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(54) **490 MPa GRADE HIGH TENSILE STEEL FOR WELDED STRUCTURE EXHIBITING EXCELLENT HIGH TEMPERATURE STRENGTH AND METHOD FOR PRODUCTION THEREOF**

(57) The present invention provides a high-strength steel for welded structures excellent in strength at a high temperature of a temperature range of 600°C to 800°C and a method of production of the same, in particular 490 MPa class high-strength steel for welded structures excellent in high temperature strength containing C: 0.005% to less than 0.040%, Si: 0.5% or less, Mn: 0.1 to less than 0.5%, P: 0.02% or less, S: 0.01% or less, Mo: 0.3 to 1.5%, Nb: 0.03 to 0.15%, Al: 0.06% or less, and N: 0.006% or less and in accordance with need one or

more of Cu, Ni, Cr, V, Ti, Ca, REM, and Mg, having a weld crack susceptible formulation P_{CM} defined as $P_{CM} = C + Si/30 + Mn/20 + Cu/20 + Ni/60 + Cr/20 + Mo/15 + V/10 + 5B$ of 0.15% or less, substantially not containing B, and a remainder Fe and unavoidable impurities, the microstructure being mainly composed of a mixed structure of ferrite and bainite, and the fraction of bainite being 20 to 90%.

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Description

RELATED APPLICATION

5 **[0001]** This is a continuation-in-part application of International Application No. PCT/JP2005/013101, filed on July 8, 2005, based on the Japanese priority application No. 2004-213511, filed on July 21, 2004.

TECHNICAL FIELD

10 **[0002]** The present invention relates to a high-strength steel for welded structures used for buildings, civil engineering, offshore structures, shipbuilding, various storage tanks, and other general welded structures and superior in high temperature strength at a temperature range of 600°C to 800°C and in a relatively short time of about 1 hour and a method of production for the same. The present invention mainly covers steel plate, steel pipe, and steel shapes, etc.

BACKGROUND ART

[0003] The strength of general steel materials for welded structures falls starting around 350°C. The allowable service temperature is considered to be about 500°C. Therefore, when using these steel materials for buildings, offices, homes, vertical parking structures, and other structures, they are required to be covered with fire-resistant coverings to ensure safety in the event of fires. The Building Standards Law in Japan requires that the temperature of steel materials not rise to 350°C or more at the time of fires. This is because steel materials fall in yield strength at 350°C or so to about 2/3 of that at an ordinary temperature or below the necessary strength. Such a fire-resistant covering has a large influence on construction costs.

25 **[0004]** To solve these problems, "fire-resistant steel" provided with yield strength at the time of high temperatures is being developed (for example, Japanese Patent Publication (A) No. 2-77523 and Japanese Patent Publication (A) No. 10-68044). The yield strengths at 600°C and 700°C supposedly can be maintained at least at 2/3 of the standard minimum yield strength at the ordinary temperature. However, only the yield strength at specific temperatures is shown. The yield strength at higher temperatures is not alluded to as well. In particular, a temperature of over 700°C falls in the temperature region for partially starting transformation depending on the steel compositions. Therefore, a stable production of practical steel has been extremely difficult - so much so that a rapid drop in the yield strength is feared.

30 **[0005]** Previously, the present inventors discovered a steel enabling high temperature strength at 700 to 800°C to be secured and a method of production of the same (for example, Japanese Patent Publication (A) No. 2004-43961). This requires, in terms of the steel compositions, the addition of B. This facilitates control of the microstructure and enables achievement of a low yield ratio in particular for steels for building structures. However, as is generally known, B has both not only advantages, but also disadvantages, such as increasing the quenchability. For example, at the time of small heat input welding, the heat affected zone (HAZ) remarkably hardens, so the toughness desgrades. Conversely when the welding heat input becomes too large, as the B precipitates at the austenite grain boundaries, the quenchability of B cannot be effectively utilized, the microstructure becomes coarse, and the toughness desgrades. Thus, there is the problem that the range of the welding heat input is limited.

