

SPECIFICATION

FLUX-CORED WIRE FOR GAS-SHIELDED ARC WELDING

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a flux-cored wire, for gas-shielded arc welding, formed by packing a hollow steel wire with a flux of a TiO_2 (titania) group containing TiO_2 as a principal component. More particularly, the present invention relates to a flux-cored wire, for gas-shielded arc welding, capable of improving welding performance and of producing a satisfactorily tough weld metal and optimum for welding workpieces of high-tensile steels.

Description of the Related Art

Ships and offshore structures are built by welding together materials of high-tensile steels. It has been desired to develop welding materials capable of producing weld metals having satisfactory toughness, particularly, low-temperature toughness, and high strength to build those structures.

Welding materials excellent in low-temperature toughness have been developed for the field of shielded arc welding and submerged arc welding. However, those welding materials have problems in working efficiency and welding position.

Gas-shielded arc welding using a flux-cored wire can form a bead of a satisfactory appearance and can improve welding performance. A flux-cored wire formed by packing a hollow steel wire with a flux of a titania group containing titania (TiO_2) as a principal component (hereinafter, referred to as "titania-flux-cored wire") is used prevalently for gas-shielded arc welding.

When the titania-flux-cored wire is applied to gas-shielded arc welding, a weld metal having a high concentration in the range of 500 to 600 ppm is liable to be produced. Such a weld metal often has low low-temperature toughness.

Various welding materials for flux-cored wires have been developed to achieve both producing a weld metal having satisfactory mechanical properties, particularly, low-temperature toughness, and improving welding performance.

A technique proposed in JP-AH3-47695 capable of improving welding performance and of producing a weld metal having satisfactory mechanical properties, such as a tensile strength TS of about 790 MPa or above and a Charpy impact value vE_{-30} at -30°C of about 100 J or above, by using a titania flux containing TiO_2 and MnO as principal components such that the ratio: TiO_2/MnO is 1.7 or above, and alloying elements including Co, Cr, C, Mn, Ni and Mo in proper content ranges.

A technique proposed in JP-A H3-294093 improves welding performance and produces a weld metal having satisfactory mechanical properties including a tensile strength TS of about 830 MPa or above and a Charpy impact value vE_{-40} at -40°C of about 108 J or above by using a flux-cored wire, for gas-shielded arc welding, containing TiO_2 , MgO, a metal fluoride and alloying elements including Si, Mn, Mg, Ni, Cu and Mo in proper content ranges.

A technique proposed in JP-A 2003-154487 improves welding performance and produces a weld metal having mechanical properties meeting the KS (Korean National Standards) and standards specified by the AWS (American Welding Society).

A technique proposed in JP-A 2002-307189 achieves reducing residual stress in a weld metal and improving the fatigue strength of the weld metal by using a titania-flux-cored wire having a flux

containing SiO_2 and Al_2O_3 for welding materials of a steel having a tensile strength TS on the order of 490 MPa.

A technique proposed in JP-A H7-314182 improves welding performance and produces a weld metal having satisfactory mechanical properties including a high tensile strength of about 580 MPa or above and a Charpy impact value vE_0 at 0°C of about 150 J or above by using a titania-flux-cored wire having a flux containing TiO_2 , at least either of MgO and FeO , SiO_2 and MnO .

Those previously proposed techniques made possible building welded structured including weld metals having comparatively high toughness. The present circumstances desire flux-cored wires capable of producing a weld metal having still higher strength and still higher toughness. It is desired to produce a weld metal having a 0.2% proof stress ($\sigma_{0.2}$) of 620 MPa or above and a Charpy impact value vE_{-60} at -60°C of 50 J or above in view of strength balance between the weld metal and high-tensile steels used as base metals, namely, metals to be welded. However, the previously proposed techniques cannot provide flux-cored wires for gas-shielded arc welding capable of producing such high-strength, high-toughness weld metals.

SUMMARY OF THE INVENTION

The present invention has been made under such circumstances and it is therefore an object of the present invention to provide a flux-cored wire, for gas-shielded arc welding, capable of producing a weld metal having a 0.2% proof stress ($\sigma_{0.2}$) of 620 MPa or above and a Charpy impact value vE_{-60} at -60°C of 50 J or above and optimum for welding welding materials of high-tensile steels.

