordinary skill in the art to which
50 the present disclosure pertains.

[Technical Solution]

- [0009]** According to an aspect of the present disclosure, wear resistant austenitic steel having superior machinability and ductility may include, by weight%, 8% to 15% of manganese (Mn), carbon (C) satisfying $23\% < 33.5\text{C-Mn} \leq 37\%$, copper (Cu) satisfying $1.6\text{C-1.4}(\%) \leq \text{Cu} \leq 5\%$, and the balance of iron (Fe) and inevitable impurities.

- [0010]** According to another aspect of the present disclosure, a method for producing wear resistant austenitic steel having superior machinability and ductility may include: reheating a steel slab to a temperature of 1050°C to 1250°C,

the steel slab including, by weight%, 8% to 15% of manganese (Mn), carbon (C) satisfying $23\% < 33.5C-Mn \leq 37\%$, copper (Cu) satisfying $1.6C-1.4(\%) \leq Cu \leq 5\%$, and the balance of iron (Fe) and inevitable impurities; performing a finish hot rolling process on the steel slab within a temperature range of 800°C to 1050°C to form a steel sheet; and cooling the hot-rolled steel sheet to a temperature of 600°C or lower at a cooling rate of 10°C/s to 100°C/s.

[Advantageous Effects]

[0011] According to the present disclosure, the formation of carbides in the austenitic steel may be suppressed to prevent the deterioration of the austenitic steel, and the wear resistance of the austenitic steel may be sufficiently improved. Therefore, the austenitic steel may be used for an extended period of time, even in corrosive environments.

[Description of Drawings]

[0012]

FIG. 1 is a graph illustrating a relationship between manganese and carbon according to an embodiment of the present disclosure.

FIG. 2 is a microstructure image of steel in an example of the present disclosure.

FIG. 3 is a graph illustrating a relationship between the content of sulfur and machinability in an example of the present disclosure.

[Best Mode]

[0013] Hereafter, wear resistant austenitic steel having superior machinability and ductility, and a method for producing the wear resistant austenitic steel will be described in detail according to embodiments of the present disclosure, so that those of ordinary skill in the related art may clearly understand the scope and spirit of the embodiments of the present disclosure.

[0014] The inventors found that if the composition of steel is properly adjusted, the steel has a high degree of wear resistance without a decrease in ductility caused by carbides and a high degree of machinability. Based on this knowledge, the inventors invented wear resistant austenitic steel and a method of producing the wear resistant austenitic steel.

[0015] That is, manganese and carbon are added to the steel of the embodiments of the present disclosure to improve the wear resistance of the steel while controlling the content of the carbon relative to the content of the manganese to minimize the formation of carbides. Furthermore, additional elements are added to the steel to further suppress the formation of carbides and thus to sufficiently improve the toughness of the steel in addition to improving the wear resistance of the steel, and in conjunction therewith, the contents of calcium and sulfur in the steel are adjusted to markedly improve the machinability of the steel (austenitic high-manganese steel).

[0016] According to the embodiments of the present disclosure, the steel may include, by weight%, 8% to 15% of manganese (Mn), carbon (C) satisfying $23\% < 33.5C-Mn \leq 37\%$, copper (Cu) satisfying $1.6C-1.4(\%) \leq Cu \leq 5\%$, and the balance of iron (Fe) and inevitable impurities.

[0017] The numerical ranges of the contents of the elements are set because of reasons described below. In the following description, the content of each element is given in weight% unless otherwise specified.

Manganese (Mn): 8% to 15%

[0018] Manganese is a main element for stabilizing austenite in high manganese steel like the steel of the embodiments of the present disclosure. In the embodiments of the present disclosure, it may be preferable that the content of manganese be 8% or greater for forming austenite as a main component of the microstructure of the steel. If the content of manganese is less than 8%, ferrite may be formed, and thus austenite may not be sufficiently formed. On the other hand, if the content of manganese is greater than 15%, problems such as decrease in a corrosion resistance of the steel, increase in difficulties in the manufacturing process and increase in manufacturing costs may occur. Also, the work hardenability of the steel may be decreased due to a decreased in tensile strength.

Carbon (C): $23\% < 33.5C-Mn \leq 37\%$

[0019] Carbon is an element for stabilizing austenite and forming austenite at room temperature. Carbon increases the strength of the steel. Particularly, carbon dissolved in austenite of the steel increases the work hardenability of the steel and thus increases the wear resistance of the steel. However, as described above, if the content of carbon in the steel is insufficient, the stability of austenite is low, and the wear resistance of the steel may be insufficient due to the

formation of martensite or a low degree of work hardenability of austenite. On the other hand, if the content of carbon in the steel is excessive, it is difficult to suppress the formation of carbides.

