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(54) 1000MPA-GRADE HIGH HOLE EXPANSION HOT-ROLLED COMPLEX PHASE STEEL PLATE AND MANUFACTURING METHOD THEREOF

(57) Disclosed are a 1000MPa-grade high hole expansion hot-rolled complex phase steel plate and a manufacturing method thereof. The steel plate contains Fe and unavoidable impurity elements, and further contains the following chemical elements in mass percent: C: 0.07-0.15%, Si: 0.1-0.8%, Mn: 1.5-2.2%, Al: 0.02-0.1%, Ti: 0.05-0.18%, Nb≤0.06%,B≤0.003%, and at least one of 0.2%≤Cr≤1.5% and 0.05%≤Mo≤0.5%;wherein the mass percent content of N, Ti and Nb additionally satisfies: 0.01%≤(Ti-3.43N+0.52Nb)/4≤0.053%.The 1000MPa-grade high hole expansion hot-rolled complex phase steel plate can be used in automobile chassis and structural parts, and satisfies the technical requirements for complex automobile component flanging and stamping and automobile lightening.

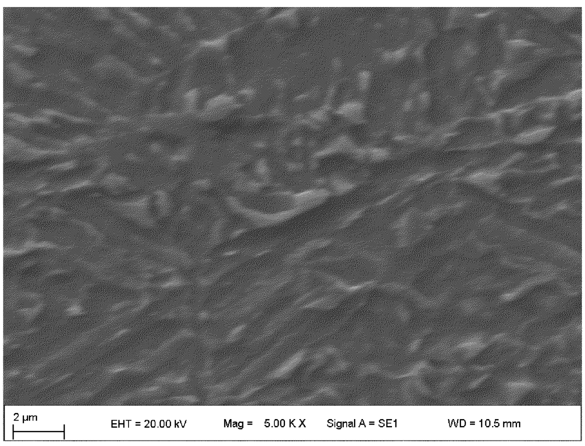

Fig. 1

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Description

Technical Field

[0001] The present disclosure relates to a complex phase steel and a manufacturing method thereof, in particular to a high hole expansion hot-rolled complex phase steel plate and manufacturing method thereof.

Background Art

[0002] In recent years, with the rapid development of the automotive industry, the market and users have become more and more demanding for the lightweight of automobiles. Lightweight has become the development trend of the automotive industry, and the proportion of high-strength steel plates in automotive structural parts is also increasing.

[0003] In order to improve the strength, many car models use 80kg grade steel plates to produce automobile chassis parts. However, the strength of the common complex phase steel in the market cannot reach the level of 1000MPa. In the technical solutions of disclosed patents, the tensile strength of most complex phase steel is at the level of 800MPa.

[0004] Therefore, in order to meet the requirements of lightweight, the inventors expect to further improve the strength of complex phase steel, so as to obtain a new 1000MPa high hole expansion complex phase steel with higher strength and ultra-high hole expansion ratio, which is also an inevitable trend in the development of complex phase steel in the future.

[0005] It is found that there are some 1000MPa grade high hole expansion complex phase steels in the prior art.

[0006] For example, the Chinese patent publication No. CN106119702A, published on November 16, 2016, with the title of "a 980MPa grade hot-rolled high-strength high-hole expansion steel and a manufacturing method thereof" discloses a 980MPa hot-rolled high-strength high-hole expansion steel and its manufacturing method. Its chemical composition design is mainly characterized by low-carbon V-Ti microalloying design, and the chemical composition contains V element. The cost of the technical solution is relatively high, and the use of B element is not considered.

[0007] For another example, Chinese Patent publication No. CN114107797A, published on March 1, 2022, with a title of "A 980MPa grade bainite precipitation strengthened high-hole expansion steel and a manufacturing method thereof" has disclosed a 980MPa grade bainite precipitation strengthened high-hole expansion steel and a manufacturing method thereof. Its chemical composition design is mainly characterized by low-carbon V-Ti microalloying design, and the chemical composition contains V. The cost is relatively high and its structure is bainite ferrite.

[0008] For still another example, Chinese Patent publication No. CN113122769A, published on July 16, 2021, with a title of "Low-silicon low-carbon equivalent X-Gpa grade complex phase steel plate/steel strip and a manufacturing method thereof" has disclosed a low-silicon low-carbon equivalent X-Gpa grade complex phase steel plate/steel strip and a manufacturing method thereof. It is designed with a low carbon content in its chemical composition, while its structure contains ferrite and the coiling temperature after hot rolling is relatively high.

[0009] To sum up, it can be seen that under normal circumstances, there is an inverse relationship among the elongation, hole-expansion ratio and strength of the material. For this reason, in order to obtain a 1000MPa grade high-hole expansion hot-rolled complex phase steel plate with high strength, high hole expansion ratio and high elongation, the present disclosure requires a good matching of alloying elements, phase transformation law and microstructure during design.

Summary

[0010] The object of the present disclosure is to provide a 1000MPa grade high-hole expansion hot-rolled complex phase steel plate. By reasonable chemical composition design of the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate, good comprehensive mechanical properties can be obtained. It has the characteristics of high strength and high elongation as well as high hole expansion ratio. It can be used not only for automobile body structural parts and automobile chassis parts, but also for other applications that require high strength, weight reduction, etc., and has a good application prospect.

[0011] In order to achieve the above object, the present disclosure provides a 1000MPa grade high-hole expansion hot-rolled complex phase steel plate, which comprises Fe and unavoidable impurity elements, as well as the following chemical elements in percentage by mass:

at least one of C: 0.07-0.15%, Si: 0.1-0.8%, Mn: 1.5-2.2%, Al: 0.02-0.1%, Ti: 0.05-0.18%, Nb≤0.06%, B≤0.003%, and 0.2%≤Cr≤1.5%, 0.05%≤Mo≤0.5%;

wherein the mass percentages of N, Ti, Nb also satisfy: 0.01%≤(Ti-3.43N+0.52Nb)/4≤0.053%.

[0012] Further, in the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate according to the present disclosure, the mass percentages of the various chemical elements are:

at least one of C: 0.07-0.15%, Si: 0.1-0.8%, Mn: 1.5-2.2%, Al: 0.02-0.1%, Ti: 0.05-0.18%, Nb≤0.06%, B≤0.003%, 0.2%≤Cr≤1.5% and 0.05%≤Mo≤0.5%;with a balance of Fe and unavoidable impurity elements; preferably, 0.015%≤Nb≤0.06%;

wherein the mass percentages of N, Ti, Nb also satisfy: 0.01%≤(Ti-3.43N+0.52Nb)/4≤0.053%.

[0013] In the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, the various chemical elements are designed according to the following principles:

C: In the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, considering that the level of C content largely determines the tensile strength level of the steel plate, C is used for solution strengthening. At the same time, C can be combined with Nb and Ti to form sufficient precipitation strengthening phase, which can ensure the strength of the steel. However, it should be noted that the C content in the steel should not be too high. When the mass percentage of C is too high, the carbide particles will be coarse, and too much martensite and residual austenite will be easily formed, which is not conducive to the hole expansion performance. Therefore, in order to obtain both high hole expansion ratio and good forming and welding performance under the premise of ensuring the strength of the steel grade, the mass percentage of C element is controlled in the range of 0.07-0.15% in the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure.

[0014] Si: In the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, Si can play a role in solution strengthening and improve the strength of the steel plate. At the same time, the addition of Si, can increase the work hardening rate and the uniform elongation under a given strength as well as the total elongation, which is conducive to improving the elongation of the steel plate. In addition, Si can also prevent the precipitation of carbides and reduce the appearance of pearlite phases. However, it should be noted that the silicon contained in the steel can easily lead to the surface defects of iron olivine ($2FeO$-SiO_2) iron oxide scale on the surface of the steel plate, which has a negative effect on the surface quality. Therefore, in the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, the mass percentage of Si element is controlled in the range of 0.1-0.8%.

