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(54) COMPLEX-PHASE STEEL HAVING HIGH HOLE EXPANSIBILITY AND MANUFACTURING METHOD THEREFOR

(57) Disclosed in the present invention is complex-phase steel having high hole expansibility. The complex-phase steel has a microstructure of ferrite and bainite. The complex-phase steel having high hole expansibility comprises the following chemical elements in percentage by mass: C: 0.06-0.09%, Si: 0.05-0.5%, Al: 0.02-0.1%, Mn: 1.5-1.8%, Cr: 0.3-0.6%, Nb≤0.03%, Ti: 0.05-0.12%, and the balance of Fe and inevitable impurities. In addition, also disclosed in the present invention is a manufacturing method for the foregoing complex-phase steel having high hole expansibility. The method comprises the following steps: (1) smelting and casting; (2) heating; (3) hot-rolling; (4) phosphorous removal; (5) laminar cooling: a relaxation time period is controlled to be 0-8s, and a laminar cooling rate is 40-70°C/s; (6) coiling; (7) leveling; and (8) pickling. The complex-phase steel having high hole expansibility can simultaneously satisfy the requirements for hole expansibility and good plasticity.

Processed by Luminess, 75001 PARIS (FR)

Description

TECHNICAL FIELD

[0001] The present disclosure relates to a steel and a manufacturing method thereof, and particularly relates to a complex-phase steel and a manufacturing method thereof.

BACKGROUND ART

[0002] With the strength-weight development of automobiles, more and more models use 80kg grade hot-rolled pickling steel plate to produce automobile chassis parts, such as control arm, tie rod, spring seat and so on. For example, the forming process of automobile chassis parts such as control arm includes stamping, flanging, reaming, etc. Therefore, it not only has certain requirements for strength and elongation, but also has certain requirements for reaming performance.

[0003] CN103602895A with the publication date of February 26, 2014, entitled "high-hole-expansion-ratio steel plate with tensile strength of 780 MPa and manufacturing process thereof', discloses a high-hole-expansion-ratio steel plate with tensile strength of 780 MPa and manufacturing process thereof. The steel plate has a Si content of 0.5-1.5%, which is high, and it is easy to form fayalite (2FeO-SiO_2) iron oxide scale which is difficult to remove. It is difficult to obtain strip steel with high-grade surface in this patent application. Meanwhile, because the red iron scale on the surface of the steel plate is difficult to control, it is difficult to measure accurately in the process of hot rolling temperature measurement, resulting in the instability of product performance.

[0004] CN108570604A with the publication date of September 25, 2018, entitled "780MPa-level hot-rolled acid-pickled high hole expansion steel tape and production method thereof', discloses a 780MPa-level hot-rolled acid-pickled high hole expansion steel tape and production method thereof. The steel tape has a Al content of 0.2-0.6%, which is high, and easy to be oxidized in the continuous casting process. Meanwhile, a three-stage cooling mode is adopted in this patent application, which has low production stability.

[0005] CN105483545A with the publication date of April 13, 2016, entitled "800MPa level hot-rolling high hole expansion steel plate and manufacturing method thereof', discloses an 800MPa level hot-rolling high hole expansion steel plate and manufacturing method thereof. The steel plate has a Si content of 0.2-1.0%, which is relatively high, and it is easy to form red scale on the surface, which is not conducive to the control of surface and coiling temperature. Meanwhile, the steel plate has an Nb content of 0.03-0.08%, which is also relatively high, the cost is high, and sectional cooling is required after rolling, and the cooling process is complex.

[0006] In the prior art, the higher the strength of the material, the more difficult it is to control the length and width stability of the material. Based on this, it is desired to obtain a complex-phase steel having high hole expansibility, which has good hole expansibility and cold formability, and can realize stable manufacturing.

SUMMARY

[0007] An object of the present disclosure is to provide a complex-phase steel having high hole expansibility. The complex-phase steel having high hole expansibility can simultaneously satisfy the requirements for good hole expansibility and plasticity, and compared with traditional material like low-alloy high-strength steel and ferrite-martensite dual-phase steel, the two phases of the complex-phase steel having high hole expansibility are ferrite and bainite, so the hardness difference is small, making the steel good hole expansibility and cold formability.

[0008] To achieve the above object, the present disclosure provides a complex-phase steel having high hole expansibility, wherein the microstructure of the complex-phase steel is ferrite + bainite, and the mass percentage of chemical elements of the complex-phase steel having high hole expansibility is:

C: 0.06-0.09%, Si: 0.05-0.5%, Al: 0.02-0.1%, Mn: 1.5-1.8%, Cr: 0.3-0.6%, Nb≤0.03%, Ti: 0.05-0.12%, and a balance of Fe and inevitable impurities.

[0009] In the complex-phase steel having high hole expansibility of the present disclosure, the design principle of each chemical element is as follows:

C: In the complex-phase steel having high hole expansibility of the present disclosure, considering that the carbon content largely determines the tensile strength level of the steel plate, carbon is used for solid solution strengthening and forming sufficient precipitation strengthening phase to ensure the strength of the steel, but the high mass percentage of carbon will make the carbide particles coarse, which is not conducive to the hole expansibility; if the mass percentage of carbon is too low, the strength of the steel plate will be reduced. In order to ensure that the steel can not only have high hole expansibility with strength, but also have good forming and welding performance, in the technical solution of the present disclosure, the mass percentage of C is controlled to be 0.06-0.09%.

[0010] Si: In the complex-phase steel having high hole expansibility of the present disclosure, silicon has a solid solution strengthening effect to improve the strength of the steel sheet. At the same time, the addition of silicon can increase the work hardening rate and the uniform elongation rate and total elongation rate under a given strength, which is helpful to improve the elongation of steel plate sheet. In addition, silicon can also prevent the precipitation of carbide and reduce the appearance of pearlite phase. However, silicon in the steel is easy to form the surface defect of fayalite ($2FeO$-SiO_2) iron oxide scale on the surface of the steel plate, which has a bad impact on the surface quality. At the same time, the appearance of red iron scale is not conducive to the temperature control in the hot rolling process, resulting in the instability of product performance. Based on this, in the complex-phase steel having high hole expansibility of the present disclosure, the mass percentage of silicon is controlled to be 0.05-0.5%.

[0011] Al: In the complex-phase steel having high hole expansibility of the present disclosure, Al is a deoxidizing element of steel, reduces oxide inclusions in steel and purifies steel quality, and is conducive to improving the formability of steel plate. However, the high mass percentage of aluminum will produce oxidation and further affect the continuous casting production. Based on this, in the complex-phase steel having high hole expansibility of the present disclosure, the mass percentage of aluminum is controlled to be 0.02-0.1%.

