

DESCRIPTION

Title of the Invention:

WIRE CONTAINING FLUX FOR GAS SHIELD ARC WELDING

5

Technical Field

[0001]

The present invention relates to a flux-cored wire for gas-shielded arc welding. More specifically, the present invention relates to a flux-cored wire for gas-shielded arc welding which can be suitably used for all-position welding including vertical-position welding.

10

Background Art

[0002]

15

In the field of offshore structures or line pipes, there is an ongoing trend of advancing development of energy resources in very deep waters, expanding resource exploration/mining zone to an extreme sea area such as Arctic sea, and growing in the equipment size. Against this background of technical trend, a high-strength and high-toughness design of the offshore structure or the line pipe is proceeding, and more stringent requirements are imposed on the performance of a weld joint.

20

[0003]

On the other hand, as for a welding material, in view of higher efficiency, a flux-cored wire for all-position welding is demanded. In addition, as for a weld metal to be obtained, high fracture toughness is also demanded.

25

However, a conventional flux-cored wire for all-position welding forms a weld metal having a high oxygen amount and therefore, when gas-shielded arc welding is performed using the wire, the weld joint part can be hardly assured of having low-temperature toughness.

[0004]

30

Then, for example, Patent Document 1 discloses a flux-cored wire which can perform highly efficient welding in all positions and has an excellent toughness.

Citation List

Patent Document

[0005]

Patent Document 1: JP-A-S62-166098

5 Summary of Invention

Technical Problems

[0006]

However, in the technique disclosed in Patent Document 1, the strength level of the weld metal is not so high (Table 2 of Patent Document 1), and currently, it is hard to
10 say that the performance required for a structure material in the field of offshore structures or line pipes is sufficiently satisfied. Further, in Patent Document 1, the evaluation temperature of impact performance (toughness) is high (Table 2 of Patent Document 1), and therefore, the weld metal obtained by the technique disclosed in Patent Document 1 cannot be decided to be excellent in low-temperature toughness.

15 In addition, as for the flux-cored wire, not only welding usability is demanded, but also it is necessary to obtain the weld metal excellent in 0.2% yield strength and hot cracking resistance and also having a small diffusible hydrogen content.

[0007]

Accordingly, an object of the present invention is to provide a flux-cored wire for
20 gas-shielded arc welding, ensuring that a weld metal excellent in welding usability in all-position welding including vertical-position welding, further excellent in low-temperature toughness, 0.2% yield strength, tensile strength and hot cracking resistance, and also having a small diffusible hydrogen content is obtained.

25 Solution to Problems

[0008]

The present invention provides the following technical means to solve the above problem(s).

The flux-cored wire for gas-shielded arc welding in the present invention has a
30 steel outer sheath filled with a flux, and includes, relative to a total mass of the wire: BaF₂: 2.0 mass% or more and 11.1 mass% or less; C: 0.01 mass% or more and 0.10 mass% or less; Si: 0.10 mass% or more and 1.50 mass% or less; Mn: 0.70 mass% or more and 3.50 mass% or less; Al: 0.45 mass% or more and less than 2.00 mass%; Mg: 0.10 mass% or

more and 2.00 mass% or less; Ni: 0.50 mass% or more and 12.00 mass% or less; Zr: 0.01 mass% or more and 1.00 mass% or less; Fe: 70.0 mass% or more and 90.0 mass% or less; and Li: 0.01 mass% or more and 1.00 mass% or less, and a value of the BaF_2 content/(the Al content + the Zr content) is 2.1 or more and 20.0 or less.

5 [0009]

According to this flux-cored wire, the contents of the predetermined components fall in the predetermined ranges, and the value of BaF_2 content/(Al content + Zr content) falls in the predetermined range. Accordingly, the weld metal excellent in welding usability in all-position welding including vertical-position welding, further excellent in low-temperature toughness, 0.2% yield strength, tensile strength and hot cracking resistance, and also having a small diffusible hydrogen content can be obtained.

[0010]

The flux-cored wire for gas-shielded arc welding in the present invention may include CaF_2 : 2.0 mass% or less relative to the total mass of the wire.

15 [0011]

According to this flux-cored wire, the content of CaF_2 is equivalent to or less than the predetermined value. Accordingly, an effect of enhancing the welding usability can be ensured.

[0012]

20 The flux-cored wire for gas-shielded arc welding in the present invention may include a metal oxide: 0.29 mass% or less relative to the total mass of the wire;

[0013]

According to this flux-cored wire, the content of the metal oxide is equivalent to or less than the predetermined value. Accordingly, the excellent low-temperature toughness of the weld metal can be ensured.

25

[0014]

The flux-cored wire for gas-shielded arc welding in the present invention may include a metal carbonate: 10.0 mass% or less relative to the total mass of the wire.

[0015]

30 According to this flux-cored wire, the content of the metal carbonate is equivalent to or less than the predetermined value. Accordingly, the excellent low-temperature toughness of the weld metal can be ensured.

[0016]

The flux-cored wire for gas-shielded arc welding in the present invention may include at least one of Cr: 1.00 mass% or less and Mo: 1.00 mass% or less, relative to the total mass of the wire.

[0017]

5 According to this flux-cored wire, the contents of Cr and Mo are equivalent to or less than the predetermined values. Accordingly, the excellent strength of the weld metal can be ensured.

[0018]

10 The flux-cored wire for gas-shielded arc welding in the present invention may include NaF: 1.00 mass% or less relative to the total mass of the wire.

[0019]

 According to this flux-cored wire, the content of NaF is equivalent to or less than the predetermined value. Accordingly, the effect of enhancing the welding usability can be ensured.

15 [0020]

 The flux-cored wire for gas-shielded arc welding in the present invention may include Ca: 1.00 mass% or less relative to the total mass of the wire.

[0021]

20 According to this flux-cored wire, the content of Ca is equivalent to or less than the predetermined value. Accordingly, the effect of enhancing the welding usability can be ensured.

[0022]

 The flux-cored wire for gas-shielded arc welding in the present invention may include Ce and La: 0.300 mass% or less in total relative to the total mass of the wire.

25 [0023]

 According to this flux-cored wire, the total content of Ce and La is equivalent to or less than the predetermined value. Accordingly, the excellent low-temperature toughness of the weld metal can be ensured.

30 Advantageous Effects of Invention

[0024]

 In the flux-cored wire for gas-shielded arc welding of the present invention, a weld metal excellent in welding usability in all-position welding including vertical-position

welding, further excellent in low-temperature toughness, 0.2% yield strength, tensile strength and hot cracking resistance, and also having a small diffusible hydrogen content can be obtained.

5 Description of Embodiments

[0025]

Embodiment for carrying out the present invention are described in detail below.

The flux-cored wire for gas-shielded arc welding in this embodiment (hereinafter appropriately referred to as a "wire" or a "flux-cored wire") is a wire used for the gas-shielded arc welding, in which a steel outer sheath is filled with a flux.

[0026]

Specifically, the wire in this embodiment includes the steel outer sheath having a cylindrical shape and the flux with which an inside of the steel outer sheath is filled. The wire may be either a seamless type having no seam in the steel outer sheath or a seam type having a seam in the steel outer sheath. In addition, the wire may be either plated on a surface (an outside of the steel outer sheath) or not plated.

The wire diameter (diameter) in this embodiment may be from 1.2 mm to 2.4 mm, although not particularly limited. In addition, the flux filling rate of the wire may be from 12 to 25 mass% relative to the total mass of the wire, in view of wire drawing properties and usability (e.g., feedability) during welding, although not particularly limited.