[0015] Mn: In the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, Mn is a solution-strengthening element. When the mass percentage of Mn in the steel is low, it will lead to insufficient strength of the steel, but when the mass percentage of Mn is too high, it will lead to the reduction of the plasticity of the steel plate. In addition, Mn can also delay the pearlite transition, improve the hardenability of the steel and reduce the bainite transition temperature, so as to refine the sub-structure of the steel and ensure that a slat substructure is obtained, so that the steel can have good formability under the premise of obtaining high tensile strength. Therefore, considering the influence of Mn content on the properties of the steel, in the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, the mass percentage of Mn element is controlled in the range of 1.5-2.2%.

[0016] Al: In the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, Al is a deoxidizing element in the steel. It can reduce oxide inclusions in the steel, purify the steel, and help improve the formability of the steel plate. However, it should be noted that the content of Al in the steel should not be too high. When the mass percentage of Al in the steel is too high, oxidation will occur, which will further affect the continuous casting production. Therefore, considering the influence of Al element on the properties of the steel plate, in the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, the mass percentage of Al is controlled in the range of 0.02-0.1%.

[0017] Ti: In the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate, Ti is one of the important fine grain strengthening and precipitation-strengthening elements, which can increase the recrystallization temperature and refine the grain size of steel during the hot rolling process. At the same time, the combination of Ti and C has a good strengthening effect. However, it should be noted that the content of Ti in the steel should not be too high. When the content of Ti in the steel is too high, it is easy to form TiN with large size, which is not good for the impact toughness of the steel. Therefore, in order to bring into play the beneficial effects of the Ti element, the mass percentage of the Ti element is controlled in the range of 0.05-0.18% in the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure.

[0018] Nb: In the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, Nb is one of the important precipitation-strengthening and fine grain strengthening elements. But when the mass percentage of Nb is higher than 0.06%, the strengthening effect of Nb is close to saturation and the cost is high. Therefore, in order to bring into play the beneficial effect of Nb element and control the production cost at the same time, in the present disclosure, the mass percentage of the Nb element is controlled at Nb≤0.06%.

[0019] B: In the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, B is conducive to expanding the bainite phase zone and ensuring that the bainite structure can be obtained in the post-rolling cooling of the steel plate, which can significantly improve the strength and hardness of the steel. However, it should be noted that the content of the B element in the steel should not be too high, as too much B element will lead to too much massive martensite structure in the steel plate, and cause a decrease in hole expansion ratio and elongation of the steel. Therefore, in the present disclosure, the mass percentage of the B element is controlled at B≤0.003%.

[0020] Correspondingly, in addition to the above-mentioned elements, in the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, Cr and/or Mo elements can also be added to the steel. The Cr and Mo elements can be used alone or in combination.

[0021] Cr: In the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, Cr is an element that inhibits the production of pearlite and is beneficial to the formation of bainite structure, which can improve the strength and hole expansion ratio of the steel. The inventors found that when the mass percentage of Cr in the steel is less than 0.15%, its effect on the phase transformation curve is not significant. When the mass percentage of Cr in the steel is too high, it will not only lead to the increase of alloy cost, but also tend to produce more martensitic structure. Therefore, in the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, the mass percentage of the Cr element, when added, is controlled in the range of 0.2%-1.5%.

[0022] Mo: In the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, Mo not only inhibits the production of pearlite, but also facilitates the formation of bainite structure and a small number of martensite-austenite islands. In addition, Mo can also promote bainite microstructure transformation at a relatively high temperature, thus allowing the coiling of steel at a higher temperature, which provides sufficient precipitation kinetics to stimulate significant precipitation strengthening. In the present disclosure, Mo also plays a very important role in its complex precipitation process with Nb and Ti, and at the same time, it can reduce the possibility of precipitated particles having coarse particle size. However, it should be noted that the content of Mo in the steel should not be too high. When the content of Mo in the steel is too high, it will not only lead to the increase of alloy cost, but also tend to form more martensite and austenite, which is not conducive to the performance of the steel. Therefore, in order to bring into play the beneficial effects of the Mo element, in the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, the mass percentage content of the Mo element, when added, is controlled in the range of 0.05%-0.5%.

[0023] In addition, it should be noted that in this technical solution designed in the present disclosure, the inventor controls the mass percentage of a single chemical element in the matrix while further controlling the mass percentage of N, Ti and Nb in the steel plate to satisfy:

0.01%≤(Ti-3.43N+0.52Nb)/4≤0.053%, where N is the impurity element in the steel plate.

[0024] In the present disclosure, the inventors adopt the design of high Ti and high Nb, which can mainly play the following three roles of grain refinement and one role of precipitation strengthening: (1) in the process of slab heating, the precipitates of Nb and Ti can prevent the growth of original austenite grains; (2) in the hot rolling process, (Nb, Ti)(C, N) is conducive to increasing the recrystallization temperature and further refining the austenite grains. (3) precipitated (Nb, Ti) (C, N) or (Nb, Ti) (Mo, Cr) (C, N) is conducive to the refinement of phase transition bainite, as well as a small number of martensitic grains; (4) in the process of laminar cooling, nanoscale precipitates of (Nb, Ti) (C, N) or (Nb, Ti) (Mo, Cr) (C, N) can have a strong precipitation-strengthening effect.

[0025] Therefore, in the present disclosure, in order to ensure the full precipitation of Ti and Nb compounds, in addition to the design of C element which needs to be matched with the content of Ti and Nb, it is also necessary to control the mass percentages of N, Ti and Nb through a reasonable combination with Nb and Ti to satisfy "0.01%≤(Ti-3.43N+0.52Nb)/4≤0.053%", and cooperate with the optimized design of the manufacturing process. Then, the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate having bainite grain size of :$_{5}$6um can be obtained.

[0026] Further, in the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, among the unavoidable impurity elements, P is :$_{50}$.02%, S is :$_{50}$.005%, N is :$_{50}$.005%.

[0027] In the above technical solution, P, Sand N are impurity elements in 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure. If the technical conditions permit, in order to obtain the steel with better performance and better quality, the content of impurity elements in the steel plate should be reduced as much as possible.

[0028] Therefore, in the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, the content of the P element is controlled at P:$_{50}$.02%, the content of the S element is controlled at S:$_{50}$.005%, and the content of the N element is controlled at N:$_{50}$.005%.

[0029] Further, in the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, the contents of Cr and Mo in the steel grade satisfy one of the following:

(1) when 0.2%:$_{5C}$r:$_{50}$.7%, the mass percentage of Mo satisfies 0.2%:$_{5M}$o:$_{50}$.35%;
(2) when 0.7%<Cr=<1.0%, the mass percentage of Mo satisfies 0.05%:$_{5M}$o<0.2%;
(3) when 1.0%<Cr=<1.5%, Mo is absent;
(4) when 0.35%<Mo:$_{50}$.5%, Cr is absent.

[0030] In the above technical solution of the present disclosure, in the design of chemical composition, Cr and Mo elements can be used alone or in combination. The addition of appropriate amount of Cr or Mo is to obtain bainite structure and martensite-austenite islands in smaller size during the hot rolling and coiling process, so as to ensure that there is no pearlite and massive martensite that affect the hole expansion performance.

[0031] Therefore, in order to further adapt to the designed manufacturing process and obtain the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate with better comprehensive mechanical performance, so as to meet the needs of users and markets, the inventor has further optimized the design of Cr and Mo content in the steel. In practical application, the Cr and Mo elements can be preferably added in any one of the ratios designed in the above (1)-(4).