The present invention provides a flux-cored wire, for gas-shielded arc welding, formed by packing a hollow steel wire with

a flux containing a flux of a TiO_2 group as a principal component, and containing 0.02 to 0.15% by mass (hereinafter, referred to simply as "%") C, 0.3 to 1.4% Si, 1.2 to 3.5% Mn, 0.2 to 3.4% Ni, 0.02 to 2.0% Cr, 2.0 to 6.0% Ti, 0.1 to 2.2% Mo and 0.01 to 1.0% Mg, wherein a TiO_2 content and a MgO content of the flux meet Expression (1):

$$(\text{TiO}_2)/(\text{MgO}) \geq 4.7 \quad \text{..... (1)}$$

where (TiO_2) and (MgO) are the TiO_2 content and the MgO content of the flux-cored wire corresponding to the respective ratios in mass of TiO_2 and MgO contained in the flux to the flux-cored wire.

Preferably, in the flux-cored wire of the present invention for gas-shielded arc welding, the TiO_2 content of the flux is between 4.5 and 6.1% and the MgO content of the flux is between 0.2 and 1.5%. Preferably, the flux-cored wire has a flux packing factor in the range of about 10 to about 30%.

The flux-cored wire of the present invention has a properly adjusted chemical composition and the proper $(\text{TiO}_2)/(\text{MgO})$ ratio. The flux-cored wire of the present invention can reduce inclusions (oxides) contained in a weld metal by reducing the amount of oxygen transferred to the weld metal and can produce a weld metal having a remarkably improved toughness and containing a deposited metal having satisfactory properties as a principal component.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The inventors of the present invention made earnest studies to solve the problems and found that the activity of TiO_2 to oxygen can be lowered by properly adjusting the overall chemical composition of a flux-cored wire and adding a predetermined amount of MgO to the flux of the flux-cored wire. The inventors found also that the oxygen concentration of a deposited metal can be reduced and inclusions

(oxides) contained in the deposited metal can be reduced even if the Ti content of the flux-cored wire is increased and thus a weld metal having a remarkably improved toughness and containing the deposited metal having satisfactory properties as a principal component can be produced. The present invention has been made on the basis of those findings.

It is an important condition to properly determine the basic element contents, such as the C, the Si, the Mn, the Ni, the Cr, the Ti and the Mg content, of a flux-cored wire of the present invention for gas-shielded arc welding. Reasons for specifying ranges for the basic element contents will be described below. The basic element contents of the flux-cored wire affect the properties of a deposited metal. Each of those basic elements is contained in the flux-cored wire in different states, such as a metal and an oxide. For example, Ti and Mg are contained in oxides in the flux-cored wire. The following contents are the ratios of the basic elements including those contained in oxides in the flux-cored wire to the mass of the flux-cored wire.

C Content: 0.02 to 0.15%

Carbon (C) is an important element affecting the strength of a weld metal, namely, a metal produced through the fusion of a deposited metal and part of a base metal. To produce a weld metal having a 0.2% proof stress ($\sigma_{0.2}$) of 620 MPa or above, the C content needs to be 0.02% or above. If the C content of the weld metal is excessively high, the weld metal has an excessively high strength and high low-temperature cracking susceptibility. The C content needs to be 0.15% or below. A preferable C content is in the range of 0.04 to 0.08%.

Si Content: 0.3 to 1.4%

Silicon (Si) serves as a deoxidizer and is an element effective in ensuring a weld metal a necessary strength and reducing the oxygen

content of the weld metal. The Si content needs to be 0.3% or above. If the Si content is excessively high and exceeds 1.4%, the viscosity of a deposited metal increases and welding performance is deteriorated. A preferable Si content is in the range of 0.4 to 0.9%.

Mn Content: 1.2 to 3.5%

Manganese (Mn) is an element effective in ensuring a weld metal a necessary strength and reducing oxygen. Deoxidation is insufficient and a weld metal having necessary strength and toughness cannot be produce if the Mn content is below 1.2%. If the Mn content is excessively high and exceeds 3.5%, the weld metal has an excessively high strength and high low-temperature cracking susceptibility. A preferable Mn content is in the range of 1.7 to 2.9%.

Ni Content: 0.2 to 3.4%

Nickel (Ni) is an important element for ensuring a weld metal necessary strength and toughness. A Ni content below 0.2% cannot satisfactorily improve toughness. A Ni content above 3.4% enhances the high-temperature cracking susceptibility of the weld metal. A preferable Ni content is in the range of 1.7 to 2.4%.

