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(54) **ULTRAHIGH REAMING STEEL AND MANUFACTURING METHOD THEREFOR**

(57) The present invention provides an ultrahigh hole expansion steel and a method for manufacturing therefor. The steel comprises the following components in percentage by mass: C: 0.03-0.09%; Si≤0.2%; Mn: 0.5-2.0%; P≤0.02%; S≤0.003%; Al: 0.2-1.2%; N≤0.004%; Ti: 0.05-0.20%; Mo: 0.05-0.5%; Mg≤0.005%; O≤0.003%; B≤0.001%; and the balance being Fe and inevitable impurities. wherein C, Mn, Mo and B in the steel satisfy the following formula:

$0.25 \leq 2 \times C + Mn/3 + Mo + 150 \times B \leq 1.5$; wherein each chemical element in the formula represent the numerical value before the percentage sign of the percentage by mass of corresponding chemical elements. The steel according to the present invention has excellent matching of strength, plasticity and hole expansion performance, and can be applied in passenger vehicle chassis parts that require high strength and thickness reduction, such as a control arm and a subframe.

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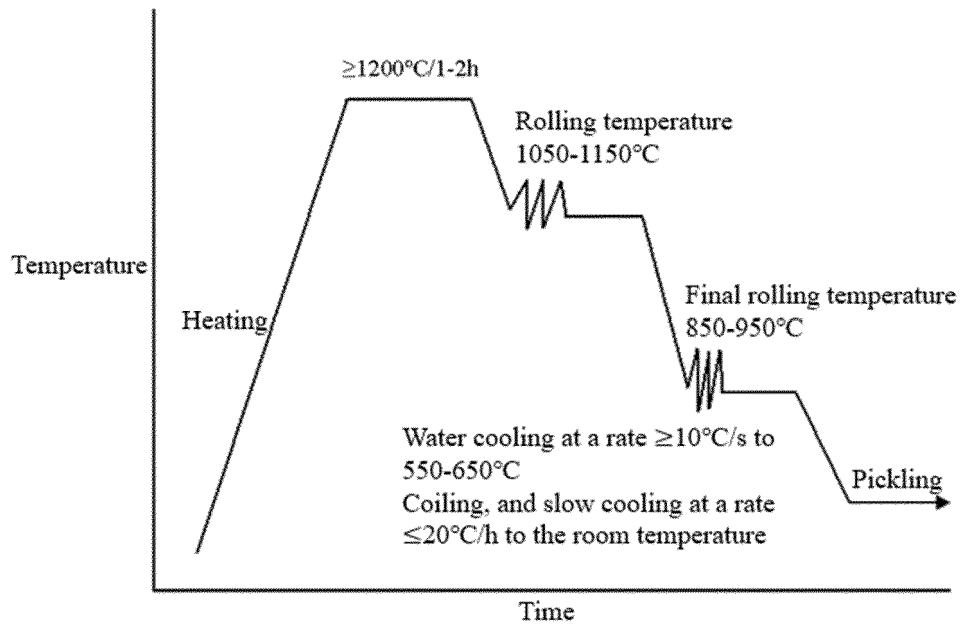


Figure 1

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Description**TECHNICAL FIELD**

- 5 **[0001]** The present invention relates to a steel and method for manufacturing therefor, in particular to an ultrahigh hole expansion steel and a method for manufacturing therefor.

BACKGROUND

- 10 **[0002]** Many parts in passenger vehicle, especially chassis and body parts, commonly use pickled products. Light-weight of passenger vehicle is a development trend in the automotive industry. High strength and weight reduction is the inevitable requirements for the subsequent new models, which will inevitably result in a higher grade of steel, while the chassis structure will also change: for example, components are more complex, placing higher requirements on material properties, surface and forming technologies such as hydroforming, hot stamping, laser welding, etc., which in turn require
- 15 higher performance on material strength, stamping, flanging, rebound, and fatigue properties.

- [0003]** At present, the high hole expansion steel used by domestic vehicle parts companies is basically high-strength steel with a tensile strength of 600MPa or less or 400MPa or less. High hole expansion steel with a tensile strength of 780MPa is gradually being used in batches in China. Due to the increase in steel strength, higher requirements have been placed on two important indicators in the forming process, that is, elongation and hole expansion rate of steel. In order to
- 20 further reduce process costs, some passenger vehicle companies have further increased the performance requirements of the materials. For example, control arms for vehicle chassis, which is a structural component, is required to have high strength and high plasticity while further improving the hole expansion rate so as to reduce the stamping process and reduce costs during the production. For instance, the hole expansion rate of present 780MPa grade high hole expansion steel is required to be further increased from $\geq 50\%$ to $\geq 70\%$. At present, 780MPa grade high hole expansion steel mostly
- 25 adopts the design idea of high silicon composition system and the structure is mainly bainite. At the same time, some trace elements are added to the steel to provide a certain precipitation strengthening effect. The surface of the strip steel after pickling not only has obvious red scale, but the hole expansion rate is basically between 50-65%, and the elongation of the bainite structure is low. None of these can meet the performance requirement of higher hole expansion rate proposed by the users.

- 30 **[0004]** There are already some solutions for 780MPa grade pickled high hole expansion steel in the prior arts. For example:

- Chinese patent CN103602895A provides a low carbon Nb-Ti micro-alloying high hole expansion steel, which adopts a composition design of low carbon and high silicon in combination with Nb-Ti micro-alloying and has a hole expansion rate of $\geq 50\%$. However, the composition design of high silicon usually results in red scale on the surface of the steel plate. In
- 35 addition, the coiling temperature required to form bainite is around 500°C, which makes it difficult to control the full-length temperature of the steel coil, resulting in large performance fluctuations on the entire length.

- [0005]** Chinese patent CN105821301A provides an 800MPa grade hot-rolled high-strength high hole expansion steel, which also adopts a composition design of low carbon and high silicon in combination with Nb-Ti micro-alloying. The Ti content in the steel is very high, ranging from 0.15 to 0.18%. Therefore, in the actual production process, the surface of strip
- 40 steel with such composition will have defects such as red scale, and ultrahigh Ti content tends to form coarse TiN in the steel, which is very detrimental to the stability of the hole expansion rate.