[0020] Therefore, in the embodiments of the present disclosure, the content of carbon in the steel may be determined according to the contents of other elements in the steel. The inventors found a relationship between carbon and manganese in the formation of carbides, and the relationship is illustrated in FIG. 1. Although carbides are formed from carbon, the formation of carbides is not affected only by carbon but is affected by a ratio of carbon and manganese. FIG. 1 illustrates a proper content of carbon in relation to the content of manganese.

[0021] If it is assumed that the contents of the other elements of the steel are within the ranges of the embodiments of the present disclosure, it may be preferable that the value of $33.5C-Mn$ be adjusted to be 37 or less (where C and Mn refer to the content of carbon and the content of manganese in weight%), so as to prevent the formation of carbides. This corresponds to the right boundary of the parallelogram region in FIG. 1. If $33.5C-Mn$ is greater than 37, carbides may be formed to a degree worsening the ductility of the steel. However, if the content of carbon in the steel is too low (that is, if $33.5C-Mn$ is less than 23), the wear resistance of the steel may not be improved by the work hardenability of the steel. Therefore, it may be preferable that $33.5C-Mn$ be equal to or greater than 23. That is, it may be preferable that the content of carbon satisfy $23 < 33.5C-Mn \leq 37$.

Copper (Cu): $1.6C-1.4(\%) \leq Cu \leq 5\%$

[0022] Due to a low solid solubility of copper in carbides and a low diffusion rate of copper in austenite, copper tends to concentrate in interfaces between austenite and carbides. Therefore, if fine carbide nuclei are formed, copper may surround the fine carbide nuclei, and thus additional diffusion of carbon and growth of carbides may be retarded. That is, copper suppresses the formation and growth of carbides. Therefore, in the embodiments of the present disclosure, copper is added to the steel. The content of copper in the steel is not independently determined but may be determined according to the formation behavior of carbides. For example, the content of copper may be set to be equal to or greater than $1.6C-1.4$ weight% so as to effectively suppress the formation of carbides. If the content of copper in the steel is less than $1.6C-1.4$ weight%, the conversion of carbon into carbides may not be suppressed. In addition, if the content of copper in the steel is greater than 5 weight%, the hot workability of the steel may be lowered. Therefore, it may be preferable that the upper limit of the content of copper be set to 5 weight%. Particularly, in the embodiments of the present disclosure, when the content of carbon added to the steel for improving wear resistance is considered, the content of copper may preferably be 0.3 weight% or greater, more preferably, 2 weight% or greater, so as to obtain a sufficient effect of suppressing the formation of carbides.

[0023] In the embodiments of the present disclosure, the other component of the steel is iron (Fe). However, impurities in raw materials or manufacturing environments may be inevitably included in the steel, and such impurities may not be able to be removed from the steel. Such impurities are well-known to those of ordinary skill in the art to which the present disclosure pertains, and thus descriptions thereof will not be given in the present disclosure.

[0024] In the embodiments of the present disclosure, sulfur (S) and calcium (Ca) may be further included in the steel in addition to the above-described elements, so as to improve the machinability of the steel.

Sulfur (S): 0.03% to 0.1%

[0025] In general, it is known that sulfur added together with manganese forms manganese sulfide which is easily cut and separated during a cutting process. That is, sulfur is known as an element improving the machinability of steel. Sulfur is melted by heat generated during a cutting process, and thus reduces friction between chips and cutting tools. That is, sulfur increases the lifespan of cutting tools by lubricating the surface of the cutting tools, reducing the wear on the cutting tools, and preventing accumulation of cutting chips on the cutting tool. However, if the content of sulfur in the steel is excessive, mechanical characteristics of the steel may deteriorate due to a large amount of coarse manganese sulfide elongated during a hot working process, and the hot workability of the steel may deteriorate due to the formation of iron sulfide. Therefore, it may be preferable that the upper limit of the content of sulfur in the steel be 0.1%. If the content of sulfur in the steel is less than 0.03%, the machinability of the steel may not be improved, and thus it may be preferable that the lower limit of the content of sulfur in the steel be 0.03%.