40 **[0006]** A steel for building structures is required to have a low yield ratio from the viewpoint of earthquake resistance. The JIS standard for "Rolled Steel Materials for Building Structures" regulates the yield ratio of 80% or less. Previous inventions of the present inventors focused on this point. However, the amended Japanese Building Standards Law enforced since June 2000 has changed what had previously been provisions on use to provisions on performance and called for early use of new technologies and materials. Regarding steel materials for building use, Article 37 of the Building Standards Law allows use of JIS materials for building structures in Paragraph 1 and use of steel materials assessed for performance in accordance with various performance requirements and certified by the Minister of Land, Infrastructure, and Transport in Paragraph 2. Therefore, the present inventors engaged in intensive studies on steel materials excellent in high temperature strength of course and also weldability and weld zone toughness in a broad range of input heat without being bound by the JIS provisions on yield ratio for steel materials for building use and thereby completed the present invention.

DISCLOSURE OF THE INVENTION

55 **[0007]** As explained above, when utilizing steel materials for buildings, since ordinary steel materials are low in high temperature strength (yield strength), they cannot be used without coverings or with reduced fire-resistant coverings and have had to be given expensive fire-resistant coverings. Further, even newly developed steel materials have fire-resistant temperatures limited to a guarantee of 600 to 700°C. Development of steel materials for use at 700 to 800°C without fire resistant coverings and thereby enabling elimination of the fire resistant covering step has therefore been

desired.

[0008] An object of the present invention is to provide a high-strength steel for welded structures excellent in high temperature strength in a temperature range of 600°C to 800°C and a method of production able to stably supply that steel on an industrial basis.

[0009] The present invention achieves the above object by limiting the steel compositions, microstructure, etc. to suitable ranges so overcome the above problems and has as its gist the following.

(1) A 490 MPa class high-strength steel for welded structures excellent in high temperature strength, comprising as steel compositions, by wt%,

C: 0.005% to less than 0.040%,

Si: 0.5% or less,

Mn: 0.1 to less than 0.5%,

P: 0.02% or less,

S: 0.01% or less,

Mo: 0.3 to 1.5%,

Nb: 0.03 to 0.15%,

Al: 0.06% or less, and

N: 0.006% or less,

having a weld crack susceptible formulation P_{CM} defined as $P_{CM}=C+Si/30+Mn/20+Cu/20+Ni/60+Cr/20+Mo/15+V/10+5B$ of 0.15% or less, substantially not containing B, and a remainder of Fe and unavoidable impurities, the microstructure mainly composed of a mixed structure of ferrite and bainite, and the percentage of bainite being 20 to 90%.

(2) A 490 MPa class high-strength steel for welded structures excellent in high temperature strength as set forth in (1), further comprising by wt% at least one of

Cu: 0.05 to 1.0%,

Ni: 0.05 to 1.0%,

Cr: 0.05 to 1.0%,

V: 0.01 to 0.1%,

Ti: 0.005 to 0.025%,

Ca: 0.0005 to 0.004%,

REM: 0.0005 to 0.004%, and

Mg: 0.0001 to 0.006%

(3) A 490 MPa class high-strength steel for welded structures superior in high temperature strength as set forth in (1) or (2), wherein an average circle equivalent diameter of the prior austenite of a cross-section parallel to the rolling direction at a 1/4 thickness position is 120 μm or less.

(4) A method of production of a 490 MPa class high-strength steel for welded structures excellent in high temperature strength comprising the steps of; reheating semi-finished products or cast products comprised of the steel compositions as set forth in (1) or (2) to a range of 1100 to 1250°C, rolling it at a temperature of 850°C or more with a cumulative amount of reduction at 1100°C or less of 30% or more, and cooling it by air cooling or accelerated cooling from a temperature of 800°C or more to a temperature of 650°C or less.

BEST MODE CARRYING OUT THE INVENTION

[0010] Below, details of the present invention will be explained.

[0011] For high temperature strength, complex addition of Mo and Nb to promote precipitation of stable carbonitrides at the time of high temperatures and increase of the dislocation density by conversion to bainite of the microstructure and delay of dislocation recovery by solute Mo and Nb are effective. In particular, to realize strength at an extremely high temperature of 700 to 800°C aimed at by the present invention, as an extension of the prior discoveries, addition of a large amount of Mo is essential, but this runs counter to the objective of securing excellent weldability and weld zone toughness of welded structure steels. Achievement of these with high temperature strength is extremely difficult.