- [0006]** Chinese patent CN108570604A provides a 780MPa grade hot-rolled pickled high hole expansion steel, which adopts a composition design of low carbon, high aluminum and high chromium, and a three-stage cooling process in the process design. However, this three-stage cooling process is difficult to control, and the actual hole expansion rate of the
- 45 steel is not high.

- [0007]** Chinese patent CN114107792A discloses a 780MPa grade hot-rolled pickled high hole expansion steel, which adopts a composition design of low carbon and high titanium and an appropriate amount of Mo is added to the steel. Since the phase transformation process of Mo-containing steel is relatively slow, the phase transformation process mainly occurs after coiling. Therefore, in the actual production process of the steel, there are problems such as low strength of the
- 50 inner and outer rings of steel coils.

SUMMARY

- [0008]** An objective of the present invention is to provide an ultrahigh hole expansion steel and a method for manufacturing therefor. The steel of the present invention has good surface quality, excellent and stable mechanical performance, which is suitable for passenger vehicle chassis parts such as control arms and subframes that require high strength and thickness reduction.
- 55

- [0009]** It is well known that, in general, the elongation of a material is inversely proportional to the hole expansion rate,

that is, the higher the elongation, the lower the hole expansion rate; conversely, the lower the elongation, the higher the hole expansion rate. Therefore, it is very difficult to achieve high elongation and ultrahigh hole expansion rate at the same time, and it is even more difficult to ensure uniform performance across the entire length of the strip steel. Under the same or similar strengthening mechanism, the higher the strength of the material, the lower the hole expansion rate. In order to obtain steel with both good plasticity and hole expansion and flanging performances, a better balance between the two is needed. To achieve a good matching between strength, plasticity and hole expansion performance, the addition of higher amount of silicon element seems to be indispensable for high-strength and high-plasticity high hole expansion steel. However, the composition design of high silicon usually leads to poor surface quality of steel plates. Specifically, the red scale defects formed during the hot rolling process are difficult to be removed completely in the subsequent pickling process, resulting in the appearance of striped red scale on the surface of the pickled high-strength steel, which seriously affect the surface quality.

[0010] In order to meet user demands for the matching of higher surface quality, better performance stability, good plasticity and ultrahigh hole expansion performance, the present pickled 780MPa grade high hole expansion steel needs to be improved.

[0011] The present invention adopts the composition design of low silicon (or even no Si), low carbon and high aluminum to avoid the appearance of red scale on the surface of the strip steel, thereby improving the surface quality of pickled high-strength steel.

[0012] Specifically, the first aspect of the present invention provides a steel, comprising the following components in percentage by mass: C: 0.03-0.09%; Si≤0.2%; Mn: 0.5-2.0%; P≤0.02%; S≤0.003%; Al: 0.2-1.2%; N≤0.004 %; Ti: 0.05-0.20%; Mo: 0.05-0.5%; Mg≤0.005%; O≤0.003%; B≤0.001%; and the balance being Fe and inevitable impurities, wherein C, Mn, Mo and B in the steel satisfy the following formula:

$$0.25 \leq 2 \times C + Mn/3 + Mo + 150 \times B \leq 1.5,$$

wherein each chemical element in the formula represent the numerical value before the percentage sign of the percentage by mass. For example, when the C content of the steel is 0.05%, the numerical value 0.05 is substituted for calculation.

[0013] Preferably, $0.25 \leq 2 \times C + Mn/3 + Mo + 150 \times B \leq 1.2$.

[0014] Unless otherwise specified, the content of chemical elements in steel refers to the weight percentage of the elements.

[0015] Preferably, the steel of the present invention further comprises one or more selected from Nb, V, Cu, Ni and Cr, wherein Nb≤0.06%, V≤0.10%, preferably ≤0.05wt%, Cu≤0.5%, preferably ≤0.3wt%, Ni≤0.5%, preferably ≤0.3%, Cr≤0.5%, preferably ≤0.3% in percentage by mass.

[0016] Preferably, the components of the steel further satisfy at least one of the following: Si≤0.15wt%, Mn: 1.0-1.6wt%, S≤0.0015wt%, Al: 0.5-1.0wt%, N≤0.003wt%, Ti: 0.07-0.11wt %, Mo: 0.15-0.45wt%, Ni≤0.03wt%, B≤0.0005wt%.

[0017] The design idea for each element in the ultrahigh hole expansion steel of the present invention are as follows: C is a basic element in steel and one of the important elements in the present invention. C can expand the austenite phase area and stabilize the austenite. As an interstitial atom in steel, C plays a very important role in improving the strength of steel, among which it has the greatest impact on the yield strength and tensile strength of steel. In the present invention, since the structure to be obtained during the hot rolling stage is close to full ferrite, in order to obtain high-strength steel with a tensile strength of 780MPa, the C content must be 0.03% or more. When the C content is 0.03% or less, the tensile strength of the ferrite structure is difficult to reach 780MPa; but the C content should not be higher than 0.09%. If the C content is too high, pearlite structure is easily formed during the phase transformation process, which is detrimental to the hole expansion performance. Therefore, the C content should be controlled between 0.03-0.09%.

[0018] Silicon, a basic element in steel, is an impurity element in the present invention. As mentioned above, in order to meet user demands for high strength, high plasticity and ultrahigh hole expansion rate, a relatively high amount of Si is usually added in the composition design. However, the composition design of high silicon brings about a reduction in the surface quality of the steel plate, which has higher amount of red scale defects. In the present invention, in order to ensure good surface quality, the Si content should be strictly controlled. According to a large amount of statistical data from actual production, when the Si content is 0.2% or less, the surface red scale defects can be avoided during the hot rolling process. Usually, when the Si content is 0.15% or less, it is guaranteed that no red scale will appear. Therefore, the Si content in steel is within 0.2%, preferably within 0.15%.

[0019] Mn is the most basic element in steel and one of the most important elements in the present invention. Mn is an important element in expanding the austenite phase area, which can stabilize austenite, refine grains, and delay the transformation of austenite to pearlite. In the present invention, in order to ensure the strength and grain refinement effect of the steel plate, the Mn content is usually 0.5% or more. At the same time, the Mn content generally should not exceed 2.0%, otherwise Mn segregation will easily occur during steelmaking, and hot cracking is also prone to occur during continuous casting of slabs. Therefore, the Mn content in the steel is at 0.5-2.0%, preferably 1.0-1.6%.