Calcium (Ca): 0.001% to 0.01%

[0026] Calcium is usually used to control the formation of manganese sulfide. Since calcium has a high affinity for sulfur, calcium forms calcium sulfide together with sulfur, and along with this, calcium is dissolved in manganese sulfide. Since manganese sulfide crystallizes around calcium sulfide functioning as crystallization nuclei, during a hot working process, manganese sulfide may be less elongated and may be maintained in a spherical shape. Therefore, the machinability of the steel may be improved. However, if the content of calcium is greater than 0.01%, the above-described effect

is saturated. In addition, since the percentage recovery of calcium is low, a large amount of calcium raw material may have to be used, and thus the manufacturing cost of the steel may be increased. On the other hand, if the content of calcium in the steel is less than 0.001%, the above-described effect is insignificant. Thus, it may be preferable that the lower limit of the content of calcium be 0.001%.

[0027] In the embodiments of the present disclosure, chromium (Cr) may be included in the steel in addition to the above-described elements so as to further improve the corrosion resistance of the steel.

Cr: 8% or less (excluding 0%)

[0028] Generally, manganese lowers the corrosion resistance of steel. That is, in the embodiments of the present disclosure, manganese included in the steel in the above-described content range may lower the corrosion resistance of the steel, and thus chromium is added to the steel to improve the corrosion resistance of the steel. In addition, if chromium is added to the steel in an amount within the range, the strength of the steel may also be improved. However, if the content of chromium in the steel is greater than 8 weight%, the manufacturing cost of the steel is increased, and carbon dissolved in the steel may be converted into carbides along grain boundaries to lower the ductility of the steel and particularly resistance of the steel to sulfide stress cracking. In addition, ferrite may be formed in the steel, and thus austenite may not be formed as a main microstructure in the steel. Therefore, it may be preferable that the upper limit of the content of chromium be 8 weight%. Particularly, to maximize the effect of improving the corrosion resistance of the steel, it may be preferable that the content of chromium in the steel be set to be 2 weight% or greater. Since the corrosion resistance of the steel is improved by the addition of chromium, the steel may be used for forming slurry pipes or as an anti sour gas material.

[0029] The steel having the above-described composition is austenitic steel having 90 area% or more of austenite. In a later processing process, austenite of the steel may be markedly hardened, and thus the steel may have a high degree of hardness. In addition to austenite, some other microstructures such as martensite, bainite, pearlite, and ferrite may be inevitably formed in the steel as impurity microstructures. In the present disclosure, the sum of the amounts of the phases of the steel is put as 100%, and the content of each microstructure is denoted as a proportion of the sum without considering the amounts of precipitates such as a carbide precipitate.

[0030] Furthermore, in the embodiments of the present disclosure, it may be preferable that the steel include 10 area% or less of carbides (based on the total area of the steel). Since carbides lower the ductility of the steel, the amounts of carbides in the steel may be adjusted to be low. For example, in the embodiments of the present disclosure, since the area fraction of carbides in the steel is 10% or less, when the steel is used as wear resistant steel, problems caused by low ductility such as premature fracturing and a decrease in impact toughness may not arise.

[0031] Hereinafter, a method for producing the wear resistant austenitic steel will be described according to an embodiment of the present disclosure. The steel may be produced by a manufacturing method commonly known in the related art, and the manufacturing method of the related art may include a conventional hot rolling process in which a slab is reheated, roughly-rolled, and finish-rolled. After the hot rolling process, the steel may be cooled by a conventional cooling method. For example, in an embodiment of the present disclosure, the steel may be produced by an exemplary method proposed by the inventors as follows.

[0032] A steel slab is prepared, which includes, by weight%, 8% to 15% of manganese (Mn), carbon (C) satisfying $23\% < 33.5C - Mn \leq 37\%$, copper (Cu) satisfying $1.6C - 1.4(\%) \leq Cu \leq 5\%$, and the balance of iron (Fe) and inevitable impurities.

[0033] As described above, the steel slab may further include sulfur (S) and calcium (Ca).

[0034] Furthermore, as described above, the steel slab may further include chromium (Cr).

[0035] The steel slab is reheated to a temperature of 1050°C to 1250°C.

[0036] The steel slab (or ingot) may be reheated in a reheating furnace for a hot rolling process. If the steel slab is reheated to a temperature lower than 1050°C, the load acting on a rolling mill may be markedly increased, and alloying elements may not be sufficiently dissolved in the steel slab. On the other hand, if the reheating temperature of the steel slab is too high, crystal grains may excessively grow, and thus the strength of the steel slab may be lowered. Particularly, in the above-described composition range of the steel of the present disclosure, carbides may melt in grain boundaries, and if the steel slab is reheated to a temperature equal to or higher than the solidus line of the steel slab, hot-rolling characteristics of the steel slab may deteriorate. Therefore, the upper limit of the reheating temperature may be set to be 1250°C.