[0012] Mn: In the complex-phase steel having high hole expansibility of the present disclosure, manganese is a solid solution strengthening element. The low mass percentage of manganese will lead to insufficient strength, but the high mass percentage of manganese will reduce the plasticity of steel plate. At the same time, manganese delays pearlite transformation, improves the hardenability of steel, reduces bainite transformation temperature, refines the substructure of steel, ensures the acquisition of lath substructure and renders good formability on the premise of ensuring the tensile strength of products. Based on this, in the complex-phase steel having high hole expansibility of the present disclosure, the mass percentage of manganese is controlled to be 1.5-1.8%.

[0013] Cr: In the complex-phase steel having high hole expansibility of the present disclosure, chromium increases the incubation period of pearlite and ferrite in the CCT curve, inhibits the formation of pearlite and ferrite, is conducive to the formation of bainite structure, and finally is conducive to the improvement of strength and hole expansion rate. When the mass percentage of chromium is less than 0.15%, it has no significant impact on the CCT curve, but when the mass percentage of Cr is relatively high, it will lead to higher cost. Based on this, in the complex-phase steel having high hole expansibility of the present disclosure, the mass percentage of chromium is controlled to be 0.3-0.6%.

[0014] Nb: In the complex-phase steel having high hole expansibility of the present disclosure, niobium is one of the important precipitation strengthening and fine grain strengthening elements. It exists in the form of fine precipitation after coiling or in the cooling after rolling, and uses precipitation strengthening to improve the strength. At the same time, the existence of niobium is conducive to refining grains, improving strength and toughness, and reducing the strength difference between ferrite and bainite matrix, which is conducive to the improvement of hole expansion rate. However, when the mass percentage of Nb is higher than 0.03%, the strengthening effect of Nb is close to saturation and the cost is high. Therefore, in the complex-phase steel having high hole expansibility of the present disclosure, the mass percentage of Nb is controlled to be $Nb \leq 0.03\%$.Considering that when the mass percentage of Nb is less than 0.015%, the precipitation of NbC is insufficient and it is difficult to achieve the purpose of precipitation strengthening, in some preferred embodiments, the mass percentage of Nb can be preferably set to 0.015-0.03%.

[0015] Ti: In the complex-phase steel having high hole expansibility of the present disclosure, titanium is one of the important precipitation strengthening and fine grain strengthening elements. Titanium plays two roles in the present disclosure. One is to combine with the impurity element nitrogen in the steel to form TiN. This is because the free nitrogen atom in the steel is unfavorable to the impact toughness of the steel. Adding a small amount of titanium can fix the free nitrogen, which is conducive to the hole expansion rate and the improvement of the impact toughness. The second is to cooperate with niobium to play the best role in refining austenite grains and precipitation strengthening.

[0016] However, in the present disclosure, the mass percentage of Ti should not be too much, which is easy to form TiN with large size, which is unfavorable to the impact toughness of steel. Therefore, in the complex-phase steel having high hole expansibility of the present disclosure, the mass percentage of Ti is controlled to be Ti: 0.05-0.12%.

[0017] Further, in the complex-phase steel having high hole expansibility of the present disclosure, the Nb content is 0.015-0.03%.

[0018] Further, in the complex-phase steel having high hole expansibility of the present disclosure, in other inevitable impurities, $P \leq 0.03\%$, $S \leq 0.02\%$, $N \leq 0.005\%$.

[0019] In the above embodiments, the inevitable impurity elements should be controlled as low as possible, but considering the cost control and process constraints, the mass percentages can be controlled at $P \leq 0.03\%$, $S \leq 0.02\%$, and $N \leq 0.005\%$.Among them, the reason why the mass percentage of N is controlled at $N \leq 0.005\%$ is that nitrogen reacts with titanium at high temperature to form TiN particle precipitates, and oversized TiN particles will become local deformation microcracks of the steel plate, which will eventually affect the hole expansion rate. Therefore, the nitrogen content in the steel must be controlled.

[0020] For P, the reason why the mass percentage of P is controlled at $P \leq 0.03\%$ is that phosphorus in steel is generally solid dissolved in ferrite, which reduces the toughness of steel, but high phosphorus is unfavorable to weldability. At the same time, phosphorus segregation at grain boundary is not conducive to the hole expansion performance of strip steel, so the phosphorus content should be reduced as much as possible.

[0021] In the above embodiments, the mass percentage of S is controlled at S≤0.02% because the sulfur content and the morphology of sulfide are the main factors affecting the formability. The more the number and size of sulfide are, the more unfavorable it is to the hole expansion performance.

[0022] Further, in the complex-phase steel having high hole expansibility of the present disclosure, the mass percentage contents of chemical elements meet at least one of the following formulae:

$$0.2\% \leq Cr-0.5(Si+Al) \leq 0.42\%;$$

$$0.08\% \leq 3.3Nb+Ti \leq 0.20\%.$$

[0023] In the above embodiments, 0.2%≤Cr-0.5(Si+Al)≤0.42% is controlled, so as to move the transformation zone of pearlite and ferrite to the right, delay the transformation of pearlite and ferrite, and be conducive to the formation of bainite phase, so as to achieve the purpose of high strength and high hole expansion.

[0024] In addition, in the present disclosure, the mass percentages of Nb and Ti are limited to meet 0.08%≤3.3Nb+Ti≤0.20%, so as to control the precipitation strengthening of about 100-200MPa, and when a design of high titanium composition is adopted, niobium does not need to be added, and the purpose of high hole expansion and plasticity requirement in the present disclosure can be achieved at the same time, and the purpose of reducing cost can also be achieved.

[0025] Further, in the complex-phase steel having high hole expansibility of the present disclosure, the microstructure has microalloy precipitates, which include (Ti, Nb)C and NbN.

[0026] Further, in the complex-phase steel having high hole expansibility of the present disclosure, the tensile strength and the mass percentages of chemical elements meet the following relationship:

$$\text{Tensile strength Rm} = 343+789\times C+170\times Si+132\times Mn+195\times Cr+843\times (Nb+Ti)-207\times Al,$$

wherein the dimension of tensile strenght Rm is MPa

[0027] In the present disclosure, based on the above formula and the chemical element composition ratio of the present disclosure, the tensile strength Rm is generally 790~850MPa.

[0028] Further, in the complex-phase steel having high hole expansibility of the present disclosure, the transverse tensile strength is ≥780MPa, the yield strength is ≥700MPa, the elongation rate A50 ≥15%, and the punching hole expansion rate is ≥50%.

[0029] Preferably, in the complex-phase steel having high hole expansibility of the present disclosure, the punching hole expansion rate is ≥70%.

[0030] Preferably, in the complex-phase steel having high hole expansibility of the present disclosure, the yield strength is ≥730MPa.

[0031] Preferably, in the complex-phase steel having high hole expansibility of the present disclosure, the transverse tensile strength is ≥8000MPa.

