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(54) **980 MPA-GRADE BAINITE HIGH HOLE EXPANSION STEEL AND MANUFACTURING METHOD THEREFOR**

(57) Disclosed are a 980 MPa-grade bainite high hole expansion steel and a manufacturing method therefor. The steel contains the following chemical components in percentages by weight: 0.05-0.10% of C, 0.5-2.0% of Si, 1.0-2.0% of Mn, P≤0.02%, S≤0.003%, 0.02-0.08% of Al, N≤0.004%, Mo≥0.1%, 0.01-0.05% of Ti, Cr≤0.5%, B≤0.002%, O≤0.0030%, and the balance of Fe and other inevitable impurities. The high hole expansion steel of the present invention has a yield strength of ≥800 MPa

and a tensile strength of ≥980MPa, has a good elongation rate (the transverse A₅₀ being ≥11%) and hole expansion performance (the hole expansion ratio being ≥40%), and can be applied to a position on a chassis part of a passenger car, such as a control arm and a vice frame, where high strength and thinning are required.

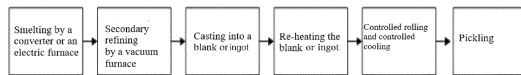


Fig. 1

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Description

Technical Field

5 **[0001]** The present disclosure relates to the technical field of high strength steel, in particular to a 980MPa grade bainite high hole expansion steel and a manufacturing method thereof.

Background Art

10 **[0002]** With the development of national economy, the production of automobiles has increased significantly and the use of steel plates has been increasing. The original design of vehicle parts, such as chassis parts of automobiles, torsion beams, subframes of cars, wheel spokes and rims, front and rear axle assemblies, body structural parts, seats, clutches, seat belts, box panels of trucks, protective nets, automotive girders, and other parts for many vehicle models in the domestic automotive industry requires the use of hot-rolled or pickled plates. Among them, the proportion of chassis steel to the total steel used in the car can reach 24-34%.

15 **[0003]** The light weighting of passenger cars is not only a development trend in the automotive industry, but also a requirement of laws and regulations. Fuel consumption is stipulated in laws and regulations, which is actually a disguised requirement to reduce the weight of the body, and the requirements reflected in the material are high strength, thinning and lightweight. High strength and weight reduction are inevitable requirements for subsequent new models. It is certain that higher steel grades are required and the chassis structure will inevitably change. For example, more complex parts result in higher requirement of material properties, surface and like and progress of molding technology, such as hydro-forming, hot stamping, laser welding, etc., which converts to higher requirement of the material performance, such as high strength, stamping, flanging, resilience and fatigue, etc.

20 **[0004]** The domestic high-strength and high hole expansion steel not only has a relatively low strength level, but also has poor performance stability compared with that in other countries. For example, the high hole expansion steel used by domestic auto parts enterprises is basically high-strength steel having a tensile strength of 600MPa or less. There is an intense competition for high hole expansion steel of 440MPa or less. High hole expansion steel having a tensile strength in a grade of 780MPa is gradually beginning to be used in large quantities, but it also puts forward high requirements for two important indicators of elongation and hole expansion ratio. The 980MPa grade high hole expansion steel is still in the stage of research and development assessment, and has not yet reached the stage of mass use. However, 980 high hole expansion steel with higher strength and higher hole expansion ratio is an inevitable development trend in the future. In order to better meet the potential future needs of users, it is necessary to develop 980MPa grade high hole expansion steel having good hole expansion performance.

25 **[0005]** At present, most of the relevant patent documents relate to 780MPa or less grade high hole expansion steel. There are very few documents involving 980MPa grade high hole expansion steel. The Chinese patent publication CN106119702A discloses a 980MPa grade hot-rolled high hole expansion steel, the main feature of which is low-carbon V-Ti microalloying design. It has a microstructure of granular bainite and a small amount of martensite with trace Nb and Cr added. It is substantially different from the present disclosure in terms of composition, process and structure.

30 **[0006]** It can be seen from the literature that under normal circumstances, the elongation of a material is inversely proportional to the hole expansion ratio, that is, the higher the elongation, the lower the hole expansion ratio; conversely, the lower the elongation, the higher the hole expansion ratio. It is very difficult to obtain high hole expansion steels having high-elongation, high-hole expansion ratio and high strength at the same time. In addition, under the same or similar strengthening mechanism, the higher the strength of the material is, the lower the hole expansion ratio is.

35 **[0007]** In order to obtain steel having good plasticity and hole expansion flanging properties, it is required to balance the relationship therebetween better. Obviously, the hole expansion ratio of a material is closely related to many factors, the most important of which include structure uniformity, level of inclusion and segregation control, different structure types, and measurement of hole expansion ratio. In general, a single homogeneous structure is conducive to obtaining higher hole expansion ratios, whereas dual or multiphase structures are generally not conducive to increasing the hole expansion ratio.

Summary

40 **[0008]** An object of the present disclosure is to provide a 980MPa grade bainite high hole expansion steel and a manufacturing method thereof. The high hole expansion steel has a yield strength of ≥ 800 MPa, a tensile strength of ≥ 980 MPa, and has good elongation (transverse A_{50} of $\geq 11\%$) and hole expansion performance (a hole expansion ratio of $\geq 40\%$). The high hole expansion steel can be applied to chassis parts of a passenger car such as control arms and subframes, where high strength and thinning are required.

45 **[0009]** To achieve the above object, the technical solution of the present disclosure is as follows:

Lower C content is adopted in the designed composition of the steel of the present disclosure to ensure that the steel has excellent weldability when used by the user and the obtained martensitic structure has good hole expansion performance and impact toughness. On the basis that the tensile strength ≥ 980 MPa is satisfied, the lower the carbon content, the better. Higher Si content is designed to match with the process for obtaining more residual austenite, thereby improving the plasticity of the material. At the same time, the higher Si content is conducive to reducing the subcrystallization temperature of steel, so that the dynamic recrystallization process can be completed in a wide final rolling temperature range, thereby improving the structure anisotropy of steel, refining the austenite grain and final bainite lath size, and improving plasticity and hole expansion ratio.