[0037] Thereafter, the steel slab is finish-rolled at a temperature of 800°C to 1050°C to form a steel sheet.

[0038] As described above, the steel slab is rolled within the temperature range of 800°C to 1050°C. If the steel slab is rolled at a temperature lower than 800°C, the load of rolling may be large, and carbides may precipitate and grow coarsely. Thus, desired ductility may not be obtained. The upper limit of the rolling temperature is set to be 1050°C.

[0039] The steel sheet formed by hot rolling is cooled to a temperature of 600°C or lower at a cooling rate of 10°C/s to 100°C/s.

[0040] After the finish rolling, the steel sheet may be cooled at a sufficiently high cooling rate to suppress the formation of carbides in grain boundaries. If the cooling rate is less than 10°C/s, the formation of carbides may not be sufficiently suppressed, and thus carbides may precipitate in grain boundaries during cooling. This may cause problems such as premature fracture, a ductility decrease, and a wear resistance decrease. Therefore, the cooling rate may be adjusted to be high, and the upper limit of the cooling rate may not be limited to a particular value as long as the cooling rate is within an accelerated cooling rate range. However, it may be difficult to increase the cooling rate to a value greater than 100°C/s by a conventional accelerated cooling technique.

[0041] Although the steel sheet is cooled at a high cooling rate, if the cooling of the steel sheet is terminated at a high temperature, carbides may be formed and grow in the steel sheet. Therefore, in the embodiment of the present disclosure, the steel sheet may be cooled to a temperature of 600°C or lower.

[Mode for Invention]

[0042] Hereinafter, the embodiments of the present disclosure will be described more specifically through examples. However, the examples are for clearly explaining the embodiments of the present disclosure and are not intended to limit the spirit and scope of the present disclosure.

[Example 1]

[0043] Slab samples having elements and compositions illustrated in Table 1 were reheated, hot-rolled, and cooled under the conditions illustrated in Table 2. Then, properties of the samples such the microstructure, elongation, strength, and carbide fraction were measured as illustrated in Table 3. In Table 1, the content of each element is given in weight%.

[Table 1]

No.	C	Mn	Cu	Cr	33.5C-Mn	1.6C-1.4
Comparative sample A1	0.5	10			6.8	-
Comparative sample A2	1.2	10			30.2	0.5
Comparative sample A3	1.45	12	0.75		36.6	0.9
Comparative sample A4	1.3	12	0.52		31.6	0.7
Comparative sample A5	1.23	14.1	1.05	1.98	27.1	0.6
Inventive sample A1	1	9	1.2		24.5	0.2
Inventive sample A2	1.2	15	1	0.5	25.2	0.5
Inventive sample A3	1.03	10	0.55	0.5	24.5	0.2
Inventive sample A4	1.4	15	1.6	1.1	31.9	0.8
Inventive sample A5	1.25	14	1.02	2	27.9	0.6
Inventive sample A6	1.15	14.6	0.87	3	23.9	0.4

[Table 2]

No.	Reheating temperature (°C)	Finish rolling temperature (°C)	Cooling rate (°C/s)	Cooling stopping temperature (°C)
Comparative sample A1	1160	895	13	550
Comparative sample A2	1140	930	8	561
Comparative sample A3	1140	924	21	568
Comparative sample A4	1140	921	16	485

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(continued)

No.	Reheating temperature (°C)	Finish rolling temperature (°C)	Cooling rate (°C/s)	Cooling stopping temperature (°C)
Comparative sample A5	1145	915	5.6	545
Inventive sample A1	1145	915	15	561
Inventive sample A2	1142	889	15	512
Inventive sample A3	1152	875	17	579
Inventive sample A4	1140	906	25	532
Inventive sample A5	1146	911	25	541
Inventive sample A6	1143	892	20	521

[Table 3]

No.	Austenite fraction (area%)	Carbide fraction (area%)	Elongation (%)	Yield strength (MPa)	Tensile strength (MPa)
Comparative sample A1	63	<1	7.8	340	590
Comparative sample A2	87	13	4.6	415	669
Comparative sample A3	88	12	3.7	572	865
Comparative sample A4	89	11	4.4	452	721
Comparative sample A5	87.6	12.4	8.2	452	765
Inventive sample A1	98	2	37	398	982
Inventive sample A2	99	1	43	420	1012
Inventive sample A3	99	1	35	406	964
Inventive sample A4	99	1	40	542	1108
Inventive sample A5	99	1	42	462	976
Inventive sample A6	99	1	43	572	1095

[0044] In addition, a wear test (ASTM G65) and an immersion test (ASTM G31) for evaluating corrosion rates were

performed on comparative samples and inventive samples, and the results are illustrated in Table 4 below.

