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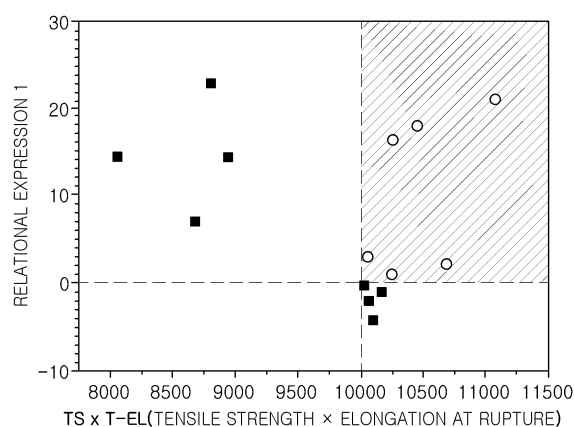
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(54) **ULTRA-HIGH STRENGTH HOT-ROLLED STEEL SHEET HAVING EXCELLENT BENDING WORKABILITY AND METHOD FOR MANUFACTURING SAME**

(57) The present invention relates to an ultra-high strength hot-rolled steel sheet which is mainly used for components requiring high strength and excellent bending workability, such as a bumper reinforcement and a door impact beam that are reinforcements for the body of a car. The present invention provides: an ultra-high strength hot-rolled steel sheet which has high strength and thus is very effective in forming a lightweight material due to the thin thickness of the material according to the high strength thereof, and at the same time has excellent bending workability so that it is easy to ensure the shape freezing property of a component through roll forming; and a method for manufacturing the same.

[Fig.1]



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Description

[Technical Field]

[0001] The present disclosure relates to an ultra-high strength hot-rolled steel sheet which may mainly be used for components requiring high strength and excellent bending workability, such as a bumper reinforcement member and a door impact beam that are reinforcement members for the body of a car. The present disclosure may provide an ultra-high strength hot-rolled steel sheet which has high strength and is thus very effective in forming a lightweight material due to thinning of the material according to the high strength thereof, and at the same time has excellent bending workability so that it is easy to ensure the shape fixability of a component through roll forming, and a method for manufacturing the same.

[Background Art]

[0002] A conventional high strength hot-rolled steel sheet is generally manufactured by adding C, Si, Mn, Ti, Nb, Mo, V, and the like to high purity steel in which an amount of impurities may be minimized, to obtain a high level of strength.

[0003] In order to manufacture the high strength hot-rolled steel sheet, known are a method for manufacturing a hot-rolled steel sheet using precipitation hardening of added elements such as Ti, Nb, V, Mo, and the like (Japanese Patent Application No. 2010-279711, Japanese Patent Application No. 2003-156473), a method for securing strength by adding a large amount of Cr or Mn (European Patent Application No. 2003-396059, Korean Patent Application No. 1996-7005330), or a method for strengthening impact strength and tensile properties of steel containing Mn and Cr by temper annealing (PCT Patent Application No. IB 2011-01436).

[0004] Ultra-high strength hot-rolled steel sheets used for a bumper reinforcement member, a door impact beam, and the like that are reinforcement members for the body of a car may require high strength as well as excellent bending workability for roll forming.

[0005] However, solid solution strengthening by alloying elements, such as C, Si, Mn, Cr, Mo, W, and the like, used in manufacturing the conventional high strength hot-rolled steel sheet proposed above, or high strength by precipitation hardening of alloying elements, such as Ti, Nb, Mo, and the like may degrade bending workability, and may decrease productivity during temper annealing, thus lowering price competitiveness.

[Disclosure]

[Technical Problem]

[0006] An aspect of the present disclosure may provide an ultra-high strength hot-rolled steel sheet having excellent high strength and bending workability.

[0007] Another aspect of the present disclosure may provide a method for manufacturing an ultra-high strength hot-rolled steel sheet having excellent high strength and bending workability.

[Technical Solution]

[0008] According to an aspect of the present disclosure, an ultra-high strength hot-rolled steel sheet having excellent bending workability may include: 0.1 to 0.25 wt % of C; 0.01 to 0.2 wt % of Si; 0.5 to 2.0 wt % of Mn; 0.005 to 0.02 wt % of P; 0.001 to 0.01 wt % of S; and a balance of Fe and other inevitable impurities, in which the ultra-high strength hot-rolled steel sheet may further include 0.001 to 0.35 wt % of at least one element selected from the group consisting of Ti, Nb, Mo, Cr, and B, and the following Relational Expression 1 may be satisfied.

