

FLUX CORED WIRE FOR GAS SHIELDED ARC WELDING OF HIGH STRENGTH STEEL

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001]

The present invention relates to a flux cored wire for gas shielded arc welding of high-strength steel having proof stress of 690MPa or more in building machines, offshore structures, and the like, and particularly relates to a flux cored wire for welding of high-strength steel which is capable of conducting all-position welding and providing an excellent cracking resistance.

2. Description of the Related Art

[0002]

For arc welding of high-strength steels to be mainly used in construction machines, offshore structures, and the like, there have been adopted: covered electrode, submerged arc welding, and gas shielded arc welding using a solid wire, and the like, providing excellent impact toughness. Among them, it is general to adopt the covered electrode, or the gas shielded arc welding used a solid wire in case of which necessitate positional welding such as vertical, overhead, and horizontal.

[0003]

However, the covered electrode is low in welding

efficiency, and the gas shielded arc welding using a solid wire is also difficult in achieving highly efficient welding because the gas shielded arc welding is required to be conducted with low welding current so as to prevent molten metal sagging in the positional welding.

[0004]

On the other hand, for all-position welding of typical low-strength steels having proof stresses less than 690MPa, the gas shielded arc welding using a flux cored wire is adopted in most cases.

[0005]

In case of the gas shielded arc welding using a flux cored wire, a slag component having a high melting point added in the cored wire solidifies upon welding in advance of a weld metal to thereby hold the weld metal, so that metal sagging is rarely caused even by positional welding such as vertical upward welding, thereby enabling to weld with a high welding current, i.e., highly depositional welding with a higher efficiency.

[0006]

However, it has been difficult to adopt the gas shielded arc welding using a flux cored wire of high-strength steels, because a slag component to be generally added into the flux cored wire is mainly constituted of oxides, so that obtainment of an impact toughness is more difficult than other welding processes, and an amount of diffusible hydrogen such as resulting from moisture

contained in a flux material and resulting from moisture absorption during storage of the flux cored wire is larger than that resulting of the solid wire.

[0007]

Further, various developments have been progressed in flux cored wires for gas shielded arc welding of high-strength steel, for example, metal-based flux cored wires without addition of slag components have been disclosed in patent-related references 1 and 2. However, these flux cored wires are focused on flat position welding, so that all-position welding based on the flux cored wires are required to be conducted at low welding current so as to prevent the molten metal sagging, similarly to the gas shielded arc welding using solid wire.

[0008]

Moreover, concerning flux cored wires for gas shielded arc welding of high-strength steels for all position, although patent-related references 3 and 4 disclose flux cored wires for providing improved low-temperature toughness by virtue of decrease of an amount of oxygen in a welded metal by adding metal fluorides, basic oxides, or the like into slag components including rutile as a main component, these flux cored wires are not considered about cracking resistance of the weld metal.

[0009]

[Patent-related reference 1] JP2006-198630A

[Patent-related reference 2] JP2007-144516A

[Patent-related reference 3] JP09-253886A

[Patent-related reference 4] JP03-047695A

SUMMARY OF THE INVENTION

[0010]

It is therefore an object of the present invention to provide a flux cored wire for gas shielded arc welding to be used for high-strength steels having proof stresses of 690MPa or more, which is capable of all-position welding with a higher efficiency and exhibits an excellent cracking resistance.

[0011]

The aspect of present invention for achieving the above object is summarized as follows.

[0012]

(1) A flux cored wire for gas shielded arc welding of high-strength steel comprising a steel sheath, and a flux filled therein, wherein the flux cored wire comprises, by mass% with respect to the total mass of the flux cored wire:

C: 0.03 to 0.10%,

Si: 0.25 to 0.7%,

Mn: 1.0 to 3.0%,

Ni: 1.0 to 3.5%,

B: 0.001 to 0.015%,

Cr: limited to 0.05% or less, and

Al: limited to 0.05% or less, and

in the flux,

TiO₂: 2.5 to 7.5%,

SiO₂: 0.1 to 0.5%,

ZrO₂: 0.2 to 0.9%,

Al₂O₃: 0.1 to 0.4%; and

the remainder comprising: Fe, an arc stabilizer, and unavoidable impurities; and

wherein the total amount of hydrogen in the flux cored wire is in 15ppm or less.