[Table 4]

No.	Weight reduction (g)	Corrosion rate (mm/year)	
		3.5% NaCl, 50°C, 2 weeks	0.05M H ₂ SO ₄ , 2 weeks
Comparative sample A1	0.72	0.14	0.48
Comparative sample A2	0.36	0.15	0.49
Comparative sample A3	0.24	0.17	0.52
Comparative sample A4	0.29	0.16	0.50
Inventive sample A1	0.35	0.14	0.48
Inventive sample A2	0.28	0.17	0.50
Inventive sample A3	0.34	0.16	0.49
Inventive sample A4	0.18	0.17	0.50
Inventive sample A5	0.31	0.09	0.41
Inventive sample A6	0.27	0.07	0.37

[0045] 33.5C-Mn of Comparative Sample A1 was 6.8 which was outside of the range of the embodiments of the present disclosure. Thus, due to a lack of carbon stabilizing austenite, a large amount of martensite was formed in Comparative Sample A1, and a desired austenitic microstructure was not formed in Comparative Sample A1.

[0046] Comparative Sample A2 had manganese and carbon within the content ranges of the embodiments of the present disclosure. However, copper was not added to Comparative Sample A2, and thus the formation of carbides was not suppressed. That is, large amounts of carbides were formed along grain boundaries of Comparative Sample A2, and thus a desired microstructure and elongation were not obtained. In Comparative Sample A2, a sufficient degree of work hardenability was not obtained due to premature fracture and a decreased amount of dissolved carbon caused by the formation of carbides. Therefore, the wear amount of Comparative Sample A2 was relatively large.

[0047] Comparative Samples A3 and A4 had manganese and carbon within the content ranges of the embodiments of the present disclosure. However, the content of copper in each of Comparative Samples A3 and A4 was outside of the range of the embodiments of the present disclosure. Therefore, like in Comparative Sample A2, large amounts of carbides were formed in Comparative Samples A3 and A4, and thus a desired microstructure and elongation were not obtained. Since the contents of copper in Comparative Samples A3 and A4 were outside of the range of the embodiments of the present disclosure, the formation of carbides was not effectively suppressed, and thus the amounts of dissolved carbon and elongation of Comparative Samples A3 and A4 were reduced to cause premature fracture. Thus, a sufficient degree of work hardenability was not obtained in Comparative Sample A3 and A4, and thus the wear resistance of Comparative Samples A3 and A4 was reduced.

[0048] Although the composition of Comparative Sample A5 satisfied the conditions of the embodiments of the present disclosure, the cooling rate of Comparative Sample A5 after a rolling process was outside of the range of the embodiments of the present disclosure. That is, due to a low cooling rate, the formation of carbides was not effectively suppressed, and thus the ductility of Comparative Sample A5 was decreased.

[0049] However, in Inventive Samples A1 to A6 having elements and compositions according to the embodiments of the present disclosure, the formation of carbides in grain boundaries was effectively suppressed owing to the addition of copper, and thus physical properties of Inventive Samples A1 to A6 were not worsened. In detail, although Inventive Samples A1 to A6 had high carbon contents, the formation of carbides was effectively suppressed owing to the addition of copper, and thus Inventive Samples A1 and A6 had desired microstructures and properties. Since carbon was sufficiently dissolved in austenite and the formation of carbides in grain boundaries was effectively suppressed, the elongation of Inventive Samples A1 to A6 was stably maintained, and the tensile strength of Inventive Samples A1 to A6 was high. Therefore, the work hardenability of Inventive Samples A1 to A6 was sufficient, and thus the wear amounts of Inventive Samples A1 to A6 were small.

[0050] Particularly, according to results of a corrosion test, the corrosion rates of Inventive Samples A5 and A6 to which chromium was additionally added were low. That is, the corrosion resistance of Inventive Samples A5 and A6 was improved. The effect of improving corrosion resistance by the addition of chromium may be clearly understood by comparison with corrosion rates of Inventive Samples A1 to A4. In addition, the strength of Inventive Samples A5 and

A6 was improved by solid-solution strengthening induced by the addition of chromium.