[Relational Expression 1]

$$69.2 - 311.5[C] - 0.1[Si] - 4.0[Mn] - 5.3[Cr] - 2.6[Ni] - 6.6[Ti] - 660.6[B] - 39[P] \geq 0,$$

where [C], [Si], [Mn], [Cr], [Ni], [Ti], [B], and [P] may refer to wt % of the content of each element.

[0009] According to another aspect of the present disclosure, a method for manufacturing an ultra-high strength hot-rolled steel sheet having excellent bending workability may include: preparing a slab comprising 0.1 to 0.25 wt % of C, 0.01 to 0.2 wt % of Si, 0.5 to 2.0 wt % of Mn, 0.005 to 0.02 wt % of P, 0.001 to 0.01 wt % of S, and a balance of Fe and

other inevitable impurities, in which the slab may further include 0.001 to 0.35 wt % of at least one element selected from the group consisting of Ti, Nb, Mo, Cr, and B, and the following Relational Expression 1 may be satisfied; reheating the slab at a temperature of 1,100-1,300°C; manufacturing a hot-rolled steel sheet by finish hot rolling the reheated slab at a finish hot rolling temperature of 850-1,000°C; cooling the hot-rolled steel sheet at a cooling rate of 100-300 °C/s, in which the following Relational Expression 3 may be satisfied; and coiling the cooled steel sheet at a coiling temperature of 350°C or lower.

[Relational Expression 1]

$$69.2 - 311.5[C] - 0.1[Si] - 4.0[Mn] - 5.3[Cr] - 2.6[Ni] - 6.6[Ti] - 660.6[B] - 39[P] \geq 0,$$

where [C], [Si], [Mn], [Cr], [Ni], [Ti], [B], and [P] may refer to wt % of the content of each element.

[Relational Expression 3]

$$85.3 - 311.5[C] - 0.1[Si] - 4.0[Mn] - 5.3[Cr] - 2.6[Ni] - 6.6[Ti] - 660.6[B] - 39[P] - 6.9[\text{cooling rate}] \geq 0,$$

where [C], [Si], [Mn], [Cr], [Ni], [Ti], [B], and [P] may refer to wt % of the content of each element, and units of the cooling rate may be °C/s, which may refer to cooling rate from finish hot rolling temperature to coiling temperature.

[Advantageous Effects]

[0010] According to an embodiment in the present disclosure, an ultra-high strength hot-rolled steel sheet having excellent bending workability while having excellent strength, according to an exemplary embodiment in the present disclosure, may be provided.

[Description of Drawings]

[0011] FIG. 1 is a graph illustrating values derived from Relational Expression 1 indicating TS×T-EL and bending workability of an Inventive Example and a Comparative Example.

[Best Mode for Invention]

[0012] The present disclosure relates to an ultra-high strength hot-rolled steel sheet which may have high strength and may thus be very effective in forming a lightweight material due to thinning of the material according to the high strength thereof, as well as having excellent bending workability so that it may be easy to ensure the shape fixability of a component through roll forming, and a method for manufacturing the same.

[0013] The present inventor derived a Relational Expression indicating bending workability through bending testing measurements of steels having various elements. Based on this Relational Expression, an ultra-high strength hot-rolled steel sheet having excellent bending workability while having a tensile strength of 1 GPa or higher and a tensile strength × elongation at rupture (TS×T-EL) of 10,000 or greater may be provided.

[0014] Hereinafter, the ultra-high strength hot-rolled steel sheet having excellent bending workability, according to an exemplary embodiment in the present disclosure, will be described in detail.

[0015] The ultra-high strength hot-rolled steel sheet having excellent bending workability, according to an exemplary embodiment in the present disclosure, may include: 0.1 to 0.25 wt % of C; 0.01 to 0.2 wt % of Si; 0.5 to 2.0 wt % of Mn; 0.005 to 0.02 wt % of P; 0.001 to 0.01 wt % of S; and a balance of Fe and other inevitable impurities, in which the ultra-high strength hot-rolled steel sheet may further include 0.001 to 0.35 wt % of at least one element selected from the group consisting of Ti, Nb, Mo, Cr, and B.

[0016] Hereinafter, the reasons for limiting the alloy composition range, according to an exemplary embodiment in the present disclosure, will be described.

Carbon (C) : 0.1 to 0.25 wt %

[0017] Carbon (C) may be the most economical and effective element in reinforcing steel. When the content of C is less than 0.1 wt %, it may be difficult to secure a desired level of strength. In contrast, when the content of C exceeds 0.25 wt %, a problem may occur in which bending workability may be degraded due to an excessive increase in strength. Thus, it may be preferable that the content of C be included in an amount of 0.1 to 0.25 wt %.

