

## DESCRIPTION

## WIRE CONTAINING FLUX FOR GAS SHIELD ARC WELDING

## Technical Field

[0001]

The present invention relates to a flux-cored wire for gas-shielded arc welding.

## Background Art

[0002]

Conventionally, in order to perform high-efficiency welding work, gas-shielded arc welding using a flux-cored wire has been carried out in various fields.

For example, Patent Document 1 discloses a titania-based flux-cored wire capable of maintaining good welding usability even at a high current and forming a good bead in vertical upward welding.

[0003]

However, Patent Document 1 is directed to a technique specialized for welding usability at a high current, and it is therefore likely that the welding usability at a low current is not excellent and a large amount of spatter is generated in short-circuiting transfer welding at a low current.

[0004]

With respect to the technique for suppressing the generation of spatter, various techniques have been heretofore created and disclosed, for example, in Patent Document 2.

## Prior Art Document

## Patent Document

[0005]

Patent Document 1: JP-A-2013-184204

Patent Document 2: JP-A-2013-252551

## Summary of the Invention

## Technical Problem

[0006]

According to the description of Patent Document 2, the flux-cored wire of Patent Document 2 is supposed to enable suppressed generation of spatter and ensure good welding usability in all positions.

However, in the welding conditions described in Patent Document 2, the welding current is 260 A or more, which assumes that the welding is applied under the high-current condition. Consequently, as with the technique according to Patent Document 1, good welding usability at a low current cannot be ensured also in the technique according to Patent Document 2.

[0007]

In addition, it is required that not only the flux-cored wire for gas-shielded arc welding has good welding usability at a high current and a low current but also a weld metal having a small diffusible hydrogen content and exhibiting good mechanical properties is obtained.

[0008]

An object of the present invention is to provide a flux-cored wire for gas-shielded arc welding, ensuring that good welding usability is maintained not only at a high current but also at a low current and a weld metal having a small diffusible hydrogen content and exhibiting good mechanical properties is obtained.

## Technical Solution

[0009]

That is, the flux-cored wire for gas-shielded arc welding in the present invention, includes, relative to a total mass of the wire: TiO<sub>2</sub>: 3.0 mass% or more and 8.0 mass% or less; C: 0.01 mass% or more and 0.10 mass% or less; at least one of Si and an Si oxide: 0.20 mass% or more and 1.70 mass% or less in total in terms of Si; ZrO<sub>2</sub>: 0.1 mass% or more and 1.0 mass% or less; Mn: 1.3 mass% or more and 3.5 mass% or less; Al: 0.10 mass% or more and 1.00 mass% or less; NaF: 0.05 mass% or more and 0.60 mass% or less; at least one of B and a B oxide: 0.0003 mass% or more and 0.0300 mass% or less in total in terms of B; Mg: less than 0.10 mass%; and MgO: less than 0.10 mass%, and a total content of an Na compound except for NaF, in terms

of Na, and a K compound, in terms of K, is 0.20 mass% or less, and a content of an F compound except for NaF, in terms of F, is 0.10 mass% or less, and  $5.00 \leq [\text{TiO}_2]/[\text{Al}] \leq 70.00$  is satisfied, wherein  $[\text{TiO}_2]$  is the content of  $\text{TiO}_2$  and  $[\text{Al}]$  is the content of Al.

[0010]

In this flux-cored wire for gas-shielded arc welding, the value calculated by  $[\text{TiO}_2]/[\text{Al}]$  is set to fall within the specific range, whereby the welding usability can be enhanced not only at a high current but also at a low current and the mechanical properties of the weld metal can be improved. In addition, the content of NaF is set to fall within the specific range, whereby the droplet transfer of an arc during welding can be stabilized and not only the arc stability is enhanced but also the hydrogen partial pressure in the welding atmosphere and the diffusible hydrogen content in the weld metal can be reduced. Furthermore, the content of each of other components is set to fall within the specific range or be not more than the specific value, whereby good welding usability can be more unfailingly satisfied and the effect of providing a decreased diffusible hydrogen content in the weld metal and enhanced mechanical properties of the weld metal can be more reliably achieved.

[0011]

The flux-cored wire for gas-shielded arc welding in the present invention may also include, relative to the total mass of the wire:  $\text{Al}_2\text{O}_3$ : 0.5 mass% or less; Ca: 0.10 mass% or less; Ti: 0.25 mass% or less; and Ni: 4.00 mass% or less.

In this flux-cored wire for gas-shielded arc welding, the contents of  $\text{Al}_2\text{O}_3$ , Ca, Ti and Ni are set to be not more than the specific values, respectively, whereby the welding usability can be more improved and the mechanical properties of the weld metal can be more enhanced.

#### Advantageous Effects of the Invention

[0012]

The flux-cored wire for gas-shielded arc welding of the present invention makes it possible to maintain good welding usability not only at a high current but also at a low current and obtain a weld metal having a small diffusible hydrogen content and good mechanical properties.

## Embodiments for Carrying Out the Invention

[0013]

Embodiment(s) for carrying out the present invention is described in detail below.

The flux-cored wire for gas-shielded arc welding (hereinafter, conveniently referred to as "wire") in this embodiment is a wire used for gas-shielded arc welding and is obtained by filling a steel sheath with a flux.

[0014]

In detail, the wire in this embodiment includes a steel sheath taking on a tubular shape and a flux filling the inner side of the steel sheath. The wire may have either form of a seamless type without a seam on the sheath or a seam type with a seam on the sheath. In the wire, the surface (outer side of the steel sheath) may or may not be subjected to plating, etc.

The wire diameter (diameter) of the wire in this embodiment is not particularly limited but may be 1.2 mm or more and 2.4 mm or less.

[0015]

In the wire in this embodiment, each component is contained in the specific amount relative to the total mass of the wire, and the contents of the specific components satisfy the specific relational expression.

The reasons for specifying the content of each component in the wire in this embodiment are described below.

[0016]

In the following description, a component simply referred to, for example, as "Si" means one or more members of "pure metal Si" and "an alloy of Si".

The "oxide" means one or more members of "a simple oxide" and "a composite oxide". The "simple oxide" means, for example, in the case of Ti, an oxide of Ti alone ( $\text{TiO}_2$ ), and the "composite oxide" means both an oxide formed by aggregation of a plurality of kinds of these simple oxides and an oxide containing a plurality of metal components such as Ti, Fe and Mn.

[0017]

[ $\text{TiO}_2$ : 3.0 mass% or more and 8.0 mass% or less]

TiO<sub>2</sub> assumes an important role in holding the weld metal. If the content of TiO<sub>2</sub> is less than 3.0 mass%, the welding usability is deteriorated, and good bead shape and good bead appearance cannot be ensured. On the other hand, if the content of TiO<sub>2</sub> exceeds 8.0 mass%, the slag melting point rises and when weaving is performed in vertical upward welding, the slag solidifies quickly, and as a result, a weld metal is formed along the weaving path not only to give a scale-like (wavy) finish to the bead but also to fail in ensuring a good bead shape.

Accordingly, the content of TiO<sub>2</sub> is 3.0 mass% or more and 8.0 mass% or less relative to the total mass of the wire.

The content of TiO<sub>2</sub> is preferably 4.0 mass% or more in view of a better bead shape, and the content of TiO<sub>2</sub> is preferably 7.0 mass% or less in view of a better bead shape.

[0018]

[C: 0.01 mass% or more and 0.10 mass% or less]

C is a component exerting an effect of enhancing the quenchability and toughness of the weld metal. However, if the content of C is less than 0.01 mass%, the weld metal lacks quenchability, making it difficult to ensure sufficient mechanical properties. On the other hand, if the content of C exceeds 0.10 mass%, the arc delivers a strong blow and digs into the matrix with the arc power during welding, and good bead shape and good bead appearance cannot be therefore ensured.

Accordingly, the content of C is 0.01 mass% or more and 0.10 mass% or less relative to the total mass of the wire. The content of C is preferably 0.01 mass% or more and 0.08 mass% or less relative to the total mass of the wire, from the viewpoint of suppressing deterioration of the toughness of the weld metal.

[0019]

[At least one of Si and Si oxide: 0.20 mass% or more and 1.70 mass% or less in total in terms of Si]

Si enhances the welding usability. However, if the total of Si and the Si oxide is less than 0.20 mass% in terms of Si, the welding usability is deteriorated, and good bead shape and good bead appearance cannot be ensured. On the other hand, if the total of Si and the Si oxide exceeds 1.70 mass% in terms of Si, precipitation of grain boundary ferrite is promoted, and the toughness of the weld metal is deteriorated.

Accordingly, the total of Si and the Si oxide is 0.20 mass% or more and 1.70 mass% or less, in terms of Si, relative to the total mass of the wire.

The total of Si and the Si oxide is preferably 0.30 mass% or more, in terms of Si, in view of a better bead shape. In addition, the total of Si and the Si oxide is preferably 1.40 mass% or less, in terms of Si, from the viewpoint of suppressing deterioration of the toughness of the weld metal.

