

Specification

WEATHERABLE STEEL PLATE AND MANUFACTURING METHOD THEREFOR

5 **Technical Field**

[0001] The present invention relates to an alloy steel plate, particularly to an atmospheric corrosion resistant steel plate for monorail turnouts and the production method therefor.

10 **Background Art**

[0002] Monorail is a railway characterized by use of a single rail. Similar to the urban rail transport system, the monorail is mainly applied in densely-populated urban areas to carry passengers. The monorail, usually elevated, has the advantages of low cost, low pollution and a short construction period, as well as occupying less land, and therefore
15 can make effective use of the median strip of roads, which is an effective way to improve urban transportation.

[0003] However, for existing atmospheric corrosion resistant steel plates used to manufacture monorail turnouts, the corrosion resistance is improved by increasing the content of P in steel plates, which ignores the toughness, plasticity and welding
20 performance of the steel plates. Moreover, the content of Cu, Cr and Ni is also relatively small, the atmospheric corrosion resistant performance is insufficient, the manufacturing process is also relatively complicated, and the performance and production cost cannot be taken into account simultaneously.

25 **Summary**

[0004] One aim of the present invention: in order to solve the defects in the prior art, the present invention provides an atmospheric corrosion resistant steel plate, which provides a steel plate with low alloy cost, excellent welding performance, ultra-high strength, high toughness and atmospheric corrosion resistance for monorail turnouts.

30 [0005] Another aim of the present invention is to provide a production method of

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the atmospheric corrosion resistant steel plate, with which the above atmospheric corrosion resistant steel plate having balance between cost and performance.

[0006] Technical solution: The atmospheric corrosion resistant steel plate as described in the present invention comprises the components in percentage by mass: C: 0.04-0.10%, Si: 0.18-0.35%, Mn: 1.00-1.60%, P: 0.008-0.015%, Cu: 0.25-0.45%, Cr: 0.40-0.60%, Ni: 0.30-0.50%, Al:0.02-0.05% and Nb:0.01-0.05%, with the balance being Fe and unavoidable impurities.

[0007] The reasons for limiting the components of the atmospheric corrosion resistant steel plate of the present invention are as follows:

10 [0008] C: Low-carbon design is adopted. A higher carbon content is very unfavorable to the impact toughness of steel, particularly to the impact energy of the upper plateau, and damages the welding performance. When it comes to the difficulty of production control, the carbon content should not be too low. As a result, the carbon content is limited to 0.04-0.10%.

15 [0009] Si: Silicon is a deoxidizing element in the steelmaking process, and an appropriate amount of silicon can inhibit the segregation of manganese and phosphorus, and can improve the strength of steel through solid solution strengthening. However, a too high content of silicon will deteriorate the welding performance and low-temperature toughness of steel. As a result, the silicon content is limited to 0.18-0.35%.

20 [0010] Mn: Manganese is also an essential deoxidizing element in the steel-making process, which improves the strength of steel through solid solution strengthening. In order to achieve high tensile strength, the manganese content should not be too low. However, a too high content of manganese will also deteriorate the welding performance and low-temperature toughness of steel. As a result, the manganese
25 content is limited to 1.00-1.60%.

[0011] P: Phosphorus is an element beneficial for atmospheric corrosion resistance. If the phosphorus content is too low, the atmospheric corrosion resistance cannot be guaranteed. However, a too high content of phosphorus will deteriorate the low-temperature toughness of base metals and welded joints. Especially in the welding
30 process, the phosphorus in the base metal will be transferred into the weld to form the

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eutectic, which will reduce the impact energy of the welded joints. As a result, the phosphorus content is limited to 0.008-0.015%.

[0012] Cu: Copper can promote the formation of a stable and compact rust layer on the surface of steel plates, and can also improve the atmospheric corrosion resistance of the steel plates. However, a too high content of copper will cause the hot shortness in the steel plate processing, and deteriorate the surface properties of the steel plates. As a result, the copper content is limited to 0.25-0.45%.

[0013] Cr: Chromium can also effectively improve the atmospheric corrosion resistance of steel, and generate solid solution strengthening. However, a too high content of chromium will reduce the toughness and welding performance of steel. As a result, the chromium content is limited to 0.40-0.60%.