[0013]

(2) The flux cored wire for gas shielded arc welding of high-strength steel as set forth in (1), wherein the flux cored wire comprises, by mass% with respect to the total mass of the flux cored wire, one or more of:

Mo: 0.1 to 1.0%,

Nb: 0.01 to 0.05%, and

V: 0.01 to 0.05%.

[0014]

(3) The flux cored wire for gas shielded arc welding of high-strength steel as set forth in (1) or (2), wherein the flux cored wire further comprises, by mass% with respect to the total mass of the flux cored wire, one or more of:

Ti: 0.1 to 1.0%;

Mg: 0.01 to 0.9%;

Ca: 0.01 to 0.5%; and

REM: 0.01 to 0.5%.

THE EFFECT OF THE INVENTION

[0015]

According to the flux cored wire for gas shielded arc welding of high-strength steel of the present invention, it becomes possible, in welding of high-strength steels having proof stresses of 690MPa or more, to exemplarily enable all-position welding with a higher efficiency and to provide the weld metal having an excellent cracking resistance and an excellent low-temperature toughness, to thereby improve the welding efficiency and the weld metal quality, as compared to a covered electrode and a gas shielded arc welding using a solid wire.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0016]

The present inventors have carried out various studies and investigations to obtain wire components in flux cored wires for all-position welding, so as to ensure mechanical properties of welded metal for high-strength steel having proof stress of 690MPa or more, such as tensile strengths, impact toughness, and so as to achieve excellent cracking resistances of the welded metals.

[0017]

As a result, the present inventors have found out such mechanical properties and resistances can be simultaneously established, by finding out optimum addition amounts of alloy components including rutile as a main

component in slag components for all-position welding, and by further decreasing a total amount of hydrogen in the wire to 15ppm or less so as to improve the cracking resistance.

[0018]

Described below are reasons of limitation of the components and the like of the flux cored wire for gas shielded arc welding of high-strength steel according to the present invention.

[0019]

[C: 0.03 to 0.10 mass%]

C is an important element for ensuring the strength of the weld metal by solid solution strengthening. If the total amount of C component in the steel sheath and a flux ("total amount of applicable element component" will be referred to as "wire component" hereinafter) is less than 0.03 mass% (hereinafter referred to as simply "%"), the effect for ensuring the strength of above-described is not obtained, and if C in the wire component exceeds 0.10%, lead to yields of excessive C in the welded metal to excessively increase proof stresses and strengths thereof, thereby decreasing toughness thereof.

[0020]

[Si: 0.25 to 0.7%]

Si is added for the purpose of improving toughness of the weld metal. If Si in the wire component is less than 0.25%, toughness decreases. On the other hand, if Si in

the wire component exceeds 0.7%, slag formation amount increases, thereby slag inclusion defect causes in case of multi-layer welding. Further, yield of Si in the welded metal is made excessive, then strength excessively increases, thereby decreasing toughness thereof.

[0021]

[Mn: 1.0 to 3.0%]

Mn is added for the purpose of ensuring toughness of the welded metal and improving strength and proof stress. If Mn in the wire component is less than 1.0%, toughness decreases. On the other hand, if Mn in the component exceeds 3.0%, slag formation amount increases, thereby causing slag inclusion defect in case of multi-layer welding. Further, yield of Mn in the welded metal is also made excessive, then strength excessively increases , thereby decreasing toughness thereof.

[0022]

[Ni: 1.0 to 3.5%]

Ni is added for the purpose of improving strength and toughness of a welded metal. If Ni in the wire component is less than 1.0%, the effect is insufficient thereof, and if Ni in the component exceeds 3.5%, the strength excessively increases, toughness decrease.

[0023]

[B: 0.001 to 0.015%]

B is added in a small amount, to enhance a hardenability of the welded metal and to improve strength

and low-temperature toughness of the welded metal. If B is less than 0.001%, the effect is insufficient thereof, and if B exceeds 0.015%, the strength is excessive, low temperature toughness decreases. Note that the effect of B can be exhibited by any simple metal substance, alloy, and oxide of B, so that the form of B to add into the flux is arbitrary.

