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(71) Applicant: **BAOSHAN IRON & STEEL CO., LTD.**
Shanghai 201900 (CN)

(72) Inventors:

• **WANG, Huanrong**
Shanghai 201900 (CN)

• **YANG, Feng**
Shanghai 201900 (CN)
• **ZHANG, Chen**
Shanghai 201900 (CN)
• **YANG, Ana**
Shanghai 201900 (CN)
• **NI, Yaping**
Shanghai 201900 (CN)
• **WANG, Ming**
Shanghai 201900 (CN)
• **BAI, Mingzhuo**
Shanghai 201900 (CN)

(74) Representative: **Kuhnen & Wacker**
Patent- und Rechtsanwaltsbüro PartG mbB
Prinz-Ludwig-Straße 40A
85354 Freising (DE)

(54) **HIGH-STRENGTH LOW-CARBON MARTENSITIC HIGH HOLE EXPANSION STEEL AND MANUFACTURING METHOD THEREFOR**

(57) A low-carbon martensitic high hole expansion steel with a tensile strength above 980 MPa, and a manufacturing method therefor, the weight percentage of the chemical components thereof being: C 0.03-0.10%, 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 0.1-0.5%, Ti 0.01-0.05%, and O≤0.0030%, and the remainder being Fe and other inevitable impurities. The high hole expansion steel of

the present invention has a yield strength of ≥800 MPa and tensile strength of ≥980 MPa, a lateral extension rate A50≥8%, and a hole expansion ratio of ≥30%, passes cold bending performance tests (d<_4a, 180°), and can be used for passenger car chassis parts that require high strength and thinning such as control arms and sub-frames.

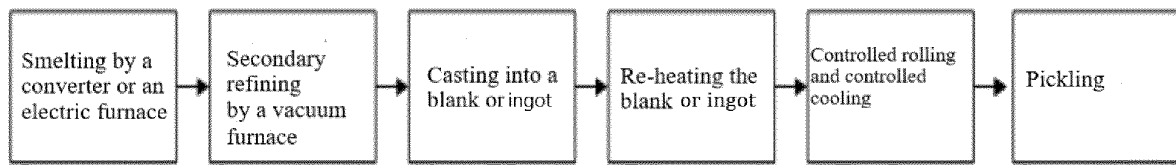


Fig. 1

Description**Technical Field**

5 **[0001]** The present disclosure relates to a high-strength steel, in particular to a high-strength low-carbon martensitic 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 high hole expansion steel having a strength of 980MPa or more is still in the stage of research and development assessment, and has not yet reached the stage of mass use. High strength high hole expansion steels having higher strength grades such as 1180MPa or more have not yet been developed. However, 980 MPa 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 high hole expansion steel having good hole expansion performance of the 980MPa grade or more.

30 **[0005]** There are very few literatures related to 980 MPa-grade high hole expansion steel and even no literature related to 1180 MPa-grade high hole expansion steel. At present, most of the relevant patent documents relate to 780MPa or less grade high hole expansion steel. There are very few documents involving high hole expansion steel of 980MPa grade or more. 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.

35 **[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.

40 **[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

55 **[0008]** An object of the present disclosure is to provide a low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more and a manufacturing method thereof. The high hole expansion steel has a yield strength of ≥ 800 MPa, a tensile strength of ≥ 980 MPa, and a transverse elongation A_{50} of $\geq 8\%$, and a hole expansion

ratio of $\geq 30\%$, preferably $\geq 50\%$. 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. In some embodiments, the high hole expansion steel has a yield strength of ≥ 900 MPa, a tensile strength of ≥ 1180 MPa, and a transverse elongation A_{50} of $\geq 10\%$, and a hole expansion ratio of $\geq 30\%$. In some embodiments, the high hole expansion steel according to the

[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. 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 refining the austenitic grain and the size of final martensitic grain, and improving plasticity and hole expansion ratio.

[0010] Specifically, the low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to the present disclosure has a chemical composition based on mass percentage of: C 0.03~0.10%, 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 0.1~0.5%, Ti 0.01~0.05%, O $\leq$ 0.0030%, and a balance of Fe and other unavoidable impurities.

[0011] Further, it further comprises one or more elements of Cr $\leq$ 0.5%, B $\leq$ 0.002%, Ca $\leq$ 0.005%, Nb $\leq$ 0.06%, V $\leq$ 0.05%, Cu $\leq$ 0.5%, Ni $\leq$ 0.5%.

[0012] In some embodiments, the low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to the present disclosure has a chemical composition based on weight percentage of: C 0.03~0.10%, 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 0.1~0.5%, Ti 0.01~0.05%, O $\leq$ 0.0030%, Cr $\leq$ 0.5%, B $\leq$ 0.002%, Ca $\leq$ 0.005%, Nb $\leq$ 0.06%, V $\leq$ 0.05%, Cu $\leq$ 0.5%, Ni $\leq$ 0.5% and a balance of Fe and other unavoidable impurities. Preferably, the low carbon martensitic high hole expansion steel comprises at least one of Cr, B, Ca, Nb, V, Cu and Ni. In some preferred embodiments, the low carbon martensitic high hole expansion steel at least comprises Ni. Preferably, the content of Ni is 0.1~0.5%, more preferably 0.1-0.3%. In some preferred embodiments, the low carbon martensitic high hole expansion steel at least comprises Cr and/or B. Preferably, the content of Cr is 0.1-0.5%, preferably 0.2-0.4%. Preferably, the content of B is 0.0005-0.002%.

[0013] In some preferred embodiments, the content of Cr is preferably 0.2-0.4%; the content of B is preferably 0.0005-0.0015%; the content of Ca is preferably $\leq$ 0.002%; the content of Nb, V is preferably $\leq$ 0.03%, respectively; and the content of Cu, Ni is preferably $\leq$ 0.03%, respectively.

[0014] Further, the low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to the present disclosure has a microstructure of martensite. In some embodiments, the microstructure is martensite or tempered martensite. Preferably, the content of residual austenite in the microstructure of the low carbon martensitic high hole expansion steel is $\leq 5\%$ by volume. In some embodiments, the content of austenite is 0.5-5%.

[0015] Further, the low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to the present disclosure has a yield strength of ≥ 800 MPa, preferably ≥ 900 MPa, a tensile strength of ≥ 980 MPa, preferably ≥ 1180 MPa, a transverse elongation A_{50} of $\geq 8\%$, preferably $\geq 10\%$, and a hole expansion ratio of $\geq 30\%$, preferably $\geq 50\%$.

[0016] Preferably, the low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to the present disclosure has an impact toughness at -40°C of $\geq 60\text{J}$, preferably $\geq 70\text{J}$. In some embodiments, the low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to the present disclosure has an impact toughness at -40°C of $\geq 140\text{J}$, preferably $\geq 150\text{J}$, more preferably $\geq 160\text{J}$.

[0017] Preferably, the low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to the present disclosure has passed cold bending test ($d \leq 4a$, 180°).

[0018] In some embodiments, the ultra-low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more provided in the present disclosure has a chemical composition based on weight percentage of: C 0.03~0.06%, 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 0.1~0.5%, Ti 0.01~0.05%, O $\leq$ 0.0030% and a balance of Fe and other unavoidable impurities.

[0019] Further, the ultra-low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more further comprises one or more elements of Cr $\leq$ 0.5%, B $\leq$ 0.002%, Ca $\leq$ 0.005%, Nb $\leq$ 0.06%, V $\leq$ 0.05%, Cu $\leq$ 0.5%, Ni $\leq$ 0.5%.

[0020] In some embodiments, the ultra-low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more has a chemical composition based on weight percentage of: C 0.03~0.06%, 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 0.1~0.5%, Ti 0.01~0.05%, O $\leq$ 0.0030%, Cr $\leq$ 0.5%, B $\leq$ 0.002%, Ca $\leq$ 0.005%, Nb $\leq$ 0.06%, V $\leq$ 0.05%, Cu $\leq$ 0.5%, Ni $\leq$ 0.5% and a balance of Fe and other unavoidable impurities. Preferably, the ultra-low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more at least comprises Cr and/or B; preferably, the content of Cr is 0.1~0.5%, preferably 0.2-0.4%. Preferably, the content of B is 0.0005-0.002%.

[0021] In some embodiments, the content of Cr is preferably 0.2-0.4%; the content of B is 0.0005-0.0015%; the content

of Ca is preferably $\leq 0.002\%$; the content of Nb, V is preferably $\leq 0.03\%$, respectively; and the content of Cu, Ni is preferably $\leq 0.03\%$, respectively.

[0022] In a preferred embodiment, the ultra-low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to the present disclosure has a microstructure of martensite or tempered martensite. In some embodiments, the structure of ultra-low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more further comprises a small amount of residual austenite. Preferably, the content of residual austenite in the microstructure of the ultra-low carbon martensitic high hole expansion steel is $\leq 5\%$ by volume. In some embodiments, the content of austenite is 0.5-5%.

[0023] In a preferred embodiment, the ultra-low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to the present disclosure has a yield strength of ≥ 800 MPa, preferably ≥ 820 MPa, a tensile strength of ≥ 980 MPa, preferably ≥ 1000 MPa, a transverse elongation A_{50} of $\geq 8\%$, preferably $\geq 10\%$, and a hole expansion ratio of $\geq 50\%$, preferably $\geq 55\%$ and has passed cold bending test ($d \leq 4a$, 180°). In a preferred embodiment, the ultra-low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to the present disclosure has an impact toughness at -40°C of $\geq 140\text{J}$, preferably $\geq 150\text{J}$, more preferably $\geq 160\text{J}$. In a preferred embodiment, the ultra-low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to the present disclosure has a yield strength of $800 \sim 890$ MPa, a tensile strength of $980 \sim 1150$ MPa, a transverse elongation A_{50} of $8 \sim 13\%$, a hole expansion ratio of $50 \sim 85\%$, and an impact toughness at -40°C of $140 \sim 185\text{J}$ and has passed cold bending test ($d < 4a$, 180°). Preferably, the ultra-low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more has a microstructure of martensite + residual austenite, wherein the volume percentage of the residual austenite in the microstructure is $\leq 5\%$ as aforementioned.

[0024] In some embodiments, the low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to the present disclosure is a high plasticity high hole expansion steel having a tensile strength of 1180MPa or more, which has a chemical composition based on weight percentage of: C 0.06~0.10%, Si 0.8~2.0%, Mn 1.5~2.0%, P $\leq 0.02\%$, S $\leq 0.003\%$, Al 0.02~0.08%, N $\leq 0.004\%$, Mo 0.1~0.5%, Ti 0.01~0.05%, O $\leq 0.0030\%$ and a balance of Fe and other unavoidable impurities.

[0025] Further, the high plasticity high hole expansion steel having a tensile strength of 1180MPa or more further comprises one or more elements of Cr $\leq 0.5\%$, B $\leq 0.002\%$, Ca $\leq 0.005\%$, Nb $\leq 0.06\%$, V $\leq 0.05\%$, Cu $\leq 0.5\%$, Ni $\leq 0.5\%$.