[0027]

Then, in the wire in this embodiment, the contents of the respective components relative to the total mass of the wire (= the mass of the steel outer sheath + the mass of the flux) and the ratio of the contents of the predetermined components are specified.

The reasons for specifying the contents of the respective components of the wire in this embodiment are described below.

[0028]

[BaF₂: 2.0 mass% or more and 11.1 mass% or less]

BaF₂ exerts an effect as a strong deoxidizer and also an effect as a slag forming agent for making excellent the welding usability in all-position welding. However, if the BaF₂ content is less than 2.0 mass%, the bead shape is not kept in vertical-position welding, and the toughness is deteriorated by an increase in the oxygen amount in the weld

metal. On the other hand, if the BaF₂ content exceeds 11.1 mass%, the diffusible hydrogen content in the weld metal is increased by moisture absorption.

Accordingly, the BaF₂ content is 2.0 mass% or more and 11.1 mass% or less relative to the total mass of the wire.

5 From the viewpoint of enhancing the above-mentioned effects, the BaF₂ content is preferably 5.1 mass% or more, and more preferably 6.0 mass% or more. In addition, from the viewpoint of suppressing an increase in the diffusible hydrogen content, the BaF₂ content is preferably 10.0 mass% or less, and more preferably 9.0 mass% or less.

[0029]

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

C exerts an effect of enhancing the strength of the weld metal. However, if the C content is less than 0.01 mass%, the yield strength or the tensile strength of the weld metal becomes insufficient. On the other hand, if the C content exceeds 0.10 mass%, Martensite-Austenite Constituent is produced in the weld metal to deteriorate the toughness. In addition, the strength of the weld metal is excessively increased to readily generate cracking.

Accordingly, the C content is 0.01 mass% or more and 0.10 mass% or less relative to the total mass of the wire.

From the viewpoint of suppressing deterioration of the toughness and from the viewpoint of suppressing generation of cracking, the C content is preferably 0.08 mass% or less.

[0030]

[Si: 0.10 mass% or more and 1.50 mass% or less]

Si exerts an effect of promoting deoxidation in the weld metal. However, if the Si content is less than 0.10 mass%, the deoxidizing effect is lost, leading to generation of a blow hole in the weld metal. On the other hand, if the Si content exceeds 1.50 mass%, the viscosity of the weld metal increases to decrease compatibility with a base metal. In addition, oxide-based inclusions are formed in the weld metal to deteriorate the toughness.

Accordingly, the Si content is 0.10 mass% or more and 1.50 mass% or less relative to the total mass of the wire.

From the viewpoint of suppressing deterioration of the welding usability (suppressing deterioration of the compatibility with the base metal), the Si content is preferably 1.20 mass% or less.

[0031]

[Mn: 0.70 mass% or more and 3.50 mass% or less]

Mn exerts an effect of promoting deoxidation in the weld metal and increasing the toughness of the weld metal. However, if the Mn content is less than 0.70 mass%, the deoxidizing effect is insufficient, leading to generation of the blow hole in the weld metal and deterioration of the toughness. On the other hand, if the Mn content exceeds 3.50 mass%, the strength of the weld metal is excessively increased to readily generate cracking and deteriorate the toughness.

Accordingly, the Mn content is 0.70 mass% or more and 3.50 mass% or less relative to the total mass of the wire.

From the viewpoint of suppressing generation of cracking and from the viewpoint of suppressing deterioration of the toughness, the Mn amount is preferably 2.50 mass% or less.

[0032]

[Al: 0.45 mass% or more and less than 2.00 mass%]

Al exerts the effect as a deoxidizer and also an effect of adjusting the viscosity of molten BaF_2 as a main component of the slag to arrange the bead shape in the vertical-position welding. However, if the Al content is less than 0.45 mass%, the viscosity of the molten slag decreases to generate dropping of the weld metal in the vertical-position welding. In addition, the slag is readily crushed by a decrease of an Al_2O_3 phase in the solidified slag to deteriorate slag removability. On the other hand, if the Al content is 2.00 mass% or more, coarse oxide-based inclusions are formed in the weld metal to deteriorate the toughness.

Accordingly, the Al content is 0.45 mass% or more and less than 2.00 mass% relative to the total mass of the wire.

From the viewpoint of suppressing deterioration of the welding usability, the Al content is preferably 0.70 mass% or more. In addition, from the viewpoint of suppressing deterioration of the toughness, the Al content is preferably 1.80 mass% or less.

[0033]

[Mg: 0.10 mass% or more and 2.00 mass% or less]

Mg exerts the effect of promoting deoxidation in the weld metal. However, if the Mg content is less than 0.10 mass%, the deoxidizing effect is insufficient, leading to generation of the blow hole in the weld metal and deterioration of the toughness. On the

other hand, if the Mg content exceeds 2.00 mass%, the solidification temperature of the molten slag is lowered to deteriorate the welding usability in the vertical-position welding.

Accordingly, the Mg content is 0.10 mass% or more and 2.00 mass% or less relative to the total mass of the wire.

5 From the viewpoint of suppressing deterioration of the toughness, the Mg content is preferably 0.50 mass% or more. In addition, from the viewpoint of suppressing deterioration of the welding usability, the Mg content is preferably 1.70 mass% or less.

[0034]

[Ni: 0.50 mass% or more and 12.00 mass% or less]

10 Ni exerts an effect of enhancing the toughness of the weld metal. However, if the Ni content is less than 0.50 mass%, the toughness of the weld metal becomes insufficient. On the other hand, if the Ni content exceeds 12.00 mass%, the possibility of generation of hot cracking of the weld metal is increased.

15 Accordingly, the Ni content is 0.50 mass% or more and 12.00 mass% or less relative to the total mass of the wire.

From the viewpoint of suppressing deterioration of the toughness, the Ni content is preferably 1.00 mass% or more, and more preferably 2.00 mass% or more. In addition, from the viewpoint of suppressing generation of hot cracking, the Ni content is preferably 9.00 mass% or less, and more preferably 5.00 mass% or less.

20 [0035]

[Zr: 0.01 mass% or more and 1.00 mass% or less]

25 Zr exerts the effect as a deoxidizer and also the effect of adjusting the viscosity of molten BaF_2 as a main component of the slag to arrange the bead shape in the vertical-position welding. However, if the Zr content is less than 0.01 mass%, the viscosity of the molten slag decreases, and dropping of the weld metal is generated in the vertical-position welding. On the other hand, if the Zr content exceeds 1.00 mass%, Zr is melted in the weld metal to significantly increase the yield strength and tensile strength of a molten metal by solid solution strengthening. As a result, the toughness of the weld metal is deteriorated.

30 Accordingly, the Zr content is 0.01 mass% or more and 1.00 mass% or less relative to the total mass of the wire.

From the viewpoint of suppressing deterioration of the welding usability, the Zr content is preferably 0.05 mass% or more, and more preferably 0.10 mass% or more. In

addition, from the viewpoint of suppressing deterioration of the toughness, the Zr content is preferably 0.90 mass% or less, and more preferably 0.80 mass% or less.

[0036]

[Fe: 70.0 mass% or more and 90.0 mass% or less]

5 Fe is a main component of the wire. If the Fe content is less than 70.0 mass%, the deposition amount is insufficient. On the other hand, if the Fe content exceeds 90.0 mass%, the relative amount of the slag is insufficient, leading to deterioration of the toughness due to insufficient deoxidation and to formation of a convex bead shape during welding in the vertical-position welding.