[0020] P is an impurity element in steel. P is very easy to segregate at the grain boundaries. When the P content in the steel is high ($\geq 0.1\%$), Fe_2P is formed and precipitated around the grains, reducing the plasticity and toughness of steel. Therefore, the lower its content, the better. Generally, when the P content is within 0.02% , the performance of the steel is better and the cost of steelmaking will not be increased.

[0021] S is an impurity element in steel. S in steel usually combines with Mn to form MnS inclusions. Especially when the contents of S and Mn are both high, more MnS will be formed in the steel. MnS itself has a certain plasticity. During the subsequent rolling process, MnS is deformed along the rolling direction, which not only reduces the transverse plasticity of the steel, but also increases the anisotropy of the structure, thus it is detrimental to the hole expansion performance. Therefore, the lower the S content in steel, the better. In order to reduce the MnS content, the S content needs to be strictly controlled. In the present invention, the S content is within 0.003% , preferably 0.0015% or less.

[0022] Al is one of the most important elements in the present invention. In addition to the conventional deoxidation and nitrogen fixation function, adding Al into steel has another important role in the present invention, which is to accelerate the phase transformation process, so that the phase transformation of the strip steel is completed on the laminar flow cooling rollers before coiling, so as to avoid uneven precipitation of nanoscale carbides due to different cooling speeds in the inner and outer rings of the steel coil after coiling, which avoids large performance fluctuations across the entire length of the strip steel. The amount of Al added to steel is closely related to the austenite stabilizing elements C and Mn, as well as the key elements Mo and B that inhibit ferrite phase transformation. Generally speaking, the higher the content of C, Mg, Mo and B, the higher the Al content. Therefore, depending on the content of C, Mg, Mo and B in the steel, the Al content is usually $0.1\text{--}1.5\%$, preferably $0.5\text{--}1.0\%$.

[0023] N is an impurity element in the present invention, and the lower its content, the better. However, N is an inevitable element in the steelmaking process. Although its content is relatively low, after combination with strong carbide forming elements such as Ti, the resulting TiN particles would adversely affect the performances of the steel, especially very detrimental to the hole expansion performance. Due to the square shape of TiN, there is a large stress concentration between its sharp corners and the substrate. During the process of hole expansion deformation, the stress concentration between TiN and the substrate can easily form crack sources, thus greatly reducing the hole expansion performance of the material. Since the present invention adopts a high Ti design in the composition system, in order to minimize the adverse effect on hole expansion caused by TiN, the N content of the present invention is 0.004% or less, preferably 0.003% or less.

[0024] Ti is one of the important elements in the present invention. Ti mainly plays two roles in the present invention: firstly, it combines with the impurity element N in the steel to form TiN, providing a sort of "nitrogen fixation" effect; secondly, it forms fine nanoscale carbides that disperse uniformly in the ferrite during the coiling phase transformation process, which improve strength, plasticity and hole expansion rate. When the Ti content is less than 0.05% , there is no obvious precipitation strengthening effect; when the Ti content is higher than 0.20% , the coarse TiN easily leads to poor impact toughness of the steel plate. Therefore, the Ti content in steel of the present invention is $0.05\text{--}0.20\%$, preferably $0.07\text{--}0.11\%$.

[0025] Mo is one of the important elements in the present invention. The addition of Mo to steel can greatly delay the phase transformation of ferrite and pearlite, which is conducive to obtaining an irregular ferrite structure. Mo and Ti are added to the steel at the same time, and the resulting nanoscale titanium-molybdenum carbide precipitated phase is resistant to high-temperature roughening, which ensures that roughening does not occur for a long period of time after coiling and avoids a reduction in strength. At the same time, Mo has strong resistance to welding softening. Since the main objective of the present invention is to obtain a ferrite plus nano-precipitation structure, adding a certain amount of Mo can effectively reduce the level of welding softening. Therefore, the Mo content of the present invention is $0.1\text{--}0.5\%$, preferably $0.15\text{--}0.45\%$.

[0026] Mg is one of the important elements in the present invention. The addition of Mg in steel can preferably form dispersed fine MgO during the steelmaking stage. These fine MgO can serve as nucleation sites for TiN, which can effectively increase the nucleation sites of TiN and reduce the size of TiN in the subsequent continuous casting process. Since TiN has a great impact on the hole expansion rate of the final steel plate, it is easy to cause the instability of the hole expansion rate. Therefore, the Mg content in steel of the present invention is within 0.005% .

[0027] O is an inevitable element in the steelmaking process. For the present invention, the O content in the steel can generally reach 30 ppm or less after deoxidation, which will not cause obvious adverse effects on the performance of the steel plate. Therefore, the O content in steel is within 30 ppm.

[0028] Nb is one of the addable elements in the present invention. Nb, similar to Ti, is a strong carbide element in steel. Adding Nb to steel can greatly increase the non-recrystallization temperature of the steel, obtain deformed austenite with higher dislocation density during the finishing rolling stage, and refine the final structure during the subsequent transformation process. However, the amount of Nb should not be too much. On one hand, if the amount of Nb added exceeds 0.06% , it is easy to form relatively coarse niobium carbonitrides in the structure, consuming part of the carbon atoms and reducing the precipitation strengthening effect of carbides. At the same time, a relatively high Nb content also tends to cause anisotropy in the hot-rolled austenite structure that is inherited to the final structure during the subsequent cooling phase transformation process, which is detrimental to the hole expansion performance. Therefore, the Nb content

in the steel is usually $\leq 0.06\%$, preferably $\leq 0.03\%$.

[0029] V is an addable element in the present invention. Similar to Ti and Nb, V is also a strong carbide forming element. However, vanadium carbides have low solid-solution or precipitate temperature and are usually fully solid-solutionized in austenite during the finishing rolling stage. Only when the temperature is lowered and phase transformation begins, V begins to form in the ferrite. Since the solid solubility of vanadium carbide in ferrite is greater than the solid solubility of Nb and Ti, the size of vanadium carbide formed in ferrite is larger, which is not conducive to precipitation strengthening and contributes much less to the strength of steel than titanium carbide or titanium molybdenum carbide. However, the formation of vanadium carbide also consumes a certain amount of C atoms, which is detrimental to the improvement of the strength of steel. Therefore, the amount of V added in steel is usually $\leq 0.10\%$, preferably $\leq 0.05\%$.