[0026] In some embodiments, the high plasticity high hole expansion steel having a tensile strength of 1180MPa or more has a chemical composition based on weight percentage of: C 0.06~0.10%, Si 0.8~2.0%, Mn 1.5~2.0%, P $\leq 0.02\%$, S $\leq 0.003\%$, Al 0.02~0.08%, N $\leq 0.004\%$, Mo 0.1~0.5%, Ti 0.01~0.05%, O $\leq 0.0030\%$, Cr $\leq 0.5\%$, B $\leq 0.002\%$, Ca $\leq 0.005\%$, Nb $\leq 0.06\%$, V $\leq 0.05\%$, Cu $\leq 0.5\%$, Ni $\leq 0.5\%$ and a balance of Fe and other unavoidable impurities. Preferably, in some embodiments, the high plasticity high hole expansion steel having a tensile strength of 1180MPa or more at least comprises Ni. Preferably, the content of Ni is 0.1-0.3%. Preferably, the high plasticity high hole expansion steel having a tensile strength of 1180MPa or more at least comprises Cr and/or B. Preferably, the content of Cr is 0.1~0.5%, preferably 0.2-0.4%. Preferably, the content of B is 0.0005-0.002%.

[0027] In some embodiments, the content of Cr is preferably 0.2-0.4%; the content of Cu, Ni is preferably $\leq 0.3\%$, respectively; the content of Nb, V is preferably $\leq 0.03\%$, respectively; the content of B is preferably 0.0005-0.0015%; and the content of Ca is preferably $\leq 0.002\%$.

[0028] In a preferred embodiment, the high plasticity high hole expansion steel having a tensile strength of 1180MPa or more has a microstructure of tempered martensite. In some embodiments, the microstructure of the high plasticity high hole expansion steel having a tensile strength of 1180MPa or more further comprises a small amount of residual austenite. Preferably, the content of residual austenite in the microstructure is $\leq 5\%$ by volume. In some embodiments, the content of austenite is 2~5%.

[0029] In a preferred embodiment, the high plasticity high hole expansion steel having a tensile strength of 1180MPa or more has a yield strength of ≥ 900 MPa, preferably ≥ 930 MPa, more preferably ≥ 950 MPa, a tensile strength of ≥ 1180 MPa, preferably ≥ 1200 MPa, more preferably ≥ 1220 MPa, a transverse elongation A_{50} of $\geq 10\%$, and a hole expansion ratio of $\geq 30\%$, preferably $\geq 35\%$. In a preferred embodiment, the ultra-low carbon martensitic high hole expansion steel having a tensile strength of 980MPa or more has an impact toughness at -40°C of $\geq 60\text{J}$, preferably $\geq 70\text{J}$, more preferably $\geq 80\text{J}$. Preferably, the high plasticity high hole expansion steel having a tensile strength of 1180MPa or more has passed cold bending test ($d < 4a$, 180°).

[0030] In a preferred embodiment, the high plasticity high hole expansion steel having a tensile strength of 1180MPa or more has a yield strength of $900 \sim 1000$ MPa, a tensile strength of $1200 \sim 1280$ MPa, a transverse elongation A_{50} of $10 \sim 13\%$, a hole expansion ratio of $30 \sim 50\%$, and an impact toughness at -40°C of $60\text{J} \sim 100\text{J}$. Preferably, the high plasticity high hole expansion steel having a tensile strength of 1180MPa or more has a microstructure of tempered martensite and residual austenite, wherein the volume percentage of residual austenite in the microstructure is $\leq 5\%$ as aforementioned. Preferably, the high plasticity high hole expansion steel having a tensile strength of 1180MPa or more has passed cold bending test ($d < 4a$, 180°).

[0031] In other preferred embodiments, the high plasticity high hole expansion steel having a tensile strength of

1180MPa or more has a yield strength of 940~1000MPa, a tensile strength of 1210~1300MPa, a transverse elongation of 10~13%, a hole expansion ratio of 30~50%, and an impact toughness at -40°C of 80J-110J and has passed cold bending test ($d \leq 4a$, 180°). Preferably, the high plasticity high hole expansion steel having a tensile strength of 1180MPa or more has a microstructure of tempered martensite and residual austenite, wherein the volume percentage of residual austenite in the microstructure is $\leq 5\%$ as aforementioned.

[0032] 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 or ultra-low-carbon martensite, 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 0.03%. If the carbon content is below 0.03%, 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 low-carbon martensite formed will be too high, and the elongation and hole expansion ratio are relatively low. Therefore, the content of C should be controlled at 0.03-0.10%. In some embodiments, the content of C is preferably 0.04-0.055%. In further embodiments, the content of C is preferably 0.07-0.09%.

[0033] 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 low temperature range. In this way, in the actual rolling process, rolling can be performed in a relatively wide range of final rolling temperature, such as 800-900 °C, so that the anisotropy of the structure can be greatly improved and thus the anisotropy of the final martensite 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 martensite-dominated structures are obtained, a certain amount of residual austenite can be retained, which is conducive to improving elongation. It is well known that under the same strength level, the elongation of martensite is usually the lowest. In order to improve the elongation of martensite, one of the important means is to retain a certain amount of stable residual austenite. This effect of Si is usually manifested 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 0.8-1.4%. In some embodiments, the content of Si is controlled at 1.0-1.4%.

[0034] Manganese is the most basic element of steel, and at the same time one of the most important elements in the present disclosure. It is well known that Mn is an important element for expanding the austenite phase region, which can reduce the critical quenching rate of steel, stabilize austenite, refine grains, and delay the transition of austenite to pearlite. In the present disclosure, to ensure the strength of the steel plate and stabilize the residual austenite at the same time, the content of Mn 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%. In some embodiments, the content of Mn is controlled at 1.6-1.9%.

[0035] 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_2P 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.

[0036] 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.

[0037] 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, Nb and V, 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%.

[0038] Nitrogen belongs to an 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.

[0039] 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%.

[0040] 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. 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, a process of air cooling first followed by water cooling or direct water cooling after rolling is adopted. The addition of molybdenum can ensure that ferrite or pearlite and other structures will not be formed in the air-cooling process; at the same time, the dynamic recovery of austenite deformed may occur during the air-cooling process, which is conducive to improving the structure uniformity. Molybdenum is highly resistant to welding softening. Since the main purpose of the present disclosure is to obtain a single structure of low-carbon martensite with a small amount of residual austenite, and low-carbon martensite tends to soften after welding, the addition of a certain amount of molybdenum can effectively reduce the degree of welding softening. Therefore, the content of Mo should be controlled at 0.1-0.5%, preferably 0.15-0.35%.

[0041] Chromium is one of the optional elements in the present disclosure. The addition of a small amount of Cr 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, the added amount of Cr in the steel is generally $\leq 0.5\%$, preferably 0.2-0.4%.

[0042] Boron is one of the optional elements in the present disclosure. 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 low-temperature toughness. The added amount of B element in steel is generally controlled at 0.002% or less, preferably 0.0005-0.0015%.

[0043] 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 $\leq 0.002\%$.

[0044] 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.

[0045] 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 $\leq 0.03\%$.

[0046] Vanadium is an optional 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 when the phase transition starts as the temperature decreases. In the present disclosure, the main purpose of adding vanadium together with molybdenum is to improve softening resistance of the welding heat-affected zone. Molybdenum and vanadium have the strongest anti-welding softening effect. If molybdenum is present, vanadium can be optionally added. Therefore, the amount of vanadium added to the steel is generally $\leq 0.05\%$, preferably $\leq 0.03\%$.

[0047] 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.

[0048] 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. Therefore, in order to minimize the cost of alloy, the added amount of nickel is typically $\leq 0.5\%$, preferably $\leq 0.3\%$.

[0049] The manufacturing method of the low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to the present disclosure comprises the following steps:

1) Smelting and casting:

wherein the above components are subjected to smelting by a converter or an electric furnace, secondary refining by a vacuum furnace, and then casting to form a blank or ingot;

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

3) Hot rolling:

wherein the blank or ingot is hot rolled at an initial rolling temperature of 950~1100°C; wherein 3-5 passes of heavy reduction rolling at $\geq 950^\circ\text{C}$ is performed and the cumulative deformation is $\geq 50\%$, with a main purpose of refining austenite grains; optionally, the intermediate blanket is held till 900-950°C, then subjected to final 3-7 passes of rolling with a cumulative deformation of $\geq 70\%$; wherein a final rolling temperature is 800-950 °C;

4) Cooling:

first, air-cooling for 0-10s is carried out for dynamic recovery and dynamic recrystallization, and then the strip steel is water cooled at a cooling rate of $\geq 30^\circ\text{C/s}$ to a certain temperature of M_s or lower (between room temperature and M_s point), then coiled and cooled (preferably at a cooling rate of $\leq 20^\circ\text{C/h}$) to room temperature after coiling, or the strip steel is air cooled for 0-10s, followed by direct water cooled at a cooling rate of $\geq 30^\circ\text{C/s}$ to room temperature for coiling, or the strip steel is air cooled for 0-10s, followed by water cooled at a cooling rate of $\geq 30^\circ\text{C/s}$ to a martensite phase transition start temperature M_s or a lower temperature, then coiled and slowly cooled (preferably at a cooling rate of $\leq 20^\circ\text{C/h}$) to room temperature after coiling;

5) Pickling

wherein a moving speed of the strip steel is adjusted within a range of 30-100 m/min during pickling; a pickling temperature is controlled at 75-85°C, and a tension leveling rate is controlled at $\leq 2\%$ to reduce elongation loss of the strip steel; wherein the strip steel is then subjected to rinsing, surface drying, and oiling.

[0050] 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 at 120-140 °C and oiled.

[0051] In some embodiments, the method further comprises step 4-1) between step 4) and 5): annealing, wherein bell type annealing is carried out at a heating rate of $\geq 20^\circ\text{C/h}$, wherein a bell type annealing temperature is 100-300 °C and a bell type annealing time is 12-48h; wherein the steel plate is cooled to $\leq 100^\circ\text{C}$ at a cooling rate of $\leq 50^\circ\text{C/h}$ and leaves the furnace.

[0052] In some embodiments, the manufacturing method of the low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to the present disclosure comprises the following steps:

1) Smelting and casting:

wherein the above components are subjected to smelting by a converter or an electric furnace, secondary refining by a vacuum furnace, and then casting to form a blank or ingot;

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

3) Hot rolling:

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

4) Cooling:

wherein air cooling is performed for 0-10 s first for dynamic recovery and dynamic recrystallization, and then the strip steel is water cooled at a cooling rate of $\geq 50^{\circ}\text{C/s}$, preferably 50-85°C/s to Ms point or a lower temperature (between room temperature and Ms point), and then coiled and cooled (preferably at a cooling rate $\leq 20^{\circ}\text{C/h}$) to room temperature after coiling;

5) Pickling

wherein a moving speed of the strip steel is adjusted within a range of 30-100 m/min during pickling; a pickling temperature is controlled at 75-85°C, and a tension leveling rate is controlled at $\leq 2\%$ to reduce elongation loss of the strip steel; wherein the strip steel is then subjected to rinsing, surface drying, and oiling.