[0032] Further, in the complex-phase steel having high hole expansibility of the present disclosure, the transverse tensile strength is ≥800MPa, the yield strength is ≥730MPa, the elongation rate A50 ≥15%, and the punching hole expansion rate is ≥70%.

[0033] Accordingly, another object of the present disclosure is to provide a manufacturing method of the above complex-phase steel having high hole expansibility, through which a complex-phase steel having high hole expansibility with good hole expansion performance and cold forming performance can be obtained.

[0034] To achieve the above object, the present disclosure provides a method for manufacturing the above complex-phase steel having high hole expansibility, comprising the following steps:

(1) Smelting and casting;
(2) Heating;
(3) Hot rolling: A total reduction rate is controlled to be ≥80%, a rough rolling is controlled to be rolled in a recrystallization zone, and a rough rolling outlet temperature is 1020-1100°C; a quasi constant speed rolling process is adopted in the finish rolling process, a finish rolling speed is controlled at 6-12m/s, and a steel rolling acceleration is controlled to be ≤0.005m/s^2; a finish rolling temperature is controlled at 840-900°C;
(4) Phosphorus removal;
(5) Laminar cooling: a relaxation time is controlled at 0-8s and a cooling rate of laminar cooling is controlled at

40-70°C/s;
(6) Coiling;
(7) Flattening;
(8) Pickling.

[0035] In the manufacturing method of the present disclosure, the total reduction rate of hot rolling is controlled to be ≥80%; at the same time, the rough rolling is ensured to be rolled in the recrystallization zone and microalloying precipitation in the austenite zone is avoided; the outlet temperature of rough rolling is controlled at 1020-1100 °C; quasi constant speed rolling process is adopted in the finish rolling process, the steel rolling acceleration is $\leq 0.005 m/s^2$, and the speed of finish rolling is controlled at 6-12m/s; the finish rolling temperature is controlled between 840-900°C and the rolling is performed in the non-recrystallization zone to refine the grain and facilitate deformation induced precipitation; on the premise of ensuring the target temperature, constant speed rolling ensures the stability of air cooling time, which is conducive to the control of delay cooling time.

[0036] In addition, in laminar cooling, the use of front cooling and delay control cooling mode is conducive to grain recovery and microalloy precipitation. The relaxation time is controlled at 0-8s and the laminar cooling rate is controlled at 40-70°C/s mainly by controlling the speed of finish rolling strip and the position of starting valve.

[0037] In addition, in some preferred embodiments, a continuous casting process can be adopted, and a superheat, a secondary cooling water and an appropriate soft reduction can be controlled to control the central segregation of the continuous casting slab.

[0038] Further, in the manufacturing method of the present disclosure, in step (2), a heating temperature is 1200-1260°C.

[0039] In the above embodiments, in order to make Ti and Nb fully solid solution, the heating temperature can be set at 1200-1260°C and kept for 1~3h to much better obtain favorable results. When the temperature exceeds 1260°C, there will be a trend of grain coarsening, which is not conducive to the toughness of the steel plate; at the same time, the iron oxide scale is thick, which is not conducive to the phosphorus removal of the iron oxide scale. Therefore, the heating temperature is preferably set to 1200-1260°C.

[0040] Further, in the manufacturing method of the present disclosure, in step (4), a phosphorus removal pressure is controlled to be 15-35MPa.

[0041] In the above embodiments, considering that fayalite ($2FeO-SiO_2$) will lead to the densification of steel oxide layer, when the phosphorus removal effect of iron oxide scale on the hot rolling surface is not good, the broken oxide scale surface will reduce the flow of water during laminar cooling due to its large roughness, and the accumulation of local water will further affect the local performance of the strip steel and the uneven local cooling of the strip steel. Therefore, the poor phosphorus removal effect will not only lead to the difference of material surface, but also lead to the difference of performance. Based on this, the high-pressure phosphorus removal water system can be preferred, and the phosphorus removal pressure can be controlled to 15-35MPa.

[0042] Further, in the manufacturing method of the present disclosure, in step (6), a coiling temperature is 480-560°C.

[0043] In the above embodiments, the coiling temperature is controlled at 480-560°C to control bainite transformation and microalloy precipitation. High coiling temperature will lead to more ferrite and pearlite content, which is not conducive to the improvement of hole expansion rate. The coiling temperature is low, the ferrite content is less, the precipitation is less, and martensite structure may appear, and the elongation is low. Therefore, controlling the coiling temperature between 480-560°C can solve the matching problem between elongation and hole expansion rate.

[0044] Further, in the manufacturing method of the present disclosure, in step (7), a flattening rolling force is controlled to be 100-800 tons, and a flattening elongation meets ≤1.5%.

[0045] In some preferred embodiments, in step (8), a pickling speed is controlled at 60-100m/min, and a temperature of the last pickling tank in the pickling process is controlled at 80-90°C and an iron ion concentration is controlled at 30-40g/L.

[0046] The complex-phase steel having high hole expansibility of the present disclosure has the following advantages and beneficial effects:

The complex-phase steel having high hole expansibility of the present disclosure can simultaneously satisfy the requirements for good hole expansibility and plasticity, and compared with traditional material like low-alloy high-strength steel and ferrite-martensite dual-phase steel, the two phases of the complex-phase steel having high hole expansibility of the present disclosure are ferrite and bainite, so the hardness difference is small, making the steel have good hole expansibility and cold formability.

[0047] In addition, the manufacturing method of the present disclosure also has the above advantages and beneficial effects.

DESCRIPTION OF THE DRAWINGS

[0048]

Fig. 1 is a metallographic microstructure photo of the complex-phase steel having high hole expansibility of Example 1.
Fig. 2 is an SEM microstructure photo of the complex-phase steel having high hole expansibility of Example 1.
Fig. 3 is a schematic diagram of the surface morphology of the surface oxide scale of the strip steel with good surface.
Fig. 4 is a schematic diagram of the surface morphology of the surface oxide scale of the strip steel with surface NG1.
Fig. 5 is a schematic diagram of the change of mechanical properties of the complex-phase steel having high hole expansibility of Example 3 under different flattening deformation.

DETAILED DESCRIPTION

[0049] The complex-phase steel having high hole expansibility of the present disclosure and its manufacturing method will be further explained and illustrated with reference to the drawings and specific examples. Nonetheless, the explanation and illustration are not intended to unduly limit the technical solution of the present disclosure.