[0024]

[Cr: 0.05% or less]

Cr is limited to 0.05% or less, because, although Cr has an effect for forming Cr-carbide in the welded metal and thereby improving the strength thereof, Cr conversely functions to decrease low temperature toughness thereof.

[0025]

[Al: 0.05% or less]

Al is limited to 0.05% or less, because, although Al exhibits an effect as a deoxidizer which bonds to dissolved oxygen in a molten pool, floating of a slag formed aluminum oxide tends to become insufficient in case of a condition of a relatively low heat input in the gas shielded arc welding using the flux cored wire, such that the oxide is left as a non metal inclusion in the weld metal, toughness decreases.

[0026]

[TiO₂: 2.5 to 7.5%]

TiO₂ is an arc stabilizer, and is a main one of slag components. TiO₂ functions to encapsulate the welded metal

upon welding to thereby shield it from the atmosphere, and to properly keep bead shape by virtue of an appropriate viscosity, and particularly, TiO_2 largely affects sagging properties of molten metal depending on the balance between TiO_2 and other metal components in case of vertical upward welding. If TiO_2 is less than 2.5%, metal sagging easily occurs in vertical upward welding, so that all-position welding is made difficult. On the other hand, if TiO_2 exceeds 7.5%, the amount of slag becomes exemplarily excessive, so that slag inclusion occurs and metallic inclusions increase, thereby decreasing the toughness.

[0027]

[SiO_2 : 0.1 to 0.5%]

SiO_2 enhances a viscosity of molten slag, thereby improving an encapsulating ability of the slag. If SiO_2 is less than 0.1%, viscosity of the molten slag is insufficient, and thereby encapsulating ability of slag becomes insufficient, so that a metal sagging is caused in vertical upward welding. On the other hand, if SiO_2 exceeds 0.5%, the viscosity of molten slag becomes excessive, thereby deteriorating slag removability and bead shape.

[0028]

[ZrO_2 : 0.2 to 0.9%]

ZrO_2 has a function to adjust a viscosity and a solidification temperature of the molten slag, and thereby enhancing an encapsulating ability of the slag. If ZrO_2 is

less than 0.2%, the effect is insufficient thereof, thereby easily causing a metal sagging in vertical upward welding. On the other hand, if ZrO_2 exceeds 0.9%, the bead shape becomes convex, thereby easily causing a slag inclusion, a lack of fusion, and the like.

[0029]

[Al_2O_3 : 0.1 to 0.4%]

Similarly to ZrO_2 , Al_2O_3 has a function to adjust a viscosity and a solidification temperature of the molten slag, thereby enhancing an encapsulating ability of the slag. If Al_2O_3 is less than 0.1%, the effect is insufficient thereof, thereby causing a metal sagging in vertical upward welding. On the other hand, if Al_2O_3 exceeds 0.4%, the bead shape becomes convex, thereby easily causing the slag inclusion, the lack of fusion, and the like.

[0030]

[Total amount of hydrogen in wire: 15ppm or less]

It is possible to measure an amount of hydrogen in the cored wire, such as by the inert gas fusion thermal conductivity detection method. Further, it is required to decrease an amount of hydrogen in the cored wire as less as possible, because such hydrogen becomes a source of diffusible hydrogen in a welded metal. If the amount of hydrogen in the wire exceeds 15ppm, the amount of diffusible hydrogen (JIS Z3118) exceeds 4ml/100g, such that the welded metals of high-strength steels are increased in

sensitivity of cold cracking.

[0031]

Note that total amount of hydrogen in the flux cored wire can be decreased, by selecting a filling flux having a lower hydrogen content, and by annealing (650 to 950°C) after flux filling.

[0032]

[Mo: 0.1 to 1.0%; Nb: 0.01 to 0.05%; and V: 0.01 to 0.05%]

Mo, Nb, and V are each added for the purpose of improving proof stress and strength of the welded metal. Although these are elements which are added into a wire by selecting one or more of them, if amount of these elements exceed the defined upper limits of 1.0% for Mo, 0.05% for Nb, and 0.05% for V, strengths of the welded metal is excessive, thereby decreasing toughness thereof.