10 Accordingly, the Fe content is 70.0 mass% or more and 90.0 mass% or less relative to the total mass of the wire.

[0037]

[Li: 0.01 mass% or more and 1.00 mass% or less]

15 Li exerts the effect of enhancing the toughness of the weld metal. However, if the Li content is less than 0.01 mass%, Al and Zr are caused to excessively remain in the weld metal, thereby significantly increasing the yield strength and tensile strength of the weld metal. As a result, the toughness of the weld metal is deteriorated. On the other hand, if the Li content exceeds 1.00 mass%, arc becomes unstable to generate lack of fusion.

20 Accordingly, the Li content is 0.01 mass% or more and 1.00 mass% or less relative to the total mass of the wire.

From the viewpoint of suppressing generation of the lack of fusion, the Li content is preferably 0.80 mass% or less, and more preferably 0.50 mass% or less.

[0038]

25 [BaF₂ Content/(Al Content + Zr Content): 2.1 or more and 20.0 or less]

In the wire in this embodiment, the ratio of the BaF₂ content to the total content of Al and Zr (the value of BaF₂ content/(Al content + Zr content)) falls in the predetermined range.

30 As described above, BaF₂ exerts the effect as a strong deoxidizer and also the effect as a slag forming agent for making excellent the welding usability in all-position welding, and Al and Zr also exert the effect as a deoxidizer and also the effect of adjusting the viscosity of molten BaF₂ as a main component of the slag to arrange the bead shape in the vertical-position welding.

By adjusting the ratio of these contents so as to fall in the predetermined range, the effect of arranging the bead shape to a preferred state is exerted in the vertical-position welding. However, if this ratio is less than 2.1, the volume of the molten slag is small, and the bead shape cannot be ensured in the vertical-position welding. In addition, the oxygen amount in the weld metal increases to deteriorate the toughness. On the other hand, if this ratio exceeds 20.0, the viscosity of molten BaF_2 as a main component of the slag decreases to form the convex bead shape in the vertical-position welding. In addition, the volume of the slag becomes excessive to generate slag inclusion.

Accordingly, the value of BaF_2 content/(Al content + Zr content) is 2.1 or more and 20.0 or less.

From the viewpoint of preventing deterioration of the toughness, this ratio is preferably 6.0 or more, and more preferably 7.0 or more. In addition, from the viewpoint of suppressing deterioration of the welding usability, this ratio is preferably 15.0 or less, and more preferably 10.0 or less.

[0039]

Although the essential components in the wire in this embodiment have been described so far, components which should be suppressed from being contained in the wire, optional components which may be contained in the wire when a further effect is desired to be obtained and unavoidable impurities are described below.

[0040]

[CaF_2 : 2.0 mass% or less]

CaF_2 is a component which should be suppressed from being contained in the wire, and the CaF_2 content is preferably low (may be 0 mass%). Then, if the CaF_2 content exceeds 2.0 mass%, the viscosity of the molten slag is decreased, leading to difficulty of welding in the vertical position.

Accordingly, when CaF_2 is contained in the wire, the CaF_2 content is 2.0 mass% or less relative to the total mass of the wire.

[0041]

[Metal Oxide: 0.29 mass% or less]

A metal oxide is a component which should be suppressed from being contained in the wire, and the metal oxide content is preferably low (may be 0 mass%). Then, if the metal oxide content exceeds 0.29 mass%, this metal oxide remains and disperses in the molten metal to deteriorate the low-temperature toughness of the weld metal.

Accordingly, when the metal oxide is contained in the wire, the metal oxide content is 0.29 mass% or less relative to the total mass of the wire.

The metal oxide is specifically one or more kinds of Al_2O_3 , Fe_2O_3 , SiO_2 and TiO_2 , and the metal oxide content is the total content of the respective components enumerated.

5 [0042]

[Metal Carbonate: 10.0 mass% or less]

A metal carbonate is a component which should be suppressed from being contained in the wire, and the metal carbonate content is preferably low (may be 0 mass%). Then, if the metal carbonate content exceeds 10.0 mass%, an increase in the oxygen
10 amount in the weld metal is caused thereby to deteriorate the low-temperature toughness. In addition, the stability of the arc is decreased by excessive gas generation to cause generation of the lack of fusion.

Accordingly, when the metal carbonate is contained in the wire, the metal carbonate content is 10.0 mass% or less relative to the total mass of the wire.

15 The metal carbonate is specifically one or more kinds of CaCO_3 and BaCO_3 , and the metal carbonate content is the total content of the respective components enumerated.
[0043]

[Cr: 1.00 mass% or less, Mo: 1.00 mass% or less]

Cr and Mo exert an effect of enhancing the tensile strength of the weld metal by
20 containing at least one thereof in the wire, although both are not an essential component. However, if the Cr content exceeds 1.00 mass%, or if the Mo content exceeds 1.00 mass%, the strength of the weld metal is excessively increased to increase a possibility of cracking generation. In addition, the toughness of the weld metal is deteriorated.

Accordingly, when Cr or Mo is contained in the wire, at least one of 1.00 mass%
25 or less of Cr and 1.00 mass% or less of Mo may be contained.

From the viewpoint of suppressing the tensile strength from being excessively increased, and from the viewpoint of suppressing deterioration of the toughness, the Cr and Mo contents are each preferably 0.30 mass% or less. In addition, from the viewpoint of more enhancing the above-mentioned effects, the Cr and Mo contents are each preferably
30 0.01 mass% or more, and more preferably 0.05 mass% or more.

[0044]

[NaF: 1.00 mass% or less]

NaF exerts the effect of enhancing the welding usability by containing in the wire, although NaF is not an essential component. However, if the NaF content exceeds 1.00 mass%, the diffusible hydrogen content in the weld metal is increased by moisture absorption.

5 Accordingly, when NaF is contained in the wire, the NaF content is 1.00 mass% or less.

From the viewpoint of more enhancing the above-mentioned effect, the NaF content is preferably 0.01 mass% or more, and more preferably 0.05 mass% or more.

[0045]

10 [Ca: 1.00 mass% or less]

Ca exerts the effect of enhancing the welding usability by containing in the wire, although Ca is not an essential component. However, if the Ca content exceeds 1.00 mass%, Ca is added as Ca oxide to the molten slag to decrease the viscosity of the slag, and dropping of the molten metal is generated in the vertical-position welding.

15 Accordingly, when Ca is contained in the wire, the Ca content is 1.00 mass% or less.

From the viewpoint of more enhancing the above-mentioned effect, the Ca content is preferably 0.01 mass% or more, and more preferably 0.05 mass% or more.

[0046]

20 [Ce and La: 0.300 mass% or less in total]

Ce and La exert the effect of enhancing the toughness by containing in the wire, although both are not an essential component. However, if the total content of Ce and La exceeds 0.300 mass%, oxidation of these components causes moisture absorption to suppress an increase in the diffusible hydrogen content in the weld metal and to decrease the low-temperature toughness.

25

Accordingly, when Ce and La are contained in the wire, the total content of Ce and La is 0.300 mass% or less.

From the viewpoint of suppressing an increase in the diffusible hydrogen content, the total content of Ce and La is preferably 0.100 mass% or less. In addition, from the viewpoint of more enhancing the above-mentioned effect, the total content of Ce and La is preferably 0.010 mass% or more.

30

[0047]

[Remainder: unavoidable impurities]

The remainder in the composition of the components of the wire in this embodiment is unavoidable impurities. Then, P, S, Nb, V, Sb, Bi, B, etc. may be contained as the unavoidable impurities in a range not disturbing the effects of the present invention. Specifically, P: 0.030 mass% or less, S: 0.030 mass% or less, Nb: 0.30 mass% or less, V: 0.30 mass% or less, Sb: 0.030 mass% or less, Bi: 0.0050 mass% or less, and B: 0.0050 mass% or less.