Silicon (Si): 0.01 to 0.2 wt %

[0018] Silicon (Si) may deoxidize molten steel, and may be effective in solid solution strengthening. When the content of Si is less than 0.01 wt %, the deoxidizing effect and the strength increasing effect may be insufficient. In contrast, when the content of Si exceeds 0.2 wt %, red scale may be formed on a surface of a steel sheet due to Si, so that a problem may occur in which the quality of the surface of the steel sheet may be greatly degraded and weldability may also be deteriorated. Thus, it may be preferable that the content of Si be included in an amount of 0.01 to 0.2 wt %.

Manganese (Mn) : 0.5 to 2.0 wt %

[0019] Manganese (Mn) may be an element effective in solid solution strengthening of steel as in Si. In an exemplary embodiment in the present disclosure, it may be preferable that the content of Mn be included in an amount of 0.5 wt % or more in order to exhibit such an effect. However, when the content of Mn exceeds 2.0 wt %, segregation may develop excessively in a thickness center portion of a slab at the time of casting the slab in a continuous casting process, so that a problem may occur in which weldability and formability of a finished product may be degraded. Thus, it may be preferable that the content of Mn be included in an amount of 0.5 to 2.0 wt %.

Phosphorus (P): 0.005 to 0.02 wt %

[0020] Phosphorus (P) may be effective in solid solution strengthening and promoting of ferrite transformation as in Si. When the content of P is less than 0.005 wt %, the content of P may be insufficient to obtain a desired level of strength in an exemplary embodiment in the present disclosure. In contrast, when the content of P exceeds 0.02 wt %, bending workability may be degraded due to band organization by microsegregation. Thus, it may be preferable that the content of P be included in an amount of 0.005 to 0.02 wt %.

Sulfur (S): 0.001 to 0.01 wt %

[0021] Sulfur (S) may be an inevitably contained impurity, and may bond with Mn or the like to form a nonmetallic inclusion. Accordingly, toughness of steel may be greatly degraded. Thus, it may be preferable to reduce the content of S to the maximum. It may be advantageous that the theoretical content of S is limited to 0 wt %. However, S may be inevitably contained in a steel manufacturing process. Thus, it may be important to manage an upper limit of the content of S. It may be preferable that the upper limit of the content of S be limited to 0.01 wt % in an exemplary embodiment in the present disclosure. Further, it may be preferable that at least one element selected from the group consisting of titanium (Ti), niobium (Nb), molybdenum (Mo), chromium (Cr), and boron (B) be added, in addition to the above-mentioned advantageous composition. The addition of the above elements may allow a high level of tensile strength and excellent bending workability to be obtained, thus further improving the effect of the present disclosure. More preferably, the at least one element selected from the group may be included in an amount of 0.001 to 0.35 wt %.

[0022] Ti may be effective in suppressing growth of crystal grains in a heating process for hot rolling as Ti is present in steel as TiN. Further, the Ti remaining after reacting with nitrogen (N) may be an element useful to improve strength of steel through solid solution strengthening thereof.

[0023] Nb as a precipitate formation element may allow for formation of a Nb-based precipitate, such as Nb (C, N). When Nb is solid solutioned in a heating furnace having a temperature of about 1,200°C, a fine precipitate may be formed during hot rolling to effectively increase strength of steel.

[0024] Mo may be an element useful to improve impact toughness and bending workability by strengthening yield strength and grain boundary through solid solution strengthening.

[0025] Cr may perform solid solution strengthening of steel, and may delay bainite phase transformation during cooling to help form martensite.

[0026] B may be contained as an alternative of Si, may improve temperability in an extremely minute amount thereof, and may strengthen grain boundary to improve strength.

[0027] In an exemplary embodiment in the present disclosure, the remainder thereof may be Fe. However, in a common steel manufacturing process, unintended impurities may be inevitably incorporated from raw materials or steel manu-

facturing environments, so that they may not be excluded. These impurities are commonly known to a person skilled in the art, and are thus not specifically mentioned in this specification.

[0028] An ultra-high strength steel having excellent bending workability, according to an exemplary embodiment in the present disclosure, may be obtained by satisfying the following Relational Expression 1 obtained by evaluating bending workability in various compositions by the present inventor, while satisfying the alloy composition range described above.

[Relational Expression 1]

$$85.3 - 311.5[C] - 0.1[Si] - 4.0[Mn] - 5.3[Cr] - 2.6[Ni] - 6.6[Ti] \\ - 660.6[B] - 39[P] - 6.9[\text{cooling rate}] \geq 0$$

[0029] Here, [C], [Si], [Mn], [Cr], [Ni], [Ti], [B], and [P] may refer to wt % of the content of each element.

[0030] The Relational Expression 1 may be a relational expression obtained from measurements of bending workability of steels having various elements, and a sufficient amount of a martensite microstructure may be secured by satisfying the Relational Expression 1.