[0010] Specifically, the 980MPa grade bainite high hole expansion steel according to the present disclosure has a chemical composition based on mass percentage of: C 0.05-0.10%, Si 0.5-2.0%, Mn 1.0%-2.0%, P \leq 0.02%, S \leq 0.003%, Al 0.02~0.08%, N \leq 0.004%, Mo \geq 0.1%, Ti 0.01-0.05%, Cr \leq 0.5%, B \leq 0.002%, O \leq 0.0030%, and a balance of Fe and other unavoidable impurities.

[0011] Further, the 980MPa grade bainite high hole expansion steel according to the present disclosure also comprises one or more elements of Nb \leq 0.06%, V \leq 0.05%, Cu \leq 0.5%, Ni \leq 0.5%, Ca \leq 0.005%.

[0012] In some embodiments, the content of Mo based on weight percentage is 0.1-0.55%.

[0013] In some embodiments, the 980MPa grade bainite high hole expansion steel according to the present disclosure has a chemical composition based on weight percentage of: C 0.05-0.10%, Si 0.5~2.0%, Mn 1.0%-2.0%, P \leq 0.02%, S \leq 0.003%, Al 0.02~0.08%, N \leq 0.004%, Mo \geq 0.1%, Ti 0.01-0.05%, Cr \leq 0.5%, B \leq 0.002%, O \leq 0.0030%, Nb \leq 0.06%, V \leq 0.05%, Cu \leq 0.5%, Ni \leq 0.5%, Ca \leq 0.005%, and a balance of Fe and other unavoidable impurities, wherein the 980MPa grade bainite high hole expansion steel comprises at least one of Nb, V, Cu, Ni and Ca, preferably the steel at least comprises at least one or both of Cr and B.

[0014] The content of Nb, V is preferably \leq 0.03%, respectively; the content of Cu, Ni is preferably \leq 0.3%, respectively, and the content of Ca is preferably \leq 0.002%.

[0015] In some embodiments, the 980MPa grade bainite high hole expansion steel according to the present disclosure has a yield strength of ≥ 800 MPa, preferably ≥ 830 MPa, more preferably ≥ 850 MPa, a tensile strength of ≥ 980 MPa, preferably ≥ 1000 MPa, more preferably ≥ 1020 MPa, a transverse A_{50} of $\geq 11\%$ and a hole expansion ratio of $\geq 40\%$, preferably $\geq 50\%$.

[0016] Preferably, the 980MPa grade bainite high hole expansion steel according to the present disclosure has a microstructure of bainite + residual austenite. In the 980MPa grade bainite high hole expansion steel, the volume fraction of residual austenite is 1~5%.

[0017] In the compositional design of the high hole expansion steel according to the present disclosure: Carbon is a basic element in steel, but also one of the important elements in the present disclosure. Carbon expands the austenite phase region and stabilizes austenite. Carbon, as a gap atom in steel, plays a very important role in improving the strength of steel, and has the greatest impact on the yield strength and tensile strength of steel. In the present disclosure, since the structure to be obtained is low-carbon bainite, in order to obtain high-strength steel with a tensile strength of 980MPa, it is necessary to ensure that the carbon content is no less than 0.05%. If the carbon content is below 0.05%, even if it is completely quenched to room temperature, its tensile strength cannot reach 980MPa. However, the carbon content should not be higher than 0.10%. If the content of C is too high, the strength of the bainite formed will be too high, and there will be more martensite-austenite islands in the structure, which are not conducive to elongation and hole expansion. Therefore, the content of C should be controlled at 0.05-0.10%, preferably 0.06-0.08%.

[0018] Silicon is a basic element in steel, but also one of the important elements in the present disclosure. The increase of Si content not only improves the solid solution strengthening effect, but more importantly, plays two roles. One is that it greatly reduces the subcrystallization temperature of the steel, so that the dynamic recrystallization of the steel can be completed in a wide temperature range. In this way, in the actual rolling process, the final rolling temperature can be performed in the final rolling temperature of 800-920 °C, so that the difference in transverse and longitudinal structure is reduced, which is conducive to improving the strength and plasticity, and also conducive to obtaining a good hole expansion ratio. Another important role of Si is that it can inhibit cementite precipitation. Under appropriate conditions of rolling process, especially when bainite-dominated structures are obtained, a certain amount of residual austenite can be retained, which is conducive to improving elongation. This effect of Si is manifested only when its content reaches more than 0.5%. However, the content of Si should not be too high, otherwise the rolling force load in the actual rolling process is too large, which is not conducive to the stable production of the product. Therefore, the content of Si in steel is usually controlled at 0.5-2.0%, preferably 0.8-1.6%.

[0019] Manganese is the most basic element of steel, and at the same time one of the most important elements in the present disclosure. Mn is an important element for expanding the austenite phase region, which can reduce the critical cooling rate of steel, stabilize austenite, refine grains, and delay the transition of austenite to pearlite. However, in the present disclosure, a certain amount of molybdenum is added, and molybdenum has a much greater effect on delaying ferrite and pearlite and reducing the critical cooling rate than manganese. Therefore, the content of Mn in steel can be appropriately reduced, and should generally be controlled at 1.0% or more. At the same time, the content of Mn should

generally not exceed 2.0%, otherwise Mn segregation is easy to occur during steelmaking, and hot cracking is also prone to occur during continuous casting of slabs. Therefore, the content of Mn in steel is generally controlled at 1.0-2.0%, preferably 1.4-1.8%.

[0020] Phosphorus is an impurity element in steel. P is very prone to segregate to grain boundaries. When the content of P in steel is high ($\geq 0.1\%$), Fe_3P is formed and precipitated around the grain, reducing the plasticity and toughness of steel. Thus, the lower the content of P, the better. The content of P is generally controlled at 0.02% or less and it does not increase the cost of steelmaking.

[0021] Sulfur is an impurity element in steel. S in steel is usually combined 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, and MnS is deformed along the rolling direction during the subsequent rolling process, which not only reduces the transverse plasticity of the steel, but also increases the anisotropy of the structure, not conducive to the hole expansion performance. Therefore, the lower the S content in the steel, the better. Considering that the content of Mn in the present disclosure must be at a higher level, in order to reduce the content of MnS, the S content should be strictly controlled. The S content is required to be controlled at 0.003% or less, preferably 0.0015% or less.

