

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

BACKGROUND OF THE INVENTION

1. Field of the Invention:

The present invention relates to a flux-cored wire for gas-shielded arc welding of high-tensile strength steel having a proof strength greater than 620 MPa. More particularly, the present invention relates to a flux-cored wire for gas-shielded arc welding of high-tensile strength steel, said flux-cored wire providing weld metal superior in low-temperature toughness and affording welding with a minimum of cracking and good usability regardless of welding positions.

2. Description of the Related Art:

Steel structures are becoming larger than before and their weight reduction is being attempted by application of high-tensile strength steel to them. Offshore structures and pressure vessels need a steel with good low-temperature toughness and a welding material for such a steel is increasing in demand. Conventional shielded metal arc welding and submerged arc welding, which employ welding materials superior in low-temperature toughness, have problems with working efficiency, welding usability, and operating position. Consequently, there has been a great demand for

flux-cored wires that meet three requirements -- high efficiency, low-temperature toughness, and good working properties for all welding positions.

Several kinds of high-performance flux-cored wires meeting such requirements have been developed. The first example is a flux-cored wire for gas shielded metal arc welding to be applied to high-tensile strength steel with a tensile strength of 690 MPa, as disclosed in Japanese Patent Laid-open No. Hei-9-253886. It is characterized by the specific content of TiO_2 , metal fluoride, C, Si, Mn, Ni, Cr, Mo, Cu, Mg, Ti, and B (based on the total weight of the wire) and also by the ratio of Mg to metal fluoride (by weight), so that it exhibits good welding usability and ensures high-temperature strength and low-temperature toughness after a long weld heat treatment (PWHT).

The second example is a flux-cored wire for high-tensile strength steel, which contains a titania flux composed mainly of TiO_2 , MgO , and MnO , as disclosed in Japanese Patent Laid-open No. Hei-3-047695. It is characterized by the specific content of C, Mn, Ni, and Mo and also by the specific ratio of TiO_2 to MgO and the addition of Co and Cr, so that it exhibits good welding usability and ensures good toughness.

The third example is a flux-cored wire for gas shielded metal arc welding to be applied to high-tensile

strength steel with a tensile strength greater than 680 N/mm², as disclosed in Japanese Patent Laid-open No. Hei-8-174275. It is characterized by the specific content of C, Si, Mn, P, S, Ni, Cr, and Mo and also by the addition of Ta in a specific amount, so that it ensures high strength and good toughness corresponding to the strength of parent metal over a broad range of heat input and it also exhibits good working efficiency (which is due to the specific ratio of metal powder in the flux).

The fourth example is a titania-based flux-cored wire for high-tensile strength steel, as disclosed in Japanese Patent Laid-open No. Hei-3-294093. It is characterized by the addition of MgO and metal fluoride, so that it permits molten slag to separate and float easily from molten metal and gives rise to weld metal containing a less amount of oxygen and having improved low-temperature toughness.

All the conventional technologies mentioned above are intended to provide low-temperature toughness at about -30 to -40°C which is estimated by Charpy impact test at -30 to -40°C. However, such low-temperature toughness is not enough for Offshore structures which are subject to extremely low temperatures, say about -60°C.

Japanese Patent Laid-open Nos. Hei-9-253885 and Hei-8-174275 do not disclose the effect produced by the addition

of MgO to the titania-based flux. Japanese Patent Laid-open No. Hei-3-294093 does not disclose the improvement in welding usability in all welding positions. Moreover, it merely specifies the ratio of TiO_2/MgO which gives rise to poor beads in vertical upward welding. Therefore, the welding wire disclosed in it cannot be easily applied to the site welding of large-size structures which does not permit the use of a positioner to select desirable welding positions.

Japanese Patent Laid-open No. Hei-3-047695 discloses the specific ratio of TiO_2/MgO which is determined by rating the welding usability in vertical upward welding with a comparatively small current of about 150 A. The disadvantage of welding in this manner is that the flux-cored wire (FCW) does not fully produce its effect for improvement in welding efficiency. Moreover, when used with a powerful current (say, about 220 A), the flux-cored wire with the specific TiO_2/MgO ratio as disclosed often gives rise to such poor beads that it cannot afford welding.

Conventional technologies mentioned above cannot provide any flux-cored wire for high-tensile strength steel which meets requirements for low-temperature toughness, good usability in all welding positions, improved welding efficiency, and good crack resistance. Consequently, there has been a strong demand for the development of such flux-

cored wires.