[0014] Ni: Nickel is also one of the elements that can improve the atmospheric corrosion resistance of steel, which can promote the formation of a stable rust layer and also improve the welding performance. However, an excessive addition of Nickel can significantly increase the cost. As a result, the Nickel content is limited to 0.30-0.50%.

[0015] Al: Aluminum is a deoxidizing element in the steel-making process, which can also reduce the quantity of solid solution N atoms to improve the toughness and aging strain resistance. And the AlN formed can refine grains to further reduce the tough-brittle transition temperature. However, an excessive addition will cause to form Al_2O_3 and AlN of large sizes, and damage the toughness. As a result, the Al content is controlled to be 0.02-0.05%.

[0016] Nb: Niobium can improve the strength of steel and increase the austenite recrystallization temperature at the same time, which can achieve the rolling in the non-recrystallization zone at a higher temperature. However, an increase in the Niobium content will limit the strengthening effect to the steel. As a result, the Niobium content is limited to 0.01-0.05%.

[0017] Wherein the composition of the steel plate in % by mass also satisfies $\text{Cu} + \text{Cr} + \text{Ni} \leq 1.35\%$; Cu, Cr and Ni are the key elements that affect the atmospheric corrosion resistance. The higher the contents of Cu, Cr and Ni are, the better the atmospheric corrosion resistance is. However, Cu, Cr and Ni, also elements to form M-A island

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constituents, are easy to form M-A islands during the cooling process of the welding heat affected zone, resulting in the deterioration of toughness. Therefore, on the premise of ensuring that the atmospheric corrosion resistance does not decrease, $\text{Cu} + \text{Cr} + \text{Ni}$ is $\leq 1.35\%$.

5 [0018] The carbon equivalent of the steel plate CEV is $\leq 0.46\%$; the carbon content of 0.04-0.10% is taken into consideration, so that the steel plate is in an easy-to-weld area to ensure good weldability. However, when the carbon equivalent is higher than 0.46%, the weldability will be deteriorated.

[0019] The cold welding crack sensitivity index of the steel plate Pcm is $\leq 0.21\%$, so
10 that cracks are not easy to appear during welding, preheating can be avoided, and heat treatment can be omitted after welding. When Pcm is higher than 0.21%, cracks are easy to appear during welding, heat treatment is required to eliminate stress after welding, and the weldability is deteriorated.

[0020] The atmospheric corrosion resistance index of the steel plate I is ≥ 6.5 , which
15 can ensure good atmospheric corrosion resistance and avoid the use of anti-corrosion coating.

[0021] Further limitation: the carbon equivalent CEV of the steel plate is 0.36-0.46%, the cold welding crack sensitivity index Pcm of the steel plate is 0.15-0.21%, and the atmospheric corrosion resistance index I of the steel plate is 6.5-7.0. When the carbon
20 equivalent is less than 0.36%, it is difficult to guarantee the yield strength and atmospheric corrosion resistance index of the steel plate. Similarly, when Pcm is less than 0.15%, it is difficult to guarantee the yield strength and atmospheric corrosion resistance index of the steel plate. However, when I is larger than 7.0, a large amount of alloying elements need to be added, so the cost will increase inevitably, and the
25 weldability will be deteriorated.

[0022] The present invention also provides a production method of the atmospheric corrosion resistant steel plate above, as described below:

[0023] The processes include smelting, refining, continuous casting, heating and rolling, wherein the heating process is to heat a casting billet to the full austenitizing
30 temperature; a two-stage rolling process of austenite recrystallization zone and

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austenite non-recrystallization zone is adopted for the rolling process, wherein the rolling in the austenite recrystallization zone is a rough rolling stage, in which austenite grains are refined by repeating austenite recrystallization, and the rolling in the austenite non-recrystallization zone is a finishing rolling stage, after which a hardened austenite structure is obtained;

[0024] The initial rolling temperature of the finishing rolling stage is 850-970°C, and the finishing rolling temperature is 780-860°C. The steel plate is cooled to 450-600°C by the ultra-fast cooling technology 10-30 seconds after the finishing rolling stage, and then air-cooled to room temperature. The austenite is retained for 10-30s after rolling deformation—that is, accelerated cooling is conducted after relaxation for a period of time. The intermediate transformation structure is refined by reduction in dislocation density, change in dislocation structure and increase in the volume fraction of precipitates in the relaxation process. In addition, the precipitation in the relaxation process can promote the nucleation, and precipitated nanoparticles not only are harmless to the properties of steel, but also can give full play to the effect of precipitation strengthening.

