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(54) NON-HEAT TREATED SEAMLESS STEEL TUBE

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(57) **ABSTRACT**

A non-heat treated seamless steel tube has a composition consisting of, by weight, C: 0.10 to 0.25%, Si: 0.05 to 1.0%, Mn: 0.5 to 2.5%, P: not more than 0.03%, S: not more than 0.05%, Cr: 0.5 to 2.0%, V: 0.03 to 0.3%, Al 0.003 to 0.10%, N: 0.001 to 0.02%,

O: not more than 0.003%, and the balance comprises Fe and impurities, in which the carbon equivalent Ceq. (%) defined by the following equation is 0.60 to 0.85%.

$$Ceq.=C+Mn/6+(Cr+Mo+V)/5+(Ni+Cu)/15$$

NON-HEAT TREATED SEAMLESS STEEL TUBE

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to a seamless steel tube used for a machine structure and the like, and more particularly, it relates to a non-heat treated seamless steel tube which can be used as being made into the hot-manufactured tube, and has high strength, high toughness and excellent weldability.

[0003] 2. Description of the Background Art

[0004] Conventionally, a seamless steel tube used for usage requiring high strength and toughness has been manufactured as follows. That is, billets are hot-work pierced and rolled to manufacture the seamless steel tube. Then, the steel tube is hardened and tempered, whereby predetermined levels of strength and toughness are applied thereto to be a product.

[0005] In the manufacturing steps of the seamless steel tube, since heat treatment is needed after the tube is formed, its cost is increased and its delivery is delayed. In order to solve the above problem, there is increased the demand for a non-heat treated seamless steel tube having high strength and high toughness without needing the heat treatment.

[0006] The non-heat treated seamless steel tube having the high strength and high toughness is disclosed in Japanese Unexamined Patent Publication No. 05-202447, Japanese Unexamined Patent Publication No. 09-25541, Japanese Unexamined Patent Publication No. 10-130783, Japanese Unexamined Patent Publication No. 10-204571, Japanese Unexamined Patent Publication No. 10-324946, Japanese Unexamined Patent Publication No. 11-36017, Japanese Unexamined Patent Publication No. 2000-328192, Japanese Unexamined Patent Publication No. 2001-247931, and Japanese Unexamined Patent Publication No. 2001-262275, for example.

[0007] Japanese Unexamined Patent Publication No. 05-202447, Japanese Unexamined Patent Publication No. 09-25541, Japanese Unexamined Patent Publication No. 10-130783, Japanese Unexamined Patent Publication No. 10-205671, Japanese Unexamined Patent Publication No. 10-324946, Japanese Unexamined Patent Publication No. 11-36017, and Japanese Unexamined Patent Publication No. 2000-328192 each disclose a method of adjusting components or a hot-manufacturing method in order to implement non-heat treated steel tube having high strength and high toughness. In addition, the above Japanese Unexamined Patent Publications are in common with each other in that carbon (C) not less than 0.2% is added by weight to design a medium carbon group component. According to the prior art, since carbon not less than 0.2% is added, the toughness is not sufficient in the strength level. Especially, at a welding part which was hardened, the toughness is lowered and/or a weld crack is generated.

[0008] Japanese Unexamined Patent Publication No.2001-323338 discloses a method of implementing hot workability, machinability and toughness for steel in which a broad range of added amounts of carbon is added. However, since vanadium (V) is not added in the steel tube in this case, the sufficient strength cannot be provided.

[0009] Japanese Unexamined Patent Publication No. 2001-247931 and Japanese Unexamined Patent Publication No. 2001-262275 disclose technique for providing the strength and toughness by restricting a hot manufacturing temperature so as to control a metal constitution, and technique for providing the hot workability, for the steel in which a broad range of added amounts of carbon is added. However, in order to implement low-temperature manufacturing disclosed in the above documents, it is necessary to convert the facility because a motor power is insufficient in the conventional facility. Furthermore, a facility such as a reheating furnace is needed in order to reheat the tube to be manufactured after cooled it once.

[0010] Still further, according to Japanese Unexamined Patent Publication No. 2001-247931, although a broad range of added amounts of carbon is defined in CLAIM, the carbon amount is 0.2% or more by weight in embodiments.

