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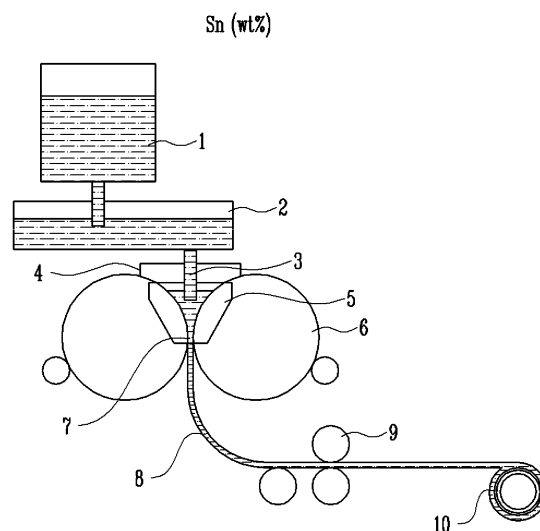
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(54) **HIGH STRENGTH AUSTENITIC STAINLESS STEEL, AND PREPARATION METHOD THEREOF**

(57) The present invention relates to control of the components of a metastable austenitic stainless steel capable of being used as a steel for a high strength spring, and a preparation method thereof. The austenitic stainless steel comprises 0.05-0.15 % of C, 0.05-0.09 % of N, 15-18 % of Cr, 6-8 % of Ni, Si in an amount exceeding 1.0 % and of no more than 1.5 %, 0.5-0.9 % of Mo, 0.4-1.2 % of Mn, 1.5 % or less of Cu, and the balance of Fe and other inevitable impurities by weight, wherein the Md30 temperature represented by the following formula (1) satisfies the temperature range of 25-30 °C, the solid solution strengthening property of the delta ferrite phase is maximized through the production of a coil using strip casting, the tensile strength is 2200 Mpa or higher at a cold rolling reduction ratio of 80%, and the hardness exceeds 570 Hv.

FIG. 1



Description

[Technical Field]

5 **[0001]** The present invention relates, generally, to an austenitic stainless steel for a high-strength spring and a method of manufacturing the austenitic stainless steel, and, more particularly, to a high-strength austenitic stainless steel for a spring and a method of manufacturing the austenitic stainless steel, which are intended to improve strength by controlling alloy design and manufacturing conditions.

10 [Background Art] ,

15 **[0002]** An austenitic stainless steel is a representative stainless steel that is excellent in physical properties such as workability, corrosion resistance or weldability and thus is most widely used. Particularly, one of the characteristics of the austenitic stainless steel is to accompany a phase transformation during processing. Consequently, if a sufficiently high alloy state is not maintained by elements for stabilizing an austenite phase, the austenite phase is likely to be transformed into a martensite phase without diffusion when plastic deformation is added. Above all, Type 301 stainless steel is widely used as one representative steel. Since such steel is unstable in terms of phase stability, the work hardening of the steel is very large depending on a plastic strain. For example, a heat-treated material has the yield strength of about 300Mpa. However, when the material is cold rolled at the ratio of 80% or more, the work hardening may be performed such that the material has the yield strength of 1800Mpa or more. Thus, Type 301 stainless steel having a high reduction ratio is utilized as a material requiring high elastic stress and high strength, such as a gasket or spring of a vehicle. A full hard material assumes the shape of the spring or gasket but requires various strength characteristics according to the application purpose, and there may be parts that require high tensile strength up to 2200Mpa. However, when a steel material is made through a conventional continuous casting with the existing Type 301 steel, it is difficult to obtain the tensile strength of 2200Mpa or more even at the high cold rolling reduction ratio. Thus, in order to provide the high-strength characteristics of 2200Mpa or more to even the austenite stainless steel that is used for a high-strength spring or the like, technical development for additional factors such as a component control or a process control is needed.

30 [Disclosure of Invention]

[Technical Problem]

35 **[0003]** Accordingly, an object of the present invention is to provide an austenitic stainless steel for a high-strength spring, which has tensile strength of 2200Mpa or more at a cold rolling reduction ratio of 80% or more.

40 **[0004]** Another object of the present invention is to provide a method of manufacturing a high-strength austenitic stainless steel, which controls the content of a substitutional alloy element and utilizes a strip casting process for the purpose of controlling the alloy design and manufacturing conditions of the austenitic stainless steel for a high-strength spring, thus enabling the austenitic stainless steel with the tensile strength of 2200Mpa or more to be obtained as a cold rolling reduction ratio increases.

[Technical Solution]

45 **[0005]** According to an aspect of the present invention, there is provided a high-strength austenitic stainless steel containing, by weight, C: 0.05 to 0.15%, N: 0.05 to 0.09%, Cr: 15 to 18%, Ni: 6 to 8%, Si: over 1.0 to 1.5%, Mo: 0.5 to 0.9%, Mn: 0.4 to 1.2%, Cu: 1.5% or less, and balance of Fe and other inevitable impurities, wherein Md30 represented by the following formula (1) satisfies a temperature range of 25 to 30 °C: (1) $Md30(^{\circ}C) = 551 - 462(C+N) - 9.2Si - 8.1Mn - 13.7Cr - 29Ni - 18.5Mo - 29Cu - 68Nb$.

50 **[0006]** According to another aspect of the present invention, there is provided a high-strength austenitic stainless steel comprising, by weight, C: 0.05 to 0.15%, N: 0.05 to 0.09%, Cr: 15 to 18%, Ni: 6 to 8%, Si: over 1.0 to 1.5%, Mo: 0.5 to 0.9%, Mn: 0.4 to 1.2%, Cu: 1.5% or less, and balance of Fe and other inevitable impurities, wherein Md30 represented by the following formula (1) satisfies a temperature range of 25 to 30 °C: (1) $Md30(^{\circ}C) = 551 - 462(C+N) - 9.2Si - 8.1Mn - 13.7Cr - 29Ni - 18.5Mo - 29Cu - 68Nb$, and the stainless steel is manufactured by strip casting.

55 **[0007]** A content of delta ferrite remaining during solidification may be 5% or more when the stainless steel is cast through strip casting.

[0008] The content of the delta ferrite remaining during the solidification may be 10% or less when the stainless steel is cast through strip casting.

[0009] The stainless steel may have tensile strength of 2200Mpa or more and hardness of 570 Hv or more, at a cold

rolling reduction ratio of 80%.

[0010] A cold rolled structure of the stainless steel may have a grain size of 8.5 or more.

