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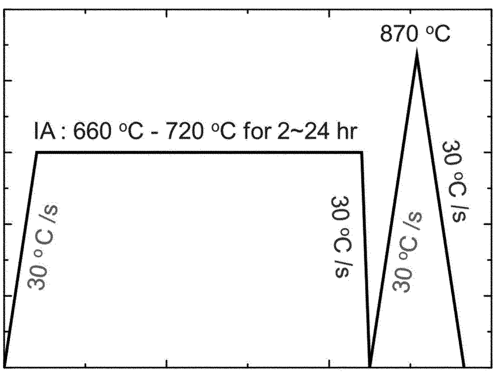
(54) ULTRA-HIGH STRENGTH COLD-ROLLED STEEL SHEET HAVING EXCELLENT ELONGATION AND MANUFACTURING METHOD THEREOF

(57) The present invention relates to an ultra-high strength cold-rolled steel sheet and a manufacturing method thereof and, more specifically, to a cold-rolled steel sheet and a manufacturing method thereof, wherein the cold-rolled steel sheet has a tensile strength of 1.5 GPa and exhibits an excellent elongation rate, and as such, can be suitably used for cold stamping.

[FIG.1]



Heat treatment was conducted by using CAL

Description

[Technical Field]

[0001] The present disclosure relates to an ultra-high strength cold-rolled steel sheet having an excellent elongation rate and a manufacturing method thereof, and more particularly, to a cold-rolled steel sheet having a tensile strength of about 1.5 GPa and also has an excellent elongation rate, and thus, may be appropriately used in cold stamping, and a manufacturing method thereof.

[Background Art]

[0002] In the domestic and international automobile industry, the purposes of improved fuel efficiency, body stability for passenger protection, and weight lightening are being highlighted together with a gradual increase in carbon dioxide regulation. In order to achieve the purposes, the use of an ultra-high steel sheet for cold stamping having a tensile strength of about 1.3 GPa or more and the development thereof are increasing. However, since a cold-rolled sheet material has an inverse relationship in which as strength increases, an elongation rate decreases, moldability is poor, so that application of a material for cold stamping is generally very limited.

[0003] In order to solve the problem described above, for securing excellent strength and elongation, an advanced high strength steel such as a dual steel and a transformation induced plasticity steep (TRIP steel) is being employed as a car body member. Gradually, with the progress of the times, for weight lightening for improving fuel efficiency, strength improvement compared with decreased thickness is demanded, and also, in order to be applied to a car member corresponding thereto, a demand for a cold-rolled steel sheet having better elongation and moldability is increasing. However, an advanced high strength steel having a strength of 1 GPa or more has poor elongation and hole expansion ratio (HER) due to occurrence of a local interphase hardness difference.

[0004] In order to overcome the demerit, an ultra-high strength steel (UHSS) formed of only bainite which is a low-temperature transformation phase, in particular, martensite is being manufactured, and is being mainly used as parts moldable by roll forming in spite of its low bendability.

[0005] Meanwhile, since the use of parts of a high strength steel is gradually increasing, in order to satisfy the characteristics of various parts, the needs for an ultra-high strength steel having high ductility and a manufacturing method thereof are increasing. However, a level of technology which may meet a high demand of having a tensile strength of about 1.5 GPa or more and high ductility and a manufacturing method therefor have not been developed.

(Patent Document 1) Korean Patent Laid-Open Publication No. 2017-7022118
(Patent Document 2) Japanese Patent Laid-Open Publication No. 2016-28760

[Disclosure]

[Technical Problem]

[0006] An aspect of the present disclosure is to provide an ultra-high strength cold-rolled steel sheet having an excellent elongation rate, and a manufacturing method thereof.

[0007] Another aspect of the present disclosure is to provide a cold-rolled steel sheet having an ultra-high strength of 1.5 GPa or more and a total elongation rate of 10% or more, and thus, may be appropriately used in cold stamping, and a manufacturing method thereof.

[0008] Objects of the present disclosure are not limited to the above description. Any person with ordinary skill in the art to which the present disclosure pertains will have no difficulty in understanding further objects of the present disclosure from the descriptions throughout the specification of the present disclosure.

[Technical Solution]

[0009] According to an aspect of the present disclosure,

[0010] a cold-rolled steel sheet includes, by weight: 0.15 to 0.3% of C, 0.1 to 1.5% of Si, 2.5 to 5.0% of Mn, 0.1% or less (excluding 0%) of P, 0.03% or less (excluding 0%) of S, 0.01 to 0.1% of Al, 0.01% or less (excluding 0%) of N, and 0.005% or less (excluding 0%) of B, with a remainder of Fe and other inevitable impurities, and

[0011] includes, by area: 0.5 to 20% of residual austenite and 80 to 99.5% of martensite, as a microstructure,

[0012] wherein the cold-rolled steel sheet satisfies the following Relation 1-1:

[Relation 1-1]

$$5 \leq \frac{AF_{Mn\_s}}{AF_{Mn\_h}} \leq 25$$

wherein AF_{Mn_s} is an area fraction of low-Mn crystal grains having a Mn content in the martensite of more than 2% and less than 5% and a unit thereof is area%, and AF_{Mn_h} is an area fraction of high-Mn crystal grains having a Mn content in the martensite of 5% or more and a unit thereof is area%.

[0013] According to another aspect of the present disclosure, a manufacturing method of a cold-rolled steel sheet includes:

reheating a steel slab having a composition including, by weight: 0.15 to 0.3% of C, 0.1 to 1.5% of Si, 2.5 to 5.0% of Mn, 0.1% or less (excluding 0%) of P, 0.03% or less (excluding 0%) of S, 0.01 to 0.1% of Al, 0.01% or less (excluding 0%) of N, and 0.005% or less (excluding 0%) of B with a remainder of Fe and other inevitable impurities at 1100 to 1300°C;
hot rolling the reheated slab at 800 to 1000°C to obtain a hot-rolled steel sheet;
coiling the hot-rolled steel sheet at 400 to 700°C;
cold rolling the coiled hot-rolled steel sheet at a reduction rate of 20 to 75% to obtain a cold-rolled steel sheet;
first annealing of heating the cold-rolled steel sheet in a range of 600 to 700°C and maintaining the steel sheet for 2 to 24 hours;
first cooling of cooling the first annealed cold-rolled steel sheet at an average cooling rate of 30°C/s or more;
second annealing of heating the first cooled cold-rolled steel sheet to a temperature higher than an austenite single-phase region at an average heating rate of 30°C/s or more; and
second cooling the second annealed cold-rolled steel sheet at an average cooling rate of 30°C/s or more.