[0031] Further, when a value of the Relational Expression 1 is less than 0 in an ultra-high strength steel having a tensile strength of 1 Gpa or higher, room temperature R/t of the following Relational Expression 2 may exceed a value of (tensile strength $\times$ 0.00517 - 2.60345), thus degrading bending workability.

[Relational Expression 2]

$$\text{Bending workability (R/t)} \leq (\text{Tensile strength} \times 0.00517 \\ - 2.60345)$$

[0032] Preferably, the Relational Expression 2 may be satisfied to enable smooth formation of the ultra-high strength steel having a tensile strength of 1 Gpa or higher into components. That is, as a value of bending workability (R/t) decreases, it may be possible to enable smooth formation of components, and when the value of bending workability (R/t) is less than or equal to a value of (tensile strength $\times$ 0.00517 - 2.60345), it may be possible to enable the formation of components through smooth roll forming.

[0033] The hot-rolled steel sheet provided in an exemplary embodiment in the present disclosure may preferably satisfy the above element conditions while having the microstructure thereof including ferrite of 95 area% or more and a second phase of 5% or less that includes at least one selected from the group consisting of bainite, martensite, and a carbide, such as cementite, and may secure a sufficient level of ductility by having the above microstructure. When a fraction of the second phase exceeds 5%, bainite and a coarse carbonitride may be formed around a ferritic grain boundary, so that a desired level of strength may not be obtained or an interphase hardness difference (상간 경도차) may occur. Thus, it may be difficult to secure bending workability.

[0034] Further, it may be preferable that the ultra-high strength hot-rolled steel sheet, according to an exemplary embodiment in the present disclosure, have a tensile strength of 1 Gpa or higher. This is the reason that, when the tensile strength is lower than 1 Gpa, a problem may occur in which thinning of the material may be limited and the effect of lightening components may be lowered.

[0035] It may be preferable that the ultra-high strength hot-rolled steel sheet, according to an exemplary embodiment in the present disclosure, have a tensile strength $\times$ elongation at rupture (TS $\times$ T-EL) of 10,000 or greater. This is the reason that, when this value is less than 10,000, a problem may occur in which formability or shape fixability may be degraded at the time of processing components.

[0036] Hereinafter, a method for manufacturing an ultra-high strength hot-rolled steel sheet having excellent bending workability, according to an exemplary embodiment in the present disclosure, will be described in detail.

[0037] As described above, a slab having a composition satisfying the alloy composition range, according to an exemplary embodiment in the present disclosure, and the Relational Expression 1 may first be prepared, in order to manufacture the ultra-high strength hot-rolled steel sheet having excellent strength and excellent bending workability, according to an exemplary embodiment in the present disclosure. Then, the prepared slab may be heated at a temperature of 1,100-1,300°C, and the heated slab may undergo hot rolling at a finish hot rolling temperature of 850-1,000°C, may be cooled, and may be coiled after termination of the cooling at 350°C or lower, so that the ultra-high strength hot-rolled

steel sheet having excellent bending workability, according to an exemplary embodiment in the present disclosure, may be completed.

[0038] Hereinafter, detailed conditions for each operation will be described.

Slab Reheating Temperature: 1,100-1,300°C

[0039] It may be preferable that a reheating temperature of the slab, according to an exemplary embodiment in the present disclosure, be 1,100°C or higher, which may secure a temperature of the slab to reduce rolling load. However, when the slab is reheated to an excessively high temperature, there may be concerns that austenite may be coarsened, and it may thus be preferable that the reheating temperature be 1,300°C or lower.

Rolling Termination Temperature 850-1,000°C

[0040] Hot rolling may be performed on the reheated slab. At this time, it may be preferable to perform finish rolling at 850-1,000°C. When the finish hot rolling temperature is lower than 850°C, rolling load may greatly increase. In contrast, when the finish hot rolling temperature exceeds 1,000°C, the microstructure of the steel sheet may be coarsened, so that the steel may be weakened, scales thereof may be thickened, and a deterioration in surface quality, such as scale defects or the like, due to high temperature rolling, may occur. Thus, it may be preferable that the finish hot rolling temperature be limited to 850-1,000°C.

Cooling Rate: 100-300 °C/s

[0041] It may be preferable to cool the hot-rolled steel sheet as described above. Further, it may be preferable to cool the hot-rolled steel sheet at a cooling rate of 100-300 °C/s from the finish hot rolling temperature to a cooling termination temperature and then coil the hot-rolled steel sheet. When the cooling rate is less than 100 °C/s, a fraction of the second phase except for martensite may exceed 5%, so that it may be difficult to secure a desired level of strength in an exemplary embodiment in the present disclosure. In contrast, when the cooling rate exceeds 300 °C/s, a problem may occur in which elongation and toughness may be reduced.

