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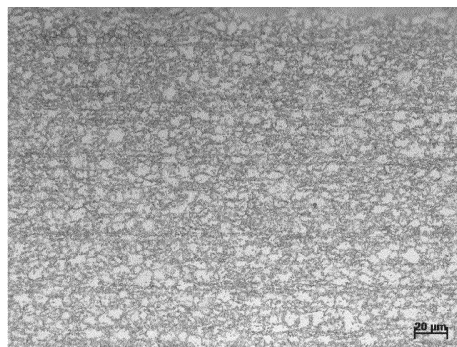
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(54) **780 MPA-CLASS COLD-ROLLED AND ANNEALED DUAL-PHASE STEEL AND MANUFACTURING METHOD THEREFOR**

(57) Disclosed is a cold-rolled and annealed dual-phase steel having a tensile strength of greater than 780 MPa. A matrix structure thereof is fine and uniform martensite + ferrite. The cold-rolled and annealed dual-phase steel contains the following chemical elements in the following mass percentages: C: 0.1%-0.13%, Si: 0.4%-0.8%, Mn: 1.65%-1.9%, Al: 0.01%-0.05%, Nb: 0.01-0.03%, and Ti: 0.01-0.03%. Furthermore, the cold-rolled annealed dual-phase steel does not contain the elements Cr or Mo. In addition, also disclosed is a method for manufacturing the cold-rolled and annealed dual-phase steel, comprising smelting and continuous casting, hot rolling, cold rolling, annealing, tempering and flattening. The cold-rolled and annealed dual-phase steel of the present invention is not only economical, but also has the characteristics of high strength, excellent elongation and cold bending properties.



Figur 1

Description**Technical Field**

5 **[0001]** The present disclosure relates to a metallic material and a method for manufacturing the same, particularly to a cold-rolled and annealed dual-phase steel and a method for manufacturing the same.

Background Art

10 **[0002]** As the global energy crisis and environmental problems are becoming more and more severe, energy conservation and safety have become the main direction of the development of the automobile manufacturing industry. One of the measures for energy saving and emission reduction is to reduce vehicle weight. High-strength dual-phase steel has good mechanical properties and usability, and can be effectively used to produce vehicle structural parts.

15 **[0003]** Along with the development of ultra-high strength steel and current market changes, it is desirable that ultra-high strength steel is economical and has better performances. At present, 780 DP steel is still the mainstream steel in applications. It accounts for 60% of the total amount of DP steel, and it is widely used for various types of structural members and safety members. Along with the ongoing trend of weight reduction and energy saving in the automobile industry, and the rapid advancement of the technical level of the steel makers around the globe, especially those in China, the main concerns in the development of dual-phase steel in the future must be low cost and high performances in combination.

20 **[0004]** Canadian Patent Application No. CA2526488 published on December 2, 2004 and entitled "A COLD-ROLLED STEEL SHEET HAVING A TENSILE STRENGTH OF 780 MPA OR MORE, AN EXCELLENT LOCAL FORMABILITY AND A SUPPRESSED INCREASE IN WELD HARDNESS" discloses a cold-rolled steel sheet having a chemical composition of: C: 0.05-0.09%; Si: 0.4-1.3%; Mn: 2.5-3.2%; optional Mo: 0.05-0.5% or Ni: 0.05-2%; P: 0.001-0.05%; $S \leq 0.08\%$ Ti-3.43%N+0.004; $N \leq 0.006\%$; Al: 0.005-0.10%; Ti: 0.001-0.045%; optional Nb $\leq 0.04\%$ or B: 0.0002-0.0015%; optional Ca for treatment, with the balance of Fe and unavoidable impurities. It requires a bainite content of greater than 7%; $P_{cm} \leq 0.3$; hot rolling at a temperature equal to or higher than A_{r3} ; coiling at 700 °C or lower; cold rolling; annealing at a temperature of 700-900 °C; and rapid cooling from a temperature of 550-700 °C. Finally, a high-strength steel having a minimum strength of 780 Mpa is obtained. The steel has the characteristics of strong local deformation ability and low hardness in the welding area. However, the high Mn content used in the design of this steel will inevitably result in a severe banded structure which will lead to nonuniform mechanical properties. In addition, while a high content of Mn is added, a relatively large amount of Si is added. This is detrimental to both the surface quality and welding performance of the steel.

25 **[0005]** United States Patent Publication No. US20050167007 published on August 4, 2005 discloses a method for manufacturing a high-strength steel sheet comprising the following chemical composition: 0.05-0.13% C, 0.5-2.5% Si, 0.5-3.5% Mn, 0.05-1% Cr, 0.05-0.6% Mo, $\leq 0.1\%$ Al, $\leq 0.005\%$ S, $\leq 0.01\%$ N, $< 0.03\%$ P, with addition of 0.005-0.05% Ti or 0.005-0.05% Nb or 0.005-0.2% V. The steel is hot rolled at a temperature equal to or higher than A_{r3} , coiled at 450-700 °C, annealed, quenched from 700-600 °C by cooling at a cooling rate of 100 °C/s, and then tempered at 180-450 °C. Finally, a high-strength steel having a tensile strength of 780 Mpa and a hole expansion rate of higher than 50% is obtained. The main problem of this steel is that the total amount of alloy is too high and the Si content is high, which is detrimental to the weldability or phosphatability of the steel.