[0020]

As described above, both Si and an Si oxide exert an effect of enhancing the welding usability but, to be exact, the action differs therebetween. More specifically, Si increases the viscosity of the weld metal during welding and makes the weld metal to be less likely to sag. On the other hand, the Si oxide covers the weld metal with slag and prevents sagging of the weld metal.

The content of each of Si and an Si oxide is not particularly limited, but the content of each component is as follows when specified.

[0021]

[Si: 0.10 mass% or more and 1.00 mass% or less]

Si enhances the welding usability by increasing the viscosity of the weld metal and making the weld metal to be less likely to sag. However, if the content of Si is less than 0.10 mass%, the viscosity of the weld metal may be lowered, leading to deterioration of the bead shape. On the other hand, if the content of Si exceeds 1.00 mass%, an austenite grain in the weld metal may be coarsened to deteriorate the toughness of the weld metal.

Accordingly, the content of Si, when specified, is preferably 0.10 mass% or more and 1.00 mass% or less relative to the total mass of the wire.

The content of Si is preferably 0.20 mass% or more in view of a better bead shape, and the content of Si is preferably 0.80 mass% or less from the viewpoint of suppressing the deterioration of toughness of the weld metal.

[0022]

[SiO<sub>2</sub>: 0.20 mass% or more and 1.50 mass% or less]

SiO<sub>2</sub> assumes a role, as a slag former, in holding the weld metal. However, if the content of SiO<sub>2</sub> is less than 0.20 mass%, the slag amount may be insufficient, leading to a bead having a sagged shape. On the other hand, if the content of SiO<sub>2</sub>

exceeds 1.50 mass%, the oxidization power of the flux may be reduced to cause deterioration of the mechanical properties of the weld metal.

Accordingly, the content of  $\text{SiO}_2$ , when specified, is preferably 0.20 mass% or more and 1.50 mass% or less relative to the total mass of the wire.

The content of  $\text{SiO}_2$  is preferably 0.40 mass% or more in view of a better bead shape, and the content of  $\text{SiO}_2$  is preferably 1.30 mass% or less from the viewpoint of suppressing deterioration of the mechanical properties of the weld metal.

[0023]

[ $\text{ZrO}_2$ : 0.1 mass% or more and 1.0 mass% or less]

As with  $\text{SiO}_2$ ,  $\text{ZrO}_2$  assumes a role, as a slag former, in holding the weld metal. However, if the content of  $\text{ZrO}_2$  is less than 0.1 mass%, the slag melting point lowers and not only the bead has a sagged shape but also a good bead appearance cannot be ensured. On the other hand, if the content of  $\text{ZrO}_2$  exceeds 1.0 mass%, the slag melting point excessively rises and not only the bead becomes a convex shape but also a good bead appearance cannot be ensured.

Accordingly, the content of  $\text{ZrO}_2$  is 0.1 mass% or more and 1.0 mass% or less relative to the total mass of the wire.

The content of  $\text{ZrO}_2$  is preferably 0.2 mass% or more in view of a better bead shape, and the content of  $\text{ZrO}_2$  is preferably less than 0.6 mass% in view of a better bead shape.

[0024]

[Mn: 1.3 mass% or more and 3.5 mass% or less]

Mn is a component exerting an effect of enhancing the quenchability and toughness of the weld metal. However, if the content of Mn is less than 1.3 mass%, the weld metal lacks quenchability, making it difficult to ensure sufficient mechanical properties. On the other hand, if the content of Mn exceeds 3.5 mass%, the weld metal lacks toughness due to excessive tensile strength.

Accordingly, the content of Mn is 1.3 mass% or more and 3.5 mass% or less relative to the total mass of the wire.

The content of Mn is preferably 2.0 mass% or more from the viewpoint of more improving the mechanical properties of the weld metal, and the content of Mn is

preferably 3.1 mass% or less from the viewpoint of suppressing deterioration of the toughness of the weld metal.

[0025]

The Mn source may be added in the form of an Mn metal powder or a metal or alloy powder such as Fe-Mn and Fe-Se-Si-Mn. In addition, an Mn oxide may be added.

[0026]

[Al: 0.10 mass% or more and 1.00 mass% or less]

Al is a strong deoxidizing element and has a role to enhance the mechanical properties by increasing the yield of a weld metal component having affinity for oxygen. Al is also effective as a denitrifying element and has an effect to enhance the mechanical properties by decreasing the yield of N in the weld metal. However, if the content of Al is less than 0.10 mass%, the yield of a weld metal component having affinity for oxygen is low, and the denitrifying effect is insufficient, making it difficult to ensure sufficient mechanical properties. On the other hand, if the content of Al exceeds 1.00 mass%, the toughness is deteriorated due to an excessive yield of the weld metal component.

Accordingly, the content of Al is 0.10 mass% or more and 1.00 mass% or less relative to the total mass of the wire.

The content of Al is preferably less than 0.40 mass% from the viewpoint of suppressing deterioration of the toughness of the weld metal.

[0027]

[NaF: 0.05 mass% or more and 0.60 mass% or less]

Na has a role in stabilizing the droplet transfer of an arc during welding, but excessive addition of Na deteriorates the moisture absorption resistance of the wire. On the other hand, F is present as a fluorine compound in the flux and has an effect to lower the hydrogen partial pressure in the welding atmosphere and decrease the diffusible hydrogen content in the weld metal, but excessive F increases the fume emission during welding and deteriorates the droplet transfer of an arc in a low current region.

However, NaF can exert both an effect of stabilizing the droplet transfer of an arc during welding (particularly, stabilization in a low current region) and an effect of

reducing the diffusible hydrogen content by fluoride. If the content of NaF is less than 0.05 mass%, the droplet transfer of an arc during welding becomes unstable in a low current region to cause an increase in the spatter generation and further a rise in the diffusible hydrogen content in the weld metal. On the other hand, if the content of NaF exceeds 0.60 mass%, the moisture absorption resistance of the wire deteriorates and the fume emission increases.

Accordingly, the content of NaF is 0.05 mass% or more and 0.60 mass% or less relative to the total mass of the wire.

The content of NaF is preferably 0.15 mass% or more from the viewpoint of enhancing the stability of arc, reducing the spatter generation, and reducing the diffusible hydrogen content, and the content of NaF is preferably 0.40 mass% or less from the viewpoint of suppressing the deterioration of moisture absorption resistance and reducing the fume emission.

[0028]

[At least one of B and B oxide: 0.0003 mass% or more and 0.0300 mass% or less in total in terms of B]

B and a B oxide ( $B_2O_3$ ) are added to the flux so as to incorporate B into the weld metal. In addition, B has an effect of suppressing production of pro-eutectoid ferrite by being segregated at the austenite grain boundary and is effective in improving the toughness of the weld metal. However, if the total of B and the B oxide is less than 0.0003 mass% in terms of B, the majority of B is fixed as nitride BN and the effect of suppressing the production of pro-eutectoid ferrite is not exerted, making it impossible to expect enhancement of the toughness of the weld metal. On the other hand, if the total of B and the B oxide exceeds 0.0300 mass% in terms of B, the strength of the weld metal extremely increases, and the toughness decreases.

Accordingly, the total of B and the B oxide is 0.0003 mass% or more and 0.0300 mass% or less, in terms of B, relative to the total mass of the wire. The total of B and the B oxide is preferably 0.0015 mass% or more and 0.0300 mass% or less, in terms of B, relative to the total mass of the wire, from the viewpoint of suppressing deterioration of the toughness of the weld metal.

[0029]

[Mg: less than 0.10 mass%, and MgO: less than 0.10 mass%]

Mg and MgO are components likely to be contained as impurities from a natural raw material such as titanium oxide. If the content of Mg is 0.10 mass% or more, the spatter generation increases and due to formation of a compound with Na, the moisture absorption resistance of the wire is deteriorated. If the content of MgO is 0.10 mass% or more, the slag viscosity is increased to provide not only a convex-shaped bead but also a poor bead appearance, and furthermore, for the same reason as Mg, the moisture absorption resistance of the wire deteriorates.

Accordingly, the content of Mg is less than 0.10 mass% relative to the total mass of the wire and may be 0 mass%, and the content of MgO is less than 0.10 mass% relative to the total mass of the wire and may be 0 mass%.

[0030]

[Total content of Na compound except for NaF, in terms of Na, and K compound in terms of K: 0.20 mass% or less]

Na and K have an effect of stabilizing the droplet transfer of an arc during welding, but this effect is fulfilled by NaF. On the other hand, excessive addition of Na and K causes deterioration of the moisture absorption resistance of the wire. More specifically, if the total content the Na compound except for NaF, in terms of Na, and the K compound in terms of K exceeds 0.20 mass%, the moisture absorption resistance of the wire deteriorates, and the diffusible hydrogen content in the weld metal increases.