In addition, the remainder may include alloying agents such as Ti, Cu, Nb, V, Bi and B, compounds thereof, arc stabilizers and slag formers, in a range not disturbing the effects of the present invention. In the case where each component other than the above-mentioned metal oxides and metal carbonates is added as an oxide or a nitride, the remainder of the wire in this embodiment includes not only O but also N.

P, S, Nb, V, Sb, Bi, B, etc. enumerated as the unavoidable impurities do not disturb the effects of the present invention, in the case where they are not only contained as the unavoidable impurities but also positively added, as long as they are added without exceeding the above-mentioned predetermined contents.

In addition, CaF_2 , the metal oxide, the metal carbonate, Cr, Mo, NaF, Ca, Ce and La in which only the upper limits described above are specified may be positively added, but may also be contained as the unavoidable impurities.

[0048]

The components of the wire in this embodiment have been described. However, the Al content does not contain Al derived from Al_2O_3 , the Fe content does not contain Fe derived from Fe_2O_3 , the Si content does not contain Si derived from SiO_2 , the C content does not contain C derived from the metal carbonate, and the Ca content does not contain Ca derived from CaCO_3 and CaF_2 .

[0049]

A method for manufacturing the wire in this embodiment is described below.

[Method for Manufacturing 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 for constituting a steel outer sheath is prepared, and this steel strip is formed on a forming roll while feeding it in the longitudinal direction to obtain a U-shaped open tube. Then, the steel outer sheath is filled with a flux in which respective components are blended to obtain a predetermined chemical composition, and then

processed to have a circular cross-section. Thereafter, the wire is drawn by cold working to form a flux-cored wire having a wire diameter of, for example, from 1.2 mm to 2.4 mm. In the middle of the cold working, annealing may be applied. In addition, both structures of the seamless wire in which a joint of the steel outer sheath formed in the course of manufacture is welded and the wire in which the above-mentioned joint is left in a state of clearance without being welded can be adopted.

Examples

[0050]

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

In these examples, a tubular outer sheath formed of a carbon steel having a component composition in the range shown in Table 1 was filled with a flux to produce flux-cored wires (diameter: 1.6 mm) of Examples and Comparative Examples. As to the components of the outer sheath shown in Table 1 below, the remainder is Fe and unavoidable impurities. The flux filling rate was adjusted to fall in the range of 17.0 to 22.0 mass% relative to the total mass of the wire.

[0051]

Table 1

Components of Steel Outer Sheath (mass%)								
C	Si	Mn	P	S	Cu	Ni	Cr	Al
≤ 0.10	≤ 0.10	0.10 to 0.90	≤ 0.03	≤ 0.03	≤ 0.10			

[0052]

In Tables 2 to 4 below, the component compositions of the entire wires of Examples and Comparative Examples are shown. As to the wire components shown in Tables 2 to 4 below, the remainder is unavoidable impurities.

In addition, "BaF₂/(Al+Zr)" in Tables 2 to 4 means "BaF₂ content/(Al content + Zr content)". Then, "Ce or La" in Tables 2 to 4 means "the total content of Ce and La".

Furthermore, in Tables 2 to 4, values which do not meet the ranges of the present invention are indicated by underlining.

[0053]

Table 2

No.	Wire Components (mass%)										Ratio	
	BaF ₂	C	Si	Mn	Al	Mg	Ni	Zr	Fe	Li	BaF ₂ /(Al+Zr)	
1	9.1	0.07	1.10	1.74	0.45	1.17	3.46	0.64	81.4	0.71	8.3	
2	2.7	0.09	1.06	2.00	0.50	0.65	2.50	0.70	89.2	0.51	2.3	
3	10.9	0.07	0.85	2.16	1.02	0.44	7.27	0.76	74.2	0.25	6.1	
4	5.2	0.06	1.21	2.03	0.70	0.86	6.98	0.20	81.8	0.68	5.8	
5	9.9	0.07	0.45	2.06	1.11	0.29	7.62	0.84	77.2	0.43	5.1	
6	6.1	0.08	0.58	2.35	0.61	0.36	10.20	0.12	78.7	0.68	8.4	
7	8.8	0.08	0.46	3.15	0.62	1.07	6.54	0.45	77.6	0.83	8.2	
8	7.3	0.06	0.57	1.38	0.60	1.64	5.68	0.25	81.3	0.89	8.6	
9	9.2	0.03	1.21	1.15	1.81	0.92	4.35	0.11	80.3	0.56	4.8	
10	8.1	0.08	0.29	0.93	0.80	0.83	8.04	0.12	80.3	0.20	8.8	
11	8.6	0.05	0.17	1.68	1.60	1.28	6.51	0.10	79.1	0.77	5.1	
12	8.4	0.05	1.39	0.88	1.00	0.15	2.53	0.12	84.6	0.32	7.5	
13	7.8	0.02	1.15	2.08	0.70	1.98	4.29	0.20	71.4	0.26	8.7	
14	8.9	0.08	0.98	1.88	0.66	0.52	10.83	0.61	74.5	0.69	7.0	
15	7.5	0.03	0.81	1.17	0.80	1.67	2.53	0.21	76.0	0.18	7.4	
16	7.6	0.05	0.19	1.05	0.90	0.37	3.69	0.09	85.8	0.02	7.7	
17	8.0	0.01	0.39	1.46	0.82	0.28	1.55	0.20	86.0	0.99	7.8	
18	7.4	0.07	0.44	2.94	0.88	0.24	7.58	0.30	79.3	0.78	6.3	
19	8.5	0.08	0.26	2.88	0.72	0.44	3.48	0.03	83.5	0.01	11.3	
20	7.9	0.07	1.23	2.58	0.80	1.63	8.37	0.20	76.7	0.48	7.9	
21	6.3	0.02	0.36	0.92	1.78	0.64	3.52	0.79	85.0	0.38	2.5	
22	11.1	0.05	1.27	1.05	0.51	1.19	2.33	0.06	81.9	0.30	19.5	
23	7.6	0.07	0.62	1.52	0.77	0.92	3.94	0.45	83.3	0.55	6.2	

Table 2 continued

No.	Wire Components (mass%)													
	CaF ₂	Metal Oxides					Metal Carbonates			Cr	Mo	NaF	Ca	Ce or La
		Al ₂ O ₃	Fe ₂ O ₃	SiO ₂	TiO ₂	Total	CaCO ₃	BaCO ₃	Total					
1	0.0	0.00	0.10	0.00	0.00	0.10	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
2	0.0	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
3	1.9	0.10	0.00	0.00	0.00	0.10	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
4	0.0	0.10	0.10	0.00	0.00	0.20	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
5	0.0	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
6	0.0	0.10	0.00	0.10	0.00	0.20	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
7	0.3	0.00	0.00	0.10	0.00	0.10	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
8	0.0	0.20	0.00	0.00	0.09	0.29	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
9	0.0	0.10	0.10	0.00	0.09	0.29	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
10	0.0	0.09	0.10	0.10	0.00	0.29	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
11	0.0	0.00	0.10	0.00	0.00	0.10	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
12	0.0	0.10	0.00	0.10	0.00	0.20	0.3	0.0	0.3	0.00	0.00	0.00	0.00	0.000
13	1.6	0.00	0.00	0.00	0.00	0.00	5.5	3.0	8.5	0.00	0.00	0.00	0.00	0.000
14	0.0	0.00	0.00	0.00	0.00	0.00	0.0	0.3	0.3	0.00	0.00	0.00	0.00	0.000
15	0.0	0.00	0.00	0.10	0.00	0.10	9.0	0.0	9.0	0.00	0.00	0.00	0.00	0.000
16	0.0	0.10	0.10	0.00	0.00	0.20	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
17	0.0	0.10	0.10	0.09	0.00	0.29	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
18	0.0	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
19	0.0	0.00	0.10	0.00	0.00	0.10	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
20	0.0	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
21	0.0	0.10	0.00	0.00	0.10	0.20	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
22	0.0	0.10	0.00	0.00	0.10	0.20	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
23	0.0	0.10	0.00	0.10	0.00	0.20	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000