[Advantageous Effects]

[0014] As set forth above, according to an exemplary embodiment in the present disclosure, an ultra-high strength cold-rolled steel sheet having an excellent elongation rate and a manufacturing method thereof may be provided.

[0015] Otherwise, according to another exemplary embodiment of the present disclosure, a cold-rolled steel sheet having an ultra-high strength of 1.5 GPa or more and a total elongation rate of 10% or more, and thus, may be appropriately used in cold stamping, and a manufacturing method thereof may be provided.

[0016] According to an exemplary embodiment of the present disclosure, a gradient in which a main structure is the same, but a chemical composition is non-uniform occurs from a Mn content gradient of a martensite main structure and residual austenite obtained in an annealing area, rather than control of a microstructure having the same chemical composition using C and Mn contents of the entire steel sheet. A yield of a microstructure having a lower Mn content occurs during working, and as hard martensite transformation proceeds, local stress and transformation within the boundary occurs, and elongation causes an additional strength rise in the microstructure having a low Mn content, thereby providing an ultra-high strength steel sheet of about 1.5 GPa.

[0017] In addition, additional distribution of C and Mn in martensite to residual austenite is performed from a Mn distribution to finally secure austenite which is more stable than before, thereby minimizing martensite transformation in a uniform stretching section during plastic deformation, and thus, a manufacturing method of a cold-rolled steel sheet having excellent workability while having high strength/high yield ratio may be provided.

[0018] Various and beneficial merits and effects of the present disclosure are not limited to the descriptions above, and may be more easily understood in a process of describing specific exemplary embodiments in the present disclosure.

[Description of Drawings]

[0019]

FIG. 1 is a schematic diagram which schematically shows a manufacturing process of a cold-rolled steel sheet according to an exemplary embodiment of the present disclosure.
FIG. 2 is photographs of a final microstructure after second annealing-second cooling measured by electron back-scatter diffraction (EBSD) at high magnification for Example 8 of Table 2, in which (a) shows a crystallographic orientation map (inverse pole figure, IPF), (b) shows a phase distribution map for inventive steel, and (c) shows a phase distribution map enlarged on a specific area in which residual austenite is distributed in the final microstructure.

[Best Mode for Invention]

[0020] Hereinafter, preferred exemplary embodiments in the present disclosure will be described. However, the embodiments in the present disclosure may be modified in many different forms and the scope of the disclosure should not be limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the concept of the disclosure to those skilled in the art.

[0021] Meanwhile, terms used in the present specification are for explaining specific exemplary embodiments rather than limiting the present disclosure. For example, a singular form used in the present specification includes a plural form also, unless the relevant definition has a clearly opposite meaning thereto. In addition, the meaning of "comprising" used in the specification is to embody the configuration and is not to exclude the presence or addition of other configurations.

[0022] Hereinafter, an ultra-high strength cold-rolled steel sheet having an excellent elongation rate according to an exemplary embodiment of the present disclosure will be described in detail.

[0023] According to an exemplary embodiment of the present disclosure, a cold-rolled steel sheet includes, by weight: 0.15 to 0.3% of C, 0.1 to 1.5% of Si, 2.5 to 5.0% of Mn, 0.1% or less (excluding 0%) of P, 0.03% or less (excluding 0%) of S, 0.01 to 0.1% of Al, 0.01% or less (excluding 0%) of N, and 0.005% or less (excluding 0%) of B, with a remainder of Fe and other inevitable impurities.

[0024] Hereinafter, the reason for adding the components of the cold-rolled steel sheet according to the present disclosure and the reason for limiting the contents will be described in detail. Herein, in the present specification, when the content of each element is shown, unless otherwise particularly defined, it is based on weight.

Carbon (C): 0.15 to 0.3%

[0025] Carbon (C) is an essential element for securing strength and hardenability of a martensite steel, and in order to have a tensile strength of about 1.5 GPa or more, it is preferred to add 0.15% or more carbon. However, when a C content is more than 0.3%, strength is excessively increased as compared with a target, so that an elongation rate is reduced, brittle fracture is highly likely to be caused, and deterioration of spot weldability is caused, and thus, it is preferred that the upper limit is controlled to 0.3% or less. Meanwhile, as the carbon content is higher, a degree of carbide occurrence is increased during production of martensite, and thus, more preferably, the upper limit of the C content may be controlled to 0.27%.

Silicon (Si): 0.1 to 1.5%

[0026] Silicon (Si) is an element which is added as a deoxidizer in a steelmaking process and suppresses carbide production with a solid solution strengthening element. In addition, Si addition serves to uniformly disperse a structure during an annealing heat treatment and increases stability of austenite during cooling, thereby allowing securing residual austenite at room temperature. Therefore, in order to secure the effects described above, it is preferred to add 0.15% or more Si. However, when a Si content is more than 1.5%, a Si-based oxide may be excessively produced on the surface of a steel surface during hot rolling to cause surface defects during cold rolling. Besides, since resistivity of a final cold-rolled steel sheet is increased to worse spot weldability, the Si content is controlled to 1.5% or less. Meanwhile, in order to improve the effects described above, more preferably, the upper limit of the Si content may be 1.25%.

Manganese (Mn): 2.5 to 5.0%

[0027] Manganese (Mn) is an austenite stable element and added for securing hardenability of martensite, and easily suppresses production of ferrite during an annealing heat treatment after cold rolling. When a Mn content is less than 2.5%, martensite hardenability may be secured, but occurrence of a Mn concentration gradient in a cold-rolled steel sheet becomes difficult, so that it is difficult to secure a non-uniform microstructure due to a Mn concentration difference pursued by the present disclosure. In addition, when the Mn content is more than 5.0%, excessive strength and a Mn band in base iron from steelmaking and soft casting steps may occur in the thickness direction, which deteriorates crash resistance, and thus, it is preferred to control the upper limit of the Mn content to 5.0% or less. However, in order to achieve the purpose of the present disclosure, more preferably, the lower limit of the Mn content may be controlled to 3.0%, and the upper limit of the Mn content may be controlled to 4.12%.