30 **[0006]** Chinese Patent Publication No. CN101363099A published on February 11, 2009 entitled "COLD-ROLLED DUAL-PHASE STEEL SHEET WITH TENSILE STRENGTH OF 1000 MPA AND METHOD FOR PREPARING SAME" discloses an ultra-high-strength dual-phase steel comprising C: 0.14-0.21%, Si: 0.4-0.9%, Mn: 1.5-2.1%, P: $< 0.02\%$, $S < 0.01\%$, Nb: 0.001-0.05%, V: 0.001-0.02%. After hot rolling and cold rolling, it is held at 760-820 °C, cooled at a cooling rate of 40-50 °C/s, and overaged at 240-320 °C for 180-300 s. The carbon equivalent is high in the design of this steel, and the steel is not characterized by balanced performances.

35 **[0007]** As it can be seen, although the 780 Mpa dual-phase steels designed according to some of the existing patent technologies exhibit good formability, they have either high contents of C and Si, or high contents of alloy elements such as Cr, Ni, and Mo. This is detrimental to the weldability, surface quality or phosphatability of the steels, and the cost is also high. In addition, for some steels with high Si contents, although the hole expansion rate is very high and the bendability is good, the yield ratio is high, and the stamping performance is degraded.

Summary

40 **[0008]** One of the objects of the present disclosure is to provide an economical 780 MPa grade cold-rolled and annealed dual-phase steel. By reasonably designing the alloy elements and the manufacturing process for the cold-rolled and annealed dual-phase steel, the resulting steel plate has a strength of 780MPa grade with no addition of Mo and Cr, and a fine and uniform martensite + ferrite dual-phase structure is obtained to ensure excellent performances of elongation

and cold bending, so that the steel has good formability. The cold-rolled and annealed dual-phase steel has a yield strength of ≥ 420 MPa; a tensile strength of > 780 MPa; an elongation at break with A50 gauge length of $\geq 18\%$; a 90-degree cold bending parameter $R/t \leq 1$, where R represents bending radius in mm, and t represents plate thickness in mm.

[0009] In order to achieve the above object, the present disclosure provides a 780MPa grade cold-rolled and annealed dual-phase steel having a matrix structure of fine and uniform martensite + ferrite, wherein the cold-rolled and annealed dual-phase steel comprises the following chemical elements in mass percentages, in addition to Fe:

C: 0.1%-0.13%, Si: 0.4%-0.8%, Mn: 1.65%-1.9%, Al: 0.01%-0.05%, Nb: 0.01-0.03%, Ti: 0.01-0.03%;
wherein the cold-rolled and annealed dual-phase steel is free of Cr and Mo elements.

[0010] Further, the cold-rolled and annealed dual-phase steel in the present disclosure comprises the following chemical elements in mass percentages:

C: 0.1%-0.13%, Si: 0.4%-0.8%, Mn: 1.65%-1.9%, Al: 0.01%-0.05%, Nb: 0.01-0.03%, Ti: 0.01-0.03%, and a balance of Fe and other unavoidable impurities.

[0011] In the cold-rolled and annealed dual-phase steel according to the present disclosure, a composition system with C and Mn as the dominant additive elements is designed for the composition of the cold-rolled and annealed dual-phase steel according to the present disclosure, so as to ensure that the cold-rolled and annealed dual-phase steel can reach a strength of 780 MPa grade. The absence of precious alloy elements such as Mo and Cr can effectively guarantee the economic efficiency. The addition of Nb and Ti in trace amounts can achieve the effect of inhibiting growth of austenite grains, and can effectively refine the grains. In addition, due to the special design of the composition with no addition of Mo or Cr, the strength of the hot rolled coil is not too high, which can guarantee the processability in cold rolling. The principles for designing the various chemical elements are described as follows:

C: In the cold-rolled and annealed dual-phase steel according to the present disclosure, the addition of the C element can improve the strength of the steel and the hardness of martensite. If the mass percentage of C in the steel is lower than 0.1%, the strength of the steel plate will be affected, and it is detrimental to formation and stability of austenite. If the mass percentage of C in the steel is higher than 0.13%, the hardness of martensitic will be too high, and the grain size will be large, which is detrimental to the formability of the steel plate. At the same time, an unduly high carbon equivalent is detrimental to welding in use. Therefore, in the cold-rolled and annealed dual-phase steel according to the present disclosure, the mass percentage of C is controlled at 0.1%-0.13%.

[0012] In some preferred embodiments, the mass percentage of C may be controlled at 0.11%-0.125%.

[0013] Si: In the cold-rolled and annealed dual-phase steel according to the present disclosure, the addition of the Si element to the steel can improve hardenability. In addition, the solid dissolved Si in the steel may have an effect on the interaction of dislocations, thereby increasing the work hardening rate. This may increase the elongation of the dual-phase steel suitably, which is beneficial to obtain better formability. However, it should be noted that if the mass percentage of Si in the steel is too high, it will be detrimental to the control of the surface quality. Therefore, in the cold-rolled and annealed dual-phase steel according to the present disclosure, the mass percentage of Si is controlled at 0.4%-0.8%.

[0014] In some preferred embodiments, the mass percentage of Si may be controlled at 0.5%-0.7%.

[0015] Mn: In the cold-rolled and annealed dual-phase steel according to the present disclosure, the addition of the Mn element is beneficial to improve the hardenability of the steel, and can effectively improve the strength of the steel plate. However, it should be noted that when the mass percentage of Mn in the steel is lower than 1.65%, the strength of the steel plate will be insufficient; when the mass percentage of Mn in the steel is higher than 1.9%, the strength of the steel plate will be too high to reduce its formability. Therefore, in the cold-rolled and annealed dual-phase steel according to the present disclosure, the mass percentage of Mn is controlled at 1.65%-1.9%.