OBJECT AND SUMMARY OF THE INVENTION

The present invention has been completed in view of the foregoing. It is an object of the present invention to provide a flux-cored wire for gas-shielded arc welding of high-tensile strength steel having a proof strength greater than 620 MPa. The flux-cored wire gives rise to weld metal superior in low-temperature toughness (at about -60°C) and affords efficient welding with a minimum of cracking and good usability regardless of welding positions.

A first aspect of the present invention is directed to a flux-cored wire for gas-shielded arc welding, which contains in its total weight C: 0.02 to 0.14 wt%, Si: 0.4 to 1.1 wt%, Mn: 0.8 to 3.0 wt%, Ni: 0.2 to 3.1 wt%, Ti: no more than 0.2 wt%, either or both of Cr and Mo: 0.1 to 4.0 wt% in total, TiO₂ and MgO: 5.0 to 7.2 wt% in total, any or all of alkali metal fluoride and oxide, alkaline earth metal fluoride and oxide, B, Al, and Mg: no more than 2.0 wt% in total, and N: no more than 0.0150 wt%, with the remainder being inevitable impurities and Fe.

A second aspect of the present invention is directed to a flux-cored wire for gas-shielded arc welding, which contains in its total weight C: 0.02 to 0.14 wt%, Si: 0.4 to 1.1 wt%, Mn: 0.8 to 3.0 wt%, Ni: 0.2 to 3.1 wt%, Ti: no

more than 0.2 wt%, either or both of Cr and Mo: 0.1 to 4.0 wt% in total, TiO₂ and MgO: 5.0 to 7.2 wt% in total, and N: no more than 0.0150 wt%, with the remainder being inevitable impurities and Fe, wherein the content of MgO and the content of TiO₂ satisfy the equation:

$$0.05 \leq x \leq 0.22 \text{ (where } x \text{ denotes the ratio of MgO/TiO}_2\text{)}.$$

A third aspect of the present invention is directed to a flux-cored wire for gas-shielded arc welding, which contains in its total weight C: 0.02 to 0.14 wt%, Si: 0.4 to 1.1 wt%, Mn: 0.8 to 3.0 wt%, Ni: 0.2 to 3.1 wt%, Ti: no more than 0.2 wt%, either or both of Cr and Mo: 0.1 to 4.0 wt% in total, TiO₂ and MgO: 5.0 to 7.2 wt% in total, any or all of alkali metal fluoride and oxide, alkaline earth metal fluoride and oxide, B, Al, and Mg: no more than 2.0 wt% in total, and N: no more than 0.0150 wt%, with the remainder being inevitable impurities and Fe, wherein the content of MgO and the content of TiO₂ satisfy the equation:

$$0.05 \leq x \leq 0.22 \text{ (where } x \text{ denotes the ratio of MgO/TiO}_2\text{)}.$$

The flux-cored wire according to the aspects of the present invention yields weld metal excelling in low-temperature toughness even at a low temperature of about -60°C. In addition, it affords good welding usability and efficiency regardless of welding position and gives

weld metal with good cracking resistance.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a graph showing the relation between $F(x)$ and $eV-60^{\circ}C$.

Fig. 2 is a diagram illustrating the method for rating the bead shape.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A detailed description will be given below of the embodiment of the present invention. The present inventors carried out extensive studies on alloy components and slag-forming agents useful for a flux-cored wire that gives weld metal excelling in low-temperature toughness when applied to gas-shielded arc welding of high tensile strength steel. The results of their studies indicate that the low-temperature toughness of weld metal is related with the amount of alloy components in the flux-cored wire for gas-shielded arc welding of high tensile strength steel and that there is a relation between the amount of TiO_2 and the amount of MgO for good low-temperature toughness and welding usability. Moreover, the present inventors investigated how metal components in the flux-cored wire for gas-shielded arc welding of high tensile strength steel affects the low-temperature toughness of weld metal in view of the fact

that the toughness of weld metal depends on the mutual actions of alloy components. Their investigation revealed the following.

When applied to a steel having a high tensile strength exceeding 620 MPa, the flux-cored wire for gas-shielded arc welding of high tensile strength steel gives weld metal which decreases in toughness in proportion to the amount of C, Cr, Ti, and Mo (particularly C and Ti) in the flux-cored wire.

Ti in a large amount dissolves more in weld metal and forms TiC which precipitates in the reheated part. This deteriorates the nucleus forming performance. The result is that weld metal is dominated by coarse lath-like bainite and remarkably poor in toughness. Incidentally, the reheated part is that part which is affected by heat given by the subsequent pass of weld metal (or welding pass by the subsequent electrode). In addition, C in a large amount forms M-A constituent in weld metal, thereby deteriorating toughness.