[0030] Cu is an addable element in the present invention. The addition of Cu to steel can improve the corrosion resistance of steel, especially when it is added together with the P element, the corrosion resistance effect is better; when the amount of Cu exceeds 1%, under certain conditions, an ϵ -Cu precipitated phase can be formed, causing a relatively strong precipitation strengthening effect. However, the addition of Cu can easily cause the "Cu brittleness" phenomenon during the rolling process. In order to make full use of Cu's corrosion resistance improvement effect in certain applications without causing significant "Cu brittleness" phenomenon, the Cu content is usually within 0.5%, preferably within 0.3%.

[0031] Ni is an addable element in the present invention. The addition of Ni to steel has a certain corrosion resistance, but it is weaker than that of Cu. Adding Ni to steel has little effect on the tensile performance of the steel, but can refine the structure and precipitated phases of the steel, which greatly improve the low-temperature toughness of the steel; at the same time, in steel added with Cu element, adding a small amount of Ni can inhibit the occurrence of "Cu brittleness". The addition of a relatively high amount of Ni has no significant adverse effect on the performance of the steel itself. If Cu and Ni are added at the same time, it can not only improve the corrosion resistance, but also refine the structure and precipitated phases of the steel, thereby greatly improving the low-temperature toughness of the steel. However, since both Cu and Ni are relatively expensive alloying elements, in order to minimize the cost of the alloy design, the amount of Ni added is usually $\leq 0.5\%$, preferably $\leq 0.3\%$.

[0032] Cr is an addable element in the present invention. Cr is added to steel to improve the strength of steel mainly through solid solution strengthening or structure refinement. Since the structure of the steel in the present invention is fine bainitic ferrite plus nano-precipitated carbides, together with the reduction of mobile dislocations in the structure after high-temperature bell annealing process, the ratio of yield strength and tensile strength of the steel, i.e., the yield ratio, is relatively high, usually reaching 0.90 or more. The addition of a small amount of Cr element can appropriately reduce the yield strength of steel, thereby reducing the yield ratio. In addition, adding a small amount of Cr can also improve corrosion resistance. The amount of Cr added is usually $\leq 0.5\%$, preferably $\leq 0.3\%$.

[0033] B is an impurity element in the present invention. Since B can rapidly segregate at the austenite grain boundary during the finishing rolling stage, it strongly inhibits the ferrite phase transformation. Considering that the present invention expects to obtain full ferrite structure as ferrite prior to hot rolling and coiling, the B element content must be strictly limited. The amount of B added to steel is usually $\leq 0.001\%$, preferably $\leq 0.0005\%$.

[0034] Preferably, the steel of the present invention has a yield strength of $\geq 700\text{MPa}$, a tensile strength of $\geq 780\text{MPa}$, a transverse elongation A50 of $\geq 17\%$, and a hole expansion rate $\geq 80\%$.

[0035] Considering the manufacturing cost of steel, preferably, the yield strength of the steel is 850MPa or less, the tensile strength is 900MPa or less, the transverse elongation A50 is 25% or less, and the hole expansion rate is 115% or less.

[0036] Preferably, the steel of the present invention has a structure containing 95 volume% or more, preferably 97 volume% or more of ferrite and 5 volume% or less, preferably 3 volume% or less of pearlite, wherein the ferrite contains dispersively distributed nanoscale carbides.

[0037] Most of the present 780MPa grade high hole expansion steel adopts high Ti design in composition design, and alloying elements such as Nb, Mo, and Cr are added at the same time. The structure transformation process mainly occurs after coiling. Considering that the cooling speed of the inner, middle and outer rings of the steel coil after coiling is different, the strength of the steel coil at different locations fluctuates greatly. In particular, the inner and outer rings of steel coils within a certain length range differ significantly from the performances of the middle ring, resulting in significant differences in the hole expansion performance of the strip steel.

[0038] In order to improve the performance uniformity throughout the entire length of the steel coil, the present invention adds more Al in the composition design, and at the same time controls the contents of C, Mn, Mo, and B elements that have an important impact on the ferrite phase transformation, so that the strip steel can complete the phase transformation process in the air-cooling stage on the laminar flow cooling rollers prior to coiling, thereby obtaining a strip steel with good uniformity of structure and precipitation, and improving the performance stability across the entire length of the strip steel.

[0039] Another aspect of the present invention provides a method for manufacturing the above steel, comprising the following steps:

- 1) Smelting and casting;

Smelting a molten steel in a converter or an electric furnace according to the above composition, then secondary refining in a vacuum furnace, and casting into a billet or an ingot;

2) Reheating the billet or the ingot;

Heating temperature $\geq 1200^{\circ}\text{C}$, holding time: 1-2 hours;

3) Hot rolling and cooling the billet or the ingot;

wherein initial rolling temperature: $1050-1150^{\circ}\text{C}$, rough rolling of 3-5 passes is carried out under high pressure at 1050°C or more to a cumulative deformation of $\geq 50\%$, obtaining an intermediate billet, thereafter, the intermediate billet is air-cooled or water-cooled to $950-1000^{\circ}\text{C}$, and finishing rolling of 5-7 passes is carried out to a cumulative deformation of $\geq 70\%$, a final rolling temperature is $850-950^{\circ}\text{C}$, obtaining a steel strip; wherein cooling adopts laminar flow cooling; after finishing rolling, water cooling the steel strip to $550-650^{\circ}\text{C}$ at a cooling speed of $\geq 10^{\circ}\text{C/s}$ and coiling, after coiling, cooling to room temperature at a cooling speed of $\leq 50^{\circ}\text{C/h}$, obtaining a hot-rolled strip steel.

[0040] Preferably, the method further comprises step 4) Pickling, wherein a pickling operating speed of the hot-rolled strip steel is 30-140m/min, a pickling temperature is $75-85^{\circ}\text{C}$, a straightening rate is $\leq 3\%$, rinsing is carried out at $35-50^{\circ}\text{C}$, and surface drying and oiling are carried out at $120-140^{\circ}\text{C}$.