[0016] In some preferred embodiments, the mass percentage of Mn may be controlled at 1.7%-1.8%.

[0017] Al: In the cold-rolled and annealed dual-phase steel according to the present disclosure, the addition of Al may have the effect of removing oxygen and refining grains. Therefore, in the cold-rolled and annealed dual-phase steel according to the present disclosure, the mass percentage of Al is controlled at 0.01%-0.05%.

[0018] In some preferred embodiments, the mass percentage of Al may be controlled at 0.015-0.045%.

[0019] Nb: In the cold-rolled and annealed dual-phase steel according to the present disclosure, the Nb element is an important element for grain refinement. With the addition of a small amount of the strong carbide forming element Nb to the micro-alloy steel, a strain-induced precipitation phase can be formed in the controlled rolling process. The strain-induced precipitation phase can significantly reduce the recrystallization temperature of deformed austenite by means of the action of particle pinning and subgrain boundaries, provide nucleation particles, and thus have a significant effect of refining grains. In the process of austenization by continuous annealing, the soaked undissolved carbide and nitride particles will prevent coarsening of soaked austenite grains by the mechanism of pinning grain boundaries by particles, thereby refining the grains effectively. Therefore, in the cold-rolled and annealed dual-phase steel according to the present disclosure, the mass percentage of Nb is controlled at 0.01-0.03%.

[0020] In some preferred embodiments, the mass percentage of Nb may be controlled at 0.015-0.025%.

[0021] Ti: The strong carbide forming element Ti added to the cold-rolled and annealed dual-phase steel according to the present disclosure also exhibits a strong effect of inhibiting growth of austenite grains at high temperatures. At the same time, the addition of Ti helps to refine grains. Therefore, in the cold-rolled and annealed dual-phase steel according to the present disclosure, the mass percentage of Ti is controlled at 0.01-0.03%.

[0022] In some preferred embodiments, the mass percentage of Ti may be controlled at 0.015-0.025%.

[0023] In the above composition design, precious alloy elements such as Mo and Cr are not added to the cold-rolled and annealed dual-phase steel, so as to ensure economy. At the same time, in order to ensure obtainment of a tensile strength of 780MPa grade at a gas cooling rate of 40-100 °C/s in normal continuous annealing, the amounts of the alloy elements C and Mn in the composition should be guaranteed to provide sufficient hardenability. Nevertheless, the upper limits of the contents of the alloy elements C and Mn need to be controlled so as to guarantee excellent welding performance and formability, and to prevent the strength from exceeding its upper limit.

[0024] Because the precipitation of Al nitrides and the precipitation of Nb, Ti carbonitrides are competitive in the steel production process, in view of the contents of Al and N in the composition system according to the present disclosure, the effect of refining grains can be achieved only when certain amounts of Nb and Ti to be added are guaranteed. Therefore, the mass percentage contents of Nb and Ti in the cold-rolled and annealed dual-phase steel may further satisfy the following formula: $Nb\% + Ti\% \times 3 \geq 0.047\%$, preferably $\geq 0.06\%$. In the above formula, Nb and Ti each represent the mass percentage content of the corresponding element, that is, the value in front of the percent sign in the formula. In some embodiments, $0.047\% \leq Nb\% + Ti\% \times 3 \leq 0.10\%$; preferably, $0.06\% \leq Nb\% + Ti\% \times 3 \leq 0.10\%$.

[0025] Further, in the cold-rolled and annealed dual-phase steel according to the present disclosure, the mass percentage contents of the chemical elements satisfy at least one of the following:

C: 0.11 %-0.125%,

Si: 0.5%-0.7%,

Mn: 1.7%-1.8%,

Al: 0.015%-0.045%,

Nb: 0.015-0.025%,

Ti: 0.015-0.025%.

[0026] Further, in the cold-rolled and annealed dual-phase steel according to the present disclosure, the unavoidable impurities include the P, S and N elements, and the contents thereof are controlled to be at least one of the following: $P \leq 0.015\%$, $S \leq 0.003\%$, $N \leq 0.005\%$.

[0027] In the above technical solution, in the cold-rolled and annealed dual-phase steel according to the present disclosure, the P, N and S elements are all unavoidable impurity elements in the steel. It's better to lower the contents of the P, N and S elements in the steel as far as possible. MnS formed from S seriously affects the formability, and N tends to incur cracks or bubbles on the surface of the slab. Therefore, in the cold-rolled and annealed dual-phase steel according to the present disclosure, the mass percentage of P is controlled at $P \leq 0.015\%$; the mass percentage of S is controlled at $S \leq 0.003\%$; and the mass percentage of N is controlled at $N \leq 0.005\%$.

[0028] Further, in the cold-rolled and annealed dual-phase steel according to the present disclosure, the phase proportion (by volume) of martensite is $>55\%$.

[0029] Further, in the cold-rolled and annealed dual-phase steel according to the present disclosure, the grain diameter of martensite is not greater than 5 microns, and the grain diameter of ferrite is not greater than 5 microns.

[0030] Further, the performances of the cold-rolled and annealed dual-phase steel according to the present disclosure satisfy at least one of the following: yield strength ≥ 420 MPa, preferably ≥ 430 MPa; tensile strength >780 MPa, preferably ≥ 800 MPa; elongation at break with A50 gauge length $\geq 18\%$; a 90-degree cold bending parameter $R/t \leq 1$, where R represents bending radius in mm, t represents plate thickness in mm.