[0032] Further, in the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, the main body of the matrix of microstructure is bainite, and there are nanoscale precipitates on the matrix.

[0033] In the present disclosure, there are nanoscale precipitates on the matrix of the microstructure of the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate designed in the present disclosure. These microalloy nanoscale precipitates include TiC, (Ti, Nb)C, and their specific precipitate sizes can be controlled at 3-20nm.

[0034] Further, in the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, bainite has a volume fraction of ≥85%.

[0035] Further, in the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, the matrix of the microstructure further comprises martensite and/or residual austenite. Further, in the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, the martensite and residual austenite have a total volume fraction of :$_{51\ 5\%}$.

[0036] Further, in the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, the nanoscale precipitates have a size of 3-20nm.

[0037] Further, in the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, the grain size of bainite is <_ 6um, and the grain size of martensite and/or residual austenite is :$_5$3um.

[0038] In some embodiments, the microstructure of the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure contains martensite with a volume fraction of 85~96% and martensite and residual austenite with a total volume fraction of 4~15%, wherein the grain size of bainite is in the range of 3.2-5um, and the grain size of martensite is in the range of 0.5-3um.

[0039] Further, in the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure, the properties satisfy: a yield strength of ≥750MPa, a tensile strength of 950-1150MPa, an elongation A50 of ≥12%, a punching hole expansion ratio of ≥45%, a reaming hole expansion ratio of ≥65%.

[0040] In some embodiments, the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure has a yield strength of ≥780MPa. In some embodiments, the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure has a yield strength of ≥800MPa. In some embodiments, the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure has a yield strength of 750~960MPa.

[0041] In some embodiments, the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure has a tensile strength of 980~1150MPa.

[0042] In some embodiments, the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure has a punching hole expansion ratio of ≥50%. In some embodiments, the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure has a punching hole expansion ratio of ≥55%.

[0043] In some embodiments, the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure has a reaming hole expansion ratio of ≥70%. In some embodiments, the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of the present disclosure has a reaming hole expansion ratio of ≥75%.

[0044] Accordingly, another object of the present disclosure is to provide a manufacturing method for the above 1000MPa grade high-hole expansion hot-rolled complex phase steel plate. The 1000MPa grade high-hole expansion hot-rolled complex phase steel plate obtained by this manufacturing method has the characteristics of high strength and high elongation as well as high hole expansion ratio, and has a good application prospect.

[0045] To achieve the above purpose, the present disclosure provides a manufacturing method for the above 1000MPa grade high-hole expansion hot-rolled complex phase steel plate, comprising steps of:

(1) smelting and casting;
(2) hot-rolling: wherein the slab is heated to 1200-1300°C and held; then rolled, wherein the rough rolling outlet temperature is 1000-1080°C and the final rolling temperautre of finishing rolling is 840-950°C;
(3) a two-stage laminar cooling is performed to water cool the steel plate to the coiling temperature: wherein the average cooling rate in the first stage is ≥ 100°C/s, the average cooling rate in the second stage is ≥3°C/s, the midpoint temperature between the first stage cooling and the second stage cooling is bainite phase transition temperature Bs ±30°C, the threading rate is controlled at 7-12m/s, and the time for cooling from the midpoint temperature to the coiling temperature is controlled at ≥ 4.5s, preferably ≥6s, and more preferably ≥6.5s, wherein $Bs=844-597xC+127xC^2-92xMn+8xMn^2-32xCr+2.2xCr^2-42xMo$, where each chemical element in the formula represents the value before the percentage sign of the mass percentage of the corresponding chemical element;
(4) coiling: the coiling temperature is controlled at 430-600°C, the steel after coiling is cooled to room temperature at a

cooling rate of ≤0.1°C/s;
(5) pickling.

[0046] In the above technical solution of the present disclosure, in step (2), with respect to the Ti-containing steel, the heating temperature of the slab is particularly important for the performance, because Ti will form a large number of large-size precipitates (Ti, Nb)(C, N) in the continuous casting process. The main purpose of setting the heating temperature≥1200 °C is to maximize solid solution of Ti and other alloying elements during the heating process, so as to ensure the nanoscale precipitation of Ti and other microalloys in the subsequent hot-rolling and coiling process. However, the heating temperature should not be too high. When the heating temperature exceeds 1300 °C, there will be a tendency of grain coarsening, which is not conducive to the toughness of the steel plate. Therefore, in the hot rolling process of the present disclosure, the heating temperature is preferably controlled in the range of 1200-1300 °C.

[0047] In addition, the rough rolling temperature control of the hot rolling process has a great influence on Ti and other microalloys, and the precipitation of Ti carbides and carbonitrides will occur at lower rough rolling temperature and during finishing rolling process with larger precipitate size, which is not conducive to the improvement of the final strength. But the precipitated (Nb, Ti) (C, N) is conducive to the refinement of austenite grains. Therefore, in the hot rolling process of the present disclosure, the rough rolling outlet temperature is controlled ate 1000-1080 °C. In some embodiments, the rough rolling outlet temperature is controlled at 1050-1080°C. In some embodiments, the final rolling temperature of finishing rolling is controlled at 880-950°C.

[0048] In addition, although the addition of Cr and/or Mo elements in the steel has inhibited the formation of ferrite and pearlite, it is still easy to form massive secondary martensite and residual austenite, which has a great influence on the volume fraction of bainite phase transition during the hot-rolling and laminar cooling process in step (3). Therefore, in the present disclosure, in order to obtain a suitable bainite phase transition and a martensite-austenite island with smaller size, it is necessary to control the laminar cooling time, cooling rate and threading rate in step (3). In particular, the time for cooling from the midpoint temperature to the coiling temperature is controlled at ≥4.5s, preferably ≥6.5s, the average cooling rate in the first section before the midpoint temperature is ≥ 100°C/s, the average cooling rate after the midpoint temperature is ≥3°C/s, and the threading rate is controlled at 7-12m/s.

[0049] It should be noted that in the present disclosure, it is also necessary to control the bainite transition and the microalloy precipitation. When the coiling temperature is too high, it will lead to more ferrite and secondary martensite and residual austenite with larger size, which is not conducive to the improvement of hole expansion ratio. When the coiling temperature is low, primary martensite microstructure may appear and lead to low elongation of the steel. Therefore, in the present disclosure, the coiling temperature is controlled in the range of 430-600 °C to solve the matching problem of elongation and hole expansion ratio. Of course, in order to achieve better implementation effects, the coiling temperature can be further controlled in the range of 430-580°C.

[0050] Correspondingly, after coiling, cooling at a cooling rate of $:_5$0.1 °C/s to room temperature can not only promote further transformation of bainite, but also facilitate the tempering of martensite and further precipitation of microalloys, which can effectively improve the strength, hole expansion ratio and elongation of the steel.

[0051] In addition, it should be noted that the present disclosure does not have a special limitation on the pickling process. But in some embodiments, during the actual pickling process, the specific parameters are as follows: the stretching-bending straightening elongation by pickling is controlled at 0.2-2%; the pickling speed is controlled at 60-150m/min, the temperature of the last pickling tank in the pickling process is controlled at 80-90°C, the iron ion concentration is controlled at 30-40g/L, and the final steel plate product is obtained after pickling.

[0052] Further, in the manufacturing method of the present disclosure, in step (2), the total rolling reduction rate is controlled at ≥80%, and the total finishing rolling reduction rate is controlled at ≥50%. Preferably, the total rolling reduction rate is 90%-95%, and the total finishing rolling reduction rate is 85%-90%. Further preferably, the thickness of the obtained finished steel plate is not more than 5mm.

[0053] Further, in the manufacturing method of the present disclosure, in step (2), the holding time is 1~3 hours.

[0054] Further, in the manufacturing method of the present disclosure, in step (3), the time for cooling from the midpoint temperature to the coiling temperature is controlled at ≥8s.