Phosphorus (P) : 0.1% or less (excluding 0%)

[0028] Phosphorus (P) is an impurity element in steel, and when it is included at more than 0.1%, weldability is deteriorated due to P segregation and brittleness of steel is highly likely to occur, and thus, the upper limit of a P content is controlled to 0.1%. Meanwhile, 0% may be excluded from the lower limit of the P content, considering the case in which P is inevitably included (that is, more than 0%). However, in order to achieve the purpose of the present disclosure, more preferably, the lower limit of the P content may be controlled to 0.005. Otherwise, the upper limit of the P content may be controlled to 0.03%, and most preferably controlled to 0.02%.

Sulfur (S) : 0.03% or less (excluding 0%)

[0029] Sulfur (S) is an impurity element which is inevitably added to steel, like P, and has a characteristic of impairing ductility and weldability of a final cold-rolled steel sheet. In addition, when an S content is more than 0.03%, precipitates produced in a hot rolling process are not completely decomposed during an annealing heat treatment due to the precipitation of MnS, and thus, ductility of a steel sheet is deteriorated. Besides, a problem may arise also in weldability, and thus, the upper limit of the S content is controlled to 0.03% or less. Meanwhile, 0% may be excluded from the lower limit of the S content, considering the case in which S is inevitably included (that is, more than 0%). However, in order to achieve the purpose of the present disclosure, more preferably, the lower limit of the S content may be controlled to 0.002%, and the upper limit of the S content may be controlled to 0.005%.

Aluminum (Al): 0.01 to 0.1%

[0030] Aluminum (Al) is an element which is added for removing oxygen in molten steel during a steelmaking process, like Si, and is favorable for removing impurity elements in steel. In addition, Al helps suppression of carbide production, though it is weaker than Si, and contributes to austenite C stabilization, and thus, allows manufacture of a steel sheet having an excellent elongation rate. Therefore, in order to secure the effects described above, an Al content is controlled to 0.01% or more. However, when Al is excessively added, cast iron cracks occur due to excessive precipitation of AlN, which may cause defects of a eutectic product, and thus, the upper limit of the Al content is limited to 0.1%. Meanwhile, in order to secure the effect to be intended in the present disclosure, more preferably, the lower limit of the Al content may be 0.02%, and the upper limit of the Al content may be 0.06%.

Nitrogen (N) : 0.01% or less (excluding 0%)

[0031] Nitrogen (N) is an impurity element in steel, and when the content is more than 0.01%, a risk of crack occurrence during soft casting is greatly increased by AlN formation, and thus, the upper limit of the N content is limited to 0.01%. Meanwhile, 0% may be excluded from the lower limit of the N content, considering the case in which N is inevitably included (that is, more than 0%) . However, in order to achieve the purpose of the present disclosure, more preferably, the lower limit of the N content may be controlled to 0.007%, and the upper limit of the N content may be controlled to 0.03%.

Boron (B): 0.005% or less (excluding 0%)

[0032] Boron (B) is an element which is favorable for suppression of ferrite phase transformation during an annealing heat treatment, and may improve hardenability of martensite through crystal grain boundary strengthening and solid solution strengthening. However, when a B content is more than 0.005%, $Fe_{23}(B,C)_6$, which is a B-based precipitated phase, is formed in an austenite crystal grain boundary, and thus, brittleness fracture may be caused in a hot rolling state, and thus, the upper limit of the B content is limited to 0.005% or less. Meanwhile, 0% may be excluded from the lower limit of the B content, considering the case in which B is inevitably included (that is, more than 0%). However, in order to achieve the purpose of the present disclosure, more preferably, the lower limit of the B content may be controlled to 0.001%, and the upper limit of the B content may be controlled to 0.003%.

[0033] The remaining component of the present disclosure is iron (Fe). However, since unintended impurities may be inevitably incorporated due to raw material or surrounding environment variables in a common steel manufacturing process, these may not be excluded. Since these impurities are known to any person skilled in the common manufacturing process, the entire contents thereof are not particularly mentioned in the present specification.

[0034] Meanwhile, according to an exemplary embodiment of the present disclosure, the cold-rolled steel sheet may optionally further include one or more selected from 0.1% or less of Cr and 0.1% or less of Mo. Hereinafter, the reason for adding each element and the reason for limiting the content thereof will be described.

Chromium (Cr): 0.1% or less (including 0%)

[0035] Chromium (Cr) is an element which increases hardenability of martensite and suppresses ferrite transformation, like Mn, thereby allowing final production of martensite having appropriate strength. Therefore, when the Mn content is designed to a certain range, an effect of a Cr content on hardenability is lowered, martensite strength may be secured without adding Cr, and thus, a small amount of Cr may be added. Meanwhile, when the Cr content is more than 0.1%, there is a concern about causing carbides during part molding due to formation of coarse Cr-based carbides and cracks due to local deformation and stress occurrence in a structure boundary in steel, and thus, the upper limit of the Cr content may be controlled to 0.1%. However, since the case of not adding Cr may also be included, the lower limit of the Cr content may be 0%. Meanwhile, in the case of adding Cr, in order to achieve the purpose of the present disclosure, more preferably, the lower limit of the Cr content may be controlled to 0.005%, and the upper limit of the Cr content may be controlled to 0.05%.

Molybdenum (Mo): 0.1% or less (including 0%)

[0036] Molybdenum (Mo) is an element which increases martensite hardenability and is effective for suppression of ferrite production in a cooling zone during an annealing heat treatment, like Cr. However, when Mo is excessively added, since Mo is more expensive than other elements, a problem of rising iron alloy costs is caused by an excessive input amount of alloy, and thus, the upper limit of a Mo content is limited to 0.1% or less in the present disclosure. However, since Mo is high-priced and may be included in the scope of the present disclosure as long as the purpose of the present disclosure may be achieved even in the case of not adding Mo, the lower limit of the Mo content may be 0%, and the upper limit of the Mo content may be 0.05%.

[0037] According to an exemplary embodiment of the present disclosure, the microstructure of the cold-rolled steel sheet includes, by area fraction: 0.5 to 20% of residual austenite and 80 to 99.5% of martensite.

[0038] When the residual austenite is less than 0.5% or the martensite is more than 99.5% in the microstructure of the cold-rolled steel sheet, a Mn content distribution is not performed well, and thus, a cold-rolled steel sheet in which a matrix is formed of martensite is manufactured, so that an elongation rate may be insufficient. However, when the residual austenite is more than 20% and the martensite is less than 80% in the microstructure of the cold-rolled steel sheet, carbon stability in the residual austenite is lowered, so that moldability may be deteriorated by martensite transformation due to strain-induced transformation during working. Meanwhile, according to an exemplary embodiment of the present disclosure, in terms of further improving the effects described above, the lower limit of the area fraction of the residual austenite may be 1.2%, or the upper limit of the area fraction of the residual austenite may be 10%. Meanwhile, according to another exemplary embodiment of the present disclosure, in terms of further improving the effects described above, the lower limit of the area fraction of the martensite may be 90%, or the upper limit of the area fraction of the martensite may be 98.5%.