[0031] Further, the performances of the cold-rolled and annealed dual-phase steel according to the present disclosure satisfy the following: yield strength ≥ 420 MPa, preferably ≥ 430 MPa; tensile strength >780 MPa, preferably ≥ 800 MPa; elongation at break with A50 gauge length $\geq 18\%$; 90 degree cold bending parameter $R/t \leq 1$, where R represents bending radius in mm, t represents plate thickness in mm.

[0032] Further, the yield ratio of the cold-rolled and annealed dual-phase steel according to the present disclosure is 0.53-0.57.

[0033] Accordingly, another object of the present disclosure is to provide a method for manufacturing a cold-rolled and annealed dual-phase steel. The cold-rolled and annealed dual-phase steel made by the manufacturing method has the characteristics of high strength, excellent elongation and cold bending performance. It has a yield strength of ≥ 420 MPa; a tensile strength of >780 MPa; an elongation at break with A50 gauge length of $\geq 18\%$; a 90-degree cold bending parameter $R/t \leq 1$, where R represents bending radius in mm, and t represents plate thickness in mm.

[0034] To achieve the above object, the present disclosure proposes a method for manufacturing the above cold-rolled and annealed dual-phase steel, comprising steps of:

- (1) Smelting and continuous casting;
- (2) Hot rolling;
- (3) Cold rolling;
- (4) Annealing: annealing soaking temperature: 770-820 °C; annealing time: 40-200 s; cooling at a rate of 3-5 °C/s to a starting temperature of rapid cooling; rapid cooling at a rate of 30-80 °C/s, wherein the starting temperature of rapid cooling is 650-730 °C, and the rapid cooling is ended at a temperature of 200-270 °C;
- (5) Tempering;
- (6) Temper rolling.

[0035] In the method for manufacturing the cold-rolled and annealed dual-phase steel according to the present disclosure, in step (4), the reason for controlling the annealing soaking temperature at 770-820 °C is as follows: when the annealing soaking temperature is lower than 770 °C, the steel having a strength of 780 MPa grade cannot be obtained; while if the annealing soaking temperature is higher than 820 °C, the grain size will be large, which will greatly degrade the formability. Therefore, controlling the annealing soaking temperature at 770-820 °C can ensure obtainment of both the tensile strength of 780MPa and the small grain size, so that the cold-rolled and annealed dual-phase steel has better formability.

[0036] In some preferred embodiments, the annealing soaking temperature may be controlled in the range of 790-810 °C in order to obtain better implementation effects, i.e. to obtain a smaller grain size, moderate mechanical properties of the steel obtained, and better formability.

[0037] Further, in the manufacturing method according to the present disclosure, in step (2), the slab is first heated to 1160-1220 °C, preferably 1165-1215 °C; held for 0.6 hours or longer, preferably 0.6-1.5 hours; hot rolled at a temperature of 850-900 °C; rapidly cooled at a rate of 30-80 °C/s after the rolling; coiled with the coiling temperature being controlled at 500-600 °C, preferably 520-600 °C; and air cooled after the coiling.

[0038] Further, in the manufacturing method according to the present disclosure, in step (3), a cold rolling reduction rate is controlled at 50-70%.

[0039] Further, in the manufacturing method according to the present disclosure, in step (5), a tempering temperature is controlled at 200-270 °C, and a tempering time is 100-400 s, preferably 150-400 s.

[0040] Further, in the manufacturing method according to the present disclosure, in step (6), a temper rolling reduction rate is controlled at $\leq 0.3\%$.

[0041] Further, in the manufacturing method according to the present disclosure, in step (4), the annealing soaking temperature is 790-810 °C.

[0042] Compared with the prior art, the cold-rolled and annealed dual-phase steel and the manufacturing method therefor according to the present disclosure have the following advantages and beneficial effects:

The alloy chemical composition in the cold-rolled and annealed dual-phase steel is designed reasonably, so that a steel plate having a strength of more than 780MPa grade and a martensite + ferrite dual-phase structure is obtained without addition of Mo and Cr. The steel plate has a yield strength of $\geq 420\text{MPa}$; a tensile strength of $> 780\text{MPa}$; an elongation at break with A50 gauge length of $\geq 18\%$; a 90-degree cold bending parameter $R/t \leq 1$, where R represents bending radius in mm, and t represents plate thickness in mm. While good economy is achieved, the steel plate has the characteristics of high strength, excellent elongation and cold bending performance.

[0043] Accordingly, by reasonably designing and controlling the specific process parameters in the manufacturing method according to the present disclosure, the cold-rolled and annealed dual-phase steel obtained by the manufacturing method according to the present disclosure not only has good economy, but also has the characteristics of high strength, excellent elongation and cold bending performance.

Description of the Drawing

[0044] Figure 1 shows the structure of the cold-rolled and annealed dual-phase steel of Example 1.

Detailed Description

[0045] The economical 780 MPa grade cold-rolled and annealed dual-phase steel and the method for manufacturing the same according to the disclosure will be further explained and illustrated with reference to the specific Examples. Nonetheless, the explanation and illustration are not intended to unduly limit the technical solution of the disclosure.

Examples 1-7 and Comparative Examples 1-14

[0046] Table 1 lists the mass percentages of various chemical elements in the steel grades corresponding to the cold-rolled and annealed dual-phase steels in Examples 1-7 and the steels in Comparative Examples 1-14.