Conversely, Si, Mn, and Ni added to the wire tend to improve toughness. This is true particularly of Si and Mn. The increased content of Si and Mn decreases the amount of oxygen in weld metal, thereby ensuring good toughness.

MgO is one of basic slag-forming agents which exhibits the strongest deoxidizing action. MgO added to a titania-

based FCW as a slag-forming agent greatly decreases the concentration of oxygen in weld metal and greatly improves the low-temperature toughness of weld metal.

On the other hand, MgO added to a titania-based flux lowers the slag viscosity and melting point. This results in convex beads in all welding positions, particularly in vertical upward welding position, thereby deteriorating the welding usability. The lowered slag viscosity and melting point allow molten slag to flow down easily without solidifying. Thus the resulting slag does not prevent weld metal from sagging. That is, MgO added in a large amount causes sagging and presents difficulties in welding.

The present inventors' investigation revealed that the ratio of the amount of MgO to the amount of TiO_2 (represented by MgO/TiO_2) is related with the improvement of low-temperature toughness and the welding usability in all welding positions. MgO is the total amount of Mg metal and Mg compounds which is expressed in terms of Mg oxides. Mg metal and Mg compounds produce a remarkable effect on de-oxidation of weld metal as in the case of MgO, thereby greatly contributing to improvement in low-temperature toughness. However, when added in a large amount, they make welding impossible due to beads in poor shape and sagging. Consequently, it was found that if the amount of Mg metal and the amount of Mg compounds is expressed in

terms of MgO, then the amount of MgO can be related with the low-temperature toughness and the welding usability in all welding positions.

The MgO/TiO₂ ratio alone is not enough to rate the welding usability in all welding positions. The bead shape in vertical upward welding is related closely with the amount of slag, and hence specifying the amount of slag is a matter of importance.

In vertical upward welding, slag in an excessively small amount cannot retain molten metal and hence causes such troubles as convex beads and sagging. By contrast, slag in an excessively large amount causes the arc to be covered by molten slag. The result is poor arc stability and excess spatters.

It is concluded from the foregoing that good welding usability in all welding positions can be ensured if an adequate MgO/TiO₂ ratio (for all compounds by weight) is established and an adequate slag amount is specified. Moreover, the selection of adequate alloy components also contributes to low-temperature toughness.

With the help of findings mentioned above, the present invention solves problems involved in conventional technologies by specifying adequate alloy components in the wire and also by establishing an adequate ratio of MgO/TiO₂ (as slag-forming agent) and an adequate amount of slag.

According to the present invention, the flux-cored wire for gas-shielded arc welding of high tensile strength steel contains specific components and has specific compositions for the reasons mentioned in the following. The components are expressed in terms of weight based on the total weight of the wire. The flux-cored wire of the present invention is made up of a steel sheath and a flux filled therein. The components listed below are added to the steel sheath and/or the filled flux.

- C: 0.02 to 0.14 wt%

C is an extremely important component that ensures the strength of weld metal. With a C content less than 0.02 wt%, the flux-cored wire does not provide weld metal having a proof stress greater than 620 MPa. With a C content more than 0.14 wt%, the flux-cored wire provides weld metal having remarkably high cold cracking susceptibility due to increased strength. Therefore, the flux-cord wire according to this embodiment should contain C in an amount of 0.02 to 0.14 wt%, preferably 0.02 to 0.08 wt%.

- Si: 0.4 to 1.1 wt%

Si is a deoxidizing agent; it imparts strength to weld metal and reduces oxygen content in weld metal. With an Si content less than 0.4 wt%, the flux-cored wire provides weld metal having blow holes and poor toughness due to

insufficient deoxidation. On the other hand, with an Si content more than 1.1 wt%, the flux-cored wire provides weld metal poor in compatibility with parent material due to high viscosity, thereby deteriorating welding usability. Therefore, the flux-cord wire according to this embodiment should contain Si in an amount of 0.4 to 1.1 wt%, preferably 0.4 to 0.9 wt%.

- Mn: 0.8 to 3.0 wt%

Mn functions as a deoxidizer like Si, and it also helps improve the toughness of weld metal. With an Mn content less than 0.8 wt%, the flux-cored wire provides weld metal having many blow holes and poor toughness due to insufficient deoxidation. On the other hand, with an Mn content more than 3.0 wt%, the flux-cored wire provides weld metal having remarkably high cold cracking susceptibility due to increased strength. Therefore, the flux-cord wire according to this embodiment should contain Mn in an amount of 0.8 to 3.0 wt%, preferably 2.1 to 2.9 wt%.