[0033]

Further, if amount of one or more of Mo is less than 0.1%, Nb is less than 0.01%, and V is less than 0.01%, the effects for improving proof stress and strength of the welded metal cannot be obtain.

[0034]

[Ti: 0.1 to 1.0%; Mg: 0.01 to 0.9%; Ca: 0.01 to 0.5%; and REM: 0.01 to 0.5%]

Ti, Mg, Ca, and REM are each added as a deoxidizer for decreasing an oxygen amount in the welded metal to thereby improve toughness thereof. Although these are

elements which are added into a wire by selecting one or more of them, if amount of these exceeds the defined upper limit of 1.0% for Ti, 0.9% for Mg, 0.5% for Ca, and 0.5% for REM, reacts intensely with oxygen within arc thereof, thereby increasing generation of spatter, fume, and the like.

[0035]

Further, if amount of Ti is less than 0.1%, Mg is less than 0.01%, Ca is less than 0.01%, and REM is less than 0.01%, the effect as deoxidizer for decreasing an oxygen amount in the welded metal to thereby improve the toughness thereof cannot be obtain.

[0036]

Note that blending amounts of alloy component in a flux are adjusted within the defined ranges, respectively, in consideration of component in a steel sheath and content thereof. Adjusting alloy component in the flux allows for provision of a flux cored wire adapted to component of various high-strength steels (parent material).

[0037]

Further, since both P and S produce compound having low melting point and strength of grain decrease, and the toughness of the weld metal decreases thereof, P and S are limited to 0.015% or less and 0.010% or less, respectively, in amount as small as possible. Moreover, although iron powder can be used to adjust flux filling rate to 10 to 20%, lower flux filling rate and smaller addition amount of iron

powder are desirable because iron powder take oxygen of the welded metal.

[0038]

As other components in wires include: Fe, in the steel sheath, and the iron powder added into a flux, and alloy components; Na_2O , K_2O , NaF , K_2SiF_6 , K_2ZrF_6 , Na_3AlF_6 , MgF_2 , or the like, as arc stabilizers comprising oxides and fluoride of alkali metals, and oxide and fluoride of alkaline earth metals and Cu, in case of Cu plating treatment on to a wire surface, which is effective for rust prevention, electro conductivity achievement, and resistance to contact tip abrasion.

Flux cored wires each have a structure forming a steel sheath into a pipe shape and the flux filled in the steel sheath, and the flux cored wires can be generally classified into: seamless wire each comprising a steel sheath, which sheath is formed in a manufacturing process, and is closed by welding without a slit-like seam exhibiting a risk of outside air penetration; and wire having slit-like gap without by welding, respectively. Although the present invention is capable of adopting both types of cross-sectional structures, it is more desirable to adopt the seamless type of wire comprising a steel sheath without a slit-like seam exhibiting the risk of outside air penetration, so as to decrease a diffusible hydrogen amount and to thereby improve the cracking resistance, because such the seamless type flux cored wire

can be subjected heat treatment so as to decrease a total amount of hydrogen in the wire and such the seamless wire is free of moisture absorption after manufacturing.

[0039]

The wire of the present invention is allowed to have a diameter within the range of 1.0 to 2.0mm, and preferably within a range of 1.2 to 1.6mm, for enabling to increase welding current density on welding and to thereby obtaining higher deposition efficiency.

[0040]

Further, it is preferable to use a mixed gas comprising Ar and 5 to 25% CO₂, as a shielding gas upon welding, so as to decrease an oxygen amount in a welded metal.

[0041]

Examples

Effects of the present invention will be explained hereinafter more concretely, based on examples.

[0042]

The flux cored wires were manufactured by way of trial, Steel sheaths were formed into "U" shape in a forming process, respectively; flux of various component was filled into them, respectively; the steel sheath was further formed into "O" shape in a manner to be made into seamless wire each comprising the applicable steel sheath closed by welding without the slit-like seam exhibiting a risk of outside air penetration, and into wire having slit-

like gap without by welding, respectively; and which each has a wire diameter of 1.2mm as listed in Table 1 and Table 2. All these examples adopted the same steel for steel sheath of all the experimentally produced the flux cored wires. The component of the steel sheath comprises, by mass%, C: 0.03%, Si: 0.25%, Mn: 0.4%, P: 0.003%, S: 0.002%, and a remainder comprising iron and unavoidable impurities. Namely, those elements lacking in these components were added by flux, thereby experimentally producing the flux cored wires having the wire component listed in Table 1 and Table 2 by way of trial. However, the present invention is not limited to only such a situation that alloy elements such as Ni are added in the flux. Namely, it is even enough for the present invention that an amount of the applicable alloy elements such as Ni are within the range defined by the present invention with respect to the total mass of the flux cored wire, when the alloy elements are already added in the steel sheath.