[0011] According to a further aspect of the present invention, there is provided a method of manufacturing a high-strength austenitic stainless steel using a strip casting apparatus, the strip casting apparatus including a pair of rolls rotating in opposite directions, edge dams provided on both sides of the rolls to form a molten-steel pool, and a meniscus shield configured to supply inert nitrogen gas to an upper surface of the molten-steel pool, the method including casting the austenitic stainless steel, wherein the austenitic stainless steel comprises, by weight, C: 0.05 to 0.15%, N: 0.05 to 0.09%, Cr: 15 to 18%, Ni: 6 to 8%, Si: over 1.0 to 1.5%, Mo: 0.5 to 0.9%, Mn: 0.4 to 1.2%, Cu: 1.5% or less, and balance of Fe and other inevitable impurities, and Md30 represented by the following formula (1) satisfies a temperature range of 25 to 30 °C: (1) $Md30(^{\circ}C) = 551 - 462(C+N) - 9.2Si - 8.1Mn - 13.7Cr - 29Ni - 18.5Mo - 29Cu - 68Nb$, and performing control such that a content of delta ferrite remaining during solidification is 5% or more.

[0012] The stainless steel having a cast structure obtained by the strip casting may have tensile strength of 2200Mpa or more and hardness of 570 Hv or more, at a cold rolling reduction ratio of 80%, the stainless steel being manufactured to a strip of 2mm or less.

[0013] A cold rolled structure of the stainless steel may have a grain size of 8.5 or more.

[Advantageous Effects]

[0014] According to the present invention, it is possible to obtain an austenitic stainless steel for a high-strength spring, which has the tensile strength of about 2200Mpa by controlling alloy design and manufacturing conditions.

[0015] According to the present invention, it is possible to obtain an austenitic stainless steel for a high-strength spring, by controlling the content of a substitutional alloy element and utilizing a strip casting process.

[Description of Drawings]

[0016]

FIG. 1 is a schematic view of an apparatus for illustrating a strip casting process according to the present invention; FIG. 2 is a graph showing an example of the production amount of strain induced martensite depending on the process when Md30 temperature is changed, through a component control for austenite and ferrite stabilizing elements;

FIG. 3 is a picture comparing a microstructure of a cold rolled coil obtained through a conventional continuous casting process with a cold rolled structure of a coil obtained through the strip casting process;

FIG. 4 is a graph illustrating a change in one of mechanical properties, namely tensile strength as a function of a cold rolling reduction ratio after Md30 temperature is changed (8°C, 28 °C, 48°C);

FIG. 5 is a graph illustrating a change in one of mechanical properties, namely hardness as a function of a cold rolling reduction ratio after Md30 temperature is changed (8°C, 28°C, 48°C); and

FIG. 6 is a graph illustrating a change in one of mechanical properties, namely tensile strength when components are optimized at the Md30 temperature of about 28 °C to enhance work hardenability through a component control.

[Best Mode for Carrying Out the Invention]

[0017] Hereinafter, embodiments of the present invention will be described in detail with reference to the accompanying drawings.

[0018] The terms used herein are provided only for illustrative purposes but are not intended to limit the present invention. The singular forms "a" and "and" include plural referents unless the context clearly dictates otherwise. Further, it should be understood that terms "comprise", "comprises", "comprising" or the like are inclusive of characteristics, numerals, steps, operations, components, parts or combination thereof, which are described herein, but are not exclusive of one or more different characteristics, numerals, steps, operations, components, parts or combination thereof.

[0019] The terms or words used in the description and the claims of the present invention should not be interpreted as being limited merely to common and dictionary meanings. On the contrary, they should be interpreted based on the meanings and concepts of the invention in keeping with the scope of the invention on the basis of the principle that the inventor(s) can appropriately define the terms in order to describe the invention in the best way.

[0020] FIG. 1 is a schematic view of an apparatus for illustrating a conventionally known strip casting process. The strip casting process is the process that produces a thin hot-rolled strip directly from molten steel. That is, the strip casting process is a novel process that excludes a hot rolling process, thus significantly reducing production cost, outlay for plant and equipment, energy consumption, and pollution emission. As shown in FIG. 1, a twin-roll strip caster used in the general strip casting process is operated as follows: molten steel is poured into a ladle 1 and then is introduced into

a tundish 2 through a nozzle. The molten steel introduced into the tundish 2 is supplied between edge dams 5 provided on ends of casting rolls 6, namely, between the casting rolls 6 through a molten-steel injection nozzle 3, so that the solidification of the molten steel is started. Here, in order to prevent the molten steel between the rolls from being oxidized, a surface of the molten steel is protected by a meniscus shield 4. A proper kind of gas is injected, thus properly controlling an atmosphere. While passing through a roll nip 7 at which both the rolls 6 meet, a strip 8 is produced and drawn. Next, the strip passes through a rolling mill 9 to be rolled and then is subjected to a cooling process. The strip is wound in a winding unit 10.

[0021] In a twin-roll strip casting process for producing the strip having the thickness of 10mm or less directly from the molten steel, the following technology is important: the molten steel is supplied through an injection nozzle between water-cooled rolls that rotate in opposite directions at high speed, thus obtaining the strip of a desired thickness without cracks and improving a yield percentage.

[0022] Such a strip casting process is to apply a very high cooling speed to a cast plate while directly casting a liquid steel to a sheet having the thickness of 1 to 5mm. The strip casting process is performed using the twin-roll strip caster, thus producing a hot-rolled coil. The twin-roll strip caster is characterized in that the molten steel is supplied between the twin-drum rolls rotating in opposite directions and between side dams, and a large quantity of heat is emitted through the surface of the water-cooled roll at the time of being cast. A solidification shell is formed on the surface of the roll at high cooling speed, and a thin hot-rolled strip of 1 to 5mm is produced by in-line rolling that is performed continuously after the casting. In an embodiment of the present invention, the strip of 2mm or less is produced.

[0023] The above-mentioned strip casting process is advantageous in that the thin sheet of about 2mm is directly cast, so that it is possible to exclude the manufacture of a slab by the continuous casting as well as a hot rolling process. The strip casting process is especially advantageous for a steel type that may suffer from a surface defect during the hot rolling process. Since Type 301 steel frequently suffers from a defect during the hot rolling process, it is advantageous to apply the strip casting process to Type 301 steel. This process may be advantageous for the manufacture of high-strength steel, in addition to effectively coping with the surface defect. The austenitic stainless steel is produced from a delta ferrite phase in the initial stage of solidification and thereafter is solidified to an austenite phase in order to secure the stability of the solidification phase during a general continuous casting. The amount (δ cal) of the delta ferrite remaining during the casting ranges from about 1 to 10% according to the steel type, based on the following theoretical empirical formula. Such a delta ferrite phase present in the structure affects work hardening in downstream rolling.