SUMMARY OF THE INVENTION

[0011] It is an object of the present invention to provide a non-heat treated seamless steel tube having high strength, high toughness and excellent weldability. Especially, it is an object to implement both high strength and high toughness and prevent a crack from being generated at a welding part and toughness from being lowered without strictly restricting the degree of manufacturing processing and a manufacturing temperature.

[0012] The inventor of the present invention found that the following matters were effective in order to attain the above objects.

[0013] (1) A carbon content is lowered. Then, in order to compensate the strength because the carbon content is lowered, manganese (Mn), chromium (Cr) and vanadium (V) are added together. Thus, high strength can be provided and preferable toughness can be provided, including the welding part.

[0014] (2) The carbon content is lowered and then the carbon equivalent (Ceq.) is adjusted in a predetermined range.

[0015] The metal structure of the non-heat treated steel is normally ferrite and perlite steel. However, when it is highly carbonized in order to satisfy the demand for the high strength, the toughness is lowered. Then, the inventor of the present invention lowers the carbon content and adds Mn, Cr and V together in order to compensate the strength. Thus provided metal structure of the non-heat treated steel becomes a bainite-based structure, so that the high strength and high toughness can be secured. In addition, although the term "bainite based structure" definitely includes a structure in which bainite exists 100%, it also includes a mixture structure of bainite and ferrite in which volume % of ferrite is 50 or less.

[0016] The essential features of the present invention are as follows.

[0017] (1) To control the carbon content so as to be less than 0.2%.

[0018] (2) To add manganese (Mn), chromium (Cr) and vanadium (V) together.

[0019] (3) To provide the bainite based metal structure, in which the carbon equivalent Ceq. defined by the following equation satisfies a range from 0.60-0.85, as a component composition range in which high strength and high toughness can be implemented.

$$Ceq.=C+Mn/6+(Cr+Mo+V)/5+(Ni+Cu)/15$$

[0020] When the Ceq. is in the range of 0.60-0.85, the strength is secured. As a method of satisfying the range, there are various kinds of adjustments in added amounts of an alloy element. Above all, the inventors of the present invention found that when Mn, Cr and V were added together at the same time, the strength and the toughness were preferably in balance. In other words, when the carbon content is the same, as compared with the case the intended carbon equivalent Ceq. is attained by adding Mn and Cr only, the more preferable toughness can be provided in the case V is added while the amount of Mn and Cr is lowered to attain the intended carbon equivalent Ceq. Therefore, regarding Mn, Cr and V, it is important to add them together.

[0021] In view of the above points, the non-heat treated seamless steel tube of the present invention has a composition consisting of, by weight, C: 0.10 to 0.25%, Si: 0.05 to 1.0%, Mn: 0.5 to 2.5%, P: not more than 0.03%, S: not more than 0.05%, Cr: 0.5 to 2.0%, V: 0.03 to 0.3%, Al: 0.003 to 0.10%, N: 0.001 to 0.02%, and

[0022] O: not more than 0.003%, in which the balance comprises Fe and impurities, and the carbon equivalent Ceq. (%) defined by the following equation is 0.60 to 0.85.

$$Ceq.=C+Mn/6+(Cr+Mo+V)/5+(Ni+Cu)/15$$

[0023] A part of Fe may be replaced with one or 2 kinds or more selected from Ni: 0.05 to 1.5%, Mo: 0.05 to 1.5%, Cu: 0.05 to 1.5%, and B: 0.0003 to 0.01%.

[0024] Alternatively, a part of Fe may be replaced with one or 2 kinds selected from Ti: 0.005 to 0.2%, and Nb: 0.005 to 0.2%.

[0025] Furthermore, a part of Fe may replaced with one or 2 kinds or more selected from Ni: 0.05 to 1.5%, Mo: 0.05 to 1.5%, Cu: 0.05 to 1.5%, and B: 0.0003 to 0.01%, and replaced with one or 2 kinds or more selected from Ti: 0.005 to 0.2% and Nb: 0.005 to 0.2%.