Cr Content: 0.02 to 2.0%

Chromium (Cr) is an element useful for stably ensuring a weld metal sufficient strength. The strength of a weld metal is insufficient when the Cr content is below 0.02%. The strength of the weld metal is excessively high and the toughness of the same is not satisfactory when the Cr content is above 2.0. A preferable Cr content is in the range of 0.1 to 0.5%.

Ti Content: 2.0 to 6.0%

Titanium (Ti) is an element having deoxidizing effect and effective in reducing the size of crystal grains. The Ti content needs to be 2.0% or above to make the effects of Ti effective. An excessively

high Ti content makes a weld metal excessively strong, increases slag and deteriorates welding performance. A preferable Ti content is in the range of 3.3% to 4.0%.

Mo Content: 0.1 to 2.2%

Molybdenum (Mo) is an important element ensuring a weld metal necessary strength. The strength of a weld metal is insufficient when the Mo content is below 0.1%. The hardness of a weld metal is very high and the toughness of the same is low when the Mo content is above 2.2%. A preferable Mo content is in the range of 0.2 to 1.0%.

Mg Content: 0.01 to 1.0%

Magnesium (Mg) has deoxidizing effect. The deoxidizing effect of Mg is insufficient and the weld metal has low toughness when the Mg content is below 0.01%. A large amount of fume is produced during welding and welding performance is deteriorated when the Mg content is as high as above 1.0%. A preferable Mg content is in the range of 0.1 to 0.8%.

It is also important for the flux-cored wire of the present invention to meet Expression (1).

$$(TiO_2)/(MgO) \geq 4.7 \quad \dots\dots\dots (1)$$

where (TiO_2) and (MgO) are the TiO_2 content and the MgO content of the flux-cored wire corresponding to the respective ratios in mass of TiO_2 and MgO contained in the flux to the flux-cored wire.

The oxygen concentration of a deposited metal can be reduced by adding MgO to the flux of the flux-cored wire to lower the activity of TiO_2 . Thus inclusions (oxide inclusions) contained in a weld metal is reduced to obtain a weld metal having satisfactorily high low-temperature toughness of a Charpy impact value vE_{60} at $60^\circ C$ of 50 J or above.

The higher the MgO content, the higher the oxygen concentration

reducing effect of MgO. However, welding performance deteriorates with the increase of the oxygen concentration reducing effect. According to the present invention, the condition: $(\text{TiO}_2)/(\text{MgO}) \geq 4.7$ needs to be satisfied at least from the view point of improving welding performance. Although welding performance is satisfactory, the oxygen reducing effect is low and the toughness of the weld metal is low when the $(\text{TiO}_2)/(\text{MgO})$ ratio is low. Therefore, a preferable $(\text{TiO}_2)/(\text{MgO})$ ratio is in the range of about 8.0 to about 16.9.

The flux of the flux-cored wire of the present invention contains at least TiO_2 as a principal component in a TiO_2 content in proper TiO_2 content range. It is difficult for the flux-cored wire to exhibit its effect, principally, welding performance improving effect, when the TiO_2 content is low. The oxygen concentration of the deposited metal and hence the oxygen content of the weld metal tends to increase when the TiO_2 content increases. A preferable TiO_2 content, namely, the ratio in mass of TiO_2 to the flux-cored wire, is in the range of about 4.5 to about 6.1%. A preferable MgO content is in the range of about 0.2 to about 1.5% because the condition: $(\text{TiO}_2)/(\text{MgO}) \geq 4.7$ needs to be satisfied.

The flux-cored wire of the present invention can achieve the object of the invention when the flux-cored wire contains those elements in contents in the specified content ranges and the condition: $(\text{TiO}_2)/(\text{MgO}) \geq 4.7$ is satisfied. The flux-cored wire may contain oxides, such as Al_2O_3 , SiO_2 and ZrO_2 , as slag-making agents and arc stabilizing agents, other than TiO_2 and MgO.

A hollow steel wire is packed with the flux of the foregoing composition to form a flux-cored wire. It is preferable that the flux-cored wire has a flux packing factor in a proper range. A proper flux packing factor is in the range of about 10 to about 30%. It is

difficult to provide the necessary alloying elements only by the flux and the hollow steel wire needs to contain those alloying elements when the flux packing factor is below 10%. The hollow steel tube containing those alloying elements increases the material cost. A hollow steel wire containing those alloying elements has high strength and low drawability. The wall thickness of the hollow steel wire is small, the hollow steel wire is easily broken and the hollow steel wire has low drawability when the flux packing factor is above 30%. A preferable flux packing factor is in the range of about 12 to about 20%.