- Ni: 0.2 to 3.1 wt%

Ni is an extremely important component for weld metal to have sufficient strength and toughness. The flux-cored wire according to this embodiment will give weld metal having insufficient toughness or high cold crack susceptibility if the Ni content is less than 0.2 wt% or more than

3.1 wt%, respectively. Therefore, it should contain Ni in an amount of 0.2 to 3.1 wt%, preferably 0.8 to 2.7 wt%.

- Ti: no more than 0.2 wt%

Ti makes crystal grains fine when added in a small amount; however, Ti added in an amount of more than 0.2 wt% deteriorates the nucleus forming performance because it dissolves more in weld metal and precipitates in the reheated part in the form of TiC. Thus, the weld metal is dominated by coarse lath-like bainite and becomes poor in toughness. Therefore, the flux-cored wire according to this embodiment should contain Ti in an amount less than 0.2 wt%. The weld metal will have good low-temperature toughness even though it contains no Ti so long as it contains adequate alloy components. Incidentally, Ti may be added in the form of Ti metal or Ti alloy (such as Fe-Ti).

- N: no more than 0.0150 wt%

When the N content in the flux-core wire exceeds 0.0150 wt%, the N content in the weld metal also increases, which leads to blow holes and poor toughness. Therefore the adequate N content in the wire should be no more than 0.0150 wt%.

- Cr + Mo: 0.1 to 4.0 wt%

Both Cr and Mo invariably contribute to the strength of weld metal. They also make crystal grains fine and

improve low-temperature toughness. The flux-cored wire according to this embodiment contains both or either of Cr and Mo. The total content of Cr+Mo added together or the individual content of Cr or Mo added alone should be no less than 0.1 wt% or no more than 4.0 wt%. A content less than 0.1 wt% is too small for weld metal to have sufficient strength. An excess content more than 4.0 wt% leads to weld metal which has increased strength and decreased toughness and is subject to cold cracking. Therefore, the flux-cored wire should contain Cr+Mo in an amount of 0.1 to 4.0 wt%, preferably 0.2 to 1.1 wt%.

- $\text{TiO}_2 + \text{MgO}$: 5.0 to 7.2 wt%

The flux-cored wire of the present invention should contain TiO_2 and MgO in an adequate amount. A total amount of TiO_2 and MgO less than 5.0 wt% is too small for weld metal to remain without sagging in vertical upward welding because of insufficient slag. On the other hand, TiO_2 and MgO in an amount more than 7.2 wt% cause the arc to be covered by molten slag. The result is unstable arc and excess spatters. Therefore, the adequate content of $\text{TiO}_2 + \text{MgO}$ should be 5.0 to 7.2 wt%. Incidentally, MgO is a total amount of MgO, metallic Mg, and Mg compounds in terms of oxides, and TiO_2 is an amount of TiO_2 added in the form of TiO_2 .

- Any one or more of alkali metal fluoride, alkali metal

oxide, alkaline earth metal fluoride, alkaline earth metal oxide, B, Al, and Mg: no more than 2.0 wt% in total

These components are optional and hence may or may not be contained in the flux-cored wire. The total content of these components should be no more than 2.0 wt%. The oxides and fluorides improve the arc stability and reduce spatters. B improves the toughness of weld metal. Al and Mg function as a deoxidizer. When these components are added more than 2.0 wt%, they adversely affect the present invention.

- Ratio (x) of MgO/TiO_2 : 0.05 to 0.22

The content of MgO and the content of TiO_2 in the flux-cored wire should be such that their ratio (x) = MgO/TiO_2 is not greater than 0.22. Otherwise, the flux-cored wire gives rise to weld metal liable to sagging in vertical upward welding, because MgO dominates over TiO_2 (MgO makes weld metal more liable to sagging) and the resulting slag does not effectively prevent weld metal from sagging. The result is convex beads or sagging. Flux-cored wires having a value of x smaller than 0.22 yield weld metal excelling characteristic properties because of the ratio of L/H greater than 10, where L and H stand for the leg length and the weld reinforcement height, respectively, in fillet welding (mentioned later in Examples). The value of x should preferably be smaller than 0.10 so

that the resulting weld metal has the ratio of L/H greater than 12, which is desirable for better characteristic properties. On the other hand, the ratio (x) of MgO/TiO₂ should have a lower limit of 0.05, so that the function F(x) mentioned later has an upper limit of 15. Therefore, the ratio (x) of MgO/TiO₂ should be 0.05 to 0.22. Incidentally, MgO is a total amount of MgO, metallic Mg, and Mg compounds in terms of oxides, and TiO₂ is an amount of TiO₂ added in the form of TiO₂.