[0042] Further, the cooling of the hot-rolled steel sheet may be performed within a cooling rate range obtained by the following Relational Expression 3.

[Relational Expression 3]

$$85.3 - 311.5[C] - 0.1[Si] - 4.0[Mn] - 5.3[Cr] - 2.6[Ni] - 6.6[Ti] \\ - 660.6[B] - 39[P] - 6.9[\text{cooling rate}] \geq 0$$

[0043] Here, [C], [Si], [Mn], [Cr], [Ni], [Ti], [B], and [P] may refer to wt % of the content of each element, and units of the cooling rate may be °C/s, which may refer to cooling rate from finish hot rolling temperature to coiling temperature.

[0044] The Relational Expression 3 may be applied to the method for manufacturing an ultra-high strength hot-rolled steel sheet having a sufficient amount of martensite by adding a factor of cooling rate capable of securing the sufficient amount of martensite to the Relational Expression 1 obtained from measurements of bending workability of steels having various elements.

Coiling Temperature: 350°C or lower

[0045] Further, it may be preferable to cool the hot-rolled steel sheet at a cooling rate of 100-300 °C/s from the finish hot rolling temperature to a temperature of 350°C or lower and then coil the hot-rolled steel sheet. When the cooling termination temperature exceeds 350°C, most of the microstructure of the steel may have bainite, so that a desired microstructure in exemplary embodiment in the present disclosure may not be secured. The coiling temperature may be a temperature at which the cooling may be terminated, and as long as the coiling temperature is 350°C or lower, the cooling may be terminated and the coiling may be performed at any temperature. However, a separate device may be required to set the cooling termination temperature to 20°C or lower, room temperature. Thus, it may be preferable to terminate the cooling and perform the coiling at a temperature of 20°C or higher.

[0046] The coiled hot-rolled steel sheet may be further subjected to an operation of natural cooling at room temperature, pickling, removing of scales from a surface layer thereof, and anointing to manufacture a pickled steel sheet.

[0047] After the coiling or the pickling, the steel sheet may be reheated at 450-480°C and hot-dip galvanized to

manufacture a hot-dip galvanized steel sheet. When the reheating temperature is lower than 450°C, there may be a disadvantage that the hot-dip galvanizing may not be performed due to a deterioration in plating adhesion. When the reheating temperature exceeds 480°C, the precipitate may be coarsened due to a heat treatment effect, so that there may be the risk of decreasing strength due to a reduction in a precipitation hardening effect. Further, an environmental problem caused by vaporization of molten zinc and a problem of plating quality degradation may occur.

[Mode for Invention]

[0048] Hereinafter, the present disclosure will be described in more detail, according to examples. However, it should be noted that the following examples are merely provided to allow for a clearer understanding of the present disclosure, rather than to limit the scope thereof. The scope of the present disclosure is defined by the appended claims and modifications and variations reasonably inferable therefrom.

[0049] A steel slab satisfying the composition shown in Table 1 below was heated to 1, 150°C, and underwent finish hot rolling at the temperature (FDT) shown in Table 2 below. Then, the steel slab was cooled to the coiling temperature (CT) shown in Table 2 at a cooling rate of 200 °C/s, and coiled at the CT shown in Table 2.

[0050] Inventive Examples 1 to 6 displayed in Table 1 illustrate the composition of slabs satisfying the alloy composition range, according to an exemplary embodiment in the present disclosure, and Comparative Examples 1 to 9 illustrate the composition of slabs having the composition beyond the alloy composition range, according to an exemplary embodiment in the present disclosure, in units of wt %. Further, a material test was performed on the manufactured hot-rolled steel sheet described above, and results thereof are shown in Table 2.

[Table 1]

Classification	C	Mn	Si	P	S	Cr	Ti	Nb	B
Comparative Example 1	0.14	1.6	0.1	0.015	0.003	0.5	0.015	0.015	0.002
Comparative Example 2	0.12	1.7	0.1	0.015	0.003	0	0.015	0.015	0.002
Comparative Example 3	0.15	1.5	0.1	0.015	0.003	0	0.015	0.015	0.002
Comparative Example 4	0.18	1	0.1	0.015	0.003	0	0.015	0	0.002
Comparative Example 5	0.19	1.2	0.1	0.015	0.003	0	0.015	0	0.002
Comparative Example 6	0.2	1.2	0.1	0.015	0.003	0.2	0.015	0	0.002
Comparative Example 7	0.19	1.4	0.1	0.015	0.003	0.5	0.015	0	0.002
Comparative Example 8	0.2	1.2	0.1	0.015	0.003	0.4	0.015	0	0.002
Comparative Example 9	0.21	1.1	0.1	0.015	0.003	0.3	0.015	0	0.002
Inventive Example 1	0.13	1.4	0.1	0.015	0.003	0	0.015	0.015	0.002
Inventive Example 2	0.15	1	0.1	0.015	0.003	0	0.015	0.015	0.002
Inventive Example 3	0.14	1.4	0.1	0.015	0.003	0	0.015	0.015	0.002
Inventive Example 4	0.19	1.2	0.1	0.015	0.003	0.2	0.015	0	0.002
Inventive Example 5	0.19	1	0.1	0.015	0.003	0.2	0.015	0	0.002
Inventive Example 6	0.2	0.7	0.1	0.015	0.003	0.2	0.015	0	0.002
(Unit: wt %)									