[0022] Al: The role of Al in steel is mainly for deoxygenation and nitrogen fixation. Under the premise of the presence of strong carbide-forming elements such as Ti, Al has the main effect of deoxygenation and grain refinement. In the present disclosure, Al is used as a common element for deoxygenation and grain refinement and its content is usually controlled at 0.02-0.08%. If the Al content is less than 0.02%, it will not have the effect of refining grains. At the same time, if the Al content is higher than 0.08%, the grain refinement effect will be saturated. Therefore, the amount of Al in the steel is controlled at 0.02%-0.08%, preferably 0.02-0.05%.

[0023] Nitrogen belongs to the impurity element in the present disclosure. The lower the N content, the better. But nitrogen is an unavoidable element in the steelmaking process. Although its content is small, it combines with strong carbide-forming elements such as Ti, etc. The formed TiN particles are very detrimental to the performance of steel, especially the hole expansion performance. Due to the square shape of TiN, there is a large stress concentration between its sharp corner and the matrix, and cracks are easily formed during the deformation process of hole expansion due to the stress concentration between TiN and the matrix, which greatly reduces the hole expansion performance of the material. Under the premise of controlling the nitrogen content as much as possible, the lower the content of strong carbide forming elements such as Ti, the better. In the present disclosure, a trace amount of Ti is added to fix nitrogen, so as to minimize the adverse effects of TiN. Therefore, the content of N should be controlled at 0.004% or less, preferably 0.003% or less.

[0024] Titanium is one of the important elements in the present disclosure. Ti mainly plays two roles in the present disclosure: one is to combine with the impurity element N in steel to form TiN, which plays a part of effect of "nitrogen fixation" and the other is to form a certain amount of dispersed fine TiN during the subsequent welding process of the material, so as to inhibit the austenite grain size, refine the structure and improve the low-temperature toughness. Therefore, the content of Ti in steel is controlled at 0.01-0.05%, preferably 0.01-0.03%.

[0025] Molybdenum, is one of the important elements of the present disclosure. The addition of molybdenum to steel can greatly delay the phase transition of ferrite and pearlite, which is conducive to obtaining bainite structure in the medium and high temperature regions. At the same time, the addition of molybdenum can also improve the microstructure and property stability of steel and refine grains. This effect of molybdenum is conducive to the adjustment of various processes in the actual rolling process, such as segmented cooling after the end of final rolling, or air cooling and then water cooling, etc. In the present disclosure, two ways of air cooling after rolling or direct cooling are adopted. In the procedure of air cooling, on one hand, the addition of molybdenum can ensure that ferrite or pearlite and other structures will not be formed in the air-cooling process; on the other hand, the dynamic recovery of austenite deformed during the air-cooling process is conducive to improving the uniformity of structure and properties, which is beneficial to the hole expansion performance. The effect of molybdenum in inhibiting the formation of ferrite and pearlite requires its content to reach 0.10% or more. Therefore, the content of Mo should be controlled at $\geq 0.10\%$, preferably $\geq 0.15\%$. In some embodiments, the content of Mo is 0.1-0.55%.

[0026] Chromium is one of the important elements of the present disclosure. Cr in the present disclosure is not intended to improve the hardenability of steel, but to combine with B, which is conducive to the formation of needle-like ferrite structure in the welding heat-affected zone after welding and can greatly improve the low-temperature toughness of the welding heat-affected zone. Since the final application parts of the present disclosure are chassis products of passenger cars, the low temperature toughness of the welding heat-affected zone is an important indicator. In addition to ensuring that the strength of the welding heat-affected zone cannot be reduced too much, the low-temperature toughness of the welding heat-affected zone must also meet certain requirements. In addition, Cr itself also has some resistance to welding softening. Therefore, a small amount of Cr needs adding to steel, and the range is generally $\leq 0.5\%$, such as 0.1-0.5%, preferably 0.2-0.4%.

[0027] Boron: The role of B in steel is mainly to be segregated at the austenite grain boundary and inhibit the formation of proeutectoid ferrite. The addition of boron to steel can also greatly improve the hardenability of steel. However, in the

present disclosure, the main purpose of adding trace B element is not to improve hardenability, but to combine with Cr to improve the structure of welding heat-affected zone and obtain a needle-like ferrite structure with good toughness. The added amount of B element in steel is generally controlled at 0.002% or less, preferably 0.0005-0.0015%.

[0028] Calcium is an optional additive element in the present disclosure. Ca can improve the morphology of sulfides such as MnS, so that long strips of MnS and other sulfides become spherical CaS, which is conducive to improving inclusion morphology, thereby reducing the adverse effects of long strips of sulfides on hole expansion performance. But the addition of too much calcium will increase the amount of calcium oxide, which is detrimental to hole expansion performance. Therefore, the added amount of Ca in steel is usually $\leq 0.005\%$, preferably $\leq 0.002\%$.

[0029] Oxygen is an inevitable element in the steelmaking process. In the present disclosure, the content of O in steel can generally reach 30ppm or less after deoxidation, and will not cause obvious adverse effects on the performance of the steel plate. Therefore, it is fine to control the content of O in steel at 30ppm or less.

[0030] Niobium is one of the optional additive elements of the present disclosure. Nb, similar to Ti, is a strong carbide element in steel. The addition of niobium in steel can greatly increase the subcrystallization temperature of steel, provide deformed austenite with higher dislocation density in the finish rolling stage, and refine the final phase transition structure in the subsequent transformation process. However, the amount of niobium added should not be too much. If the amount of niobium added exceeds 0.06%, it is prone to form a relatively coarse niobium carbonitride in the structure, which consumes part of the carbon atoms and reduces the precipitation and strengthening effect of carbide. At the same time, larger amount of niobium is easy to cause anisotropy of hot-rolled austenite structure, which is inherited to the final structure during the subsequent cooling phase transition, which is not conducive to the hole expansion performance. Therefore, the content of Nb in steel is usually controlled at $\leq 0.06\%$, preferably $\leq 0.03\%$.

[0031] Vanadium is an optional additive element in the present disclosure. Vanadium, similar to Ti and Nb, is also a strong carbide-forming element. However, the solid solution or precipitation temperature of vanadium carbide is low and vanadium carbide is usually all solid dissolved in austenite in the finish rolling stage. Vanadium carbides begins to form in ferrite only when the phase transition starts as the temperature decreases. Since the solid solubility of vanadium carbide in ferrite is greater than that of niobium and titanium, 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. But because the formation of vanadium carbide also consumes a certain amount of carbon atoms, it is not conducive to the strength of steel. Therefore, the added amount of vanadium in steel is usually $\leq 0.05\%$, preferably $\leq 0.03\%$.