- F(x): 11 to 15

The function F(x) is defined by the formula (1) below. The variable x in this function is MgO/TiO₂ described above. Formula (1)

$$F(x) = 37.2 \times x^{-0.0665} - 30$$

The function F(x) is an empirical formula which represents the relation between the ratio (x) of MgO/TiO₂ and low-temperature toughness. It was obtained by statistical calculations from the relation between the ratio (x) of MgO/TiO₂ in the wire and the result of Charpy impact test (at -60°C) of weld metal. Specimens were prepared from ten-odd kinds of wires each containing alloys and slag-forming agent specified below.

C: 0.02 to 0.14 wt%

Si: 0.4 to 1.1 wt%

Mn: 0.8 to 3.0 wt%

Ni: 0.2 to 3.1 wt%

Cr: 0.1 to 4.0 wt%

Mo: 0.1 to 4.0 wt%

Ti: 0 to 0.2 wt%

Fe: 84.1 to 90.1 wt%

N: no more than 0.0150 wt%

Other components (B, Na, F, K, Li, Al, Ca, Mg, P, and S):
0.10 to 3.25 wt%

TiO₂: 3.5 to 7.8 wt%

MgO: 0.1 to 5.0 wt%

Fig. 1 is a graph in which the values of $F(x)$ obtained by the present inventors' experiments are plotted against Charpy impact values at -60°C (denoted by $eV-60^{\circ}\text{C}$ hereinafter). It is noted that there is a monotonously decreasing relation between $F(x)$ and $vE-60^{\circ}\text{C}$. In the region where $F(x) \leq 15$, $vE-60^{\circ}\text{C} \geq 47$ J in which good low-temperature toughness is obtained. Since the ratio (x) of MgO/TiO_2 has an upper limit of 0.22, the function $F(x)$ inevitably has a lower limit of 11. Thus, the function $F(x)$ makes it possible to predict the relation between the constituents of the flux-cored wire and the low-temperature toughness of the weld metal resulting from the flux-cored wire.

The foregoing suggests that the value of x and the

function of $F(x)$ should be within the range of $0.005 \leq x \leq 0.22$ according to the present invention.

The requirement for the value of x in the range specified above is not essential, but the flux-cored wire meeting other conditions than mentioned above will have good welding usability and yield weld metal having good low-temperature toughness. However, the flux-core wire meeting the requirement for the specified value of x will yield weld metal having improved low-temperature toughness.

The flux-cored wire according to the present invention has the remainder (other than those components mentioned above) which includes Fe alloys (such as Fe-Si, Fe-Mn, Fe-Cr, Fe-Mo, and Fe-Ti) and Fe derived from iron powder, which are contained in the steel sheath and the flux filled therein. The content of Fe is no less than 80 wt% of the total weight of the wire. The flux-cored wire according to the present invention may additionally contain alkali metal fluoride and oxide, alkaline earth metal fluoride and oxide, B, Al, and Mg.

The flux-cored wire used for the test contains N in an amount no more than 0.0150 wt%. If the content of N exceeds 0.0150 wt%, the resulting weld metal contains more N, thereby increasing blow holes.

EXAMPLES

The invention will be described below in more detail

with reference to Examples and Comparative Examples. The sample wires used in Examples and Comparative Examples have the composition (in terms of per cent on the total weight of the wire) and the value of the function $F(x)$. The sample wires have the hoop composition as shown in Table 6. Table 7 shows the kind of hoop used in each example. As shown in Table 7, those wires shown in Table 3 and 4 employ the hoop A and B shown in Table 6. Incidentally, the sample wires in Examples and Comparative Examples contain P, S, Nb, and V as additional components.

(Flat position welding)

The sample wires were used for flat position welding of HT780 steel under the conditions shown in Table 1. The resulting weld metal was made into specimens (conforming to JIS Z3111 A No. 1 and JIS Z3111 A No. 4) for tensile test and Charpy impact test, respectively. The results of mechanical tests for 0.2% proof stress and Charpy impact value are shown, together with the rating of welding usability, in Tables 8 and 9. The overall rating of samples are indicated by symbol "O" or "x", which stands for "good" or "poor", respectively.