Table 1 (wt%, the balance is Fe and unavoidable impurities other than P, S and N)

	Steel grade	Chemical elements									
		C	Si	Mn	Al	P	S	N	Nb	Ti	Nb%+Ti%×3
Ex. 1	A	0.103	0.45	1.74	0.012	0.014	0.0015	0.0035	0.012	0.021	0.075
Ex. 2	B	0.106	0.52	1.68	0.032	0.013	0.0016	0.0033	0.017	0.015	0.062
Ex. 3	C	0.110	0.55	1.85	0.022	0.009	0.0018	0.0045	0.015	0.026	0.093
Ex. 4	D	0.115	0.43	1.82	0.028	0.011	0.0020	0.0042	0.024	0.024	0.096
Ex. 5	E	0.118	0.61	1.69	0.018	0.012	0.0022	0.0038	0.029	0.023	0.098
Ex. 6	F	0.123	0.66	1.76	0.025	0.011	0.0024	0.0045	0.021	0.021	0.084
Ex. 7	G	0.129	0.72	1.80	0.045	0.009	0.0012	0.0027	0.0195	0.014	0.0615
Comp. Ex. 1	H	0.091	0.63	1.77	0.044	0.011	0.0022	0.0037	0.015	0.018	0.069
Comp. Ex. 2	I	0.138	0.64	1.81	0.047	0.009	0.0022	0.0033	0.018	0.022	0.084
Comp. Ex. 3	J	0.121	0.58	1.62	0.033	0.012	0.0015	0.0028	0.026	0.021	0.089
Comp. Ex. 4	K	0.124	0.63	1.99	0.038	0.013	0.0015	0.0035	0.026	0.019	0.083
Comp. Ex. 5	L	0.118	0.62	1.69	0.035	0.011	0.0017	0.0034	0.005	0.024	0.077
Comp. Ex. 6	M	0.117	0.57	1.72	0.026	0.008	0.0012	0.0029	0.020	0.004	0.032
Comp. Ex. 7-14	N	0.109	0.72	1.75	0.024	0.010	0.0014	0.0043	0.023	0.027	0.104

[0047] The cold-rolled and annealed dual-phase steels in Examples 1-7 according to the present disclosure and the steels in Comparative Examples 1-14 were all prepared by the following steps:

- (1) Smelting and continuous casting: the required alloy components were obtained, and the contents of S and P were minimized;
- (2) Hot rolling: a slab was first heated to 1160-1220 °C which was held for 0.6 hours or more; then hot-rolling at a temperature of 850-900 °C was conducted; after the rolling, rapid cooling was conducted at a rate of 30-80 °C/s; the coiling temperature was controlled at 500-600 °C; air cooling was conducted after coiling;
- (3) Cold rolling: the cold rolling reduction rate was controlled at 50-70%;
- (4) Annealing: the annealing soaking temperature was controlled at 770-820 °C, alternatively and preferably at 790-810 °C; the annealing time was controlled at 40-200 s; the temperature was decreased to a starting temperature of rapid cooling by cooling at a rate of 3-5 °C/s; rapid cooling was conducted at a rate of 30-80 °C/s, wherein the starting temperature of the rapid cooling was 650-730 °C, and the rapid cooling was ended at a temperature of 200-270 °C;
- (5) Tempering: the tempering temperature was controlled at 200-270 °C, and the tempering time was 100-400 s;
- (6) Temper rolling: the temper rolling reduction rate was controlled at $\leq 0.3\%$.

[0048] It should be noted that the chemical compositions of the cold-rolled and annealed dual-phase steel in Examples 1-7 and the related process parameters all met the control requirements of the design specification according to the present disclosure. The chemical compositions of the steels in Comparative Examples 1-6 all included parameters that failed to meet the requirements of the design according to the present disclosure. Although the chemical composition of steel grade N in Comparative Examples 7-14 met the requirements of the design according to the present disclosure, the related process parameters all included parameters that failed to meet the requirements of the design according to the present disclosure.

[0049] Tables 2-1 and 2-2 list the specific process parameters for the cold-rolled and annealed dual-phase steels in Examples 1-7 and the steels in Comparative Examples 1-14.

Table 2-1

No.	Steel grade	Step (2)					Step (3)
		Heating temperature (°C)	Holding time (h)	Finishing hot rolling temperature (°C)	Cooling rate (°C/s)	Coiling temperature (°C)	Cold rolling reduction rate (%)
Ex. 1	A	1210	0.75	855	32	585	52
Ex. 2	B	1205	0.65	870	30	525	67
Ex. 3	C	1195	1.2	890	47	545	58
Ex. 4	D	1187	1.5	886	54	575	50
Ex. 5	E	1169	0.8	864	68	590	55
Ex. 6	F	1211	1.1	895	74	588	62
Ex. 7	G	1191	0.9	885	44	600	48
Comp. Ex. 1	H	1187	0.7	875	50	548	50
Comp. Ex. 2	I	1175	1.1	850	62	566	56
Comp. Ex. 3	J	1200	0.95	890	68	535	55
Comp. Ex. 4	K	1213	1.3	900	76	505	52
Comp. Ex. 5	L	1178	1.4	895	46	586	67
Comp. Ex. 6	M	1194	0.8	890	38	533	48

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(continued)