[0025] Beneficial effects: the atmospheric corrosion resistant steel plate of the present invention obtains excellent welding performance and simultaneously has ultra-high strength, high toughness and high atmospheric corrosion resistance under the condition of a low P content by adopting a reasonable alloy composition proportion. Its mechanical properties are as follows: yield strength $R_{p0.2} \geq 485$ MPa, tensile strength $R_m \geq 585$ MPa, elongation $A \geq 20\%$, yield ratio $YR \leq 0.85$, impact energy at -60°C $KV_2 \geq 200J$, and the tough-brittle transition temperature is lower than -80°C. The welding performance is as follows: the steel plate less than 60 mm in thickness needs no preheating before welding and no heat treatment after welding, having good weldability and high welding efficiency, which can well satisfy the application in monorail turnouts. According to the production method of the atmospheric corrosion resistant steel plate, the austenite grain structure is repeatedly refined by adopting a two-stage rolling process of austenite recrystallization zone and austenite non-recrystallization zone, to improve the strength of the steel plate. No quenching or

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tempering is needed during the production, which reduces the production cost and shortens the production period.

Brief Description of the Drawings

- 5 [0026] FIG. 1 shows a metallograph of the microstructure of the atmospheric corrosion resistant steel plate.

Detailed Description

[0027] The present invention is further detailed hereafter through an embodiment.

- 10 [0028] The atmospheric corrosion resistant steel plate of the present invention is obtained by adopting the production method of the atmospheric corrosion resistant steel plate of the present invention, through the processes of smelting, refining, continuous casting, heating and rolling, wherein the heating process is to heat a casting billet to the full austenitizing temperature; a two-stage rolling process of austenite recrystallization zone and austenite non-recrystallization zone is adopted for the rolling process, which
- 15 can also be referred to as a two-stage rolling process of rough rolling and finishing rolling, wherein the initial rolling temperature of the finishing rolling stage is 850-970 °C and the finishing rolling temperature is 780-860 °C; and the steel plate is cooled to 450-600 °C by the ultra-fast cooling technology 10-30 seconds after the finishing rolling
- 20 stage, and then air-cooled to the room temperature. As shown in FIG. 1, the metallograph shows that the microstructure of the atmospheric corrosion resistant steel plate is a fine ferrite + bainite + pearlite grain structure.

[0029] Wherein the calculation formula between the value of carbon equivalent and each chemical component is:

- 25 [0030] $CEV(\%) = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15$.

[0031] The calculation formula between the cold welding crack sensitivity index and each chemical component is:

[0032] $Pcm(\%) = C + Si/30 + (Mn + Cu + Cr)/20 + Ni/60 + Mo/15 + V/10 + 5B$.

- [0033] The calculation formula between the atmospheric corrosion resistance index and
- 30 each chemical component is:

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[0034] $I=26.01 \cdot Cu + 3.88 \cdot Ni + 1.2 \cdot Cr + 1.49 \cdot Si + 17.28 \cdot P - 7.29 \cdot$

[0035] $Cu \cdot Ni - 9.1 \cdot Ni \cdot P - 33.39 \cdot Cu \cdot Cu.$

[0036] Six groups of atmospheric corrosion resistant steel plates are manufactured by the production method above, the components of which in % by mass are as follows:

5 [0037] S1: C: 0.04%, Si: 0.35%, Mn: 1.20%, P: 0.012%, Cu: 0.30%, Cr: 0.40%, Ni: 0.30%, Al: 0.02%, Nb: 0.035%, CEV: 0.36%, Pcm: 0.15%, I: 6.50 and $Cu+Cr+Ni=1.0\%$.