[0054]

Table 3

No.	Wire Components (mass%)											Ratio BaF ₂ /(Al+Zr)
	BaF ₂	C	Si	Mn	Al	Mg	Ni	Zr	Fe	Li		
24	10.3	0.06	0.32	1.20	0.45	1.51	7.35	0.29	77.5	0.84	13.9	
25	8.9	0.03	0.82	2.33	0.60	1.53	5.60	0.51	79.2	0.19	8.0	
26	10.2	0.03	0.28	1.31	1.10	1.40	3.40	0.10	79.6	0.55	8.5	
27	7.2	0.06	0.57	1.38	0.60	1.64	5.68	0.25	80.1	0.89	8.5	
28	9.1	0.03	1.21	1.15	1.81	0.92	4.35	0.11	79.1	0.56	4.7	
29	8.0	0.08	0.29	0.93	0.80	0.83	8.04	0.12	78.4	0.20	8.7	
30	8.5	0.05	0.17	1.68	1.60	1.28	6.51	0.10	77.5	0.77	5.0	
31	8.3	0.05	1.39	0.88	1.00	0.15	2.53	0.12	84.1	0.32	7.4	
32	7.7	0.02	1.15	2.08	0.70	1.98	4.29	0.20	70.4	0.26	8.6	
33	8.8	0.08	0.98	1.88	0.66	0.52	10.83	0.61	73.0	0.69	6.9	
34	7.4	0.03	0.81	1.17	0.80	1.67	2.53	0.21	75.2	0.18	7.3	
35	7.5	0.05	0.19	1.05	0.90	0.37	3.69	0.09	84.0	0.02	7.6	
36	7.9	0.01	0.39	1.46	0.82	0.28	1.55	0.20	84.7	0.99	7.7	
37	8.6	0.02	0.26	2.86	0.85	0.37	4.71	0.10	81.2	0.02	9.1	
38	7.3	0.07	0.44	2.94	0.88	0.24	7.58	0.30	77.5	0.78	6.2	
39	8.4	0.08	0.26	2.88	0.72	0.44	3.48	0.03	82.6	0.01	11.2	
40	7.8	0.07	1.23	2.58	0.80	1.63	8.37	0.20	75.6	0.48	7.8	
41	6.2	0.02	0.36	0.92	1.78	0.64	3.52	0.79	83.4	0.38	2.4	
42	11.0	0.05	1.27	1.05	0.51	1.19	2.33	0.06	81.2	0.30	19.3	
43	7.5	0.07	0.62	1.52	0.77	0.92	3.94	0.45	82.3	0.55	6.1	
44	10.2	0.06	0.32	1.20	0.45	1.51	7.35	0.29	77.2	0.84	13.8	
45	8.8	0.03	0.82	2.33	0.60	1.53	5.60	0.51	78.0	0.19	7.9	
46	9.0	0.07	1.10	1.74	0.45	1.17	3.46	0.64	79.7	0.71	8.3	
47	8.9	0.03	0.82	2.33	0.60	1.53	5.60	0.51	79.0	0.19	8.0	
48	8.9	0.03	0.82	2.33	0.60	1.53	5.60	0.51	79.0	0.19	8.0	
49	8.9	0.03	0.82	2.33	0.60	1.53	5.60	0.51	79.0	0.19	8.0	
50	8.9	0.03	0.82	2.33	0.60	1.53	5.60	0.51	79.0	0.19	8.0	
51	8.9	0.03	0.82	2.33	0.60	1.53	5.60	0.51	79.1	0.19	8.0	

Table 3 continued

No.	Wire Components (mass%)													
	CaF ₂	Metal Oxides					Metal Carbonates			Cr	Mo	NaF	Ca	Ce or La
		Al ₂ O ₃	Fe ₂ O ₃	SiO ₂	TiO ₂	Total	CaCO ₃	BaCO ₃	Total					
24	0.0	0.00	0.00	0.10	0.00	0.10	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
25	0.0	0.00	0.10	0.00	0.10	0.20	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
26	0.0	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.24	0.20	0.64	0.86	0.065
27	0.0	0.20	0.00	0.00	0.09	0.29	0.0	0.0	0.0	0.21	0.23	0.58	0.25	0.030
28	0.0	0.10	0.10	0.00	0.09	0.29	0.0	0.0	0.0	0.21	0.21	0.49	0.39	0.016
29	0.0	0.10	0.10	0.09	0.00	0.29	0.0	0.0	0.0	1.00	0.06	0.67	0.22	0.040
30	0.0	0.00	0.10	0.00	0.00	0.10	0.0	0.0	0.0	0.10	0.21	0.35	0.93	0.059
31	0.0	0.10	0.00	0.10	0.00	0.20	0.3	0.0	0.3	0.02	0.06	0.16	0.36	0.012
32	1.6	0.00	0.00	0.00	0.00	0.00	5.5	3.0	8.5	0.30	0.08	0.09	0.61	0.030
33	0.0	0.00	0.00	0.00	0.00	0.00	0.0	0.3	0.3	0.02	0.30	0.58	0.61	0.054
34	0.0	0.00	0.00	0.10	0.00	0.10	9.0	0.0	9.0	0.23	0.02	0.49	0.09	0.062
35	0.0	0.10	0.10	0.00	0.00	0.20	0.0	0.0	0.0	0.03	1.00	0.11	0.64	0.100
36	0.0	0.10	0.10	0.09	0.00	0.29	0.0	0.0	0.0	0.07	0.09	0.90	0.28	0.016
37	0.0	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.01	0.09	0.41	0.40	0.016
38	0.0	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.08	0.05	0.82	0.89	0.052
39	0.0	0.00	0.10	0.00	0.00	0.10	0.0	0.0	0.0	0.06	0.12	0.59	0.22	0.003
40	0.0	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.16	0.19	0.74	0.06	0.072
41	0.0	0.10	0.00	0.00	0.10	0.20	0.0	0.0	0.0	0.17	0.20	0.60	0.73	0.064
42	0.0	0.10	0.00	0.00	0.10	0.20	0.0	0.0	0.0	0.07	0.10	0.27	0.27	0.057
43	0.0	0.10	0.00	0.10	0.00	0.20	0.0	0.0	0.0	0.23	0.06	0.21	0.30	0.300
44	0.0	0.00	0.00	0.10	0.00	0.10	0.0	0.0	0.0	0.10	0.15	0.14	0.01	0.008
45	0.0	0.00	0.10	0.00	0.10	0.20	0.0	0.0	0.0	0.05	0.30	0.45	0.51	0.020
46	0.0	0.00	0.10	0.00	0.00	0.10	0.0	0.0	0.0	0.10	0.03	0.84	0.79	0.007
47	0.0	0.00	0.10	0.00	0.10	0.20	0.0	0.0	0.0	0.20	0.00	0.00	0.00	0.000
48	0.0	0.00	0.10	0.00	0.10	0.20	0.0	0.0	0.0	0.00	0.20	0.00	0.00	0.000
49	0.0	0.00	0.10	0.00	0.10	0.20	0.0	0.0	0.0	0.00	0.00	0.20	0.00	0.000
50	0.0	0.00	0.10	0.00	0.10	0.20	0.0	0.0	0.0	0.00	0.00	0.00	0.20	0.000
51	0.0	0.00	0.10	0.00	0.10	0.20	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.100