[0032] Copper is an optional additive element in the present disclosure. The addition of copper in steel can improve the corrosion resistance of steel. The corrosion resistance effect is better when Cu is added with P element. When the amount of Cu added exceeds 1%, the precipitation phase of ϵ -Cu may be formed under certain conditions, which has a relatively strong precipitation strengthening effect. However, the addition of Cu is easy to form "Cu brittleness" phenomenon in the rolling process. In order to make full use of Cu to improve corrosion resistance in some applications, without causing significant "Cu brittleness" phenomenon, the content of Cu is usually controlled at 0.5% or less, preferably 0.3% or less.

[0033] Nickel is an optional additive element in the present disclosure. The addition of nickel in steel provides certain corrosion resistance. But its corrosion resistance effect is weaker than copper. The addition of nickel in steel has little effect on the tensile properties of steel, but can refine the structure and precipitation phase of steel and greatly improve the low-temperature toughness of steel. At the same time, in steel with copper added, the addition of a small amount of nickel can inhibit the occurrence of "Cu brittleness". The addition of higher amount of nickel has no obvious adverse effect on the properties of the steel itself. If copper and nickel are added at the same time, it can not only improve the corrosion resistance, but also refine the structure and precipitated phase of the steel, greatly improving the low-temperature toughness. However, copper and nickel are relatively valuable alloying elements. In order to minimize the cost of alloy design, the added amount of nickel is typically $\leq 0.5\%$, preferably $\leq 0.3\%$.

[0034] The manufacturing method of the 980MPa grade bainite high hole expansion steel according to the present disclosure comprises the following steps:

1) Smelting and casting:

Smelting the above composition by a converter or an electric furnace, secondary refining by a vacuum furnace, and then casting it into a blank or ingot;

2) Re-heating the blank or ingot at a heating temperature of 1100-1200°C, holding for 1-2 hours;

3) Hot rolling:

the blank or ingot is hot rolled at an initial rolling temperature of 950~1100°C. Its cumulative deformation after 3-5 passes of heavy reduction rolling at $\geq 950^\circ\text{C}$ is $\geq 50\%$, preferably $\geq 60\%$ with a main purpose of refining austenite grains; the intermediate blank is then held till 920-950°C, then subjected to final 3-7 passes of rolling with cumulative deformation of $\geq 70\%$, preferably $\geq 85\%$, wherein a final rolling temperature is 800-920 °C;

4) Cooling:

first, air-cooling for 0-10s is carried out for dynamic recovery to make the deformed austenite more uniform, and

then the strip steel is water cooled to 400-550 °C at a cooling speed of ≥ 10 °C/s, preferably ≥ 30 °C/s for coiling, and naturally cooled to room temperature after coiling;

5) Pickling

the running speed of the strip steel during pickling is adjusted in the range of 30~100m/min, the pickling temperature is controlled at 75-85 °C, and the tensile levelling rate is controlled at $\leq 2\%$ to reduce the loss of strip steel elongation, and then the strip steel is rinsed, and the strip steel surface is dried and oiled.

[0035] Preferably, after step 5) of pickling, the strip steel is rinsed at a temperature of 35-50 °C to ensure the surface quality of the strip steel, and the strip steel surface is dried and oiled at 120-140 °C.

[0036] The innovation of the present disclosure lies in:

The composition of the present disclosure is designed with a lower C content, which can ensure that the steel has excellent weldability during use by the user, and the obtained martensitic structure has good hole expansion performance and impact toughness. On the basis that the tensile strength of ≥ 980 MPa is satisfied, the lower the carbon content, the better. The design of higher Si content can match with the process and obtain more residual austenite, thereby improving the plasticity of the material. At the same time, the higher Si content is conducive to reducing the subcrystallization temperature of steel, so that the dynamic recrystallization process can be completed in a wide final rolling temperature range, thereby improving the structure anisotropy of steel, refining the austenite grain and final bainite lath size, and improving plasticity and hole expansion ratio.

[0037] In the structure design, the design idea of low-carbon bainite is adopted, and higher silicon is added to inhibit and reduce the formation of cementite. At the same time, the subcrystallization temperature is reduced and the range of final rolling temperature increases. A bainite structure with fine and uniform grains and containing a small amount of residual austenite can be obtained by cooling directly after rolling or air cooling for a certain period followed by cooling. The bainite structure imparts higher strength to steel plate, while residual austenite imparts higher plasticity to steel plate, and their combination can make the steel plate show excellent matching of strength, plasticity and hole expansion ratio.

[0038] In the design of the rolling process, in the rough rolling and finish rolling stages, the rolling process should be completed as quickly as possible. After the end of the final rolling, air cooling is carried out for a certain period of time followed by water cooling or water cooling is directly carried out. The air cooling is carried out mainly because a certain amount of manganese and molybdenum is comprised in the composition. Manganese is an element that stabilizes austenite, while molybdenum greatly delays the phase transition of ferrite and pearlite and promotes bainite transition. Therefore, in the short time air cooling process, the rolled deformed austenite does not undergo a phase change. That is, it does not form a ferrite structure, but a dynamic recovery process occurs. After the dynamic recovery, the dislocation inside the austenite grain is greatly reduced. Thus, the austenite structure is more uniform, and the bainite structure formed during the subsequent phase transition is more uniform. In order to avoid the formation of ferrite during continuous cooling, the water-cooling rate of the strip steel is required to be ≥ 10 °C/s.