[0051] FIG. 2 is a microstructure image of Inventive Sample A2. Referring to FIG. 2, although Inventive Sample A2 has a high carbon content, carbides are not present in Inventive Sample A2 owing to the addition of copper within the content range of the embodiments of the present disclosure.

[Example 2]

[0052] Steel slabs (Inventive Samples and Comparative Samples) having compositions illustrated in Table 5 were manufactured by a continuous casting process. In Table 5, the content of each element is given in weight%.

[Table 5]

No.	C	Mn	Cu	Cr	Ca	S	33.5C-Mn	1.6C-1.4
Comparative sample B1	1	9	1.2				24.5	0.2
Comparative sample B2	1.2	15	1	0.5		0.02	25.2	0.5
Comparative sample B3	1.03	10	0.55	0.5			24.5	0.2
Comparative sample B4	1.4	15	1.6	1.1		0.01	31.9	0.8
Comparative sample B5	1.25	14	1.02	2			27.9	0.6
Inventive sample B1	0.98	9.2	1.5		0.006	0.06	23.6	0.2
Inventive sample B2	1.02	9.8	0.53	0.48	0.007	0.05	24.4	0.2
Inventive sample B3	1.04	10.5	0.53	0.45	0.007	0.07	24.3	0.3
Inventive sample B4	0.98	10.6	0.57	0.53	0.008	0.09	22.2	0.2
Inventive sample B5	1.23	14.8	1.11	1.95	0.006	0.08	26.4	0.6

[0053] The steel slabs were reheated, finish-rolled, and cooled under the conditions illustrated in Table 6 so as to form steel sheets.

[Table 6]

No.	Reheating temperature (°C)	Finish rolling temperature (°C)	Cooling rate (°C/s)	Cooling stopping temperature (°C)
Comparative sample B1	1145	915	15	561
Comparative sample B2	1142	889	15	512
Comparative sample B3	1152	875	17	579
Comparative sample B4	1140	906	25	532
Comparative sample B5	1146	911	25	541
Inventive sample B1	1142	889	15	552
Inventive sample B2	1152	875	17	579
Inventive sample B3	1150	890	19	580
Inventive sample B4	1146	886	19	575

(continued)

No.	Reheating temperature (°C)	Finish rolling temperature (°C)	Cooling rate (°C/s)	Cooling stopping temperature (°C)
Inventive sample B5	1143	892	24	541

[0054] The austenite fraction, carbide fraction, elongation, yield strength, and tensile strength of each of the steel sheets were measured as illustrated in Table 7. Holes were repeatedly formed in each of the steel sheets by using a drill having a diameter of 10 mm and formed of high speed tool steel in conditions of a drill speed of 130 rpm and a drill movement rate of 0.08 mm/rev. The number of holes formed in each steel sheet until the drill was worn down to the end of its lifespan was counted as illustrated in Table 3.

[Table 7]

No.	Austenite fraction (area%)	Carbide fraction (area%)	Elongation (%)	Yield strength (MPa)	Tensile strength (MPa)	Number of holes
Comparative sample B1	98	2	37	398	982	1
Comparative sample B2	99	1	43	420	1012	0
Comparative sample B3	99	1	35	406	964	1
Comparative sample B4	99	1	40	542	1108	0
Comparative sample B5	98	1	42	462	976	0
Inventive sample B1	99	1	36	386	991	3
Inventive sample B2	99	1	36	410	960	4
Inventive sample B3	99	1	34	405	953	5
Inventive sample B4	99	1	35	408	955	6
Inventive sample B5	99	1	41	461	984	3

[0055] In addition, a wear test (ASTM G65) and an immersion test (ASTM G31) for evaluating corrosion rates were performed on each of the steel sheets (comparative samples and inventive samples), and the results are illustrated in Table 8 below.

[Table 8]

No.	Wear test	Corrosion rate (mm/year)	
	Weight reduction (g)	3.5% NaCl, 50°C 2 weeks	0.05M H ₂ SO ₄ , 2 weeks
Comparative sample B1	0.35	0.14	0.48
Comparative sample B2	0.28	0.17	0.50
Comparative sample B3	0.34	0.16	0.49
Comparative sample B4	0.18	0.17	0.50

(continued)

No.	Wear test	Corrosion rate (mm/year)	
		3.5% NaCl, 50°C 2 weeks	0.05M H ₂ SO ₄ , 2 weeks
Comparative sample B5	0.31	0.09	0.41
Inventive sample B1	0.34	0.15	0.50
Inventive sample B2	0.34	0.16	0.48
Inventive sample B3	0.33	0.17	0.50
Inventive sample B4	0.32	0.16	0.47
Inventive sample B5	0.30	0.09	0.40

