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

(72) Inventors:
- **XUE, Peng**
  Shanghai 201900 (CN)
- **ZHU, Xiaodong**
  Shanghai 201900 (CN)
- **LI, Wei**
  Shanghai 201900 (CN)

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

(54) **1,300-MPA-GRADE OR MORE COLD-ROLLED STEEL PLATE HAVING HIGH EXTENSION AND HIGH HOLE-EXPANSION PERFORMANCE AND MANUFACTURING METHOD THEREFOR**

(57) Disclosed in the present invention is a 1,300-MPa-grade or more cold-rolled steel plate having high extension and high hole-expansion performance and a manufacturing method therefor. The cold-rolled steel plate contains Fe and inevitable impurities, and further contains the following chemical elements in percentage by mass: C: 0.15%-0.30%; Si: 0.3%-0.5%; Mn: 1.8%-2.5%; Al: 0.01 %-0.03%; B: 0.001%-0.003%; and Ti: 0-0.05%. Moreover, the percentage by mass of C and Mn satisfies: C+Mn/6≥0.52. A microstructure of the cold-rolled steel plate has nano-precipitates having an average diameter less than 30 nm. The cold-rolled steel plate has ultra-high strength, high extension and high hole-expansion performance, and excellent molding performance.

Description

Technical Field

[0001] The present disclosure relates to a steel and a manufacturing method thereof, in particular to a cold-rolled steel plate and a manufacturing method thereof.

Background Art

[0002] In recent years, with the exaggeration of global energy crisis and environmental problems, "energy saving" and "safety" have become the main development direction of the automobile manufacturing industry. It is one of the important measures to reduce energy consumption and emission reduction by adopting lightweight design to reduce vehicle weight in the manufacture of automobiles.

[0003] In recent years, the use of ultra-high-strength steel in the automotive industry is very common. Ultra-high-strength steel has good mechanical properties and use performance, which can be used to manufacture automotive structural parts, and realize the lightweight of parts, so as to effectively reduce the weight of vehicles.

[0004] In the current automotive industry, there are many varieties of ultra-high-strength steels for automobiles, which usually includes: dual phase steel, quenched ductile steel, bainite steel and complex phase steel. Among them, dual phase steel and quenched ductile steel have good strength and plasticity, but their hole expansion ratio (about 20% - 35%) is much lower than that of traditional automotive mild steel. Bainite steel and complex phase steel have high hole expansion ratio, but their elongation is too low. Therefore, in order to satisfy more diverse market needs, it is necessary to develop an ultra-high-strength cold-rolled steel plate with high elongation and high hole expansion performance.

[0005] Therefore, in view of the technical problems of the existing ultra-high-strength steel, it is expected to obtain a 1,300-MPa-grade or more cold-rolled steel plate having high elongation and high hole-expansion performance in the present disclosure, so as to ensure that it has excellent formability while obtaining ultra-high strength.

[0006] In the current prior art, although some researchers have developed ultra-high-strength steel, the high elongation and high hole expansion performance corresponding to that of the steel plate of the present disclosure cannot be obtained in these technical solutions.

[0007] For example, Chinese patent publication No. CN104451436A, published on March 25, 2015, with the title of "A bainite-martensite-austenite complex phase wear-resistant steel plate and a manufacturing method thereof" discloses a bainite-martensite-austenite complex phase wear-resistant steel plate and a manufacturing method thereof. It comprises the following chemical composition in percentage by weight: C: 0.20-0.40; Mn: 0.30-1.50; Si: 0.80-1.20; Cr: 0.60-1.00; Ni: 0.20-0.60; Mo: 0.20-0.40; Cu: 0.20-0.50; B: 0.0005-0.003; S≤0.010, P≤0.015, and a balance of Fe and unavoidable impurity elements. The bainite-martensite-residual austenite complex phase structure with a volume fraction of residual austenite of 5-15% can be obtained by metal rolling. The material has a yield strength of greater than 1000MPa, a tensile strength of greater than 1300MPa, an elongation of greater than 15% and a hardness of HB420-500. The machinability and welding performance meet the requirements of equipment manufacturing. The abrasive grain wear resistance is more than 1.3 times that of Hardox450 and more than 1.5 times that of Hardox450 in weakly acidic environments. In this technical solution, the addition of high Si and Al is used to obtain sufficient residual austenite, and high elongation is obtained through the TRIP effect of residual austenite. The hole expansion performance of the steel is not considered.

[0008] For another example, Chinese Patent publication No. CN102776438A, published on November 14, 2012, with a title of "A niobium-lanthanum microalloyed Mn-B series ultra-high-strength steel plate and a heat treatment process therefor" discloses a niobium-lanthanum microalloyed Mn-B series ultra-high-strength steel plate and a heat treatment process therefor. The chemical composition of the steel plate and the content thereof (weight percentage) are: C 0.14%-0.35%, Mn 1.5%-2.0%, Si 0.6%-1.0%, P≤0.015%, S≤0.002%, Nb 0.01%-0.06%, B 0.0005%-0.0040%, La 0.001%-0.5%, with a balance of Fe and unavoidable impurities. In this technical solution, the heat treatment process adopted is as follows: the austenitization temperature is 880-940 °C, and water quenching is performed after holding for 0.5-5 hours; the tempering temperature is 190-250°C, and the holding time is 1-15 hours. In the technical solution, the designed steel plate has excellent mechanical properties with a tensile strength reaching 1200-1400MPa, a yield strength of 1000-1300MPa, and an elongation of 6-15%. It has the characteristics of low production cost and can be used in industrial production of 5-25mm thickness specification steel plate.