[0038] S: C: 0.06%, Si: 0.18%, Mn: 1.40%, P: 0.015%, Cu: 0.25%, Cr: 0.60%, Ni: 0.45%, Al: 0.04%, Nb: 0.015%, CEV: 0.46%, Pcm: 0.19%, I: 6.50 and
10 $Cu+Cr+Ni=1.3\%$.

[0039] S3: C: 0.1%, Si: 0.35%, Mn: 1.10%, P: 0.014%, Cu: 0.25%, Cr: 0.55%, Ni: 0.45%, Al: 0.04%, Nb: 0.01%, CEV: 0.44%, Pcm: 0.21%, I: 6.70 and $Cu+Cr+Ni=1.25\%$.

[0040] S4: C: 0.04%, Si: 0.35%, Mn: 1.00%, P: 0.008%, Cu: 0.45%, Cr: 0.6%, Ni: 0.30%, Al: 0.02%, Nb: 0.01%, CEV: 0.38%, Pcm: 0.16%, I: 6.50 and $Cu+Cr+Ni=1.3\%$.

[0041] S5: C: 0.08%, Si: 0.34%, Mn: 1.00%, P: 0.015%, Cu: 0.30%, Cr: 0.55%, Ni: 0.5%, Al: 0.05%, Nb: 0.05%, CEV: 0.41%, Pcm: 0.19%, I: 7.00 and $Cu+Cr+Ni=1.35\%$.

[0042] S6: C: 0.04%, Si: 0.35%, Mn: 1.60%, P: 0.008%, Cu: 0.30%, Cr: 0.5%, Ni: 0.4%, Al: 0.03%, Nb: 0.02%, CEV: 0.45%, Pcm: 0.18%, I: 6.70 and $Cu+Cr+Ni=1.2\%$.

20 [0043] For the steel plates made from the above 6 groups of components, 2 sample plates of different thickness are rolled for each group, and one sample plate 60 mm in thickness is rolled for each composition. The production process parameters are shown in Table 1:

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[0044] Table 1 Production Process Parameters of Each Atmospheric Corrosion Resistant Steel Plate for Monorail Turnouts

[0045]

Steel Billet Number	[0046] Thickness of Steel Plate (mm)	[0047] Heating Temperature (°C)	Rough Rolling Stage		Finishing Rolling Stage		[0048] Relaxation Time (sec.)	Ultra-fast Cooling Temperature (°C)
			[0049] Total Reduction Rate (%)	Finishing Rolling Temperature (°C)	Initial Rolling Temperature (°C)	Finishing Rolling Temperature (°C)		
S1	12	1240	50	1030	970	850	11	520
	60	1250	55	1040	850	830	25	500
S2	18	1180	53	1000	950	820	13	480
	60	1170	56	1020	850	800	28	460
S3	14	1190	55	1020	960	860	10	580
	60	1200	54	1030	910	820	24	600
S4	16	1165	52	1010	950	830	12	470
	60	1190	55	1000	860	780	30	450
S5	18	1230	60	1030	950	840	16	580
	60	1220	55	1040	870	810	22	600
S6	12	1150	52	1040	950	840	16	530
	60	1160	54	1050	900	830	19	550

[0050] A mechanical property experiment is conducted on the 6 groups of steel plates.

5 The results are shown in Table 2:

[0051] Table 2 Mechanical Properties of Each Atmospheric Corrosion Resistant Steel Plate for Monorail Turnouts

[0048]

Steel Billet Number	[0052] Thickness of Steel Plate (mm)	Tension at Normal Temperature				Impact Energy at -60°C KV2(J)			Tough-brittle Transition Temperature	Reduction of Area in Z Direction (%)	Cold Bending Properties
		ReL (MPa)	Rm (MPa)	A(%)	Yield Ratio YR	1	2	3	FATT(°C)		180°, b=2a, D=2a
S1	12	508	620	27	0.82	303	312	358	-90	64,60,59	Intact
	60	516	637	26	0.81	298	304	314	-86	62,58,60	Intact
S2	18	524	632	27.5	0.83	304	311	287	-90	70,65,66	Intact
	60	510	655	24	0.78	317	300	315	-93	71,68,64	Intact
S3	14	543	646	26	0.84	292	310	304	-95	62,64,68	Intact
	60	528	642	25	0.82	306	321	324	-98	61,59,64	Intact
S4	16	518	629	26	0.82	305	317	355	-91	66,62,59	Intact
	60	524	639	27	0.82	302	332	324	-88	62,59,61	Intact