[0026] The above restricted reason is described hereinafter.

[0027] C: 0.10 to 0.25%

[0028] C is an element which increases the strength but lowers the toughness and weldability. Therefore, in order to secure the toughness and weldability at high level, it is necessary to limit the content of C in a range to 0.25% by weight. In view of the toughness and weldability, the lower content of C is preferable but when it is less than 0.10% by weight, it is difficult to secure the strength. Therefore, the content of C is limited in the range of 0.10 to 0.25% by weight. In view of the most preferable balance between the strength and the toughness, the content of C is preferably in a range of 0.13 to less than 0.20%, more preferably in a range of 0.13 to 0.17%.

[0029] Si: 0.05 to 1.0%

[0030] Si serves as a deoxidizer and has a property improving the strength. However, when the content is less than 0.05%, the effect cannot be provided and when it exceeds 1.0%, the toughness is lowered. Thus, the content of Si is limited to a range of 0.05 to 1.0% by weight. In view of securing the most preferable balance between the strength and the toughness, the content of Si is preferably in a range of 0.1 to 0.4%.

[0031] Mn: 0.5 to 2.5%

[0032] Mn is an element which increases the strength without lowering the toughness by being added together with Cr and V to the steel in which the content of C is lowered. In order to secure a predetermined strength, the content has to be not less than 0.5%. Meanwhile, when it exceeds 2.5%, the weldability and toughness are lowered. Therefore, the content of Mn is limited to the range of 0.5% to 2.5%. In view of securing the most preferable balance between the strength and the toughness, the content of Mn is preferably in a range of 1.5 to 2.0% by weight.

[0033] P: not more than 0.03%

[0034] P is an impurity element which incrassates in the vicinity of final solidification point at the time of solidification and segregates at a grain boundary to lower the hot workability and the toughness. Therefore, it is preferably lowered as much as possible. However, since it is permissible until 0.03%, the content of P is determined to not more than 0.03%. However, in order to secure the higher toughness, it is preferably not more than 0.02% and it is more preferably not more than 0.01% by weight.

[0035] S: not more than 0.05%

[0036] S is also an impurity element like P, which segregates at a grain boundary at the time of solidification to lower the hot workability and the toughness. Therefore, it is preferably lowered as much as possible. However, since it is permissible until 0.05%, the content of S is determined to not more than 0.05% by weight. However, the machinability is lowered in some cases when it is lowered too much. Therefore, a lower limit value of S is preferably set at 0.01% when the machinability is emphasized. Meanwhile, when the toughness is emphasized more than the machinability, the content of S is preferably not more than 0.02% and it is more preferably not more than 0.01% by weight.

[0037] Cr: 0.5 to 2.0%

[0038] Cr is an element which increases the strength without lowering the toughness by being added together with Mn and V to the steel in which the content of C is lowered. In order to secure a predetermined strength, the content has to be not less than 0.5% by weight. Meanwhile, when it exceeds 2.0%, the weldability and toughness are lowered. Therefore, the content of Cr is limited to the range of 0.5% to 2.0%. In view of securing the most preferable balance between the strength and the toughness, the content of Cr is preferably in a range of 0.9 to 1.5% by weight.

[0039] V: 0.03 to 0.3%

[0040] V is added because it segregates fine V- carbide to increase the strength. When it is added together with Mn and Cr, the toughness can be prevented from being lowered while high strength is maintained. In order to obtain this effect, V has to be added by not less than 0.03%. Meanwhile, when it exceeds 0.3%, the toughness is lowered. Therefore, the content of V is limited to the range of 0.03 to 0.3%. In view of securing the most preferable balance between the strength and the toughness, the content of V is preferably in a range of 0.05 to 0.15% by weight.

[0041] Al: 0.003 to 0.10%

[0042] Al is an element which serves as a deoxidizer. In order to obtain this effect, the content has to be not less than 0.003%. When it exceeds 0.10%, aluminum group inclusions are increased and surface defects could frequently occur. Therefore, the content of Al is limited to the range of 0.003 to 0.10%. In addition, in order to secure a stable surface quality, it is preferable in a range of 0.003 to 0.05% by weight.