[0009] For another example, Chinese Patent publication No. CN102321841A, published on January 18, 2012, with a title of "A steel for track plate with a tensile strength up to 1300MPa and a manufacturing method thereof", discloses a steel for track plate with a tensile strength up to 1300MPa and a manufacturing method thereof. It comprises the following chemical composition in percentage by weight: C: 0.20-0.30%, Mn: 0.80-1.40%, Si: 0.15-0.35%, P: 0-0.015%, S: 0-0.016%, Cr: 0-0.30%, Ni: 0-0.25%, Cu: 0-0.30%, Ti: 0.01-0.02%, Al: 0.02-0.06%, B: 0.0005-0.0035%, with a balance of Fe and unavoidable impurity elements. The steel designed in the technical solution has a tensile strength reaching 1340MPa or more, the elongation after fracture of less than 12%, "U" notch impact absorption work of greater than 72J, high strength, few quenching cracks and internal cracks, and long service life.

[0010] In the two patent documents of the above-mentioned CN102776438A and CN102321841A, the ultra-high-strength steels have good mechanical properties by adding microalloying elements such as niobium, lanthanum, nickel, cadmium, copper, etc. respectively. The performance of the steel plate finally prepared cannot reach the high elongation and high hole expansion performance index covered by the present disclosure.

Summary

[0011] The object of the present disclosure is to provide a 1,300-MPa-grade or more cold-rolled steel plate having high elongation and high hole-expansion performance. By reasonable chemical composition design of the 1,300-MPa-grade or more cold-rolled steel plate and manufacturing process, it has the characteristics of high elongation and high hole expansion ratio while having ultra-high strength. It has excellent molding performance and thus can be used in automobile industry and has a good application prospect.

[0012] In order to achieve the above object, the present disclosure provides a 1,300-MPa-grade or more cold-rolled steel plate having high elongation and high hole-expansion performance, which comprises Fe and unavoidable impurity elements, as well as the following chemical elements in percentage by mass:

C: 0.15%-0.30%, Si: 0.3%-0.5%, Mn: 1.8%-2.5%, Al: 0.01%-0.03%, B: 0.001-0.003%; Ti: 0-0.05%;
and the mass percentages of C and Mn satisfy: C+ Mn/6≥0.52%;
wherein the cold-rolled steel plate has a microstructure comprising nanoprecipitates with an average diameter of less than 30nm.

[0013] Further, in the 1,300-MPa-grade or more cold-rolled steel plate according to the present disclosure, the mass percentages of the various chemical elements are:

C: 0.15%-0.30%, Si: 0.3%-0.5%, Mn: 1.8%-2.5%, Al: 0.01%-0.03%, B: 0.001-0.003%; Ti: 0-0.05%, with a balance of Fe and unavoidable impurity elements;
and the mass percentages of C and Mn satisfy: C+ Mn/6≥0.52%;
wherein the cold-rolled steel plate has a microstructure comprising nanoprecipitates with an average diameter of less than 30nm.

[0014] Further, in the 1,300-MPa-grade or more cold-rolled steel plate according to the present disclosure, the microstructure comprises nanoprecipitates with an average diameter of 15-28nm.

[0015] In the 1,300-MPa-grade or more cold-rolled steel plate according to the present disclosure, the various chemical elements are designed according to the following principles:

C: in the 1,300-MPa-grade or more cold-rolled steel plate according to the present disclosure, the addition of the C element can not only improve the strength of the steel, but also ensure the occurrence of martensitic phase transformation. The inventors find that when the mass percentage of the C element in the steel is less than 0.15%, the strength of the steel plate will be affected and it is not conducive to the formation and stability of residual austenite. When the mass percentage of the C element in the steel is higher than 0.30%, it is easy to cause too high martensite hardness and lead to coarse grain size, which is not conducive to the forming performance of the steel plate. Therefore, considering the influence of the C element content on the properties of the steel, in the 1,300-MPa-grade or more cold-rolled steel plate of the present disclosure, the mass percentage content of the C element is controlled in the range of 0.15%-0.30%.

Si: in the 1,300-MPa-grade or more cold-rolled steel plate according to the present disclosure, Si can play a role in solution strengthening. In the 1,300-MPa-grade or more cold-rolled steel plate according to the present disclosure, the mass percentage of Si is controlled in the range of 0.3%-0.5%.

Mn: in the 1,300-MPa-grade or more cold-rolled steel plate according to the present disclosure, the addition of the Mn element can not only improve the hardenability of the steel, but also effectively improve the strength of the steel plate. The mass percentage of Mn in the steel is selected in the range of 1.8%-2.5% because of the following reasons: in the present disclosure, a large amount of carbide produced during hot rolling will result in insufficient carbon equivalent in the matrix structure. When the mass percentage of Mn in the steel is less than 1.8%, the insufficient carbon equivalent will lead to insufficient hardenability of the prepared steel, and it cannot produce enough martensite in the annealing process and the strength of the steel plate is insufficient. When the mass percentage of Mn in the steel is higher than 2.5%, the carbon equivalent will be increased significantly, which has a negative impact on the weldability and delayed cracking resistance of the steel. Therefore, considering the influence of Mn element content on the steel properties, in the 1,300-MPa-grade or more cold-rolled steel plate according to the present disclosure, the mass percentage of Mn is controlled in the range of 1.8%-2.5%.

Al: in the 1,300-MPa-grade or more cold-rolled steel plate according to the present disclosure, the addition of an appropriate amount of Al in the steel can play a role in deoxidation and grain refinement. Therefore, in order to bring into play the beneficial effect of the Al element, in the present disclosure, the mass percentage of the Al element is controlled in the range of 0.01% and 0.03%.