[0039] In addition, according to an exemplary embodiment of the present disclosure, the cold-rolled steel sheet may satisfy the following Relation 1-1:

[Relation 1-1]

$$5 \leq \frac{AF_{Mn\_s}}{AF_{Mn\_h}} \leq 25$$

wherein AF_{Mn_s} is an area fraction of low-Mn crystal grains having a Mn content in the martensite of more than 2% and less than 5% and a unit thereof is area%, and AF_{Mn_h} is an area fraction of high-Mn crystal grains having a Mn content in the martensite of 5% or more and a unit thereof is area%.

[0040] According to the present disclosure, when the value of $\frac{AF_{Mn\_s}}{AF_{Mn\_h}}$ is less than 5, an additional strength effect arising from a difference in the Mn content is difficult to be expressed and it is difficult to secure residual austenite, and thus, there may be a limitation in manufacture of a cold-rolled steel sheet having a total elongation rate of 10% or more. However, when the value of $\frac{AF_{Mn\_s}}{AF_{Mn\_h}}$ is more than 25, the C and Mn contents corresponding thereof are increased, and thus, workability may be deteriorated by formation of a Mn band and carbides in the cold-rolled steel sheet. Meanwhile, according to an exemplary embodiment of the present disclosure, in terms of further improving the effects described above, the lower limit of the value of $\frac{AF_{Mn\_s}}{AF_{Mn\_h}}$ may be 9 and the upper limit of the value of $\frac{AF_{Mn\_s}}{AF_{Mn\_h}}$ may be 19.

[0041] The methods of measuring AF_{Mn_s} and AF_{Mn_h} are not particularly limited. However, as a representative example, based on a total thickness t of a steel sheet, mechanical polishing is performed from a steel sheet surface to a position of 1/4t, and then qualitative EPMA surface analysis of the Mn content is performed at an area fraction of 30 μm×30 μm. Subsequently, measurement may be performed by analyzing an area having a martensite structure with a high Mn content and an area having a martensite structure with a low Mn content, respectively.

[0042] Meanwhile, though it is not particularly limited, according to an exemplary embodiment of the present disclosure, the cold-rolled steel sheet may satisfy the following Relation 1-2. Herein, by satisfying the following Relation 1-2, additional strength in an area having a lower Mn content is implemented to allow manufacture of a cold-rolled steel sheet of about 1.5 GPa, and thus, a hardness difference in the structure is reduced to secure an excellent elongation rate as compared with a conventional martensite steel. Meanwhile, according to an exemplary embodiment of the present disclosure, the lower limit of the value of $\Delta\sigma_{TS}$ may be 829 MPa, or the upper limit of the value of $\Delta\sigma_{TS}$ may be 1844 MPa.

[Relation 1-2]

$$\Delta\sigma_{TS} = \sigma_{TS\_Mn\_h} - \sigma_{TS\_Mn\_s} \geq 600\ MPa$$

wherein $\Delta\sigma_{TS}$ is a difference between a tensile strength average value ($\sigma_{TS\_Mn\_h}$) of high-Mn crystal grains having a Mn content in the martensite of 5% or more and a tensile strength average value ($\sigma_{TS\_Mn\_s}$) of low-Mn crystal grains having a Mn content in the martensite of more than 2% and less than 5%, and a unit thereof is MPa.

[0043] Meanwhile, $\sigma_{TS\_Mn\_h}$ and $\sigma_{TS\_MD\_s}$ may be calculated based on $\Delta\sigma_{TS}$ defined by the following Relation 1-3, for each area. Therefore, $\sigma_{TS\_Mn\_h}$ may be calculated from the content of each component secured by EPMA analysis in an area having a martensite structure with a locally high Mn content. In addition, $\sigma_{TS\_MD\_s}$ may be calculated from the content of each component secured by EPMA analysis in an area having a martensite structure with a locally low Mn content.

$$\sigma_{TS} = 77 + 750 \times [P] + 60 \times [Si] + 80 \times [Cu] + 45 \times [Ni] + 60 \times [Cr] + 80 \times [Mn] + 11 \times [Mo] + 5000 \times [Nss]$$

wherein [P], [Si], [Cu], [Ni], [Cr], [Mn], and [Mo] denote a content of each element in parentheses by wt% in a steel sheet, and [Nss] denotes a content of nitrogen by wt% in a solid solution of a steel sheet.

[0044] In order to achieve the effect to be intended in the present disclosure, an annealing heat treatment process is controlled to distribute the Mn concentration in martensite, thereby obtaining a hard/soft phase depending on the Mn concentration, and inducing additional strengthening in the hard phase from strain distribution therefrom. Due to the Mn concentration gradient as such, austenite stability in a hard Mn phase is secured, thereby securing residual austenite at room temperature to provide an ultra-high strength steel having an excellent elongation rate.

[0045] The cold-rolled steel sheet according to the present disclosure may satisfy a tensile strength of 1500 MPa or more (or 1500 MPa or more and 1700 MPa or less or 1554 MPa or more and 1660 MPa or less) and a total elongation rate of 10% or more (or 10% or more and 12% or less or 10.2% or more and 11.2% or less), and by satisfying them, may be appropriately used in cold stamping as an ultra-high strength cold-rolled steel sheet having an excellent elongation rate. Meanwhile, though it is not particularly limited, in order to achieve the purpose of the present disclosure, more preferably, the yield strength of the cold-rolled steel sheet may be 940 MPa or more (or 940 MPa or more and 1200 MPa or less, 1000 MPa or more, or 1000 MPa or more and 1200 MPa or less). In addition, according to an exemplary embodiment of the present disclosure, a uniform elongation rate of the cold-rolled steel sheet may be 5.0% or more, or 5.0% or more and 7.0% or less.

[0046] Hereinafter, a manufacturing method of a cold-rolled steel sheet according to an exemplary embodiment of the present disclosure will be described in detail. However, it does not mean that the manufacturing method of a cold-rolled steel sheet according to the present disclosure should be necessarily the following manufacturing method.

