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(54) STEEL FOR WELDED STRUCTURES EXCELLENT IN HIGH TEMPERATURE STRENGTH AND LOW TEMPERATURE TOUGHNESS AND METHOD OF PRODUCTION OF SAME

STAHL FÜR GESCHWEIßTE KONSTRUKTIONEN MIT EXZELLENTER HOCHTEMPERATURFESTIGKEIT UND TIEFTEMPERATURZÄHIGKEIT UND VERFAHREN ZU SEINER HERSTELLUNG

ACIER POUR CONSTRUCTION SOUDÉE AYANT UNE EXCELLENTE RÉSISTANCE À TEMPÉRATURE ÉLEVÉE ET UNE EXCELLENTE RÉSILIENCE AUX BASSES TEMPÉRATURES ET PROCÉDÉS DE PRODUCTION DE L'ACIER

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Description

TECHNICAL FIELD

[0001] The present invention mainly targets fire-resistant steel for building structures aimed at maintaining the proof strength at the time of fires and other high temperature conditions, but is not limited to building applications and can also be applied to steel for welded structures for offshore structures, ships, bridges, various storage tanks, and a broad range of other applications. Note that the strength level of the steel plate mainly covered is a yield strength of 235 to 475 MPa and a tensile strength of 400 to 640 MPa, i.e., the classes generally called "40 kg" and "50 kg steels".

PRIOR ART

[0002] So-called "fire-resistant steel" is disclosed in Japanese Patent Publication (A) No. 2-77523 and numerous other publications. However, almost all contain Mo. It is true that Mo is an element extremely effective in securing the high temperature proof strength of steel, but at the same time it is an expensive element. JP2007119861 A discloses a method for producing a high tensile-strength steel for welding structure, excellent in high temperature strength and low temperature toughness.

[0003] In this regard, steel for general structures for which standards are set by the Japan Industrial Standard (JIS) etc. fall in strength starting from about 350°C, so the allowable temperature is about 350°C. That is, when using such a steel material for buildings, offices, homes, multistory parking structures, and other structures, to secure safety at the time of a fire, it is obligatory to apply a sufficient fire-resistant coating. Japanese building laws stipulate that at the time of a fire, the temperature of steel materials not reach 350°C or more. This is because with such steel materials, at 350°C or so, the proof strength becomes about 2/3 that of ordinary temperature or falls below the required strength. For this reason, when utilizing a general steel material for a structure, it is necessary to apply a fire-resistant coating so that the temperature of the steel material does not reach 350°C.

[0004] To eliminate or reduce this fire-resistant coating, fire-resistant steel enhanced in high temperature proof strength at high temperature tensile tests of 600°C etc. (below, when not particularly clearly indicated, a "high temperature" indicates 600°C and a "high temperature strength" indicates a high temperature proof strength) has been coming into use.

[0005] In general, fire-resistant steel has Mo added to it for the purpose of maintaining the high temperature strength. However, the market for Mo greatly fluctuates. While depending on the amount of addition as well, in many cases it results in a higher cost compared with the cost of fire-resistant coating. For this reason, development and commercialization of inexpensive fire-resistant steel to which Mo is not added have been awaited.

[0006] The present invention has as its object to obtain steel for welded structures excellent in high temperature strength without adding expensive Mo and also excellent in low temperature toughness - one of the basic performances of steel materials. For this purpose, by limiting the steel compositions to a specific range and further limiting the method of production, there is provided a method able to supply fire-resistant steel - excellent in high temperature strength, suppressed in weld cracking parameter, and securing low temperature toughness - industrially stably and further at a low cost.

[0007] According to the present invention, steel for welded structures having sufficient proof strength even at the time of a fire or other environment exposed to a high temperature can be supplied in large amounts inexpensively, so this can contribute to the improvement of safety of welded steel structures for a broad range of applications.

[0008] The point of the present invention is that to stably secure a high temperature strength at 600°C, instead of expensive Mo, a relatively small amount of C and co-addition of Cr and Nb are used for transformation strengthening and precipitation strengthening using Cr or Nb precipitates (carbonitrides).

[0009] That is, the inventors discovered that by addition and inclusion of a suitable amount of Cr in an Mo-free composition, the hardenability of the steel is improved, the transformation temperature falls, and the hard structure including cementite becomes bainitic.

[0010] Due to this, the ordinary temperature and high temperature strengths rise and the matrix is transformed at a relatively low temperature resulting in a fine bainitic structure. Because of this, the inventors discovered that at the time of a high temperature, carbonitrides of Cr and Nb alone or together resulting from the addition of Cr and Nb precipitate extremely finely in the matrix and a high temperature strength can be secured and maintained at a high level and thereby reached the present invention.

[0011] In the above way, fire-resistant steel not containing Mo is in itself extremely epochmaking. At the same time, since no Mo with its high hardenability is contained, this leads to improvement of the basic performance of steel for welded structures (strength and toughness) of course and also conversely the weldability and gas cutting performance.