Accordingly, the total content of the Na compound except for NaF, in terms of Na, and the K compound in terms of K is 0.20 mass% or less relative to the total mass of the wire.

Either the content of the Na compound except for NaF, in terms of Na, or the content of the K compound in terms of K may be 0 mass%, or both may be 0 mass%.

[0031]

[Content of F compound except for NaF, in terms of F: 0.10 mass% or less]

F is present as a fluorine compound in the flux and has an effect to lower the hydrogen partial pressure in the welding atmosphere and decrease the diffusible hydrogen content in the weld metal, but this effect is fulfilled by NaF. On the other hand, excessive addition of F increases the fume emission during welding. More specifically, if the content of the F compound except for NaF, in terms of F, exceeds

0.10 mass%, not only the fume emission but also the spatter generation are increased, and the arc stability deteriorates.

Accordingly, the content of the F compound except for NaF, in terms of F, is 0.10 mass% or less relative to the total mass of the wire and may be 0 mass%.

[0032]

$[5.00 \leq [\text{TiO}_2]/[\text{Al}] \leq 70.00]$

When  $[\text{TiO}_2]$  is the content of  $\text{TiO}_2$  and  $[\text{Al}]$  is the content of Al,  $[\text{TiO}_2]/[\text{Al}]$  is an important index for satisfying both mechanical properties of the weld metal and good welding usability. The value calculated by this formula is specified to fall within the specific range, whereby good welding usability (particularly, in vertical upward welding) can be maintained not only at a high current but also in short-circuiting transfer welding at a low current. However, if the value calculated by  $[\text{TiO}_2]/[\text{Al}]$  is less than 5.00, the weld metal has excessive tensile strength and deteriorated toughness due to excessive deoxidizing power of Al and furthermore, the bead is sagged in vertical upward welding, resulting in a poor bead appearance. On the other hand, if the value calculated by  $[\text{TiO}_2]/[\text{Al}]$  exceeds 70.00, the tensile strength and toughness of the weld metal are deteriorated due to insufficient deoxidizing power of Al.

Accordingly, the value calculated by  $[\text{TiO}_2]/[\text{Al}]$  is 5.00 or more and 70.00 or less.

The value calculated by  $[\text{TiO}_2]/[\text{Al}]$  is preferably 7.00 or more, more preferably 14.00 or more, from the viewpoint of more improving the welding usability and the mechanical properties of the weld metal. In addition, the value calculated by  $[\text{TiO}_2]/[\text{Al}]$  is preferably 60.00 or less, more preferably 40.00 or less, in view of better mechanical properties of the weld metal.

[0033]

The wire in this embodiment may contain the following components ( $\text{Al}_2\text{O}_3$ , Ca, Ti and Ni) as optional components.

[0034]

$[\text{Al}_2\text{O}_3: 0.5 \text{ mass\% or less}]$

$\text{Al}_2\text{O}_3$  is a component necessary as a slag former for bead formation, but this effect is fulfilled by other slag formers. If the content of  $\text{Al}_2\text{O}_3$  exceeds 0.5 mass%, the arc may be unstable, and the spatter generation may increase.

Accordingly, in the case of incorporating  $\text{Al}_2\text{O}_3$  into the wire, the content of  $\text{Al}_2\text{O}_3$  is 0.5 mass% or less relative to the total mass of the wire. The content of  $\text{Al}_2\text{O}_3$  is preferably small, and is preferably 0.4 mass% or less relative to the total mass of the wire.

[0035]

[Ca: 0.10 mass% or less]

As with Mg, Ca is a component likely to be contained as an impurity from a natural raw material such as titanium oxide. If the content of Ca exceeds 0.10 mass%, the arc may be unstable, and the spatter generation may increase.

Accordingly, in the case of incorporating Ca into the wire, the content of Ca is 0.10 mass% or less relative to the total mass of the wire. The content of Ca is preferably small, and is preferably 0.08 mass% or less relative to the total mass of the wire.

[0036]

[Ti: 0.25 mass% or less]

Ti is a component enhancing the mechanical properties of the weld metal. However, if the content of Ti exceeds 0.25 mass%, significant hardening of the weld metal may occur to cause prominent deterioration of the toughness.

Accordingly, in the case of incorporating Ti into the wire, the content of Ti is 0.25 mass% or less relative to the total mass of the wire.

The content of Ti is preferably 0.10 mass% or less from the viewpoint of suppressing deterioration of the toughness of the weld metal. The content of Ti is preferably 0.04 mass% or more.

[0037]

[Ni: 4.00 mass% or less]

Ni has an effect of enhancing the mechanical properties of the weld metal. However, if the content of Ni exceeds 4.00 mass%, the weld metal may have excessive strength.

Accordingly, in the case of incorporating Ni into the wire, the content of Ni is 4.00 mass% or less relative to the total mass of the wire. The content of Ni is preferably 0.05 mass% or more and 3.85 mass% or less relative to the total mass of the

wire, from the viewpoint of suppressing deterioration of the toughness of the weld metal.

[0038]

[Fe: 75.0 mass% or more and 92.0 mass% or less]

Fe is a main component of the wire. In relation to the deposition amount and the composition of other components, the content of Fe is preferably 75.0 mass% or more and 92.0 mass% or less, more preferably 80.0 mass% or more and 90.0 mass% or less, relative to the total mass of the wire.

[0039]

[Remainder: Fe and unavoidable impurities]

The remainder of the wire in this embodiment is Fe described above and unavoidable impurities. Other than the above components of the wire, in the flux, Cu, Mo and Cr as a further hardening agent of the weld metal and MnO, FeO and V<sub>2</sub>O<sub>5</sub> as a slag former may be contained each in a small amount. The object of the present invention is not affected by these elements.

In addition, Cu, Mo, Cr, etc. each in an amount of less than 0.1 mass%, and MnO, FeO and V<sub>2</sub>O<sub>5</sub> each in an amount of less than 0.5 mass% may be contained as unavoidable impurities. If the content exceeds the upper limit above, excessive strength, deterioration of welding usability, etc. may be caused. Furthermore, P, S, etc. may be contained each in an amount of 0.030% or less. If the content exceeds the upper limit above, hot crack or reduction in toughness may be caused.

As for the component(s) or optional component(s), only the upper limit(s) of the content(s) of which is specified as described above, the component(s) may be positively added or may be contained as unavoidable impurities.

In the case where each of the elements above is added as an oxide or a nitride, the remainder of the flux-cored wire in this embodiment includes also O or N.

[0040]

[Others: flux filling rate]

The flux filling rate  $(= (\text{mass of flux}) / (\text{total mass of wire}) \times 100)$  of the wire in this embodiment is not particularly limited. However, if the flux filling rate is less than 10 mass%, the arc stability may be bad, and the spatter generation may increase, and as a result, the welding usability may deteriorate. On the other hand, if the flux

filling rate exceeds 25 mass%, for example, breaking of the wire may occur, or the powder may spill out during filling with flux, and the productivity may be thus significantly deteriorated.

Accordingly, the flux filling rate is preferably 10 mass% or more and 25 mass% or less.

[0041]

The method for manufacturing the wire in this embodiment is described below.  
[Manufacturing Method of Wire]

The method for manufacturing the wire in this embodiment is not particularly limited, but the wire can be manufactured, for example, by the following method.

First, a steel strip constituting the steel sheath is prepared, and the steel strip is formed with a forming roll while feeding it in the longitudinal direction to obtain a U-shaped open tube. Next, the steel sheath is filled with a flux having blended therein various raw materials to afford a predetermined chemical composition, then it is processed so as to have a circular cross-section and thereafter extended by cold working to obtain a flux-cored wire having a wire diameter of, for example, 1.2 mm or more and 2.4 mm or less. In the middle of cold working, annealing may be applied. Furthermore, either the structure of a wire without seam, in which the seam on the steel sheath has been weld in the course of manufacture, or the structure of a wire in which the seam is not welded but is left to remain as a gap, may be employed.

Examples

[0042]

The effects of the present invention are specifically described below by referring to Examples of the present invention and Comparative Examples.

[Method for Manufacturing Wire for Use in Various Tests]

A steel strip was formed into an open tube with a forming roll while feeding the steel strip in the longitudinal direction. A metal, an alloy, an Fe powder, and various raw materials each in the specific amount were appropriately added to the flux to afford the chemical composition shown in Tables 1 and 2. After processing so as to have a circular cross-section, the processed wire was subjected to cold drawing, thereby adjusting to have a wire diameter of about 1.2 mm.

A flux-cored wire was manufactured by the above-described manufacturing method.

[0043]

The content of each component shown in Tables 1 and 2 is the content relative to the total mass of the wire. In Tables 1 and 2, "T.Si" indicates the total content of Si and an Si oxide, in terms of Si, "T.B" indicates the total content of B and a B oxide, in terms of B, "Na+K" indicates the total content of an Na compound except for NaF, in terms of Na, and a K compound in terms of K, and "F" indicates the content of an F compound except for NaF, in terms of F.