[0053] In some embodiments, the manufacturing method of the high plasticity high hole expansion steel having a tensile strength of 1180MPa or more according to the present disclosure comprises the following steps:

1) Smelting and casting:

wherein the above components are subjected to smelting by a converter or an electric furnace, secondary refining by a vacuum furnace, and then casting to form a blank or ingot;

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

3) Hot rolling:

wherein the blank or ingot is hot rolled at an initial rolling temperature of 950~1100°C; wherein 3-5 passes of heavy reduction rolling at $\geq 950^{\circ}\text{C}$ is performed and the cumulative deformation is $\geq 50\%$, preferably $\geq 60\%$; then subjected to 3-7 passes of rolling with a cumulative deformation of $\geq 70\%$, preferably $\geq 85\%$; wherein a final rolling temperature is 800-950 °C;

4) Cooling:

wherein air cooling is performed for 0-10 s first, and then the strip steel is water cooled at a cooling rate of $\geq 30^{\circ}\text{C/s}$, preferably 30-65°C/s to room temperature and then coiled;

5) Annealing

wherein bell type annealing is carried out at a heating rate of $\geq 20^{\circ}\text{C/h}$, preferably 20-40°C/h, wherein a bell type annealing temperature is 100-300 °C and a bell type annealing time is 12-48h; wherein the steel plate is cooled to $\leq 100^{\circ}\text{C}$ at a cooling rate of $\leq 50^{\circ}\text{C/h}$, preferably 15-50 °C/h and leaves the furnace;

6) Pickling

wherein a moving speed of the strip steel is adjusted within a range of 30-90 m/min during pickling; a pickling temperature is controlled at 75-85°C, and a tension leveling rate is controlled at $\leq 1.5\%$; wherein the strip steel is then subjected to rinsing at a temperature of 35-50°C, surface drying at a temperature of 120-140°C, and oiling.

[0054] Preferably, after step 6) of pickling, the strip steel is subjected to rinsing at a temperature of 35-50°C, surface drying at a temperature of 120-140°C, and oiling.

[0055] In some other embodiments, the manufacturing method of the high plasticity high hole expansion steel having a tensile strength of 1180MPa or more according to the present disclosure comprises the following steps:

1) Smelting and casting:

wherein the above components are subjected to smelting by a converter or an electric furnace, secondary refining by a vacuum furnace, and then casting to form a blank or ingot;

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

3) Hot rolling:

wherein the blank or ingot is hot rolled at an initial rolling temperature of 950~1100°C; wherein 3-5 passes of heavy reduction rolling at $\geq 950^{\circ}\text{C}$ is performed and the cumulative deformation is $\geq 50\%$, preferably $\geq 60\%$; then the intermediate blank is held till 900-950°C, then subjected to 3-7 passes of rolling with a cumulative deformation of $\geq 70\%$, preferably $\geq 85\%$; wherein a final rolling temperature is 800-900 °C;

4) Cooling:

wherein air cooling is performed for 0-10 s first, and then the strip steel is water cooled at a cooling rate of $\geq 30^{\circ}\text{C/s}$, preferably 30-70°C/s to martensite phase transition start temperature Ms or a lower temperature, then coiled and cooled slowly (preferably at a cooling rate of $\leq 20^{\circ}\text{C/h}$) to room temperature;

5) Annealing

wherein bell type annealing is carried out at a heating rate of $\geq 20^{\circ}\text{C/h}$, preferably $20\text{--}50^{\circ}\text{C/s}$, wherein a bell type annealing temperature is $100\text{--}300^{\circ}\text{C}$ and a bell type annealing time is $12\text{--}48\text{h}$; wherein the steel plate is cooled to $\leq 100^{\circ}\text{C}$ at a cooling rate of $\leq 50^{\circ}\text{C/h}$, preferably $20\text{--}50^{\circ}\text{C/h}$ and leaves the furnace;

6) Pickling

wherein a moving speed of the strip steel is adjusted within a range of $30\text{--}90\text{ m/min}$ during pickling; a pickling temperature is controlled at $75\text{--}85^{\circ}\text{C}$, and a tension leveling rate is controlled at $\leq 1.5\%$ to reduce elongation loss of the strip steel; wherein the strip steel is then subjected to rinsing, surface drying, and oiling.

[0056] Preferably, after step 6) of pickling, the strip steel is subjected to rinsing at a temperature of $35\text{--}50^{\circ}\text{C}$, surface drying at a temperature of $120\text{--}140^{\circ}\text{C}$, and oiling.

The innovation of the present disclosure lies in:

[0057] 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. In the case of the tensile strength of $\geq 1180\text{MPa}$, on the basis that the tensile strength of $\geq 1180\text{MPa}$ 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 refining the austenite grain and the size of final martensitic grain, and improving plasticity and hole expansion ratio. In addition, in the process of bell type annealing, part of quenching stress is eliminated, so that it can improve the structure uniformity, increase the plasticity and the hole expansion ratio.

[0058] In the composition design, the design idea of low-carbon martensite is adopted, and higher silicon is added to inhibit and reduce the formation of cementite. At the same time, the subcrystallization temperature is reduced. Rolling and air cooling after rolling in a relatively wide final rolling temperature range allows for formation of original austenite grains with fine and uniform equiaxed structure, so that a uniform structure of martensite and residual austenite is finally obtained. The residual austenite endows the steel plate with high plasticity and cold bending performance, and martensite endows the steel plate with high strength, and the uniform and fine structure endows the steel plate higher hole expansion performance and low temperature impact toughness.

[0059] In terms of the design of the rolling process, at the rough rolling stage and the finishing rolling stage, the rolling procedure shall be completed as quickly as possible. After the final rolling is completed, air cooling is carried out for a certain period of time first. The main purpose of air cooling is explained as follows: the designed composition comprises relatively high contents of manganese and molybdenum. Manganese is an element that stabilizes austenite, while molybdenum significantly delays phase transformation of ferrite and pearlite. Therefore, during the air cooling for a certain period of time, the deformed austenite in the rolled steel will not undergo phase transformation. That is, no ferrite structure will be formed. Instead, dynamic recrystallization and relaxation will occur. The dynamic recrystallization of the deformed austenite allows for formation of quasi-equiaxed austenite having a uniform structure, and the dislocations in the relaxed austenite grains will be reduced notably. The combination of these two aspects enables obtainment of martensite having a uniform structure in the subsequent water hardening process. In order to obtain the martensite structure, the water-cooling rate should be greater than the critical cooling rate of low-carbon martensite. In the present disclosure, in order to ensure that all compositions in conformity with the design can provide martensite, the rate for water cooling the strip steel is required to be $\geq 30^{\circ}\text{C/s}$.

[0060] Since the microstructure involved in the present disclosure is low-carbon or ultra-low-carbon martensite, after the final rolling is completed, the steel strip only needs to be cooled to the martensite phase transition start temperature M_s or a lower temperature at a cooling rate greater than the critical cooling rate. The content of residual austenite at room temperature varies as a function of the cooling stop temperature. Generally, there is an optimal range of quenching stop temperature, which varies as a function of the alloy composition, generally in the range of $150\text{--}350^{\circ}\text{C}$. In order to obtain a high-strength steel having both good plasticity and hole expansion ratio, it is necessary to quench the strip steel to a temperature that is not higher than the M_s point. According to theoretical calculations and as verified by practical tests, when the strip steel is quenched to a temperature $\leq 400^{\circ}\text{C}$, a structure having excellent comprehensive performances can be obtained. If the quenching temperature is $\geq 400^{\circ}\text{C}$, although the amount of residual austenite is large, bainite will appear in the structure, so that the required strength of 980 MPa or higher cannot be achieved. For the above reasons, the coiling temperature needs to be controlled at $\leq 400^{\circ}\text{C}$. It is based on this innovative concept in the design of the composition and process that the 980 MPa -grade ultra-low-carbon martensite high hole expansion steel having excellent strength, plasticity, toughness, cold bending performance and hole expansion performance according to the present disclosure is obtained.

[0061] In some embodiments, the microstructure involved in the present disclosure is low-carbon tempered martensite.

Thus, after the final rolling is completed, the steel strip only needs to be cooled to room temperature at a cooling rate greater than the critical cooling rate. In the subsequent bell type annealing process, the bell type annealing temperature and time are controlled at a certain range, so that an ultra-high strength hole expansion steel having a balanced performance of strength, plasticity, hole expandability, and the like can be obtained.

[0062] During the bell type annealing process, the steel coil is heated at a heating rate of $\geq 20^{\circ}\text{C/s}$ to $100\text{--}300^{\circ}\text{C}$ first, held at this temperature range for a relatively long period of $12\text{--}48\text{h}$, so that the temperature across the whole steel coil is uniform, which is conducive to stabilization of the structure and performance. The lower the holding temperature, the longer the corresponding holding time; conversely, the higher the holding temperature, the shorter the corresponding holding time. Finally, the steel coil is cooled at a cooling rate of $\leq 50^{\circ}\text{C/s}$ to 100°C or lower and leaves the bell type annealing furnace for natural cooling.

[0063] Generally, the bell type annealing temperature is inversely proportional to the bell type annealing time. The lower the bell type annealing temperature, the longer the bell type annealing time; conversely, the higher the bell type annealing temperature, the shorter the bell type annealing time. If the bell type annealing temperature is lower than 100°C , the strength is relatively high and the hole expansion ratio is relatively low and cannot reach 30% or more; if the bell type annealing temperature is higher than 300°C , the strength cannot satisfy the requirement of $\geq 1180\text{MPa}$. Therefore, the bell type annealing temperature is selected to be $100\text{--}300^{\circ}\text{C}$. Since the design concept of high silicon composition is adopted, during the low temperature bell type annealing process, silicon can effectively inhibit formation of cementite in the steel and promote dispersion of carbon atoms from martensite to residual austenite, further increasing stability of residual austenite. Thus, the strip steel has higher elongation and better formability than other high strength steels of the same strength grade.

[0064] The present disclosure has the following beneficial effects:

(1) A 980MPa grade high hole expansion steel having excellent strength, plasticity, toughness, cold bending and hole expansion performance can be obtained by adopting the design concept of a relatively economical composition and adopting innovative cooling process routes;

(2) Steel coil or steel plate has excellent matching of strength, plasticity and toughness and also has good cold bending performance and hole expandability/flanging ability. It has a yield strength of $\geq 800\text{MPa}$, a tensile strength of $\geq 980\text{MPa}$, and has good elongation (transverse $A_{50} \geq 8\%$) and hole expansion performance (hole expansion ratio $\geq 30\%$) and has passed cold bending test ($d \leq 4a$, 180°). 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

[0065]

Fig. 1 is a process flow diagram of the manufacturing method of 980MPa grade ultra-low-carbon martensitic 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 ultra-low-carbon martensitic 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 ultra-low-carbon martensitic high hole expansion steel described in the present disclosure.

Fig. 4 is a process flow diagram of the manufacturing method of the high plasticity high hole expansion steel of 1180MPa grade described in Preparation Example II and III of the present disclosure.

Fig. 5 is a schematic diagram of the rolling process in the manufacturing method of the high plasticity high hole expansion steel of 1180MPa grade described in Preparation Example II of the present disclosure.

Fig. 6 is a schematic diagram of the cooling process in the manufacturing method of the high plasticity high hole expansion steel of 1180MPa grade described in Preparation Example II of the present disclosure.

Fig. 7 is a schematic diagram of the bell type annealing process in the manufacturing method of the high plasticity high hole expansion steel of 1180MPa grade described in Preparation Example II and III of the present disclosure.

Fig. 8 is a typical metallographic photo of the high hole expansion steel of Example 10 according to the present disclosure.

Fig. 9 is a typical metallographic photo of the high hole expansion steel of Example 12 according to the present disclosure.

Fig. 10 is a typical metallographic photo of the high hole expansion steel of Example 14 according to the present disclosure.

Fig. 11 is a typical metallographic photo of the high hole expansion steel of Example 16 according to the present disclosure.

Fig. 12 is a schematic diagram of the rolling process in the manufacturing method of the high plasticity high hole expansion steel of 1180MPa grade described in Preparation Example III of the present disclosure.