No.	Steel grade	Step (2)					Step (3)
		Heating temperature (°C)	Holding time (h)	Finishing hot rolling temperature (°C)	Cooling rate (°C/s)	Coiling temperature (°C)	Cold rolling reduction rate (%)
Comp. Ex. 7	N	<u>1153</u>	1.6	866	55	564	62
Comp. Ex. 8	N	<u>1237</u>	1.5	885	60	592	50
Comp. Ex. 9	N	1195	1.4	886	70	<u>480</u>	55
Comp. Ex. 10	N	1186	0.9	895	75	<u>622</u>	58
Comp. Ex. 11	N	1209	1.1	858	49	578	56
Comp. Ex. 12	N	1193	1.3	864	55	555	60
Comp. Ex. 13	N	1169	1.5	877	62	511	52
Comp. Ex. 14	N	1178	0.9	855	48	548	54

Table 2-2

No.	Step (4)						Step (5)		Step (6)
	Annealing soaking temperature (°C)	Annealing time (s)	Cooling rate (°C/s)	Starting temperature of rapid cooling (°C)	Rapid cooling rate (°C/s)	Ending temperature of rapid cooling (°C)	Tempering temperature (°C)	Tempering time (s)	
Ex. 1	815	150	5	705	55	200	200	220	0.3
Ex. 2	785	90	4	715	44	250	250	300	0.2
Ex. 3	796	105	5	670	65	265	265	210	0.3
Ex. 4	784	180	3	720	70	270	270	250	0.2
Ex. 5	810	60	4	680	66	235	235	175	0.1
Ex. 6	808	175	5	725	58	240	240	205	0.2
Ex. 7	777	85	3	695	57	266	266	380	0.1
Comp. Ex. 1	790	150	3	675	48	216	216	330	0.1
Comp. Ex. 2	796	90	3	670	36	208	208	205	0.3
Comp. Ex. 3	800	120	4	705	48	262	262	190	0.1
Comp. Ex. 4	811	180	5	720	62	225	225	210	0.3
Comp. Ex. 5	789	60	5	725	58	239	239	250	0.2
Comp. Ex. 6	812	75	5	700	80	252	252	120	0.1
Comp. Ex. 7	786	140	4	655	70	227	227	300	0.3
Comp. Ex. 8	793	135	4	700	62	264	264	125	0.3
Comp. Ex. 9	811	95	3	680	48	240	240	175	0.2

(continued)

No.	Step (4)						Step (5)		Step (6)
	Annealing soaking temperature (°C)	Annealing time (s)	Cooling rate (°C/s)	Starting temperature of rapid cooling (°C)	Rapid cooling rate (°C/s)	Ending temperature of rapid cooling (°C)	Tempering temperature (°C)	Tempering time (s)	
Comp. Ex. 10	806	165	5	685	80	215	215	205	0.1
Comp. Ex. 11	<u>758</u>	125	4	675	35	235	235	380	0.1
Comp. Ex. 12	<u>835</u>	65	4	705	56	242	242	280	0.3
Comp. Ex. 13	810	75	3	710	48	<u>178</u>	<u>178</u>	300	0.2
Comp. Ex. 14	795	120	3	695	72	<u>292</u>	<u>292</u>	280	0.1

[0050] It should be noted that, as shown in Table 2-2, the ending temperature of rapid cooling and the tempering temperature in each Example and in each Comparative Example are the same. The reason is that, in the actual process operation, the tempering operation was performed right after the rapid cooling operation was ended.

[0051] A variety of performance tests were performed on the cold-rolled and annealed dual-phase steels in Examples 1-7 and the steels in Comparative Examples 1-14. The test results obtained are listed in Table 3. As to the performance test method, GB/T 13239-2006 Metallic Materials - Tensile Testing at Low Temperature was referred to. A standard sample was prepared, and subjected to static stretching on a tensile testing machine to obtain a corresponding stress-strain curve. After data processing, the parameters of yield strength, tensile strength and elongation at break were obtained finally.

[0052] Table 3 lists the performance test results for the cold-rolled and annealed dual-phase steels in Examples 1-7 and the steels in Comparative Examples 1-14.

Table 3

No.	Yield strength (MPa)	Tensile strength (MPa)	Elongation at break A_{50} (%)	90° bending radius R (mm)	Plate thickness t (mm)	R/t
Ex. 1	454	800	22.3	1.0	1.1	0.91
Ex. 2	435	812	21.5	1.0	1.1	0.91
Ex. 3	474	856	19.5	1.0	1.1	0.91
Ex. 4	449	832	20.5	1.0	1.2	0.83
Ex. 5	458	827	20.8	1.0	1.2	0.83
Ex. 6	476	872	19.7	1.0	1.2	0.83
Ex. 7	489	884	18.4	1.0	1.1	0.91
Comp. Ex. 1	<u>386</u>	<u>768</u>	25.2	1.0	1.2	0.83
Comp. Ex. 2	525	934	<u>14.6</u>	1.5	1.0	1.50
Comp. Ex. 3	<u>393</u>	<u>777</u>	24.3	1.0	1.0	1.00
Comp. Ex. 4	518	941	<u>15.1</u>	1.5	1.1	1.36
Comp. Ex. 5	<u>404</u>	835	19.6	1.0	1.0	1.00
Comp. Ex. 6	<u>408</u>	828	20.1	1.0	1.1	0.91
Comp. Ex. 7	<u>383</u>	<u>765</u>	24.7	1.0	1.1	0.91
Comp. Ex. 8	525	936	<u>16.6</u>	1.5	1.3	1.15
Comp. Ex. 9	543	952	<u>15.8</u>	1.5	1.0	1.50
Comp. Ex. 10	<u>394</u>	<u>774</u>	24.5	1.0	1.0	1.00
Comp. Ex. 11	<u>390</u>	<u>772</u>	24.5	1.0	1.0	1.00
Comp. Ex. 12	537	947	<u>15.5</u>	1.5	1.2	1.25