[0051] In Table 2 below, FDT and CT may refer to finish hot rolling temperature and coiling temperature, and YS, TS, T-El, and TS×T-EL may refer to yield strength, tensile strength, elongation, and tensile strength × elongation, respectively. Further, YS may refer to 0.2% offset yield strength or lower yield point, and yield ratio may be a ratio of yield strength to tensile strength. The tensile test was performed with a specimen collected, according to JIS 5, based on a 90° direction with respect to a rolling direction of a rolled sheet.

[0052] R/t (actual measurement) shown in Table 2 may be a value obtained by collecting a specimen based on the 90° direction with respect to the rolling direction of the rolled sheet, performing a 90° bending test thereon, and dividing the minimum bending radius R, at which cracking may not occur, by a thickness t of the material, and R/t (limit) may represent a value of (Tensile strength × 0.00517 - 2.60345). When R/t (actual measurement) exceeds R/t (limit), bending workability was evaluated as being degraded.

[Table 2]

Specimen	FDT	CT	Relational Expression 3	Martensite Area Fraction (%)	YS	TS	T-E L	TS×T-EL	R/t (Actual Measurement)	R/t (Limitations)	Bending Workability
Comparative Example 1	947	172	14.5	96	1195	1343	6.0	8058	3.5	4.3	○
Comparative Example 2	949	170	23.0	99	968	1257	7.0	8799	3.3	3.9	○
Comparative Example 3	968	402	14.5	53	730	784	11.4	8938	1.3	1.4	○
Comparative Example 4	952	367	7.1	64	877	964	9.0	8676	2.3	2.4	○
Comparative Example 5	954	378	3.2	78	916	985	6.2	6107	2.2	2.5	○
Comparative Example 6	955	163	-1.0	96	1264	1542	6.6	10174	5.8	5.4	X
Comparative Example 7	961	174	-0.2	97	1215	1519	6.6	10027	5.6	5.2	X
Comparative Example 8	958	198	-2.0	98	1207	1548	6.5	10061	6.0	5.4	X
Comparative Example 9	965	155	-4.2	99	1232	1579	6.4	10103	6.3	5.6	X
Inventive Example 1	971	188	21.1	96	1017	1287	8.6	11065	3.3	4.1	○
Inventive Example 2	849	195	16.5	97	1094	1350	7.6	10261	3.5	4.4	○
Inventive Example 3	905	222	18.0	97	1032	1323	7.9	10450	3.4	4.2	○
Inventive Example 4	909	204	2.2	96	1204	1505	7.1	10688	4.1	5.2	○
Inventive Example 5	912	221	3.0	96	1186	1501	6.7	10057	4.1	5.2	○

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(continued)

Specimen	FDT	CT	Relational Expression 3	Martensite Area Fraction (%)	YS	TS	T-E L	TS×T-EL	R/t (Actual Measurement)	R/t (Limitations)	Bending Workability
InventiveExample 6	915	212	1.0	98	1225	1531	6.7	10255	4.3	5.3	○

[0053] Processability was satisfactory. However, the value of TS×T-EL was beyond the range of the present disclosure due to a lack of elongation at rupture caused by Mn segregation.

[0054] Comparative Examples 3 to 5 illustrate a tensile strength lower than 1 Gpa due to formation of a bainite structure, rather than a martensite structure of 95% or more, at the CT outside the range of the present disclosure.

[0055] All of Comparative Examples 6 to 9 did not satisfy the Relational Expression 3, and results of bending workability evaluation were inferior.

[0056] FIG. 1 illustrates a graph of TS×T-EL and the values derived from the Relational Expression 3, according to the Comparative Example and the Inventive Example. The parts indicated by the square points are the Comparative Example, and the parts indicated by the round points are the Inventive Example. It can be seen that all of the round points corresponding to the Inventive Example, according to an exemplary embodiment in the present disclosure, are located within the part indicated by the deviant crease lines.