δ cal=

$$\left(\frac{Cr + Mo + 1.5Si + 0.5Nb + 2Ti + 18}{Ni + 30(C + N) + 0.5Mn + 36} + 0.262 \right) \times 161 - 161$$

[0024] After the general slab casting process is done, the delta ferrite phase remaining in the slab is heated for 2 hours or more in a reheating furnace for the purpose of hot rolling. In this case, most of the delta ferrite phase is decomposed to the austenite phase by solid phase transformation, and then the hot rolling process is also performed at high temperature. Hence, most of the delta ferrite phase present in the cast structure of the slab is decomposed. Indeed, the content of the delta ferrite in the hot rolled coil of the austenite stainless steel is less than 0.5%.

[0025] As for the strip casting process, the strip of about 2mm is cast directly from the molten steel using the water-cooled roll. Thus, this realizes the same cast structure as the slab made by the existing continuous casting process, and obtains a high content of delta ferrite, namely, 1 to 10%. Generally, the delta ferrite phase may deteriorate workability at high temperature and corrosion resistance, and besides, may restrict the purpose of a finished product due to magnetic properties. However, when the high-strength steel having a high cold rolling reduction ratio is manufactured, a trace amount of delta ferrite phase is provided during the cold rolling, thus contributing to a reduction in the grain size and the activation of the work hardening.

[0026] Several enhancement mechanisms affect an increase in strength of a material. In the case of the metastable austenite stainless steel, such as Type 301 steel, the production of the strain induced martensite phase depending on a strain may be the most important reason that increases the work hardening. Meanwhile, a solid solution strengthening effect resulting from the addition of the alloy element is also important. In this case, it is possible to obtain various effects by interstitial elements such as C and N as well as substitutional elements such as Si and Mo. Generally, the strength may be improved by controlling the interstitial elements such as C and N in terms of economic efficiency. However, in

the case of the high-strength steel having a high rolling reduction ratio, the substitutional elements may be more effectively utilized.

[0027] Hereinafter, the composition range of the austenitic stainless steel according to an embodiment of the present invention and the reason for this range will be described in detail.

[0028] First, the alloy composition of the present invention contains, by weight, Cr: 15.0 to 18%, Ni: 6 to 8%, N: 0.05 to 0.09%, C: 0.05 to 0.15%, Mn: 0.4 to 1.2%, Mo: 0.5 to 0.9%, Si: over 1.0 to 1.5%, and Cu: 1.5% or less. Here, the Md30 temperature satisfies the range of 25 to 30 °C. The Md30 temperature is represented by the following formula (1).

$$(1) \text{Md30}(^{\circ}\text{C}) = 551 - 462(\text{C} + \text{N}) - 9.2\text{Si} - 8.1\text{Mn} - 13.7\text{Cr} - 29\text{Ni} - 18.5\text{Mo} - 29\text{Cu} - 68\text{Nb}$$

[0029] More preferably, Cr ranges from 16 to 17wt%, Ni ranges from 6 to 7wt%, and Mo ranges from 0.6 to 0.8wt%.

[0030] Si is the element that may improve a solid solution strengthening property in the austenite stainless steel. However, if an excessive amount of Si is added, hot workability may be undesirably reduced. Thus, the amount of Si is controlled to be within a range from at least 1.0 to 1.5%. However, the optimal range for Si is 1.1 to 1.3wt%.

[0031] Since the alloy design of the present invention is well known as the component of the austenitic stainless steel, a detailed description thereof will be omitted herein. The characteristics of the alloy design according to the present invention are to optimize the alloy components through the Md30 control.

[0032] The austenitic stainless steel used in the present invention is the steel characterized by a microstructure that is metastable at room temperature. This is a steel type accompanying the phase transformation from the austenite phase that may be processed by external force to the strain induced martensite phase. A representative index representing the metastability of the austenitic stainless steel is marked by Md30, which may be expressed by the following formula (1).

$$(1) \text{Md30}(^{\circ}\text{C}) = 551 - 462(\text{C} + \text{N}) - 9.2\text{Si} - 8.1\text{Mn} - 13.7\text{Cr} - 29\text{Ni} - 18.5\text{Mo} - 29\text{Cu} - 68\text{Nb}$$

[0033] When the components are adjusted according to the above formula, C, N, Mn, Ni and Cu are elements that are intended to stabilize the austenite phase, and Si, Cr, Mo and Nb are elements that are intended to stabilize the ferrite phase or the martensite phase. The combination of these elements determines the phase stability of the steel. The present invention is characterized in that the value of the Md30 is controlled to be 25 to 30 °C or less.

[0034] FIG. 2 is a graph showing an example of the production amount of strain induced martensite depending on the process when Md30 temperature is changed, through the component control for austenite and ferrite stabilizing elements.

[0035] FIG. 2 shows the phase stability depending on the change in Md30 temperature. As shown in FIG. 2, as the Md30 temperature increases, the production amount of the strain induced martensite tends to be increased. However, this shows a different behavior as the reduction ratio increases. That is, it can be seen that a very metastable material whose Md30 temperature exceeds 45 degrees does not undergo phase transformation any more after the cold rolling reduction ratio reaches 50%. In other words, the transformation to the strain induced martensite phase is rapidly performed in the initial reduction ratio, and then the reduction ratio does not contribute to work hardening any more. In contrast, as for the material whose Md30 is 25 to 30, the phase transformation is continued until the cold rolling reduction ratio reaches 80%, so that strength is continuously increased. According to the present invention, in order to manufacture an intended high-strength steel, it is necessary to ensure a condition where the phase transformation is continuously performed as the cold rolling reduction ratio increases. In the present invention, the condition of Md30 is set to a range of 25 to 30. FIG. 2 shows an experiment that is performed with 27.4 °C as the value of Md30.

[0036] If the temperature of Md30 is less than 25 degrees, the work hardening degree is not high depending on the cold rolling. On the other hand, if the temperature of Md30 is more than 30 degrees, the phase transformation is not performed any more after the cold rolling reduction ratio reaches a predetermined value as shown in FIG. 2, so that the cold rolling effect is not high.

[0037] In order to increase the work hardening, the promotion of the phase transformation as well as the control of the production process may be required. According to the present invention, in order to manufacture the high-strength austenite coil, the strip casting process is adopted instead of the existing continuous casting process. As illustrated in FIG. 1, the strip casting process of the present invention is the process that casts a thin sheet of about 2mm directly from the molten steel using the water cooled roll. The cast sheet is directly subjected to cold rolling without the reheating process or the hot rolling process, thus forming a desired shape. In order to manufacture the high-strength steel, an alloy component system serves as the index of the work hardenability separately from the production process, but the microstructure in the material varies depending on the effect of the process. The microstructure is determined according to the size of a grain boundary, a precipitate, a second phase, dislocation, a twin, etc. In such a metastable austenite stainless steel, the biggest difference between the continuous casting structure and the strip casting structure is a

difference in content of the delta ferrite phase. In the continuous casting structure, most of the delta ferrite phase produced during solidification is decomposed because a heating process is performed for a lengthy period of time to reheat the slab. In contrast, in the strip casting structure, such a heating process is omitted, so that a larger amount of delta ferrite phase is present in the material. In order to manufacture a very high-strength steel depending on the cold rolling reduction ratio, the delta ferrite phase serves to intensify the work hardening.