Fig. 13 is a schematic diagram of the cooling process in the manufacturing method of the high plasticity high hole expansion steel of 1180MPa grade described in Preparation Example III of the present disclosure.

Detailed Description

[0066] In the following examples, the tensile performances (yield strength, tensile strength, elongation) were tested in accordance with International Standard ISO6892-2-2018; the hole expansion ratio was tested in accordance with International Standard ISO16630-2017; the impact toughness at -40°C was tested in accordance with International Standard ISO14556-2015; and the bending performance was tested in accordance with International Standard ISO7438-2005.

Preparation Example I

[0067] Referring to Fig. 1-Fig. 3, the method for manufacturing the 980 MPa-grade ultra-low-carbon martensitic high hole expansion steel according to the present disclosure comprises the following steps:

1) Smelting and casting:

wherein the above components are subjected to smelting by a converter or an electric furnace, secondary refining by a vacuum furnace, and then casting to form a blank or ingot;

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

3) Hot rolling:

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

4) Cooling:

wherein air cooling is performed for 0-10 s first for dynamic recovery and dynamic recrystallization, and then the strip steel is water cooled at a cooling rate of $\geq 50^{\circ}\text{C/s}$ to Ms point or a lower temperature (between room temperature and Ms point), and then coiled and cooled (preferably at a cooling rate $\leq 20^{\circ}\text{C/h}$) to room temperature;

5) Pickling

wherein a moving speed of the strip steel is adjusted within a range of 30-100 m/min during pickling; a pickling temperature is controlled at 75-85°C, and a tension leveling rate is controlled at $\leq 2\%$; wherein the strip steel is then subjected to rinsing at a temperature of 35-50°C, surface drying at a temperature of 120-140°C, and oiling.

[0068] In the Preparation Example, the compositions of the Examples of the high hole expansion steel according to the present disclosure are shown in Table 1. The production process parameters for the Examples of the steel according to the present disclosure are listed in Table 2 and Table 3, wherein the thickness of the steel blank in the rolling process is 120 mm. The mechanical performances of the Examples of the steel plates according to the present disclosure are listed in Table 4.

[0069] It can be seen from Table 4, the yield strength of the steel coil is ≥ 800 MPa, while the tensile strength is ≥ 980 MPa, and the elongation is usually in the range of 8-13%. The impact energy is relatively stable. The low-temperature impact energy at -40°C is stabilized in the range of 140-180 J. The content of residual austenite varies as a function of the coiling temperature, generally by 1.5-5%. The hole expansion ratio satisfies $\geq 50\%$.

[0070] It can be seen from the above Examples, the 980 MPa high-strength steel according to the present disclosure exhibits good matching of strength, plasticity, toughness and hole expandability. It is especially suitable for parts that require high strength, reduced thickness, hole expansion and flanging forming, such as a control arm in an automobile chassis structure. It can also be used for parts such as wheels that need hole flanging. Therefore, it has broad application prospects.

Table 1 (unit: weight%)

Ex.	C	Si	Mn	P	S	Al	N	Mo	Ti	Cr	B	Ca	Nb	V	Cu	Ni	O
1	0.060	1.98	1.76	0.0011	0.0028	0.066	0.0030	0.10	0.030	0.11	0.0011	/	0.035	/	/	/	0.0027
2	0.032	1.77	1.40	0.0013	0.0029	0.047	0.0027	0.17	0.025	0.35	/	0.0025	/	0.050	/	/	0.0020
3	0.048	0.84	1.68	0.0016	0.0030	0.023	0.0028	0.49	0.042	0.50	0.0005	/	0.058	/	/	0.30	0.0025
4	0.055	1.26	1.90	0.0014	0.0024	0.039	0.0029	0.29	0.014	0.28	0.0012	0.0030	/	/	0.50	/	0.0029
5	0.042	1.18	1.88	0.0010	0.0028	0.065	0.0038	0.38	0.028	/	/	/	0.020	0.040	/	/	0.0024
6	0.057	0.89	1.07	0.0015	0.0022	0.054	0.0033	0.33	0.050	0.37	0.0013	0.0020	/	0.030	/	0.50	0.0028
7	0.053	0.53	1.96	0.0014	0.0027	0.080	0.0035	0.43	0.010	0.43	0.0020	/	/	/	0.15	0.25	0.0021
8	0.041	1.64	1.73	0.0012	0.0025	0.036	0.0022	0.18	0.020	/	0.0019	0.0050	/	0.015	0.30	0.10	0.0030

Table 2

	Heating temperature °C	Holding time h	Initial rolling temperature °C	Rough rolling cumulative deformation %	Intermediate blank temperature °C	Finish rolling cumulative deformation %	Final rolling temperature °C	Air cooling time s	Water cooling rate °C/s	Steel plate thickness mm	Coiling temperature °C
Ex. 1	1170	1.2	1040	70	950	89	880	5	60	6	390
Ex. 2	1160	1.4	1100	50	920	92	860	9	50	5	125
Ex. 3	1200	1.0	1030	65	930	90	920	4	55	3	280
Ex. 4	1130	1.8	950	55	925	94	820	7	70	4	250
Ex. 5	1150	1.5	1020	60	940	88	850	10	65	4	Rt
Ex. 6	1100	2.0	1000	75	935	93	800	6	80	2	180
Ex. 7	1140	1.6	980	80	930	90	890	0	75	3	230
Ex. 8	1180	1.1	1050	70	945	91	830	8	85	2	150

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Table 3

	Moving speed of strip steel during pickling m/min	Pickling temperature °C	Tension leveling rate %	Rinsing temperature °C	Drying temperature °C
Ex. 1	65	80	1.8	40	135
Ex. 2	30	83	1.1	35	120
Ex. 3	90	77	0.4	47	128
Ex. 4	45	81	1.3	42	140
Ex. 5	70	85	0.6	50	133
Ex. 6	100	75	2.0	37	125
Ex. 7	60	82	1.0	41	134
Ex. 8	85	78	1.6	38	130

Table 4: Mechanical performances of steel plates

	Yield strength MPa	Tensile strength MPa	Elongation %	Hole expansion ratio %	-40 °C impact energy J	Residual austenite content %
Ex. 1	809	1002	11.5	51.6	168	1.86
Ex. 2	821	1034	13.0	60.9	170	2.49
Ex. 3	806	1104	9.0	75.1	154	4.58
Ex. 4	850	1011	10.5	62.8	144	2.64
Ex. 5	819	1033	11.0	56.9	158	0.57
Ex. 6	820	1032	9.5	57.2	182	4.33
Ex. 7	883	1039	8.0	83.5	162	4.02
Ex. 8	866	1050	10.5	60.7	180	3.56

Note: The impact energy is obtained by converting the measured impact energy of a sample having an actual thickness into the impact energy of a standard sample of 10*10*55 mm in proportion based on equivalent effect.

Preparation Example II

[0071] Referring to Fig. 4-Fig. 7, the method for manufacturing the high plasticity high hole expansion steel of 1180MPa grade according to the present disclosure comprises the following steps:

1) Smelting and casting:

wherein the above components are subjected to smelting by a converter or an electric furnace, secondary refining by a vacuum furnace, and then casting to form a blank or ingot;

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

3) Hot rolling:

wherein an initial rolling temperature is 950~1100°C; wherein cumulative deformation after 3-5 passes of heavy reduction rolling at $\geq 950^{\circ}\text{C}$ is $\geq 50\%$; then final 3-5 passes of rolling is carried out and the cumulative deformation is $> 70\%$; wherein a final rolling temperature is 800-950 °C;

4) Cooling:

wherein air cooling is performed for 0-10 s first, and then the strip steel is water cooled at a cooling rate of $\geq 30^{\circ}\text{C/s}$ to room temperature and then coiled;

5) Annealing:

wherein bell type annealing is carried out at a heating rate of $\geq 20^{\circ}\text{C/h}$, wherein a bell type annealing temperature is 100-300 °C and a bell type annealing time is 12-48h; wherein the steel plate is cooled to $\leq 100^{\circ}\text{C}$ at a cooling rate of $\leq 50^{\circ}\text{C/h}$ and leaves the furnace.

6) Pickling:

wherein a moving speed of the strip steel is adjusted within a range of 30-90 m/min during pickling; a pickling temperature is controlled at 75-85°C, and a tension leveling rate is controlled at $\leq 1.5\%$; wherein the strip steel is then subjected to rinsing at a temperature of 35-50°C, surface drying at a temperature of 120-140°C, and oiling.

[0072] In the Preparation Example, the compositions of the Examples of the high hole expansion steel according to the present disclosure are shown in Table 5. The production process parameters for the Examples of the steel according to the present disclosure are listed in Table 6 and Table 7, wherein the thickness of the steel blank in the rolling process is 120 mm. The mechanical performances of the Examples of the steel plates according to the present disclosure are listed in Table 8.

[0073] It can be seen from Table 8, the yield strength of the steel coil is ≥ 900 MPa, while the tensile strength is ≥ 1180 MPa, and the elongation is usually in the range of 10-13%. The impact energy is relatively stable. The low-temperature impact energy at -40°C is stabilized in the range of 60-100 J. The content of residual austenite varies as a function of the coiling temperature. The hole expansion ratio satisfies $\geq 30\%$.

[0074] It can be seen from the above Examples, the high hole expansion steel of 1180MPa grade according to the present disclosure exhibits good matching of strength, plasticity, toughness and hole expandability. It is especially suitable for parts that require high strength, reduced thickness, hole expansion and flanging forming, such as a control arm in an automobile chassis structure. It can also be used for parts such as wheels that need hole flanging and has broad application prospects.

[0075] Fig. 8-Fig. 11 shows the typical metallographic structure of the steel plate of Example 10#, 12#, 14# and 16#, respectively. It can be seen from the metallographic photos that the structure is single-phase low-carbon martensite with a certain amount of residual austenite, which exhibits relatively higher elongation and hole expansion ratio at the same strength level.