The flux packing factor is defined by the following expression.

Flux packing factor (percent by mass) = { (Mass of the flux) / (Mass of the flux cored wire) } × 100

The element content of the flux-cored wire of the present invention is dependent basically on the amount of metals contained in the form of oxides in the flux, and the amount of the metals contained in the hollow steel wire. There are limits to the respective amounts of oxides that can be contained in the flux and to the flux packing factor, and restrictions on the amounts of elements that can be contained in the hollow steel wire. Therefore, in some cases, it is difficult to adjust the element contents of the flux-cored wire only through the adjustment of the amounts of the metals contained in the form of oxides in the flux and the metal contents of the hollow steel wire. Sometimes, it is difficult to adjust the Ti content in particular of the flux-cored wire of the present invention only through the adjustment of the Ti content of the oxides and the Ti content of the hollow steel wire. In such a case, Ti powder is added to the flux to adjust the Ti content of the flux-cored wire.

Examples

The present invention will be concretely described in terms of

examples of the present invention.

Example 1

A flux containing oxides including TiO_2 , MgO , Al_2O_3 , SiO_2 and ZrO was packed in a hollow steel wire while the hollow steel wire is being formed by winding a soft steel hoop (which includes C: 0.05% by mass, Si: 0.05% by mass, Mn: 0.50% by mass, Ti: 0.02% by mass and other elements: Fe, unavoidable impurities) of HT80 grade, the hollow steel wire packed with the flux was processed by a drawing process to obtain a 1.2 mm diameter flux-cored wire having a flux packing factor of 13.5%. Various flux-cored wires of the foregoing basic construction having different element contents were made by adjusting the chemical composition of the steel hoop and adding metal powder to the flux. Chemical compositions of those flux-cored wires are shown in Table 1, and oxide contents of the flux-cored wires, namely, the respective ratios in mass of oxides contained in the flux to the flux-cored wire, are shown in Table 2.

Table 1

Test No.	Chemical composition of flux-cored wires (percent by mass)							
	C	Si	Mn	Ni	Cr	Mo	Ti	Mg
1	0.07	0.4	2.3	2.4	0.1	0.2	3.3	0.5
2	0.08	0.6	2.9	2.7	0.5	1.2	3.6	0.5
3	0.08	0.9	1.7	2.7	0.4	0.2	3.6	0.5
4	0.02	0.5	2.1	1.7	0.2	0.3	4.0	0.5
5	0.04	0.5	2.1	1.7	0.02	0.3	4.0	0.5
6	0.01	0.4	2.1	1.9	0.2	0.9	3.3	0.5
7	0.16	0.4	2.3	2.4	0.2	0.4	3.3	0.5
8	0.07	0.2	2.1	1.7	0.1	0.1	1.8	0.5
9	0.07	1.5	2.3	2.4	0.2	0.4	3.3	0.5
10	0.09	0.7	1.1	1.0	0.3	0.5	3.3	0.5
11	0.08	0.7	3.6	1.5	0.6	0.5	4.9	0.5
12	0.09	0.7	2.2	0.1	0.3	0.6	4.0	0.5
13	0.04	0.4	2.4	3.5	0.3	0.8	3.3	0.5
14	0.05	0.8	2.1	1.2	0.01	0.2	3.3	0.5
15	0.02	0.4	2.3	2.0	2.2	0.3	3.2	0.5
16	0.08	0.4	2.3	2.1	0.3	0	3.3	0.5
17	0.06	0.4	1.6	1.9	0.1	2.5	3.5	0.5
18	0.03	0.4	2.4	1.0	0.2	1.2	1.7	0.5
19	0.05	0.4	2.1	1.9	0.2	0.9	6.3	0.5
20	0.07	0.4	2.3	2.3	0.2	0.2	3.3	0.005
21	0.07	0.5	2.2	2.4	0.1	0.2	3.6	1.1

* Other elements: Fe, elements originating from the flux and unavoidable impurities