The flux cored wires were annealed at 600 to 950°C in the process of wire manufacturing; and in case of annealing those wires having slit-like gap, annealing was performed in an atmosphere of Ar gas so as to prevent that the filled flux in the wires were contacted with the atmosphere through the gap. Further, after production of the wires, the wires were encapsulated into vinyl-made packs so as to prevent moisture absorption by the flux, and were stored in such a state until just before commencement of welding.

[0043]

Table 1

Class	Wire mark	*Wire Type	Chemical component of wire (mass% with respect to total mass of wire)										
			C	Si	Mn	Ni	B	Cr	Al	TiO ₂	SiO ₂	ZrO ₂	Al ₂ O ₃
Example of present invention	A1	SF	0.04	0.50	2.1	1.0	0.008	0.01	0.008	5.0	0.3	0.5	0.3
	A2	SF	0.05	0.44	2.0	1.5	0.005	0.02	0.010	5.3	0.2	0.4	0.2
	A3	SF	0.05	0.41	3.0	1.4	0.001	0.05	0.007	4.4	0.4	0.2	0.2
	A4	SF	0.07	0.38	2.7	1.9	0.006	0.01	0.005	4.2	0.2	0.9	0.1
	A5	SF	0.06	0.36	1.0	2.5	0.008	0.03	0.020	3.7	0.1	0.3	0.3
	A6	SF	0.08	0.25	1.4	2.3	0.014	0.01	0.010	2.5	0.3	0.6	0.2
	A7	SF	0.10	0.34	2.6	2.5	0.011	0.04	0.010	7.5	0.2	0.4	0.2
	A8	C	0.03	0.57	2.4	3.0	0.004	0.01	0.030	4.2	0.5	0.3	0.4
	A9	C	0.04	0.70	2.5	3.5	0.005	0.02	0.050	5.3	0.3	0.2	0.3
	A10	C	0.06	0.35	1.8	2.7	0.006	0.01	0.008	5.1	0.4	0.5	0.1
	A11	SF	0.05	0.51	1.9	1.8	0.005	0.02	0.005	6.2	0.3	0.4	0.3
	A12	SF	0.05	0.64	2.2	2.1	0.007	0.01	0.006	7.1	0.2	0.7	0.2
Comparative Example	B1	SF	0.02	0.36	1.4	1.3	0.002	0.02	0.010	5.4	0.3	0.3	0.3
	B2	SF	0.11	0.39	2.4	1.5	0.007	0.01	0.040	7.8	0.4	0.5	0.4
	B3	SF	0.04	0.23	2.2	2.1	0.005	0.02	0.010	4.2	0.04	0.4	0.1
	B4	SF	0.05	0.76	2.7	1.8	0.006	0.01	0.007	3.6	0.5	0.1	0.2
	B5	SF	0.04	0.36	0.9	2.5	0.008	0.03	0.008	2.7	0.6	0.2	0.3
	B6	SF	0.06	0.25	3.2	2.3	0.011	0.01	0.007	4.0	0.4	0.6	0.02
	B7	SF	0.07	0.34	2.6	0.8	0.010	0.04	0.007	3.2	0.5	0.4	0.3
	B8	C	0.05	0.57	2.4	3.8	0.004	0.01	0.030	4.8	0.2	0.7	0.5
	B9	C	0.05	0.70	2.5	3.5	—	0.02	0.020	5.0	0.1	0.3	0.3
	B10	SF	0.06	0.35	1.8	2.7	0.019	0.01	0.006	7.0	0.3	1.1	0.2
	B11	SF	0.04	0.50	2.1	1.2	0.004	0.06	0.008	7.2	0.5	0.2	0.3
	B12	SF	0.06	0.44	2.0	1.5	0.005	0.03	0.060	5.2	0.4	0.8	0.1
	B13	SF	0.07	0.29	3.0	2.0	0.001	0.04	0.010	7.9	0.3	0.4	0.2
	B14	C	0.03	0.53	2.7	2.0	0.006	0.01	0.005	5.0	0.2	0.5	0.1
	B15	C	0.06	0.42	1.0	2.5	0.008	0.03	0.020	3.3	0.05	0.2	0.3
	B16	SF	0.07	0.28	2.2	2.3	0.007	0.03	0.009	2.3	0.1	0.4	0.4