[0043] N: 0.001 to 0.02%

[0044] N is an element which miniaturizes crystal grains together with Al and Ti to improve the toughness. However, when it is less than 0.001%, the effect is small. Meanwhile, when it exceeds 0.02%, the toughness is lowered to the contrary. Therefore, the content of N is limited to a range of 0.001 to 0.02% by weight.

[0045] O: not more than 0.003%

[0046] o lowers the toughness and fatigue strength when the content exceeds 0.003% by weight. Therefore, the content of o is set to be not more than 0.003%.

[0047] One or 2 kinds or more selected from Ni: 0.05 to 1.5%, Mo: 0.05 to 1.5%, Cu: 0.05 to 1.5%, and B: 0.0003 to 0.01% All of Ni, Mo, Cu and B are elements which improve a hardening property and increase the strength of the steel, and one kind or two or more kinds can be selected from them and added according to need. The effect can be provided when 0.05% or more is added regarding Ni, Mo and Cu and 0.0003% or more is added regarding B. Meanwhile, in a case 1.5% or more is added regarding Ni, Mo and Cu, the strengthen effect is saturated and cost is increased in the case of Ni, the weldability and toughness are lowered in the case of Mo, and the hot workability is lowered in the case of Cu. Therefore, the upper limit values of Ni, Mo and Cu are set at 1.5% by weight, respectively. When B is added more than 0.01%, since the toughness is lowered, the upper limit value is set at 0.01%.

[0048] One or two kinds selected from Ti: 0.005 to 0.2% and Nb: 0.005 to 0.2%

[0049] Both Ti and Nb are elements which contribute to miniaturize the structure by forming carbide to improve the toughness, and segregate in a matrix to increase the strength. Therefore, the above one kind or two kinds can be added according to need. The effect can be obtained when 0.005% or more are added regarding both elements. Meanwhile, when they are added more than 0.2%, the toughness is lowered. Therefore, both of them are limited to a range of 0.005 to 0.2% by weight.

[0050] Carbon equivalent Ceq. (%): 0.60 to 0.85%

$$Ceq.=C+Mn/6+(Cr+Mo+V)/5+(Ni+Cu)/15$$

[0051] The alloy element contents are defined by weight %, respectively. In addition to the restriction of the above component composition, in view of preferably keeping the strength, toughness and weldability, it is preferable that the Ceq. is limited to the range of 0.60 to 0.85%. When the Ceq. is lower than 0.60%, the strength cannot be secured and when the Ceq. is more than 0.85%, the toughness is lowered and the weld crack is likely to be generated. In addition, in view of high strength, it is preferably 0.65 to 0.85% and more preferably it is in a range of 0.70 to 0.85%.

[0052] The balance comprises Fe and impurities.

[0053] Ca, Mg and REM (rare-earth metal) in which 0.01% is set as an upper limit value, respectively can be contained in the impurities. Although these elements do not largely affect the strength, toughness and weldability, since they prevent a nozzle of a tundish from clogging at the time of casting of a round billet especially, they are added in some cases. When the content of the elements exceed 0.01%, a surface nature state deteriorates and yield is lowered. Therefore, they may be added as impurities by setting 0.01% as their upper limit.

[0054] The seamless steel tube according to the present invention can be manuractured as follows. That is, the molten steel having the above composition is treated in a converter, an electric furnace or a vacuum melting furnace, and solidified by a continuous casting method or ingot making method. Then, the solidified object becomes a steel tube material as it is or through blooming. Then, the steel tube goes through a normal manufacturing process of the seamless steel tube, then it is air-cooled.

[0055] Although the cooling after the hot rolling is preferably air cooling by natural cooling, warm cooling such as air blast cooling (cooling with a wind shelter cover) or wind cooling (cooling with some wind) may be performed.

EXAMPLES

[0056] Steels having chemical compositions shown in a table 1 are melted, then casted into ingots and then formed into billets by casting. The billets are heated to 1250° C. and formed into tubes by a Mannessman mandrel type of mill. Thus, the seamless steel tubes each having an outer diameter of 150 mm and a wall thickness of 24.2 mm are provided. The steel tubes are rolled and then air-cooled. Then, mechanical characteristics (tensile characteristics and impact characteristics by a Charpy test) and weld crack properties of these steel tubes are examined as being made into the tube.