[0056] In the inventive samples having carbon and manganese within the content ranges of the embodiments of the present disclosure, the formation of carbides in grain boundaries was effectively suppressed owing to the addition of copper, and thus physical properties of the inventive samples were not worsened. In detail, although the inventive samples had high carbon contents, the formation of carbides was effectively suppressed owing to the addition of copper, and thus the inventive samples had desired microstructures and properties. Since carbon was sufficiently dissolved in austenite and the formation of carbides in grain boundaries was effectively suppressed, the elongation of the inventive samples was stably maintained, and the tensile strength of the inventive samples was high. Therefore, the work hardenability of the inventive samples was sufficient, and thus the wear amounts of the inventive samples were small.

[0057] The machinability of Comparative Samples B1 to B5 was poor because sulfur and calcium were not added to Comparative Samples B1 to B5 or the contents of sulfur and calcium in Comparative Samples B1 to B5 were outside of the ranges of the embodiments of the present disclosure.

[0058] However, Inventive Samples B1 to B5 including sulfur and calcium within the content ranges of the embodiments of the present disclosure had superior machinability as compared with the comparative samples. Particularly, in Inventive Samples B2 to B4 having different sulfur contents, the machinability thereof was improved in proportion to the content of sulfur.

[0059] FIG. 3 illustrates machinability with respect to the content of sulfur. Referring to FIG. 3, machinability improves in proportion to the content of sulfur.

Claims

1. Wear resistant austenitic steel having superior machinability and ductility, the wear resistant austenitic steel comprising, by weight%, 8% to 15% of manganese (Mn), carbon (C) satisfying $23\% < 33.5C-Mn \leq 37\%$, copper (Cu) satisfying $1.6C-1.4(\%) \leq Cu \leq 5\%$, and the balance of iron (Fe) and inevitable impurities.
2. The wear resistant austenitic steel of claim 1, further comprising, by weight%, 0.03% to 0.1% of sulfur (S) and 0.001% to 0.01% of calcium (Ca).
3. The wear resistant austenitic steel of claim 1 or 2, further comprising 8 weight% or less (excluding 0 weight%) of chromium (Cr).
4. The wear resistant austenitic steel of claim 1 or 2, wherein the wear resistant austenitic steel has a microstructure comprising 90 area% or more of austenite.
5. The wear resistant austenitic steel of claim 1 or 2, wherein the wear resistant austenitic steel comprises 10 area% or less of carbides.
6. A method for producing wear resistant austenitic steel having superior machinability and ductility, the method comprising:

reheating a steel slab to a temperature of 1050°C to 1250°C, the steel slab comprising, by weight%, 8% to 15% of manganese (Mn), carbon (C) satisfying $23\% < 33.5C-Mn \leq 37\%$, copper (Cu) satisfying $1.6C-1.4(\%) \leq Cu \leq$

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5%, and the balance of iron (Fe) and inevitable impurities;
performing a finish hot rolling process on the steel slab within a temperature range of 800°C to 1050°C to form a steel sheet; and
cooling the hot-rolled steel sheet to a temperature of 600°C or lower at a cooling rate of 10°C/s to 100°C/s.

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7. The method of claim 6, wherein the steel slab further comprises, by weight%, 0.03% to 0.1% of sulfur (S) and 0.001% to 0.01% of calcium (Ca).
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8. The method of claim 6 or 7, wherein the steel slab further comprises 8 weight% or less (excluding 0 weight%) of chromium (Cr).