Samples are rated as good in mechanical properties if the weld metal has a 0.2% proof stress greater than 620 MPa and a Charpy impact value (at -60°C) greater than 27 J.

Moreover, samples are rated as good in low-temperature toughness if the weld metal has a Charpy impact value (at -60°C) greater than 47 J.

Table 1

Welding current (A)	Arc voltage (V)	Welding speed (mm/min)	Preheat-interpass temperature (°C)	Heat input (kJ/mm)
280	30	300	150	1.7

Welding conditions are as follows:

Shield gas: 80% Ar - 20% CO₂, 25 L/min

Wire diameter: 1.2 mm

Welding position: Flat position

Sample steel plate: JIS G 3128 SHY685 (20 mm thick)

Edge shape: 45° V

Groove gap: 12 mm

(Fillet welding)

The sample wires were rated for welding usability by vertical upward fillet welding under the conditions shown in Table 2. The bead form was rated by the method illustrated in Fig. 2. The symbols L and H in Fig. 2 represent the leg length of fillet weld bead and the reinforcement height of fillet weld, respectively. The ratio of L/H is an index indicating the tendency of bead toward sagging. Samples are rated as good if the ratio of L/H is greater than 10. A value of 0 is given to the ratio of L/H if the

fillet welding is impossible to carry out due to sagging.

Table 2

Welding current (A)	Arc voltage (V)	Welding speed (mm/min)	Weaving width (mm)	Heat input (kJ/mm)
220	24	150	10	2.1

Welding conditions are as follows:

Shield gas: 80% Ar - 20% CO₂, 25 L/min

Wire diameter: 1.2 mm

Welding position: Vertical upward

Sample steel plate: JIS G 3128 SHY685 (12 mm thick)

Groove gap: 0 mm

In the welding tests of flat position welding and fillet welding, samples were rated for cold cracking and hot cracking in the following manner.

Cold cracking: The specimen is allowed to stand for 96 hours after welding. With the backing metal removed, the weld metal is examined for defects by ultrasonic testing (JIS Z 3060) and magnetic particle testing (JIS G 0565).

And the fracture is observed under a SEM (Scanning Electron Microscope) to identify the form of cracking.

Hot cracking: With the backing metal removed after welding, the weld metal is examined for defects by ultrasonic testing (JIS Z 3060) and radiographic testing (JIS Z 3104).

And the fracture is observed under a SEM to identify the

form of cracking.

The tensile test and Charpy impact test were carried out according to JIS Z 3111 (which specifies the method for tensile test and impact test of weld metal).

Table 3

	C	Si	Mn	Ni	Cr	Mo	Cr+ Mo	Ti	Fe	N	Others	TiO ₂	MgO
1	0.07	0.4	2.3	2.4	0	0.2	0.2	0	88.4	0.0022	0.2	6.0	0
2	0.08	0.6	2.9	0.8	0.7	1.5	2.2	0.1	86.1	0.0011	0.7	6.5	0
3	0.08	0.9	1.7	2.7	0.4	0.2	0.6	0.2	87.3	0.0056	1.0	5.5	0
4	0.02	0.5	2.1	1.7	0.2	0.3	0.5	0.1	88.1	0.0111	1.0	6.0	0
5	0.04	0.5	2.1	1.7	0	1.0	1.0	0	89.0	0.0032	0.5	5.2	0
6	0.01	0.4	2.1	1.9	0.1	0.9	1.0	0.3	88.1	0.0056	0.7	5.4	0
7	0.15	0.4	2.3	2.4	0.3	0.4	0.7	0.1	87.2	0.0023	0.7	6.1	0
8	0.07	0.2	2.1	1.8	0.3	0.1	0.4	0.1	88.5	0.0045	1.2	5.6	0
9	0.07	1.3	2.3	2.4	0.6	0.4	1.0	0.4	86.8	0.0090	0.2	5.5	0
10	0.09	0.7	0.7	1.7	0.3	0.5	0.8	0.1	89.3	0.0098	0.3	6.3	0
11	0.08	0.7	3.2	1.5	0.6	0.8	1.4	0	87.1	0.0011	0.4	5.6	0
12	0.09	0.7	2.2	0.1	0.3	1.4	1.7	0	89.0	0.0034	0.8	5.4	0
13	0.04	0.4	2.4	3.3	0.3	0.8	1.1	0	85.8	0.0055	0.6	6.3	0
14	0.04	0.8	2.1	1.4	0	0	0	0	89.1	0.0019	0.3	6.3	0
15	0.03	0.3	2.3	2.0	2.2	1.9	4.1	0	85.1	0.0044	0.9	5.3	0
16	0.07	0.5	2.2	2.1	0.5	0.9	1.4	0.4	86.7	0.0045	1.3	5.3	0
Example		Comparative Example											