[0055] Further, in the manufacturing method of the present disclosure, in step (3), the average cooling rate in the first stage is 100~160°C/s, preferably 120~160°C/s.

[0056] Further, in the manufacturing method of the present disclosure, in step (3), the average cooling rate in the second stage is 3~25°C/s, preferably 3~22°C/s.

[0057] Further, in the manufacturing method of the present disclosure, in step (4), the coiling temperature is controlled at 430-580°C. In some embodiments, in step (4), the coiling temperature is controlled at 430-550°C.

[0058] Compared with the prior art, the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate and manufacturing method thereof according to the present disclosure have the following advantages and beneficial effects:
In the present disclosure, an economical and reasonable chemical composition design is adopted. At the same time, cooperated with the existing hot continuous rolling production line, a new type of 1000MPa grade high hole expansion hot

rolled complex phase steel plate with ultra-high strength and hole expansion ratio can be produced.

[0059] The 1000MPa grade high-hole expansion hot-rolled complex phase steel plate prepared in the present disclosure has characteristics of relatively high hole expansion ratio, high strength and high formability with a yield strength of ≥750MPa, a tensile strength of 950-1150MPa, an elongation A50 of >_12°i$_{o}$, a punching hole expansion ratio of ≥45% and a reaming hole expansion ratio of ≥65%. It can be used not only for automobile body structural parts and automobile chassis parts, but also for other applications that require high strength, weight reduction, etc., and has a good application prospect.

Description of the Drawings

[0060]

Fig. 1 is a metallographic structure photograph of the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate in Example 3.

Fig. 2 is a metallographic structure photograph of the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate in Example 5.

Fig. 2 is a metallographic structure photograph of the comparative steel in Comparative Example 6.

Detailed Description

[0061] The 1000MPa grade high-hole expansion hot-rolled complex phase steel plate according to the present disclosure and the manufacturing method therefor will be further interpreted and explained below in combination with specific examples and Figures, but the interpretation and explanation do not constitute an undue limitation to the technical solution of the present disclosure.

Example 1-13 and Comparative Example 1-11

[0062] Table 1-1 lists the mass percentages of various chemical elements in the 1000MPa grade high-hole expansion hot-rolled complex phase steel plates of Examples 1-13 and the comparative steel plates of Comparative Examples 1-11.

Table 1-1. (wt%, a balance of Fe and other unavoidable impurities besides P, Sand N)

No.	No.	Chemical element											
		C	Si	Mn	Cr	Mo	Ti	Nb	P	S	N	Al	B
Ex. 1-5; CEx. 1-2	A	0.095	0.35	1.85	0.73	0.15	0.12	0.035	0.01	0.0009	0.0045	0.038	-
Ex. 6-8; CEx. 3-6	B	0.085	0.52	1.76	0.38	0.28	0.09	-	0.013	0.0011	0.0042	0.035	-
Ex. 9; CEx. 7	C	0.07	0.8	2.2	0.95	-	0.15	-	0.01	0.005	0.004	0.025	-
Ex. 10	D	0.15	0.1	1.5	1.5	-	0.18	-	0.014	0.0009	0.0023	0.029	0.001
Ex. 11	E	0.12	0.51	1.68	-	0.5	0.09	0.015	0.011	0.0013	0.005	0.1	-
Ex. 12	F	0.092	0.65	2.03	-	0.36	0.1	-	0.02	0.0015	0.0025	0.033	0.015
Ex. 13	G	0.093	0.72	1.98	0.68	0.21	0.05	0.06	0.02	0.0015	0.0025	0.033	0.003
CEx. 8	H	0.095	0.35	1.85	**0.73**	**0.35**	0.12	0.035	0.01	0.0009	0.0045	0.038	-
CEx. 9	I	0.095	0.35	1.85	0.73	0.15	**0.04**	0.035	0.01	0.0009	0.0045	0.038	-
CEx. 10	J	0.095	0.35	1.85	0.73	0.15	**0.04**	0.035	0.01	0.0009	**0.01**	0.038	-
CEx. 11	K	**0.052**	0.35	**1.45**	0.73	0.15	0.12	0.035	0.01	0.0009	0.0045	0.038	-

[0063] Table 1-2 lists the matching of various chemical elements in the steel plates of Examples 1-13 and Comparative Examples 1-11.

Table 1-2.

No.	Steel No.	TiCeq	Bainite phase transition temperature Bs (°C)
Ex. 1-5; CEx. 1-2	A	0.031	617
Ex. 6-8; CEx. 3-6	B	0.019	633
Ex. 9; CEx. 7	C	0.034	611
Ex. 10	D	0.043	594
Ex. 11	E	0.020	621
Ex. 12	F	0.023	621
Ex. 13	G	0.018	609
CEx. 8	H	0.031	609
CEx. 9	I	0.006	617
CEx. 10	J	0.011	617
CEx. 11	K	0.031	668
Note: in the above Table 1-2, $Bs=844-597xC+127xC^2-92xMn+8xMn^2-32xCr+2.2xCr^2-42xMo$, where each chemical element in this equation represents the value before the percent sign of the mass percentage; TiCeq= (Ti-3.43N+0.52Nb)/4, wherein N, Ti, Nb each represents the mass percentage of each corresponding chemical element.			

[0064] The 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of Examples 1-13 of the present disclosure and the comparative steel plates of Comparative Examples 1-11 were all prepared with the following steps:

(1) The chemical compositions shown in Table 1-1 and 1-2 were smelted and casted.
(2) hot-rolling: the slab obtained by smelting and continuous casting was heated to 1200-1300°C and held for 1-3 h; then rolled, wherein the rough rolling outlet temperature was controlled at 1000-1080°C and the final rolling temperautre of finishing rolling was controlled at 840-950°C; wherein the total rolling reductaion rate was ≥80%, the total finishing rolling reduction rate was ≥50%.
(3) after finish rolling, two-stage laminar cooling was performed to water cool the steel plate to the coiling temperature: wherein the average cooling rate in the first stage was >_ 100°C/s, the average cooling rate in the second stage was >_3°C/s, the midpoint temperature between the first stage cooling and the second stage cooling was bainite phase transition temperature Bs±30°C, the threading rate was controlled at 7-12m/s, and the time for cooling from the midpoint temperature to the coiling temperature was controlled at ≥ 4.5s, preferably the time for cooling from the midpoint temperature to the coiling temperature was controlled at ≥6s.
(4) coiling: the steel plate after water cooling was coiled, wherein the coiling temperature was controlled at 430-600°C, preferably 430-580°C; the steel plate after coiling was cooled to room temperature at a cooling rate of ≤0.1 °C/s.
(5) pickling: the stretching-bending straightening elongation by pickling was controlled at 0.2-2%; the pickling speed was controlled at 60-150m/min, the temperature of the last pickling tank in the pickling process was controlled at 80-90°C, the iron ion concentration was controlled at 30-40g/L, and the steel plate with a thickness of $:_5$5mm was obtained after pickling.

[0065] In the present disclosure, the chemical compositions designed for the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate in Examples 1-13 and the relevant process all meet the specification requirements designed according to the present disclosure. Although the comparative steel plates of Comparative Examples 1-11 were also prepared according to the above steps (1)-(5), there are parameters that do not meet the design requirements of the present disclosure in the chemical composition design and/or relevant manufacturing process of the comparative steel plates of Comparative Examples 1-11.
[0066] Table 2-1 and Table 2-2 list the specific process parameters for the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of Examples 1-13 and the comparative steel plates of Comparative Examples 1-11.

Table 2-1.