[0012] According to research of the present inventors, by introducing suitable alloy elements and controlling the microstructure, in particular by obtaining heat stability of the matrix structure at a high temperature and a suitable coherent precipitation strengthening effect and dislocation recovery delaying effect, it is possible to achieve both excellent weldability and weld zone toughness and high temperature strength.

[0013] First, the reasons for limiting the steel compositions as in the claims in the present invention will be explained.

[0014] C has the most remarkable effect on the properties of the steel material, so has to be controlled to a narrow range. 0.005% to less than 0.040% is the range of limitation. With an amount of C of less than 0.005%, the strength is insufficient, while with 0.040% or more, in the present invention with the large amount of addition of Mo, the weldability

and weld zone toughness are degraded and, when the cooling rate after the end of rolling is excessive, the percentage of formation of bainite increases and the risk of the strength becoming excessive rises. Further, to stably maintain the mixed matrix structure of bainite and ferrite thermodynamically at the time of high temperature heating corresponding to a fire and maintain the coherency with the complex carbonitride precipitates of Mo, Nb, V, and Ti to secure a strength-

5 ening effect, C has to be made less than 0.040%.
[0015] Si is an element contained in steel for deoxidation. It has a substitution type solid solution hardening action, so is effective for improving the base material strength at ordinary temperature, but there is no effect of improvement of the over 600°C high temperature strength. Further, if added too much, the weldability and weld zone toughness deteri-

10 orate, so the upper limit was made 0.5%. Steel can be deoxidized even with only Ti and Al. The lower the content the better from the viewpoint of the weld zone toughness, quenchability, etc. Addition is not necessarily required.
[0016] Mn is an element essential for securing strength and toughness. As a substitutional type solid solution strength-

15 ening element, Mn is effective for raising the strength at room temperature, but the effect of improvement is not that large for over 600°C high temperature strength. Therefore, in steel containing a relatively large amount of Mo like in the present invention, the content must be made less than 0.5% from the viewpoint of improvement of the weldability, that is, the reduction of P_{CM} . Keeping the upper limit of the Mn low is also advantageous from the viewpoint of the center segregation of the continuously cast slab. Note that, for the lower limit, at least 0.1% has to be added for securing the strength and toughness of the base material.

20 **[0017]** P and S are impurities in the steel of the present invention, the lower the better. P segregates at the grain boundaries and encourages grain boundary fracture, while S forms a sulfide such as MnS and causes deterioration of the toughness of the base material and weld zone, so the upper limits are made 0.02% and 0.01%, respectively.

[0018] Mo is an essential element along with Nb from the viewpoint of achieving and maintaining high temperature strength in the steel of the present invention. Simply for the high temperature strength, the greater the amount added, the more advantageous, but this should be limited if considering also the base material strength and weldability and the weld zone toughness. In the present invention with the C being kept low, if within the later explained range of P_{CM} (0.16% or less), Mo may be contained up to an amount of 1.5%. As the lower limit, to stably secure high temperature strength even with complex addition with Nb or addition of V and Ti effective for improving the high temperature strength explained later, its addition of 0.3% or more is necessary.

25 **[0019]** Nb is an element added complexly together with Mo. First, as a general effect of Nb, it raises the recrystallization temperature of austenite and is useful in bringing out to the maximum extent the effect of controlled rolling at the time of hot rolling. Further, it also contributes to increased fineness of the heated austenite at the time of reheating before rolling. Further, it has the effect of improvement of the high temperature strength by suppressing precipitation hardening and dislocation recovery. Complex addition with Mo contributes to even greater improvement of the strength. If less than 0.03%, the effect of suppressing precipitation hardening and dislocation recovery at 700°C and 800°C is small. If over 0.15%, the degree of hardening is reduced with respect to the amount of addition. Not only is this not preferably eco-

30 nomically, the weld zone also deteriorates in toughness. For these reasons, Nb is limited to the range of 0.03 to 0.15%.
[0020] Al is an element generally included in steel for deoxidation, but sufficient deoxidation is achieved by just Si or Ti. In the present invention, no lower limit is set (including 0%). However, if the amount of Al becomes larger, not only does the cleanliness of the steel become poorer, but also the toughness of the weld zone deteriorates, so the upper limit was made 0.06%.