[0057] In addition, referring to the weld crack properties, welding is performed by a shielded metal arc welding method with heat input of 20 kJ/cm without preheating, based on JIS Z 3158 "Y-shaped weld cracking test" and cracking existence is examined. The results of the examinations are also shown in the table 1. In the table, reference character TS (Ma) designates a tensile strength. In addition, reference character 2uE20 (J) designates a Charpy breaking energy value based on JIS Z 2202 and JIS Z 2242, as an index of toughness, which corresponds to a Charpy breaking energy value (J) in a test at 20° C. for a 2mm U-notch chip.

TABLE 1

	Nos.	C	Si	Mn	P	S	Cr	V	Al	N	O	Ni
inventive	1	0.15	0.19	1.80	0.015	0.020	1.20	0.10	0.019	0.0011	0.0020	
examples	2	0.15	0.35	1.71	0.011	0.012	1.31	0.14	0.016	0.0061	0.0019	
	3	0.17	0.29	1.65	0.013	0.025	0.98	0.07	0.015	0.0055	0.0008	

TABLE 1-continued

	4	0.14	0.32	1.74	0.014	0.018	1.19	0.12	0.017	0.0034	0.0007	
	5	0.13	0.38	1.89	0.010	0.013	0.91	0.05	0.023	0.0057	0.0010	
	6	0.13	0.13	1.76	0.014	0.025	1.37	0.12	0.025	0.0021	0.0007	
	7	0.13	0.35	1.60	0.010	0.023	1.38	0.06	0.024	0.0180	0.0011	
	8	0.17	0.16	1.86	0.013	0.022	1.26	0.07	0.017	0.0091	0.0013	
	9	0.12	0.28	1.97	0.013	0.015	1.02	0.14	0.017	0.0020	0.0005	
	10	0.13	0.39	1.96	0.013	0.021	0.95	0.10	0.018	0.0058	0.0015	
	11	0.15	0.10	1.56	0.013	0.008	1.24	0.08	0.021	0.0076	0.0004	0.50
	12	0.16	0.34	1.53	0.011	0.008	1.22	0.13	0.019	0.0096	0.0016	
	13	0.12	0.23	1.91	0.012	0.023	1.15	0.13	0.020	0.0076	0.0001	0.10
	14	0.13	0.33	1.50	0.014	0.015	1.48	0.11	0.022	0.0010	0.0004	
	15	0.16	0.21	1.70	0.013	0.019	0.91	0.12	0.021	0.0042	0.0009	0.42
	16	0.17	0.36	1.91	0.014	0.016	1.21	0.12	0.017	0.0044	0.0010	
	17	0.17	0.36	1.65	0.014	0.006	1.46	0.14	0.022	0.0070	0.0019	
	18	0.17	0.35	1.69	0.011	0.023	1.26	0.11	0.020	0.0071	0.0004	
	19	0.16	0.23	1.90	0.014	0.008	1.01	0.11	0.021	0.0045	0.0011	0.45
	20	0.14	0.28	1.78	0.012	0.023	0.92	0.10	0.022	0.0080	0.0015	0.53
	21	0.16	0.37	1.73	0.012	0.007	1.03	0.14	0.019	0.0038	0.0019	
comparative examples	22	0.45	0.11	1.00	0.011	0.024	0.70	0.05	0.023	0.0066	0.0014	
	23	0.41	0.25	0.60	0.010	0.007	0.90	0.15	0.024	0.0051	0.0005	0.13
	24	0.17	0.30	1.95	0.014	0.019	1.49	—	0.018	0.0068	0.0004	
	25	0.16	0.11	2.48	0.014	0.012	—	0.27	0.020	0.0078	0.0018	
	26	0.19	0.27	0.46	0.010	0.014	1.48	0.28	0.016	0.0033	0.0010	
	27	0.15	0.31	2.35	0.010	0.020	1.40	—	0.015	0.0089	0.0005	
	28	0.11	0.26	0.61	0.010	0.006	0.57	0.04	0.017	0.0086	0.0019	