Table 4

	C	Si	Mn	Ni	Cr	Mo	Cr+ Mo	Ti	Fe	N	Others	TiO ₂	MgO
17	0.05	0.6	2.5	2.0	0	0.2	0.2	0.1	86.5	0.0012	1.0	6.0	0.5
18	0.05	0.6	2.2	2.1	0.1	0.5	0.6	0.0	88.7	0.0025	0.4	6.5	0.8
19	0.05	0.5	2.6	2.2	0.1	0.3	0.4	0.0	87.1	0.0056	0.5	5.5	1.1
20	0.06	0.5	2.6	1.9	0.2	0.2	0.4	0.0	88.1	0.0148	0.1	6.0	0.3
21	0.05	0.4	2.5	1.7	0.1	1.0	1.1	0.0	86.9	0.0023	0.6	5.2	1.2
22	0.05	0.6	2.7	2.1	0.2	0.6	0.8	0.1	86.9	0.0029	0.6	5.4	3.0
23	0.05	0.6	2.8	2.2	0.1	0.4	0.5	0.2	85.8	0.0046	1.3	6.1	4.0
24	0.06	0.7	2.3	2.0	0.3	0.2	0.5	0.1	88.0	0.0085	1.6	5.6	0.6
25	0.06	0.5	2.5	1.8	0.5	0.4	0.9	0.0	86.5	0.0023	0.2	5.5	1.1
26	0.07	0.6	2.2	2.5	0.2	0.6	0.8	0.0	87.1	0.0099	0.6	6.3	1.4
27	0.06	0.8	2.5	1.5	0.3	1.0	1.3	0.0	86.9	0.0122	0.8	5.6	0.1
28	0.07	0.4	2.5	2.0	0.2	1.0	1.2	0.0	88.1	0.0019	0.6	5.4	0.2
29	0.06	0.5	2.6	2.3	0.1	0.5	0.6	0.0	86.4	0.0065	0.8	6.3	1.3
30	0.05	0.6	2.5	2.0	0	0.2	0.2	0.0	86.5	0.0013	1.1	6.3	0.0
Example		Comparative Example											

The column "Others" in Tables 3 and 4 denotes the total amount of alkali metal fluoride and oxide, alkaline earth metal fluoride and oxide, B, Al, Mg, and inevitable impurities (P, S, V, and Nb). The total amount of inevitable impurities is 0.1 wt%. It follows therefore that "Others" in Example 17 in Table 4, which is 1.0 wt%, is composed of 0.9 wt% of alkali metal fluoride and oxide, alkaline earth metal fluoride and oxide, B, Al, and Mg, and 0.1 wt% of inevitable impurities. "Others" in Example 20 simply denotes the amount of inevitable impurities and it does not include alkali metal fluoride and oxide, alkaline earth metal fluoride and oxide, B, Al, and Mg.

Table 5

		TiO ₂ +MgO	MgO/TiO ₂	F(x)
Example	17	7.0	0.08	14
	18	5.3	0.18	12
	19	6.6	0.20	11
	20	6.3	0.05	15
	21	6.7	0.22	11
Comparative Example	22	6.1	0.97	7
	23	6.5	1.60	6
	24	4.7	0.15	12
	25	7.5	0.17	12
	26	6.1	0.30	10
	27	6.1	0.02	19
	28	5.1	0.04	16
	29	6.7	0.24	11
	30	7.0	0.00	-*

* Indeterminate

Table 6

Kind of hoop	Fe	C	Si	Mn	Ni	Cr	Mo	Ti	N	Others
A	99.3	0.05	0.05	0.50	0	0	0	0.02	0.0020	0.1
B	98.4	0.03	0.02	0.70	0.50	0.10	0.10	0	0.0100	0.1

Table 7

	Kind of hoop		Kind of hoop		Kind of hoop
Example 1	A	Comparative Example 11	B	Example 21	A
Example 2	B	Comparative Example 12	A	Comparative Example 22	A
Example 3	B	Comparative Example 13	A	Comparative Example 23	A
Example 4	A	Comparative Example 14	A	Comparative Example 24	A
Example 5	A	Comparative Example 15	B	Comparative Example 25	B
Comparative Example 6	A	Comparative Example 16	A	Comparative Example 26	A
Comparative Example 7	A	Example 17	A	Comparative Example 27	B
Comparative Example 8	A	Example 18	A	Comparative Example 28	B
Comparative Example 9	B	Example 19	A	Comparative Example 29	A
Comparative Example 10	A	Example 20	B	Comparative Example 30	A