Examples 1-7 and Comparative Examples 1-6

[0050] The complex-phase steels having high hole expansibility of Examples 1-7 and its manufacturing method and the comparison steel plates of Comparative Examples 1-6 are prepared by the following steps:

(1) Smelting and casting were carried out according to the chemical composition shown in Table 1. Converter steelmaking was adopted. The molten steel was subject to RH vacuum degassing treatment and LF furnace desulfurization treatment, wherein P≤ 0.015% and S≤0.005% were controlled. During continuous casting, the degree of superheat, secondary cooling water and appropriate soft reduction were controlled to control the central segregation of continuous casting slab.
(2) Heating: the heating temperature is 1200-1260°C.
(3) Hot rolling: the total reduction rate was controlled to be ≥80%, the rough rolling was controlled to be rolled in the recrystallization zone, and the rough rolling outlet temperature was 1020-1100°C; quasi constant speed rolling process was adopted in the finish rolling process, the finish rolling speed was controlled at 6-12m/s, and the steel rolling acceleration was controlled to be ≤0.005m/s^2; the finish rolling temperature was controlled at 840-900°C.
(4) Phosphorus removal: the phosphorus removal pressure was controlled at 15-35MPa.
(5) Laminar cooling: the relaxation time was controlled at 0-8s and the cooling rate of laminar cooling was controlled at 40-70°C/s.
(6) Coiling: the coiling temperature is 480-560°C.
(7) Flattening: the flattening rolling force was controlled to be 100-800 tons, and the flattening elongation met ≤1.5%.
(8) Pickling: the pickling speed was controlled at 60-100m/min, and the temperature of the last pickling tank in the pickling process was controlled at 80-90°C and the iron ion concentration was controlled at 30-40g/L.

[0051] Table 1 shows the mass percentage of each chemical element of the complex-phase steels having high hole expansibility of Examples 1-7 and its manufacturing method and the steel plates of Comparative Examples 1-6.

Table 1 (unit: weight %, and a balance of Fe and inevitable impurities other than P, S and N)

No	C	Si	Mn	Cr	Nb	Ti	Al	Cr-0.5 (Si+Al)	3.3Nb+Ti	Predicted Rm/MPa
Example 1	0.07	0.25	1.65	0.45	0.015	0.08	0.03	0.31	0.13	820
Example 2	0.07	0.2	1.77	0.45	0	0.1	0.03	0.34	0.10	832
Example 3	0.09	0.12	1.65	0.42	0.03	0.05	0.02	0.35	0.15	797
Example 4	0.06	0.5	1.53	0.6	0	0.08	0.08	0.31	0.08	845
Example 5	0.07	0.12	1.79	0.3	0.02	0.12	0.04	0.22	0.19	823
Example 6	0.06	0.05	1.79	0.45	0.015	0.075	0.02	0.42	0.12	795
Example 7	0.07	0.45	1.68	0.55	0	0.075	0.1	0.28	0.08	846

(continued)

No	C	Si	Mn	Cr	Nb	Ti	Al	Cr-0.5 (Si+Al)	3.3Nb+Ti	Predicted Rm/MPa
Comparativ e Example 1	0.07	***0.8***	1.65	0.45	0.015	0.08	0.03	***0.14***	0.12	914
Comparativ e Example 2	0.07	0.25	1.65	***0.22***	0.015	0.08	0.03	***0.08***	0.13	775
Comparativ e Example 3	0.07	0.2	1.77	0.45	0	***0.04***	0.03	0.34	***0.04***	781
Comparativ e Example 4	0.07	0.25	1.65	0.45	0.015	0.08	0.03	0.31	0.13	820
Comparativ e Example 5	0.07	0.25	1.65	0.45	0.015	0.08	0.03	0.31	0.13	820
Comparativ e Example 6	0.07	0.25	1.65	0.45	0.015	0.08	0.03	0.31	0.13	820

[0052] Table 2 shows the specific process parameters of the complex-phase steels having high hole expansibility of Examples 1-7 and its manufacturing method and the steel plates of Comparative Examples 1-6.

Table 2

No.	Heating Temperature/°C	Rough Rolling Outlet Temperature/°C	Finish rolling speed/m/s	Steel Rolling Acceleration/m/s^2	Reduction Rate/%	Finish Rolling Temperature/°C	Phosphorus Removal Pressure/MPa	Relaxation time/s	Cooling Rate of Laminar Cooling °C/s	Coiling Temperature/°C	Flattening Rolling Force/ton	Flattening Elongation Rate/%
Example 1	1230	1060	9	0.003	98.4	880	20	4	50	520	148	0.2
Example 2	1250	1070	11	0.003	99.0	890	20	3	60	520	223	0.3
Example 3	1200	1020	6	0.003	97.3	840	20	8	50	540	574	0.8
Example 4	1220	1030	7	0.003	97.5	850	35	7	40	560	706	1.0
Example 5	1260	1100	12	0.003	99.2	900	30	0	60	500	154	0.2
Example 6	1230	1050	8	0.003	98.2	860	15	5	70	480	146	0.2
Example 7	1250	1080	10	0.003	98.5	890	30	2	50	500	451	0.6
Comparative Example 1	1230	1060	9	0.003	98.4	880	20	4	50	520	136	0.2
Comparative Example 2	1230	1060	9	0.003	98.4	880	20	4	50	520	136	0.2
Comparative Example 3	1250	1070	11	0.003	98.4	890	20	3	50	520	198	0.3

(continued)

No.	Heating Temperature/°C	Rough Rolling Outlet Temperature/°C	Finish rolling speed/m/s	Steel Rolling Acceleration/m/s^2	Reduction Rate/%	Finish Rolling Temperature/°C	Phosphorus Removal Pressure/MPa	Relaxation time/s	Cooling Rate of Laminar Cooling °C/s	Coiling Temperature/°C	Flattening Rolling Force/ton	Flattening Elongation Rate/%
Comparative Example 4	*1150*	1060	9	0.003	98.4	880	20	4	50	520	131	0.2
Comparative Example 5	*1230*	1060	9	0.003	98.4	880	20	4	50	***430***	160	0.2
Comparative Example 6	*1230*	1060	9	0.003	98.4	880	20	4	50	520	785	***1.8***

[0053] According to the test method of hole expansion rate specified in ISO/DIS16630 standard, the size of the experimental sample was 150×150mm, punching size was Φ10mm, the clearance was set as 12.5%, the hole was punched from the shear plane with a 60° conical heavy head, and the inner diameter d was calculated when the crack passed through the plate thickness. If the inner diameter before punching is set to do, the limit hole expansion value λ% is calculated from the following formula. Limit hole expansion value $\lambda\%=(d-d_0)/d_0\times 100\%$.Tensile standard: the transverse JIS 5# tensile sample was taken to measure the mechanical properties; 180° bending performance was conducted according to GB/T232-2010 standard.

[0054] Table 3 shows the mechanical property test results of the complex-phase steels having high hole expansibility of Examples 1-7 and its manufacturing method and the steel plates of Comparative Examples 1-6.