B: in the 1,300-MPa-grade or more cold-rolled steel plate according to the present disclosure, B is an element that can significantly improve the hardenability of the steel, and the addition of B element can promote martensitic formation and ensure the strength of martensitic steel. However, it should be noted that the content of B element in the steel should not be too high. After the grain boundary defects are filled, if more B is added, the plasticity of the steel will decrease due to the precipitation of "boron phase" of the grain boundaries. The inventors find that when the content of the B element in the steel is less than 0.001%, it cannot effectively play the role of the B element. When the content of the B element in the steel is higher than 0.003%, it will adversely affect the shaping of the steel. Therefore, considering the influence of B element content on the steel properties, in the 1,300-MPa-grade or more cold-rolled steel plate according to the present disclosure, the mass percentage of B is controlled in the range of 0.001%-0.003%.

Ti: in the 1,300-MPa-grade or more cold-rolled steel plate according to the present disclosure, the addition of the strong carbide-forming element **Ti** shows a strong inhibition of austenite grain growth at high temperatures. At the same time, the addition of **Ti** to the steel also helps to refine the grains. Therefore, in order to bring into play the beneficial effect of the **Ti** element, in the present disclosure, the mass percentage of the **Ti** element is controlled in the range of 0-0.05%. In some embodiments, the mass percentage of the Ti element is controlled in the range of 0.01-0.05%.

[0016] In addition, it should be noted that, in order to ensure that the strength of the steel is larger than 1300MPa, in the 1,300-MPa-grade or more cold-rolled steel plate according to the present disclosure, while controlling the mass percentage of a single chemical element, the inventors further control the mass percentage of C and Mn elements in the steel to satisfy the following requirements: C+Mn/6≥0.52%. In some embodiments, the mass percentages of C and Mn in the steel are controlled to satisfy 0.52%≤C+Mn/6≤0.61%. In some embodiments, the mass percentages of C and Mn in the steel are controlled to satisfy 0.55%≤C+Mn/6≤0.605%.

[0017] Further, in the 1,300-MPa-grade or more cold-rolled steel plate according to the present disclosure, among the unavoidable impurity elements, P is ≤0.015%, S is ≤0.003%, N is ≤0.006%.

[0018] In the 1,300-MPa-grade or more cold-rolled steel plate according to the present disclosure, P, S and N are impurity elements in the steel. 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. Therefore, except for special requirements, the content of the P element in the steel should be reduced as much as possible. In particular, the mass percentage of the P element is controlled at P≤0.015%.

[0019] In addition, MnS formed by compounding with the impurity element S can seriously affect the formability of the steel. So, in the present disclosure, the mass percentage of the S element in the steel needs to be strictly controlled to satisfy S≤0.003%. Further, because the impurity element N is easy to cause cracks or bubbles on the surface of the slab, in the present disclosure, the mass percentage of the N element is controlled to satisfy N≤0.006%.

[0020] Further, in the 1,300-MPa-grade or more cold-rolled steel plate according to the present disclosure, the microstructure is residual austenite + fine massive martensite + bainite + said nanoprecipitates.

[0021] Further, in the 1,300-MPa-grade or more cold-rolled steel plate according to the present disclosure, the volume phase fraction of martensite is ≥55%, and the volume phase fraction of bainite is more than 0 and <15%.

[0022] Further, in the 1,300-MPa-grade or more cold-rolled steel plate according to the present disclosure, the volume phase fraction of martensite is 55~90%, preferably 70~86%.

[0023] Further, in the 1,300-MPa-grade or more cold-rolled steel plate according to the present disclosure, the volume phase fraction of bainite is 7~14%.

[0024] Further, in the 1,300-MPa-grade or more cold-rolled steel plate according to the present disclosure, the diameter of martensite is no more than 10 μm.

[0025] Further, in the 1,300-MPa-grade or more cold-rolled steel plate according to the present disclosure, the average diameter of martensite is in the range of 5-9 μm.

[0026] In the present disclosure, the composition designed for the steel of the present disclosure is a composition system dominated by C+Mn+B, and the volume phase fraction of martensite can be guaranteed to be greater than 55% through the matching design of C, Mn and B elements. At the same time, it ensures that the bainite C curve is shifted to the left, and the ferrite and pearlite C curves are shifted to the right, so as to ensure that the final microstructure comprises bainite with a certain volume fraction, and the volume phase fraction of bainite is less than 15%.

[0027] It should be noted that, in the present disclosure, through the reasonable design of alloying elements and manufacturing process, a microstructure of residual austenite + fine massive martensite (with a diameter of not more than 10 microns) + bainite + nanoprecipitates is particularly obtained, wherein the average diameter of the nanoprecipitates is less than 30nm. The structure determines that the cold-rolled steel plate described in the present disclosure has good elongation and hole expansion ratio.

[0028] Further, in the 1,300-MPa-grade or more cold-rolled steel plate according to the present disclosure, its properties satisfy:

when a tensile strength is 1300-1400MPa, an elongation is higher than 10% and a hole expansion ratio is higher than 40%; when the tensile strength is greater than 1400 and ≤1500MPa, the elongation is higher than 9% and the hole expansion ratio is higher than 40%; when the tensile strength is greater than 1500MPa, the elongation is higher than 8% and the hole expansion ratio is higher than 40%.

[0029] Accordingly, another object of the present disclosure is to provide a manufacturing method for the above 1,300-MPa-grade or more cold-rolled steel plate. Through optimized design of manufacturing process, the 1,300-MPa-grade or more cold-rolled steel plate prepared by the manufacturing method has good elongation performance and high hole expansion performance while having ultra-high strength.