Table 8

		PS (0.2% proof stress)	vE-60	L/H	Welding usability	Others	Overall rating
Example	1	708	38	15.1	good	--	○
	2	778	42	12.5	good	--	○
	3	742	48	13.5	good	--	○
	4	633	28	16.1	good	--	○
	5	685	35	12.4	good	--	○
Comparative Example	6	567	52	15.1	good	--	x
	7	944	17	12.1	good	cold crack	x
	8	501	45	14.3	blow hole	--	x
	9	825	22	8.9	incompatible	--	x
	10	556	25	15.6	blow hole	--	x
	11	921	8	14.6	good	cold crack	x
	12	608	21	15.1	good	--	x
	13	755	31	13.2	good	hot crack	x
	14	596	24	12.2	good	--	x
	15	934	8	15.4	good	--	x
	16	898	7	13.2	good	--	x

Table 9

		PS (0.2% proof stress)	vE-60	L/H	Welding usability	Overall rating
Example	17	670	53	12.4	good	○
	18	723	75	10.5	good	○
	19	694	73	11.0	good	○
	20	699	49	14.3	good	○
	21	741	54	10.8	good	○
Comparative Example	22	755	98	0	sagging	x
	23	701	101	0	sagging	x
	24	712	45	0	sagging	x
	25	760	51	12.0	unstable arc many spatters	x
	26	766	55	5.8	convex bead	x
	27	644	32	15.4	good	x
	28	689	28	10.1	good	x
	29	705	66	8.9	convex bead	x
	30	681	28	15.4	good	x

The results of the tests are shown in Tables 8 and 9. Examples 1 to 5 and 17 to 21 show that the sample wires have good characteristic properties in 0.2% proof stress (PS), low-temperature toughness at -60°C, and welding usability (including bead shape). By contrast, Comparative Examples 6 to 16 and 22 to 30 show that the sample wires are poor in these characteristic properties.

WHAT IS CLAIMED IS:

1. A flux-cored wire for gas-shielded arc welding, which contains in its total weight C: 0.02 to 0.14 wt%, Si: 0.4 to 1.1 wt%, Mn: 0.8 to 3.0 wt%, Ni: 0.2 to 3.1 wt%, Ti: no more than 0.2 wt%, either or both of Cr and Mo: 0.1 to 4.0 wt% in total, TiO₂ and MgO: 5.0 to 7.2 wt% in total, any or all of alkali metal fluoride and oxide, alkaline earth metal fluoride and oxide, B, Al, and Mg: no more than 2.0 wt% in total, and N: no more than 0.0150 wt%, with the remainder being inevitable impurities and Fe.

2. A flux-cored wire for gas-shielded arc welding, which contains in its total weight C: 0.02 to 0.14 wt%, Si: 0.4 to 1.1 wt%, Mn: 0.8 to 3.0 wt%, Ni: 0.2 to 3.1 wt%, Ti: no more than 0.2 wt%, either or both of Cr and Mo: 0.1 to 4.0 wt% in total, TiO₂ and MgO: 5.0 to 7.2 wt% in total, and N: no more than 0.0150 wt%, with the remainder being inevitable impurities and Fe, wherein the content of MgO and the content of TiO₂ satisfy the equation:

$$0.05 \leq x \leq 0.22 \text{ (where } x \text{ denotes the ratio of MgO/TiO}_2\text{)}.$$

3. A flux-cored wire for gas-shielded arc welding, which contains in its total weight C: 0.02 to 0.14 wt%, Si: 0.4 to 1.1 wt%, Mn: 0.8 to 3.0 wt%, Ni: 0.2 to 3.1 wt%, Ti: no more than 0.2 wt%, either or both of Cr and Mo: 0.1 to

4.0 wt% in total, TiO₂ and MgO: 5.0 to 7.2 wt% in total, any or all of alkali metal fluoride and oxide, alkaline earth metal fluoride and oxide, B, Al, and Mg: no more than 2.0 wt% in total, and N: no more than 0.0150 wt%, with the remainder being inevitable impurities and Fe, wherein the content of MgO and the content of TiO₂ satisfy the equation:

$0.05 \leq x \leq 0.22$ (where x denotes the ratio of MgO/TiO₂).