	Nos.	Mo	Cu	B	Ti	Nb	Ceq. (%)	TS(MPa)	2uE20 (J)	cracking existence
inventive examples	1						0.71	843	54	○
	2						0.73	878	68	○
	3						0.66	756	66	○
	4						0.69	823	64	○
	5						0.67	719	58	○
	6						0.76	857	60	○
	7						0.70	768	63	○
	8						0.75	886	53	○
	9						0.77	873	66	○
	10						0.67	788	66	○
	11						0.67	759	61	○
	12	0.20					0.69	765	62	○
	13		0.15				0.72	802	58	○
	14			0.0031			0.78	878	57	○
	15	0.31					0.68	757	64	○
	16					0.15	0.75	861	64	○
	17				0.021		0.77	868	62	○
	18				0.009	0.018	0.73	832	69	○
	19				0.012		0.73	833	57	○
	20	0.22			0.007	0.02	0.72	806	53	○
	21	0.15		0.0009	0.025		0.71	786	54	○
comparative examples	22						0.77	856	9	X
	23						0.73	788	13	X
	24						0.79	893	25	○
	25						0.63	725	24	○
	26						0.62	722	26	○
	27	0.11		0.0011	0.021		0.84	913	22	○
	28						0.33	580	86	○

[0058] In the table 1, sample numbers 1 to 21 designate examples according to the present invention, in which the tensile strength exceeds 700 MPa at lowest and reaches nearly 900 MPa at highest. Even when the strength is high, toughness evaluated by an impact value is 50 J or more and a weld crack is not generated.

[0059] The sample numbers 22 to 28 designate comparative examples. The sample numbers 22 and 23 show examples of medium carbon group components which becomes the conventional ferrite perlite steel. In this case, although the strength can be secured, the toughness is low and the weld crack is generated. In addition, the sample numbers 24 to 27 designate examples in which Mn, Cr and V are not added together or which is out of an applicable range. In this case, although the weld crack is not generated, the toughness is insufficient. The sample number 28 designates an example in which although a component composition range is satisfied, carbon equivalent Ceq. is low. In this case, since the strength is far below 700 MPa, it cannot be used for a non-heat treated high strength seamless steel tube.

[0060] As described above, according to the present invention, there can be provided the non-heat treated seamless steel tube having high strength, high toughness and preferable weldability, without strictly controlling the degree of tube-manufacturing processing nor tube-manufacturing temperature.

What is claimed is:

1. A non-heat treated seamless steel tube having a composition consisting of, by weight,

C: 0.10 to 0.25%,

Si: 0.05 to 1.0%,

Mn: 0.5 to 2.5%,

P: not more than 0.03%,

S: not more than 0.05%,

Cr: 0.5 to 2.0%,

V: 0.03 to 0.3%,

Al: 0.003 to 0.10%,

N: 0.001 to 0.02%, and

O: not more than 0.003%,

wherein the balance comprises Fe and impurities, and

the carbon equivalent Ceq. (%) defined by the following equation is 0.60 to 0.85.

$$Ceq.=C+Mn/6+(Cr+Mo+V)/5+(Ni+Cu)/15$$

2. The non-heat treated seamless steel tube according to claim 1, wherein a part of Fe is replaced with at least one kind selected from,

Ni: 0.05 to 1.5%,

Mo: 0.05 to 1.5%,

Cu: 0.05 to 1.5%, and

B: 0.0003 to 0.01%.

3. The non-heat treated seamless steel tube according to claim 1, wherein a part of Fe is replaced with one or 2 kinds selected from,

Ti: 0.005 to 0.2%, and

Nb: 0.005 to 0.2%.

4. The non-heat treated seamless steel tube according to claim 1, wherein a part of Fe is replaced with at least one kind selected from,

Ni: 0.05 to 1.5%,

Mo: 0.05 to 1.5%,

Cu: 0.05 to 1.5%, and

B: 0.0003 to 0.01%, and

replaced with one or 2 kinds selected from,

Ti: 0.005 to 0.2%, and

Nb: 0.005 to 0.2%.

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