*Wire Type: SF means seamless, and C means seamed

[0044]

Table 2

Class	Wire mark	Chemical component of wire (mass% with respect to total mass of wire)								Total amount of hydrogen (ppm)
		Mo	Nb	V	Ti	Mg	Ca	**REM	****others	
Example of present invention	A1	0.3	—	0.02	0.1	0.1	—	—	remainder	10
	A2	0.4	0.01	0.01	—	0.2	0.01	0.01	remainder	11
	A3	0.1	0.02	—	—	—	—	—	remainder	8
	A4	0	—	—	—	—	—	—	remainder	5
	A5	0	—	—	—	0.5	—	—	remainder	9
	A6	0	—	—	—	—	—	—	remainder	6
	A7	0	—	—	—	—	—	—	remainder	12
	A8	0	—	0.05	0.2	—	0.10	—	remainder	13
	A9	0	0.05	—	—	—	—	—	remainder	12
	A10	0	—	—	—	—	—	—	remainder	15
	A11	0.5	0.02	—	0.2	0.3	—	0.05	remainder	7
	A12	0	—	—	—	—	—	—	remainder	9
Comparative Example	B1	0.2	0.01	—	1.2	—	0.02	—	remainder	9
	B2	0	—	—	—	—	—	—	remainder	10
	B3	0	—	—	—	—	—	—	remainder	15
	B4	0	—	—	—	—	—	0.02	remainder	13
	B5	0.3	—	—	—	—	—	—	remainder	8
	B6	0	—	—	—	—	—	—	remainder	7
	B7	0	—	0.04	—	—	—	0.60	remainder	9
	B8	0	—	—	—	—	—	—	remainder	13
	B9	0.1	0.01	0.02	—	0.3	—	—	remainder	22
	B10	0	—	—	—	0.1	0.01	—	remainder	11
	B11	0.2	—	—	—	—	0.60	—	remainder	8
	B12	0	—	—	—	—	—	—	remainder	16
	B13	0	—	—	—	1.0	—	—	remainder	9
	B14	0	0.06	0.01	—	0.1	—	0.1	remainder	18
	B15	0.4	0.02	0.07	—	0.2	0.10	—	remainder	12
	B16	1.2	—	0.02	—	—	—	—	remainder	10

** CeF₃ was used as REM.

***Others are Fe in envelope, Fe component in iron powder and iron alloy, arc stabilizer (Na₂O, K₂O), and unavoidable impurities.

[0045]

Using the experimentally produced wires, the total amount of hydrogen was measured by the hydrogen analyzer: EMGA-621 manufactured by HORIBA, Ltd., and thereafter an evaluation of welding workability and a deposited metal test were executed, based on vertical upward fillet welding using steel plates prescribed in JIS G3128 SHY685. Further, those steel plates, which were excellent in welding workability in vertical upward fillet welding, were subjected to a cracking test. These welding conditions are collectively listed in Table 3.

[0046]

Table 3

Test item	Plate thickness (mm)	Groove shape	Welding current (A)	Arc Voltage (V)	Welding speed (cm/min)	Preheating/interpass temperature (deg.C)	Shield gas flow rate
Welding workability test	12.7	T-joint	210	22	about 10	Preheating: 100	80%Ar- 20%CO ₂ 25 liter/min
Deposited metal test	20	Gap: 12mm 45deg. Groove	270	28	25	Preheating: 100 Interpass: 150	
Cracking test	40	Single side 20deg. U-groove	240	25	24	75	

[0047]

The vertical upward fillet welding was performed by semi-automatic welding, and investigations were conducted for metal sagging, spatter generation state, slag removability, and bead shape, followed by investigation of presence/absence of slag inclusion defects by collecting five macroscopic cross-sections.