Slab reheating

[0047] The manufacturing method of a cold-rolled steel sheet according to an exemplary embodiment of the present disclosure includes reheating a steel slab having the composition described above at 1,100 to 1,300°C. Herein, the composition of the steel slab is the same as the composition of the cold-rolled steel sheet described above, and the reason for adding each component and the reason for limiting the content in the slab may be as described for the cold-rolled steel sheet described above.

[0048] Meanwhile, in the present disclosure, before performing hot rolling, it is preferred to perform a process of reheating the steel slab to be homogenized, and a temperature in the reheating is preferably 1,100 to 1,300°C. When the reheating temperature is lower than 1100°C, a load during subsequent hot rolling may be rapidly increased. In addition, the reheating temperature is higher than 1,300°C, an amount of surface scale is increased, which leads to loss of materials.

Hot rolling

[0049] It is preferred that the reheated slab described above is hot rolled at 800 to 1,000°C to manufacture a hot-rolled steel sheet. When a hot rolling temperature is lower than 800°C, there is a concern that a rolling load is increased by introduction of unrecrystallized ferrite, which is thus not preferred. However, when the hot rolling temperature is higher than 1,000°C, surface defects and rolling roll wear are more likely to be increased by scale, which is thus not preferred.

Coiling

[0050] It is preferred that the hot-rolled steel sheet manufactured according to the hot rolling described above is coiled at 400 to 700°C. When a coiling temperature is higher than 700°C, an excessive oxide film is formed on the surface of a steel sheet to cause defects, and thus, it is preferred to limit the temperature. Meanwhile, when the coiling temperature is lower than 400°C, the strength of the hot-rolled steel sheet is excessively high, so that a rolling load in a cold rolling process is increased and control variables in a cold rolling process for controlling it are increased, which may deteriorate productivity.

Cold rolling

[0051] After the hot rolling, an oxide layer formed on the surface of the coiled hot-rolled steel sheet is removed by a pickling process, and then a cold rolling is performed at a reduction rate of 20 to 75% to manufacture a cold-rolled steel sheet. When the reduction rate during the cold rolling is less than 20%, it is difficult to secure a target thickness, and austenite production and final physical properties are affected during an annealing heat treatment due to remaining hot-rolled crystal grains. Therefore, it is preferred that the reduction rate during the cold rolling is performed in a range of 20 to 75%.

[0052] The present disclosure is for manufacturing a high elongation cold-rolled steel sheet having mechanical properties of an elongation rate of 10% or more, while securing a tensile strength of about 1.5 GPa, and to this end, as shown in FIG. 1, a two-stage annealing process including first annealing - first cooling - second annealing - second cooling processes is performed. Hereinafter, detailed description will be provided.

First annealing

[0053] The cold-rolled steel sheet obtained from the cold rolling described above is heated in a range of 600 to 700°C (or 620 to 700°C) and maintained for 2 to 24 hours. In the present disclosure, in order to reduce the effect of reverse transformation due to an average heating rate during heating in the first annealing, the maintenance time is controlled to 2 hours or more so that Mn decomposition may occur at an annealing temperature where an ideal area temperature (T_{IA}) range is 600 to 700°C at which cementite is decomposed at a heating rate of 30°C/s or more (more preferably in a range of 30 to 50°C/s).

[0054] Without particular limitation, when the heating rate during the first annealing is less than 30°C/s, a C and Mn inhomogeneity effect may be insignificant. However, when the heating rate during the first annealing is more than 50°C/s, a first annealing target temperature accuracy is lowered to cause a material problem of a final steel type due to an annealing area temperature deviation.

[0055] Controlling is performed so that heat treatment conditions in the first annealing described above are met, and also cooling is performed at an average cooling rate of 30°C/s or more in the first cooling described later. The heat treatment as such is for causing a Mn concentration difference between ferrite and austenite produced in an ideal area and obtaining ferrite having a low Mn concentration and martensite having a high Mn content during cooling. In order to more preferably significantly increase a Mn concentration in the first annealing, it is performed in a maintenance time range of up to 24 hours.

[0056] Meanwhile, without particular limitation, in order to further improve the effect to be intended in the present disclosure, preferably, the first annealing is performed by heating so that the highest temperature is in a range of 600 to 700°C and maintaining a temperature range of 600 to 700°C from the time the highest temperature is reached for 2 to 24 hours.

[0057] In addition, when the maintenance time during the first annealing is less than 2 hours, a C and Mn distribution effect in an ideal area temperature section is insignificant, so that the C and Mn concentrations in ferrite and martensite may be uniform during cooling. However, when the maintenance time during the first annealing is more than 24 hours, material deterioration may occur due to crystal grain coarsening and heterogeneity of the C and Mn concentrations in ferrite and austenite during the annealing may be deteriorated.

First cooling

[0058] First cooling of cooling the first annealed cold-rolled steel sheet at an average cooling rate of 30°C/s or more is performed. More specifically, the first cooling may be cooled to 25°C or lower at an average cooling rate in a range of 30 to 50°C/s.

[0059] When the average cooling rate in the first cooling is less than 30°C/s, C and Mn redistribution occurs during cooling after the first annealing to cause a problem in securing chemical inhomogeneity. In addition, when the temperature range in the first cooling is higher than 25°C, martensite production and end temperatures are different between each crystal grains due to extreme Mn and C distributions during the first annealing, and thus, a problem with introducing a second phase may arise due to a untransformed austenite fraction even at a low temperature range.

Second annealing

[0060] For finally securing an annealed cold-rolled steel sheet having 80% or more of martensite (and 20% or less of residual austenite) as an area fraction, second annealing of heating the first cooled cold-rolled steel sheet to a temperature at or higher than an austenite single-phase region at an average heating rate of 30°C/s or more (more preferably in a range of 30 to 50°C/s) is performed.

[0061] Herein, in the second annealing, controlling the average heating rate to 30°C/s or more is for maintaining Mn distribution obtained from first annealing, and when the average heating rate in the second annealing is less than 30°C/s, a Mn concentration difference may become uniform due to Mn redistribution.

[0062] In addition, in the second annealing, the temperature at or higher than an austenite single-phase region may be 820°C or higher (more preferably 850°C or higher and 900°C or lower), and the reason for controlling to the temperature range is for producing 80% or more martensite which is the final microstructure from Mn-distributed austenite.