[0041] The advantageous effects of the method for manufacturing the steel in the present invention are as follows: The present invention adopts a specially controlled low carbon and high aluminum composition design to obtain a high surface ultrahigh hole expansion steel with excellent performance stability through high-temperature coiling process on the hot continuous rolling production line. Due to the innovative design of the composition system, the strip steel can complete the phase transformation before coiling, which avoids the problem of structure uniformity caused by different cooling speeds at the inner, middle and outer rings of the steel coils after coiling, and greatly improves the uniformity of the performances of the steel coils.

[0042] The present invention adopts Mg deoxygenation in the steelmaking process, which gives priority to the formation of dispersed and fine MgO in the molten steel, creating more nucleation sites for the formation of TiN in the subsequent continuous casting process, which can effectively refine the TiN particles and improve the stability of the hole expansion rate.

[0043] The initial rolling temperature of the present invention is $1050-1150^{\circ}\text{C}$, rolling of 3-5 passes is carried out under high pressure at 1050°C or more to a cumulative deformation of $\geq 50\%$, the main purpose of which is to refine the austenite grain while retaining more solid-solutionized Ti. Subsequently, an intermediate billet is air-cooled or water-cooled to $950-1000^{\circ}\text{C}$, and rolling of 5-7 passes is carried out to a cumulative deformation of $\geq 70\%$. Then, after final rolling between $850-950^{\circ}\text{C}$, the steel plate was water-cooled to $550-650^{\circ}\text{C}$ at a cooling rate of $\geq 10^{\circ}\text{C/s}$, and then slowly cooled to room temperature after coiling. The specific manufacturing process is shown in Figure 2.

[0044] During the rough rolling and finishing rolling stages, the rolling pace should be completed as quickly as possible to ensure that more Ti is solid-solutionized in austenite. After the final rolling, the strip steel is cooled in-line to $550-650^{\circ}\text{C}$ at a cooling rate of $\geq 10^{\circ}\text{C/s}$ to obtain ferrite and nano-precipitation structures. According to the actual production experience, depending on the thickness and composition of the strip steel, the strip steel completes the whole phase transformation process within 5-20s on the laminar flow cooling rollers, so as to obtain a more uniform structure and precipitation.

[0045] In the subsequent pickling process, the inhomogeneity of thermal stress formed within the steel coil during the high-temperature coiling will be reduced and homogenized during pickling and straightening, which can further improve the structure uniformity of the steel, and is conducive to obtain pickled ultrahigh hole expansion steels with high surface performance, high plasticity, ultrahigh hole expansion rate, and good performance stability.

[0046] Compared with the prior arts, the advantages of the present invention are as follows:

Compared with the high silicon composition design used in Chinese patents CN103602895A and CN105821301A, the present invention adopts a unique, i.e., low-silicon or even silicon-free, low carbon and high vanadium composition design to avoid the appearance of red scale on the surface of the strip steel and improve the surface quality of pickled high-strength steel.

[0047] The steel in Chinese patent CN108570604A is designed with a low silicon composition, in which the Si content is 0.05-0.5%. However, it is still not guaranteed to completely eliminate red scale defects on the surface of the strip steel. Moreover, the three-stage cooling process is difficult to control and the performance stability is difficult to guarantee.

[0048] In Chinese patents CN105154769A and CN114107792A, because the composition of steel contains elements such as Mo that inhibit ferrite phase transformation, making the phase transformation process occur after coiling, and there are problems such as large performance fluctuations in the inner and outer rings of steel coils during actual production.

[0049] The present invention adopts an innovative low carbon and high vanadium composition design. By precisely controlling the content of C, Mn, Mo and B, a hot-rolled steel coil with a good matching of high strength, high plasticity, ultrahigh hole expansion rate and performance stability across the entire length can be obtained by using a simple rolling process.

[0050] After the pickling step, the internal stress in the ferrite structure is reduced and homogenized. The uniformly fine and dispersively distributed nano-scale carbides in the ferrite on one hand give the steel plate high strength and high

plasticity, and at the same time, the good structure and uniform distribution of internal stress give the steel plate an ultrahigh hole expansion rate.

[0051] The method of the present invention can be used to manufacture ultrahigh hole expansion steel with yield strength ≥ 700 MPa and tensile strength ≥ 780 MPa, but with good elongation (transverse A50 $\geq 17\%$) and high hole expansion performance (hole expansion rate $\geq 80\%$), showing good performance stability and achieving excellent matching of surface performance, strength, plasticity, and hole expansion performance, which is suitable for the manufacture of vehicle chassis, subframe and other complex parts that require high strength, thickness reduction and hole expansion flanging.

BRIEF DESCRIPTION OF THE DRAWINGS

[0052]

Figure 1 is a schematic diagram of the rolling and cooling process for the steel according to the present invention;
Figure 2 is a typical metallographic photograph of the steel of Example 2 of the present invention;
Figure 3 is a typical metallographic photograph of the steel of Example 4 of the present invention;
Figure 4 is a typical metallographic photograph of the steel of Example 6 of the present invention.

DETAILED DESCRIPTION

[0053] The present invention is further described below with reference to the accompanying examples and drawings.

[0054] The steel compositions of Examples and Comparative Examples of the present invention are shown in Table 1, and the balance of the composition in Table 1 are Fe and inevitable impurities.

[0055] The process path for manufacturing the steel in Examples of the present invention is:

1) Smelting and casting;

Smelting the composition shown in Table 1 in a converter or an electric furnace, then secondary refining in a vacuum furnace, and casting into a billet or an ingot;

2) Reheating the billet or the ingot;

Heating temperature $\geq 1200^\circ\text{C}$, holding time: 1-2 hours.

3) Hot rolling and cooling the billet or the ingot;

wherein initial rolling temperature: $1050-1150^\circ\text{C}$, rough rolling of 3-5 passes was carried out under high pressure at 1050°C or more to a cumulative deformation of $\geq 50\%$, obtaining an intermediate billet; thereafter, the intermediate billet was air-cooled or water-cooled to $950-1000^\circ\text{C}$, and finishing rolling of 5-7 passes were carried out to a cumulative deformation of $\geq 70\%$, a final rolling was completed between $850-950^\circ\text{C}$, obtaining a strip steel; wherein cooling adopts laminar flow cooling, the strip steel is water-cooled to $550-650^\circ\text{C}$ at a cooling speed of $\geq 10^\circ\text{C/s}$ and coiling, after coiling, cooling to room temperature at a cooling speed of $\leq 50^\circ\text{C/h}$ after coiling.