(continued)

No.	Yield strength (MPa)	Tensile strength (MPa)	Elongation at break A_{50} (%)	90° bending radius R (mm)	Plate thickness t (mm)	R/t
Comp. Ex. 13	534	942	<u>15.3</u>	1.5	1.1	1.36
Comp. Ex. 14	<u>385</u>	<u>774</u>	24.5	1.0	1.0	1.00

[0053] As it can be seen from Table 3, Examples 1-7 meeting the control requirements of the design specification according to the present disclosure have excellent performances, including yield strength ≥ 420 MPa; tensile strength > 780 MPa; elongation at break with A_{50} gauge length $\geq 18\%$; a 90-degree cold bending parameter $R/t \leq 1$ (R represents bending radius in mm, t represents plate thickness in mm). The various performances of the cold-rolled and annealed dual-phase steels of the various Examples are quite excellent. With no addition of precious alloy elements such as Mo and Cr, the steels achieve a tensile strength of greater than 780 MPa, and exhibit good elongation and superior cold bending performance.

[0054] It's to be noted that the prior art portions in the protection scope of the present disclosure are not limited to the examples set forth in the present application file. All the prior art contents not contradictory to the technical solution of the present disclosure, including but not limited to prior patent literature, prior publications, prior public uses and the like, may all be incorporated into the protection scope of the present disclosure. In addition, the ways in which the various technical features of the present disclosure are combined are not limited to the ways recited in the claims of the present disclosure or the ways described in the specific examples. All the technical features recited in the present disclosure may be combined or integrated freely in any manner, unless contradictions are resulted.

[0055] It should also be noted that the Examples set forth above are only specific examples according to the present disclosure. Obviously, the present disclosure is not limited to the above Examples. Similar variations or modifications made thereto can be directly derived or easily contemplated from the present disclosure by those skilled in the art. They all fall in the protection scope of the present disclosure.

Claims

1. A cold-rolled and annealed dual-phase steel having a tensile strength of > 780 MPa, wherein the cold-rolled and annealed dual-phase steel has a matrix structure of fine and uniform martensite + ferrite, wherein the cold-rolled and annealed dual-phase steel comprises the following chemical elements in mass percentages, in addition to Fe:

C: 0.1%-0.13%, Si: 0.4%-0.8%, Mn: 1.65%-1.9%, Al: 0.01%-0.05%, Nb: 0.01-0.03%, Ti: 0.01-0.03%;
wherein the cold-rolled and annealed dual-phase steel is free of Cr and Mo elements.

2. The cold-rolled and annealed dual-phase steel according to claim 1, wherein the chemical elements have the following mass percentages:

C: 0.1%-0.13%, Si: 0.4%-0.8%, Mn: 1.65%-1.9%, Al: 0.01%-0.05%, Nb: 0.01-0.03%, Ti: 0.01-0.03%, and a balance of Fe and other unavoidable impurities.

3. The cold-rolled and annealed dual-phase steel according to claim 1 or 2, wherein the chemical elements have mass percentage contents satisfying at least one of the following:

C: 0.11-0.125%,
Si: 0.5%-0.7%,
Mn: 1.7%-1.8%,
Al: 0.015%-0.045%,
Nb: 0.015-0.025%,
Ti: 0.015-0.025%.

4. The cold-rolled and annealed dual-phase steel according to claim 2, wherein the unavoidable impurities include P, S and N elements, and contents thereof are controlled to be at least one of the following: $P \leq 0.015\%$, $S \leq 0.003\%$,

$N \leq 0.005\%$.

5 5. The cold-rolled and annealed dual-phase steel according to any one of claims 1-3, wherein mass percentage contents of Nb and Ti further satisfy: $Nb\% + Ti\% \times 3 \geq 0.047\%$.

6. The cold-rolled and annealed dual-phase steel according to any one of claims 1-3, wherein the martensite has a phase proportion of $>55\%$.

10 7. The cold-rolled and annealed dual-phase steel according to any one of claims 1-3, wherein the martensite has a grain diameter of not greater than 5 microns, and ferrite has a grain diameter of not greater than 5 microns.

8. The cold-rolled and annealed dual-phase steel according to any one of claims 1-3, wherein its performances satisfy at least one of the following: yield strength ≥ 420 MPa; tensile strength > 780 MPa; elongation at break with A_{50} gauge length $\geq 18\%$; 90 degree cold bending parameter $R/t \leq 1$, where R represents bending radius in mm, t represents plate thickness in mm.

9. The cold-rolled and annealed dual-phase steel according to claim 5, wherein the mass percentage contents of Nb and Ti further satisfy: $0.047\% \leq Nb\% + Ti\% \times 3 \leq 0.10\%$.

20 10. A manufacturing method for the cold-rolled and annealed dual-phase steel according to any one of claims 1-9, wherein the method comprises steps of:

(1) Smelting and continuous casting;

(2) Hot rolling;

25 (3) Cold rolling;

(4) Annealing: annealing soaking temperature: 770-820 °C; annealing time: 40-200 s; cooling at a rate of 3-5 °C/s to a starting temperature of rapid cooling; rapid cooling at a rate of 30-80 °C/s, wherein the starting temperature of rapid cooling is 650-730 °C, and the rapid cooling is ended at a temperature of 200-270 °C;

(5) Tempering;

30 (6) Temper rolling.