[0038] FIG. 3 is a picture comparing a microstructure of a cold rolled coil obtained through a conventional continuous casting process with a cold rolled structure of a coil obtained through the strip casting process. The upper part of FIG. 3 shows the microstructure produced through the strip casting, the grain size of the microstructure ranging from about 8.5 to 9. In contrast, the microstructure of the lower part, which is subjected to the continuous casting and the hot rolling, has the grain size of about 7 to 8. The reason why the strength of a material produced by the strip casting is larger than that of the material produced by the continuous casting in the same component system is due to grain refining effect depending on a difference in content of remaining delta ferrite. Therefore, the present invention improves strength and hardness, so that it can be advantageously applied to a high-strength material such as a spring.

[0039] As shown in FIG. 2, when comparing the microstructure of the cold rolled coil produced by the continuous casting with the microstructure of the cold rolled coil produced by the strip casting, the strip cast material (the upper part of the drawing) is smaller in grain size than the continuous cast material (the lower part of the drawing) because of the distribution in the structure of the delta ferrite phase, so that the delta ferrite phase may have the solid solution strengthening property, similarly to the second phase.

[0040] FIGS. 4 and 5 are graphs illustrating change in mechanical properties, tensile strength and hardness as the function of the cold rolling reduction ratio after Md30 temperature is changed (8°C, 28 °C, 48 °C). As shown in FIG. 4, all the materials having different Md30 temperatures are increased in tensile strength in proportion to the cold rolling reduction ratio. Meanwhile, as shown in FIG. 5, all the materials having different Md30 temperatures also tend to be increased in hardness in proportion to the cold rolling reduction ratio. But, in the case that the Md30 temperature is high (48.7 °C), improvement on hardness is slight when the reduction ratio exceeds a predetermined value. This shows that the work hardening effect is high because the strain induced martensite is produced in the initial reduction ratio, but improvement on hardness is limited after the production is saturated. Thus, in order to increase the hardness depending on the cold rolling reduction ratio, it is necessary to set the Md30 condition.

[0041] Referring to FIG. 4, when the Md30 value of the steel according to the present invention assumes 27.4 °C that is within the range of 25 to 30 (test piece: Type C901), it can be seen that the value of the tensile strength increases up to 2200Mpa. Since this was measured at the cold rolling reduction ratio of 80% or less, namely, about 78%, the tensile strength may be further increased when measured at the cold rolling reduction ratio of 80%. However, as for other types of steel, the Md30 value thereof is beyond the range of the present invention. In this case, the value of the tensile strength is only 2200Mpa or less.

[0042] FIG. 6 is a graph illustrating improvement on mechanical properties when the components are optimized at the Md30 temperature of 25 to 30 °C, namely, about 28 °C to enhance work hardenability through the component control. FIG. 6 shows an example (Type C901) where the component control is performed at the Md30 temperature of 25 to 30 °C, namely, about 28 °C to enhance work hardenability through the component control. Based on the result of FIG. 6, it can be seen that the tensile strength is substantially increased up to 2200Mpa at the reduction ratio of 80%. But, this is manufactured using the strip casting process and the cast sheet is a 2mm. Here, the remaining content of delta ferrite of the 2mm material, made through the strip casting process, is 5% or more. Subsequently, even after the coil undergoes heat treatment and pickling, the delta ferrite phase of 1% or more is present throughout the width of the sheet.

[0043] As shown in FIG. 3, the delta ferrite phase is refined in grain size as compared to a part that is obtained by reheating, hot rolling, annealing, and pickling a slab made through the continuous casting. Thus, the grain size of the continuous cast material is about 7.5, whereas the grain size of the strip cast material is about 8.5.

[0044] According to the present invention, by adjusting the Md30 and adding the substitutional alloy element, the strength of the metastable austenite stainless steel can be increased using the strip casting process.

(Embodiment)

[0045] Hereinafter, an embodiment of the present invention will be described, in which the mechanical properties are changed through component and process control using the austenitic stainless steel containing 15 to 18% of Cr. Table 1 shows the example of the change in component when the Md30 temperature is changed through the component control of the austenite and ferrite stabilizing elements. First, as shown in FIGS. 4 and 5, after the Md30 temperature (about 8 °C, 28 °C, 48 °C) is changed, the mechanical properties (tensile strength and hardness) are changed depending on the cold rolling reduction ratio. Referring to the drawings, the tensile strength and hardness of all the materials having different Md30 temperatures tend to increase in proportion to the cold rolling reduction ratio. However, when the Md30 temperature is high (about 48 °C), the improvement on strength is little beyond a predetermined reduction ratio. This shows that the work hardening effect is high because of the production of the strain induced martensite in the initial

reduction ratio, but the improvement on strength is limited after the production is saturated. A proper Md30 condition is required to increase the strength and hardness depending on the cold rolling reduction ratio. According to the present invention, the temperature range of the Md30 is set to a range from 25 to 30.

[0046] Further, FIG. 6 shows an example (Type C901) where the component control is performed at the Md30 temperature of about 28 °C to enhance work hardenability through the component control. It can be seen that the tensile strength is close to approximately 2200Mpa at the reduction ratio of 80%. In this type of steel, the remaining content of delta ferrite is 5% or more in the thin sheet of 2mm. Subsequently, even after the coil undergoes heat treatment and pickling, the delta ferrite phase of 1% or more is present throughout the width of the sheet.