[0044]

Table 1

| Wire | Composition of Components of Wire (mass%) |      |      |      |                  |                  |     |      |      |        |                          |      |      |      |      |                                |      |      |      |      |        |
|------|-------------------------------------------|------|------|------|------------------|------------------|-----|------|------|--------|--------------------------|------|------|------|------|--------------------------------|------|------|------|------|--------|
| No.  | TiO <sub>2</sub>                          | C    | T.Si | Si   | SiO <sub>2</sub> | ZrO <sub>2</sub> | Mn  | Al   | NaF  | T.B    | [TiO <sub>2</sub> ]/[Al] | Mg   | MgO  | Na+K | F    | Al <sub>2</sub> O <sub>3</sub> | Ca   | Ti   | Ni   | Fe   | Others |
| J1   | 5.9                                       | 0.04 | 0.83 | 0.47 | 0.78             | 0.3              | 2.4 | 0.30 | 0.27 | 0.0070 | 19.67                    | 0.01 | 0.01 | 0.03 | 0.01 | 0.1                            | 0.02 | 0.01 | 0.01 | 89.3 | 0.08   |
| J2   | 7.5                                       | 0.08 | 0.93 | 0.51 | 0.89             | 0.5              | 1.8 | 0.52 | 0.51 | 0.0011 | 14.42                    | 0.05 | 0.02 | 0.02 | 0.02 | 0.2                            | 0.03 | 0.12 | 0.12 | 87.0 | 0.12   |
| J3   | 7.2                                       | 0.06 | 0.63 | 0.33 | 0.64             | 0.5              | 2.4 | 0.34 | 0.41 | 0.0083 | 21.18                    | 0.04 | 0.08 | 0.11 | 0.03 | 0.3                            | 0.03 | 0.18 | 0.17 | 87.1 | 0.12   |
| J4   | 3.1                                       | 0.05 | 1.43 | 0.82 | 1.30             | 0.3              | 1.9 | 0.21 | 0.47 | 0.0064 | 14.76                    | 0.07 | 0.02 | 0.07 | 0.01 | 0.3                            | 0.01 | 0.25 | 0.04 | 91.0 | 0.11   |
| J5   | 7.9                                       | 0.08 | 0.88 | 0.30 | 1.23             | 0.5              | 1.8 | 0.35 | 0.29 | 0.0046 | 22.57                    | 0.05 | 0.07 | 0.12 | 0.05 | 0.3                            | 0.08 | 0.11 | 0.11 | 86.5 | 0.15   |
| J6   | 6.8                                       | 0.01 | 0.72 | 0.37 | 0.75             | 0.4              | 2.7 | 0.66 | 0.40 | 0.0061 | 10.03                    | 0.04 | 0.08 | 0.12 | 0.05 | 0.2                            | 0.03 | 0.25 | 0.25 | 86.8 | 0.10   |
| J7   | 7.4                                       | 0.09 | 0.68 | 0.40 | 0.60             | 0.2              | 2.1 | 0.34 | 0.33 | 0.0074 | 21.76                    | 0.05 | 0.08 | 0.08 | 0.02 | 0.3                            | 0.02 | 0.20 | 0.02 | 87.6 | 0.18   |
| J8   | 6.1                                       | 0.04 | 0.26 | 0.10 | 0.35             | 0.5              | 2.5 | 0.71 | 0.49 | 0.0045 | 8.59                     | 0.06 | 0.07 | 0.01 | 0.01 | 0.1                            | 0.07 | 0.25 | 0.03 | 88.6 | 0.02   |
| J9   | 7.2                                       | 0.06 | 1.60 | 0.95 | 1.40             | 0.3              | 2.0 | 0.82 | 0.44 | 0.0079 | 8.78                     | 0.05 | 0.03 | 0.04 | 0.05 | 0.3                            | 0.02 | 0.12 | 0.11 | 86.1 | 0.03   |
| J10  | 7.3                                       | 0.02 | 0.75 | 0.40 | 0.75             | 0.2              | 2.5 | 0.70 | 0.57 | 0.0040 | 10.43                    | 0.06 | 0.09 | 0.05 | 0.05 | 0.3                            | 0.04 | 0.15 | 0.14 | 86.5 | 0.15   |
| J11  | 8.0                                       | 0.05 | 0.54 | 0.31 | 0.50             | 0.9              | 2.9 | 0.65 | 0.47 | 0.0104 | 12.31                    | 0.06 | 0.07 | 0.03 | 0.02 | 0.2                            | 0.03 | 0.13 | 0.13 | 85.5 | 0.02   |
| J12  | 7.8                                       | 0.02 | 0.96 | 0.62 | 0.73             | 0.7              | 1.4 | 0.34 | 0.44 | 0.0055 | 22.94                    | 0.06 | 0.02 | 0.02 | 0.02 | 0.3                            | 0.07 | 0.15 | 0.15 | 87.0 | 0.18   |
| J13  | 6.8                                       | 0.08 | 1.03 | 0.70 | 0.70             | 0.2              | 3.4 | 0.66 | 0.32 | 0.0015 | 10.30                    | 0.07 | 0.05 | 0.06 | 0.03 | 0.2                            | 0.08 | 0.17 | 0.02 | 86.4 | 0.10   |
| J14  | 7.1                                       | 0.04 | 0.44 | 0.20 | 0.51             | 0.5              | 2.8 | 0.13 | 0.54 | 0.0133 | 54.62                    | 0.05 | 0.04 | 0.04 | 0.01 | 0.1                            | 0.02 | 0.20 | 0.04 | 87.6 | 0.09   |
| J15  | 6.8                                       | 0.07 | 1.05 | 0.68 | 0.80             | 0.2              | 2.2 | 0.95 | 0.36 | 0.0094 | 7.16                     | 0.05 | 0.03 | 0.09 | 0.04 | 0.0                            | 0.03 | 0.16 | 0.07 | 87.4 | 0.08   |
| J16  | 6.2                                       | 0.02 | 0.69 | 0.30 | 0.83             | 0.4              | 1.9 | 0.74 | 0.06 | 0.0057 | 8.38                     | 0.04 | 0.05 | 0.12 | 0.04 | 0.2                            | 0.03 | 0.16 | 0.16 | 88.6 | 0.15   |
| J17  | 6.4                                       | 0.04 | 0.81 | 0.62 | 0.40             | 0.2              | 3.3 | 0.34 | 0.58 | 0.0066 | 18.82                    | 0.02 | 0.04 | 0.03 | 0.02 | 0.1                            | 0.05 | 0.17 | 0.02 | 87.6 | 0.08   |
| J18  | 7.2                                       | 0.07 | 0.59 | 0.40 | 0.40             | 0.3              | 2.6 | 0.46 | 0.32 | 0.0004 | 15.65                    | 0.02 | 0.06 | 0.04 | 0.02 | 0.3                            | 0.07 | 0.19 | 0.19 | 87.2 | 0.11   |
| J19  | 6.0                                       | 0.03 | 0.64 | 0.40 | 0.51             | 0.3              | 2.1 | 0.58 | 0.40 | 0.0295 | 10.34                    | 0.06 | 0.02 | 0.04 | 0.04 | 0.2                            | 0.04 | 0.18 | 0.28 | 88.7 | 0.05   |
| J20  | 4.2                                       | 0.06 | 0.91 | 0.40 | 1.10             | 0.4              | 2.2 | 0.84 | 0.23 | 0.0077 | 5.00                     | 0.05 | 0.05 | 0.02 | 0.06 | 0.3                            | 0.07 | 0.16 | 0.02 | 89.8 | 0.05   |