Table 5 (unit: weight%)

Ex.	C	Si	Mn	P	S	Al	N	Mo	Ti	Cr	B	Ca	Nb	V	Cu	Ni	O
9	0.082	1.48	1.51	0.009	0.0023	0.065	0.0039	0.42	0.011	0.49	0.0010	/	/	/	/	/	0.0022
10	0.061	1.89	1.77	0.011	0.0018	0.034	0.0023	0.15	0.023	0.23	0.0009	/	0.015	/	/	/	0.0023
11	0.080	0.82	1.95	0.008	0.0009	0.078	0.0033	0.35	0.015	/	/	0.003	/	0.015	0.15	0.30	0.0020
12	0.068	1.74	1.55	0.009	0.0014	0.043	0.0025	0.17	0.036	/	/	/	0.020	/	/	0.20	0.0028
13	0.094	0.94	1.90	0.012	0.0015	0.052	0.0030	0.23	0.020	0.30	0.0015	0.002	0.060	/	0.30	0.50	0.0024
14	0.075	1.55	1.68	0.008	0.0010	0.022	0.0024	0.50	0.048	/	/	/	/	0.05	/	0.10	0.0026
15	0.083	1.02	1.83	0.013	0.0009	0.071	0.0028	0.28	0.018	/	0.0005	0.005	/	0.03	0.25	0.15	0.0025
16	0.100	1.13	1.59	0.010	0.0024	0.058	0.0038	0.18	0.014	/	/	0.001	0.030	/	0.50	0.25	0.0028

Table 6

	Heating Temperature °C	Holding time h	Initial rolling temperature °C	Rough rolling cumulative deformation %	Finish rolling cumulative deformation %	Final rolling temperature °C	Air cooling time s	Water cooling rate °C/s	Steel plate thickness mm
Ex. 9	1180	1.2	1050	70	89	950	3	55	4
Ex. 10	1160	1.4	1100	50	92	820	7	30	2
Ex. 11	1200	1.0	1050	65	90	900	2	50	6
Ex. 12	1140	1.7	1060	55	94	800	6	35	3
Ex. 13	1150	1.5	950	60	88	870	9	60	2
Ex. 14	1130	1.8	980	75	93	830	0	45	4
Ex. 15	1160	1.3	1000	80	90	880	5	40	5
Ex. 16	1100	2.0	1020	70	91	850	7	65	3

Table 7

	Heating rate °C/h	Bell type annealing temperature °C	Bell type annealing time h	Cooling rate °C/h	Temperature for leaving the furnace °C	Moving speed of strip steel during pickling m/min	Pickling temperature °C	Tension leveling rate %	Rinsing temperature °C	Drying temperature °C
Ex. 9	30	230	20	30	75	80	82	1.3	40	135
Ex. 10	23	200	24	40	80	45	76	0.8	35	120
Ex. 11	35	100	48	20	50	70	75	1.5	47	128
Ex. 12	20	280	12	45	55	35	80	0.5	42	140
Ex. 13	32	150	36	20	60	50	77	1.0	50	133
Ex. 14	27	300	28	50	100	30	79	0.3	37	125
Ex. 15	25	125	42	25	65	90	81	0.9	41	134
Ex. 16	40	180	30	15	95	60	83	1.2	38	130

Table 8: Mechanical performances of steel plates

	Yield strength MPa	Tensile strength MPa	Elongation %	Hole expansion ratio %	Residual austenite content %	-40 °C impact energy J
Ex. 9	905	1206	10.5	35	2.38	70
Ex. 10	953	1234	11.5	41	3.85	62
Ex. 11	932	1213	120	36	3.26	81
Ex. 12	941	1225	11.0	44	2.77	73
Ex. 13	990	1263	100	37	3.34	86
Ex. 14	963	1209	13.0	42	4.22	75
Ex. 15	975	1279	11.5	47	2.51	90
Ex. 16	966	1247	11.0	38	4.28	88
Note: The impact energy is obtained by converting the measured impact energy of a sample having an actual thickness into the impact energy of a standard sample of 10*10*55 mm in proportion based on equivalent effect.						

Preparation Example III

[0076] Referring to Fig. 4, 7, 12 and Fig. 13, the method for manufacturing the high plasticity high hole expansion steel of 1180MPa grade according to the present disclosure comprises the following steps:

1) Smelting and casting:

wherein the above components are subjected to smelting by a converter or an electric furnace, secondary refining by a vacuum furnace, and then casting to form a blank or ingot;

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

3) Hot rolling:

wherein an initial rolling temperature is 950~1100°C; wherein cumulative deformation after 3-5 passes of heavy reduction rolling at $\geq 950^{\circ}\text{C}$ is $\geq 50\%$; then the intermediate blank is held till 900-950°C, then subjected to final 3-7 passes of rolling with a cumulative deformation of $>70\%$; wherein a final rolling temperature is 800-900 °C;

4) Cooling:

wherein air cooling is performed for 0-10 s first, and then the strip steel is water cooled at a cooling rate of $\geq 30^{\circ}\text{C/s}$ to Ms or a lower temperature, coiled and cooled slowly (at a cooling rate of $\leq 20^{\circ}\text{C/h}$) to room temperature;

5) Annealing:

wherein bell type annealing is carried out at a heating rate of $\geq 20^{\circ}\text{C/h}$, wherein a bell type annealing temperature is 100-300 °C and a bell type annealing time is 12-48h; wherein the steel plate is cooled to $\leq 100^{\circ}\text{C}$ at a cooling rate of $\leq 50^{\circ}\text{C/h}$ and leaves the furnace.

6) Pickling:

wherein a moving speed of the strip steel is adjusted within a range of 30-90 m/min during pickling; a pickling temperature is controlled at 75-85°C, and a tension leveling rate is controlled at $\leq 1.5\%$; wherein the strip steel is then subjected to rinsing at a temperature of 35-50°C, surface drying at a temperature of 120-140°C, and oiling.

[0077] In the Preparation Example, the compositions of the Examples of the high hole expansion steel according to the present disclosure are shown in Table 9. The production process parameters for the Examples of the steel according to the present disclosure are listed in Table 10 and Table 11, wherein the thickness of the steel blank in the rolling process is 120 mm. The mechanical performances of the Examples of the steel plates according to the present disclosure

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are listed in Table 12.

[0078] It can be seen from Table 12, the yield strength of the steel coil is ≥ 900 MPa, while the tensile strength is ≥ 1180 MPa, and the elongation is usually in the range of 10-13%. The impact energy is relatively stable. The low-temperature impact energy at -40°C is stabilized in the range of 80-110 J. The content of residual austenite varies as a function of the coiling temperature. The hole expansion ratio satisfies $\geq 30\%$.

[0079] It can be seen from the above Examples, the high strength steel of 1180MPa grade according to the present disclosure exhibits good matching of strength, plasticity, toughness and hole expandability. It is especially suitable for parts that require high strength, reduced thickness, hole expansion and flanging forming, such as a control arm in an automobile chassis structure. It can also be used for parts such as wheels that need hole flanging and has broad application prospects.

Table 9 (unit: weight%)

Ex.	C	Si	Mn	P	S	Al	N	Mo	Ti	Cr	B	Ca	Nb	V	Cu	Ni	O
17	0.065	1.98	1.76	0.0011	0.0028	0.066	0.0030	0.10	0.029	0.33	0.0010	/	0.030	/	0.50	/	0.0028
18	0.097	1.77	1.50	0.0013	0.0019	0.047	0.0027	0.15	0.025	0.35	/	0.002	/	0.030	/	/	0.0024
19	0.088	0.83	1.68	0.0016	0.0005	0.023	0.0028	0.49	0.022	0.29	0.0012	/	0.060	/	/	0.15	0.0026
20	0.090	1.01	1.98	0.0014	0.0024	0.039	0.0029	0.29	0.014	0.40	0.0011	0.001	/	/	0.10	/	0.0027
21	0.062	1.18	1.88	0.0010	0.0008	0.065	0.0038	0.38	0.050	0.28	0.0013	/	0.015	0.025	/	/	0.0024
22	0.080	1.89	1.77	0.0015	0.0022	0.054	0.0033	0.35	0.015	0.50	0.0005	0.005	/	0.013	/	0.30	0.0029
23	0.093	1.40	1.96	0.0014	0.0010	0.080	0.0035	0.43	0.011	0.33	0.0017	0.003	0.045	/	0.20	0.50	0.0022
24	0.071	1.64	1.83	0.0012	0.0025	0.036	0.0022	0.18	0.020	/	0.0019	/	/	0.050	0.30	0.10	0.0020

Table 10

Ex.	Heating temperature °C	Holding time h	Initial rolling temperature °C	Rough rolling cumulative deformation %	Intermediate blank temperature °C	Finish rolling cumulative deformation %	Final rolling temperature °C	Air cooling time s	Water cooling rate °C/s	Steel plate thickness mm	Coiling temperature °C
17	1170	1.4	1040	70	950	89	880	3	50	6	Rt
18	1160	1.5	1100	50	900	92	800	8	60	5	225
19	1200	1.0	1070	65	930	90	840	4	35	3	200
20	1130	1.8	950	55	910	94	900	5	70	4	350
21	1150	1.6	1020	60	940	88	860	0	65	4	225
22	1100	2.0	1000	75	920	93	830	6	30	2	180
23	1140	1.7	980	80	930	90	870	0	55	3	330
24	1180	1.2	1050	70	925	91	820	6	65	2	250

Table 11

Ex.	Heating rate °C/h	Bell type annealing temperature °C	Bell type annealing time h	Cooling rate °C/h	Temperature for leaving the furnace °C	Moving speed of strip steel during pickling m/min	Pickling temperature °C	Tension leveling rate %	Rinsing temperature °C	Drying temperature °C
17	40	140	26	26	80	70	82	1.4	40	135
18	32	240	18	20	65	90	76	0.8	35	120
19	25	260	14	40	100	30	75	1.2	47	128
20	44	120	32	34	40	65	80	1.0	42	140
21	30	300	12	50	75	80	77	0.7	50	133
22	35	150	40	22	55	40	79	1.5	37	125
23	20	100	48	30	85	85	81	0.5	41	134
24	37	200	20	38	70	55	83	1.1	38	130

Table 12: Mechanical performances of steel plates

Ex.	Yield strength MPa	Tensile strength MPa	Elongation %	Hole expansion ratio %	-40 °C impact energy J	Residual austenite content %
17	968	1223	11.0	44.0	84	3.52
18	971	1276	12.0	36.0	96	4.26
19	983	1213	12.0	48.0	87	3.84
20	945	1283	12.5	42.0	110	4.88
21	994	1228	11.5	31.0	103	3.03
22	948	1282	12.0	39.0	85	3.95
23	953	1218	11.0	35.0	94	4.99
24	975	1279	11.5	46.0	99	3.87
Note: The impact energy is obtained by converting the measured impact energy of a sample having an actual thickness into the impact energy of a standard sample of 10*10*55 mm in proportion based on equivalent effect.						

Claims

1. A low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more, comprising a chemical composition based on weight percentage of: C 0.03~0.10%, 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 0.1~0.5%, Ti 0.01-0.05%, O ≤0.0030%, and a balance of Fe and other unavoidable impurities.
2. The low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to claim 1 comprising a chemical composition based on weight percentage of: C 0.03~0.06%, 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 0.1~0.5%, Ti 0.01~0.05%, O≤0.0030% and a balance of Fe and other unavoidable impurities.
3. The low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to claim 1 comprising a chemical composition based on weight percentage of: C 0.06~0.10%, Si 0.8~2.0%, Mn 1.5~2.0%, P≤0.02%, S≤0.003%, Al 0.02~0.08%, N≤0.004%, Mo 0.1~0.5%, Ti 0.01~0.05%, O≤0.0030% and a balance of Fe and other unavoidable impurities.
4. The low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to any one of claims 1-3, wherein the low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more further comprises one or more elements of Cr≤0.5%, B≤0.002%, Ca≤0.005%, Nb≤0.06%, V≤0.05%, Cu≤0.5%, and Ni≤0.5%; wherein the content of Cr is preferably 0.2~0.4%, the content of B is preferably 0.0005~0.0015%, the content of Ca is preferably ≤0.002%; the content of Nb, V is preferably ≤0.03%, respectively; and the content of Cu, Ni is preferably ≤0.3%, respectively.
5. The low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to claim 2 or 4, wherein the low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more has one or more of the following characteristics: the content of C is 0.04-0.055%, the content of Si is 0.8-1.4%, the content of Mn is 1.4-1.8%, the content of S is controlled at 0.0015% or lower, the content of Al is 0.02-0.05%, the content of N is controlled at 0.003% or lower, the content of Ti is 0.01-0.03% and the content of Mo is 0.15-0.35%.
6. The low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to claim 3 or 4, wherein the low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more has one or more of the following characteristics: the content of C is 0.07-0.09%, the content of Si is 1.0-1.4%, the content of Mn is 1.6-1.9%, the content of S is controlled at 0.0015% or lower, the content of Al is 0.02-0.05%, the content of N is controlled at 0.003% or lower, the content of Ti is 0.01-0.03% and the content of Mo is 0.15-0.35%.