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Table 1

No.	C	Si	Mn	S	Cr	Ni	Mo	Cu	N	δ_{cal} (%)	Md30 (°C)	Tensile Strength (Mpa)	Hard -ness (Hv)
Inventive Steel 1	0.0095	1.1	0.6	0.003	16.6	6.4	0.65	0.25	0.065	6.3	29.8	2210	570
Inventive Steel 2	0.095	1.1	0.6	0.003	16.6	6.4	0.65	0.4	0.065	6.3	25.5	2200	570
Inventive Steel 3	0.095	1.1	0.6	0.003	16.6	6.4	0.65	0.25	0.065	5.5	25.2	2200	570
Inventive Steel 4	0.095	1.25	0.6	0.003	16.6	6.4	0.65	0.25	0.065	7	28.4	2210	580
Inventive Steel 5	0.095	1.1	0.7	0.003	16.6	6.4	0.65	0.25	0.065	6.1	29	2210	580
Inventive Steel 6	0.095	1.1	0.6	0.003	16.6	6.4	0.7	0.25	0.065	6.4	28.9	2210	580
Inventive Steel 7	0.095	1.1	0.6	0.003	16.6	6.4	0.65	0.25	0.075	5.5	25.2	2200	570
Comparative Steel 1	0.095	1.1	0.6	0.003	16.6	6.6	0.65	0.25	0.065	5.7	24	2150	550
Comparative Steel 2	0.095	1.1	0.6	0.003	16.6	6.4	0.65	0.25	0.055	7	34.4	2160	550
Comparative Steel 3	0.095	1.1	0.6	0.003	16.6	6.4	0.65	0.1	0.065	6.3	34.2	2160	550
Comparative Steel 4	0.095	1.1	0.6	0.003	16.6	6.4	0.65	0.25	0.065	7	34.4	2160	550
Comparative Steel 5	0.095	1.1	0.6	0.003	16.2	6.4	0.65	0.25	0.065	5	35	2160	550
Comparative Steel 6	0.095	1.1	0.6	0.003	17	6.4	0.65	0.25	0.065	7.6	24.3	2140	540
Comparative Steel 7	0.095	1.1	0.6	0.003	16.6	6.3	0.65	0.25	0.065	6.5	32.7	2170	560
Comparative Steel 8	0.109	1.164	1.08	0.003	17.2	6.43	0.64	0.25	0.0623	6.96	11.2	2150	550
Comparative Steel 9	0.09	1.1	0.59	0.003	16.6	6.2	0.6	0.25	0.05	8.24	45.85	2150	550

[0047] When a material going through the continuous casting process is compared with a material of the present invention going through the strip casting process in terms of quality characteristics, inherent components are as follows; the content of Cr is about 16.5% and the content of Ni is about 6.5%. Mn that is the austenite stabilizing element is about 0.6%, and Mo and Si that are the substitutional alloy element are about 0.7% and 1.1% or more, respectively. For such a component design, the theoretical content of the delta ferrite during the solidification should be 5% or more and the Md30 temperature that is the index of metastability is preferably set to be within the range of 25 to 30. Further, in order to secure the quality characteristics of the full hard material that has the tensile strength of 2200Mpa or more and the hardness of 570Hv or more, the material should be cast to be about 2mm using the strip casting process. In this case, the grain size of the material should be about 8.5 and the cold rolling reduction ratio should be 80% or more.

[0048] Referring to Table 1, the inventive steel 1 to inventive steel 7 according to the present invention have Md30 of 25 to 30 °C which is within the range of the present invention. On the other hand, the comparative steel 1 to comparative steel 9 have Md30 which is beyond the range of the present invention. As shown in Table 1, when the Md30 is controlled to be substantially within the range of 25 to 30 and the strip casting process is employed, the tensile strength is 2200Mpa or more and the hardness is 570Hv or more.

[0049] While the present invention has been described in connection with certain exemplary embodiments, it is to be understood that the invention is not limited to the disclosed embodiments, but, on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims, and equivalents thereof.

Claims

1. A high-strength austenitic stainless steel comprising, by weight, C: 0.05 to 0.15%, N: 0.05 to 0.09%, Cr: 15 to 18%, Ni: 6 to 8%, Si: over 1.0 to 1.5%, Mo: 0.5 to 0.9%, Mn: 0.4 to 1.2%, Cu: 1.5% or less, and balance of Fe and other inevitable impurities,
wherein Md30 represented by the following formula (1) satisfies a temperature range of 25 to 30 °C: (1) $Md30(^{\circ}C) = 551 - 462(C + N) - 9.2Si - 8.1Mn - 13.7Cr - 29Ni - 18.5Mo - 29Cu - 68Nb$.
2. A high-strength austenitic stainless steel comprising, by weight, C: 0.05 to 0.15%, N: 0.05 to 0.09%, Cr: 15 to 18%, Ni: 6 to 8%, Si: over 1.0 to 1.5%, Mo: 0.5 to 0.9%, Mn: 0.4 to 1.2%, Cu: 1.5% or less, and balance of Fe and other inevitable impurities,
wherein Md30 represented by the following formula (1) satisfies a temperature range of 25 to 30 °C: (1) $Md30(^{\circ}C) = 551 - 462(C + N) - 9.2Si - 8.1Mn - 13.7Cr - 29Ni - 18.5Mo - 29Cu - 68Nb$, and
the stainless steel is manufactured by strip casting.
3. The high-strength austenitic stainless steel of claim 1 or 2, wherein a content of delta ferrite remaining during solidification is 5% or more when the stainless steel is cast through strip casting.
4. The high-strength austenitic stainless steel of claim 3, wherein the content of the delta ferrite remaining during the solidification is 10% or less when the stainless steel is cast through strip casting.
5. The high-strength austenitic stainless steel of claim 1 or 2, wherein the stainless steel has tensile strength of 2200Mpa or more and hardness of 570 Hv or more, at a cold rolling reduction ratio of 80%.
6. The high-strength austenitic stainless steel of claim 1 or 2, wherein a cold rolled structure of the stainless steel has a grain size of 8.5 or more.
7. The high-strength austenitic stainless steel of claim 1 or 2, wherein a content of the Si is 1.1 to 1.3% by weight.
8. The high-strength austenitic stainless steel of claim 1 or 2, wherein a content of the Cr is 16 to 17%, a content of the Ni is 6 to 7%, and a content of the Mo is 0.6 to 0.8%, by weight.
9. A method of manufacturing a high-strength austenitic stainless steel using a strip casting apparatus, the strip casting apparatus comprising a pair of rolls rotating in opposite directions, edge dams provided on both sides of the rolls to form a molten-steel pool, and a meniscus shield configured to supply inert nitrogen gas to an upper surface of the molten-steel pool, the method comprising:

casting the austenitic stainless steel, wherein the austenitic stainless steel comprises, by weight, C: 0.05 to

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0.15%, N: 0.05 to 0.09%, Cr: 15 to 18%, Ni: 6 to 8%, Si: over 1.0 to 1.5%, Mo: 0.5 to 0.9%, Mn: 0.4 to 1.2%, Cu: 1.5% or less, and balance of Fe and other inevitable impurities, and Md30 represented by the following formula (1) satisfies a temperature range of 25 to 30 °C: (1) $Md30(^{\circ}C) = 551 - 462(C+N) - 9.2Si - 8.1Mn - 13.7Cr - 29Ni - 18.5Mo - 29Cu - 68Nb$; and

performing control such that a content of delta ferrite remaining during solidification is 5% or more.

10. The method of claim 9, wherein the stainless steel having a cast structure obtained by the strip casting has tensile strength of 2200Mpa or more and hardness of 570 Hv or more, at a cold rolling reduction ratio of 80%, the stainless steel being manufactured to a strip of 2mm or less.