Table 3

	Thickness/mm	Predicted Rm/MPa	Rp0.2/MPa	Rm/MPa	A50/%	λ/%	180° Cold Bending
Example 1	3.5	820	742	824	17.5	88	1.5a
Example 2	2.2	832	743	833	16.2	87	1.5a
Example 3	6.0	797	718	793	18.5	82	1.5a
Example 4	5.5	845	706	789	20.1	58	1.5a
Example 5	1.8	823	771	859	15.6	78	1.5a
Example 6	4.0	795	732	812	15.1	76	1.5a
Example 7	3.2	846	752	845	16.8	85	1.5a
Comparative Example 1	3.5	914	812	895	***11.2***	54	2.5a
Comparative Example 2	3.5	775	***678***	***765***	17.5	53	1.5a
Comparative Example 3	3.5	781	***661***	***759***	16.8	76	1.5a
Comparative Example 4	3.5	820	***653***	***768***	17.6	82	1.5a
Comparative Example 5	3.5	820	798	923	***11.4***	***34***	2.5a
Comparative Example 6	3.5	820	785	863	***14.2***	68	2.0a

[0055] It can be seen from Table 3 that the transverse tensile strength of the complex-phase steel having high hole expansibility of each example of the disclosure is ≥780MPa, the yield strength is ≥700MPa, the elongation rate A_{50} ≥15%, and the punching hole expansion rate is ≥50%.

[0056] It can be seen combined with Table 1 that Cr-0.5(Si+Al) in Comparative Example 1 does not meet the requirement of 0.2%≤Cr-0.5(Si+Al)≤0.42%. Compared with Example 1, the two adopted the same process system, but the Si content is higher in Comparative Example 1, so it is easy to form fayalite ($2FeO\text{-}SiO_2$) iron oxide scale, which is difficult to remove, and it is difficult to obtain strip steel with high-grade surface. At the same time, because the red iron scale on the surface is difficult to control, it is difficult to measure accurately in the process of hot rolling temperature measurement, resulting in unstable product performance. The strength of the region having fayalite ($2FeO\text{-}SiO_2$) is too high and the elongation is low. In Table 1, Cr-0.5(Si+Al) in Comparative Example 2 does not meet the requirement of 0.2%≤Cr-0.5(Si+Al)≤0.42%. Compared with Example 1, the two adopted the same process system, but Comparative Example 2 is not conducive to the transformation of bainite structure, and a large number of polygonal ferrite and pearlite exists in the structure, which is not conducive to the improvement of strength and hole expansion rate. In Table 1, comparing Comparative Example 3 with Example 2, it can be found that the Ti content of Comparative Example 3 is low, which does not meet the requirement of 0.08%≤3.3Nb+Ti≤0.20%. The two adopted the same process system, but the grain refinement effect is less and the precipitation strengthening effect is weak in Comparative Example 3, and the tensile strength can not reach more than 780MPa.

[0057] In addition, it can be seen combined with table 2 that in Comparative Example 4, the heating temperature is relatively low, which is not conducive to the solid solution of Ti and Nb, the precipitation of fine carbides of Nb and Ti in the subsequent cooling and coiling process, and the improvement of strength .A Low coiling temperature is adopted in Comparative Example 5, and there will be a certain amount of martensite in the undercooled structure, which is not conducive to the improvement of elongation and hole expansion rate. A large amount of flatness is adopted in Comparative Example 6, and the elongation loss is 3.4% compared with Example 1.

[0058] Comparing the effects of different surface states of hot rolling on the uniformity of mechanical properties, the composition and process of Example 4 were adopted, and steel strips with different surface states were obtained by setting different phosphorus removal pressure. The worse the surface treatment effect, the greater the surface roughness, the higher the corresponding strength and the lower the elongation.

[0059] Table 4 lists the effects of different surface states on mechanical properties. In addition, Figures 3 and 4 show the morphology of different surface states respectively. Among them, Fig. 3 shows the surface morphology of the surface oxide scale of the strip steel with good surface, and Fig. 4 shows the surface morphology of the surface oxide scale of the strip steel with surface "NG1".

Table 4

	Thickness/mm	Phosphorus Removal Pressure/MPa	Surface Roughness/μm	Rp0.2/MPa	Rm/MPa	A50/%
Good Surface	3.5	20	1.33	706	789	20.1
Surface NG1	3.5	8	4.78	835	897	13.5
Surface NG2	3.5	5	5.34	864	937	11.8
Surface NG3	3.5	9	3.15	760	856	14.5

[0060] Fig. 1 is the metallographic microstructure photo of the complex-phase steel having high hole expansibility of Example 1.

[0061] Fig. 2 is the SEM microstructure photo of the complex-phase steel having high hole expansibility of Example 1.

[0062] It can be seen combined with figures 1 and 2 that the microstructure of the complex-phase steel having high hole expansibility of the present disclosure is ferrite + bainite, and the microstructure has microalloy precipitates, which include (Ti, Nb)C and NbN.

[0063] Fig. 5 illustrates the change of mechanical properties of the complex-phase steel having high hole expansibility of Example 3 under different flattening deformation.

[0064] As shown in Fig. 5, the strength tends to rise with the increase of flatness.

[0065] In conclusion, the complex-phase steel having high hole expansibility of the present disclosure can simultaneously satisfy the requirements for good hole expansibility and plasticity, and compared with traditional material like low-alloy high-strength steel and ferrite-martensite dual-phase steel, the two phases of the complex-phase steel having high hole expansibility of the present disclosure are ferrite and bainite, so the hardness difference is small, making the steel have good hole expansibility and cold formability. In addition, the manufacturing method of the present disclosure also has the above advantages and beneficial effects.

[0066] It should be noted that the prior art part of the protection scope of the present disclosure is not limited to the embodiments given in the present disclosure, and all prior technologies that do not conflict with the solution of the present disclosure, including but not limited to prior patent documents, prior public publications, prior public use, etc., can be included in the protection scope of the present disclosure.

[0067] In addition, the combination mode of the technical features in the present disclosure is not limited to the combination mode recorded in the claims or the combination mode recorded in the specific embodiment of the present disclosure. All the technical features recorded in present disclosure can be combined or integrated in any way, unless there is a contradiction between them.

[0068] It should also be noted that the embodiments listed above are only specific embodiments of the present disclosure. Obviously, the present disclosure is not limited to the above embodiments, and the subsequent similar changes or deformations can be directly obtained or easily thought of by those skilled in the art from the contents disclosed in the present disclosure, which should belong to the protection scope of the present disclosure.

Claims

1. A complex-phase steel having high hole expansibility, wherein the microstructure of the complex-phase steel having high hole expansibility is ferrite + bainite, and mass percentages of chemical elements of the complex-phase steel having high hole expansibility are:
C: 0.06-0.9%, Si: 0.05-0.5%, Al: 0.02-0.1%, Mn: 1.5-1.8%, Cr: 0.3-0.6%, Nb≤0.03%, Ti: 0.05-0.12%, and a balance of Fe and inevitable impurities.