[0055]

Table 4

No.	Wire Components (mass%)											Ratio BaF ₂ /(Al+Zr)
	BaF ₂	C	Si	Mn	Al	Mg	Ni	Zr	Fe	Li		
52	1.8	0.08	0.87	2.86	1.53	1.55	8.72	0.69	81.1	0.63		0.8
53	11.2	0.05	0.96	2.66	0.75	0.38	7.82	0.84	74.7	0.40		7.0
54	8.5	0.00	0.96	2.63	1.09	1.09	4.94	0.10	80.1	0.05		7.1
55	8.3	0.12	1.37	2.36	0.75	0.99	6.94	0.11	78.2	0.69		9.7
56	9.4	0.02	0.08	3.03	0.72	1.55	8.46	0.54	75.4	0.62		7.5
57	8.6	0.02	1.53	2.50	0.91	1.74	11.42	0.24	72.0	0.79		7.5
58	8.1	0.03	0.61	0.64	0.81	0.80	10.62	0.12	77.5	0.48		8.7
59	8.9	0.08	0.48	3.58	0.75	1.05	6.18	0.35	78.3	0.03		8.1
60	8.6	0.03	1.21	1.70	0.41	0.23	0.74	0.74	86.1	0.07		7.5
61	11.0	0.02	1.36	2.34	2.11	0.54	9.63	0.10	72.1	0.48		5.0
62	8.7	0.08	1.01	1.03	0.75	0.04	3.55	0.50	83.3	0.81		7.0
63	8.7	0.07	1.01	2.06	1.03	2.12	7.51	0.20	76.3	0.81		7.1
64	8.3	0.07	0.92	2.48	0.78	0.32	0.41	0.25	85.8	0.21		8.1
65	8.8	0.08	0.46	3.40	0.87	1.06	12.50	0.25	71.4	0.78		7.9
66	8.5	0.06	0.79	1.19	0.89	0.82	4.59	0.00	81.4	0.84		9.6
67	9.0	0.03	1.29	2.67	0.70	1.59	9.20	1.10	73.9	0.36		5.0
68	8.9	0.04	0.70	3.20	0.78	0.33	6.00	0.45	69.1	0.71		7.2
69	6.1	0.04	0.51	1.10	0.78	0.40	0.90	0.02	90.1	0.07		7.6
70	8.8	0.02	0.65	2.23	0.75	1.76	8.42	0.24	76.0	0.00		8.9
71	8.1	0.04	1.21	0.99	0.79	1.74	4.40	0.35	81.1	1.05		7.1
72	3.8	0.04	0.70	1.35	1.79	1.31	3.05	0.10	87.4	0.46		2.0
73	11.0	0.05	1.38	2.74	0.51	0.68	10.45	0.01	72.3	0.80		21.2
74	8.8	0.08	1.44	1.64	1.04	1.26	8.68	0.11	74.3	0.33		7.7
75	7.2	0.06	1.42	1.81	0.71	0.28	5.31	0.15	82.2	0.44		8.4
76	8.2	0.05	0.97	1.63	0.89	0.58	2.32	0.24	74.2	0.11		7.3
77	8.3	0.04	0.60	0.82	0.87	1.77	1.93	0.20	83.7	0.50		7.8
78	6.4	0.03	0.32	3.23	0.71	1.14	6.50	0.20	79.5	0.74		7.0
79	8.0	0.03	0.36	3.24	0.80	1.20	7.75	0.20	77.1	0.09		8.0
80	8.0	0.07	0.99	3.27	0.89	1.10	6.60	0.11	77.6	0.18		8.0
81	8.5	0.02	0.96	2.63	1.09	1.09	4.94	0.10	80.1	0.05		7.1

Table 4 continued

No.	Wire Components (mass%)													
	CaF ₂	Metal Oxides					Metal Carbonates			Cr	Mo	NaF	Ca	Ce or La
		Al ₂ O ₃	Fe ₂ O ₃	SiO ₂	TiO ₂	Total	CaCO ₃	BaCO ₃	Total					
52	0.0	0.00	0.00	0.00	0.10	0.10	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
53	0.0	0.10	0.10	0.00	0.00	0.20	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
54	0.0	0.10	0.00	0.10	0.00	0.20	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
55	0.0	0.00	0.10	0.00	0.00	0.10	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
56	0.0	0.10	0.00	0.00	0.00	0.10	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
57	0.0	0.00	0.00	0.10	0.10	0.20	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
58	0.0	0.00	0.00	0.10	0.10	0.20	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
59	0.0	0.19	0.10	0.00	0.00	0.29	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
60	0.0	0.10	0.00	0.00	0.00	0.10	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
61	0.1	0.10	0.00	0.10	0.00	0.20	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
62	0.0	0.00	0.10	0.00	0.10	0.20	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
63	0.0	0.00	0.00	0.00	0.10	0.10	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
64	0.0	0.00	0.00	0.00	0.10	0.10	0.0	0.0	0.0	0.00	0.00	0.00	0.30	0.000
65	0.0	0.10	0.10	0.00	0.00	0.20	0.0	0.0	0.0	0.00	0.00	0.20	0.00	0.000
66	0.0	0.00	0.00	0.00	0.00	0.00	0.3	0.0	0.3	0.10	0.10	0.00	0.00	0.000
67	0.0	0.00	0.00	0.10	0.00	0.10	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
68	1.5	0.10	0.00	0.10	0.00	0.20	4.0	4.0	8.0	0.00	0.00	0.00	0.00	0.000
69	0.0	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
70	0.0	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.050
71	0.0	0.10	0.00	0.10	0.00	0.20	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
72	0.0	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
73	0.0	0.00	0.00	0.10	0.00	0.10	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
74	2.1	0.00	0.10	0.10	0.00	0.20	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
75	0.0	0.15	0.00	0.10	0.10	0.35	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.000
76	0.0	0.00	0.10	0.10	0.00	0.20	5.8	4.8	10.6	0.00	0.00	0.00	0.00	0.000
77	0.0	0.00	0.00	0.10	0.10	0.20	0.0	0.0	0.0	1.05	0.00	0.00	0.00	0.000
78	0.0	0.00	0.00	0.10	0.00	0.10	0.0	0.0	0.0	0.00	1.05	0.00	0.00	0.000
79	0.0	0.00	0.00	0.10	0.00	0.10	0.0	0.0	0.0	0.00	0.00	1.05	0.00	0.000
80	0.0	0.00	0.00	0.10	0.00	0.10	0.0	0.0	0.0	0.00	0.00	0.00	1.06	0.000
81	0.0	0.10	0.00	0.10	0.00	0.20	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.310

[0056]

Next, gas-shielded arc welding was performed on the base metal shown in Table 5 below by using each of the flux-cored wires of Examples and Comparative Examples. As to the base metal composition shown in Table 5 below, the remainder is Fe and unavoidable impurities.

[0057]

Table 5

	Components of Base metal (mass%)									
	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	Al
JIS G3106 SHY685	0.12	0.26	0.78	0.008	< 0.001	0.19	0.77	0.43	0.43	0.08

[0058]

- 10 The welding conditions are as follows.
- Shielding gas: 100 volume% CO₂, 25 liters/min
 - Wire diameter: ϕ 1.6 mm
 - Groove shape: 20°
 - Root interval: 16 mm
 - 15 · Welding current: 260 A
 - Arc voltage: 26 V
 - Welding position: flat
 - Welding speed: 250 mm/min
 - Welding heat input: 1.8 kJ/mm
 - 20 · Welding length: 400 mm
 - Preheating temperature: 100 to 110°C
 - Interpass temperature: 140 to 160°C
 - Polarity: Direct current electrode negative (DCEN)

[0059]

- 25 With respect to the weld metal obtained by gas-shielded arc welding using each of the flux-cored wires of Examples and Comparative Examples, the mechanical properties (the low-temperature toughness, the 0.2% yield strength and the tensile strength), the diffusible hydrogen content, the hot cracking resistance, the lack of fusion and the generation of a blow hole were evaluated by the following methods.