[0030] To achieve the above purpose, the present disclosure provides a manufacturing method for the above 1,300-MPa-grade or more cold-rolled steel plate, comprising steps of:

(1) smelting and casting;
(2) hot-rolling;
(3) hot coiling insulation cover annealing: wherein the steel plate is rapidly subjected to insulation cover annealing after coiling, wherein an annealing time is 0.5-6 hours, and a temperature drop per hour is less than or equal to 6 °C;
(4) cold rolling;
(5) annealing: wherein an annealing soaking temperature is controlled at 830-860°C with a holding time of 40-80s, then the steel plate is cooled at a cooling rate of 5-15°C/s to 730-780°C; then cooled to an isothermal insulation temperature at a rate of 50-700°C/s;
(6) isothermal insulation treatment: wherein an insulation temperature is 400-550°C, and an insulation time is 100-300s;
(7) cooling: wherein the steel plate is cooled to room temperature at a rate of 30°C/s-100°C/s;
(8) temper rolling.

[0031] In this technical solution designed in the present disclosure, the inventors have optimized the design of the manufacturing process, and have improved the process flow.

[0032] In the present disclosure, the adoption of insulation cover annealing immediately after hot coiling is one of the unique innovations of the present inventors. Based on the reasonable composition and process design, in the process of step (3), the steel is held and annealed at a lower temperature for a long time, so that fine and diffusely distributed nanoprecipitates ε carbides will be generated. Then, through reasonable process design, the fine diffused ε carbides can be inherited into the final continuously annealed steel plate product. This kind of diffusely precipitated carbide can not only improve the overall strength, reduce the strength difference in each phase, reduce the strength difference between grain boundaries and intragranules, but also strengthen the grain boundaries during the deformation process, so as to improve the strength and the hole expansion ratio of the steel.

[0033] In addition, in the above technical solution of the present disclosure, in the annealing step of step (5), the annealing soaking temperature is limited in the range of 830-860 °C, because what is to be achieved is a complete austenitization temperature soaking annealing. When the annealing soaking temperature is lower than 830°C, complete austenitization cannot be achieved to provide sufficient tensile strength. When the annealing soaking temperature is higher than 860°C, the hole expansion ratio of the steel will be significantly reduced. Correspondingly, in some preferred embodiments, the annealing soaking temperature can be preferably controlled in the range of 830-850 °C, so as to ensure not only the complete austenitization, but also ensure that the obtained grain size is not coarsened, thereby maintaining fine diffused nanoprecipitates with an average size of less than 30 nm in the final microstructure.

[0034] In addition, the austenite isothermal insulation treatment process of step (6) designed in the present disclosure is another unique innovation point of the present disclosure, which is controlled above the bainite phase transition end temperature after annealing for isotherm. This process determines the shape and size of the final martensite. The process mainly comprises: full austenitization temperature soaking (i.e., the soaking temperature of continuous annealing is 830-860 °C) - rapid cooling (i.e., cooling to an isothermal insulation temperature at a rate of 50-700 °C/s) - bainite phase transition zone insulation (i.e., isothermal insulation treatment, with the insulation temperature of 400-550 °C) - cooling at a controlled cooling rate. In the process of austenite isothermal quenching, part of the bainite is obtained first, which can ensure that the subsequent martensite does not grow violently around the small diffused nuclei of bainite, so as to finally form a fine massive martensite.

[0035] In the cold-rolled steel plate designed in the present disclosure, the martensite in the final microstructure is a fine massive martensite with a diameter of not more than 10 microns, and the bainite in the steel can be controlled at 15% or less through reasonable process design, so as to avoid causing great influence on the strength of the steel. Correspondingly, through the subsequent process design of reasonably controlling the cooling rate, it is necessary to ensure that the martensite structure with a volume phase fraction of ≥55% is generated, and that some of the untransformed austenite is still retained in the form of residual austenite after martensite phase transformation. The fine martensite structure is conductive to the strength and elongation, while the residual austenite greatly increases the elongation through the TRIP effect.

[0036] In the manufacturing method of the present disclosure, the isothermal insulation temperature and the isothermal insulation time of each specific component need to be specifically set according to the dynamic CCT curve.

[0037] In step (6) designed by the present disclosure, in the isothermal insulation treatment, the insulation temperature is controlled at 400-550 °C, and the insulation time is controlled at 100-300s. When the insulation temperature is lower than 400 °C or the insulation time is less than 100s, it is not conducive to the formation of bainite, and it is not conducive to the formation of residual austenite from the carbon enrichment of the untransformed austenite. When the insulation temperature is higher than 550 °C or the insulation time is higher than 300s, it cannot be guaranteed that the nanoprecipitates produced by hot rolling will not be coarsened.

[0038] Further, in the manufacturing method according to the present disclosure, wherein, in step (2), the steel plate is heated to 1100-1250°C and held for 0.5h or more (such as 0.5~2h), then hot rolled at a temperature of Ar3 or higher, and rapidly cooled at a rate of 30-80°C/s after rolling, wherein the coiling temperature is controlled at 150-250°C.

[0039] Further, in the manufacturing method according to the present disclosure, in step (2), the hot rolling temperature is not higher than 920 °C.

[0040] Further, in the manufacturing method according to the present disclosure, in step (2), the coiling temperature is preferably 150-230 °C.

[0041] Further, in the manufacturing method according to the present disclosure, in step (3), the starting temperature of insulation cover annealing is the same as the coiling temperature, and the temperature dropping rate is 2-6 °C per hour.

[0042] Further, in the manufacturing method according to the present disclosure, in step (4), the cold rolling reduction rate is controlled at 50-70%.

[0043] Further, in the manufacturing method according to the present disclosure, in step (5), the annealing soaking temperature is 830-850°C.

[0044] Further, in the manufacturing method according to the present disclosure, in step (8), the temper rolling rate is 0-0.3%.

[0045] Compared with the prior art, the 1,300-MPa-grade or more cold-rolled steel plate and the manufacturing method thereof according to the present disclosure have the following advantages and beneficial effects:

The present disclosure develops a new 1,300-MPa-grade or more cold-rolled steel plate and a manufacturing method thereof. Through reasonable design of composition matching and process, a 1,300-MPa-grade or more cold-rolled steel plate having both high elongation and high hole expansion performance can be obtained.