Table 2

Test No.	Oxide contents of the flux (percent by mass)					[TiO ₂]/[MgO]	Flux packing factor (percent by mass)
	TiO ₂	MgO	Al ₂ O ₃	SiO ₂	ZrO ₂		
1	4.51	0.50	0.05	0.30	0.04	9.0	13.5
2	4.51	0.50	0.05	0.30	0.04	9.0	13.5
3	4.51	0.50	0.05	0.30	0.04	9.0	13.5
4	4.51	0.50	0.05	0.30	0.04	9.0	13.5
5	4.51	0.50	0.05	0.30	0.04	9.0	13.5
6	4.51	0.50	0.05	0.30	0.04	9.0	13.5
7	4.51	0.50	0.05	0.30	0.04	9.0	13.5
8	4.51	0.50	0.05	0.30	0.04	9.0	13.5
9	4.51	0.50	0.05	0.30	0.04	9.0	13.5
10	4.51	0.50	0.05	0.30	0.04	9.0	13.5
11	4.51	0.50	0.05	0.30	0.04	9.0	13.5
12	4.51	0.50	0.05	0.30	0.04	9.0	13.5
13	4.51	0.50	0.05	0.30	0.04	9.0	13.5
14	4.51	0.50	0.05	0.30	0.04	9.0	13.5
15	4.51	0.50	0.05	0.30	0.04	9.0	13.5
16	4.51	0.50	0.05	0.30	0.04	9.0	13.5
17	4.51	0.50	0.05	0.30	0.04	9.0	13.5
18	4.51	0.50	0.05	0.30	0.04	9.0	13.5
19	4.51	0.50	0.05	0.30	0.04	9.0	13.5
20	4.51	0.50	0.05	0.30	0.04	9.0	13.5
21	4.51	0.50	0.05	0.30	0.04	9.0	13.5

Welding experiments were conducted using the flux-cored wires under the following welding conditions to deposit deposited metals. Test specimens (Z3111, A1, JIS) for tensile test and specimens (Z3111, A4, JIS) for Charpy impact test were sampled from the deposited metals. The test specimens were tested to determine values of 0.2% proof stress ($\sigma_{0.2}$) and those of V Charpy impact values vE_{60} at -60°C of the deposited metals.

Welding Conditions

Welding position: Flat position

Shielding gas: 80% Ar and 20% CO₂

Welding current: 280 A

Welding voltage: 31 V

Welding speed: 300 mm/min

Preheating and interpass temperature: 150°C

Heat input: 1.7 kJ/mm

Base metal: 20 mm thick plate, SHY865 (G3128 JIS)

Groove: V groove of 45° groove angle

Welding experiments were conducted under the following welding conditions in a vertical up welding mode to evaluate welding performance. Welding performance was evaluated to be good (marked with a blank circle) when vertical up welding was possible and a weld metal had a smooth surface. Welding performance was graded fair (marked with a blank triangle) when vertical up welding was possible and a weld metal had considerable irregularities. Welding performance was evaluated to be bad (marked with a cross) when slag and globules dripped down and vertical up welding could not be achieved.

Welding Conditions for Welding Performance Rating

Welding position: Vertical up position

Shielding gas: 80% Ar and 20% CO₂

Welding current: 220A

Welding voltage 22 to 24 V

Welding speed: 14 cm/min

Groove: V groove of 90° groove angle

Weaving width: 7 mm

Measured values of $\sigma_{0.2}$, vE₋₆₀ and welding performance are shown in Table 3. Values of $\sigma_{0.2} \geq 620$ MPa and those of vE₋₆₀ ≥ 50 J were evaluated to be acceptable. Shown also in Table 3 are values of oxygen concentration of deposited metals determined by an inert gas fusion method.