[0056] The specific process is shown in Figure 1.

[0057] Table 2 shows the manufacturing process parameters of the steel of the Examples of the present invention. Table 3 shows the performance evaluation of the steel of the Examples and the Comparative Examples of the present invention.

[0058] The steel in Comparative Examples 1-3 is selected from CN103602895A, and the steel in Comparative Example 4 is selected from CN114107792A.

[0059] Table 1 provides composition differences between the Examples and the Comparative Examples. It can be seen from Table 1 that the composition designs of the Comparative Examples are all low aluminum designs, and the composition designs of Comparative Examples 1-3 also include high silicon designs, while the composition design of the present invention is silicon-free and high aluminum. The two are completely different in composition design.

[0060] As can be seen from Table 3, the steel coil obtained according to the compositions and processes of the present invention have a yield strength of ≥ 700 MPa, a tensile strength of ≥ 780 MPa, a transverse elongation A50 of $\geq 17\%$, and a hole expansion rate of $\geq 80\%$.

[0061] It can also be seen from Table 3 that, although Comparative Examples 1-3 are similar to the present invention in terms of yield strength, tensile strength and elongation, the hole expansion rate of Comparative Examples 1-3 are significantly lower than those of the Examples of the present invention.

[0062] The yield strength, tensile strength and elongation of the steel in Table 3 were tested in accordance with GB/T 228.1-2021 "Tensile Test of Metallic Materials Part 1: Room Temperature Test Methods".

[0063] The hole expansion rate of steel was tested in accordance with GB/T 24524-2021 "Experimental Methods for Hole Expansion of Thin Plates and Thin Strips of Metallic Materials".

[0064] Figures 2-4 respectively show typical metallographic photographs of the steels in Examples 2, 4 and 6 of the present invention.

[0065] It is clear from the figures that using the composition and process path designed by the present invention, a ferrite-dominated structure is obtained with a very small amount of pearlite. Specifically, the ferrite in the steel is 97 volume% or more, the pearlite is 3 volume% or less, and the ferrite contains dispersively distributed nanoscale carbides.

[0066] The steel of the Examples of the present invention exhibits a good matching of high strength, high plasticity and ultrahigh hole expansion rate with excellent comprehensive performance.

[0067] As can be seen from the above Examples and Comparative Examples, the 780MPa high-strength steel of the present invention has a good matching of high strength, high plasticity and ultrahigh hole expansion rate, and is particularly suitable for manufacturing vehicle chassis structure and other parts that require high strength, thickness reduction, hole expansion and flanging forming such as the control arm, etc., and can be used for wheels and other complex parts that need flanging, which has a broad application prospect.

Table 1 unit: percentage by mass

	C	Si	Mn	P	S	Al	N	Mo	Ti	O	Mg	Cu	Ni	Cr	Nb	V	B
Example 1	0.055	0.13	1.79	0.010	0.0026	0.92	0.0037	0.27	0.15	0.0030	0.001	-	0.3	0.3	-	0.02	-
Example 2	0.088	0.05	0.51	0.013	0.0020	0.39	0.0031	0.06	0.12	0.0025	0.005	-	-	-	0.04	-	0.0005
Example 3	0.041	0.07	1.46	0.020	0.0027	1.05	0.0028	0.5	0.05	0.0028	-	-	0.2	0.2	-	0.10	0.0008
Example 4	0.070	0.10	0.88	0.018	0.0029	0.62	0.0035	0.16	0.07	0.0024	0.004	-	-	-	-	-	-
Example 5	0.035	0.12	0.51	0.015	0.0019	0.21	0.0038	0.05	0.18	0.0029	-	-	0.1	0.1	0.02	0.06	0.0006
Example 6	0.062	0.06	1.98	0.008	0.0022	1.48	0.0025	0.42	0.11	0.0027	0.003	-	-	-	0.06	-	-
Example 7	0.045	0.14	0.75	0.017	0.0025	0.81	0.0040	0.36	0.20	0.0026	-	-	-	0.5	-	-	0.0010
Example 8	0.075	0.08	1.22	0.014	0.0024	0.53	0.0033	0.05	0.09	0.0023	0.002	-	0.5	-	0.03	0.04	-
Comparative Example 1	0.045	<u>1.10</u>	1.70	0.010	0.0009	<u>0.057</u>	0.0031	-	0.13	-	-	-	-	-	0.045	-	-
Comparative Example 2	0.050	<u>0.85</u>	1.90	0.011	0.0020	<u>0.024</u>	0.0031	-	0.11	-	0.001	-	-	-	0.060	-	-
Comparative Example 3	0.080	<u>0.55</u>	1.65	0.009	0.0010	<u>0.051</u>	0.0045	-	0.15	-	-	-	-	-	0.024	-	-
Comparative Example 4	0.052	0.09	1.51	0.008	0.0008	<u>0.035</u>	0.0029	0.18	0.09	0.0020	-	-	-	-	-	-	-

Table 2

Example	Heating temperature °C	Initial rolling temperature °C	Cumulative deformation of rough rolling %	Intermediate billet temperature °C	Cumulative deformation of finishing rolling %	Final rolling temperature °C	Water-cooling rate °C/s	Air-cooling time s	Coiling temperature °C
1	1310	1150	80	1000	95.0	950	50	8	560
2	1270	1130	65	990	94.5	890	25	15	610
3	1220	1060	75	970	97.6	860	80	5	580
4	1280	1110	60	995	95.8	920	38	12	550
5	1240	1090	71	980	96.8	880	65	6	630
6	1200	1050	50	950	95.2	850	10	20	600
7	1300	1140	55	990	96.8	930	46	10	650
8	1230	1070	75	975	91.4	870	20	16	620

Table 3

	Steel plate thickness mm	Yield strength MPa	Tensile strength MPa	Transverse elongation A50 %	Hole expansion rate %
Example 1	2.5	759	810	20	95.5
Example 2	4.8	776	849	18	101.2
Example 3	1.5	746	833	20	94.4
Example 4	4.2	761	842	19	98.9
Example 5	2.3	755	828	21	97.7
Example 6	6.0	732	815	19	103.6
Example 7	3.6	797	854	18	87.8
Example 8	5.4	738	803	20	110.3
Comparative Example 1	2.9	720	790	19	<u>58</u>
Comparative Example 2	2.8	710	820	17	<u>65</u>
Comparative Example 3	4.0	750	856	15	<u>50</u>
Comparative Example 4	2.5	736	803	20	93

Claims

1. A steel, comprising the following components in percentage by mass:

C: 0.03-0.09%; Si≤0.2%; Mn: 0.5-2.0%; P≤0.02%; S≤0.003%; Al: 0.2-1.2%; N≤0.004 %; Ti: 0.05-0.20%; Mo: 0.05-0.5%; Mg≤0.005%; O≤0.003%; B≤0.001%; and the balance being Fe and inevitable impurities, wherein C, Mn, Mo and B in the steel satisfy the following formula:

$$0.25 \leq 2 \times C + Mn/3 + Mo + 150 \times B \leq 1.5,$$

wherein each chemical element in the formula represent the numerical value before the percentage sign of the percentage by mass of corresponding chemical elements.