[0046] The 1,300-MPa-grade or more cold-rolled steel plate has very excellent mechanical properties, and its microstructure of residual austenite + fine massive martensite + bainite + nanoprecipitates can ensure that the steel plate has excellent elongation, hole expansion performance and good formability. The properties of the cold-rolled steel plate designed in the present disclosure satisfy: when the tensile strength is 1300-1400MPa, the elongation is higher than 10% and the hole expansion ratio is higher than 40%; when the tensile strength is greater than 1400 and ≤1500MPa, the elongation is higher than 9% and the hole expansion ratio is higher than 40%; when the tensile strength is greater than 1500MPa, the elongation is higher than 8% and the hole expansion ratio is higher than 40%. It can be effectively used in the automotive industry and has good promotion prospects and application value.

Detailed Description

[0047] The 1,300-MPa-grade or more cold-rolled steel plate having high elongation and high hole-expansion performance according to the present disclosure and the manufacturing method therefor will be further interpreted and explained below in combination with specific examples, but the interpretation and explanation do not constitute an undue limitation to the technical solution of the present disclosure.

Example 1-18

[0048] Table 1 lists the mass percentages of various chemical elements in the 1,300-MPa-grade or more cold-rolled steel plates of Examples 1-18.

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

No.	Chemical element									C+ Mn/6 (wt%)
	C (wt%)	Si (wt%)	Mn (wt%)	Al (wt%)	P (wt%)	S (wt%)	N (wt%)	Ti (wt%)	B (wt%)	
Ex. 1	0.153	0.34	2.42	0.023	0.012	0.0029	0.0012	0.032	0.0022	0.556
Ex. 2	0.154	0.35	2.43	0.023	0.014	0.0028	0.0012	0.033	0.0023	0.559
Ex. 3	0.154	0.33	2.42	0.022	0.014	0.0028	0.0015	0.031	0.0023	0.557
Ex. 4	0.296	0.47	1.81	0.026	0.005	0.0016	0.0047	0.047	0.0016	0.598
Ex. 5	0.292	0.48	1.82	0.027	0.008	0.0017	0.0045	0.049	0.0016	0.595
Ex. 6	0.293	0.49	1.83	0.024	0.005	0.0017	0.0046	0.047	0.0017	0.598
Ex. 7	0.189	0.41	2.45	0.012	0.015	0.0012	0.0026	0.021	0.0027	0.597
Ex. 8	0.187	0.42	2.46	0.011	0.015	0.0013	0.0027	0.024	0.0028	0.597
Ex. 9	0.188	0.43	2.45	0.011	0.012	0.0012	0.0026	0.023	0.0029	0.596
Ex. 10	0.267	0.36	1.93	0.029	0.004	0.0025	0.0035	0.013	0.0011	0.589
Ex. 11	0.265	0.32	2.01	0.029	0.005	0.0022	0.0036	0.015	0.0012	0.600
Ex. 12	0.263	0.37	2.03	0.029	0.005	0.0025	0.0034	0.014	0.0013	0.601
Ex. 13	0.202	0.45	2.23	0.021	0.009	0.0012	0.0057	0.028	0.0022	0.574
Ex. 14	0.204	0.43	2.23	0.026	0.010	0.0012	0.0052	0.025	0.0022	0.576
Ex. 15	0.205	0.48	2.25	0.022	0.011	0.0012	0.0053	0.027	0.0026	0.580
Ex. 16	0.245	0.31	2.05	0.014	0.009	0.0012	0.0044	0.033	0.0011	0.587
Ex. 17	0.244	0.43	2.02	0.017	0.008	0.0017	0.0047	0.037	0.0012	0.581
Ex. 18	0.246	0.50	2.05	0.015	0.008	0.0012	0.0045	0.032	0.0011	0.588

[0049] The 1,300-MPa-grade or more cold-rolled steel plates of Examples 1-18 of the present disclosure were all prepared with the following steps:

(1) the chemical compositions shown in Table 1 were smelted and casted to obtain a cast slab.
(2) hot-rolling: the obtained slab was firstly heated to 1100-1250°C and held for 0.5h or more, then hot rolled at a temperature of Ar3 or higher, and rapidly cooled at a rate of 30-80°C/s after rolling, then coiled after it was cooled to a coiling temperature, wherein the coiling temperature is controlled at 150-250°C.
(3) hot coiling insulation cover annealing: wherein the steel plate was quickly subjected to insulation cover annealing after coiling, wherein an annealing time was controlled at 0.5-6 hours, and the insulation cover used the internal heat of the steel coil, the temperature drop per hour was less than 6°C;
(4) cold rolling: the cold rolling reduction rate was controlled at 50-70%;
(5) annealing: wherein the annealing soaking temperature was controlled at 830-860°C, preferably 830-850°C, with a holding time of 40-80s, then the steel plate was cooled at a cooling rate of 5-15°C/s to 730-780°C; then cooled to an isothermal insulation temperature at a rate of 50-700°C/s;
(6) isothermal insulation treatment: the annealed steel plate was subjected to isothermal insulation treatment, wherein the insulation temperature was controlled at 400-550°C, and the insulation time was controlled at 100-300s;
(7) cooling: wherein the steel plate after isothermal insulation treatment was cooled to room temperature at a rate of 30°C/s-100°C/s;
(8) temper rolling : the temper rolling rate was controlled at 0-0.3%.

[0050] The chemical compositions designed for the 1,300-MPa-grade or more cold-rolled steel plates in Examples 1-18 and the relevant process all met the specification requirements designed according to the present disclosure.
[0051] Table 2-1 and Table 2-2 list the specific process parameters for the 1,300-MPa-grade or more cold-rolled steel plates of Examples 1-18 in the above process steps.

Table 2-1.