[0012] The present invention defines the amounts of not only Cr and Nb, but also individual elements such as C, Si, and Mn and the weld cracking parameter P_{CM} and further limits the production conditions so as to not only achieve both excellent high temperature strength and low temperature toughness without using expensive Mo, but also secure various usage performances for steel for welded structures. Its gist is defined in the claims.

BEST MODE FOR CARRYING OUT THE INVENTION

[0013] The ranges of addition of the different alloy elements defined in the present invention will be explained first.

C: 0.003 to 0.05%

[0014] C is limited to an extremely low level in high strength steel. This is closely related to the other elements and to the method of production. Even among the steel compositions, C has the greatest effect on the properties of a steel material. A lower limit of 0.003% is the smallest value for securing strength and preventing the weld and other heat affected zones from softening more than necessary.

[0015] If the amount of C is too great, the hardenability rises more than necessary and the balance of strength and toughness of the steel material, the weldability, etc. are adversely affected. Further, as explained later, depending on the targeted plate thickness and strength, the accelerated cooling is stopped at a relatively low temperature in some cases. To suppress excessive hardening near the top and bottom surfaces of the steel material at that time or fluctuations in property in the plate thickness direction, the upper limit was made 0.05%.

[0016] From the fluctuations in operation and balance with the other elements, to avoid a drop in strength, the lower limit is preferably made 0.005%, more preferably 0.01%. Further, to avoid excessive hardening by accelerated cooling and fluctuations in property, the upper limit is preferably made 0.04%, more preferably 0.03%.

Si: 0.60% or less

[0017] Si is an element included in steel for deoxidation, but if overly added, the weldability and HAZ toughness deteriorate, so the upper limit was made 0.60%. Steel can be deoxidized by Ti and Al as well, so the content may be determined by the balance with these elements. However, from the viewpoint of the HAZ toughness, hardenability, etc., the lower the better. Zero addition is also possible. For this reason, the upper limit may be limited to 0.40%, 0.20%, or 0.10%. Note that when a steelmaking plant produces steel, even when using Ti and Al for deoxidation without the addition of Si, 0.01% or more of Si is generally included.

Mn: 0.6 to 2.0%

[0018] Mn is an element essential for securing room temperature strength and toughness. The lower limit is 0.6%. Preferably, the content is 0.8% or more or 1.0% or more. However, if the amount of Mn is too large, the hardenability rises and the weldability and HAZ toughness are degraded. Not only that, but also center segregation at the continuously cast slab is enhanced, so the upper limit was made 2.0%. Preferably, the content is made 1.8% or less, more preferably 1.6% or less or 1.4% or less.

P: 0.020% or less

[0019] P, if small in amount, tends to reduce the intergranular fractures at the HAZ, so the smaller, the better. If the content is large, it degrades the low temperature toughness of the base material and the weld zone, so the upper limit is made 0.020%. 0.015% or less, 0.010% or less, or 0.008% or less is more preferable. Of course, zero addition is also possible.

S: 0.010% or less

[0020] S is preferably small in amount from the viewpoint of the low temperature toughness of the base material. If the content is large, the low temperature toughness of the base material and the weld zone is degraded, so the upper limit is made 0.010%. 0.008% or less, 0.006%, or 0.004% is more preferable. Of course, zero addition is also possible.

Cr: 0.8 to 1.5%

[0021] Cr is one of the most important elements in the present invention. To secure high temperature strength, together with Nb, addition of Cr is essential. This is because due to the effect of improvement of hardenability by Cr, the transformation temperature falls and the hard structure containing cementite becomes bainitic, so the room temperature and high temperature strengths are raised and further, because at the time of high temperature, precipitation strengthening by precipitates of Cr (carbonitrides) is utilized.

[0022] To obtain these effects, the content of Cr has to be a minimum of 0.8%. 1.0% or more is preferable. However, if the amount of addition is too great, deterioration of the toughness and weldability of the base material and weld zone is caused and economy is also lost, so the upper limit was made 1.5%. Preferably, it may be 1.3% or less.

Nb: 0.005 to 0.05%

[0023] Nb, along with Cr, is the most important element in the present invention. In the same way as Cr, this is because precipitation strengthening by precipitates (carbonitrides) of Nb is utilized to secure high temperature strength.

[0024] For this reason, at least 0.005% is necessary. Preferably, the amount of addition is 0.010% or more. However, if the amount of addition is too great, this causes deterioration in the toughness of the weld zone, so the upper limit was made 0.05%. Preferably, the amount of addition is 0.045% or less, more preferably 0.030% or less. Note that addition of Nb also contributes to raising the non-recrystallization temperature of austenite and bringing out the effect of controlled rolling at the time of hot rolling to its maximum extent.