Table 1 continued

| Wire | Composition of Components of Wire (mass%) |      |      |      |                  |                  |     |      |      |        |                          |      |      |      |      |                                |      |      |      |      |        |
|------|-------------------------------------------|------|------|------|------------------|------------------|-----|------|------|--------|--------------------------|------|------|------|------|--------------------------------|------|------|------|------|--------|
| No.  | TiO <sub>2</sub>                          | C    | T.Si | Si   | SiO <sub>2</sub> | ZrO <sub>2</sub> | Mn  | Al   | NaF  | T.B    | [TiO <sub>2</sub> ]/[Al] | Mg   | MgO  | Na+K | F    | Al <sub>2</sub> O <sub>3</sub> | Ca   | Ti   | Ni   | Fe   | Others |
| J21  | 7.6                                       | 0.03 | 0.86 | 0.58 | 0.60             | 0.7              | 2.3 | 0.16 | 0.11 | 0.0065 | 47.50                    | 0.06 | 0.03 | 0.03 | 0.01 | 0.2                            | 0.08 | 0.15 | 0.01 | 87.2 | 0.16   |
| J22  | 3.8                                       | 0.07 | 0.74 | 0.55 | 0.41             | 0.5              | 2.2 | 0.72 | 0.29 | 0.0073 | 5.28                     | 0.02 | 0.02 | 0.07 | 0.03 | 0.2                            | 0.02 | 0.24 | 0.03 | 90.7 | 0.15   |
| J23  | 7.7                                       | 0.03 | 0.98 | 0.65 | 0.71             | 0.4              | 2.0 | 0.14 | 0.23 | 0.0066 | 55.00                    | 0.02 | 0.05 | 0.01 | 0.04 | 0.3                            | 0.03 | 0.15 | 0.04 | 87.5 | 0.02   |
| J24  | 5.1                                       | 0.05 | 0.82 | 0.54 | 0.60             | 0.3              | 2.2 | 0.63 | 0.32 | 0.0062 | 8.10                     | 0.09 | 0.01 | 0.12 | 0.04 | 0.3                            | 0.03 | 0.08 | 0.08 | 89.4 | 0.06   |
| J25  | 6.4                                       | 0.06 | 1.02 | 0.70 | 0.68             | 0.5              | 2.5 | 0.57 | 0.29 | 0.0070 | 11.23                    | 0.05 | 0.08 | 0.12 | 0.03 | 0.2                            | 0.03 | 0.14 | 0.04 | 87.5 | 0.15   |
| J26  | 6.3                                       | 0.05 | 0.68 | 0.30 | 0.82             | 0.2              | 1.9 | 0.32 | 0.48 | 0.0029 | 19.69                    | 0.03 | 0.05 | 0.18 | 0.07 | 0.1                            | 0.02 | 0.04 | 0.32 | 88.7 | 0.10   |
| J27  | 4.8                                       | 0.05 | 0.90 | 0.43 | 1.00             | 0.4              | 2.5 | 0.65 | 0.32 | 0.0066 | 7.38                     | 0.03 | 0.01 | 0.05 | 0.09 | 0.1                            | 0.04 | 0.15 | 0.15 | 89.1 | 0.10   |
| J28  | 7.5                                       | 0.08 | 1.07 | 0.70 | 0.80             | 0.5              | 2.4 | 0.47 | 0.38 | 0.0138 | 15.96                    | 0.05 | 0.02 | 0.01 | 0.06 | 0.4                            | 0.05 | 0.19 | 0.20 | 86.0 | 0.15   |
| J29  | 6.7                                       | 0.07 | 0.80 | 0.42 | 0.81             | 0.3              | 2.8 | 0.65 | 0.33 | 0.0099 | 10.31                    | 0.02 | 0.06 | 0.03 | 0.02 | 0.1                            | 0.09 | 0.07 | 0.07 | 87.4 | 0.10   |
| J30  | 8.0                                       | 0.08 | 1.07 | 0.63 | 0.95             | 0.5              | 2.3 | 0.64 | 0.41 | 0.0100 | 12.50                    | 0.07 | 0.01 | 0.02 | 0.05 | 0.3                            | 0.07 | 0.23 | 0.19 | 85.5 | 0.05   |
| J31  | 7.3                                       | 0.07 | 0.91 | 0.72 | 0.40             | 0.4              | 3.1 | 0.45 | 0.42 | 0.0044 | 16.22                    | 0.00 | 0.03 | 0.11 | 0.02 | 0.2                            | 0.05 | 0.16 | 3.85 | 82.5 | 0.17   |
| J32  | 5.9                                       | 0.04 | 0.83 | 0.50 | 0.70             | 0.3              | 2.4 | 0.30 | 0.27 | 0.0070 | 19.67                    | 0.01 | 0.01 | 0.03 | 0.01 | -                              | -    | -    | -    | 89.4 | 0.10   |
| J33  | 6.0                                       | 0.05 | 0.70 | 0.50 | 0.60             | 0.3              | 2.4 | 0.32 | 0.29 | 0.0070 | 18.75                    | 0.01 | 0.01 | 0.03 | 0.01 | -                              | -    | -    | -    | 89.4 | 0.10   |

[0045]

Table 2

| Wire No. | Composition of Components of Wire (mass%) |      |      |      |                  |                  |     |      |      |        |                          |      |      |      |      |                                |      |      |      |      |        |  |
|----------|-------------------------------------------|------|------|------|------------------|------------------|-----|------|------|--------|--------------------------|------|------|------|------|--------------------------------|------|------|------|------|--------|--|
|          | TiO <sub>2</sub>                          | C    | T.Si | Si   | SiO <sub>2</sub> | ZrO <sub>2</sub> | Mn  | Al   | NaF  | T.B    | [TiO <sub>2</sub> ]/[Al] | Mg   | MgO  | Na+K | F    | Al <sub>2</sub> O <sub>3</sub> | Ca   | Ti   | Ni   | Fe   | Others |  |
| H1       | 2.8                                       | 0.05 | 0.85 | 0.41 | 0.94             | 0.3              | 3.1 | 0.42 | 0.31 | 0.0066 | 6.67                     | 0.05 | 0.03 | 0.02 | 0.03 | 0.3                            | 0.06 | 0.20 | 0.02 | 90.8 | 0.16   |  |
| H2       | 8.1                                       | 0.08 | 0.66 | 0.22 | 0.95             | 0.8              | 2.2 | 0.55 | 0.29 | 0.0020 | 14.73                    | 0.06 | 0.06 | 0.06 | 0.04 | 0.4                            | 0.07 | 0.22 | 0.03 | 85.7 | 0.13   |  |
| H3       | 5.6                                       | 0.00 | 1.02 | 0.70 | 0.68             | 0.3              | 2.6 | 0.73 | 0.33 | 0.0034 | 7.67                     | 0.02 | 0.08 | 0.04 | 0.03 | 0.2                            | 0.04 | 0.03 | 0.03 | 88.6 | 0.02   |  |
| H4       | 7.1                                       | 0.11 | 0.51 | 0.32 | 0.40             | 0.2              | 2.5 | 0.60 | 0.44 | 0.0043 | 11.83                    | 0.03 | 0.06 | 0.03 | 0.05 | 0.3                            | 0.05 | 0.05 | 0.06 | 87.6 | 0.06   |  |
| H5       | 5.8                                       | 0.08 | 0.19 | 0.10 | 0.20             | 0.6              | 2.6 | 0.34 | 0.42 | 0.0055 | 17.06                    | 0.08 | 0.02 | 0.03 | 0.01 | 0.1                            | 0.03 | 0.05 | 0.50 | 89.0 | 0.04   |  |
| H6       | 5.8                                       | 0.03 | 1.73 | 1.10 | 1.35             | 0.4              | 2.8 | 0.46 | 0.30 | 0.0065 | 12.61                    | 0.06 | 0.04 | 0.04 | 0.04 | 0.2                            | 0.02 | 0.11 | 0.12 | 87.1 | 0.02   |  |
| H7       | 7.0                                       | 0.03 | 1.08 | 0.84 | 0.51             | 0.0              | 2.7 | 0.38 | 0.48 | 0.0079 | 18.42                    | 0.02 | 0.05 | 0.02 | 0.03 | 0.3                            | 0.07 | 0.02 | 0.03 | 87.4 | 0.10   |  |
| H8       | 6.8                                       | 0.06 | 0.91 | 0.63 | 0.60             | 1.1              | 3.1 | 0.54 | 0.27 | 0.0084 | 12.59                    | 0.04 | 0.02 | 0.01 | 0.04 | 0.2                            | 0.07 | 0.19 | 0.19 | 86.1 | 0.00   |  |
| H9       | 6.3                                       | 0.04 | 0.95 | 0.60 | 0.75             | 0.4              | 1.2 | 0.64 | 0.39 | 0.0091 | 9.84                     | 0.03 | 0.05 | 0.00 | 0.03 | 0.3                            | 0.02 | 0.17 | 0.17 | 88.7 | 0.17   |  |
| H10      | 6.5                                       | 0.03 | 0.70 | 0.33 | 0.80             | 0.7              | 3.7 | 0.59 | 0.30 | 0.0132 | 11.02                    | 0.04 | 0.07 | 0.01 | 0.03 | 0.0                            | 0.05 | 0.04 | 0.40 | 86.3 | 0.14   |  |
| H11      | 4.2                                       | 0.05 | 0.92 | 0.40 | 1.11             | 0.4              | 2.4 | 0.08 | 0.38 | 0.0072 | 52.50                    | 0.02 | 0.07 | 0.04 | 0.04 | 0.3                            | 0.04 | 0.05 | 0.05 | 90.2 | 0.14   |  |
| H12      | 7.9                                       | 0.02 | 0.87 | 0.50 | 0.80             | 0.5              | 2.7 | 1.02 | 0.33 | 0.0098 | 7.75                     | 0.06 | 0.02 | 0.16 | 0.01 | 0.1                            | 0.03 | 0.03 | 0.40 | 85.3 | 0.09   |  |
| H13      | 6.4                                       | 0.04 | 0.81 | 0.53 | 0.60             | 0.6              | 1.9 | 0.75 | 0.04 | 0.0078 | 8.53                     | 0.02 | 0.03 | 0.12 | 0.02 | 0.2                            | 0.05 | 0.08 | 0.08 | 88.4 | 0.13   |  |
| H14      | 7.0                                       | 0.07 | 0.88 | 0.60 | 0.60             | 0.2              | 2.8 | 0.42 | 0.62 | 0.0150 | 16.67                    | 0.05 | 0.06 | 0.04 | 0.01 | 0.2                            | 0.06 | 0.08 | 0.08 | 86.9 | 0.19   |  |
| H15      | 7.5                                       | 0.06 | 0.83 | 0.40 | 0.93             | 0.3              | 2.4 | 0.61 | 0.33 | 0.0001 | 12.30                    | 0.06 | 0.08 | 0.02 | 0.05 | 0.3                            | 0.03 | 0.09 | 0.09 | 86.7 | 0.07   |  |
| H16      | 7.0                                       | 0.07 | 0.91 | 0.58 | 0.70             | 0.4              | 3.2 | 0.39 | 0.47 | 0.0305 | 17.95                    | 0.07 | 0.05 | 0.08 | 0.01 | 0.1                            | 0.07 | 0.03 | 0.40 | 86.3 | 0.02   |  |
| H17      | 3.2                                       | 0.07 | 0.77 | 0.30 | 1.00             | 0.3              | 2.8 | 0.93 | 0.35 | 0.0065 | 3.44                     | 0.04 | 0.04 | 0.07 | 0.06 | 0.1                            | 0.02 | 0.03 | 0.18 | 90.4 | 0.15   |  |
| H18      | 7.9                                       | 0.03 | 0.85 | 0.60 | 0.53             | 0.5              | 2.4 | 0.11 | 0.39 | 0.0078 | 71.82                    | 0.06 | 0.03 | 0.06 | 0.03 | 0.2                            | 0.07 | 0.07 | 0.67 | 86.2 | 0.19   |  |
| H19      | 3.5                                       | 0.02 | 0.59 | 0.40 | 0.40             | 0.6              | 2.8 | 0.82 | 0.47 | 0.0068 | 4.27                     | 0.05 | 0.04 | 0.03 | 0.03 | 0.3                            | 0.07 | 0.11 | 0.11 | 90.2 | 0.07   |  |
| H20      | 7.8                                       | 0.02 | 0.53 | 0.34 | 0.40             | 0.6              | 2.3 | 0.10 | 0.29 | 0.0073 | 78.00                    | 0.02 | 0.03 | 0.03 | 0.02 | 0.1                            | 0.03 | 0.17 | 0.18 | 87.6 | 0.00   |  |
| H21      | 7.8                                       | 0.04 | 0.56 | 0.40 | 0.35             | 0.5              | 2.5 | 0.42 | 0.27 | 0.0067 | 18.57                    | 0.11 | 0.03 | 0.04 | 0.04 | 0.2                            | 0.03 | 0.14 | 0.10 | 86.8 | 0.20   |  |
| H22      | 6.2                                       | 0.04 | 0.73 | 0.36 | 0.80             | 0.3              | 3.2 | 0.65 | 0.37 | 0.0055 | 9.54                     | 0.04 | 0.11 | 0.03 | 0.02 | 0.1                            | 0.02 | 0.05 | 0.04 | 87.6 | 0.04   |  |
| H23      | 5.9                                       | 0.07 | 0.97 | 0.80 | 0.37             | 0.3              | 2.5 | 0.48 | 0.34 | 0.0047 | 12.29                    | 0.05 | 0.01 | 0.23 | 0.05 | 0.3                            | 0.06 | 0.08 | 0.05 | 88.3 | 0.13   |  |
| H24      | 7.4                                       | 0.05 | 0.71 | 0.43 | 0.60             | 0.5              | 3.1 | 0.73 | 0.30 | 0.0064 | 10.14                    | 0.06 | 0.04 | 0.15 | 0.11 | 0.2                            | 0.04 | 0.09 | 0.03 | 86.1 | 0.11   |  |