[0063] Meanwhile, in order to further improve the effect to be intended in the present disclosure, preferably, the average heating rate in the first annealing and the second annealing may be controlled to satisfy the following Relation 2:

[Relation 2]

$$1.0 \leq TH1/TH2 \leq 1.5$$

wherein TH1 is a highest temperature on a surface of the cold-rolled steel sheet in the first annealing, and TH2 is a highest temperature on a surface of the cold-rolled steel sheet in the second annealing.

Second cooling

[0064] Subsequently, second cooling of cooling the second annealed cold-rolled steel sheet at an average cooling rate of 30°C/s or more (more preferably in a range of 30 to 50°C/s) is performed. Herein, when the average cooling rate in the second cooling is less than 30°C/s, a problem with securing an elongation rate may arise due to C and Mn redistribution during cooling.

[0065] According to the present disclosure, in order to secure a cold-rolled steel sheet having mechanical properties of a 1.5 level strength and a total elongation rate of 10% or more, precise control of a critical heating rate and a heat treatment temperature in the two-stage annealing process, and a critical cooling rate and a cooling temperature in the cooling process is required. When being out of the range, it may be difficult to secure the tensile strength and the elongation rate in the range intended in the present disclosure.

[Mode for Invention]

[0066] Hereinafter, the present disclosure will be specifically described through the following examples. However, it should be noted that the following examples are only for describing the present disclosure by illustration, and not intended to limit the right scope of the present disclosure. The reason is that the right scope of the present disclosure is determined by the matters described in the claims and reasonably inferred therefrom.

(Examples)

[0067] Steels having compositions of the following Table 1 were melted under vacuum into ingots, maintained at a temperature of 1200°C for 1 hour, finish-rolled at 900°C, charged into a furnace preheated to 600°C, and maintained for 1 hour, and hot-rolled coiling was simulated by furnace cooling. After pickling, cold rolling was performed at a reduction rate of 50% to manufacture cold-rolled steel sheets.

[0068] The thus-manufactured cold-rolled steel sheets were heated in various ideal region temperature ranges at an average heating rate of 30°C/s under the conditions described in the following Table 2, and first annealed with varied maintenance times. Subsequently, the steel sheets were first cooled to 25°C at an average cooling rate of 30°C/s, second annealed to be heated at an average heating rate of 30°C/s in an austenite single-phase region of 870°C, and second cooled at an average cooling rate of 30°C/s to simulate a continuous annealing heat treatment.

[0069] For each specimen which was subjected to the heat treatment, a residual austenite fraction in the specimen including micro-austenite was measured using magnetic induction method (Metis), and then other fractions were calculated with martensite. In order to analyze a Mn concentration difference in the same martensite, EPMA surface analysis was performed at 1,000 times or higher and is shown in the following Table 2, and the results of measuring mechanical properties are shown in the following Table 3. At this time, for measuring mechanical properties, a tensile tester and an extensometer were attached by machining perpendicular to the rolling direction in accordance with JIS standard specifications, thereby measuring a yield strength, a tensile strength, and an elongation rate. In addition, $\frac{AF_{Mn\_s}}{AF_{Mn\_h}}$ and $\Delta\sigma_{TS}$ were measured in the same manner as described in the present specification.

[Table 1]

Steel type	Component composition (wt%)												
	C	Si	Mn	P	S	Al	Cr	Ti	Nb	B	N	Mo	
A	0.18	0.1	3.5	0.01	0.002	0.025	0	0.02	0	0.002	40	0	Inventive steel
B	0.18	0.1	4.0	0.01	0.002	0.025	0.05	0.02	0	0.002	40	0	Inventive steel
C	0.15	1.4	3.5	0.01	0.002	0.025	0.05	0.02	0	0.002	40	0	Inventive steel
D	0.24	0.1	2.0	0.01	0.002	0.025	0.1	0.025	0.04	0.002	40	0.05	Comparative steel
E	0.26	0.2	1.5	0.01	0.001	0.025	0.2	0.025	0.04	0.002	40	0.1	Comparative steel
F	0.15	0.1	1.7	0.01	0.001	0.025	0.3	0.025	0	0.002	40	0.2	Comparative steel
G	0.18	0.6	2.0	0.01	0.001	0.025	0.25	0.025	0.04	0.004	40	0.15	Comparative steel

[Table 2]

Remarks	Steel type	Annealing process	Annealing heat treatment conditions			Microstructure characteristics (area fraction%)				
			First annealing temperature (IA)	Maintenance time	Second annealing temperature	AF_{Mh_S}/ AF_{Mh_h}	F	M	P	γ
			(°C)	hr	(°C)		(%)	(%)	(%)	(%)
Example 1	A	CAL	500	2	870	19	0	99.7	0	0.3
Example 2	A	CAL	600	12	870	19	0	98	0	2
Example 3	A	CAL	660	24	870	9	0	98.5	0	1.5
Example 4	A	CAL	720	2	870	1	0	100	0	0
Example 5	B	CAL	660	2	870	9	0	98.8	0	1.2

(continued)

Remarks	Steel type	Annealing process	Annealing heat treatment conditions			Microstructure characteristics (area fraction%)				
			First annealing temperature (IA)	Maintenance time	Second annealing temperature	AF_{Mh_S}/ AF_{Mh_h}	F	M	P	γ
			(°C)	hr	(°C)		(%)	(%)	(%)	(%)
Example 6	B	CAL	720	24	870	19	0	99.45	0	0.55
Example 7	B	CAL	660	24	870	5.7	0	99.2	0	0.8
Example 8	C	CAL	660	2	870	9	0	97	0	3
Example 9	D	CAL	660	24	870	3	0	100	0	0
Example 10	D	CAL	720	24	870	1	0	100	0	0
Example 11	E	CAL	600	12	870	1	0	100	0	0
Example 12	E	CAL	660	12	870	1	0	100	0	0
Example 13	E	CAL	720	12	870	1	0	100	0	0
Example 14	F	CAL	660	2	870	1	0	100	0	0
Example 15	G	CAL	660	2	870	1	0	100	0	0
wherein F: ferrite, M: martensite, P: pearlite, and γ: residual austenite.										