[0025] Due to the above addition of Cr and Nb, it is possible to secure high temperature strength even under Mo-free conditions. Therefore, in the present invention, Mo is not intentionally added. Further, even when Mo is unintentionally mixed in as an impurity, it is restricted to 0.03% or less.

Al: 0.060% or less

[0026] Al is an element generally included in steel for deoxidation. Deoxidation is also performed by Si and Ti, so the amount should be determined by the balance with these elements. However, if the amount of Al becomes large, not only will the cleanliness of the steel become poorer, but also the toughness of the weld metal will deteriorate, so the upper limit is made 0.060%. Preferably, it may be 0.040% or less. The smaller the amount the better. Zero addition is also possible. Note that when a steelmaking plant produces steel, even when not using Al for deoxidation, 0.001% or more of Al is generally included.

N: 0.001 to 0.006%

[0027] N is included in the steel as an unavoidable impurity, but bonds with Nb to form carbonitrides to increase the strength. Further, it forms TiN to enhance the properties of the steel as explained above. For this reason, as an amount of N, a minimum of 0.001% is required. Preferably, the amount may be 0.0015% or more. However, addition of an amount of N is harmful to the weld heat affected zone toughness and weldability. In the present invention steel, the upper limit is 0.006%. More preferably it may be 0.0045% or less.

[0028] Next, the reasons for addition of V which may be included in accordance with need will be explained.

V: 0.01 to 0.10%

[0029] V has substantially the same effects as Nb. The role of V in the present invention is to complement the Nb. However, V has a smaller effect than Nb and also has an effect on the hardenability, so upper and lower limits were set. The lower limit was made 0.01% as the smallest amount at which the effect of addition of V can be reliably obtained. Preferably, the lower limit may be 0.025% or more. The upper limit was made 0.10% considering also the effects on the later explained weld cracking parameter P_{CM}. Preferably, the upper limit is 0.08% or less, more preferably 0.05% or less.

[0030] Next, the reasons for addition of Ni, Cu, B, and Mg will be explained.

[0031] The main purpose for further adding these elements to the basic compositions is to improve the strength, toughness, and other properties without detracting from the excellent characteristics of the invention steels. Therefore, the amounts of addition by nature should be self restricted.

Ni: 0.05 to 0.50%

[0032] Ni, if not added in excess, improves the strength and toughness of the base material without having a detrimental effect on the weldability. To bring out these effects, addition of at least 0.05% is essential.

[0033] On the other hand, excessive addition is not only expensive, but also is not preferable for the weldability. Further, if adding a large amount of Ni, the possibility of inducing stress corrosion cracking (SCC) in liquid ammonia has been pointed out. According to experiments of the inventors, addition of up to 1.0% does not greatly degrade the weldability or SCC in liquid ammonia and rather has a greater effect in improving the strength and toughness, but giving priority to economy, the upper limit was made 0.50%. Further, when giving priority to economy, the upper limit may also be set to 0.35%.

Cu: 0.05 to 0.50%

[0034] Cu exhibits substantially the same effects and phenomena as Ni. The upper limit of 0.50% is set since in addition to deterioration of the weldability, excessive addition results in Cu cracks at the time of hot rolling and therefore difficult production. The lower limit should be made the smallest amount by which the substantial effect can be obtained and therefore is 0.05%. When giving priority to economy, the upper limit may also be set to 0.30%.

B: 0.0002 to 0.003%

[0035] B segregates at the austenite grain boundaries and suppresses formation of ferrite to thereby improve the hardenability and contribute to improvement of the strength. To obtain this effect, a minimum of 0.0002% or more is required.

[0036] However, with addition of too much, not only would the effect of improvement of the hardenability become saturated, but also B precipitates harmful to the toughness might be formed, so the upper limit is made 0.003%. Preferably, it may be 0.002% or less. Note that in cases such as steel for storage tanks etc. where stress corrosion cracking is a concern, reduction of the hardness of the base material and weld heat affected zone often becomes the point (for example, to prevent sulfide stress corrosion cracking (SSCC), in terms of Rockwell hardness, HRC≤22(HV≤248) is considered essential). In such a case, addition of B, which increases the hardenability, is not preferable. Note that B has the above effect of improving the strength, but there is the problem that addition of B causes deterioration of the heat affected zone toughness and other material quality, so to avoid these problems, it is more preferable to limit B to 0.0003% or less or not add it.

Mg: 0.0002 to 0.005%

[0037] Mg has the action of controlling the growth of the austenite grains in the weld heat affected zone and refining so as to strengthen and toughen the weld zone. To obtain this effect, Mg has to be 0.0002% or more. On the other hand, if the amount of addition increases, the effect on the amount of addition becomes smaller, so this is not a wise course in terms of cost, so the upper limit was made 0.005%. Preferably, it may be 0.0035% or less.

[0038] Next, the reasons for addition of Ca or REM will be explained.