[0046]

[Welding Usability]

(Welding Conditions)

In order to confirm the welding usability, welding was performed under the conditions shown in Table 4 by using each wire of Examples and Comparative Examples and using, as a matrix, a steel plate having the composition shown in Table 3.

In the composition of components of the steel plate shown in Table 3, the remainder is Fe and unavoidable impurities.

[0047]

Table 3

| Composition of Components of Matrix (mass%)(*) |      |      |      |       |       | Plate Thickness (mm) | Length (mm) |
|------------------------------------------------|------|------|------|-------|-------|----------------------|-------------|
| JIS G 3106:2015                                | C    | Si   | Mn   | P     | S     |                      |             |
| SM490A                                         | 0.14 | 0.20 | 1.10 | 0.015 | 0.005 | 12                   | 400         |

(\*) The remainder is Fe and unavoidable impurities.

[0048]

Table 4

|                                |     |                                                         |
|--------------------------------|-----|---------------------------------------------------------|
| Welding conditions             | [1] | welding current: about 150 A<br>arc voltage: about 25 V |
|                                | [2] | welding current: about 230 A<br>arc voltage: about 28 V |
|                                | [3] | welding current: about 280 A<br>arc voltage: about 34 V |
| Welding power supply, polarity |     | 350-A capacity thyristor power supply, DCEP             |
| Welding position               |     | horizontal fillet and vertical upward                   |
| Kind of shielding gas          |     | 100 vol% CO <sub>2</sub>                                |
| Shielding gas flow rate        |     | 25 L/min                                                |
| Wire diameter                  |     | 1.2 mm                                                  |
| Wire stick out                 |     | [1]=15 mm, [2]=20 mm, [3]=25 mm                         |

[0049]

(Arc Stability)

With respect to the arc stability, welding was conducted in two positions of horizontal fillet and vertical upward each under three kinds of welding conditions [1] to [3] shown in Table 4, that is, six kinds of welding tests were conducted in total. In respective welding conditions, the sample was rated "A" when the arc was stable in two positions, was rated "B" when the arc was stable in one position and the arc was slightly unstable in one position or when the arc was slightly unstable in two positions, and was rated "C" when the arc was unstable at least in one position.

As for the arc stability, "A" or "B" was judged as Pass, and "C" was judged as Fail.

[0050]

(Bead Shape)

With respect to the bead shape, welding was conducted in two positions of horizontal fillet and vertical upward each under three kinds of welding conditions [1] to [3] shown in Table 4, that is, six kinds of welding tests were conducted in total, and each weld part formed was thereafter observed and visually evaluated. Specifically, the sample was rated "A" when the bead shape was smooth and good in all welds obtained in six kinds of welding tests, and was rated "C" when the bead shape was poor, such as convex or sagged shape, even in one of the welds obtained in six kinds of welding tests.

[0051]

(Bead Appearance)

With respect to the bead appearance, welding was conducted in two positions of horizontal fillet and vertical upward each under three kinds of welding conditions [1] to [3] shown in Table 4, that is, six kinds of welding tests were conducted in total, and each weld part formed was thereafter observed and visually evaluated. Specifically, the sample was rated "A" when the bead appearance was not wavy but good in all welds obtained in six kinds of welding tests, and was rated "C" when the bead appearance was wavy, etc. and poor even in one of the welds obtained in six kinds of welding tests.

[0052]

(Spatter Generation)

With respect to the spatter generation, welding was conducted in two positions of horizontal fillet and vertical upward each under three kinds of welding conditions [1]

to [3] shown in Table 4, that is, six kinds of welding tests were conducted in total, and the sample was quantitatively evaluated based on the spatter generation in each welding test. More specifically, in accordance with WES 2807:2000, welding was performed in an environment where a collection box for keeping spatter was placed. The arc time was set to 60 seconds and after the completion of welding, the spatter in the collection box was collected and measured for the weight. This operation was repeated twice, and the average value was employed as the spatter generation. The sample was rated "A" when the spatter generation was less than 2 g/min in all of six kinds of welding tests, and was rated "C" when the spatter generation was 2 g/min or more even in one of six kinds of welding tests.

[0053]

(Fume Emission)

With respect to the fume emission, welding was conducted in two positions of horizontal fillet and vertical upward each under three kinds of welding conditions [1] to [3] shown in Table 4, that is, six kinds of welding tests were conducted in total, and the sample was quantitatively evaluated based on the fume emission in each welding test. More specifically, in accordance with JIS Z 3930:2013, welding was performed in an environment not affecting the fume emission. The arc time was set to 60 seconds, suction by a filter and sampler attached was started simultaneously with the start of welding, and after the completion of welding, suction was performed for 30 seconds. The fume emission was calculated from the difference in mass between before and after fume collection on the filter. This operation was performed twice, and the average value was employed as the fume emission. The sample was rated "A" when the fume emission was less than 1.5 g/min in all of six kinds of welding tests, and was rated "C" when the fume emission was 1.5 g/min or more even in one of six kinds of welding tests.

[0054]

[Evaluation of Weld Metal]

(Welding Conditions)

In order to evaluate the weld metal, welding was performed under the conditions shown in Table 6 by using each wire of Examples and Comparative Examples and using, as a matrix, a steel plate having the composition shown in Table 5.