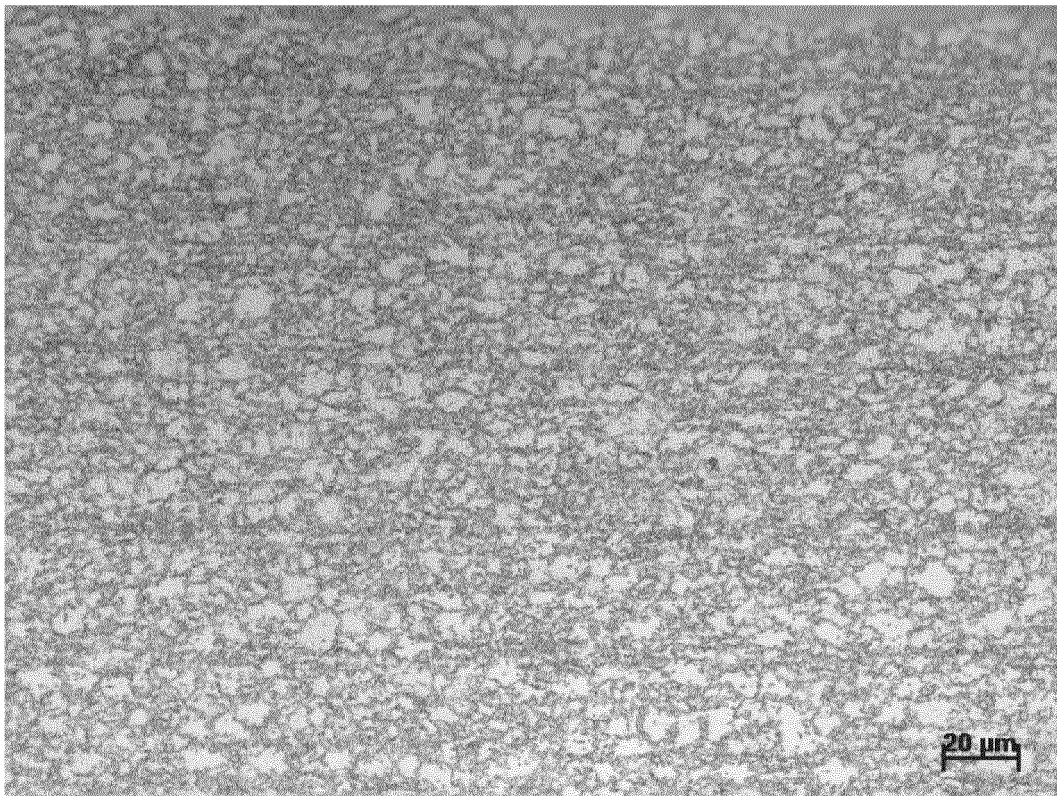
11. The manufacturing method according to claim 10, wherein in step (2), a slab is first heated to 1160-1220 °C; held for 0.6 hours or longer; hot rolled at a temperature of 850-900 °C; rapidly cooled at a rate of 30-80 °C/s after rolling; coiled with the coiling temperature being controlled at 500-600 °C; and air cooled after the coiling.

35 12. The manufacturing method according to claim 10, wherein in step (3), a cold rolling reduction rate is controlled at 50-70%.

13. The manufacturing method according to claim 10, wherein in step (5), a tempering temperature is controlled at 200-270 °C, and a tempering time is 100-400 s.

40 14. The manufacturing method according to claim 10, wherein in step (6), a temper rolling reduction rate is controlled at $\leq 0.3\%$.

45 15. The manufacturing method according to any one of claims 10-14, wherein in step (4), the annealing soaking temperature is 790-810 °C.



Figur 1

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2021/095808

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/02(2006.01)i; C22C 38/04(2006.01)i; C22C 38/06(2006.01)i; C22C 38/12(2006.01)i; C22C 38/14(2006.01)i; C21D 1/18(2006.01)i; C21D 1/26(2006.01)i; C21D 6/00(2006.01)i; C21D 8/02(2006.01)i; C21D 9/00(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C; C21D

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

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

CNABS; CNTXT; CNKI; VEN; USTXT; WOTXT; EPTXT; ISI WEB OF SCIENCE; 万方; 超星读秀; 宝山钢铁, 宝钢, 冷轧, 双相, 复相, 两相, 碳, 硅, 锰, 钛, 铌, 退火, 铁素体, 马氏体, C, Si, Mn, Nb, Ti, cold, roll+, dual, double, two, phase, carbon, silicon, manganese, niobium, columbium, titanium, anneal+, ferrite, martensite

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	CN 109207841 A (BAOSHAN IRON & STEEL CO., LTD.) 15 January 2019 (2019-01-15) description, paragraphs 13-34	1-15
X	CN 107406931 A (JFE STEEL CORPORATION) 28 November 2017 (2017-11-28) claims 1 and 5	1-5, 8, 9
A	CN 103930585 A (JFE STEEL CORPORATION) 16 July 2014 (2014-07-16) entire document	1-15
A	CN 109371317 A (HANDAN IRON & STEEL GROUP CO., LTD. et al.) 22 February 2019 (2019-02-22) entire document	1-15

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

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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

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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

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Date of the actual completion of the international search

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Name and mailing address of the ISA/CN

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

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