Ca: 0.0005 to 0.004%

REM: 0.0005 to 0.008%

[0039] The Ca and REM control the shape of the MnS and improve the low temperature toughness of the base material. In addition, they reduce the hydrogen induced cracking (HIC, SSC, and SOHIC) susceptibility under a wet hydrogen sulfide environment. To obtain these effects, a minimum of 0.0005% is necessary.

[0040] However, addition of too much conversely causes the cleanliness of the steel to deteriorate and raises the base material toughness and hydrogen induced cracking (HIC, SSC, and SOHIC) susceptibility under a wet hydrogen sulfide environment, so the upper limits of the amounts of addition were respectively made, for Ca and REM, 0.004% and 0.008%. Preferably, the limits may be made 0.003% and 0.006% or less. Note that Ca and REM have substantially equivalent effects, so it is sufficient to add either of these in the above range. Addition of both is also possible.

[0041] Even if limiting the individual elements of the steel, unless the system of compositions as a whole is suitable, excellent characteristics cannot be obtained. In the present invention, from the contents of the different elements (mass%), the value of the weld cracking parameter P_{CM}, defined by the following formula, is limited to 0.22% or less.

$$P_{CM}=C+Si/30+Mn/20+Cu/20+Ni/60+Cr/20+Mo/15+V/10+5B$$

[0042] P_{CM} is a parameter expressing the weldability. The lower, the better the weldability. In JIS G 3106 "Rolled Steels for Welded Structure", while differing depending on the strength level and the plate thickness, at the strictest, it is limited to 0.24% or less.

[0043] According to the broad range of various weld crack tests of the inventors, P_{CM} is limited to 0.22% or less as a condition able to reliably prevent weld cold cracking even under harsher restraint conditions and environmental conditions. Note that the lower limit is not particularly set, but is restricted naturally from the ranges of limitation of the compositions.

[0044] Next, the production conditions will be explained.

[0045] The reason for limiting the heating temperature before the hot rolling to 1000 to 1300°C is to keep the austenite grains at the time of heating small and refine the rolled structure. 1300°C is the upper limit temperature at which the austenite will not become extremely coarse at the time of heating. If the heating temperature exceeds this, the austenite grains become coarse mixed grains. The structure after transformation also becomes coarse, so the steel remarkably deteriorates in toughness.

[0046] On the other hand, if the heating temperature is too low, depending on the plate thickness, not only does securing the later mentioned finish rolling temperature become difficult, but also the non-recrystallization temperature of the austenite is raised. From the viewpoint of the solubility of Nb for bringing out precipitation strengthening, the lower limit was made 1000°C. The most preferable heating temperature range is 1050 to 1250°C.

[0047] The steel material heated under the above-mentioned conditions is hot rolled at 800°C or more, then cooled. The cooling means is not particularly an issue. The material may also be allowed to stand in the atmosphere for cooling, but by accelerated cooling from a temperature of 750°C or more to a temperature of 550°C or less, it is possible to improve the characteristics of the steel material more.

[0048] If the finish rolling temperature falls below 800°C, in the invention steels, where the amount of C is relatively small, the ferrite is liable to precipitate by transformation and ferrite is liable to be worked (rolled). This is not preferable from the viewpoint of securing the low temperature toughness. For this reason, the finish rolling temperature is limited to 800°C or more. Preferably, it may be 820°C or more.

[0049] The relatively low strength so-called "40 kg class steel" (for example, JIS standard SM400 and SN400 steel) after being hot rolled at 800°C or more can satisfy a predetermined strength even if allowed to stand in the atmosphere for cooling.

[0050] However, even with 50 kg class steel (for example, JIS standard SM490 and SN490 steel) or 40 kg class steel, if the plate thickness becomes greater, it becomes difficult to secure stability of the strength as cooled by standing in the atmosphere, so accelerated cooling from a temperature of 750°C or more after hot rolling at 800°C or more is preferable. Accelerated cooling after rolling improves the characteristics of the steel material and does not harm the excellent features of the present invention.

[0051] Accelerated cooling inherently increases the cooling rate in the transformation region and thereby refines the structure and simultaneously raises the strength and toughness. Therefore, unless started before the start of transformation or at least started before the end of transformation, it has substantially no meaning. For this reason, the accelerated cooling start temperature is limited to 750°C or more. This accelerated cooling has to be performed down to a temperature of 550°C or less in order to obtain this effect. With a temperature over 550°C, the transformation does not sufficiently proceed at the time of accelerated cooling and the refinement of the structure becomes insufficient. The preferable start temperature of the accelerated cooling is 760°C or more. The preferable range of stop temperature of the accelerated cooling is 520 to 300°C.

[0052] Note that the cooling rate at the time of accelerated cooling depends on the steel compositions and the intended strength or low temperature toughness level, but the average cooling rate from the accelerated cooling start temperature to 550°C at a position of 1/4 the plate thickness from the surface in the direction of plate thickness is made 3°C/sec or more.