7. The low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to any one of claims 1-6, wherein the high hole expansion steel has a microstructure of martensite or tempered martensite and residual austenite, wherein the content of residual austenite in the microstructure is $\leq 5\%$ by volume.
8. The low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to any one of claims 1-7, wherein the high hole expansion steel has a yield strength of ≥ 800 MPa, a tensile strength of ≥ 980 MPa, a transverse elongation A_{50} of $\geq 8\%$, a hole expansion ratio of $\geq 30\%$; preferably, the high hole expansion steel has an impact toughness at -40°C of ≥ 60 J.
9. The low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to claim 2 or 5, wherein the high hole expansion steel has a yield strength of ≥ 800 MPa, a tensile strength of ≥ 980 MPa, a transverse elongation A_{50} of $\geq 8\%$, a hole expansion ratio of $\geq 50\%$, and has passed cold bending test ($d < 4a$, 180°); preferably, the high hole expansion steel has an impact toughness at -40°C of ≥ 140 J.
10. The low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to claim 9, wherein the low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more has a yield strength of $800\sim 890$ MPa, a tensile strength of $980\sim 1150$ MPa, a transverse elongation A_{50} of $8\sim 13\%$, a hole expansion ratio of $50\sim 85\%$, an impact toughness at -40°C of $140\sim 185$ J, and has passed cold bending test ($d < 4a$, 180°); wherein the low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more has a microstructure of martensite + residual austenite, wherein the content of residual austenite in the microstructure is $\leq 5\%$ by volume.
11. The low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to claim 3 or 6, wherein the high hole expansion steel has a yield strength of ≥ 900 MPa, a tensile strength of ≥ 1180 MPa, a transverse elongation A_{50} of $\geq 10\%$, a hole expansion ratio of $\geq 30\%$; preferably, the high hole expansion steel has an impact toughness at -40°C of ≥ 60 J; preferably, the high hole expansion steel has passed cold bending test ($d < 4a$, 180°).
12. The low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to claim 11, wherein the high hole expansion steel has a yield strength of $900\sim 1000$ MPa, a tensile strength of $1200\sim 1280$ MPa, a transverse elongation of $10\sim 13\%$, a hole expansion ratio of $30\sim 50\%$, an impact toughness at -40°C of $60\sim 100$ J; preferably, the high hole expansion steel has a microstructure of tempered martensite + residual austenite, wherein the content of residual austenite in the microstructure is $\leq 5\%$ by volume as aforementioned; or the high hole expansion steel has a yield strength of $940\sim 1000$ MPa, a tensile strength of $1210\sim 1300$ MPa, a transverse elongation of $10\sim 13\%$, a hole expansion ratio of $30\sim 50\%$, an impact toughness at -40°C of $80\sim 110$ J and has passed cold bending test ($d < 4a$, 180°); preferably, the high hole expansion steel has a microstructure of tempered martensite + residual austenite, wherein the content of residual austenite in the microstructure is $\leq 5\%$ by volume as aforementioned.
13. A method for manufacturing the low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to any one of claims 1-12, comprising the following steps:
 - 1) Smelting and casting:
wherein the above components according to any one of claims 1-6 are subjected to smelting by a converter or an electric furnace, secondary refining by a vacuum furnace, and then casting to form a blank or ingot;
 - 2) Re-heating of the blank or ingot at a heating temperature of $1100\sim 1200^\circ\text{C}$, holding for 1-2 hours;
 - 3) Hot rolling:
wherein the blank or ingot is hot rolled at an initial rolling temperature of $950\sim 1100^\circ\text{C}$; wherein 3-5 passes of heavy reduction rolling at $\geq 950^\circ\text{C}$ is carried out and the cumulative deformation is $\geq 50\%$; then final 3-7 passes of rolling is carried out and the cumulative deformation is $> 70\%$; wherein a final rolling temperature is $800\sim 950^\circ\text{C}$; optionally, after 3-5 passes of heavy reduction rolling, an intermediate blank is held till $900\sim 950^\circ\text{C}$, and then subjected to final 3-7 passes of rolling;
 - 4) Cooling:
first, air-cooling for 0-10s is carried out, and then the strip steel is water cooled at a cooling rate of $\geq 50^\circ\text{C/s}$ to a certain temperature between room temperature and M_s point, then coiled and cooled to room temperature after coiling, or the strip steel is air cooled for 0-10s, followed by direct water cooled at a cooling rate of $\geq 30^\circ\text{C/s}$ to room temperature for coiling, or the strip steel is air cooled for 0-10s, followed by water cooled at a cooling rate of $\geq 30^\circ\text{C/s}$ to a martensite phase transition start temperature M_s or a lower temperature, then coiled and slowly cooled to room temperature after coiling;

5) Pickling

wherein a moving speed of the strip steel is adjusted within a range of 30-100 m/min during pickling; a pickling temperature is controlled at 75-85°C, and a tension leveling rate is controlled at $\leq 2\%$; wherein the strip steel is then subjected to rinsing, surface drying, and oiling.

14. The method for manufacturing the low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to claim 13, wherein, after step 5) of pickling, the strip steel is subjected to rinsing at a temperature of 35-50°C, surface drying at a temperature of 120-140°C, and oiling.

15. The method for manufacturing the low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to claim 13 or 14, wherein the method further comprises step 4-1) between step 4) and 5): annealing, wherein bell type annealing is carried out at a heating rate of $\geq 20^\circ\text{C/h}$, wherein a bell type annealing temperature is 100-300 °C and a bell type annealing time is 12-48h; wherein the steel plate is cooled to $\leq 100^\circ\text{C}$ at a cooling rate of $\leq 50^\circ\text{C/h}$ and leaves the furnace.

16. The method for manufacturing the low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to claim 13 or 14, wherein the method comprises the following steps:

1) Smelting and casting:

wherein the above components according to claim 2, 4 or 5 are subjected to smelting by a converter or an electric furnace, secondary refining by a vacuum furnace, and then casting to form a blank or ingot;

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

3) Hot rolling:

wherein the blank or ingot is hot rolled at an initial rolling temperature of 950~1 100°C; wherein 3-5 passes of heavy reduction rolling is performed at a temperature of $\geq 950^\circ\text{C}$ with a cumulative deformation of $\geq 50\%$, preferably $\geq 60\%$, to obtain an intermediate blank; wherein the intermediate blank is held till 920-950°C, then subjected to 3-5 passes of rolling with a cumulative deformation of $\geq 70\%$, preferably $\geq 85\%$; wherein a final rolling temperature is 800-920 °C;

4) Cooling:

wherein air cooling is performed for 0-10 s first for dynamic recovery and dynamic recrystallization, and then the strip steel is water cooled at a cooling rate of $\geq 50^\circ\text{C/s}$, preferably 50-85°C/s to a certain temperature of Ms or lower (between room temperature and Ms point), coiled, and cooled to room temperature after coiling;

5) Pickling

wherein a moving speed of the strip steel is adjusted within a range of 30-100 m/min during pickling; a pickling temperature is controlled at 75-85°C, and a tension leveling rate is controlled at $\leq 2\%$ to reduce elongation loss of the strip steel; wherein the strip steel is then subjected to rinsing, surface drying, and oiling.

17. The method for manufacturing the low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to claim 13 or 14, wherein the method comprises the following steps:

1) Smelting and casting:

wherein the above components according to claim 3, 4 or 6 are subjected to smelting by a converter or an electric furnace, secondary refining by a vacuum furnace, and then casting to form a blank or ingot;

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

3) Hot rolling:

wherein the blank or ingot is hot rolled at an initial rolling temperature of 950~1 100°C; wherein 3-5 passes of heavy reduction rolling is performed at a temperature of $\geq 950^\circ\text{C}$ with a cumulative deformation of $\geq 50\%$, preferably $\geq 60\%$; then 3-7 passes of rolling is performed with a cumulative deformation of $\geq 70\%$, preferably $\geq 85\%$; wherein a final rolling temperature is 800-950 °C;

4) Cooling:

wherein air cooling is performed for 0-10 s first, and then the strip steel is water cooled at a cooling rate of $\geq 30^\circ\text{C/s}$, preferably 30-65°C/s to room temperature, and coiled;

5) Annealing

wherein bell type annealing is carried out at a heating rate of $\geq 20^\circ\text{C/h}$, preferably 20-40°C/h, wherein a bell type annealing temperature is 100-300 °C and a bell type annealing time is 12-48h; wherein the steel plate is cooled to $\leq 100^\circ\text{C}$ at a cooling rate of $\leq 50^\circ\text{C/h}$, preferably 15-50 °C/h and leaves the furnace;

6) Pickling

wherein a moving speed of the strip steel is adjusted within a range of 30-90 m/min during pickling; a pickling

temperature is controlled at 75-85°C, and a tension leveling rate is controlled at $\leq 1.5\%$; wherein the strip steel is then subjected to rinsing at a temperature of 35-50°C, surface drying at a temperature of 120-140°C, and oiling.

18. The method for manufacturing the low carbon martensitic high hole expansion steel having a tensile strength of 980MP or more according to claim 13 or 14, wherein the method comprises the following steps:

1) Smelting and casting:

wherein the above components according to claim 3, 4 or 6 are subjected to smelting by a converter or an electric furnace, secondary refining by a vacuum furnace, and then casting to form a blank or ingot;

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

3) Hot rolling:

wherein the blank or ingot is hot rolled at an initial rolling temperature of 950~1100°C; wherein 3-5 passes of heavy reduction rolling is performed at a temperature of $\geq 950^\circ\text{C}$ with a cumulative deformation of $\geq 50\%$, preferably $\geq 60\%$ to obtain an intermediate blank; wherein the intermediate blank is held till 900-950°C, then 3-7 passes of rolling is performed with a cumulative deformation of $\geq 70\%$, preferably $\geq 85\%$; wherein a final rolling temperature is 800-900 °C;

4) Cooling:

wherein air cooling is performed for 0-10 s first, and then the strip steel is water cooled at a cooling rate of $\geq 30^\circ\text{C/s}$, preferably 30-70°C/s to a martensite phase transition start temperature M_s or a lower temperature, coiled and slowly cooled to room temperature after coiling;

5) Annealing

wherein bell type annealing is carried out at a heating rate of $\geq 20^\circ\text{C/h}$, preferably 20-50°C/s, wherein a bell type annealing temperature is 100-300 °C and a bell type annealing time is 12-48h; wherein the steel plate is cooled to $\leq 100^\circ\text{C}$ at a cooling rate of $\leq 50^\circ\text{C/h}$, preferably 25-50 °C/h and leaves the furnace;

6) Pickling

wherein a moving speed of the strip steel is adjusted within a range of 30-90 m/min during pickling; a pickling temperature is controlled at 75-85°C, and a tension leveling rate is controlled at $\leq 1.5\%$ to reduce elongation loss of the strip steel; wherein the strip steel is then subjected to rinsing, surface drying and oiling.