2. The complex-phase steel having high hole expansibility according to claim 1, wherein the Nb content is 0.015-0.03%.

3. The complex-phase steel having high hole expansibility according to claim 1, wherein in the inevitable impurities, P≤0.03%, S≤0.02%, and N≤0.005%.

4. The complex-phase steel having high hole expansibility according to claim 1, wherein the mass percentage contents of chemical elements satisfy one of the following formulas:

$$0.2\% \leq Cr-0.5(Si+Al) \leq 0.42\%;$$

$$0.08\% \leq 3.3Nb+Ti \leq 0.20\%.$$

5. The complex-phase steel having high hole expansibility according to claim 1, wherein the microstructure has micro-alloy precipitates, which include (Ti, Nb)C and NbN.

6. The complex-phase steel having high hole expansibility according to any one of claims 1-5, wherein a tensile strength and the mass percentage contents of chemical elements satisfy:

$$\text{tensile strength } Rm = 343+789\times C+170\times Si+132\times Mn+195\times Cr+843\times(Nb+Ti)-207\times Al,$$

wherein the dimension of the tensile strenght Rm is MPa.

7. The complex-phase steel having high hole expansibility according to claim 6, wherein the complex-phase steel having high hole expansibility has a transverse tensile strength of ≥780MPa, a yield strength of ≥700MPa, an elongation rate A_{50} of ≥15%, and a punching hole expansion rate of ≥50%.

8. The complex-phase steel having high hole expansibility according to claim 1, wherein the complex-phase steel having high hole expansibility has a transverse tensile strength of ≥800MPa, a yield strength of ≥730MPa, an elongation rate A_{50} of ≥15%, and a punching hole expansion rate of ≥70%.

9. A method for manufacturing the complex-phase steel having high hole expansibility of any one of claims 1-8, comprising the following steps:

   (1) Smelting and casting;
   (2) Heating;
   (3) Hot rolling: a total reduction rate is controlled to be ≥80%, a rough rolling is controlled to be rolled in a recrystallization area, and a rough rolling outlet temperature is 1020-1100°C; a quasi constant speed rolling process is adopted in a finish rolling process, a finish rolling speed is controlled at 6-12m/s, and a steel rolling acceleration is controlled to be ≤0.005m/s^2; a finish rolling temperature is controlled at 840-900°C;
   (4) Phosphorus removal;
   (5) Laminar cooling: a relaxation time is controlled at 0-8s and a cooling rate of laminar cooling is controlled at 40-70°C/s;
   (6) Coiling;
   (7) Flattening;
   (8) Pickling.

10. The method for manufacturing the complex-phase steel having high hole expansibility according to claim 9, wherein

in step (2), a heating temperature is 1200-1260°C.

11. The method for manufacturing the complex-phase steel having high hole expansibility according to claim 9, wherein in step (4), a phosphorus removal pressure is controlled to be 15-35MPa.

12. The method for manufacturing the complex-phase steel having high hole expansibility according to claim 9, wherein in step (6), a coiling temperature is 480-560°C.

13. The method for manufacturing the complex-phase steel having high hole expansibility according to claim 9, wherein in step (7), a flattening rolling force is controlled to be 100-800 tons, and a flattening elongation rate meets ≤1.5%.