[0053] Further, even if tempering after rolling at the Ac1 temperature or less, the excellent features of the present invention are not impaired. This cancels out the unevenness of cooling and improves the uniformity of quality in the plate, so is rather preferable.

EXAMPLES

[0054] Steel plates of various steel compositions (thickness 19 to 100 mm) were produced by a converter-continuous casting- plate rolling process and investigated for properties.

[0055] Table 1 shows the steel compositions of the comparative steels and the invention steels, while Table 2 shows the production conditions and properties of steel plates. Steels 6 and 9 are inventive examples, whereas all other examples are comparative.

[0056] The steel plates produced in accordance with the present invention (invention steels) all have good properties. As opposed to this, it was learned that the steel plates not produced according to the present invention (comparative steels) were inferior in one or more of the propereties.

[0057] Comparative Steel 11 is high in the amount of C, so compared with the invention steels, both the base material and simulated HAZ are inferior in low temperature toughness.

[0058] Comparative Steel 12 does not have any Nb added. Further, Comparative Steel 13 is low in the amount of Cr. Both are therefore low in high temperature strength.

[0059] Comparative Steel 14 is low in the amount of C, so is low in high temperature strength.

[0060] Comparative Steel 15 is high in the amount of Cr, so both the base material and simulated HAZ are inferior in toughness.

[0061] Comparative Steel 16 is high in Nb and inferior in HAZ toughness.

[0062] Comparative Steels 17-1 to 3 are the same in compositions as the Invention Steel 5. However, Comparative Steel 17-1 is low in finish rolling temperature and as a result an accelerated cooling start temperature cannot be secured and ends up becoming low, so is low in both room temperature and high temperature strength. Comparative Steel 17-2 is low in accelerated cooling start temperature, so is low in both room temperature and high temperature strength. Comparative Steel 17-3 is high in accelerated cooling stop temperature, so is low in both room temperature and high temperature strength.

[0063] Comparative Steel 18 has individual elements and a method of production within the scope of the present invention and has an ordinary temperature and a high temperature strength or toughness etc. satisfying the characteristics required for the 490 MPa class, but has a high P_{CM}, so cracks occurred in terms of the weldability (y-groove weld cracking test).

Table 1

Class	Steel	C	Si	Mn	P	S	Cr	Nb	Al	N	Mo	Others	P_{CM} 1)
		Chemical compositions (mass%)											
	1	0.003	0.31	0.95	0.006	0.003	0.81	0.018	0.028	0.0030	0.01	0.011Ti, 0.0010B	0.107
	2	0.01	0.16	1.31	0.004	0.002	0.65	0.020	0.033	0.0024	0.01	0.18Cu, 0.18Ni	0.126
	3	0.02	0.57	1.87	0.005	0.002	1.45	0.007	0.021	0.0029	0.02	0.20Ni, 0.052V, 0.009Ti	0.215
	4	0.02	0.22	1.45	0.007	0.002	0.41	0.012	0.023	0.0051	0	0.062V	0.127
	5	0.03	0.38	1.48	0.007	0.004	0.68	0.033	0.006	0.0028	0.01	0.21Cu, 0.22Ni, 0.010Ti, 0.0012Mg	0.166
	6	0.03	0.19	1.66	0.006	0.006	1.01	0.028	0.005	0.0022	0.03	0.00098, 0.0014Ca	0.176
	7	0.03	0.44	0.62	0.007	0.003	0.22	0.047	0.045	0.0043	0.01	0.32Cu, 0.32Ni, 0.062V, 0.0018REM	0.115
	8	0.04	0.27	1.31	0.005	0.002	0.50	0.024	0.003	0.0036	0		0.140
	9	0.04	0.08	1.81	0.005	0.004	1.20	0.019	0.032	0.0027	0	0.25Cu, 0.25Ni	0.210
	10	0.05	0.24	1.89	0.006	0.005	0.56	0.021	0.016	0.0032	0.02	0.014Ti, 0.0013B, 0.0012Ca	0.188
	19	0.02	0.20	1.57	0.005	0.004	0.61	0.026	0.022	0.0028	0.01	0.009Ti	0.136
Comp. steel	11	<u>0.06</u>	0.23	1.28	0.006	0.004	0.41	0.034	0.020	0.0030	0.02	0.012Ti	0.153
	12	0.02	0.28	1.56	0.007	0.002	0.80	<u>0</u>	0.027	0.0035	0.01	0.25Ni	0.153
	13	0.03	0.29	1.27	0.008	0.008	<u>0.14</u>	0.020	0.028	0.0026	0.01	0.0015Ca	0.111
	14	<u>0.001</u>	0.33	1.57	0.006	0.004	0.69	0.018	0.031	0.0032	0		0.125
	15	0.04	0.25	1.31	0.008	0.005	<u>1.72</u>	0.025	0.024	0.0027	0		0.200
	16	0.04	0.31	1.25	0.006	0.004	0.51	<u>0.065</u>	0.033	0.0025	0.02		0.139
	17	0.03	0.03	1.48	0.007	0.004	0.68	0.028	0.006	0.0028	0.01	0.21Cu, 0.22Ni, 0.010Ti, 0.0012Mg	0.166
	18	0.04	0.39	1.83	0.007	0.005	1.38	0.030	0.031	0.0033	0.02	0.25Cu, 0.25Ni, 0.070V, 0.011Ti	<u>0.237</u>