No.	Steel No.	Step (2)					Step (3)			
		Heating temperature (°C)	Rough rolling outlet temperature (°C)	Finishing rolling outlet temperature (°C)	Total rolling reduction rate (%)	Total finishing rolling reduction rate (%)	Average cooling rate in the first stage (°C/s)	Midpoint temperature (°C)	Average cooling rate in the second stage (°C/s)	Time for cooling from the midpoint temperat ure to the coiling temperature (s)
Ex. 1	A	1250	1050	910	92	88	140	630	20	10
Ex. 2		1250	1050	910	92	88	140	630	15	10
Ex. 3		1250	1050	910	92	88	140	630	11	10
Ex. 4		1250	1050	910	92	88	140	630	8	10
Ex. 5		1250	1050	910	92	88	140	630	3	10
CEx. 1		1250	1050	910	92	88	140	630	25	10
CEx. 2		1250	1050	910	92	88	**70**	**700**	8	10
Ex. 6	B	1250	1050	880	92	88	125	630	15	10
Ex. 7		1250	1050	950	92	88	160	630	16.5	9.1
Ex. 8		1200	1050	910	92	88	140	630	16.5	9.1
CEx. 3		1250	1050	910	92	88	185	**540**	12	5.0
CEx. 4		1250	1050	910	98	**20**	140	630	16.5	9.1
CEx. 5		1250	**930**	**820**	92	88	**95**	630	16.5	9.1
CEx. 6		**1120**	**920**	910	92	88	140	630	16.5	9.1
Ex. 9	C	1250	1050	910	92	88	140	630	15	10
CEx. 7		1250	1050	910	92	88	140	630	15	10
Ex. 10	D	1300	1080	910	92	50	141	570	7.7	11.7
Ex. 11	E	1250	1000	880	92	88	142	600	13.2	9.1
Ex. 12	F	1230	1050	910	80	88	143	650	22.0	6.8
Ex. 13	G	1250	1050	910	83	52	140	630	11	10
CEx. 8	**H**	1250	1050	910	92	88	140	630	11	10
CEx. 9	**I**	1250	1050	910	92	88	140	630	11	10

(continued)

No.	Steel No.	Step (2)					Step (3)			
		Heating temperature (°C)	Rough rolling outlet temperature (°C)	Finishing rolling outlet temperature (°C)	Total rolling reduction rate (%)	Total finishing rolling reduction rate (%)	Average cooling rate in the first stage (°C/s)	Midpoint temperature (°C)	Average cooling rate in the second stage (°C/s)	Time for cooling from the midpoint temperat ure to the coiling temperature (s)
CEx. 10	**J**	1250	1050	910	92	88	140	630	11	10
CEx. 11	**K**	1250	1050	910	92	88	140	**630**	11	10

Table 2-2.

No.	Steel No.	Step (3)	Step (4)	
		Threading rate (m/s)	Coiling temperature (°C)	Cooling rate after coiling (°C/s)
Ex. 1	A	8.2	430	0.02
Ex. 2		8.2	480	0.02
Ex. 3		8.2	520	0.02
Ex. 4		8.2	550	0.02
Ex. 5		8.2	600	0.02
CEx. 1		8.2	**380**	0.02
CEx. 2		8.2	**620**	0.02
Ex. 6	B	9.0	480	0.02
Ex. 7		9.0	480	0.02
Ex. 8		9.0	480	0.02
CEx. 3		9.0	480	0.02
CEx. 4		9.0	480	0.02
CEx. 5		9.0	480	0.02
CEx. 6		9.0	480	0.02
Ex. 9	C	8.2	480	0.02
CEx. 7		8.2	480	**0.2**
Ex. 10	D	7	480	0.02
Ex. 11	E	9	480	0.02
Ex. 12	F	12	500	0.02
Ex. 13	G	8.2	520	0.02
CEx. 8	H	8.2	520	0.02
CEx. 9	I	8.2	520	0.02
CEx. 10	J	8.2	520	0.02
CEx. 11	K	8.2	520	0.02

[0067] In the present disclosure, the inventor sampled the products of the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of Examples 1-13 and the comparative steel plates of Comparative Examples 1-11 prepared by the above process steps respectively, observed and analyzed the microstructure of the steel plate in each Example and Comparative Example. The results obtained by the observation and analysis are listed in Table 3 below.

[0068] Table 3 lists the microstructure observation results of the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of Examples 1-13 and the comparative steel plates of Comparative Examples 1-11.

Table 3.

No.	Microstructure					
	bainite		Martensite and/or residual austenite			Nanoscale precipitate
	Volume fraction (%)	Grain size (um)	Microstructure type	Volume fraction (%)	Grain size (um)	Diameter (nm)
Ex. 1	96	3.2	Martensite	4	0.5-2	3-15
Ex. 2	93	4.0	Martensite + residual austenite	7	0.5-2	3-15

(continued)

No.	Microstructure					
	bainite		Martensite and/or residual austenite			Nanoscale precipitate
	Volume fraction (%)	Grain size (um)	Microstructure type	Volume fraction (%)	Grain size (um)	Diameter (nm)
Ex. 3	92	4.3	Martensite + residual austenite	8	0.5-2	3-15
Ex. 4	88	4.5	Martensite + residual austenite	12	0.5-3	3-15
Ex. 5	85	5.0	Residual austenite	15	0.5-3	3-20
Ex. 6	94	3.8	Martensite + residual austenite	6	0.5-2	3-15
Ex. 7	94	4.2	Martensite + residual austenite	6	0.5-2	3-15
Ex. 8	94	4.0	Martensite + residual austenite	6	0.5-2	3-15
Ex. 9	93	4.0	Martensite + residual austenite	7	0.5-2	3-15
Ex. 10	90	4.0	Martensite + residual austenite	10	0.5-2	3-15
Ex. 11	88	4.0	Martensite + residual austenite	12	0.5-2	3-15
Ex. 12	92	4.3	Martensite + residual austenite	8	0.5-2	3-15
Ex. 13	94	4.3	Martensite + residual austenite	6	0.5-2	3-15
CEx. 1	**20**	3.0	Martensite	**80**	**>3**	3-15
CEx. 2	**30**	**7.5**	No	No	No	3-15
CEx. 3	**84**	4.0	Martensite + residual austenite	**16**	0.5-2	3-15
CEx. 4	94	**8.0**	Martensite + residual austenite	6	0.5-2	3-15
CEx. 5	94	4.0	Martensite + residual austenite	6	0.5-2	**3-40**
CEx. 6	94	4.0	Martensite + residual austenite	6	0.5-2	**3-50**
CEx. 7	**84**	4.0	Martensite + residual austenite	**16**	0.5-2	3-15
CEx. 8	**82**	4.3	Martensite + residual austenite	**18**	0.5-2	3-15
CEx. 9	94	4.3	Martensite + residual austenite	6	0.5-2	3-15
CEx. 10	94	4.3	Martensite	6	0.5-8	3-15
CEx. 11	94	4.3	Martensite	6	0.5-2	3-15

[0069] It can be seen through observation that in the present disclosure, the matrix of the microstructure of the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate prepared in Examples 1-13 is bainite + a small amount of martensite and residual austenite. The volume fraction of bainite is in the range of 85%-96%, the volume fraction of martensite and/or residual austenite is in the range of 4-15%, the grain size of bainite is in the range of 3.2-5um, and the grain size of martensite is in the range of 0.5-3um.

[0070] It should be noted that, in the actual preparation, the matrix of the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of Example 1-13 also has nanoscale precipitates thereon, which include TiC, (Ti, Nb)C, and the diameter of the nanoscale precipitates is in the range of 3-20nm.

[0071] Correspondingly, after the analysis of the microstructure, the products of the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of Examples 1-13 and the comparative steel plates of Comparative Examples 1-11 prepared by the above process steps were sampled respectively, and the mechanical properties of the steel plate of each Example and Comparative Example were tested, and the relevant mechanical properties test results are listed in Table 4 below.