[0057] It can also be seen that all of the Inventive Examples 1 to 6 do satisfy criteria for bending workability and are excellent in yield strength, as well as in tensile strength and elongation.

[0058] While exemplary embodiments have been shown and described above, it will be apparent to those skilled in the art that modifications and variations could be made without departing from the scope of the present invention, as defined by the appended claims.

Claims

1. An ultra-high strength hot-rolled steel sheet having excellent bending workability, comprising:

0.1 to 0.25 wt % of C;
0.01 to 0.2 wt % of Si;
0.5 to 2.0 wt % of Mn;
0.005 to 0.02 wt % of P;
0.001 to 0.01 wt % of S; and
a balance of Fe and other inevitable impurities,

wherein the ultra-high strength hot-rolled steel sheet further comprises 0.001 to 0.35 wt % of at least one element selected from the group consisting of Ti, Nb, Mo, Cr, and B, and the following Relational Expression 1 is satisfied,

[Relational Expression 1]

$$69.2 - 311.5[C] - 0.1[Si] - 4.0[Mn] - 5.3[Cr] - 2.6[Ni] - 6.6[Ti] \\ - 660.6[B] - 39[P] \geq 0,$$

where [C], [Si], [Mn], [Cr], [Ni], [Ti], [B], and [P] refer to wt % of the content of each element.

2. The ultra-high strength hot-rolled steel sheet of claim 1, wherein tensile strength of the ultra-high strength hot-rolled steel sheet is 1 GPa or higher, and tensile strength × elongation (TS×T-EL) is 10,000 or greater.

3. The ultra-high strength hot-rolled steel sheet of claim 1, wherein bending workability (R/t) of the ultra-high strength hot-rolled steel sheet satisfies the following Relational Expression 2,

[Relational Expression 2]

$$\text{bending workability (R/t)} \leq (\text{tensile strength} \times 0.00517 \\ - 2.60345),$$

where R is the minimum bending radius at which cracking does not occur after 90° bending testing, and t is steel sheet thickness.

4. The ultra-high strength hot-rolled steel sheet of claim 1, wherein the microstructure of the ultra-high strength hot-

rolled steel sheet includes, by area fraction %, martensite of 95% or more, and a second phase of less than 5%.

5. A method for manufacturing an ultra-high strength hot-rolled steel sheet having excellent bending workability, comprising:

5 preparing a slab comprising 0.1 to 0.25 wt % of C, 0.01 to 0.2 wt % of Si, 0.5 to 2.0 wt % of Mn, 0.005 to 0.02 wt % of P, 0.001 to 0.01 wt % of S, and a balance of Fe and other inevitable impurities, wherein the slab further comprises 0.001 to 0.35 wt % of at least one element selected from the group consisting of Ti, Nb, Mo, Cr, and B, and the following Relational Expression 1 is satisfied;

10 reheating the slab at a temperature of 1,100-1,300°C;

manufacturing a hot-rolled steel sheet by finish hot rolling the reheated slab at a finish hot rolling temperature of 850-1,000°C;

cooling the hot-rolled steel sheet at a cooling rate of 100-300 °C/s, wherein the following Relational Expression 3 is satisfied; and

15 coiling the cooled steel sheet at a coiling temperature of 350°C or lower,

[Relational Expression 1]

$$69.2 - 311.5[C] - 0.1[Si] - 4.0[Mn] - 5.3[Cr] - 2.6[Ni] - 6.6[Ti]$$

$$- 660.6[B] - 39[P] \geq 0,$$

where [C], [Si], [Mn], [Cr], [Ni], [Ti], [B], and [P] refer to wt % of the content of each element,

[Relational Expression 3]