1) P_{CM}=C+Si/30+Mn/20+Cu/20+Ni/60+Cr/20+Mo/15+V/10+5B

Table 2

Class	Steel	Targeted strength grade	Heating temp. (°C)	Finish rolling temp. (°C)	Acc. cooling start temp. (°C)	Acc. cooling stop temp. (°C)	Plate thick. (mm)	Yield strength (MPa)	Tensile strength (MPa)	vTrs (°C)	Proof strength at 600°C (MPa) 1)	Simulated HAZ toughness 2), vE0(J)	Root cracking at y-crack test without preheating (room temp.) 3)
	1	400MPa	1250	920	980	340	50	332	477	-98	182	163	None
	2	490MPa	1200	820	780	460	25	386	551	-84	250	124	None
	3	400MPa	1200	850	-	-	40	395	548	-81	246	109	None
	4	490MPa	1280	860	820	480	50	431	545	-75	242	112	None
	5	490MPa	1200	900	860	430	32	433	563	-78	256	98	None
	6	490MPa	1100	950	930	450	100	338	518	-71	237	106	None
	7	490MPa	1100	930	900	300	80	376	522	-65	234	121	None
	8	490MPa	1050	870	840	410	60	386	536	-68	245	101	None
	9	490MPa	1150	810	-	-	19	454	582	-75	261	126	None
	10	490MPa	1150	850	800	290	50	414	547	-67	243	95	None
	19	490MPa	1150	840	-	-	28	298	452	-80	164	156	None
Comp· steel	11	490MPa	1150	860	820	230	50	408	553	-12	248	18	None
	12	400MPa	1150	850	800	250	40	283	479	-78	142	141	None
	13	490MPa	1150	850	-	-	40	376	529	-67	197	130	None
	14	400MPa	1200	850	-	-	40	319	487	-86	151	139	None
	15	490MPa	1200	850	-	-	40	362	541	-10	236	23	None
	16	490MPa	1200	900	-	-	40	348	561	-55	251	14	None
	17-1	490MPa	1100	750	720	280	32	431	488	-82	198	111	None
	17-2	490MPa	1100	800	730	300	32	322	484	-79	195	106	None
	17-3	490MPa	1100	830	770	600	32	317	496	-80	197	99	None
	18	490MPa	1100	810	-	-	40	363	527	-21	220	73	Yes

1) Judgment criteria for passage: 400 MPa class steel: 157 MPa or more (235x(2/3)), 490 MPa steel, 217 MPa or more (325x(2/3))
2) Charpy impact absorption energy of simulated heat cycle (conditions: after holding at 1400°Cx10 sec, then cooling from 800 to 500°C by 100 sec) (average value of three samples)
3) y-groove weld cracking test (JIS Z 3158)

INDUSTRIAL APPLICABILITY

[0064] According to the present invention, steel for welded structures excellent in high temperature strength and low temperature toughness can be provided in large amounts inexpensively. As a result, it becomes possible to reduce or eliminate the fire-resistant coating for building structures. Further, in applications other than buildings as well, since the strength, toughness, and other basic performances are provided and further high temperature strength is also provided, it becomes possible obtain steel for welded structures able to be exposed to a high temperature and to enhance much more the safety of buildings.

Claims

1. A method of production of steel for welded structures excellent in high temperature strength and low temperature toughness **characterized by** comprising heating a steel material comprising, by mass%,
C: 0.003 to 0.05%,
Si: 0.60% or less,
Mn: 0.6 to 2.0%,
P: 0.020% or less,
S: 0.010% or less,
Cr: 0.8 to 1.5%,
Nb: 0.005 to 0.05%,
Al: 0.060% or less, and
N: 0.001 to 0.006%,
further limiting, as an impurity, Mo to 0.03% or less, and further optionally comprising
V: 0.01 to 0.10%,
one or more of
Ni: 0.05 to 0.50%,
Cu: 0.05 to 0.50%,
B: 0.0002 to 0.003%, and
Mg: 0.0002 to 0.005%, and/or
one of
Ca: 0.0005 to 0.004% and
an REM: 0.0005 to 0.008%,
having a balance of iron and unavoidable impurities, and
having a weld cracking parameter P_{CM} value defined by

$$P_{CM}=C+Si/30+Mn/20+Cu/20+Ni/60+Cr/20+Mo/15+V/10+5B$$

of 0.22% or less, to 1000 to 1300°C in temperature,
finishing the hot rolling at a temperature of 800°C or more, and then cooling.