[0060]

<Mechanical Properties>

The mechanical properties of the weld metal were evaluated by a tensile test and an impact test in conformity with "Methods for Tensile and Impact Tests of Weld Metal" specified in JIS Z 3111:2005. As a result, as to the low-temperature toughness, the weld metal was judged as Pass when the impact value at -80°C (CVN-80) was 100 J or more. As to the 0.2% yield strength (0.2% PS), the weld metal was judged as Pass when it was 690 MPa or more. Further, as to the tensile strength (TS), the weld metal was judged as Pass when it was from 770 MPa or more and 930 MPa or less.

10 [0061]

<Diffusible Hydrogen Content>

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

As a result, the weld metal where the diffusible hydrogen content ($[H]_d$) was 8.0 mL/100 g or less was judged as Pass.

[0062]

<Hot Cracking Resistance, Lack of fusion and Blow Hole>

The hot cracking resistance and the lack of fusion were evaluated based on "Method for Radiolucence Test of Steel Welded Joint" specified in JIS Z 3104:1995.

20 After the completion of welding, the generation of the lack of fusion, the hot cracking and the blow hole in the welded part (welding length: 400 mm, however, a crater part is excluded) were confirmed by an X-ray transmission test, and the total length of parts where these were generated was measured. When the value calculated by (the total length of the parts where the lack of fusion, the hot cracking or the blow hole were generated)/(the length of the welded part) $\times$ 100 was 0%, it was rated as A. When the value was more than 0% and 5% or less, it was rated as B, and when the value was more than 5%, it was rated as C. The case of C was evaluated to be unweldable. Then, A and B were judged as Pass. When welding itself was impossible, it was indicated as "-".

[0063]

30 With respect to each of the flux-cored wires of Examples and Comparative Examples, the welding usability was evaluated by the following method.

<Welding Usability>

The welding usability was evaluated by the compatibility between base metal and bead and the cross-sectional shape of bead by performing vertical upward fillet welding on

the base metal shown in Table 5. As a result, the weld usability was rated "A" when vertical upward welding was possible and a bead surface after welding was smooth, it was rated "B" when vertical upward welding was possible but unevenness was generated on the bead surface after welding, and it was rated "C" when the slag or molten metal dropped
 5 down to make welding impossible or the bead surface took on a largely concave shape due to an insufficient deposition amount. Then, A and B were judged as Pass.

In addition, the slag removability was also evaluated.

The slag removability was rated "A" when a boundary portion (welding length: 400 mm) between slag and base metal was hit once with an air chipper (FCH-20
 10 manufactured by Fuji Air Tools Co., Ltd., air pressure: 0.5 MPa) and the slag having a length of 70% or more relative to the length of the hit portion was removed, it was rated "B" when the slag having a length of 50% or more and less than 70% was removed, and it was rated "C" when the slag having a length of less than 50% was removed. The case of C was evaluated to be unweldable. Then, A and B were judged as Pass.

15 [0064]

The detailed welding conditions in evaluating the welding usability are as follows.

Base metal: the base metal shown in Table 5

Welding current: 220 A

Arc voltage: 24 V

20 Welding speed: 110 mm/min

Wire stick-out length: 20 mm

Weaving width: 5 mm

Automatic welding apparatus: manufactured by Kobe Steel, Ltd., PICOMAX-2Z

[0065]

25 The above results are shown in Table 6 to 8 below. In Tables 6 to 8, values which do not meet the evaluation criteria are indicated by underlining.

[0066]

Table 6

No.	CVN-80 (J)	0.2% PS (MPa)	TS (MPa)	[H] _d (mL/100g)	Welding Usability (Bead Shape)	Slag Removability	Hot Cracking Resistance, Lack of fusion, Blow Hole
1	160	789	853	2.3	A	A	A
2	104	753	871	3.0	B	A	A
3	129	750	809	7.5	B	A	A
4	125	718	846	2.3	B	A	A
5	125	716	863	6.8	B	A	A
6	198	744	887	3.6	A	A	A
7	179	709	836	3.6	A	A	A
8	164	703	833	2.0	B	B	A
9	102	783	791	3.4	B	A	A
10	154	706	889	2.9	A	A	A
11	100	775	801	2.4	B	A	A
12	111	732	814	3.1	A	A	B
13	151	735	824	2.1	B	A	A
14	153	707	815	2.3	A	A	A
15	164	766	832	3.6	A	A	A
16	106	799	889	4.5	A	A	A
17	129	756	792	2.7	A	A	B
18	129	769	841	1.9	B	A	B
19	167	764	847	2.9	A	A	A
20	192	777	793	4.1	A	A	A
21	101	789	881	3.0	B	A	A
22	150	695	820	2.8	B	A	B
23	128	783	795	1.7	B	A	A

[0067]

Table 7

No.	CVN-80 (J)	0.2% PS (MPa)	TS (MPa)	[H] _d (mL/100g)	Welding Usability (Bead Shape)	Slag Removability	Hot Cracking Resistance, Lack of fusion, Blow Hole
24	179	786	861	2.0	B	A	B
25	138	772	811	2.4	A	A	A
26	155	720	830	7.5	A	A	A
27	168	715	842	1.8	B	B	A
28	106	794	800	3.2	B	A	A
29	156	713	896	2.8	A	A	A
30	102	786	808	2.2	B	A	A
31	114	739	823	2.9	A	A	B
32	154	738	837	1.9	B	A	A
33	156	713	822	2.1	A	A	A
34	167	773	840	3.4	A	A	A
35	108	807	897	4.3	A	A	A
36	133	764	800	2.5	A	A	B
37	121	781	868	2.1	A	A	A
38	131	777	849	1.7	B	A	B
39	169	772	855	2.7	A	A	A
40	194	785	801	3.9	A	A	A
41	101	797	889	2.8	B	A	A
42	155	703	828	2.6	B	A	B
43	131	791	803	1.5	B	A	A
44	180	794	869	1.8	B	A	B
45	145	780	819	2.2	A	A	A
46	167	799	863	2.0	A	A	A
47	144	784	821	2.4	A	A	A
48	142	790	840	2.4	A	A	A
49	135	772	811	2.8	A	A	A
50	139	750	805	2.5	A	A	A
51	144	765	808	2.5	A	A	A

[0068]

Table 8

No.	CVN-80 (J)	0.2% PS (MPa)	TS (MPa)	[H] _d (mL/100g)	Welding Usability (Bead Shape)	Slag Removability	Hot Cracking Resistance, Lack of fusion, Blow Hole
52	<u>75</u>	798	893	2.5	-	-	A
53	135	728	854	<u>9.1</u>	A	A	A
54	130	<u>680</u>	<u>760</u>	4.5	A	A	A
55	<u>87</u>	849	<u>956</u>	3.3	A	A	A
56	180	784	889	4.9	A	A	C
57	<u>90</u>	762	849	1.7	C	A	A
58	<u>59</u>	859	846	2.9	A	A	C
59	<u>95</u>	792	<u>963</u>	3.7	A	A	A
60	198	737	899	1.8	C	C	A
61	<u>91</u>	719	824	4.2	B	A	A
62	<u>81</u>	757	823	2.9	A	A	C
63	135	742	842	1.7	-	-	A
64	<u>89</u>	783	884	4.8	A	A	A
65	111	780	866	1.9	A	A	C
66	159	795	876	2.1	-	-	A
67	<u>79</u>	898	<u>949</u>	2.0	B	A	A
68	192	707	804	2.6	C	A	A
69	<u>84</u>	707	829	3.3	-	-	A
70	<u>79</u>	846	<u>936</u>	1.7	A	A	A
71	Test stop			3.5	A	A	C
72	<u>80</u>	768	867	2.5	C	A	A
73	Test stop			1.3	C	-	C
74	181	728	831	2.7	-	-	A
75	<u>94</u>	736	888	3.8	A	A	A
76	<u>69</u>	742	851	1.5	A	A	C
77	<u>98</u>	911	<u>989</u>	3.5	A	A	A
78	<u>92</u>	970	<u>1025</u>	2.8	A	A	A
79	160	780	841	<u>10.9</u>	A	A	A
80	179	744	881	4.5	C	A	A
81	135	744	880	<u>12.3</u>	A	A	A

[0069]

As shown in Tables 6 and 7, Nos. 1 to 51 satisfying the requirements specifying the present invention were good in all evaluation items.