[Table 3]

Remarks	Yield strength (MPa)	Tensile strength (MPa)	Total elongation rate (%)	$\Delta\sigma_{TS}$ (MPa)	Uniform elongation rate (%)
Example 1	1095	1643	9.1	1390	5.2
Example 2	943	1554	11.2	1844	6.7
Example 3	1021	1643	10.2	829	5.0
Example 4	1020	1561	8.9	277	4.6
Example 5	1200	1660	10.5	922	6.2
Example 6	1050	1580	9.8	720	4.7
Example 7	1158	1645	10.1	645	5.3
Example 8	1011	1632	10.5	829	6.7
Example 9	1020	1520	8.9	450	4.2
Example 10	975	1508	7.8	225	3.8
Example 11	1011	1570	8.3	425	3.5

(continued)

Remarks	Yield strength (MPa)	Tensile strength (MPa)	Total elongation rate (%)	$\Delta\sigma_{TS}$ (MPa)	Uniform elongation rate (%)
Example 12	987	1562	7.8	389	3.9
Example 13	950	1523	6	150	2.8
Example 14	980	1565	9.2	438	4.6
Example 15	1080	1589	8.9	573	3.7

[0070] In Examples 2, 3, 5, 7, and 8 which satisfied the alloy compositions and manufacturing conditions of the present disclosure, since Relation 1-1 was satisfied, the tensile strength of 1500 MPa or more, the yield strength of 1000 MPa or more, the total elongation rate of 10% or more, and the uniform elongation rate of 5.0% or more were satisfied, and also, since Relation 1-2 was satisfied, uniformity was also secured.

[0071] In particular, photographs of the final microstructure of Example 8 after the second annealing-second cooling which was measured at high magnification by electron backscatter diffraction (EBSD) are shown in FIG. 2. In FIG. 2, (a) shows an inverse pole figure (IPF), (b) shows a phase distribution map for an inventive steel, and (c) shows a phase distribution map enlarged on a specific area where residual austenite in the final microstructure is distributed.

[0072] However, in Examples 9 to 15 which did not satisfy the alloy composition of the present disclosure, it was confirmed that one or more of the tensile strength of 1500 MPa or more, the yield strength of 1000 MPa or more, the total elongation rate of 10% or more, and the uniform elongation rate of 5.0% or more were not satisfied.

[0073] In addition, in Example 1 which satisfied the alloy composition of the present disclosure, but did not satisfy the manufacturing conditions due to its too low first annealing temperature, cementite produced in ferrite was not completely melted, so that it remained after the second annealing, and thus, the total elongation rate was 10% or less.

[0074] In addition, in Examples 4 and 6 which satisfied the alloy composition of the present disclosure, but did not satisfy the manufacturing conditions due to its too high first annealing temperature, the first annealing temperature was 720°C which was out of the annealing range where maximum Mn distribution may occur, so that a Mn concentration difference was small, and thus, it was difficult to secure a residual austenite fraction in the final microstructure and the elongation rate was less than 10%.

Claims

1. A cold-rolled steel sheet comprising, by weight: 0.15 to 0.3% of C, 0.1 to 1.5% of Si, 2.5 to 5.0% of Mn, 0.1% or less (excluding 0%) of P, 0.03% or less (excluding 0%) of S, 0.01 to 0.1% of Al, 0.01% or less (excluding 0%) of N, and 0.005% or less (excluding 0%) of B, with a remainder of Fe and other inevitable impurities, and

   comprising, by area: 0.5 to 20% of residual austenite and 80 to 99.5% of martensite, as a microstructure, wherein the cold-rolled steel sheet satisfies the following Relation 1-1:

   [Relation 1-1]

$$5 \leq \frac{AF_{Mn\_s}}{AF_{Mn\_h}} \leq 25$$

   wherein AF_{Mn_s} is an area fraction of low-Mn crystal grains having a Mn content in the martensite of more than 2% and less than 5% and a unit thereof is area%, and AF_{Mn_h} is an area fraction of high-Mn crystal grains having a Mn content in the martensite of 5% or more and a unit thereof is area%.

2. The cold-rolled steel sheet of claim 1, wherein the cold-rolled steel sheet satisfies the following Relation 1-2 :

   [Relation 1-2]

$$\Delta\sigma_{TS} = \sigma_{TS\_Mn\_h} - \sigma_{TS\_Mn\_s} \geq 600\ MPa$$

wherein $\Delta\sigma_{TS}$ is a difference between a tensile strength average value ($\sigma_{TS\_Mn\_h}$) of high-Mn crystal grains having a Mn content in the martensite of 5% or more and a tensile strength average value ($\sigma_{TS\_Mn\_s}$) of low-Mn crystal grains having a Mn content in the martensite of more than 2% and less than 5%, and a unit thereof is MPa.

3. The cold-rolled steel sheet of claim 1, further comprising: one or more selected from 0.1% or less (including 0%) of Cr and 0.1% or less (including 0%) of Mo.

4. The cold-rolled steel sheet of claim 1, wherein the cold-rolled steel sheet has a tensile strength of 1500 MPa or more and a total elongation rate of 10% or more.

5. The cold-rolled steel sheet of claim 1, wherein the cold-rolled steel sheet has a yield strength of 1000 MPa or more.

6. A manufacturing method of a cold-rolled steel sheet, the method comprising:

reheating a steel slab having a composition including, by weight: 0.15 to 0.3% of C, 0.1 to 1.5% of Si, 2.5 to 5.0% of Mn, 0.1% or less (excluding 0%) of P, 0.03% or less (excluding 0%) of S, 0.01 to 0.1% of Al, 0.01% or less (excluding 0%) of N, and 0.005% or less (excluding 0%) of B with a remainder of Fe and other inevitable impurities at 1100 to 1300°C;
hot rolling the reheated slab at 800 to 1000°C to obtain a hot-rolled steel sheet;
coilcoiling the hot-rolled steel sheet at 400 to 700°C;
cold rolling the coiled hot-rolled steel sheet at a reduction rate of 20 to 75% to obtain a cold-rolled steel sheet;
first annealing of heating the cold-rolled steel sheet in a range of 600 to 700°C and maintaining the cold-rolled steel sheet for 2 to 24 hours;
first cooling of cooling the first annealed cold-rolled steel sheet at an average cooling rate of 30°C/s or more;
second annealing of heating the first cooled cold-rolled steel sheet to a temperature higher than an austenite single-phase region at an average heating rate of 30°C/s or more; and
second cooling the second annealed cold-rolled steel sheet at an average cooling rate of 30°C/s or more.

7. The manufacturing method of a cold-rolled steel sheet of claim 6, wherein the first annealing is performed at an average heating rate of 30°C/s or more.