2. A method of production of steel for welded structures excellent in high temperature strength and low temperature toughness as set forth in claim 1, **characterized by**, after finishing said hot rolling, starting accelerated cooling from 750°C or more in temperature, and stopping the accelerated cooling at 550°C or less wherein the average cooling rate of the accelerated cooling at a position of 1/4 the plate thickness from the surface in the direction of plate thickness is 3°C/sec or more.

3. A steel for welded structures excellent in high temperature strength and low temperature toughness **characterized by** being obtained by heating a steel material comprising, by mass%,
C: 0.003 to 0.05%,
Si: 0.60% or less,
Mn: 0.6 to 2.0%,
P: 0.020% or less,
S: 0.010% or less,
Cr: 0.8 to 1.5%,
Nb: 0.005 to 0.05%,
A1: 0.060% or less, and

N: 0.001 to 0.006%,
further limiting, as an impurity, Mo to 0.03% or less, and further optionally comprising
V: 0.01 to 0.10%,
one or more of
Ni: 0.05 to 0.50%,
Cu: 0.05 to 0.50%,
B: 0.0002 to 0.003%, and
Mg: 0.0002 to 0.005%, and/or
one of
Ca: 0.0005 to 0.004% and
an REM: 0.0005 to 0.008%,
having a balance of iron and unavoidable impurities, and having a weld cracking parameter P_{CM} value defined by

$$P_{CM}=C+Si/30+Mn/20+Cu/20+Ni/60+Cr/20+Mo/15+V/10+5B$$

of 0.22% or less, to 1000 to 1300°C in temperature,
finishing the hot rolling at a temperature of 800°C or more, and then cooling.

Patentansprüche

1. Verfahren zur Herstellung von Stahl für Schweißstrukturen mit ausgezeichneter Hochtemperaturfestigkeit und Tieftemperaturzähigkeit, **dadurch gekennzeichnet, dass** es das Erwärmen eines Stahlmaterials, das in Masseprozent aufweist:

    C: 0,003 bis 0,05 %,
    Si: 0,60 % oder weniger,
    Mn: 0,6 bis 2,0 %,
    P: 0,020 % oder weniger,
    S: 0,010 % oder weniger,
    Cr: 0,8 bis 1,5 %,
    Nb: 0,005 bis 0,05%
    Al: 0,060 % oder weniger und
    N: 0,001 bis 0,006 %,
    ferner Mo als Verunreinigung auf 0,03 % oder weniger begrenzt und ferner wahlweise aufweist:

        V: 0,01 bis 0,10 %,
        einen oder mehrere von:
        Ni: 0,05 bis 0,50 %,
        Cu: 0,05 bis 0,50 %,
        B: 0,0002 bis 0,003% und
        Mg: 0,0002 bis 0,005% und/oder

    eines von
    Ca: 0,0005 bis 0,004 % oder
    ein Seltenerdmetall: 0,0005 bis 0,008 %,
    mit Eisen und unvermeidlichen Verunreinigungen als Rest und einem Schweißnaht-Rissbildungsparameter P_{CM}, definiert durch

$$P_{CM}=C+Si/30+Mn/20+Cu/20+Ni/60+Cr/20+Mo/\ 15+V/10+5B$$

    von 0,22 % oder weniger, auf eine Temperatur von 1000 bis 1300 °C, Fertigstellen des Warmwalzens bei einer Temperatur von 800 °C oder mehr und nachfolgendes Abkühlen aufweist.

2. Verfahren zur Herstellung von Stahl für Schweißstrukturen mit ausgezeichneter Hochtemperaturfestigkeit und Tieftemperaturzähigkeit nach Anspruch 1, **gekennzeichnet dadurch, dass** nach Fertigstellen des Warmwalzens mit

einem beschleunigten Kühlen von einer Temperatur von 750 °C oder mehr begonnen wird und das beschleunigte Kühlen bei 550 °C oder weniger gestoppt wird, wobei die durchschnittliche Abkühlrate des beschleunigten Kühlens an einer Stelle, die sich in Blechdickenrichtung bei 1/4 der Blechdicke von der Oberfläche befindet, 3 °C/s oder mehr beträgt.