[0070]

5 On the other hand, as shown in Table 8, Nos. 52 to 81 did not satisfy the requirements specifying the present invention, resulting in being poor in any one of the evaluation items. The details are as follows.

[0071]

10 In No. 52, the BaF_2 content was less than the lower limit, and the ratio ($= \text{BaF}_2$ content/(Al content + Zr content)) was less than the lower limit. Accordingly, the toughness was deteriorated, and the vertical upward fillet welding could not be performed.

In No. 53, the BaF_2 content exceeded the upper limit. Accordingly, the diffusible hydrogen content was large.

15 In No. 54, the C content was less than the lower limit. Accordingly, the values of the yield strength and the tensile strength were low.

In No. 55, the C content exceeded the upper limit. Accordingly, the strength became excessive to deteriorate the toughness.

In No. 56, the Si content was less than the lower limit. Accordingly, the blow hole was generated.

20 In No. 57, the Si content exceeded the upper limit. Accordingly, the bead shape was bad, the welding usability was poor, and the toughness was deteriorated.

[0072]

In No. 58, the Mn content was less than the lower limit. Accordingly, the blow hole was generated to deteriorate the toughness.

25 In No. 59, the Mn content exceeded the upper limit. Accordingly, the strength became excessive to deteriorate the toughness.

In No. 60, the Al content was less than the lower limit. Accordingly, the bead shape was bad, the welding usability was poor, and the slag removability was also deteriorated.

30 In No. 61, the Al content exceeded the upper limit. Accordingly, the bead shape became somewhat convex, and the toughness was deteriorated.

In No. 62, the Mg content was less than the lower limit. Accordingly, the toughness was deteriorated, and the blow hole was generated.

In No. 63, the Mg content exceeded the upper limit. Accordingly, the weld metal dropped in the vertical upward fillet welding to make welding impossible.

[0073]

5 In No. 64, the Ni content was less than the lower limit. Accordingly, the toughness was deteriorated.

In No. 65, the Ni content exceeded the upper limit. Accordingly, the hot cracking was generated.

In No. 66, the Zr content was less than the lower limit. Accordingly, the weld metal dropped in the vertical upward fillet welding to make welding impossible.

10 In No. 67, the Zr content exceeded the upper limit. Accordingly, the bead shape became somewhat convex, and the strength became excessive to deteriorate the toughness.

In No. 68, the Fe content was less than the lower limit. Accordingly, the deposition amount was insufficient to make the bead shape concave.

15 In No. 69, the Fe content exceeded the upper limit. Accordingly, the toughness was deteriorated, and the vertical upward fillet welding could not be performed.

[0074]

In No. 70, the Li content was less than the lower limit. Accordingly, the strength became excessive to deteriorate the toughness.

20 In No. 71, the Li content exceeded the upper limit. Accordingly, the lack of fusion was generated.

In No. 72, the ratio ($= \text{BaF}_2 \text{ content} / (\text{Al content} + \text{Zr content})$) was less than the lower limit. Accordingly, the bead shape was bad, the welding usability was poor, and the toughness was deteriorated.

25 In No. 73, the ratio ($= \text{BaF}_2 \text{ content} / (\text{Al content} + \text{Zr content})$) exceeded the upper limit. Accordingly, by generation of slag inclusion, the lack of fusion was generated, and the bead shape became convex.

[0075]

In No. 74, the CaF_2 content exceeded the upper limit. Accordingly, the vertical upward fillet welding could not be performed.

30 In No. 75, the metal oxide content exceeded the upper limit. Accordingly, the toughness was deteriorated.

In No. 76, the metal carbonate content exceeded the upper limit. Accordingly, the toughness was deteriorated, and the lack of fusion was generated.

[0076]

In No. 77, the Cr content exceeded the upper limit. Accordingly, the strength became excessive to deteriorate the toughness.

In No. 78, the Mo content exceeded the upper limit. Accordingly, the strength became excessive to deteriorate the toughness.

5 In No. 79, the NaF content exceeded the upper limit. Accordingly, the diffusible hydrogen content was increased.

[0077]

In No. 80, the Ca content exceeded the upper limit. Accordingly, the vertical upward fillet welding became difficult.

10 In No. 81, the total content of Ce and La exceeded the upper limit. Accordingly, the diffusible hydrogen content was large.

[0078]

While the present invention has been described in detail with reference to embodiments and examples, the spirit of the invention is not limited to the above contents, and the scope of the invention in which patent rights are claimed should be broadly interpreted based on the claims. It goes without saying that various modification and variations can be made in the contents of the invention based on the above descriptions.

15 [0079]

20 This application is based on Japanese Patent Application No. 2015-143365 filed on July 17, 2015, the contents of which are incorporated herein by way of reference.

Industrial Applicability

[0080]

25 The flux-cored wire for gas-shielded arc welding of the present invention is useful particularly for welding of structures in the field of offshore structures or line pipes.

CLAIMS

1. A flux-cored wire for gas-shielded arc welding which has a steel outer sheath filled with a flux, comprising, relative to a total mass of the wire:
- 5 BaF₂: 2.0 mass% or more and 11.1 mass% or less;
C: 0.01 mass% or more and 0.10 mass% or less;
Si: 0.10 mass% or more and 1.50 mass% or less;
Mn: 0.70 mass% or more and 3.50 mass% or less;
Al: 0.45 mass% or more and less than 2.00 mass%;
- 10 Mg: 0.10 mass% or more and 2.00 mass% or less;
Ni: 0.50 mass% or more and 12.00 mass% or less;
Zr: 0.01 mass% or more and 1.00 mass% or less;
Fe: 70.0 mass% or more and 90.0 mass% or less; and
Li: 0.01 mass% or more and 1.00 mass% or less,
- 15 wherein a value of the BaF₂ content/(the Al content + the Zr content) is 2.1 or more and 20.0 or less.
2. The flux-cored wire for gas-shielded arc welding according to claim 1, comprising at least one of the following (a) to (g):
- 20 (a) CaF₂: 2.0 mass% or less relative to the total mass of the wire;
(b) a metal oxide: 0.29 mass% or less relative to the total mass of the wire;
(c) a metal carbonate: 10.0 mass% or less relative to the total mass of the wire;
(d) at least one of Cr: 1.00 mass% or less and Mo: 1.00 mass% or less, relative to the total mass of the wire;
- 25 (e) NaF: 1.00 mass% or less relative to the total mass of the wire;
(f) Ca: 1.00 mass% or less relative to the total mass of the wire; and
(g) Ce and La: 0.300 mass% or less in total relative to the total mass of the wire.