[0072] The methods for testing the relevant properties are as follows:

(1) Tensile property test: a JIS 5# stretched specimen along the longitudinal direction was taken and a tensile test was conducted in accordance with the standard of GB/T 228.1-2010 "Metallic materials-tensile testing-Part 1: Method of

test at room temperature" to test the yield strength, tensile strength and elongation of the steel plate in each Example and Comparative Example.

(2) Hole expansion test: the hole expansion ratio was measured by the hole expansion test. The specimen with a hole in the center was pressed into the die with a punch, so that the center hole of the specimen was expanded until necking or through cracks appeared on the edge of the plate hole. Since the preparation method of the original hole in the center of the specimen had a great influence on the test results of the hole expansion ratio, the original hole in the center of the specimen was prepared by punching and reaming, respectively. The subsequent tests and test methods were carried out according to the hole expansion test method specified in the ISO/DIS 16630 standard, and the test results are shown in Table 4.

[0073] Table 4 lists the mechanical property test results of the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate of Examples 1-13 and the comparative steel plates of Comparative Examples 1-11.

Table 4.

No.	Yield strength Rp0.2 (MPa)	Tensile strength Rm (MPa)	Elongation A50 (%)	Punching hole expansion ratio (%)	Reaming hole expansion ratio (%)
Ex. 1	843	986	12.0	65	81
Ex. 2	829	996	13.0	56	75
Ex. 3	806	1009	14.5	53	71
Ex. 4	789	1035	16.5	48	66
Ex. 5	755	1049	18.5	45	65
Ex. 6	849	998	14.0	52	71
Ex. 7	862	1030	12.5	61	77
Ex. 8	814	982	14.0	56	76
Ex. 9	829	996	13.0	56	75
Ex. 10	918	1080	12.0	47	69
Ex. 11	953	1150	12.0	45	65
Ex. 12	871	1032	12.5	51	68
Ex. 13	826	991	14.0	56	78
CEx. 1	953	**1198**	**9.0**	67	86
CEx. 2	**689**	**946**	20.5	**32**	59
CEx. 3	923	1058	**10.0**	**31**	57
CEx. 4	796	983	**11.0**	**41**	69
CEx. 5	**753**	**945**	16.5	45	70
CEx. 6	**738**	**936**	16.5	48	70
CEx. 7	883	1051	**10.0**	**34**	61
CEx. 8	**1030**	**1203**	**9.5**	**28**	53
CEx. 9	**803**	**936**	14.5	68	99
CEx. 10	**762**	**896**	14.5	58	79
CEx. 11	809	**948**	14.0	59	82

[0074] As shown in Table 4, compared with the comparative steel plates of Comparative Examples 1-11, the 1000MPa-grade high hole expansion hot-rolled complex phase steel plates of Examples 1-13 according to the present disclosure have more excellent comprehensive mechanical properties.

[0075] In the present disclosure, Examples 1-13 adopted reasonable ratios of Cr, Mo in Table 1-1 and Table 1-2, with the addition of Ti and Nb at the same time to increase the precipitation strengthening effect in the annealing process, and also satisfied the hot rolling process of Table 2-1 and Table 2-2. The finally obtained products of the 1000MPa-grade high hole expansion hot-rolled complex phase steel plates of Examples 1-13 have the microstructure shown in Table 3.

[0076] Referring to Table 4, it can be seen that in the present embodiment, the 1000MPa-grade high hole expansion hot-rolled complex phase steel plates designed in Examples 1-13 have the yield strength of 755-953MPa, the tensile strength of 982-1150MPa, the elongation A50 of 12-18.5%, the punching hole expansion ratio of 45-65%, and the reaming hole expansion ratio of 65-81 %.

[0077] Compared with Examples 1-5, Comparative Examples 1-2 used the same steel grade A, but different coiling temperatures after hot-rolling . Among them, a lower coiling temperature selected as 380°C was used for Comparative Example 1 and the martensite content in the final microstructure reached 80%, which ultimately led to higher tensile strength and lower elongation. In contrast, a higher coiling temperature selected as 620°C was used for Comparative Example 2 and the ferrite content in the microstructure was low, resulting in a low bainite content and insufficient tensile strength of the steel.

[0078] Compared with Examples 6-8, Comparative Examples 3-6 used the same steel grade B, but their process did not satisfy the design requirement. Among them, due to the low midpoint temperature of Comparative Example 3, the time for cooling from the midpoint temperature to the coiling temperature in the laminar cooling process was shorter and the bainite phase transformation in the laminar cooling process was insufficient, resulting in a large proportion of the phase transformation of supercooled austenite in the coiling process and higher martensite content in the final microstructure. The elongation and hole expansion ratio of the obtained comparative steel are relatively low.

[0079] In Comparative Example 4, due to the low total finishing rolling reduction rate, only 20%, its recrystallization was insufficient, resulting in relatively coarse grains, and relatively low elongation and hole expansion ratio. In Comparative Example 5, due to the fact that in the hot rolling process of step (2), the rough rolling outlet temperature and the final rolling temperature of finishing rolling were low, coarser microalloy particles had precipitated during the rolling process and the contribution to the strength was not obvious, which ultimately led to insufficient tensile strength of the steel. In Comparative Example 6, because the heating temperature used in the hot rolling process of step (2) was low, only 1120 °C, it resulted in insufficient Nb and Ti contents, and the coarse (Ti, Nb) (C, N) particles were not completely solidly dissolved in the solid solution continuous casting process. Since its contribution to the strength was small, the tensile strength of the steel plate was insufficient.

[0080] Compared with Example 9, Comparative Example 7 used the same steel grade C. But in Comparative Example 7, the cooling rate after hot-rolling and coiling being 0.2 °C/s was too fast, it resulted in more martensite phase transformation and less bainite phase transformation in supercooled austenite after coiling, which ultimately led to lower elongation and hole expansion ratio of the steel.

[0081] Different from the above Comparative Examples 1-7, the final steels in Comparative Example 8-11 had poor performance because the chemical composition did not meet the requirements of the present disclosure.

[0082] In Comparative Example 8, due to the unreasonable ratio of Cr and Mo in the steel, the bainite phase transformation was low and the martensite and residual austenite phase transformation was high, which contributed more to the strength, but reduced the elongation and hole expansion ratio.

[0083] In Comparative Example 9, due to the low Ti content in the steel, the precipitation strengthening effect produced therein was weak and the contribution to the strength of the steel was small, resulting in insufficient strength of the final steel plate.

[0084] In Comparative Example 10, due to the high N content in the steel, a large amount of Ti was consumed, resulting in the precipitation of a large amount of massive TiN. The contribution of 5-20um TiN to the strength was small, which reduced the strength of the steel plate.

[0085] In Comparative Example 11, due to the low content of C and Mn in the steel, the solid solution strengthening and bainite phase transformation strengthening effects produced therein are weak, resulting in lower strength of the final steel plate.

[0086] Fig. 1 is a metallographic structure photograph of the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate in Example 3.

[0087] As shown in Fig.1, in the embodiment, the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate in Example 3 has a microstructure of 92% bainite + 8% martensite and residual austenite, wherein the grain size of bainite is 4.3 um and the grain size of martensite and residual austenite is in the range of 0.5-2um.

[0088] Fig. 2 is a metallographic structure photograph of the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate in Example 5.

[0089] As shown in Fig.2, in the embodiment, the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate in Example 5 has a microstructure of 85% bainite + 15% martensite and residual austenite, wherein the grain size of bainite is 5.0 um and the grain size of martensite and residual austenite is in the range of 0.5-3 um.

[0090] Fig. 3 is a metallographic structure photograph of the comparative steel in Comparative Example 6.