[0039] In order to obtain a single-phase uniform bainite structure, the strip steel needs to be cooled to the bainite phase transition temperature range. In the present disclosure, the bainite transition temperature range is 400-550 °C, depending on the composition. In this temperature range, as the coiling temperature decreases, the bainite laths are smaller, the structure is relatively more uniform, the strength increases and the plasticity decreases. Conversely, as the coiling temperature increases, the lath bainite in the structure can be partially transformed into granular bainite, which reduces the strength and increases the plasticity. It has been confirmed by theoretical calculations and experiments that a bainite structure having excellent comprehensive properties can be obtained by cooling the strip steel to the range of 400-550 °C. When the coiling temperature is ≥ 550 °C, a relatively coarse upper bainite will be formed in the structure, which cannot meet the strength requirements not less than 980MPa; when the coiling temperature is ≤ 400 °C, the structure transforms into martensite. For the above reasons, the coiling temperature needs controlling between 400-550 °C. Based on this innovative composition and process design idea, the present disclosure can obtain 980MPa grade high hole expansion steel having excellent strength, plasticity and hole expansion performance. After coiling, the steel coil is cooled naturally and slowly, and the microstructure of bainite + residual austenite can be obtained. Generally, the cooling rate of natural slow cooling is ≤ 20 °C/h, preferably ≤ 15 °C/h.

[0040] The present disclosure has the following beneficial effects:

(1) Relatively economical component design ideas are adopted, such as no or less precious metal element is added. And innovative cooling process routes are adopted. 980MPa grade high hole expansion steel having excellent strength, plasticity, toughness, cold bending and hole expansion performance can be obtained;

(2) Steel coil or steel plate has excellent matching of strength, plasticity and hole expansion flanging performance. It has a yield strength of ≥ 800 MPa, a tensile strength of ≥ 980 MPa, and has good elongation (transverse $A_{50} \geq 11\%$) and hole expansion performance (hole expansion ratio $\geq 40\%$). It can be applied to automobile chassis, subframe and other parts that require high strength and thinning, and hole expansion and flanging, and has a very broad

application prospect.

Description of the Drawings

[0041]

Fig. 1 is a process flow diagram of the manufacturing method of 980MPa grade bainite high hole expansion steel described in the present disclosure.

Fig. 2 is a schematic diagram of the rolling process in the manufacturing method of 980MPa grade bainite high hole expansion steel described in the present disclosure.

Fig. 3 is a schematic diagram of the cooling process in the manufacturing method of 980MPa grade bainite high hole expansion steel described in the present disclosure.

Fig. 4 is a typical metallographic photo of the 980MPa grade bainite high hole expansion steel of Example 2 according to the present disclosure.

Fig. 5 is a typical metallographic photo of the 980MPa grade bainite high hole expansion steel of Example 4 according to the present disclosure.

Fig. 6 is a typical metallographic photo of the 980MPa grade bainite high hole expansion steel of Example 6 according to the present disclosure.

Fig. 7 is a typical metallographic photo of the 980MPa grade bainite high hole expansion steel of Example 8 according to the present disclosure.

Detailed Description

[0042] Referring to Fig. 1 to 3, the manufacturing method of 980MPa grade bainite high hole expansion steel according to the present disclosure comprises the following steps:

1) Smelting and casting:

Smelting the above composition by a converter or an electric furnace, secondary refining by a vacuum furnace, and then casting it into a blank or ingot;

2) Re-heating the blank or ingot at the heating temperature of 1100-1200°C, holding for 1-2 hours;

3) Hot rolling:

the blank or ingot is hot rolled at an initial rolling temperature of 950~1100°C. Its cumulative deformation after 3-5 passes of heavy reduction rolling at $\geq 950^\circ\text{C}$ is $\geq 50\%$; the intermediate blanket is then held till 920-950°C, then subjected to final 3-7 passes of rolling with cumulative deformation of $\geq 70\%$; the final rolling temperature is 800-920 °C;

4) Cooling:

first, air-cooling for 0-10s is carried out for dynamic recovery to make the deformed austenite more uniform, and then the strip steel is water cooled to 400-550 °C at a cooling speed of $\geq 10^\circ\text{C/s}$ for coiling, and naturally cooled to room temperature after coiling;

5) Pickling

the running speed of pickling of the strip steel is adjusted in the range of 30~100m/min, the pickling temperature is controlled at 75-85 °C, and the tensile levelling rate is controlled at $\leq 2\%$, and the strip steel is rinsed at the temperature of 35-50 °C, and the surface is dried and oiled at the temperature of 120-140 °C.

[0043] The composition of the high hole expansion steel in examples of the present disclosure is described in Table 1. Table 2-3 show the production process parameters of the steel in the examples of the present disclosure, wherein the thickness of the blank in the rolling process is 120mm. Table 4 shows the mechanical properties of the steel plate in the examples of the present disclosure. In the examples, the tensile properties (yield strength, tensile strength, elongation) were tested in accordance with the International Standard ISO6892-2-2018; the hole expansion ratio was tested in accordance with the International Standard ISO16630-2017.

[0044] As can be seen from Table 4, the yield strength of the steel coil is $\geq 800\text{MPa}$, the tensile strength is $\geq 980\text{MPa}$, the elongation is between 10-13%, and the hole expansion ratio is $\geq 40\%$.

[0045] Typical metallographic photographs of Examples 2, 4, 6 and 8 are shown in Figs. 4-7, respectively. It can be seen that the typical microstructure is bainite and contains a small amount of residual austenite.

[0046] As can be seen from the above Examples, the 980MPa high hole expansion steel of the present disclosure has excellent matching of strength, plasticity and hole expansion performance, especially suitable for automotive chassis structure and other parts that require high strength and thinning, and hole expansion and flange forming, such as control arms, etc., and can also be used for wheels and other parts that need hole flanging. It has broad application prospects.

Table 1 unit: weight %

Example	C	Si	Mn	P	S	Al	N	Mo	Ti	Cr	B	Ca	Nb	V	Cu	Ni	O
1	0.077	0.95	1.75	0.009	0.0026	0.043	0.0038	0.11	0.019	0.42	0.0008	/	0.030	/	/	/	0.0025
2	0.084	1.89	1.13	0.011	0.0020	0.035	0.0028	0.22	0.050	0.11	/	0.002	/	0.025	/	/	0.0024
3	0.099	0.50	1.04	0.013	0.0012	0.079	0.0032	0.55	0.015	0.28	0.0015	/	0.033	/	/	0.12	0.0028
4	0.061	1.98	1.98	0.009	0.0028	0.022	0.0035	0.18	0.033	/	0.0010	0.003	0.025	/	0.20	0.21	0.0025
5	0.080	1.60	1.85	0.008	0.0011	0.065	0.0029	0.24	0.011	/	/	0.005	/	0.033	/	0.50	0.0023
6	0.065	1.77	1.40	0.015	0.0023	0.058	0.0034	0.42	0.023	0.36	0.0018	/	/	0.048	0.25	0.43	0.0020
7	0.090	1.24	1.94	0.013	0.0005	0.028	0.0029	0.31	0.018	0.31	0.0005	0.001	0.059	/	/	/	0.0027
8	0.051	1.40	1.80	0.012	0.0024	0.071	0.0040	0.37	0.029	0.50	0.0011	/	/	/	0.50	0.30	0.0029