In the composition of components of the steel plate shown in Table 5, the remainder is Fe and unavoidable impurities.

[0055]

Table 5

| Composition of Components of Matrix (mass%)(*) |      |      |      |       |       | Plate Thickness (mm) | Length (mm) |
|------------------------------------------------|------|------|------|-------|-------|----------------------|-------------|
| JIS G 3106:2015                                | C    | Si   | Mn   | P     | S     |                      |             |
| SM490A                                         | 0.15 | 0.22 | 1.15 | 0.014 | 0.006 | 20                   | 300         |

(\*) The remainder is Fe and unavoidable impurities.

[0056]

Table 6

|                                |                                             |
|--------------------------------|---------------------------------------------|
| Welding current                | 280 A                                       |
| Welding voltage                | 30 V                                        |
| Welding power supply, polarity | 350-A capacity thyristor power supply, DCEP |
| Welding position               | flat welding                                |
| Kind of shielding gas          | 100 vol% CO <sub>2</sub>                    |
| Shielding gas flow rate        | 25 L/min                                    |
| Interpass temperature          | 135 to 165°C                                |
| Heat input                     | about 1.8 kJ/mm                             |
| Wire diameter                  | 1.2 mm                                      |
| Wire stick out                 | 25 mm                                       |

[0057]

(Mechanical Properties)

The mechanical properties of the weld metal were evaluated by a tensile test and an impact test in accordance with "Methods for Tensile and Impact Tests of Weld Metal" specified in JIS Z 3111:2005.

As the tensile test specimen, a No. A0 test specimen sampled from the position corresponding to the center of the weld metal and the center of the plate thickness was used. As for the impact test specimen, a V notch test specimen sampled from the position corresponding to the center of the weld metal and the center of the plate thickness was used.

[0058]

The tensile strength was rated "A" when the tensile strength was from 500 to 600 MPa, was rated "B" when the tensile strength was from 490 to 650 MPa (excluding those of 500 to 600 MPa), and was rated "C" when the tensile strength was less than 490 MPa or more than 650 MPa.

The toughness was rated "A" when the absorbed energy at -20°C was 80 J or more, was rated "B" when the absorbed energy at -20°C was 27 J or more and less than 80 J, and was rated "C" when the absorbed energy at -20°C was less than 27 J.

As for the tensile strength and toughness, "A" or "B" was judged as Pass, and "C" was judged as Fail.

[0059]

(Diffusible Hydrogen Content)

The diffusible hydrogen content in the weld metal was evaluated by the method in accordance with JIS Z 3118:2007.

Those where the diffusible hydrogen content ( $[H]_d$ ) was 8.0 mL/100 g or less were rated as "A", and those where the diffusible hydrogen content ( $[H]_d$ ) was more than 8.0 mL/100 g were rated as "C".

[0060]

[Moisture Absorption Resistance]

In the evaluation of moisture absorption resistance, three samples each obtained by cutting the manufactured wire into 3 cm were prepared, subjected to prior-test heating of 110°C×1 hour, and allowed to absorb moisture for 24 hours in an atmosphere of 30°C × relative humidity 80% RH. The wire was then heated at 750°C in an argon atmosphere, and the amount of water generated by the heating was measured. The sample was rated "A" when the water amount of the wire after moisture absorption was less than 800 ppm, and was rated "C" when 800 ppm or more.

[0061]

The results of these various tests are shown in Tables 7 and 8 below.

[0062]

Table 7

| No. | Wire No. | Welding Usability |      |      |            |                 |                    |               | Diffusible Hydrogen | Moisture Absorption Resistance | Mechanical Properties |        |                     |        |
|-----|----------|-------------------|------|------|------------|-----------------|--------------------|---------------|---------------------|--------------------------------|-----------------------|--------|---------------------|--------|
|     |          | Arc Stability     |      |      | Bead Shape | Bead Appearance | Spatter Generation | Fume Emission |                     |                                | Tensile Strength      |        | vE <sub>-20°C</sub> |        |
|     |          | 150A              | 230A | 280A |            |                 |                    |               |                     |                                | MPa                   | Rating | J                   | Rating |
| 1   | J1       | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 565                   | A      | 100                 | A      |
| 2   | J2       | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 571                   | A      | 88                  | A      |
| 3   | J3       | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 565                   | A      | 102                 | A      |
| 4   | J4       | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 550                   | A      | 121                 | A      |
| 5   | J5       | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 586                   | A      | 115                 | A      |
| 6   | J6       | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 596                   | A      | 84                  | A      |
| 7   | J7       | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 570                   | A      | 95                  | A      |
| 8   | J8       | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 565                   | A      | 99                  | A      |
| 9   | J9       | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 574                   | A      | 104                 | A      |
| 10  | J10      | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 581                   | A      | 109                 | A      |
| 11  | J11      | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 560                   | A      | 100                 | A      |
| 12  | J12      | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 573                   | A      | 103                 | A      |
| 13  | J13      | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 580                   | A      | 94                  | A      |
| 14  | J14      | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 558                   | A      | 87                  | A      |
| 15  | J15      | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 548                   | A      | 99                  | A      |
| 16  | J16      | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 555                   | A      | 89                  | A      |
| 17  | J17      | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 560                   | A      | 85                  | A      |
| 18  | J18      | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 573                   | A      | 93                  | A      |
| 19  | J19      | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 564                   | A      | 97                  | A      |
| 20  | J20      | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 560                   | A      | 105                 | A      |

Table 7 continued

| No. | Wire No. | Welding Usability |      |      |            |                 |                    |               | Diffusible Hydrogen | Moisture Absorption Resistance | Mechanical Properties |        |         |        |
|-----|----------|-------------------|------|------|------------|-----------------|--------------------|---------------|---------------------|--------------------------------|-----------------------|--------|---------|--------|
|     |          | Arc Stability     |      |      | Bead Shape | Bead Appearance | Spatter Generation | Fume Emission |                     |                                | Tensile Strength      |        | vE-20°C |        |
|     |          | 150A              | 230A | 280A |            |                 |                    |               |                     |                                | MPa                   | Rating | J       | Rating |
| 21  | J21      | A                 | A    | A    | A          | A               | A                  | A             | A                   | 573                            | A                     | 108    | A       |        |
| 22  | J22      | A                 | A    | A    | A          | A               | A                  | A             | A                   | 562                            | A                     | 112    | A       |        |
| 23  | J23      | A                 | A    | A    | A          | A               | A                  | A             | A                   | 560                            | A                     | 104    | A       |        |
| 24  | J24      | A                 | A    | A    | A          | A               | A                  | A             | A                   | 570                            | A                     | 125    | A       |        |
| 25  | J25      | A                 | A    | A    | A          | A               | A                  | A             | A                   | 584                            | A                     | 105    | A       |        |
| 26  | J26      | A                 | A    | A    | A          | A               | A                  | A             | A                   | 569                            | A                     | 108    | A       |        |
| 27  | J27      | A                 | A    | A    | A          | A               | A                  | A             | A                   | 563                            | A                     | 113    | A       |        |
| 28  | J28      | A                 | A    | A    | A          | A               | A                  | A             | A                   | 574                            | A                     | 106    | A       |        |
| 29  | J29      | A                 | A    | A    | A          | A               | A                  | A             | A                   | 576                            | A                     | 96     | A       |        |
| 30  | J30      | A                 | A    | A    | A          | A               | A                  | A             | A                   | 568                            | A                     | 103    | A       |        |
| 31  | J31      | A                 | A    | A    | A          | A               | A                  | A             | A                   | 593                            | A                     | 112    | A       |        |
| 32  | J32      | A                 | A    | A    | A          | A               | A                  | A             | A                   | 530                            | A                     | 87     | A       |        |
| 33  | J33      | A                 | A    | A    | A          | A               | A                  | A             | A                   | 540                            | A                     | 95     | A       |        |

[0063]