[0091] As shown in Fig.2, in the embodiment, the comparative steel in Comparative Example 6 has a microstructure of 20% bainite + 80% martensite, wherein the grain size of bainite is 3.0 um and the grain size of martensite is >3um.

[0092] It should be noted that the combinations of the various technical features inthe present disclosure are not limited to the combinations described in the claims of the present disclosure or the combinations described in the specific Examples. All technical features recorded in the present disclosure can be combined or associated freely in any way unless there is a contradiction between them.

[0093] It should also be noted that the Examples listed above are only specific embodiments of the present disclosure. Obviously, the present disclosure is not limited to the above examples, and variations or modifications made to them can be derived directly or contemplated easily by those skilled in the art from the contents of the present disclosure, and should all fall within the protection scope of the present disclosure.

Claims

1. A 1000MPa grade high-hole expansion hot-rolled complex phase steel plate, which comprises Fe and unavoidable impurity elements, wherein it further comprises the following chemical elements in percentage by mass:

at least one of C: 0.07-0.15%, Si: 0.1-0.8%, Mn: 1.5-2.2%, Al: 0.02-0.1%, Ti: 0.05-0.18%, Nb≤0.06%, B≤0.003%, and 0.2%≤Cr≤1.5%, 0.05%≤Mo≤0.5%;
wherein the mass percentages of N, Ti, Nb also satisfy: 0.01%≤(Ti-3.43N+0.52Nb)/4≤0.053%.

2. The 1000MPa grade high-hole expansion hot-rolled complex phase steel plate according to claim 1, wherein the mass percentages of the various chemical elements are:

at least one of C: 0.07-0.15%, Si: 0.1-0.8%, Mn: 1.5-2.2%, Al: 0.02-0.1%, Ti: 0.05-0.18%, Nb≤0.06%, B≤0.003%, 0.2%≤Cr≤1.5% and 0.05%≤Mo≤0.5%;with a balance of Fe and unavoidable impurity elements; preferably, 0.015%≤Nb≤0.06%;
wherein the mass percentages of N, Ti, Nb also satisfy: 0.01%≤(Ti-3.43N+0.52Nb)/4≤0.053%.

3. The 1000MPa grade high-hole expansion hot-rolled complex phase steel plate according to claim 1 or 2, wherein, among the unavoidable impurity elements, P is ≤0.02%, S is ≤0.005%, N is ≤0.005%.

4. The 1000MPa grade high-hole expansion hot-rolled complex phase steel plate according to claim 1 or 2, wherein the contents of Cr and Mo in the steel grade satisfy one of the following:

(1) when 0.2%≤Cr≤0.7%, the mass percentage of Mo satisfies 0.2%≤Mo≤0.35%;
(2) when 0.7%<Cr≤1.0%, the mass percentage of Mo satisfies 0.05%≤Mo<0.2%;
(3) when 1.0%<Cr≤1.5%, Mo is absent;
(4) when 0.35%<Mo0≤0.5%, Cr is absent.

5. The 1000MPa grade high-hole expansion hot-rolled complex phase steel plate according to claim 1 or 2, wherein the main body of the matrix of microstructure is bainite, and there are nanoscale precipitates on the matrix.

6. The 1000MPa grade high-hole expansion hot-rolled complex phase steel plate according to claim 5, wherein the volume fraction of bainite is ≥85%.

7. The 1000MPa grade high-hole expansion hot-rolled complex phase steel plate according to claim 1 or 2, wherein the matrix of the microstructure further comprises martensite and/or residual austenite.

8. The 1000MPa grade high-hole expansion hot-rolled complex phase steel plate according to claim 5, wherein the size of the nanoscale precipitates is 3-20nm.

9. The 1000MPa grade high-hole expansion hot-rolled complex phase steel plate according to claim 7, wherein the grain size of bainite is ≤6um; and the grain size of martensite and/or residual austenite is ≤3um.

10. The 1000MPa grade high-hole expansion hot-rolled complex phase steel plate according to claim 1 or 2, wherein the microstructure of the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate contains martensite with a volume fraction of 85~96% and martensite and residual austenite with a total volume fraction of 4~15%, wherein the grain size of bainite is in the range of 3.2-5um, and the grain size of martensite is in the range of 0.5-3um.

11. The 1000MPa grade high-hole expansion hot-rolled complex phase steel plate according to claim 1 or 2, wherein the properties satisfy: a yield strength of ≥750MPa, a tensile strength of 950-1150MPa, an elongation A50 of >_12°i_o, a punching hole expansion ratio of ≥45%, a reaming hole expansion ratio of ≥65%.

12. A manufacturing method of the 1000MPa grade high-hole expansion hot-rolled complex phase steel plate according to any one of claims 1-11, wherein the method comprises the following steps:

(1) smelting and casting;
(2) hot-rolling: wherein the slab is heated to 1200-1300°C and held; then rolled, wherein the rough rolling outlet temperature is controlled at 1000-1080°C and the final rolling temperautre of finishing rolling is 840-950°C;
(3) a two-stage laminar cooling is performed to water cool the steel plate to the coiling temperature: wherein the average cooling rate in the first stage is ≥ 100°C/s, the average cooling rate in the second stage is ≥3°C/s, the midpoint temperature between the first stage cooling and the second stage cooling is bainite phase transition temperature Bs±30°C, the threading rate is controlled at 7-12m/s, and the time for cooling from the midpoint temperature to the coiling temperature is controlled at ≥ 4.5s, wherein $Bs=844-597\times C+127\times C^2-92\times Mn+8\times Mn^2-32\times Cr+2.2\times Cr^2-42\times Mo$, where each chemical element in the formula represents the value before the percentage sign of the mass percentage of the corresponding chemical element;
(4) coiling: the coiling temperature is controlled at 430-600°C, the steel after coiling is cooled to room temperature at a cooling rate of ≤0.1°C/s;
(5) pickling.

13. The manufacturing method according to claim 12, wherein, in step (2), the total rolling reduction rate is controlled at ≥80%, and the total finishing rolling reduction rate is controlled at ≥50%; preferably, the total rolling reduction rate is 90%-95%, and the total finishing rolling reduction rate is 85%-90%; further preferably, the thickness of the obtained finished steel plate is not more than 5mm.

14. The manufacturing method according to claim 12, wherein, in step (3), the time for cooling from the midpoint temperature to the coiling temperature is ≥6s.

15. The manufacturing method according to claim 12, wherein, in step (4), the coiling temperature is controlled at 430-580°C.

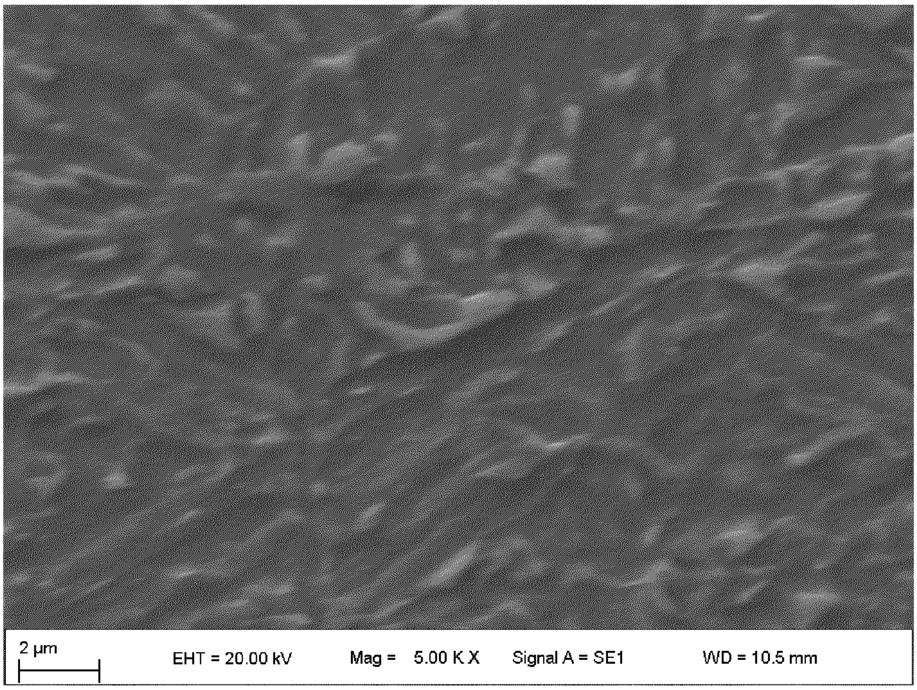
2 µm
EHT = 20.00 kV
Mag = 5.00 K X
Signal A = SE1
WD = 10.5 mm