3. Stahl für Schweißstrukturen mit ausgezeichneter Hochtemperaturfestigkeit und Tieftemperaturzähigkeit, **dadurch gekennzeichnet, dass** er durch Erwärmen eines Stahlmaterials, das in Masseprozent aufweist:

C: 0,003 bis 0,05 %,
Si: 0,60% oder weniger,
Mn: 0,6 bis 2,0 %,
P: 0,020 % oder weniger,
S: 0,010 % oder weniger,
Cr: 0,8 bis 1,5 %,
Nb: 0,005 bis 0,05 %
Al: 0,060 % oder weniger und
N: 0,001 bis 0,006 %,
ferner Mo als Verunreinigung auf 0,03 % oder weniger begrenzt und ferner wahlweise aufweist:

V: 0,01 bis 0,10 %,
einen oder mehrere von:
Ni: 0,05 bis 0,50 %,
Cu: 0,05 bis 0,50 %,
B: 0,0002 bis 0,003 % und
Mg: 0,0002 bis 0,005 % und/oder

eines von
Ca: 0,0005 bis 0,004 % oder
ein Seltenerdmetall: 0,0005 bis 0,008 %,
mit Eisen und unvermeidlichen Verunreinigungen als Rest und einem Schweißnaht-Rissbildungsparameter P_{CM}, definiert durch

$$P_{CM}=C+Si/30+Mn/20+Cu/20+Ni/60+Cr/20+Mo/15+V/10+5B$$

von 0,22% oder weniger, auf eine Temperatur von 1000 bis 1300 °C, Fertigstellen des Warmwalzens bei einer Temperatur von 800 °C oder mehr und nachfolgendes Abkühlen erhalten wird.

Revendications

1. Procédé de production d'acier pour structures soudées d'excellentes résistance à haute température et ténacité à basse température **caractérisé en ce qu'**il comprend le chauffage d'un matériau d'acier comprenant, en % en masse,
C : 0,003 à 0,05 %,
Si : 0,60 % ou inférieur,
Mn : 0,6 à 2,0 %,
P : 0,020 % ou inférieur,
S : 0,010 % ou inférieur,
Cr : 0,8 à 1,5 %,
Nb : 0,005 à 0,05 %,
Al : 0,060 % ou inférieur, et
N : 0,001 à 0,006 %,
limitant de plus, comme une impureté, Mo à 0,03 % ou inférieur, et comprenant de plus éventuellement
V : 0,01 à 0,10 %,
un ou plusieurs de
Ni : 0,05 à 0,50 %,
Cu : 0,05 à 0,50 %,
B : 0,0002 à 0,003 %, et

Mg : 0,0002 à 0,005 %, et/ou
un de
Ca : 0,0005 à 0,004 % et
un REM : 0,0005 à 0,008 %,
présentant un reste de fer et d'impuretés inévitables, et présentant une valeur P_{CM} de paramètre de fissuration de soudure définie par

$$P_{CM}=C+Si/30+Mn/20+Cu/20+Ni/60+Cr/20+Mo/15+V/10+5B$$

de 0,22 % ou inférieure, à de 1 000 à 1 300°C en température,
la finition du laminage à chaud à une température de 800°C ou supérieure, et puis le refroidissement.

2. Procédé de production d'acier pour structures soudées d'excellentes résistance à haute température et ténacité à basse température selon la revendication 1, **caractérisé par**, après la finition dudit laminage à chaud, le démarrage d'un refroidissement accéléré de 750°C ou supérieur en température, et l'arrêt du refroidissement accéléré à 550°C ou inférieur dans lequel la vitesse moyenne de refroidissement du refroidissement accéléré à une position de 1/4 l'épaisseur de plaque à partir de la surface dans la direction d'épaisseur de plaque est de 3°C/s ou supérieure.

3. Acier pour structures soudées d'excellentes résistance à haute température et ténacité à basse température **caractérisé en ce qu'**il est obtenu par chauffage d'un matériau d'acier comprenant, en % en masse,
C : 0,003 à 0,05 %,
Si : 0,60 % ou inférieur,
Mn : 0,6 à 2,0 %,
P : 0,020 % ou inférieur,
S : 0,010 % ou inférieur,
Cr : 0,8 à 1,5 %,
Nb : 0,005 à 0,05 %,
Al : 0,060 % ou inférieur, et
N : 0,001 à 0,006 %,
limitant de plus, comme une impureté, Mo à 0,03 % ou inférieur, et comprenant de plus éventuellement
V : 0,01 à 0,10 %,
un ou plusieurs de
Ni : 0,05 à 0,50 %,
Cu : 0,05 à 0,50 %,
B : 0,0002 à 0,003 %, et
Mg : 0,0002 à 0,005 %, et/ou
un de
Ca : 0,0005 à 0,004 % et
un REM : 0,0005 à 0,008 %,
présentant un reste de fer et d'impuretés inévitables, et présentant une valeur P_{CM} de paramètre de fissuration de soudure définie par

$$P_{CM}=C+Si/30+Mn/20+Cu/20+Ni/60+Cr/20+Mo/15+V/10+5B$$

de 0,22 % ou inférieure, à de 1 000 à 1 300°C en température,
finition du laminage à chaud à une température de 800°C ou supérieure, et puis refroidissement.

REFERENCES CITED IN THE DESCRIPTION

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