No .	Step (2)					Step (3)			Step (4)
	Heating temperature (°C)	Holding time (h)	Hot rolling temperature (°C)	Cooling rate (°C/s)	Coiling temperature (°C)	Initial temperature of annealing (°C)	Annealing time (h)	Temperature drop rate (°C/h)	Cold rolling reduction rate (%)
Ex. 1	1220	0.5	870	80	230	230	0.5	5.4	50
Ex. 2	1220	0.5	870	80	230	230	0.5	2.5	50
Ex. 3	1220	0.5	870	80	230	230	0.5	5.3	50
Ex. 4	1250	2	890	30	160	160	1	2.6	55
Ex. 5	1250	2	890	30	160	160	1	4.8	55
Ex. 6	1250	2	890	30	160	160	1	3.6	55
Ex. 7	1100	1.5	920	50	210	210	1.5	3.2	65
Ex. 8	1100	1.5	920	50	210	210	1.5	3.2	65
Ex. 9	1100	1.5	920	50	210	210	1.5	3.0	65
Ex. 10	1200	1	910	40	200	200	4	4.1	70
Ex. 11	1200	1	910	40	200	200	4	5.2	70
Ex. 12	1200	1	910	40	200	200	4	2.3	70
Ex. 13	1140	2.5	880	60	150	150	6	2.3	65
Ex. 14	1140	2.5	880	60	150	150	6	2.5	60
Ex. 15	1140	2.5	880	60	150	150	6	2.7	55
Ex. 16	1120	0.5	870	30	220	220	0.5	4.1	70
Ex. 17	1200	1	890	60	160	160	3	3.5	65
Ex. 18	1250	1.5	920	80	200	200	6	3.7	50
Note: in the above Table 2-1, the hot-rolling temperatures used in Examples 1-18 were >Ar3, and Ar3 within the range of process requirement in each Example was in the range of 740-860 °C.									

Table 2-2.

No.	Step (5)						Step (6)		Step (7)	Step (8)
	Annealing soaking temperature (°C)	Holding time (s)	Cooling rate in the first stage (°C/s)	Rapid cooling initial temperature in the second stage (°C)	Rapid cooling rate in the second stage (°C/s)	Terminal temperature °C	Isothermal insulation temperature (°C)	Isothermal insulation time (s)	Cooling rate (°C/s)	Temper rolling rate (%)
Ex. 1	860	40	15	780	650	400	400	300	30	0.1
Ex. 2	860	40	15	780	650	400	400	300	30	0.1
Ex. 3	860	40	15	780	650	400	400	300	30	0.1
Ex. 4	830	80	7	730	50	550	550	100	40	0.3
Ex. 5	830	80	7	730	50	550	550	100	40	0.3
Ex. 6	830	80	7	730	50	550	550	100	40	0.3
Ex. 7	840	70	5	750	250	500	500	210	100	0.2

(continued)

No.	Step (5)						Step (6)		Step (7)	Step (8)
	Annealing soaking temperature (°C)	Holding time (s)	Cooling rate in the first stage (°C/s)	Rapid cooling initial temperature in the second stage (°C)	Rapid cooling rate in the second stage (°C/s)	Terminal temperature °C	Isothermal insulation temperature (°C)	Isothermal insulation time (s)	Cooling rate (°C/s)	Temper rolling rate (%)
Ex. 8	840	70	5	750	250	500	500	210	100	0.2
Ex. 9	840	70	5	750	250	500	500	210	100	0.2
Ex. 10	850	50	12	760	100	520	520	200	70	0.1
Ex. 11	850	50	12	760	100	520	520	200	70	0.1
Ex. 12	850	50	12	760	100	520	520	200	70	0.1
Ex. 13	830	60	10	770	500	490	490	150	60	0
Ex. 14	830	60	10	770	500	490	490	150	60	0
Ex. 15	830	60	10	770	500	490	490	150	60	0
Ex. 16	855	55	5	730	100	460	460	250	50	0.15
Ex. 17	855	55	12	750	200	460	460	200	50	0.15
Ex. 18	855	55	15	780	200	460	460	150	50	0.15

[0052] In the present disclosure, the products of the 1,300-MPa-grade or more cold-rolled steel plates of Examples 1-18 prepared by the above process steps (1)-(8) were sampled respectively, and the microstructure of the steel plates of each Example was observed and analyzed. It was observed that the cold-rolled steel plates in Examples 1-18 had a microstructure of residual austenite + fine massive martensite + bainite + nanoprecipitates.

[0053] In addition, the inventor further analyzed the volume phase fraction of each component in the microstructure of the 1,300-MPa-grade or more cold-rolled steel plate products of Examples 1-18, and measured the diameter of martensite and nanoprecipitates. The relevant analysis and test results were listed in Table 3 below. In the present disclosure, the microstructure was observed with a ZEISS Axio Imager M2m Optical Microscope. In addition, the details of the nanoprecipitates and the microstructure were further observed and analyzed by Spherical Aberration-corrected Field Emission Transmission Electron Microscopy (TEM; Model JEOL ARM-200F) at a TEM operating acceleration voltage of 200kV.

[0054] Table 3 lists the analysis and test results of the 1,300-MPa-grade or more cold-rolled steel plates of Examples 1-18.

Table 3.