Fig. 1

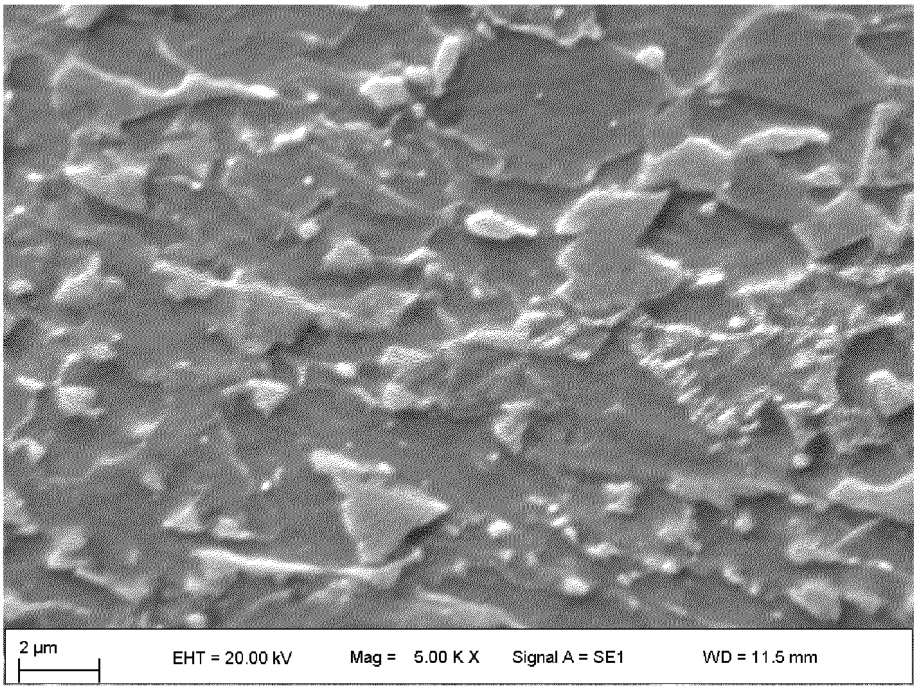
2 µm
EHT = 20.00 kV
Mag = 5.00 K X
Signal A = SE1
WD = 11.5 mm

Fig. 2

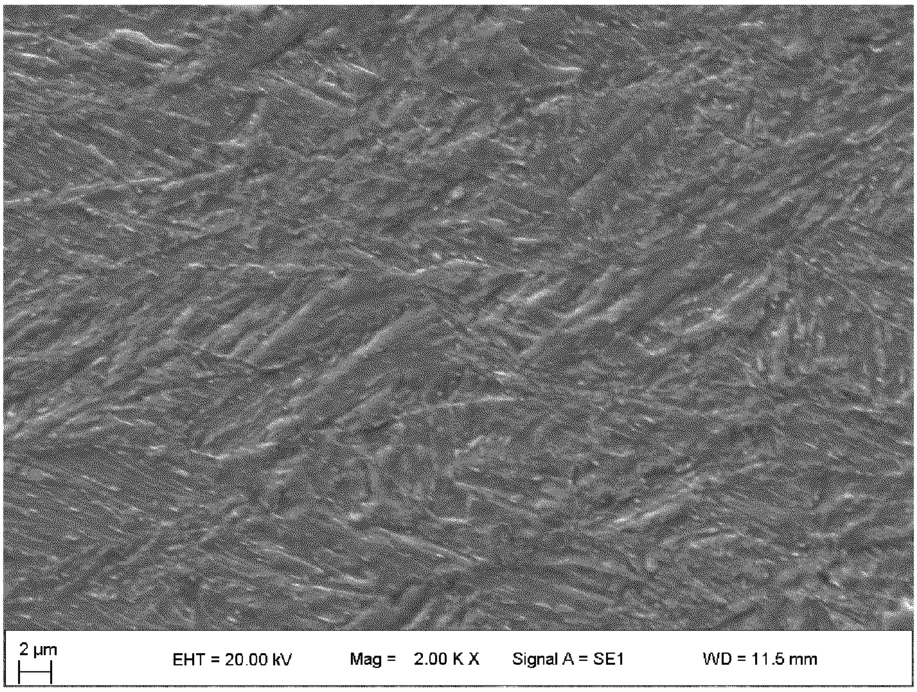

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2023/099840

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/02(2006.01)i; C22C 38/38(2006.01)i; C22C 38/06(2006.01)i; C22C 38/14(2006.01)i; C22C 38/32(2006.01)i; C22C 38/26(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC:C22C

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)

CNTXT, ENTXT, SIPOABS, DWPI, CNKI: 钢, 铁, Fe, 碳, C, 硅, Si, 锰, Mn, 铝, Al, 钛, Ti, 铌, Nb, 硼, B, 铬, Cr, 钼, Mo, steel, iron, ferro+, carbon, silicon, manganese, aluminium, titanium, niobium, boron, chrom+, molybdenum

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 108441763 A (MAGANG (GROUP) HOLDING CO., LTD.) 24 August 2018 (2018-08-24) description, paragraphs 6-53	1-15
X	CN 114107791 A (BAOSHAN IRON & STEEL CO., LTD.) 01 March 2022 (2022-03-01) description, paragraphs 8-44	1-15
X	CN 114107792 A (BAOSHAN IRON & STEEL CO., LTD.) 01 March 2022 (2022-03-01) description, paragraphs 9-58	1-15
X	WO 2022042727 A1 (BAOSHAN IRON & STEEL) 03 March 2022 (2022-03-03) description, page 3, line 5 to page 8, line 15	1-15
X	WO 2022042728 A1 (BAOSHAN IRON & STEEL) 03 March 2022 (2022-03-03) description, paragraphs 9-50	1-15

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

* Special categories of cited documents:
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"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 September 2023	**20 September 2023**
Name and mailing address of the ISA/CN **China National Intellectual Property Administration (ISA/CN)** **China No. 6, Xitucheng Road, Jimenqiao, Haidian District, Beijing 100088**	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2023/099840

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
CN 108441763 A	24 August 2018	CN 108441763 B	19 November 2019
CN 114107791 A	01 March 2022	WO 2022042728 A1	03 March 2022
		KR 20230059806 A	03 May 2023
CN 114107792 A	01 March 2022	WO 2022042733 A1	03 March 2023
WO 2022042727 A1	03 March 2022	KR 20230059808 A	03 May 2023
		EP 4206348 A1	05 July 2023
		CN 114107789 A	01 March 2022
		CN 114107789 B	09 May 2023
WO 2022042728 A1	03 March 2022	KR 20230059806 A	03 May 2023
		EP 4206349 A1	05 July 2023
		CN 114107791 A	03 March 2022

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- CN 106119702 A **[0006]**
- CN 114107797 A **[0007]**
- CN 113122769 A **[0008]**
- GB 22812010 T **[0072]**