Table 8

| No. | Wire No. | Welding Usability |      |      |            |                 |                    |               | Diffusible Hydrogen | Moisture Absorption Resistance | Mechanical Properties |        |                     |        |
|-----|----------|-------------------|------|------|------------|-----------------|--------------------|---------------|---------------------|--------------------------------|-----------------------|--------|---------------------|--------|
|     |          | Arc Stability     |      |      | Bead Shape | Bead Appearance | Spatter Generation | Fume Emission |                     |                                | Tensile Strength      |        | vE. <sub>20°C</sub> |        |
|     |          | 150A              | 230A | 280A |            |                 |                    |               |                     |                                | MPa                   | Rating | J                   | Rating |
| 34  | H1       | A                 | A    | A    | C          | C               | A                  | A             | A                   | A                              | 553                   | A      | 71                  | B      |
| 35  | H2       | A                 | A    | A    | C          | C               | A                  | A             | A                   | A                              | 562                   | A      | 65                  | B      |
| 36  | H3       | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 480                   | C      | 26                  | C      |
| 37  | H4       | A                 | A    | A    | C          | C               | A                  | A             | A                   | A                              | 610                   | B      | 51                  | B      |
| 38  | H5       | A                 | A    | A    | C          | C               | A                  | A             | A                   | A                              | 583                   | A      | 77                  | B      |
| 39  | H6       | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 635                   | B      | 18                  | C      |
| 40  | H7       | A                 | A    | A    | C          | C               | A                  | A             | A                   | A                              | 559                   | A      | 60                  | B      |
| 41  | H8       | A                 | A    | A    | C          | C               | A                  | A             | A                   | A                              | 580                   | A      | 75                  | B      |
| 42  | H9       | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 485                   | C      | 21                  | C      |
| 43  | H10      | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 655                   | C      | 25                  | C      |
| 44  | H11      | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 479                   | C      | 31                  | B      |
| 45  | H12      | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 624                   | B      | 10                  | C      |
| 46  | H13      | C                 | B    | B    | A          | A               | C                  | A             | C                   | A                              | 570                   | A      | 81                  | A      |
| 47  | H14      | A                 | A    | A    | A          | A               | A                  | C             | A                   | C                              | 565                   | A      | 83                  | A      |
| 48  | H15      | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 500                   | A      | 23                  | C      |
| 49  | H16      | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 635                   | B      | 9                   | C      |
| 50  | H17      | A                 | A    | A    | C          | C               | A                  | A             | A                   | A                              | 624                   | B      | 12                  | C      |
| 51  | H18      | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 506                   | A      | 22                  | C      |
| 52  | H19      | A                 | A    | A    | C          | C               | A                  | A             | A                   | A                              | 635                   | B      | 10                  | C      |
| 53  | H20      | A                 | A    | A    | A          | A               | A                  | A             | A                   | A                              | 482                   | C      | 14                  | C      |
| 54  | H21      | A                 | A    | A    | A          | A               | C                  | A             | A                   | C                              | 562                   | A      | 55                  | B      |
| 55  | H22      | A                 | A    | A    | C          | C               | A                  | A             | A                   | C                              | 579                   | A      | 45                  | B      |
| 56  | H23      | A                 | A    | A    | A          | A               | A                  | A             | C                   | C                              | 592                   | A      | 59                  | B      |
| 57  | H24      | C                 | B    | A    | A          | A               | C                  | C             | A                   | A                              | 583                   | A      | 63                  | B      |

[0064]

As seen from Table 7, in Nos. 1 to 33 using the wire Nos. J1 to J33 satisfying the requirements of the present invention, a weld metal having a small diffusible hydrogen content and exhibiting good mechanical properties could be obtained while maintaining good welding usability not only at a high current but also at a low current.

In addition, the wire Nos. J1 to J33 satisfying the requirements were excellent also in the moisture absorption resistance.

[0065]

On the other hand, as seen from Table 8, in Nos. 34 to 57 where the wire Nos. H1 to H24 used did not satisfy the requirements of the present invention, the result in any of evaluation items was not Pass. Details are as follows.

[0066]

In No. 34 (wire No. H1) where the content of  $\text{TiO}_2$  of the wire was less than the lower limit, the bead shape and the bead appearance were deteriorated.

In No. 35 (wire No. H2) where the content of  $\text{TiO}_2$  of the wire exceeded the upper limit, a scale-like bead was generated, and the bead shape and the bead appearance were deteriorated.

In No. 36 (wire No. H3) where the content of C of the wire was less than the lower limit, the tensile strength and the toughness were reduced.

In No. 37 (wire No. H4) where the content of C of the wire exceeded the upper limit, the arc power was strong, and the bead shape and the bead appearance were deteriorated.

[0067]

In No. 38 (wire No. H5) where the content of T.Si of the wire was less than the lower limit, the bead shape and the bead appearance were deteriorated.

In No. 39 (wire No. H6) where the content of T.Si of the wire exceeded the upper limit, the tensile strength was slightly increased, and the toughness was reduced.

In No. 40 (wire No. H7) where the content of  $\text{ZrO}_2$  of the wire was less than the lower limit, the bead shape and the bead appearance were deteriorated.

In No. 41 (wire No. H8) where the content of  $\text{ZrO}_2$  of the wire exceeded the upper limit, a scale-like bead was generated, and the bead shape and the bead appearance were deteriorated.

[0068]

In No. 42 (wire No. H9) where the content of Mn of the wire was less than the lower limit, the tensile strength and the toughness were reduced.

In No. 43 (wire No. H10) where the content of Mn of the wire exceeded the upper limit, the tensile strength was increased, and the toughness was reduced.

In No. 44 (wire No. H11) where the content of Al of the wire was less than the lower limit, the tensile strength was reduced.

In No. 45 (wire No. H12) where the content of Al of the wire exceeded the upper limit, the toughness was reduced.

[0069]

In No. 46 (wire No. H13) where the content of NaF of the wire was less than the lower limit, the arc stability was deteriorated, and the spatter generation and the diffusible hydrogen content were increased.

In No. 47 (wire No. H14) where the content of NaF of the wire exceeded the upper limit, the fume emission was increased, and the moisture absorption resistance was deteriorated.

In No. 48 (wire No. H15) where the content of T.B of the wire was less than the lower limit, the toughness was reduced.

In No. 49 (wire No. H16) where the content of T.B of the wire exceeded the upper limit, the tensile strength was slightly increased, and the toughness was reduced.

[0070]

In No. 50 (wire No. H17) and No. 52 (wire No. H19) where the value calculated by  $[\text{TiO}_2]/[\text{Al}]$  of the wire was less than the lower limit, the bead shape and the bead appearance were deteriorated, the tensile strength was slightly increased, and the toughness was reduced.

In No. 51 (wire No. H18) and No. 53 (wire No. H20) where the value calculated by  $[\text{TiO}_2]/[\text{Al}]$  of the wire exceeded the upper limit, the toughness was reduced.

In No. 54 (wire No. H21) where the content of Mg of the wire exceeded the upper limit, the spatter generation was increased, and the moisture absorption resistance was deteriorated.

In No. 55 (wire No. H22) where the content of MgO of the wire exceeded the upper limit, the bead shape and the bead appearance were deteriorated, and the moisture absorption resistance was degraded.

[0071]

In No. 56 (wire No. H23) where the content of Na+K of the wire exceeded the upper limit, the diffusible hydrogen content was increased, and the moisture absorption resistance was deteriorated.

In No. 57 (wire No. H24) where the content of F of the wire exceeded the upper limit, the arc stability in a low current region was deteriorated, and the spatter generation and the fume emission was increased.

[0072]

While the present invention has been described in detail with reference to embodiments and examples thereof, the gist of the present invention is not limited to the contents described above, and the scope of its right is to be broadly interpreted based on the appended claims. Here, it is obvious that modifications, alterations, etc. to the contents of the present invention can be broadly made based on the foregoing descriptions.

This application is based on Japanese Patent Application No. 2016-062573 filed on March 25, 2016, the entire subject matter of which is incorporated herein by reference.

#### Industrial Applicability

[0073]

The flux-cored wire for gas-shielded arc welding of the present invention makes it possible to maintain good welding usability not only at a high current but also at a low current and obtain a weld metal having a small diffusible hydrogen content and good mechanical properties.

## CLAIMS

1. A flux-cored wire for gas-shielded arc welding, comprising, relative to a total mass of the wire:

TiO<sub>2</sub>: 3.0 mass% or more and 8.0 mass% or less;

C: 0.01 mass% or more and 0.10 mass% or less;

at least one of Si and an Si oxide: 0.20 mass% or more and 1.70 mass% or less

in total in terms of Si;

ZrO<sub>2</sub>: 0.1 mass% or more and 1.0 mass% or less;

Mn: 1.3 mass% or more and 3.5 mass% or less;

Al: 0.10 mass% or more and 1.00 mass% or less;

NaF: 0.05 mass% or more and 0.60 mass% or less;

at least one of B and a B oxide: 0.0003 mass% or more and 0.0300 mass% or less in total in terms of B;

Mg: less than 0.10 mass%; and

MgO: less than 0.10 mass%,

wherein a total content of an Na compound except for NaF, in terms of Na, and a K compound, in terms of K, is 0.20 mass% or less, and

a content of an F compound except for NaF, in terms of F, is 0.10 mass% or less, and

$5.00 \leq [\text{TiO}_2]/[\text{Al}] \leq 70.00$  is satisfied, wherein  $[\text{TiO}_2]$  is the content of TiO<sub>2</sub> and  $[\text{Al}]$  is the content of Al.

2. The flux-cored wire for gas-shielded arc welding according to claim 1, further comprising, relative to the total mass of the wire;

Al<sub>2</sub>O<sub>3</sub>: 0.5 mass% or less;

Ca: 0.10 mass% or less;

Ti: 0.25 mass% or less; and

Ni: 4.00 mass% or less.