No.	Volume phase fraction of martensite (%)	Volume phase fraction of bainite (%)	Martensite diameter (μm)	Average diameter of nanoprecipitates (nm)
Ex. 1	76-83	8-14	7.3	15
Ex. 2	77-85	9-13	7.7	23
Ex. 3	76-84	8-13	6.8	21
Ex. 4	71-80	8-14	6.2	17
Ex. 5	70-80	9-13	7.1	21
Ex. 6	72-79	8-13	6.7	19
Ex. 7	76-85	8-12	6.6	21
Ex. 8	76-85	7-13	7.8	20

(continued)

No.	Volume phase fraction of martensite (%)	Volume phase fraction of bainite (%)	Martensite diameter (μm)	Average diameter of nanoprecipitates (nm)
Ex. 9	77-84	7-13	7.7	23
Ex. 10	70-81	9-14	6.2	28
Ex. 11	72-79	8-13	7.1	27
Ex. 12	72-81	9-13	6.7	27
Ex. 13	76-86	7-12	7.2	22
Ex. 14	76-85	8-13	7.1	21
Ex. 15	75-86	8-13	7.0	24
Ex. 16	73-80	8-14	5.1	17
Ex. 17	76-84	8-12	6.6	19
Ex. 18	78-84	9-13	8.9	27

[0055] It can be seen through analysis and test that in the present disclosure, in the 1,300-MPa-grade or more cold-rolled steel plates of Examples 1-18, the volume phase fraction of martensite is in the range of 70-86%, the volume phase fraction of bainite is in the range of 7-14%, and the diameter of martensite is in the range of 5.1-8.9 microns, and the average diameter of nanoprecipitates is in the range of 15-28nm.

[0056] Correspondingly, after the above observation and analysis, the 1,300-MPa-grade or more cold-rolled steel plate products of Examples 1-18 were further sampled respectively, and the mechanical properties of the steel plate of each Example were tested to obtain the mechanical strength, elongation and hole expansion ratio. The relevant mechanical properties test results are listed in Table 4 below

[0057] The methods for testing the relevant mechanical properties are as follows:

Tensile property test: a tensile test was conducted in accordance with the standard of GB/T 228 "Metallic materials-tensile testing-Part 1: Method of test at room temperature" to test the yield strength, tensile strength and elongation of the 1,300-MPa-grade or more cold-rolled steel plates in Examples 1-18.

[0058] Hole expansion test: a test was conducted in accordance with the standard of GB/T 24524-2021 "Metallic materials- Sheet and strip- Hole expanding test" to test the hole expansion ratio of the 1,300-MPa-grade or more cold-rolled steel plates in Examples 1-18.

[0059] Table 4 lists the mechanical property test results of the 1,300-MPa-grade or more cold-rolled steel plates of Examples 1-18.

Table 4.

No.	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Hole expansion ratio (%)
Ex. 1	1151	1434	9.3	55
Ex. 2	1128	1436	9.2	52
Ex. 3	1134	1447	9.1	54
Ex. 4	1067	1373	11.8	43
Ex. 5	1081	1375	11.9	45
Ex. 6	1073	1356	12.1	45
Ex. 7	1251	1506	9.1	50
Ex. 8	1273	1503	9.3	50
Ex. 9	1228	1522	9.7	50
Ex. 10	1201	1332	12.3	45
Ex. 11	1209	1328	11.5	45
Ex. 12	1191	1331	11.1	46
Ex. 13	1292	1547	8.7	50

(continued)

No.	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Hole expansion ratio (%)
Ex. 14	1288	1552	8.5	49
Ex. 15	1267	1537	8.8	47
Ex. 16	1134	1429	9.7	50
Ex. 17	1172	1482	9.1	46
Ex. 18	1191	1497	9.3	47

[0060] As shown in the above Table 4, the 1,300-MPa-grade or more cold-rolled steel plates of Examples 1-18 designed by the present disclosure has good elongation performance and hole expansion performance while having ultra-high strength.

[0061] Referring to Table 4, it can be seen that the 1,300-MPa-grade or more cold-rolled steel plates of Examples 1-18 have a yield strength of 1067-1292MPa, a tensile strength of 1328-1552MPa, an elongation of 8.5-12.3%, and a hole expansion ratio of 43-54%.

[0062] Moreover, in Examples 1-18 designed in the present disclosure, when the tensile strength of the prepared steel plate is 1300-1400MPa (i.e., Examples 4-6, Examples 10-12), the specific elongation is in the range of 11.1-12.3%, and the specific hole expansion ratio is in the range of 53-46%; when the tensile strength is greater than 1400 and ≤1500MPa (i.e., Examples 1-3, Examples 16-18), the specific elongation is in the range of 9.1-9.7%, and the specific hole expansion ratio is in the range of 46-55%; when the tensile strength is greater than 1500MPa (i.e., Examples 7-9, Examples 13-15), the specific elongation is in the range of 8.5-9.7%, and the specific hole expansion is in the range of 47-50%.

[0063] It should be noted that the combinations of the various technical features in this disclosure are not limited to the combinations described in the claims of this disclosure or the combinations described in the specific Examples. All technical features recorded in this case can be combined or associated freely in any way unless there is a contradiction between them.

[0064] 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 1,300-MPa-grade or more cold-rolled steel plate having high elongation and high hole-expansion performance, which comprises Fe and unavoidable impurity elements, wherein it further comprises the following chemical elements in percentage by mass:

C: 0.15%-0.30%, Si: 0.3%-0.5%, Mn: 1.8%-2.5%, Al: 0.01%-0.03%, B: 0.001-0.003%; Ti: 0-0.05%;
the mass percentages of C and Mn satisfy: C+ Mn/6≥0.52%;
wherein the cold-rolled steel plate has a microstructure comprising nanoprecipitates with an average diameter of less than 30nm.

2. The 1,300-MPa-grade or more cold-rolled steel plate according to claim 1, wherein the mass percentages of the various chemical elements are:

C: 0.15%-0.30%, Si: 0.3%-0.5%, Mn: 1.8%-2.5%, Al: 0.01%-0.03%, B: 0.001-0.003%; Ti: 0-0.05%, with a balance of Fe and unavoidable impurity elements;
the mass percentages of C and Mn satisfy: C+ Mn/6≥0.52%;
wherein the cold-rolled steel plate has a microstructure comprising nanoprecipitates with an average diameter of less than 30nm.