2. The steel as claimed in claim 1, **characterized in that**, the steel further comprises one or more elements selected from Nb, V, Cu, Ni and Cr, wherein Nb≤0.06%, V≤0.10%, preferably ≤0.05%, Cu≤0.5%, preferably ≤0.3wt%, Ni≤0.5%, preferably ≤0.3%, Cr≤0.5%, preferably ≤0.3% in percentage by mass.
3. The steel as claimed in claim 1, **characterized in that**, the components of the steel further satisfy at least one of the following: Si≤0.15wt%, Mn: 1.0-1.6wt%, S≤0.0015wt%, Al: 0.5-1.0wt%, N≤0.003wt%, Ti: 0.07-0.11wt %, Mo: 0.15-0.45wt%, Ni≤0.03wt%, B≤0.0005wt%.
4. The steel as claimed in any one of claims 1-3, **characterized in that**, the steel has a yield strength of ≥700MPa, a tensile strength of ≥780MPa, a transverse elongation A50 of ≥17%, and a hole expansion rate ≥80%.
5. The steel as claimed in any one of claims 1-4, **characterized in that**, the steel has a structure containing 95 volume% or more, preferably 97 volume% or more of ferrite, and 5 volume% or less, preferably 3 volume% or less, of pearlite, wherein the ferrite contains dispersively distributed nanoscale carbides.
6. A method for manufacturing the steel as claimed in any one of claims 1-5, comprising the following steps:

1) Smelting and casting;

Smelting a molten steel in a converter or an electric furnace according to the composition as claimed in any one of claims 1-5, then secondary refining in a vacuum furnace, and casting into a billet or an ingot;

2) Reheating the billet or the ingot;

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Heating temperature $\geq 1200^{\circ}\text{C}$, holding time: 1-2 hours;

3) Hot rolling and cooling the billet or the ingot;

wherein initial rolling temperature: $1050-1150^{\circ}\text{C}$, rough rolling of 3-5 passes is carried out under high pressure at 1050°C or more to a cumulative deformation of $\geq 50\%$, obtaining an intermediate billet, thereafter, the intermediate billet is air-cooled or water-cooled to $950-1000^{\circ}\text{C}$, and finishing rolling of 5-7 passes is carried out to a cumulative deformation of $\geq 70\%$, a final rolling temperature is $850-950^{\circ}\text{C}$, obtaining a steel strip; wherein cooling adopts laminar flow cooling; after final rolling, water cooling the steel strip to $550-650^{\circ}\text{C}$ at a cooling speed of $\geq 10^{\circ}\text{C/s}$ and coiling, after coiling, cooling to room temperature at a cooling speed of $\leq 50^{\circ}\text{C/h}$, obtaining a hot-rolled strip steel.

7. The method as claimed in claim 6, **characterized in that**, the method further comprises step 4) Pickling, wherein a pickling operating speed of the hot-rolled strip steel is $30-140\text{m/min}$, a pickling temperature is $75-85^{\circ}\text{C}$, a straightening rate is $\leq 3\%$, rinsing is carried out at $35-50^{\circ}\text{C}$, and surface drying and oiling are carried out at $120-140^{\circ}\text{C}$.