35 **[0021]** N is contained in steel as an unavoidable impurity, but when adding Nb and the later explained Ti, it bonds with the Nb to form a carbonitride to increase the strength and forms TiN to improve the properties of the steel. Therefore, as the amount of N, a minimum of 0.001% is necessary. However, an increase in the amount of N is harmful to the weld zone toughness and weldability. In the present invention, the upper limit is therefore made 0.006%. Note that the upper limit does not necessarily have any limitative significance in terms of characteristics and is set in the range confirmed by the present inventors.

40 **[0022]** Next, the reasons for addition and amounts of addition of the Cu, Ni, Cr, V, Ti, Ca, REM, and Mg able to be contained in accordance with need will be explained.

[0023] The main purpose of adding these elements to the basic compositions is to improve the strength, toughness, and other characteristics without detracting from the excellent features of the steel of the present invention. Therefore,

45 the amounts of addition by nature should be naturally limited.
[0024] Cu improves the strength and toughness of the base material without having a remarkably detrimental effect on the weldability and weld zone toughness. To realize these effects, its addition of at least 0.05% is essential. On the other hand, excessive addition not only causes the weldability to deteriorate, but also leads to increased risk of occurrence of Cu cracks at the time of hot rolling, so the upper limit is set to 1.0%. Note that it is known that Cu cracks themselves can be avoided by suitable addition of Ni in accordance with the amount of Cu. The weldability is also related to the amount of C and other alloy element, so the upper limit does not necessarily have any limitative significance.

50 **[0025]** Ni exhibits an effect substantially the same as Cu and in particular has a large effect on the improvement of the toughness of the base material. To reliably enjoy these effects, addition of at least 0.05% is essential. On the other

hand, excess addition causes the weldability to deteriorate even with Ni. Since it is a relatively expensive element, the economy is impaired, so in the present invention, the upper limit is made 1.0% considering also targeting 490 MPa class steel.

[0026] Cr improves the strength of the base material, so can be added in accordance with need. To enable clear differentiation with the entry of trace amounts as trap elements from scrap etc. and reliably obtain the effects, addition of a minimum of 0.05% or more is necessary. Too great an addition, like with other elements, causes the weldability and weld zone toughness to deteriorate, so the upper limit is set at 1.0%.

[0027] As explained above, Cu, Ni, and Cr are effective not only from the viewpoint of the mechanical properties of the base material, but also the weather resistance. For this purpose, they are preferably positively added in a range not greatly detracting from the weldability and weld zone toughness.

[0028] V has substantially the same effect and action as Nb including improvement of the high temperature strength, but the effect is small compared with Nb. Further, V, as will be understood from the fact that it is also included in the expression of P_{CM} , also influence the quenchability and weldability. Therefore, to reliably obtain the effect of addition of V, the lower limit is made 0.01%. To eliminate any detrimental effect, the upper limit is made 0.1%.

[0029] Ti, like Nb, V, etc., is effective in improving the high temperature strength. In addition, when in particular the demands on the base material and weld zone toughness are severe, its addition is preferable. The reason is that when the amount of Al is small (for example, 0.003% or less), Ti bonds with O to form a precipitate mainly comprised of Ti_2O_3 which form nuclei for the production of in-grain transformed ferrite and improve the weld zone toughness. Further, Ti bonds with N and finely precipitates in the slab as TiN. It suppresses the coarsening of the austenite grains at the time of heating and is effective for increasing the fineness of the rolled structure. Further, the fine TiN present in the steel plate increases the fineness of the structure of the weld heat affected zone at the time of welding. To enjoy these effects, the content of Ti has to be a minimum of 0.005%. However, if too great, it forms TiC and causes the low temperature toughness and weldability to deteriorate, so the upper limit is made 0.025%.