11. The method of claim 10, wherein a cold rolled structure of the stainless steel has a grain size of 8.5 or more.

12. The method of claim 9, wherein a content of the Si is 1.1 to 1.3% by weight.

13. The method of claim 9, wherein a content of the Cr is 16 to 17%, a content of the Ni is 6 to 7%, and a content of the Mo is 0.6 to 0.8%, by weight.

FIG. 1

Sn (wt%)

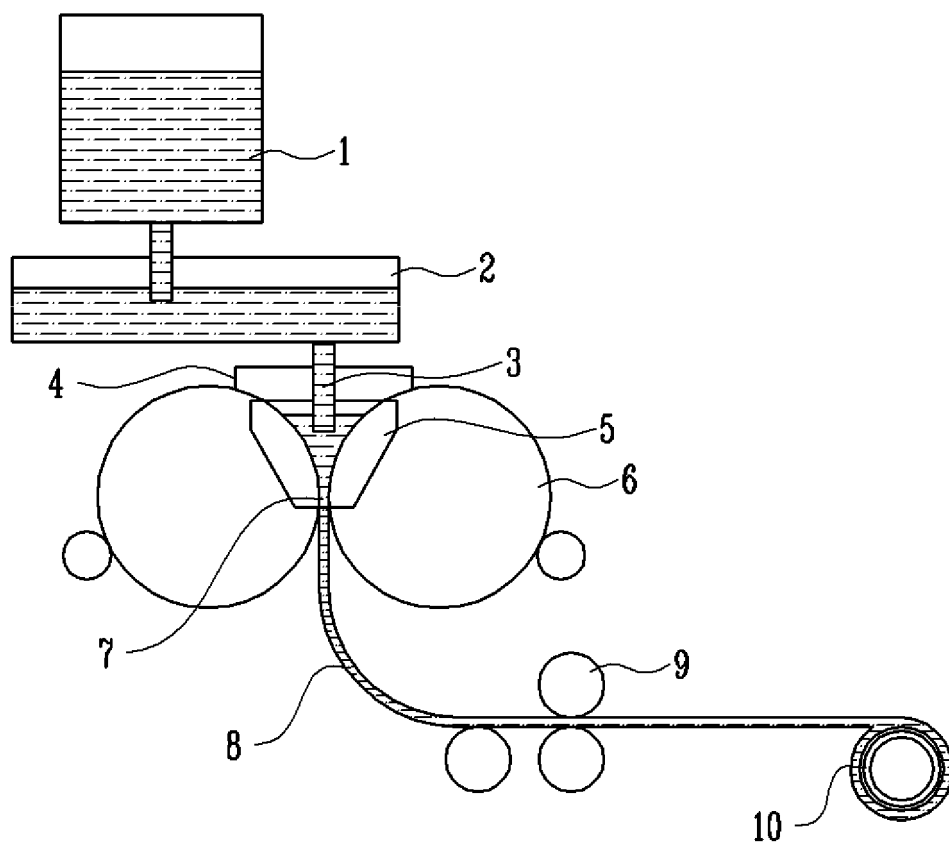


FIG. 2

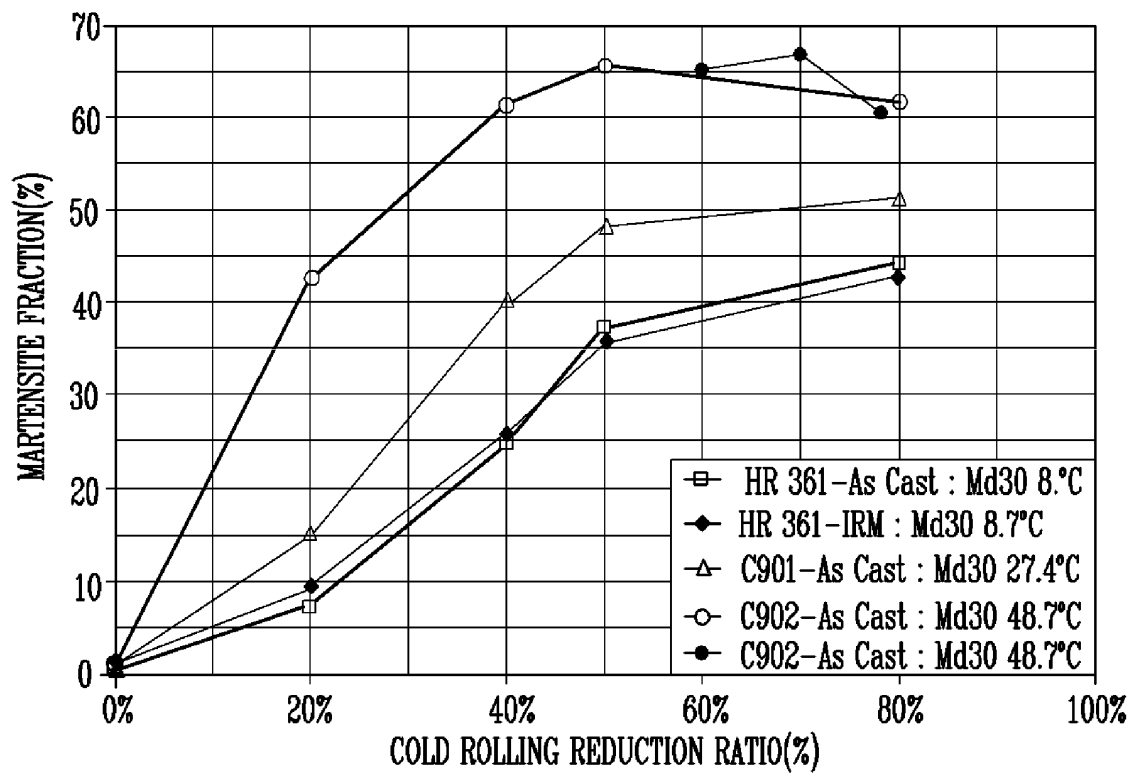


FIG. 3

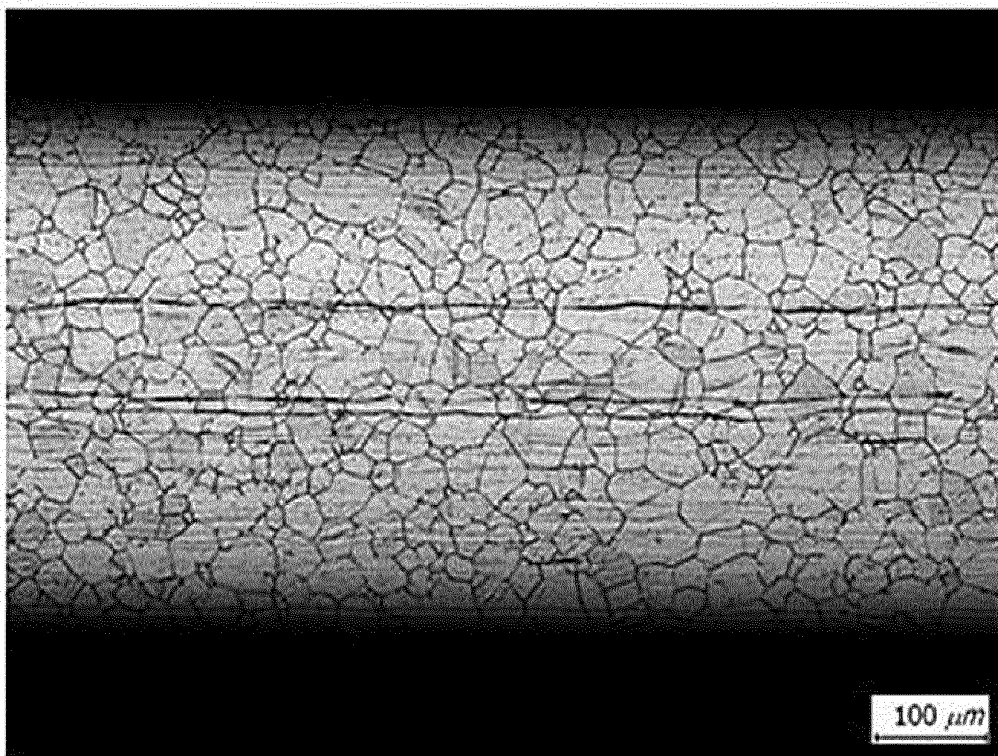
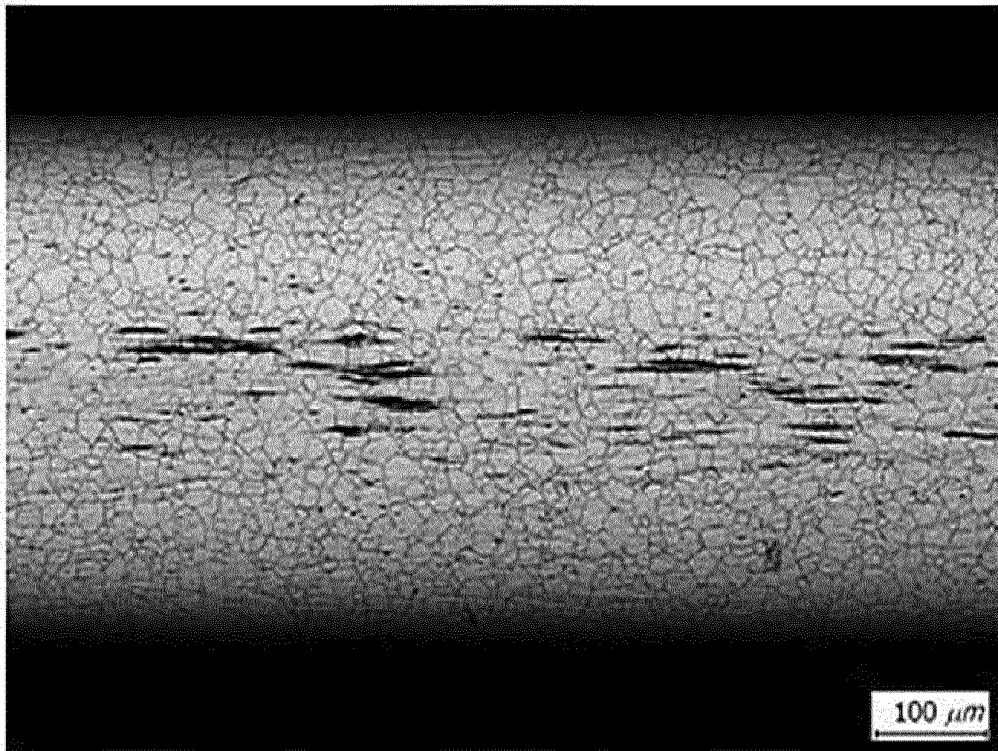