Table 3

Test No.	$\sigma_{0.2}$	vE ₅₀	Oxygen concentration of deposited metal (percent by mass)	Welding performance	Remarks
1	708	61	0.046	○	Sufficient low-temperature toughness and good welding performance
2	729	51	0.045	○	Sufficient low-temperature toughness and good welding performance
3	691	58	0.044	○	Sufficient low-temperature toughness and good welding performance
4	625	54	0.044	○	Sufficient low-temperature toughness and good welding performance
5	633	57	0.044	○	Sufficient low-temperature toughness and good welding performance
6	541	52	0.049	○	Insufficient strength
7	922	47	0.045	○	Excessively high strength and low-temperature cracking
8	475	22	0.063	○	Insufficient strength and insufficient toughness
9	825	53	0.050	△	Bad welding performance
10	561	38	0.052	○	Insufficient strength and insufficient toughness
11	911	18	0.055	○	Excessively high strength and low-temperature cracking
12	707	27	0.057	○	Insufficient toughness
13	764	53	0.050	○	High-temperature cracking
14	605	51	0.055	○	Insufficient strength
15	934	36	0.053	○	Excessively high strength and insufficient toughness
16	666	50	0.050	○	Insufficient strength
17	766	32	0.053	○	Excessively high strength and insufficient toughness
18	741	26	0.045	○	Insufficient toughness
19	898	18	0.060	△	Excessively high strength and much slag
20	710	47	0.065	○	Insufficient toughness
21	726	65	0.042	△	Much welding fume

As obvious from the measured values, strength and toughness are directly opposed to each other; toughness tends to decrease with the increase of strength. The deposited metals meeting the conditions required by the present invention, namely, deposited metals of test Nos. 1 to 5, are satisfactory in both strength and toughness. Welding performance in producing those deposited metals was satisfactory.

The deposited metals not meeting some of the conditions required by the present invention, namely, deposited metals of test Nos. 6 to 21, are satisfactory in strength, and are not satisfactory in toughness and welding performance.

Flux-cored wires were fabricated by a procedure similar to that for forming the flux-cored wire in Example 1, except that the oxide contents of the fluxes were changed. Chemical compositions of the flux-cored wires are shown in Table 4, and oxide contents of the

flux-cored wires, namely, the respective ratios in mass of oxides contained in the flux to the flux-cored wire, are shown in Table 5.

Table 4

Test No.	Chemical composition of flux-cored wires (percent by mass)							
	C	Si	Mn	Ni	Cr	Mo	Ti	Mg
22	0.04	0.8	2.1	1.7	0.05	0.1	3.8	0.5
23	0.04	0.5	2.1	1.7	0.2	0.1	3.9	0.5
24	0.07	0.4	2.4	2.4	0.1	0.4	3.1	0.5
25	0.04	0.5	2.1	1.7	0.1	0.1	3.8	0.5
26	0.04	0.8	2.1	1.7	0.1	0.1	2.7	0.5
27	0.04	0.5	2.1	1.7	0.2	0.2	3.6	0.5
28	0.04	0.5	2.1	2.7	0.2	0.1	3.6	0.5
29	0.04	0.5	2.1	1.7	0.02	0.1	3.5	0.5
30	0.04	0.8	2.1	1.7	0.1	0.1	3.3	0.5
31	0.04	0.8	2.1	1.7	0.2	0.1	2.7	0.5
32	0.04	0.5	2.1	1.7	0.1	0.1	2.7	0.5
33	0.04	0.5	2.1	1.7	0.1	0.1	2.9	0.5
34	0.04	0.8	2.1	1.7	0.2	0.1	1.2	0.5
35	0.04	0.8	2.1	1.0	0.2	0.1	3.8	0.5

* Other elements: Fe, elements originating from the flux and unavoidable impurities

Table 5

Test No.	Oxide contents of the flux (percent by mass)					[TiO ₂]/[MgO]	Flux packing factor (percent by mass)
	TiO ₂	MgO	Al ₂ O ₃	SiO ₂	ZrO ₂		
22	6.38	0.11	0.04	0.31	0.06	60.6	13.5
23	6.19	0.30	0.05	0.31	0.06	20.5	13.5
24	5.14	0.30	0.22	0.17	0.06	16.9	13.5
25	6.03	0.46	0.05	0.31	0.06	13.1	13.5
26	4.51	0.50	0.05	0.29	0.04	9.0	13.5
27	5.76	0.71	0.05	0.31	0.05	8.1	13.5
28	5.78	0.71	0.05	0.31	0.05	8.1	13.5
29	5.78	1.22	0.05	0.31	0.05	4.7	13.5
30	5.50	1.00	0.05	0.30	0.05	5.5	13.5
31	4.51	2.01	0.05	0.30	0.04	2.2	13.5
32	4.51	2.01	0.05	0.30	0.04	2.2	13.5
33	4.51	2.01	0.05	0.30	0.04	2.2	13.5
34	2.00	4.50	0.05	0.28	0.02	0.4	13.5
35	6.50	0.00	0.05	0.30	0.06	-	13.5

Deposited metals were produced by carrying out welding using those flux-cored wires under the same welding conditions as those for Example 1. Measured values of $\sigma_{0.2}$, vE_{-60} and oxygen concentration were measured, and welding performance was evaluated by the same method as that of evaluating the welding performance in producing the deposited metals

in Example 1.