[0030] Ca and REM traps the impurity S and act to improve the toughness and suppress cracking due to diffused hydrogen at the weld zone. If too great in amount, however, coarse inclusions are formed and the toughness is detrimentally affected, so both elements are limited to the range of 0.0005 to 0.004%, respectively. The two elements have substantially equivalent effects, so to obtain the above effect, it is sufficient to add either of the two.

[0031] Mg acts to suppress the growth of austenite grains and increase fineness in HAZ (heat affected zone) and increases the toughness of the weld zone. To obtain such an effect, Mg has to be at least 0.0001%. On the other hand, if the amount of addition is increased, the extent of the effect with regard to the amount of addition becomes smaller and economy is lost, so the upper limit is made 0.006%.

[0032] Note that in the present invention, B is not intentionally added. The point is that it is not substantially contained over the level included as an impurity in the steelmaking process. B remarkably improves the quenchability by addition in a small amount, so when used for high-strength steel, it is advantageous in terms of control of the microstructure or improvement of the strength and simultaneously has the risk of deterioration of the weldability and weld zone toughness. The present invention avoids intentional addition of B and is made substantially B-free for the purpose of greatly improving not only the high temperature characteristics, but also the performance when used as welded structure steel.

[0033] Even if limiting the individual ingredients of the steel as explained above, if the system of the compositions as a whole is not suitable, the characteristic feature of the present invention, that is, the excellent characteristics, is not obtained. In particular, based on a previous invention (Japanese Patent Application No. 2004-43961), since the invention is aimed at greatly improving the weldability and weld zone toughness, the value of P_{CM} is limited to 0.15% or less. Here, P_{CM} is defined by the following formula as an index of the weld crack susceptibility:

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

[0034] In general, the lower the P_{CM} , the better the weldability. If 0.22% or less, the preheating at the time of welding (for preventing weld cold cracks) is said to be unnecessary. In high-strength steel, in particular high-strength steel superior in high temperature strength like in the present invention and substantially not containing B, which is an element remarkably raising the quenchability, a P_{CM} of 0.15% or less is an extremely low value.

[0035] Further, in the present invention, the specific microstructure is also required. With limiting just the steel compositions, superior weldability or weld zone toughness as welded structure steel can be secured, but it is not possible to obtain satisfactory high temperature characteristics or the basic characteristics as 490 MPa class steel, in particular the strength. Therefore, to attain the object of the present invention, the microstructure is limited to mainly a mixed structure of ferrite and bainite in which the fraction of bainite is 20 to 90%. This is limited so as to clarify the characteristic feature of the present invention based on the results of experiments by the present inventors showing that if the percentage of bainite is low, securing 490 MPa class room temperature strength and high temperature strength is difficult, while if the fraction of bainite is too high, the risk of exceeding the range of strength of 490 MPa class steel defined by the JIS etc. increases and does not necessarily have any limitative sense.

[0036] Note that these microstructures are assumed to represent a position of 1/4 thickness in the direction of the thickness cross-section direction. Further, the term "bainite" is widely used as the name of the structure among persons skilled in the art, but in view of the diverse variations, some uncertainty may arise in terms of the specific points in the region when measuring the fraction. In this case, there is also the method of judgment by another structure, "ferrite", in the composition of the structure. The fraction of ferrite in this case is 10 to 80%. The ferrite referred to here is polygonal or pseudo-polygonal ferrite (not including acicular ferrite) not containing any cementite.

[0037] The grain size of the austenite before transformation after rolling has to be suitably limited in order to control the toughness of the steel containing a relatively high percentage of Mo such as in the present invention (increasing the toughness). The finer the grains of the austenite, the finer the final transformed microstructure and the better the toughness. To obtain a toughness no different from ordinary steel with low Mo, the austenite grain size at a position of 1/4 thickness in the plate thickness cross-section direction is made an average circle equivalent diameter of 120 μm or less. Depending on the plate thickness or steel ingredients, sufficient toughness is obtained even over 120 μm in some cases, while the grain size is limited to enable toughness to be reliably and stably secured, but there is not necessarily any limitative significance. Note that the austenite grain size is not necessarily easy to judge in quite a few cases. In such a case, a notched impact test piece taken from the steel plate in a direction perpendicular to the final rolling direction centered at a 1/4 thickness position of the plate, for example, a JIS Z 2202 2 mm V-notch test piece, is used. The fracture unit of brittle fracture at a sufficiently low temperature is defined as the effective crystal grain size, able to be read as the "austenite grain size", and the average circle equivalent diameter is measured. In this case as well, similarly it must be 120 μm or less.