[0048]

In the deposited metal test, a tensile test specimen (JIS Z3111 No.A1) and a impact test specimen (JIS Z3111

No.4) were collected from a central portion of each deposited metal in its thickness direction, and subjected to the tests respectively. Mechanical properties were evaluated to be acceptable, for 0.2% proof stresses of 690MPa or more, and for absorbed energies of 47J or more at the test temperature of -40°C.

[0049]

The cracking test was performed in conformity to an U-groove weld cracking test method (JIS Z3257). Further, the specimen passed over 48 hours after welding was investigated for presence/absence of surface crack and cross-section cracks (five cross sections), by a penetrant testing (JIS Z2343). The results thereof are collectively listed in Table 4.

[0050]

Table 4

Class	Wire mark	Welding performance test result					Deposited metal test result		Cracking test result	Overall evaluation
		Metal sagging	Amount of caused spatter	Slag removability	Bead shape	Slag inclusion defect	0.2% proof stress (MPa)	vE-40 (J)	cracking	
Example of present invention	A1	none	less	good	good	no defect	735	71	none	good
	A2	none	less	good	good	no defect	744	84	none	good
	A3	none	less	good	good	no defect	732	55	none	good
	A4	none	less	good	good	no defect	745	62	none	good
	A5	none	less	good	good	no defect	715	75	none	good
	A6	none	less	good	good	no defect	726	51	none	good
	A7	none	less	good	good	no defect	760	63	none	good
	A8	none	less	good	good	no defect	751	76	none	good
	A9	none	less	good	good	no defect	750	66	none	good
	A10	none	less	good	good	no defect	725	54	none	good
	A11	none	less	good	good	no defect	745	81	none	good
	A12	none	less	good	good	no defect	742	60	none	good
Comparative Example	B1	none	much	good	good	no defect	670	104	-	bad
	B2	none	less	good	good	defect	790	20	-	bad
	B3	none	less	bad	bad	no defect	688	37	-	bad
	B4	yes	less	good	good	defect	775	19	-	bad
	B5	none	less	bad	bad	no defect	699	40	-	bad
	B6	yes	less	good	good	defect	777	26	-	bad
	B7	none	much	good	good	no defect	696	17	-	bad
	B8	none	less	good	bad	defect	762	26	-	bad
	B9	none	less	good	good	no defect	708	25	yes	bad
	B10	none	less	good	bad	defect	754	24	-	bad
	B11	none	much	good	good	no defect	713	36	-	bad
	B12	none	less	good	good	no defect	726	32	yes	bad
	B13	none	much	good	good	defect	784	44	-	bad
	B14	none	less	good	good	no defect	759	28	yes	bad
	B15	none	less	bad	bad	no defect	795	16	-	bad
	B16	yes	less	good	good	no defect	799	24	-	bad

[0051]

In Table 1, Table 2, and Table 4, wires marks A1 to A12 are the Embodiments of the present invention respectively, and wires marks B1 to B16 are Comparative Examples respectively.

[0052]

The wires as Examples of the present invention designated by wire A1 to A12 respectively, were appropriate in amounts of C, Si, Mn, Ni, B, Cr, Al, TiO₂, SiO₂, ZrO₂, and Al₂O₃ and in total amount of hydrogen, and were also

appropriate in amounts of one or more of Mo, Nb, and V, and in amount of one or more of Ti, Mg, Ca, and REM, so that these wires were excellent in welding workability and allowed for obtainment of excellent values for proof stresses and absorbed energies of the deposited metals, without occurrence of cold cracks, thereby providing extremely satisfactory results.

[0053]

The wire B1 in Comparative Example was much in Ti, and thus an amount of spatter was large. Further, this wire was less in C, and thus had a lower value of 0.2% proof stress.

[0054]

The wire B2 was much in TiO_2 , and thus occurred of slag inclusion defects. Further, this wire was much in C, and thus had a higher value of 0.2% proof stress and a lower value of absorbed energy.

[0055]

The wire B3 was less in SiO_2 , and was defective in slag removability and bead shape. Further, this wire was less in Si, and thus had a lower value of absorbed energy.