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[0049]

S5	18	533	633	25	0.84	315	329	307	-92	69,63,65	Intact
	60	522	642	24	0.81	317	309	326	-95	69,66,65	Intact
S6	16	545	651	27	0.84	298	315	322	-96	71,66,68	Intact
	60	541	638	25	0.85	321	317	323	-93	70,64,66	Intact

[0053] A welding performance experiment is conducted on 6 sample plates 60 mm in thickness. The results are shown in Table 3:

[0054] Table 3 Welding Performance of Each Atmospheric Corrosion Resistant Steel Plate for Monorail Turnouts

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[0055]

Steel Billet Number	Thickness of Steel Plate (mm)	Preheating Temperature (°C)	Post-weld Heat Treatment Temperature (°C)	Tension of Welding Joints at Normal Temperature Rm (MPa)	Impact Energy at -60°C in the Welding Heat Affected Zone KV2 (J)			Cold Bending Properties
					1	2	3	
S1	60	20	20	630	201	179	236	Intact
S2	60	20	20	644	198	213	165	Intact
S3	60	20	20	639	177	205	213	Intact
S4	60	20	20	636	201	206	215	Intact
S5	60	20	20	629	206	192	189	Intact
S6	60	20	20	628	205	205	214	Intact

[0056] The experimental data above fully prove that the atmospheric corrosion resistant steel plate of the present invention has good atmospheric corrosion resistance and welding performance.

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CLAIMS

1. An atmospheric corrosion resistant steel plate, characterized in that the steel plate comprises the components in percentage by mass: C: 0.04-0.10%, Si: 0.18-0.35%, Mn:
5 1.00-1.60%, P: 0.008-0.015%, Cu: 0.25-0.45%, Cr: 0.40-0.60%, Ni: 0.30-0.50%, Al: 0.02-0.05% and Nb: 0.01-0.05%, with the balance being Fe and unavoidable impurities, wherein the atmospheric corrosion resistant steel plate is configured to have an impact energy (KV2) of more than 300 J at a temperature of -60°C.
2. The atmospheric corrosion resistant steel plate according to Claim 1, characterized in that
10 the composition of the steel plate in % by mass also satisfies $Cu + Cr + Ni \leq 1.35\%$.
3. The atmospheric corrosion resistant steel plate according to Claim 1, characterized in that the carbon equivalent CEV of the steel plate is $\leq 0.46\%$, the cold welding crack sensitivity index Pcm is $\leq 0.21\%$, and the atmospheric corrosion resistance index I is ≥ 6.5 .
4. The atmospheric corrosion resistant steel plate according to Claim 3, characterized in that
15 the carbon equivalent of the steel plate CEV is 0.36-0.46%, the cold welding crack sensitivity index Pcm is 0.15-0.21%, and the atmospheric corrosion resistance index is 6.5-7.0.
5. A method of manufacturing the atmospheric corrosion resistant steel plate according to any one of Claims 1-4, characterized in that the method comprises the processes of smelting,
20 refining, continuous casting, heating and rolling, wherein the heating process is to heat a casting billet to the full austenitizing temperature; and the rolling process comprises a two-stage rolling process including a rough rolling stage in austenite recrystallization zone and a finishing rolling stage in austenite non-recrystallization zone, wherein the atmospheric corrosion resistant steel plate is configured to have an impact energy (KV2) of substantially
25 more than 300 J at a temperature of -60°C.
6. The method of manufacturing the atmospheric corrosion resistant steel plate according to Claim 5, characterized in that the finishing rolling stage comprises an initial rolling temperature of 850-970 °C, and a finishing rolling temperature of 780-860 °C in the austenite non-recrystallization zone; and the steel plate is cooled to 450-600 °C by an ultra-
30 fast cooling technology for 10-30 seconds after the finishing rolling stage, and then air-cooled to a room temperature.