[0038] The above limited microstructure (microstructure, fraction of microstructure, prior austenite grain size, etc.) and the high temperature characteristics and other excellent characteristics aimed at by the present invention can be easily obtained by limiting the method of production as follows.

[0039] The reheating temperature of the ingots or slabs having the predetermined steel compositions is limited to the range of 1100 to 1250°C. The lower limit 1100°C is for making the Mo and Nb and the V and Ti added according to need solute for the primary purpose of securing the high temperature characteristics. To achieve this object, the higher the reheating temperature, the better, but the heated austenite grains coarsen which is not preferable from the viewpoint of the base material toughness, so the upper limit is made 1250°C.

[0040] The rolling conditions are limited in order to directly control the austenite grain size after rolling and before transformation to relatively fine grains as explained above and for mainly securing toughness. Therefore, the rolling has to be performed with an amount of cumulative reduction at 1100°C or less of 30% or more. The rolling end temperature is limited to 850°C or more as the lower limit temperature for the Mo and Nb or the V and Ti added in accordance with need to precipitate as carbides under low temperature rolling.

[0041] The cooling after rolling should also be limited from the viewpoint of control of the structure. While depending on the steel compositions, when producing relatively thin plates, even with the cooling rate of an extent of air cooling, a predetermined microstructure can be obtained, but if thick plates, the cooling rate becomes slow with air cooling and accelerated cooling becomes necessary in some cases. The accelerated cooling in this case is, in steel plate production, most generally water cooling, but it does not necessarily have to be water cooling. Further, the accelerated cooling is meant to raise the cooling rate of the transformation region for controlling the microstructure, so has to be performed from a temperature of 800°C or more to a temperature of 650°C or less.

[0042] Note that, in the present invention, "high temperature strength" targets 600°C to 800°C. The quantitative target is a ratio p of the high temperature yield strength to the ordinary temperature yield strength (=high temperature yield strength/ordinary temperature yield strength) of $p \geq -0.0033 \times T + 2.80$ in the range of a steel material temperature T (°C) of 600°C to 800°C.

EXAMPLES

[0043] Using the converter-continuous casting-plate rolling process, steel plates of various ingredients (thickness of 12 to 80 mm) were produced, evaluated for their mechanical properties and weldability and weld zone toughness, and investigated for the presence of root cracks in a JIS-based y-groove weld crack test and for simulated HAZ toughness corresponding to small input heat and extra large input heat welding by a weld simulating thermal cycle. Table 1 shows the steel compositions of comparative examples and examples of the present invention, the production conditions, the microstructure and results of investigation of the various characteristics.

[0044] The examples of the present invention all satisfy the ranges of limitation of the present invention and are extremely good in high temperature strength, simulated HAZ toughness, and other various characteristics. As opposed to this, the comparative examples have at least one of the steel compositions, production conditions, structure, etc. outside the ranges of limitation of the present invention, so it is learned that the characteristics are poor compared with the examples of the present invention. That is, Comparative Example 19 has a low amount of C, so the fraction of bainite is low and the ordinary temperature strength and high temperature strength (ratio) are both low. Comparative Example

20 has a high amount of C, so the fraction of bainite is high and the ordinary temperature strength is high. Further, the base material toughness and the simulated HAZ toughness is also poor. Comparative Example 21 has a low amount of Mo and is low in accelerated cooling start temperature as well, so the fraction of bainite is low and due in part to this the high temperature strength (ratio) is low. Comparative Example 22 has a low amount of Nb and is low in the heating temperature and rolling end temperature as well and further is high in accelerated cooling stop temperature, so is low in ordinary temperature strength and high temperature strength (ratio). Comparative Example 23 has B added to it, so when using accelerated cooling, the fraction of bainite is high and the base material toughness is poor. Further, the simulated HAZ toughness is also poor. Comparative Example 24 has a high amount of Mn and is high in P_{CM} and further is low in the cumulative amount of reduction at 1100°C or less, so the fraction of bainite becomes high, the base material strength of the 490 MPa class steel, and the base material toughness and simulated HAZ toughness are poor.