Table 2

	Heating temperature °C	Holding time h	Rolling process (thickness of steel blank is 120mm)								Coiling temperature °C	Cooling rate after coiling °C/h
			Initial rolling temperature °C	Rough rolling cumulative deformation n %	Intermediate blank temperature °C	Finish rolling cumulative deformation n%	Final rolling temperature °C	Air cooling time s	Water cooling rate °C/s	Steel plate thickness mm		
Ex. 1	1170	1.3	1040	70	920	89	870	8	50	2	430	10
Ex. 2	1180	1.2	1080	50	930	92	920	5	40	3	550	20
Ex. 3	1130	2.0	1100	65	935	90	840	3	45	5	470	13
Ex. 4	1190	1.0	950	55	925	94	820	2	60	4	400	8
Ex. 5	1150	1.7	1020	60	940	88	830	5	35	6	510	18
Ex. 6	1150	1.5	1000	75	950	93	800	7	50	4	480	15
Ex. 7	1130	1.9	980	80	920	90	850	0	45	2	450	12
Ex. 8	1160	1.4	1060	70	945	91	860	10	30	3	500	16

Table 3

	Strip steel pickling running rate m/min	Pickling temperature °C	Tensile levelling rate %	Rinsing temperature °C	Drying temperature °C
Ex. 1	100	82	1.8	40	135
Ex. 2	60	76	1.1	35	120
Ex. 3	70	75	1.6	47	128
Ex. 4	80	80	0.8	42	140
Ex. 5	30	77	2.0	50	133
Ex. 6	55	79	1.2	37	125
Ex. 7	45	81	0.5	41	134
Ex. 8	90	83	1.4	38	130

Table 4: mechanical performance of the steel plate

Example	Yield strength MPa	Tensile strength MPa	Elongation %	Hole expansion ratio %	Residual austenite content
1	809	1015	13.0	44	4.24
2	888	1057	13.0	49	2.33
3	868	1020	11.5	61	4.39
4	812	1039	12.5	43	1.85
5	877	1056	12.0	55	3.57
6	804	1024	12.5	45	4.92
7	834	1008	13.0	77	4.88
8	846	1031	11.0	40	3.86

Claims

1. A 980MPa grade bainite high hole expansion steel having a chemical composition based on weight percentage of: C 0.05-0.10%, Si 0.5-2.0%, Mn 1.0%~2.0%, P≤0.02%, S≤0.003%, Al 0.02-0.08%, N≤0.004%, Mo≥0.1%, Ti 0.01-0.05%, Cr≤0.5%, B≤0.002%, O≤0.0030%, and a balance of Fe and other unavoidable impurities, wherein the high hole expansion steel has a microstructure of bainite + residual austenite.
2. The 980MPa grade bainite high hole expansion steel according to claim 1 further comprising one or more elements of Nb≤0.06%, V≤0.05%, Cu≤0.5%, Ni≤0.5% and Ca≤0.005%, wherein the content of Nb, V is preferably ≤0.03%, respectively, the content of Cu, Ni is preferably ≤0.3%, respectively, and the content of Ca is preferably ≤0.002%.
3. The 980MPa grade bainite high hole expansion steel according to claim 1 having a chemical composition based on weight percentage of: C 0.05-0.10%, Si 0.5-2.0%, Mn 1.0%-2.0%, P≤0.02%, S≤0.003%, Al 0.02-0.08%, N≤0.004%,

EP 4 206 351 A1

Mo \geq 0.1%, Ti 0.01-0.05%, Cr \leq 0.5%, B \leq 0.002%, O \leq 0.0030%, Nb \leq 0.06%, V \leq 0.05%, Cu \leq 0.5%, Ni \leq 0.5%, Ca \leq 0.005%, and a balance of Fe and other unavoidable impurities, wherein the 980MPa grade bainite high hole expansion steel comprises at least one of Nb, V, Cu, Ni and Ca.

4. The 980MPa grade bainite high hole expansion steel according to claim 1, wherein the content of C is 0.06-0.08%.
5. The 980MPa grade bainite high hole expansion steel according to claim 1, wherein the content of Si is 0.8-1.6%.
6. The 980MPa grade bainite high hole expansion steel according to claim 1, wherein the content of Mn is 1.4-1.8%.
7. The 980MPa grade bainite high hole expansion steel according to claim 1, wherein the content of S is controlled at 0.0015% or less, and/or the content of N is controlled at 0.003% or less.
8. The 980MPa grade bainite high hole expansion steel according to claim 1, wherein the content of Al is 0.02-0.05%.
9. The 980MPa grade bainite high hole expansion steel according to claim 1, wherein the content of Ti is 0.01-0.03%.
10. The 980MPa grade bainite high hole expansion steel according to claim 1, wherein the content of Mo is \geq 0.15%.
11. The 980MPa grade bainite high hole expansion steel according to claim 1, wherein the content of Cr is 0.2-0.4%, and/or the content of B is 0.0005-0.0015%, and/or the content of Mo is 0.1-0.55%.
12. The 980MPa grade bainite high hole expansion steel according to claim 1, wherein the high hole expansion steel has a yield strength of \geq 800MPa, a tensile strength of \geq 980MPa, a traverse elongation $A_{50}\geq$ 10%, and a hole expansion ratio of \geq 40%.
13. The 980MPa grade bainite high hole expansion steel according to claim 1, wherein the high hole expansion steel has a preferred yield strength of \geq 850MPa, a tensile strength of \geq 1000MPa, a traverse elongation $A_{50}\geq$ 11%, and a hole expansion ratio of \geq 50%.
14. A manufacture method of the 980MPa grade bainite high hole expansion steel according to any one of claims 1-13, which comprises the following steps:
 - 1) Smelting and casting:
Smelting the above composition according to claims 1-11 by a converter or an electric furnace, secondary refining by a vacuum furnace, and then casting it into a blank or ingot;
 - 2) Re-heating the blank or ingot at the heating temperature of 1100-1200°C, holding for 1-2 hours;
 - 3) Hot rolling:
the blank or ingot is hot rolled at an initial rolling temperature of 950~1100°C and has a cumulative deformation of $>50\%$, preferably $\geq 60\%$, after 3-5 passes of heavy reduction rolling at $\geq 950^\circ\text{C}$; the intermediate blank is then held till 920-950°C, then subjected to final 3-7 passes of rolling with cumulative deformation of $\geq 70\%$, preferably $\geq 85\%$; the final rolling temperature is 800-920 °C;
 - 4) Cooling:
first, air-cooling for 0-10s is carried out, and then the strip steel is water cooled to 400-550 °C at a cooling speed of $\geq 10^\circ\text{C/s}$, preferably $\geq 30^\circ\text{C/s}$, for coiling, and naturally cooled to room temperature after coiling;
 - 5) Pickling
the running speed of pickling of the strip steel is adjusted in the range of 30~100m/min, the pickling temperature is controlled at 75-85 °C, and the tensile levelling rate is controlled at $\leq 2\%$, and the strip steel is rinsed, and the strip steel surface is dried and oiled at the temperature of 120-140 °C.
15. The manufacture method of the 980MPa grade bainite high hole expansion steel according to claim 14, wherein after step 5) of pickling, the strip steel is rinsed at a temperature of 35-50 °C, and the strip steel surface is dried and oiled at 120-140 °C.