The measured values of $\sigma_{0.2}$ and vE_{-60} , and grades of welding performance are shown in Table 6. The deposited metals meeting $\sigma_{0.2} \geq 620$ MPa and $vE_{-60} \geq 50$ J were evaluated to be acceptable.

Table 6

Test No.	$\sigma_{0.2}$	vE_{-60}	Oxygen concentration of deposited metal (percent by mass)	Welding performance	Remarks
22	634	60	0.049	○	Sufficient low-temperature toughness and good welding performance
23	641	64	0.045	○	Sufficient low-temperature toughness and good welding performance
24	720	72	0.046	○	Sufficient low-temperature toughness and good welding performance
25	634	82	0.048	○	Sufficient low-temperature toughness and good welding performance
26	643	92	0.044	○	Sufficient low-temperature toughness and good welding performance
27	649	74	0.042	○	Sufficient low-temperature toughness and good welding performance
28	626	80	0.040	○	Sufficient low-temperature toughness and good welding performance
29	650	71	0.042	○	Sufficient low-temperature toughness and good welding performance
30	678	85	0.041	○	Sufficient low-temperature toughness and good welding performance
31	703	78	0.039	△	Irregularities found on weld metal surface
32	625	72	0.039	△	Irregularities found on weld metal surface
33	697	89	0.040	×	Vertical up welding was impossible
34	630	102	0.038	×	Vertical up welding was impossible
35	604	45	0.050	×	Vertical up welding was impossible

It is considered from those measured results that the addition of MgO to a titanium-containing flux is effective in reducing the oxygen concentration of the deposited metal. The followings can be deduced from the measured data. The oxygen concentration of the deposited metal has a tendency to decrease with the increase of the MgO content resulting in the reduction of the TiO_2/MnO ratio. The oxygen concentration is 0.044% or below (440 ppm or below) when the TiO_2/MnO ratio is 9.0 or below.

Welding performance deteriorates (Test Nos. 31 to 35) when the MgO content is excessively high, i.e., when the TiO_2/MnO ratio is excessively low. Welding performance is satisfactory when the TiO_2/MnO ratio is 4.7 or above.

Thus it can be deduced that the oxygen concentration of the

deposited metal can be reduced and a welding metal of high toughness can be produced in a satisfactory welding performance by adjusting the TiO_2/MnO ratio of the titanium-containing flux of the flux-cored wire for gas-shielded arc welding to a value in a proper range.

Although the invention has been described in its preferred embodiments with a certain degree of particularity, obviously many changes and variations are possible therein. It is therefore to be understood that the present invention may be practiced otherwise than as specifically described herein without departing from the scope and spirit thereof.

What Is Claimed Is:

1. A flux-cored wire, for gas-shielded arc welding, formed by packing a hollow steel wire with a flux containing a flux of a TiO_2 group as a principal component, and containing 0.02 to 0.15% by mass C, 0.3 to 1.4% by mass Si, 1.2 to 3.5% by mass Mn, 0.2 to 3.4% by mass Ni, 0.02 to 2.0% by mass Cr, 2.0 to 6.0% by mass Ti, 0.1 to 2.2% by mass Mo and 0.01 to 1.0% by mass Mg;

wherein a TiO_2 content and a MgO content of the flux meet Expression (1):

$$(\text{TiO}_2)/(\text{MgO}) \geq 4.7 \quad \text{..... (1)}$$

where (TiO_2) and (MgO) are a TiO_2 content and a MgO content of the flux-cored wire corresponding to the respective ratios in mass of TiO_2 and MgO contained in the flux to the flux-cored wire.

2. The flux-cored wire according to claim 1, wherein the TiO_2 content of the flux is between 4.5 and 6.1% by mass and the MgO content of the flux is between 0.2 and 1.5% by mass.

3. The flux-cored wire according to claim 1, wherein the flux-cored wire has a flux packing factor in the range of about 10 to about 30%.

4. The flux-cored wire according to claim 2, wherein the flux-cored wire has a flux packing factor in the range of about 10 to about 30%.