[0045] Note that for root cracks in the y-groove weld crack test did not occur even in cases such as Comparative Example 24 where the P_{CM} is about 0.185% though higher than the range of limitation of the present invention.

Class	Steel	Room temp. yield strength (MPa)	Room temp. tensile stress (MPa)	Ratio of yield strength to room temp. yield strength (p)			vTrs (°C)	Fraction of bainite in base material microstructure (%)	prior austenite grain size (μm)	Simulated HAZ toughness, vE ₀ (J)		Root Cracks
				600°C	700°C	800°C				Heat history 1	Heat history 2	
Inv. Ex.	1	476	541	0.87	0.61	0.25	-45	54	50	89	69	No crack
	2	451	537	0.85	0.57	0.24	-31	52	71	82	62	No crack
	3	438	534	0.86	0.57	0.25	-36	61	63	97	84	No crack
	4	442	533	0.87	0.55	0.25	-40	29	47	87	64	No crack
	5	407	509	0.87	0.55	0.25	-35	37	74	83	67	No crack
	6	421	547	0.90	0.58	0.24	-31	65	83	79	65	No crack
	7	425	545	0.88	0.57	0.22	-34	57	109	78	69	No crack
	8	433	548	0.86	0.54	0.27	-37	60	68	80	88	No crack
	9	419	530	0.86	0.59	0.25	-30	42	55	82	65	No crack
	10	410	516	0.85	0.59	0.24	-32	48	61	96	63	No crack
	11	431	553	0.85	0.58	0.24	-30	51	97	88	69	No crack
	12	424	523	0.85	0.59	0.22	-28	45	60	90	83	No crack
	13	451	564	0.85	0.58	0.25	-35	64	64	79	86	No crack
	14	462	570	0.84	0.58	0.24	-32	67	52	86	71	No crack
	15	433	528	0.86	0.59	0.25	-38	59	67	82	68	No crack
	16	415	532	0.86	0.62	0.24	-35	65	55	83	74	No crack
	17	442	526	0.84	0.62	0.24	-32	62	58	91	67	No crack
	18	480	571	0.85	0.61	0.23	-37	76	46	88	65	No crack
Comp. Ex.	19	322	478	0.69	0.46	0.14	-47	16	59	78	96	No crack
	20	517	631	0.81	0.52	0.17	-3	96	62	31	22	No crack
	21	392	501	0.72	0.44	0.15	-49	18	51	80	56	No crack
	22	358	484	0.78	0.45	0.14	-21	47	70	83	61	No crack

(continued)												
Class	Steel	Room temp. yield strength (MPa)	Room temp. tensile stress (MPa)	Ratio of yield strength to room temp. yield strength (p)			vTrs (°C)	Fraction of bainite in base material microstructure (%)	prior austenite grain size (μm)	Simulated HAZ toughness, vE ₀ (J)		Root Cracks
				600°C	700°C	800°C				Heat history 1	Heat history 2	
	23	465	566	0.86	0.57	0.23	-3	95	68	13	16	No crack
	24	481	628	0.83	0.55	0.22	-1	93	132	38	19	No crack
Tensile test piece: Thickness 40 mm or less, JIS Z 2201 1A (total thickness); thickness over 50 mm, JIS Z 2201 4 (1/4 thickness), direction perpendicular to rolling direction Charpy impact test piece: JIS Z 2202 2 mm V-notch, rolling direction High temperature tensile test piece: rod (8 mm or 10 mmφ), 1/4 thickness position, direction perpendicular to rolling direction Heat history 1: 1400°C x 1 sec, cooling time 800→500°C 8 sec Heat history 2: 1400°C x 30 sec, cooling time 800→500°C 330 sec												