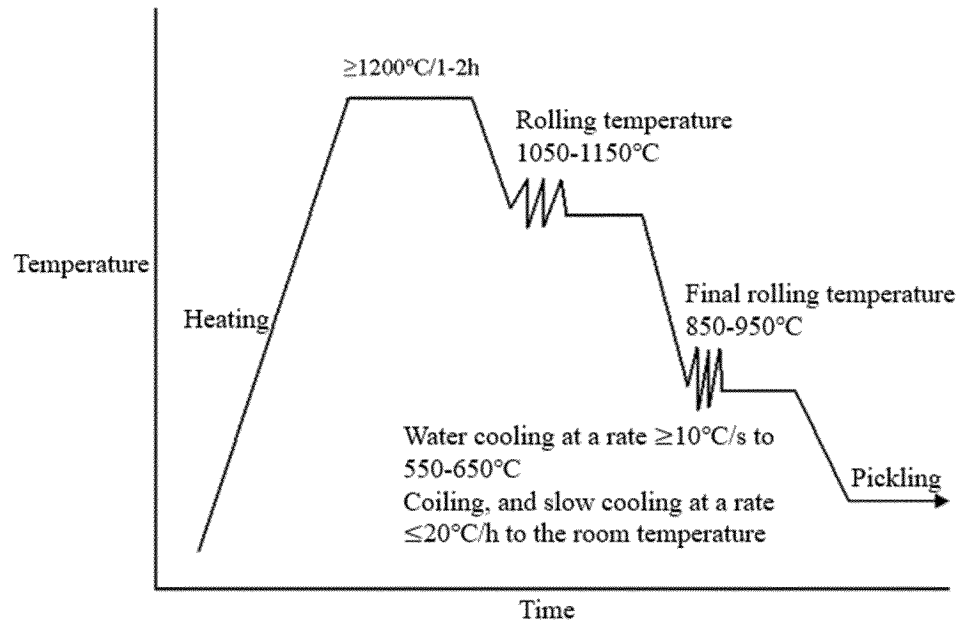


Figure 1

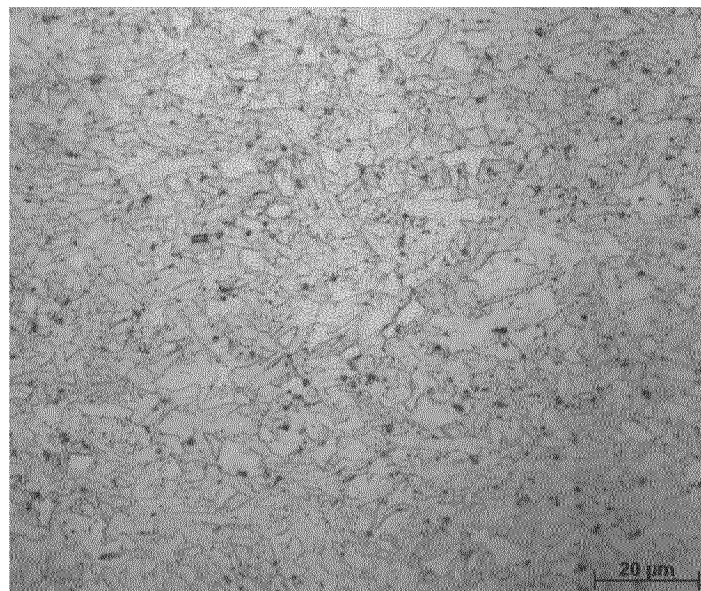


Figure 2

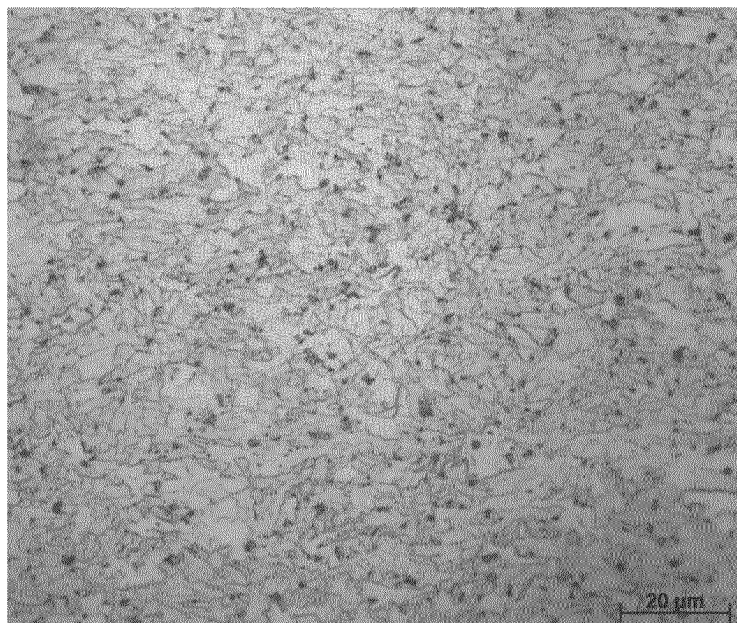


Figure 3

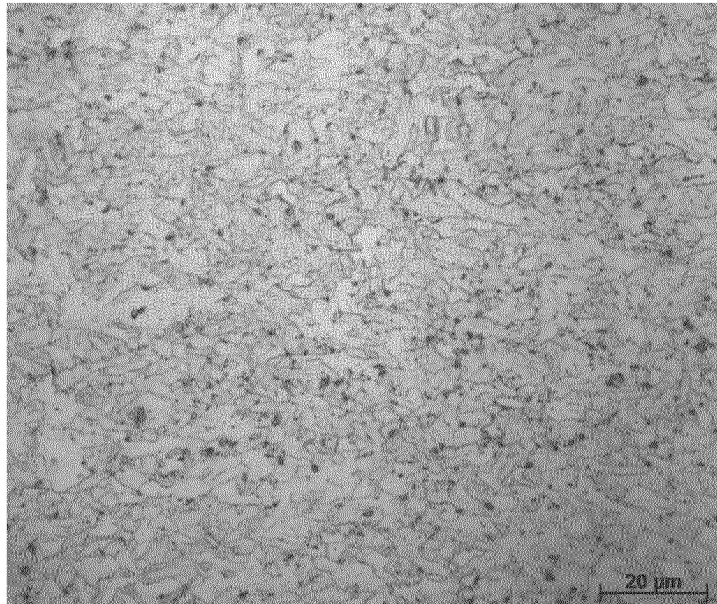


Figure 4

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2023/101852

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/02(2006.01)i; C22C 38/04(2006.01)i; C22C 38/06(2006.01)i; C22C 38/08(2006.01)i; C22C 38/12(2006.01)i;
C22C 38/14(2006.01)i; C22C 38/32(2006.01)i; C22C 38/38(2006.01)i; C22C 38/54(2006.01)i; C21D 6/00(2006.01)i;
C21D 8/02(2006.01)i; C22C 33/04(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)

IPC:C22C,C21D

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

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

CNXT, ENTXT, SIPOABS, DWPI, CNKI: 钢, 铁, Fe, 碳, C, 硅, Si, 锰, Mn, 铝, Al, 钛, Ti, 硼, B, 钼, Mo, 磷, P, 硫, S, steel,
iron, ferrum, carbon, silicon, manganese, aluminium, titanium, boron, molybdenum, phosph+, sulfur, sulphur

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	CN 110512146 A (SHOUGANG GROUP CO., LTD. et al.) 29 November 2019 (2019-11-29) description, paragraphs [0005]-[0038]	1-7
X	CN 114107789 A (BAOSHAN IRON & STEEL CO., LTD.) 01 March 2022 (2022-03-01) description, paragraphs 15-67	1-7
X	CN 114107791 A (BAOSHAN IRON & STEEL CO., LTD.) 01 March 2022 (2022-03-01) description, paragraphs 11-44	1-7
A	CN 108441763 A (MAGANG (GROUP) HOLDING CO., LTD.) 24 August 2018 (2018-08-24) entire document	1-7
A	WO 8701735 A1 (SHERBY, O. D.) 26 March 1987 (1987-03-26) entire document	1-7

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

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“&” document member of the same patent family

Date of the actual completion of the international search

19 September 2023

Date of mailing of the international search report

23 September 2023

Name and mailing address of the ISA/CN

China National Intellectual Property Administration (ISA/
CN)
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Beijing 100088

Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2023/101852

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Form PCT/ISA/210 (patent family annex) (July 2022)

REFERENCES CITED IN THE DESCRIPTION

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