3. The 1,300-MPa-grade or more cold-rolled steel plate according to claim 1 or 2, wherein, among the unavoidable impurity elements, P is ≤0.015%, S is ≤0.003%, N is ≤0.006%.

4. The 1,300-MPa-grade or more cold-rolled steel plate according to claim 1 or 2, wherein the microstructure is residual austenite + fine massive martensite + bainite + the nanoprecipitates.

5. The 1,300-MPa-grade or more cold-rolled steel plate according to claim 4, wherein the volume phase fraction of martensite is ≥55%, and the volume phase fraction of bainite is more than 0 and <15%.

6. The 1,300-MPa-grade or more cold-rolled steel plate according to claim 5, wherein the volume phase fraction of martensite is 70~86% and the volume phase fraction of bainite is 7~14%.

7. The 1,300-MPa-grade or more cold-rolled steel plate according to claim 4, wherein martensite has a diameter of no more than 10 μm.

8. The 1,300-MPa-grade or more cold-rolled steel plate according to claim 7, wherein martensite has an average diameter of 5-9 μm.

9. The 1,300-MPa-grade or more cold-rolled steel plate according to claim 1 or 2, wherein its properties satisfy:

when a tensile strength is 1300-1400MPa, an elongation is higher than 10% and a hole expansion ratio is higher than 40%;
when the tensile strength is greater than 1400 and ≤1500MPa, the elongation is higher than 9% and the hole expansion ratio is higher than 40%;
when the tensile strength is great than 1500MPa, the elongation is higher than 8% and the hole expansion ratio is higher than 40%.

10. A manufacturing method of the 1,300-MPa-grade or more cold-rolled steel plate according to any one of claims 1-9, wherein the method comprises the following steps:

(1) smelting and casting;
(2) hot-rolling;
(3) hot coiling insulation cover annealing: wherein the steel plate is rapidly subjected to insulation cover annealing after coiling, wherein an annealing time is 0.5-6 hours, and a temperature drop per hour is less than or equal to 6 °C ;
(4) cold rolling;
(5) annealing: wherein an annealing soaking temperature is controlled at 830-860°C with a holding time of 40-80s, then the steel plate is cooled at a cooling rate of 5-15°C/s to 730-780°C; then cooled to an isothermal insulation temperature at a rate of 50-700°C/s;
(6) isothermal insulation treatment: wherein an insulation temperature is 400-550°C, and an insulation time is 100-300s;
(7) cooling: wherein the steel plate is cooled to room temperature at a rate of 30°C/s-100°C/s;
(8) temper rolling.

11. The manufacturing method according to claim 10, wherein, in step (2), the steel plate is heated to 1100-1250°C and held for 0.5h or more, then hot rolled at a temperature of Ar3 or higher, and rapidly cooled at a rate of 30-80°C/s after rolling, wherein the coiling temperature is controlled at 150-250°C.

12. The manufacturing method according to claim 11, wherein, in step (2), the hot rolling temperature is not higher than 920°C, and the coiling temperature is 150-230 °C; preferably, in step (3), the starting temperature of insulation cover annealing is the same as the coiling temperature, and the temperature dropping rate is 2-6 °C per hour.

13. The manufacturing method according to claim 10, wherein, in step (4), the cold rolling reduction rate is controlled at 50-70%.

14. The manufacturing method according to claim 10, wherein, in step (5), the annealing soaking temperature is 830-850°C.

15. The manufacturing method according to claim 10, wherein, in step (8), the temper rolling rate is 0-0.3%.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2023/101458

A. CLASSIFICATION OF SUBJECT MATTER

C22C38/02(2006.01)i; C22C38/04(2006.01)i; C22C38/06(2006.01)i; C21D1/20(2006.01)i; C21D8/02(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)

CNTXT, DWPI, ENTXT, WPABS, CNKI, ISI WEB OF SCIENCE: 钢板, 抗拉强度, 冷轧, 钢组织, 微观组织, 奥氏体, 马氏体, 贝氏体, 碳, C, Mn, 锰, Si, 硅, Al, 铝, B, 硼, Ti, 钛, 碳化物, 纳米, 析出物, 保温罩, 等温保温, steel plate, steel sheet, cold roll+, tensile strength, steel microstructure, microstructure, austenite, martensite, bainite, carbon, manganese, silicon, aluminum, boron, titanium, carbide, nanometer, precipitate, heat insulat+, isothermal insulat+

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	CN 109628846 A (TANGSHAN IRON AND STEEL GROUP CO., LTD. et al.) 16 April 2019 (2019-04-16) description, paragraphs 5-8, and table 1	1, 3
Y	WO 2017169869 A1 (JFE STEEL CORPORATION) 05 October 2017 (2017-10-05) description, paragraphs 40, 44, and 65	1, 3
A	CN 106119694 A (WUHAN IRON AND STEEL CORPORATION) 16 November 2016 (2016-11-16) entire document	1-15
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A	CN 109023055 A (JINGYE IRON AND STEEL CO., LTD.) 18 December 2018 (2018-12-18) entire document	1-15
A	CN 112752862 A (POSCO) 04 May 2021 (2021-05-04) entire document	1-15

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

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"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
12 September 2023	**15 September 2023**

Name and mailing address of the ISA/CN	Authorized officer
China National Intellectual Property Administration (ISA/CN) **China No. 6, Xitucheng Road, Jimenqiao, Haidian District, Beijing 100088**	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2023/101458

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2022049412 A1 (ARCELORMITTAL) 10 March 2022 (2022-03-10) entire document	1-15

Form PCT/ISA/210 (second sheet) (July 2022)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2023/101458

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				KR	20200036759	A	07 April 2020
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				EP	3859041	A4	15 December 2021
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