INDUSTRIAL APPLICABILITY

[0046] The steel material produced by the steel compositions and method of production based on the present invention satisfies the range of limitation of in terms of the microstructure as well and is excellent in high temperature strength, weldability and weld zone toughness. The development of welded structure steel having high temperature characteristics far superior to the fire-resistant steel guaranteeing high temperature characteristics up to the conventional 600°C or so can be stably mass produced on an industrial basis. In particular, as building applications, a major increase in the buildings used for and complete elimination of fire-resistant coverings can be expected.

Claims

1. A 490 MPa class high-strength steel for welded structures excellent in high temperature strength, comprising as steel compositions, by wt%,
C: 0.005% to less than 0.040%,
Si: 0.5% or less,
Mn: 0.1 to less than 0.5%,
P: 0.02% or less,
S: 0.01% or less,
Mo: 0.3 to 1.5%,
Nb: 0.03 to 0.15%,
Al: 0.06% or less, and
N: 0.006% or less,
having a weld crack susceptible formulation P_{CM} defined as $P_{CM} = C + Si/30 + Mn/20 + Cu/20 + Ni/60 + Cr/20 + Mo/15 + V/10 + 5B$ of 0.15% or less, substantially not containing B, and a remainder of Fe and unavoidable impurities, the microstructure mainly composed of a mixed structure of ferrite and bainite, and the percentage of bainite being 20 to 90%.
2. A 490 MPa class high-strength steel for welded structures excellent in high temperature strength as set forth in claim 1, further comprising by wt% at least one of
Cu: 0.05 to 1.0%,
Ni: 0.05 to 1.0%,
Cr: 0.05 to 1.0%,
V: 0.01 to 0.1%,
Ti: 0.005 to 0.025%,
Ca: 0.0005 to 0.004%,
REM: 0.0005 to 0.004%, and
Mg: 0.0001 to 0.006%
3. A 490 MPa class high-strength steel for welded structures excellent in high temperature strength as set forth in claim 1 or 2, wherein an average circle equivalent diameter of the prior austenite of a cross-section parallel to the rolling direction at a 1/4 thickness position is 120 μm or less.
4. A method of production of a 490 MPa class high-strength steel for welded structures excellent in high temperature strength comprising the steps of; reheating semi-finished products or cast products comprised of the steel compositions as set forth in claim 1 or 2 to a range of 1100 to 1250°C, rolling it at a temperature of 850°C or more with a cumulative amount of reduction at 1100°C or less of 30% or more, and cooling it by air cooling or accelerated cooling from a temperature of 800°C or more to a temperature of 650°C or less.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2005/013101

A. CLASSIFICATION OF SUBJECT MATTER

C22C38/00 (2006.01), *C22C38/12* (2006.01), *C22C38/50* (2006.01),
C21D8/02 (2006.01)

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)

C22C38/00-38/60, *C21D8/00-8/10*

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2005
Kokai Jitsuyo Shinan Koho	1971-2005	Toroku Jitsuyo Shinan Koho	1994-2005

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

WPI (DIALOG)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2004-43961 A (Nippon Steel Corp.), 12 February, 2004 (12.02.04), & WO 03/087414 A1 & EP 1493828 A1 & KR 2004089746 A	1-4
A	JP 7-56044 B2 (Nippon Steel Corp.), 14 June, 1995 (14.06.95), (Family: none)	1-4
A	JP 5-171265 A (Sumitomo Metal Industries, Ltd.), 09 July, 1993 (09.07.93), (Family: none)	1-4

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

* Special categories of cited documents:

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"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

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
 06 October, 2005 (06.10.05)

Date of mailing of the international search report
 25 October, 2005 (25.10.05)

Name and mailing address of the ISA/
 Japanese Patent Office

Authorized officer

Facsimile No.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2005/013101

Claims 1 to 4 are not fully supported by the specification.

REFERENCES CITED IN THE DESCRIPTION

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- JP 10068044 A [0004]
- JP 2004043961 A [0005] [0033]