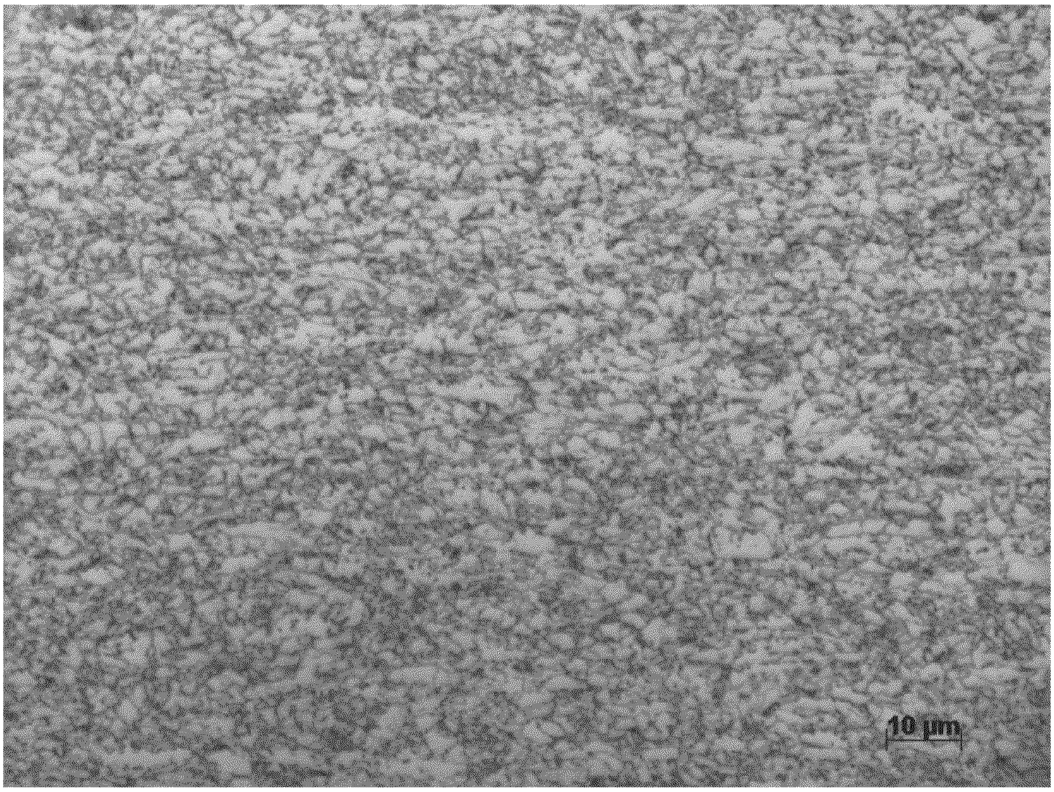

Figure 1

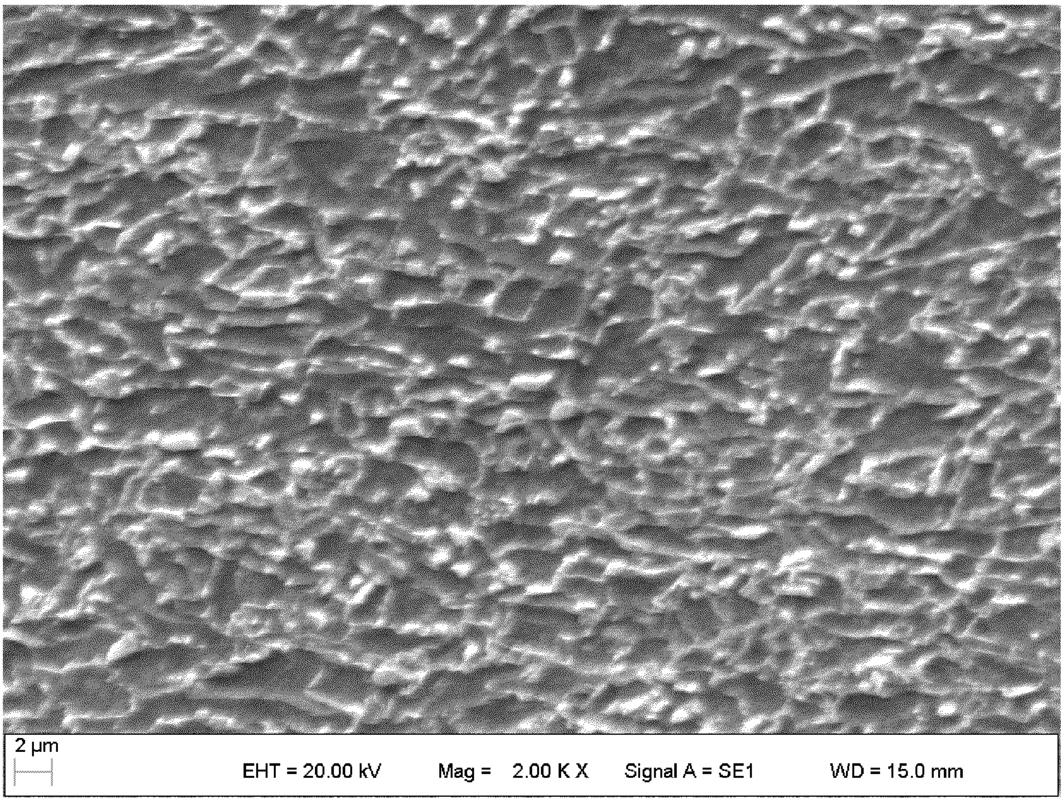

Figure 2

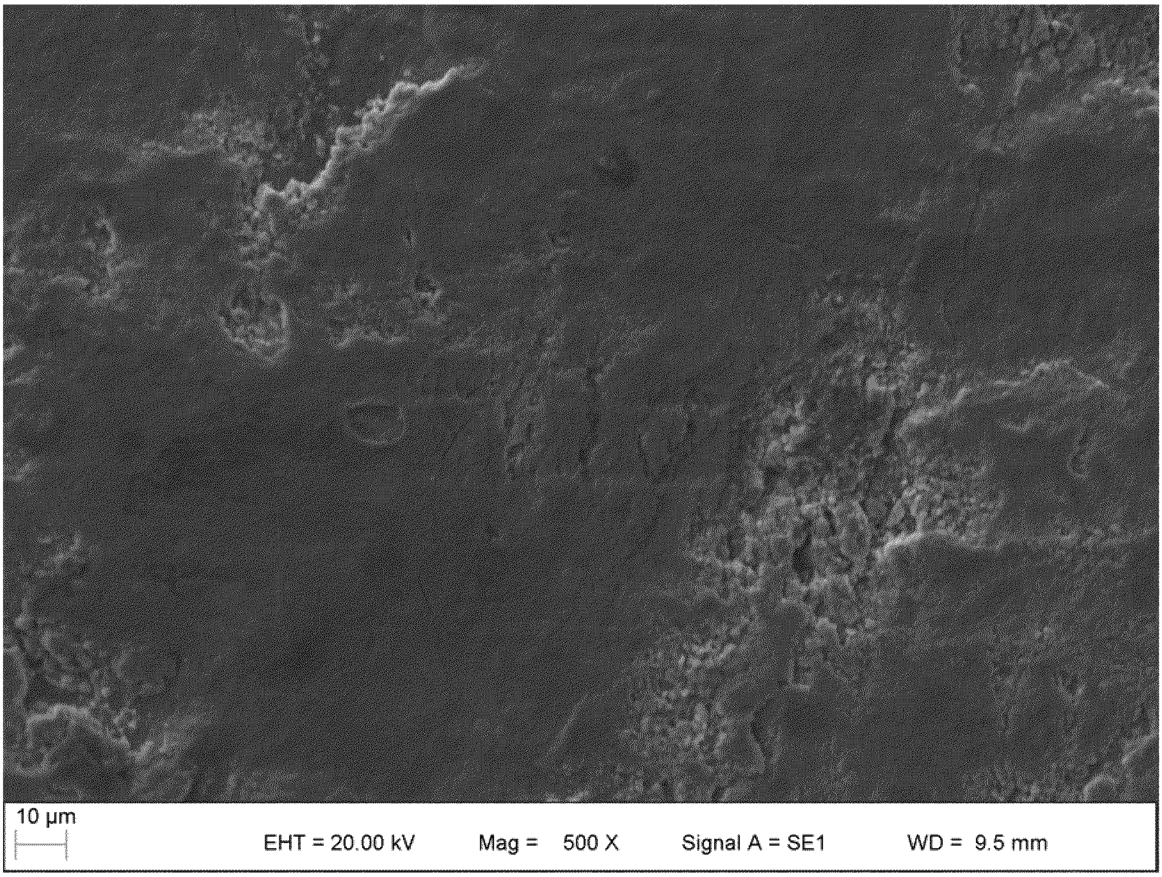

Figure 3

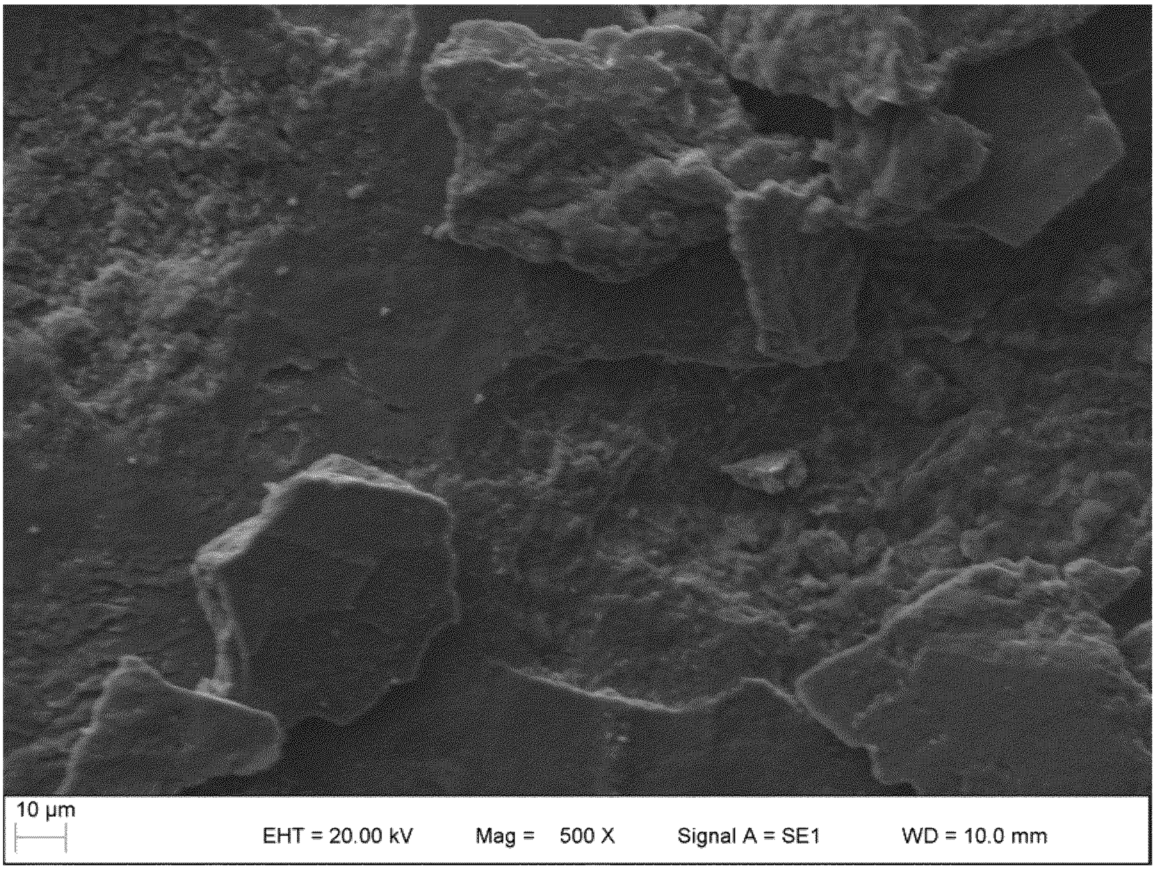

Figure 4

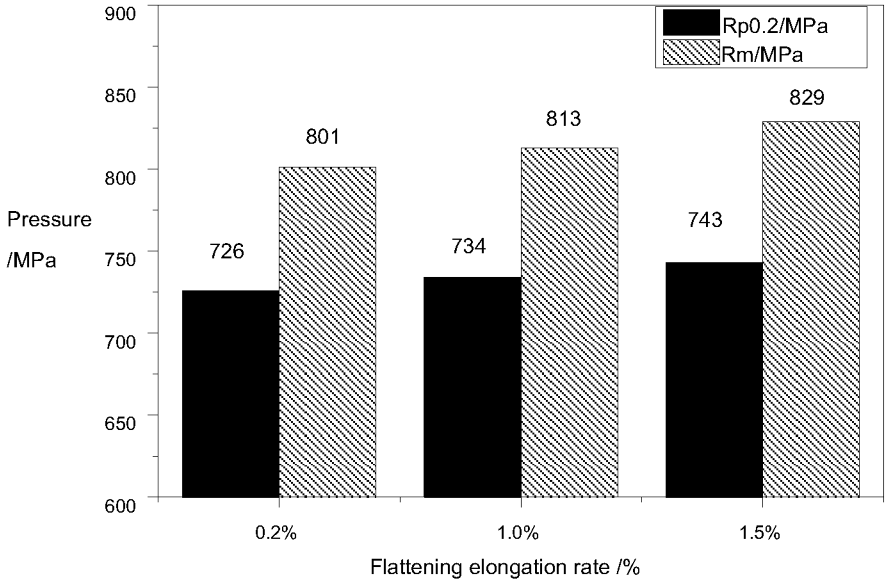

Figure 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2020/117724

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/38(2006.01)i；C22C 38/00(2006.01)i；C21D 9/46(2006.01)i；C21D 8/02(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)

C22C38，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)

DWPI, SIPOABS, CN-PAT, CNKI: 硅, 锰, 铬, 钛, 贝氏体, 铁素体, 扩孔, Si, Silicon, Silicium, Silicone, Mn, Manganese, Manganous, Manganum, Mangan, Cr, Chromium, Chrome, Chrom, Ti, Titanium, Titanic, bainite, ferrite, ferritic, hole expand+

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2015199987 A (NIPPON STEEL & SUMITOMO METAL CORP.) 12 November 2015 (2015-11-12) paragraphs 0010, 0017, 0018, 0034, 0047, 0055, 0056, steel type F in table 1, embodiment 23 in table 2	1-13
X	JP 2009263685 A (NIPPON STEEL CORP.) 12 November 2009 (2009-11-12) claims 1, 3 and 4	1-3
A	CN 108570604 A (TANGSHAN IRON & STEEL GROUP CO., LTD. et al.) 25 September 2018 (2018-09-25) entire document	1-13
A	CN 109594020 A (SHOUGANG GROUP CO., LTD.) 09 April 2019 (2019-04-09) entire document	1-13
A	CN 104513930 A (BAOSHAN IRON & STEEL CO., LTD.) 15 April 2015 (2015-04-15) entire document	1-13
A	JP 2017025397 A (NIPPON STEEL & SUMITOMO METAL CORP.) 02 February 2017 (2017-02-02) entire document	1-13

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