[0056]

The wire B4 was less in ZrO_2 , and thus occurred of metal sagging. Further, this wire was much in Si, and thus occurred of slag inclusion defect and also had a lower value of absorbed energy.

[0057]

The wire B5 was much in SiO_2 , and was defective in slag removability and bead shape. Further, this wire was less in Mn, and thus had a lower value of absorbed energy.

[0058]

The wire B6 was less in Al_2O_3 , and thus occurred of metal sagging. Further, this wire was much in Mn, and thus occurred of slag inclusion defects and had a higher value of 0.2% proof stress and a lower value of absorbed energy.

[0059]

The wire B7 was much in REM, and thus resulted in an increased amount of caused spatter. Further, this wire was less in Ni, and thus had a lower value of absorbed energy.

[0060]

The wire B8 was much in Al_2O_3 , and thus was defective in bead shape and occurred of slag inclusion defects. Further, this wire was much in Ni, and thus had a higher value of 0.2% proof stress and a lower value of absorbed energy.

[0061]

The wire B9 was less in B, and thus had a lower value of absorbed energy. Further, this wire was much in total amount of hydrogen, and thus occurred of cracking.

[0062]

The wire B10 was much in ZrO_2 , and thus was defective in bead shape and occurred of slag inclusion defect. Further, this wire was much in B, and thus had a higher value of 0.2% proof stress and a lower value of absorbed

energy.

[0063]

The wire B11 was much in Ca, and thus resulted in an increased amount of caused spatter. Further, this wire was much in Cr, and thus had a lower value of absorbed energy.

[0064]

The wire B12 was much in Al, and thus had a lower value of absorbed energy. Further, this wire was much in total amount of hydrogen, and thus occurred of cracking.

[0065]

The wire B13 was much in Mg, and thus resulted in an increased amount of caused spatter. Further, this wire was much in TiO_2 , and thus occurred of a slag inclusion defects and also had a lower value of absorbed energy.

[0066]

The wire B14 was much in Nb, and thus had a higher value of 0.2% proof stress and a lower value of absorbed energy. Further, this wire was much in total amount of hydrogen, and thus occurred of cracking.

[0067]

The wire B15 was less in SiO_2 , and was thus defective in slag removability and bead shape. Further, this wire was much in V, and thus had a higher value of 0.2% proof stress and a lower value of absorbed energy.

[0068]

The wire B16 was less in TiO_2 , and thus occurred of metal sagging. Further, this wire was much in Mo, and thus

had a higher value of 0.2% proof stress and a lower value of absorbed energy.

CLAIMS

1. A flux cored wire for gas shielded arc welding of high-strength steel comprising a steel sheath, and a flux filled therein, wherein the flux cored wire comprises, by mass% with respect to the total mass of the flux cored wire:

C: 0.03 to 0.10%,

Si: 0.25 to 0.7%,

Mn: 1.0 to 3.0%,

Ni: 1.0 to 3.5%,

B: 0.001 to 0.015%,

Cr: limited to 0.05% or less, and

Al: limited to 0.05% or less, and

in the flux,

TiO₂: 2.5 to 7.5%,

SiO₂: 0.1 to 0.5%,

ZrO₂: 0.2 to 0.9%, and

Al₂O₃: 0.1 to 0.4%; and

the remainder comprising: Fe, arc stabilizer, and unavoidable impurities; and

wherein the total amount of hydrogen in the flux cored wire is in 15ppm or less.

2. The flux cored wire for gas shielded arc welding of high-strength steel as set forth in claim 1, wherein the flux cored wire further contains, by mass% relative to the total mass of the flux cored wire, one or more of:

Mo: 0.1 to 1.0%,

Nb: 0.01 to 0.05%, and

V: 0.01 to 0.05%.

3. The flux cored wire for gas shielded arc welding of high-strength steel as set forth in claim 1 or 2, wherein the flux cored wire further contains, by mass% relative to the total mass of the flux cored wire, one or more of:

Ti: 0.1 to 1.0%;

Mg: 0.01 to 0.9%;

Ca: 0.01 to 0.5%; and

REM: 0.01 to 0.5%.