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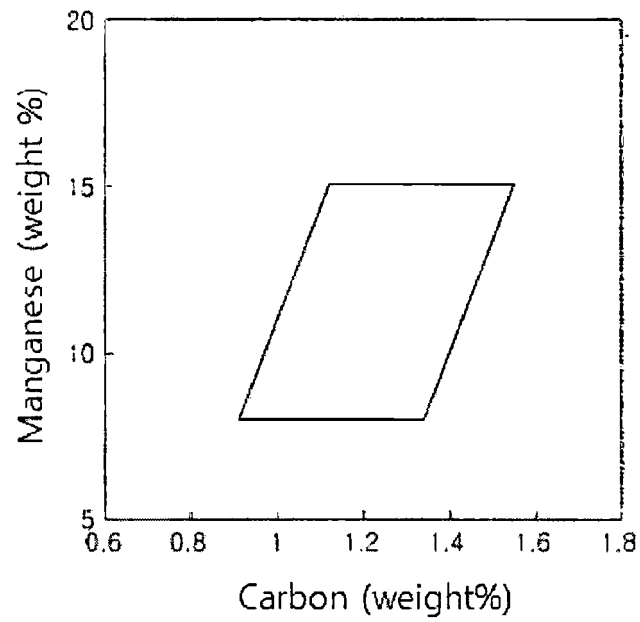
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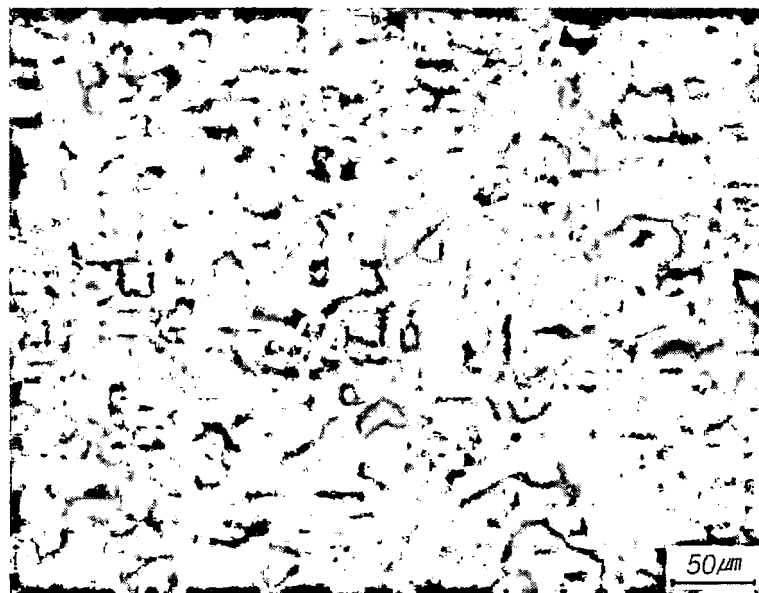
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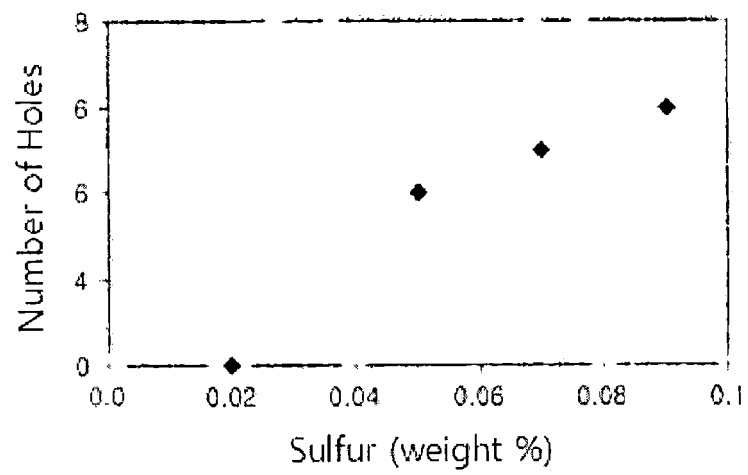
【Figure 1】



【Figure 2】



【Figure 3】



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2012/011536

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/04(2006.01)i, C22C 38/38(2006.01)i, C21D 8/02(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 38/00; C22C 38/04; C21D 8/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
 Korean Utility models and applications for Utility models: IPC as above
 Japanese Utility models and applications for Utility models: IPC as above

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

eKOMPASS (KIPO internal) & Keywords: austenite, manganese, carbon, copper, machinability, ductility, chrome, carbide

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	KR 10-2011-0075610 A (POSCO) 06 July 2011 See paragraphs [0014]-[0029], claims 1, 2.	1,4,5 2,3,6-8
X	KR 10-2007-0023831 A (POSCO) 02 March 2007 See claims 4-6, page 5.	6
A	KR 10-2007-0099684 A (TATA STEEL ILMUIDEN B.V.) 09 October 2007 See claims 1, 2.	1-8
A	KR 10-2008-0061861 A (POSCO) 03 July 2008 See claim 1.	1-8
A	KR 10-2009-0046236 A (KOREA INSTITUTE OF MACHINERY & MATERIALS) 11 May 2009 See claim 1.	1-8

☐ 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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Date of the actual completion of the international search

11 APRIL 2013 (11.04.2013)

Date of mailing of the international search report

12 APRIL 2013 (12.04.2013)

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

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