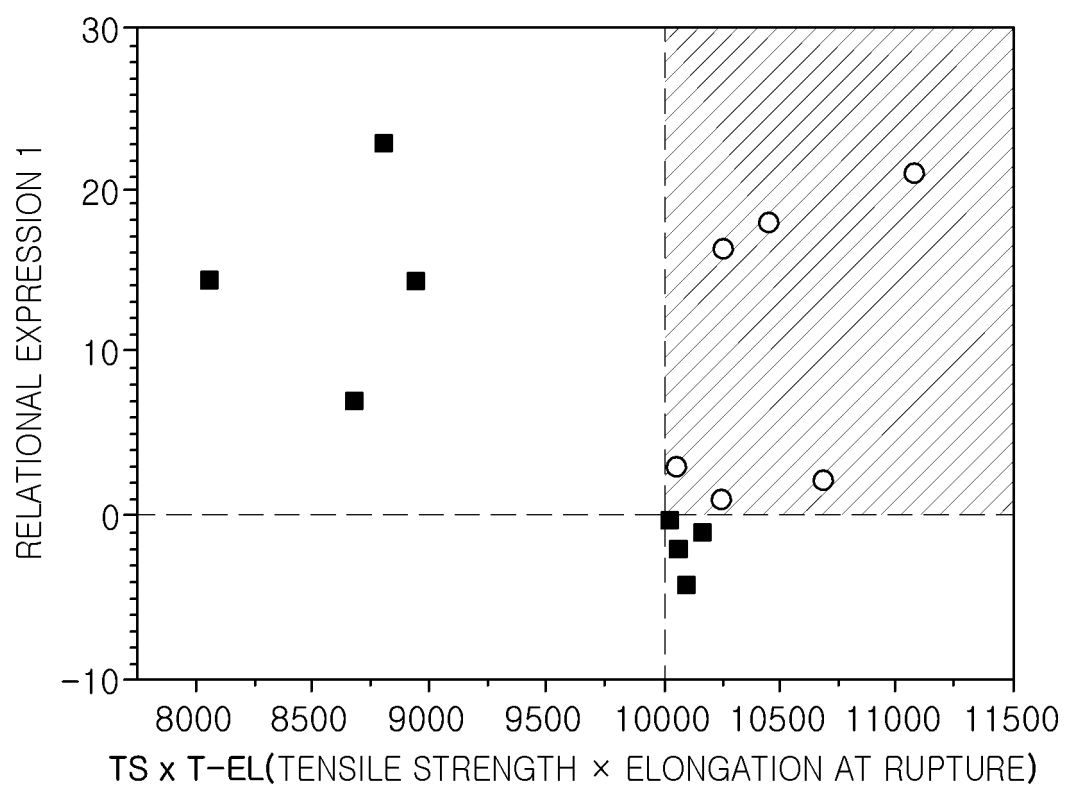
$$85.3 - 311.5[C] - 0.1[Si] - 4.0[Mn] - 5.3[Cr] - 2.6[Ni] - 6.6[Ti]$$

$$- 660.6[B] - 39[P] - 6.9[\text{cooling rate}] \geq 0,$$

where [C], [Si], [Mn], [Cr], [Ni], [Ti], [B], and [P] refer to wt % of the content of each element, and units of the cooling rate are °C/s, which refer to cooling rate from finish hot rolling temperature to coiling temperature.

6. The method of claim 5, further comprising: after pickling the coiled hot-rolled steel sheet, reheating the hot-rolled steel sheet at a temperature of 450-480°C and hot dip galvanizing the hot-rolled steel sheet, forming a galvanized layer on a surface thereof.

【Fig.1】



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2015/004766

A. CLASSIFICATION OF SUBJECT MATTER

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

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C 38/02; B21D 22/02; C21D 8/02; C22C 38/00; C21D 8/00; B21B 3/00; C22C 38/04

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: hot rolled steel sheets, bending workability, super high strength, tensile strength, yield strength, elongation, martensite

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KR 10-2013-0046941 A (HYUNDAI STEEL COMPANY) 08 May 2013 See abstract, paragraphs [0018]-[0069], [0081]-[0093], claims 1-4, 9-11 and figure 1.	1-5
Y		6
Y	KR 10-2014-0083814 A (POSCO) 04 July 2014 See abstract, paragraphs [0045]-[0050] and claim 1.	6
A	KR 10-2013-0002208 A (HYUNDAI STEEL COMPANY) 07 January 2013 See abstract, paragraphs [0059]-[0082] and claims 1-12.	1-6
A	KR 10-2015-0049692 A (HYUNDAI STEEL COMPANY) 08 May 2015 See abstract, paragraphs [0022]-[0044] and claims 1-8.	1-6
A	KR 10-2013-0143278 A (HYUNDAI HYSCO CO., LTD.) 31 December 2013 See abstract, paragraphs [0021]-[0054] and claim 1.	1-6

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

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INTERNATIONAL SEARCH REPORT
Information on patent family members

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PCT/KR2015/004766

Patent document cited in search report	Publication date	Patent family member	Publication date
KR 10-2013-0046941 A	08/05/2013	KR 10-1344537 B1	26/12/2013
KR 10-2014-0083814 A	04/07/2014	KR 10-1528011 B1	10/06/2015
KR 10-2013-0002208 A	07/01/2013	KR 10-1290426 B1	26/07/2013
KR 10-2015-0049692 A	08/05/2015	NONE	
KR 10-2013-0143278 A	31/12/2013	KR 10-1388392 B1	25/04/2014

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2010279711 A [0003]
- JP 2003156473 A [0003]
- EP 2003396059 A [0003]
- KR 19967005330 [0003]
- WO IB201101436 A [0003]