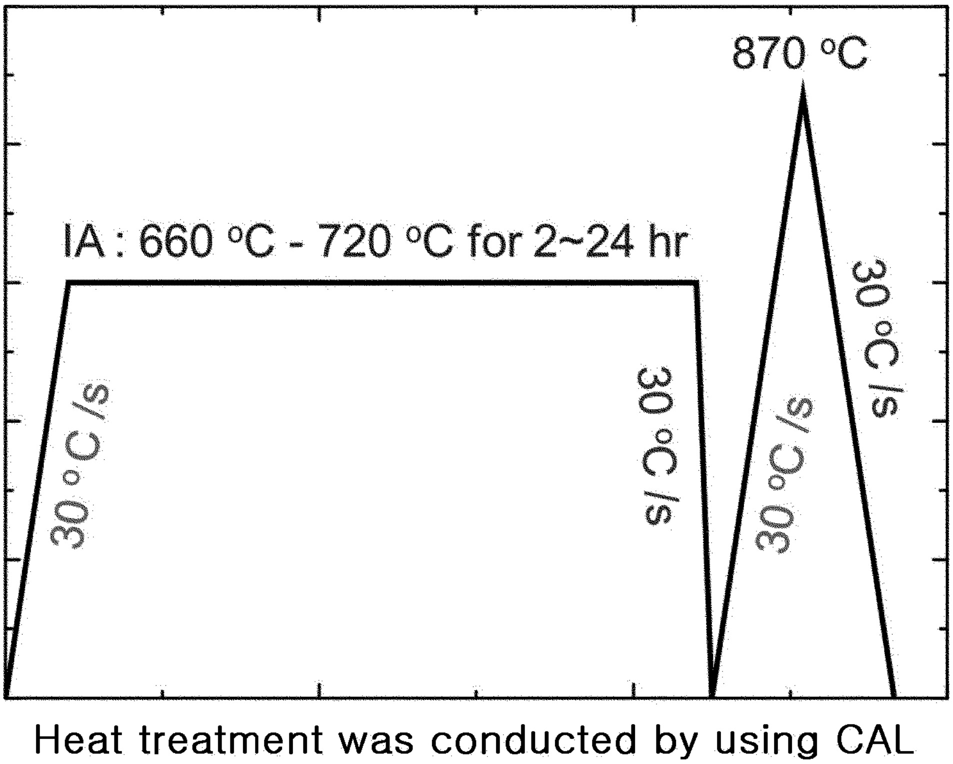
8. The manufacturing method of a cold-rolled steel sheet of claim 6, wherein the cold-rolled steel sheet satisfies the following Relation 2:

[Relation 2]

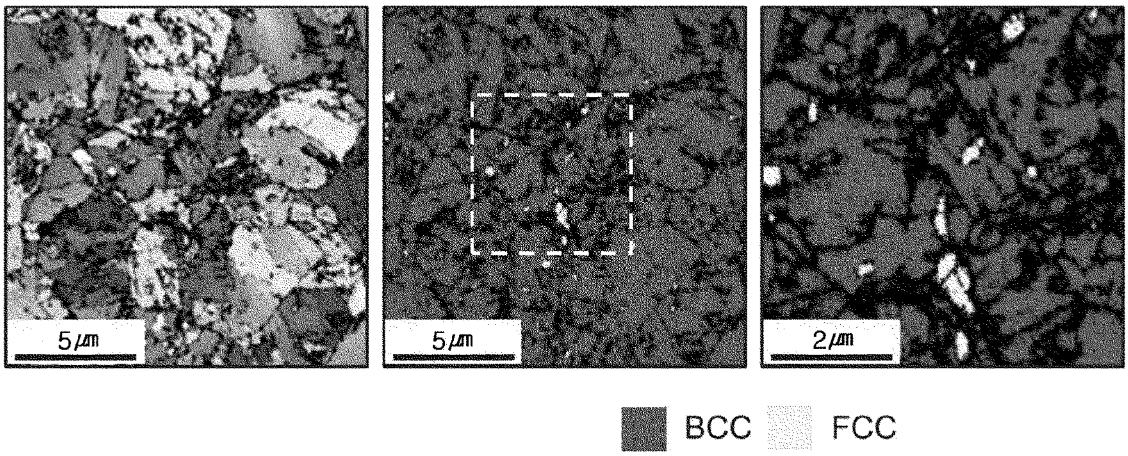
$$1.0 \leq TH1/TH2 \leq 1.5$$

wherein TH1 is a highest temperature on a surface of the cold-rolled steel sheet in the first annealing, and TH2 is a highest temperature on a surface of the cold-rolled steel sheet in the second annealing.

[FIG.1]


870 °C
IA : 660 °C - 720 °C for 2~24 hr
30 °C /s
30 °C /s
30 °C /s
30 °C /s
Heat treatment was conducted by using CAL

[FIG.2]


5 µm
5 µm
2 µm
BCC
FCC

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2022/019037

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/04(2006.01)i; **C22C 38/02**(2006.01)i; **C22C 38/06**(2006.01)i; **C22C 38/00**(2006.01)i; **C22C 38/38**(2006.01)i; **C22C 38/22**(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 38/04(2006.01); B21B 1/04(2006.01); B22D 11/124(2006.01); C21D 8/02(2006.01); C21D 9/46(2006.01); C22C 38/00(2006.01)

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

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

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

eKOMPASS (KIPO internal) & keywords: 냉연강판(cold rolled steel), 연신율(elongation), 고강도(high strength), 소둔(annealing), 냉각(cooling), 오스테나이트(austenite), 마르텐사이트(martensite)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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A	KR 10-2021-0132856 A (HYUNDAI STEEL COMPANY) 05 November 2021 (2021-11-05) See paragraphs [0057]-[0062] and [0065]-[0076] and claims 1 and 3.	1-8
A	KR 10-2017-0113858 A (POSCO) 13 October 2017 (2017-10-13) See paragraph [0033] and claim 1.	1-8
A	KR 10-2018-0021161 A (JFE STEEL CORPORATION) 28 February 2018 (2018-02-28) See paragraphs [0178]-[0183].	1-8
A	WO 2016-147549 A1 (JFE STEEL CORPORATION) 22 September 2016 (2016-09-22) See paragraph [0043] and claim 1.	1-8

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

* Special categories of cited documents:
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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
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
06 March 2023	**06 March 2023**

Name and mailing address of the ISA/KR	Authorized officer
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Form PCT/ISA/210 (second sheet) (July 2022)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2022/019037

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