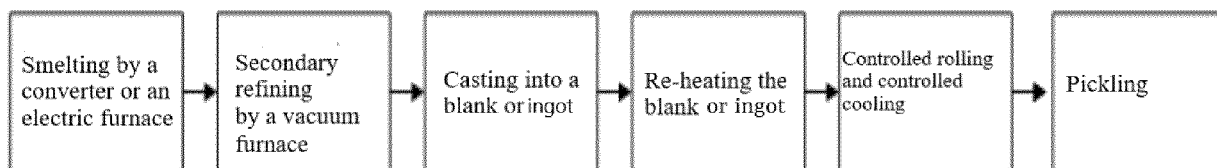


Fig. 1

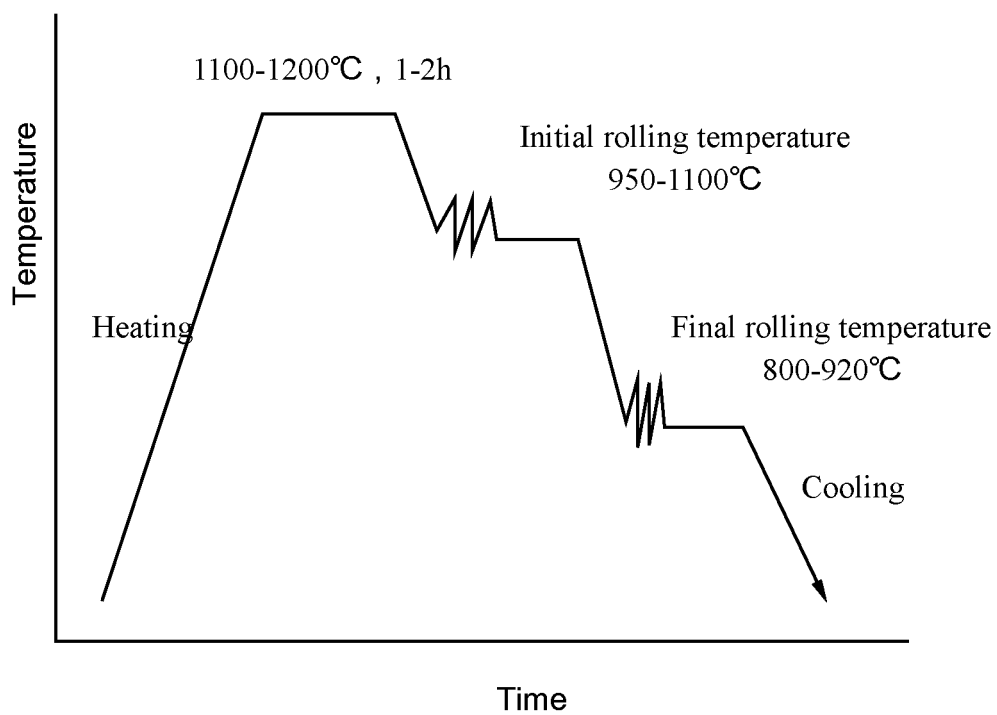


Fig. 2

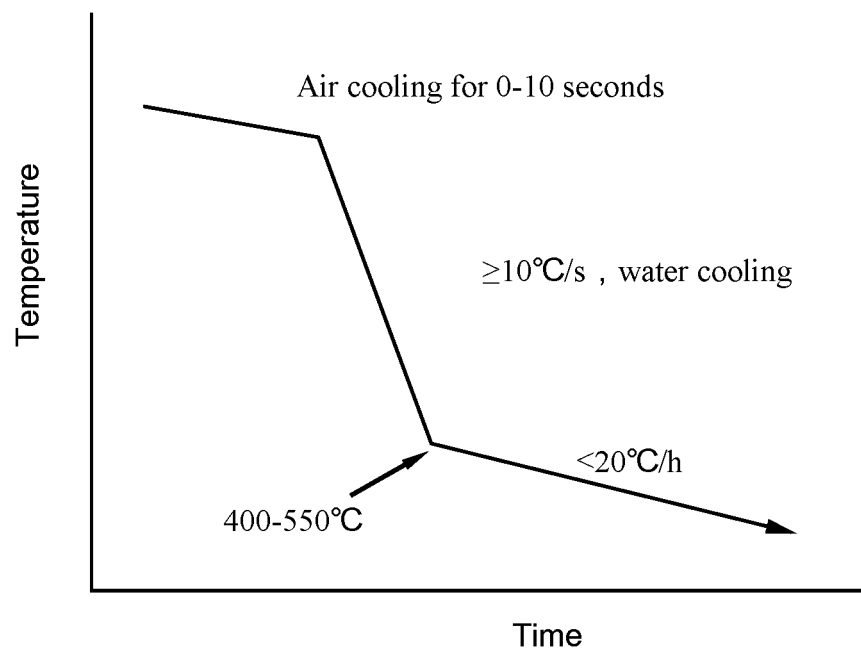


Fig. 3

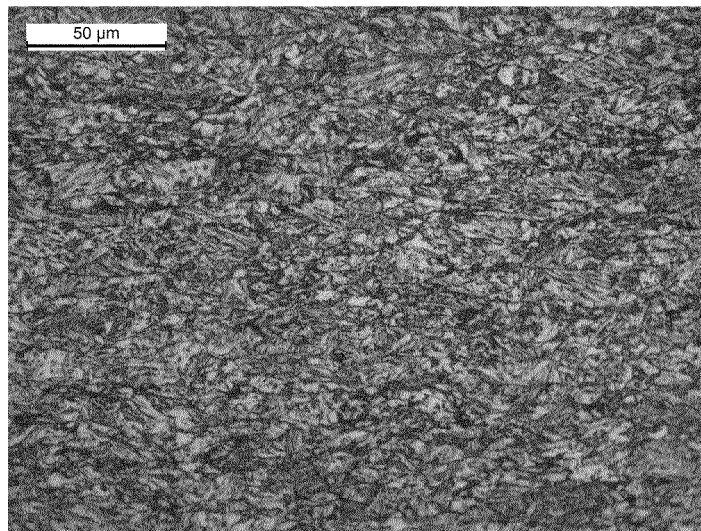


Fig. 4

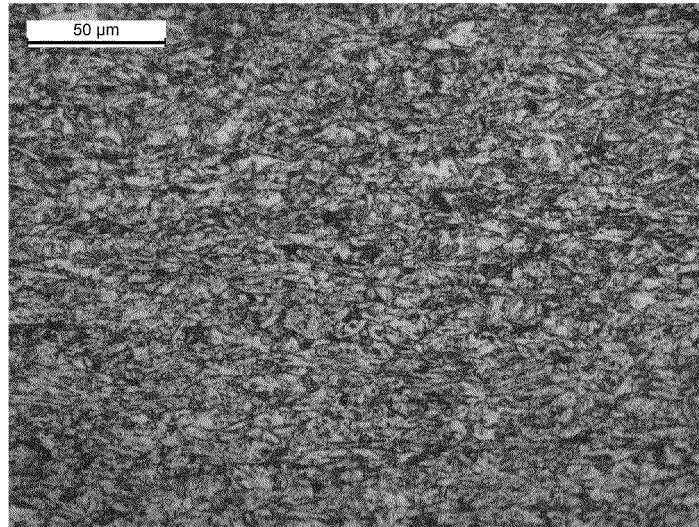


Fig. 5

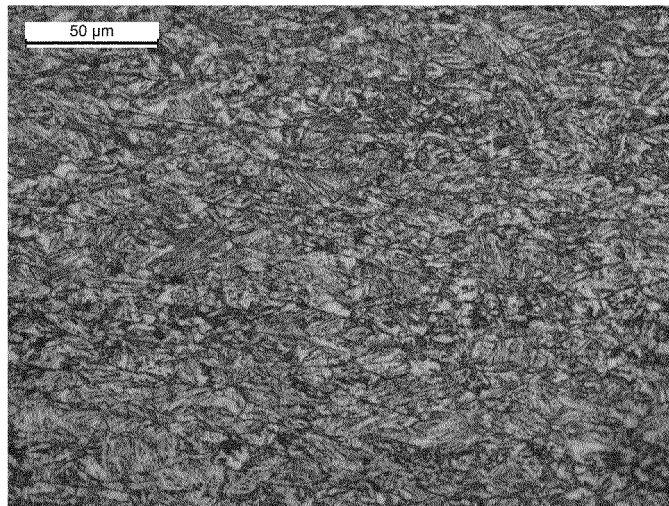


Fig. 6

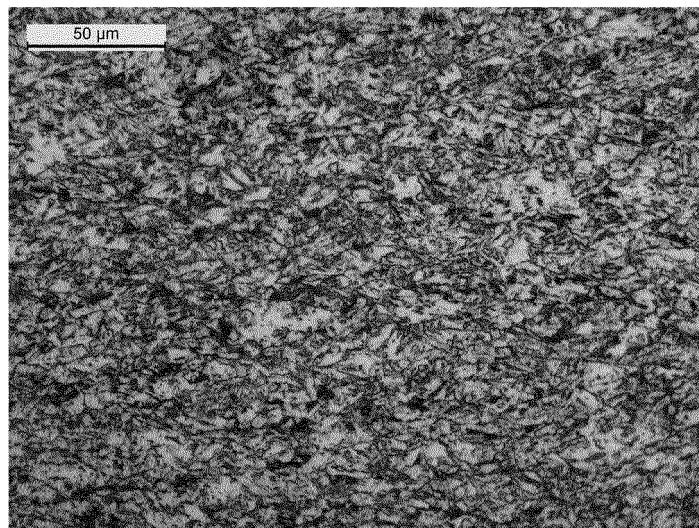


Fig. 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2021/115433

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/02(2006.01)i; C22C 38/04(2006.01)i; C22C 38/06(2006.01)i; C22C 38/20(2006.01)i; C22C 38/22(2006.01)i;
C22C 38/24(2006.01)i; C22C 38/26(2006.01)i; C22C 38/28(2006.01)i; C22C 38/32(2006.01)i; C22C 38/42(2006.01)i;
C22C 38/44(2006.01)i; C22C 38/46(2006.01)i; C22C 38/48(2006.01)i; C22C 38/50(2006.01)i; C22C 38/54(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)

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)

CNABS; CNTXT; CNKI; VEN; WOTXT; EPTXT; USTXT; ISI_WEB OF SCIENCE; 宝山钢铁股份有限公司, 980MPa, 抗拉
强度, 碳, 硅, 锰, 铝, 铜, 钛, 铬, 硼, 扩孔, 贝氏体, TS, tensile strength, C, Si, Mn, Al, Mo, Ti, Cr, B, carbon, silicon, manganese,
aluminium, molybdenum, titanium, chrome, chromium, boron, expansion rate, bainite

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Date of the actual completion of the international search

02 November 2021

Date of mailing of the international search report

18 November 2021

Name and mailing address of the ISA/CN

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Information on patent family members

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