* Special categories of cited documents:	"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
"A" document defining the general state of the art which is not considered to be of particular relevance	"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
"E" earlier application or patent but published on or after the international filing date	"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
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search **22 December 2020**	Date of mailing of the international search report **30 December 2020**
Name and mailing address of the ISA/CN **China National Intellectual Property Administration (ISA/CN)** **No. 6, Xitucheng Road, Jimenqiao, Haidian District, Beijing 100088** **China**	Authorized officer
Facsimile No. **(86-10)62019451**	Telephone No.

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

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2020/117724

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 6287623 B2 (NIPPON STEEL & SUMITOMO METAL CORP.) 07 March 2018 (2018-03-07) entire document	1-13

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2020/117724

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2015199987 A	12 November 2015	JP 6354271 B2	11 July 2018
JP 2009263685 A	12 November 2009	None	
CN 108570604 A	25 September 2018	None	
CN 109594020 A	09 April 2019	CN 109594020 B	24 July 2020
CN 104513930 A	15 April 2015	None	
JP 2017025397 A	02 February 2017	JP 6515386 B2	22 May 2019
JP 6287623 B2	07 March 2018	JP 2015028207 A	12 February 2015

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- CN 103602895 A **[0003]**
- CN 108570604 A **[0004]**
- CN 105483545 A **[0005]**