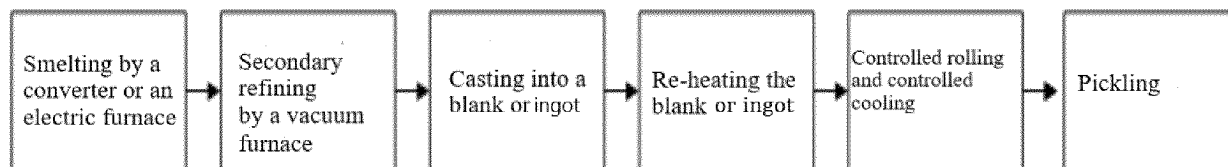


Fig. 1

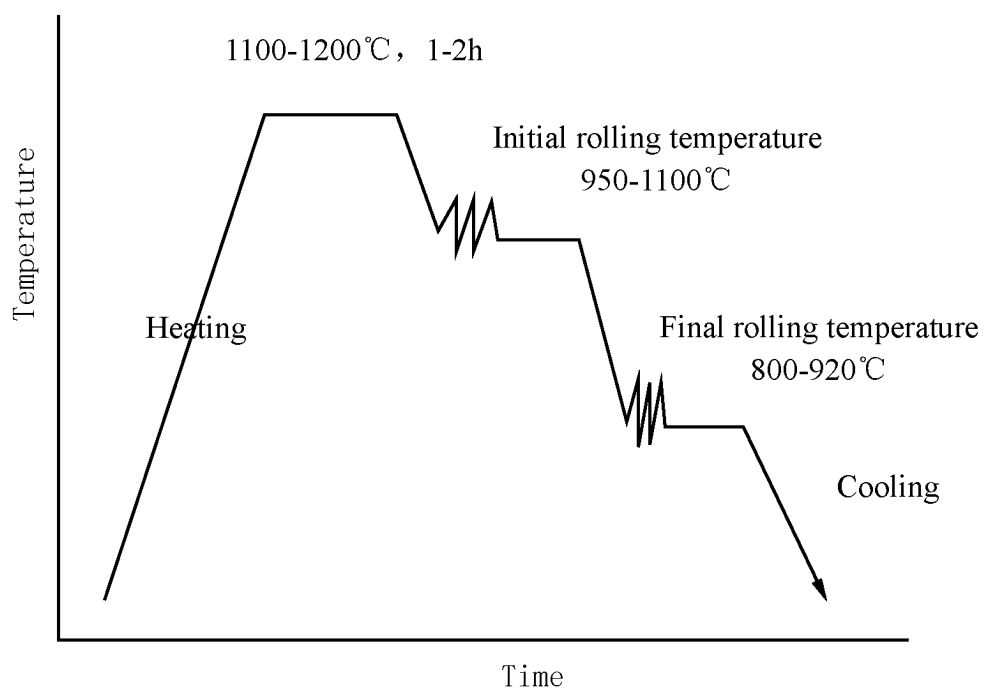


Fig. 2

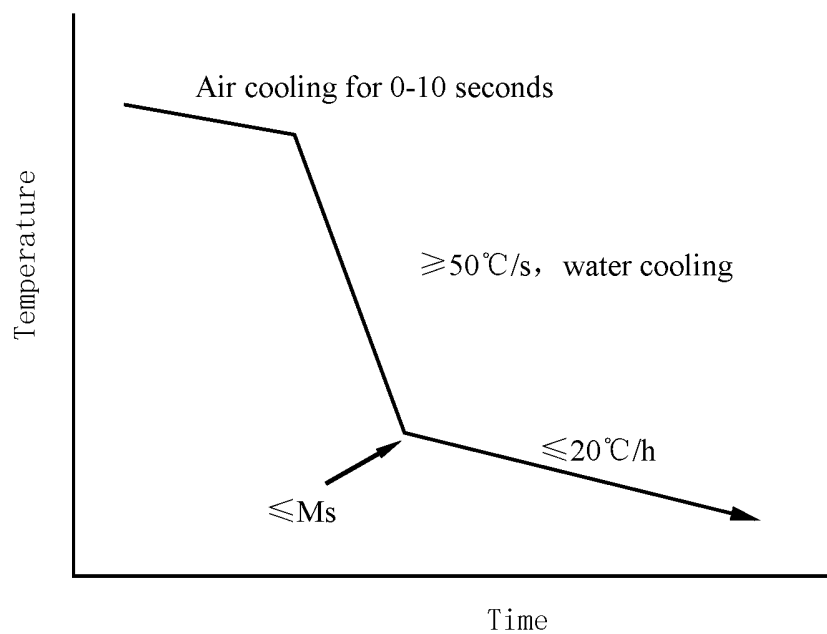


Fig. 3

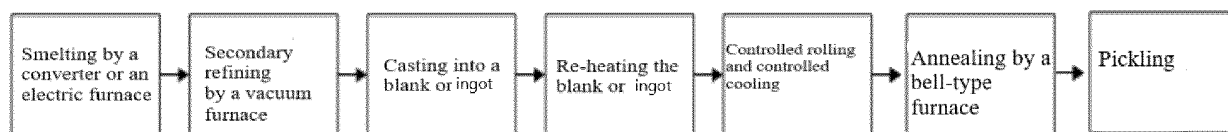


Fig. 4

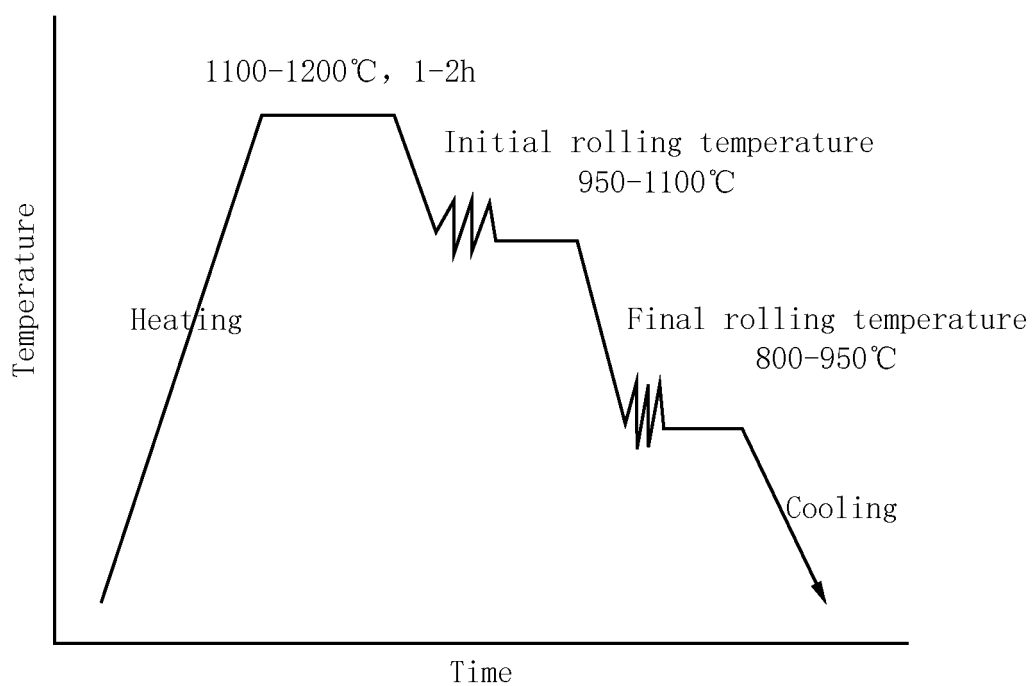


Fig. 5

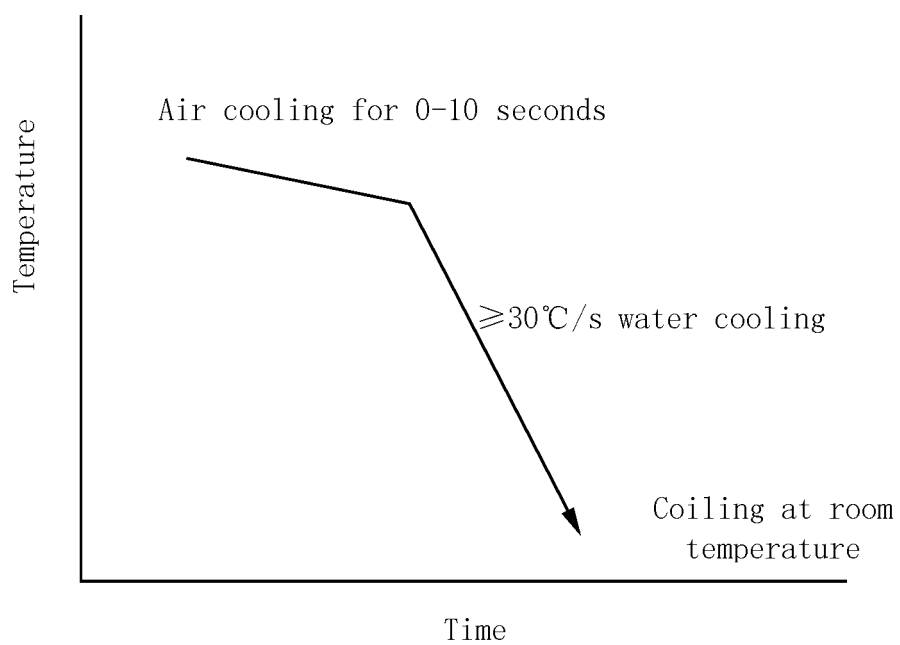


Fig. 6

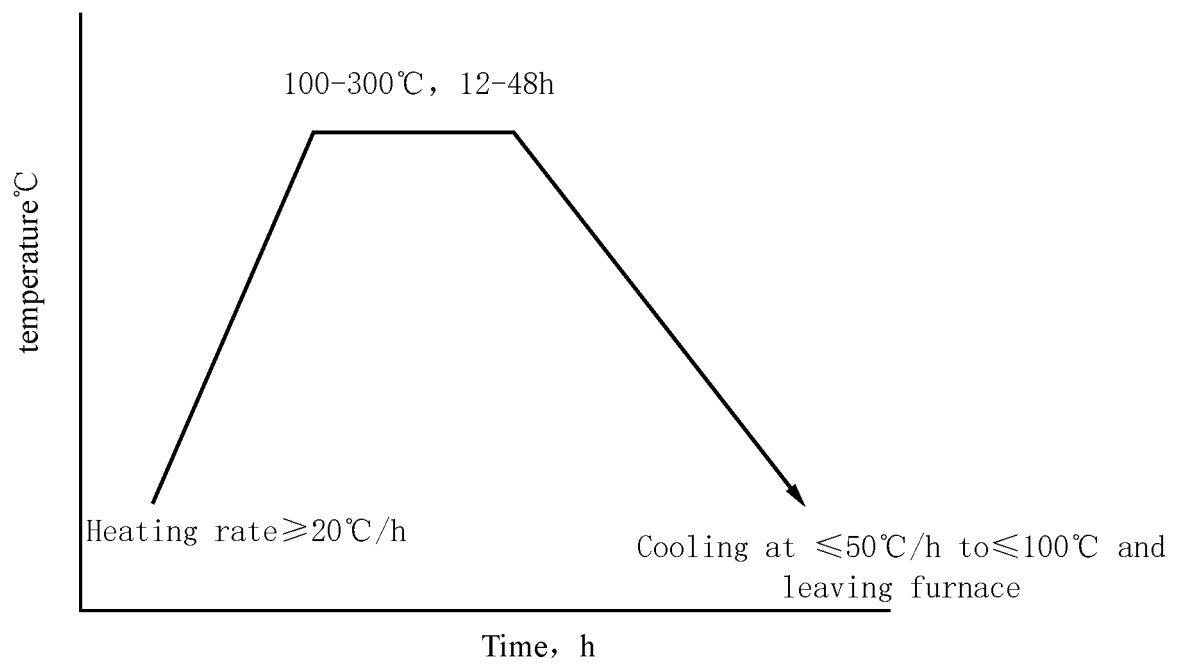


Fig. 7

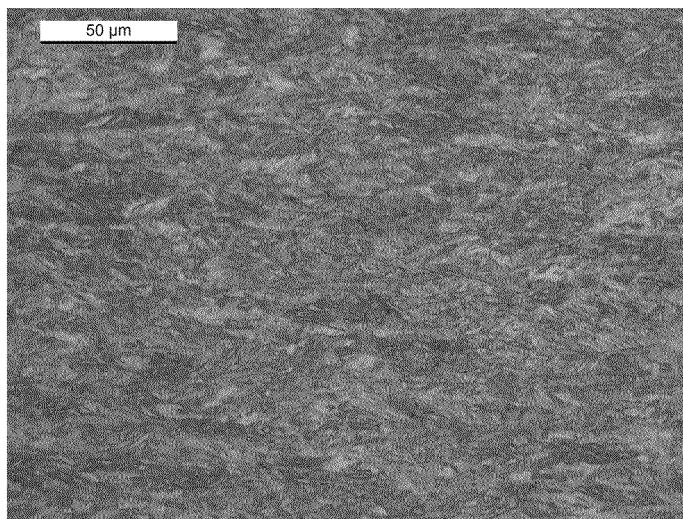


Fig. 8

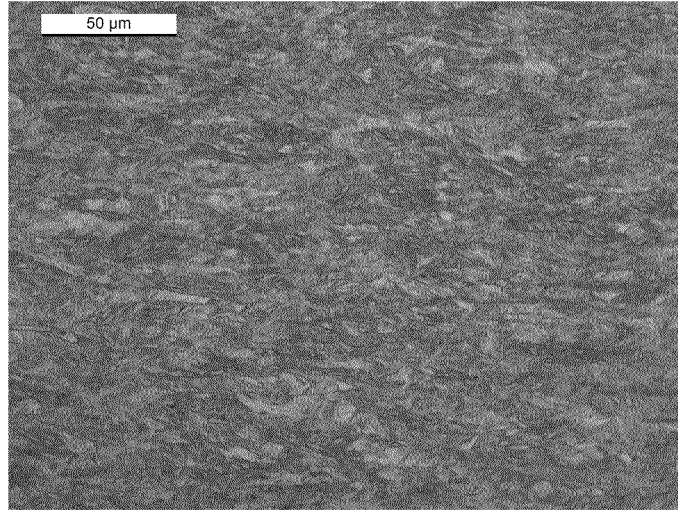


Fig. 9

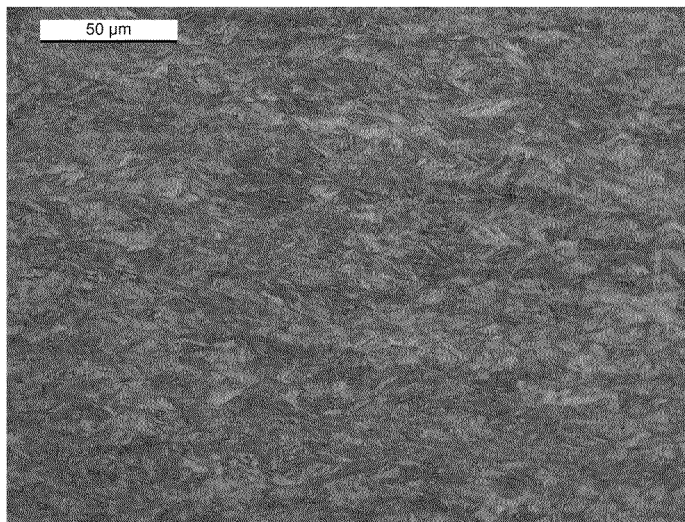


Fig. 10

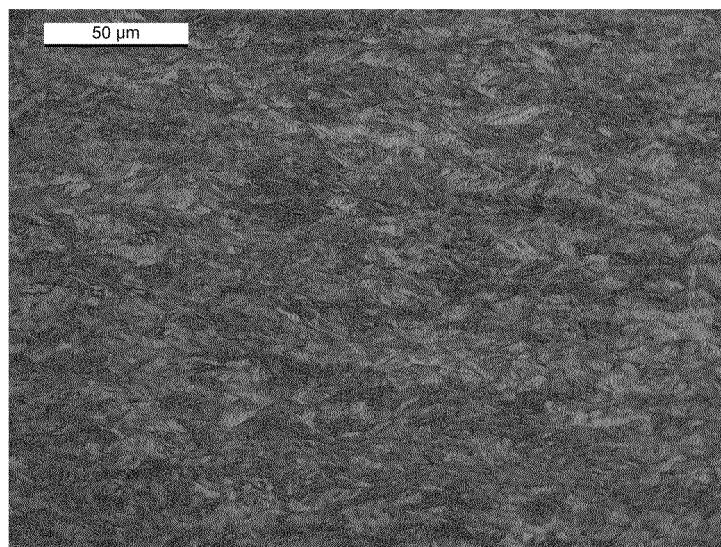


Fig. 11

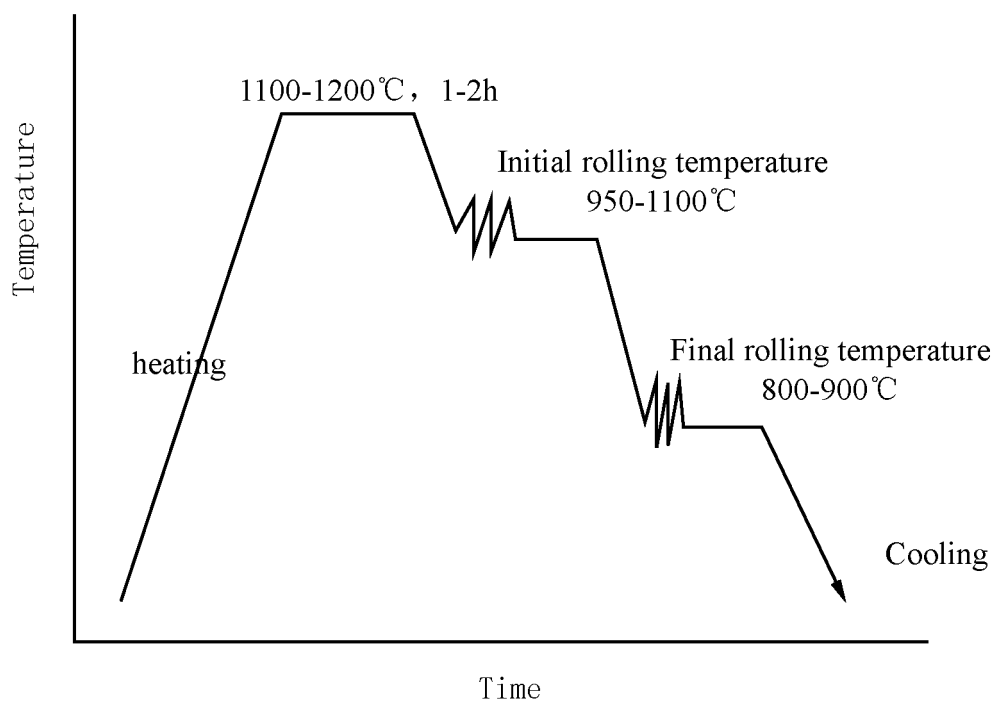


Fig. 12

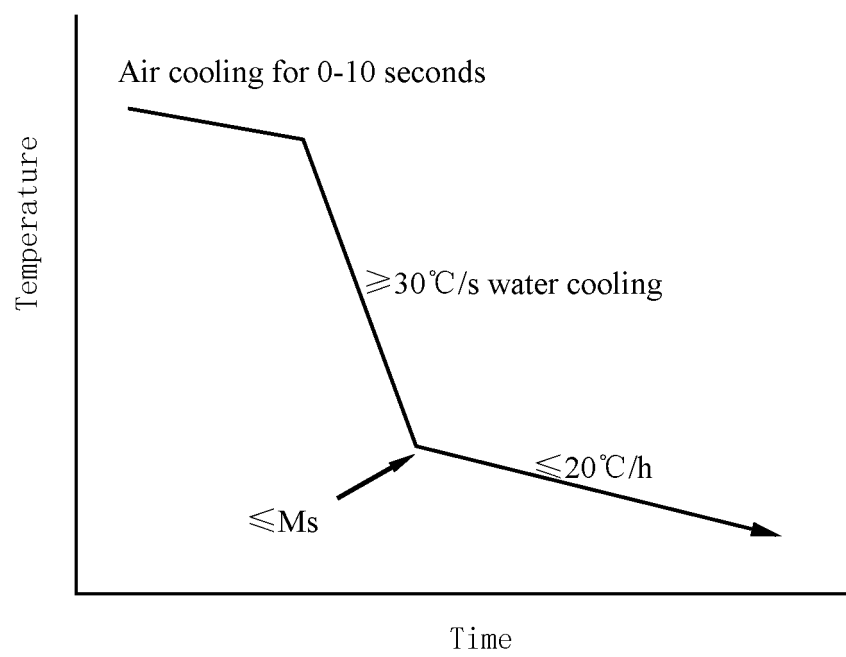


Fig. 13

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2021/115431

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/02(2006.01)i; C22C 38/04(2006.01)i; C22C 38/06(2006.01)i; C22C 38/12(2006.01)i; C22C 38/14(2006.01)i;
C21D 8/02(2006.01)i; C22C 33/04(2006.01)i; C22C 38/58(2006.01)i; C22C 38/34(2006.01)i; C22C 38/54(2006.01)i;
C22C 38/50(2006.01)i; C22C 38/44(2006.01)i; C22C 38/48(2006.01)i; C22C 38/46(2006.01)i; C22C 38/42(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, 安赛乐米塔
尔公司, THYSSENKRUPP, 980MPa, 抗拉强度, 马氏体, 碳, 硅, 锰, 钼, 钨, 钛, 扩孔, TS, tensile strength, C, Si, Mn, Al, Mo,
Ti, carbon, silicon, manganese, aluminium, molybdenum, titanium, expansion rate, martensite

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 110088326 A (THYSSENKRUPP STEEL EUROPE AG et al.) 02 August 2019 (2019-08-02) description paragraphs [0013]-[0069]	1-18
X	CN 106471147 A (ARCELOR MITTAL) 01 March 2017 (2017-03-01) description paragraphs [0009]-[0036], [0042]-[0060]	1-18
A	CN 111235470 A (BAOSHAN IRON & STEEL CO., LTD.) 05 June 2020 (2020-06-05) entire document	1-18
A	US 2020010921 A1 (TATA STEEL LTD) 09 January 2020 (2020-01-09) entire document	1-18

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

* Special categories of cited documents:

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“O” document referring to an oral disclosure, use, exhibition or other means

“P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search

05 November 2021

Date of mailing of the international search report

18 November 2021

Name and mailing address of the ISA/CN

China National Intellectual Property Administration (ISA/
CN)
No. 6, Xitucheng Road, Jimenqiao, Haidian District, Beijing
100088, China

Facsimile No. (86-10)62019451

Authorized officer

Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2021/115431

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