FIG. 4

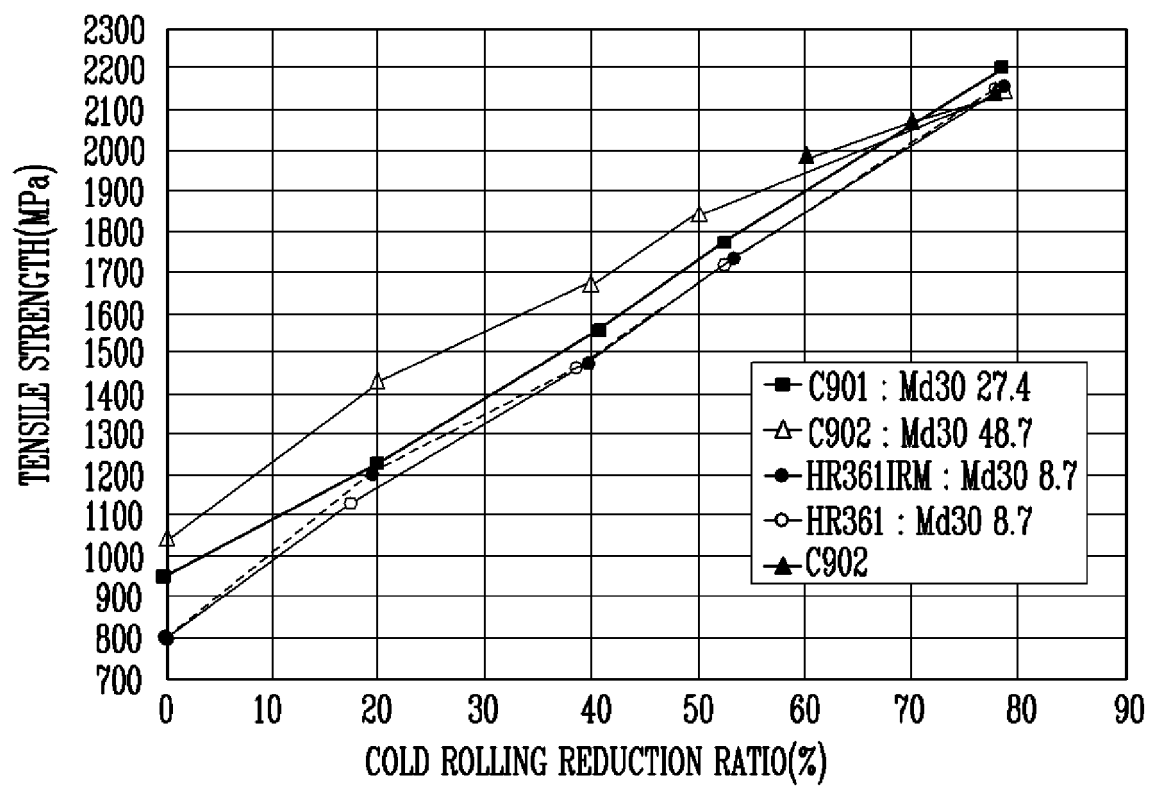


FIG. 5

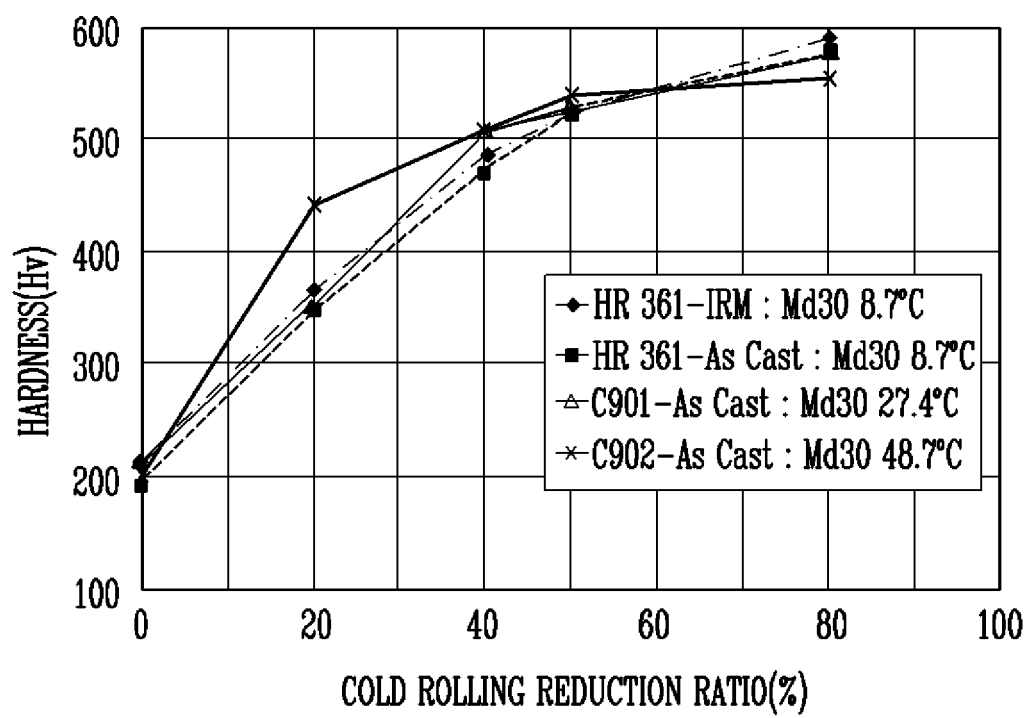
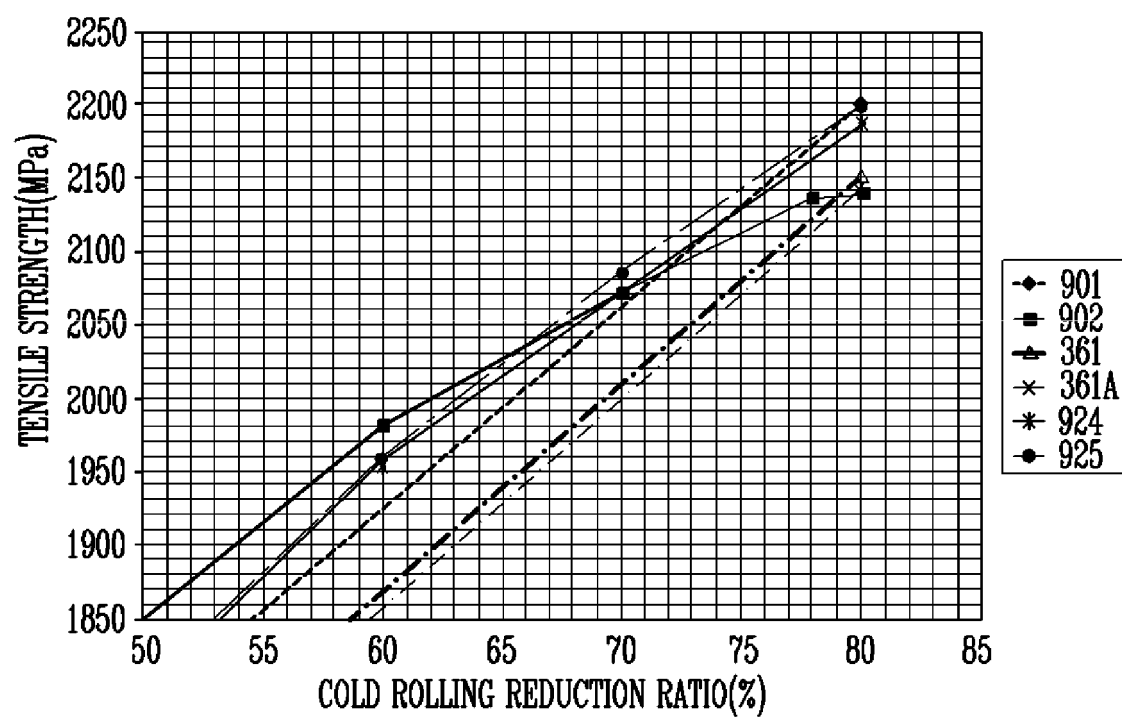


FIG. 6



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2012/011696

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/00(2006.01)i, B22D 11/06(2006.01)i, C22C 38/40(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; C21D 9/46; C21D 8/02; C21D 9/52; C21D 8/06; B22D 11/06; B21B 1/46; C21D 38/58

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: strip casting, austenitic, MD30, deltaferrite

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	JP 2000-063947 A (KAWASAKI STEEL CORP.) 29 February 2000 See paragraphs [0007],[0009]-[0011] and table 1.	1,7,8 2 3-6,9-13
Y	KR 10-2006-0074641 A (POSCO) 03 July 2006 See page 4, lines 5-9 and claim 1.	2
A	JP 05-230538 A (NIPPON STEEL CORP.) 07 September 1993 See claim 1 and paragraph [0018].	1-13
A	JP 10-121208 A (NIPPON STEEL CORP.) 12 May 1998 See claim 1.	1-13
A	JP 2005-290538 A (NIPPON STEEL & SUMIKIN STAINLESS STEEL CORP.) 20 October 2005 See claim 1.	1-13

☐ 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

23 APRIL 2013 (23.04.2013)

Date of mailing of the international search report

25 APRIL 2013 (25.04.2013)

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Authorized officer

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2012/011696

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