

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

BACKGROUND

Technical Field

[0001]

The present invention relates to a flux-cored wire for gas-shield arc welding of 780 MPa-class high tensile steel, and particularly, to a flux-cored wire for gas-shield arc welding of high tensile steel which has excellent welding workability and superior toughness of a weld metal at a low-temperature range.

Related Art

[0002]

In recent years, as demands have been growing for an increase in size and a reduction in weight of steel structures such as buildings, bridges, or marine structures, tensile strength of steel sheet to be used becomes higher. Recently, high tensile steel having tensile strength of 780 MPa class is generally used.

[0003]

In the production of structures in which the high tensile steel having tensile strength of 780 MPa class is used, a method of gas-shield arc welding is widely used in which the amount of hydrogen in a weld metal is small, crack resistance is excellent, and higher efficiency is achieved.

[0004]

In the related arts, for example, a solid wire for gas-shield arc welding containing compositions such as Ni, Cr, and Mo as disclosed in JP 60-57953 B2 or JP 2000-301379 A was used for the gas-shield arc welding of the high tensile steel. However, since the solid wires for gas-shield arc welding disclosed in JP 60-57953 B2 or JP 2000-301379 A contain a large amount of alloy compositions, the rigidity of the wire becomes harder and thus resistance becomes larger in a wire feeder during welding. As a result, there were problems that a wire feeding property was not stabilized, an arc became unstable, and thus a large amount of spatter was generated.

[0005]

Accordingly, flux-cored wires for gas-shield arc welding disclosed in JP 2006-281223 A or JP 2007-144516 A were used. However, since the flux-cored wires for gas-shield arc welding disclosed in JP 2006-281223 A or JP 2007-144516 A were excellent in wire feeding property or arc stability but contained a large amount of slag forming agents, there were problems that a large amount of oxygen was contained in the weld metal and thus toughness could not be improved at a low temperature.

[0006]

As a technique of reducing the amount of oxygen contained in the weld metal to achieve excellent low-temperature toughness, JP 2011-20154 A discloses a flux-

cored wire for gas-shield arc welding which contains a large amount of metal fluorides. However, since the wire for gas-shield arc welding disclosed in JP 2011-20154 A has excellent toughness at a low temperature but contains a large amount of metal fluorides, there are problems that an arc becomes rough and a large amount of spatter is generated.

[0007]

Furthermore, a technique relating to so-called metallic flux-cored wire containing a large amount of alloy powders is disclosed in JP 2007-144516 A or JP 2008-93715 A. However, even in the metallic flux-cored wire disclosed in JP 2007-144516 A or JP 2008-93715 A, there were problems that an arc became rough, a bead appearance/shape was not excellent, and toughness could not be further ensured at a low temperature.

SUMMARY

[0009]

The invention has been made to solve the above problems and is to provide a flux-cored wire for gas-shield arc welding of high tensile steel which can obtain a weld metal having appropriate strength in welding of 780 MPa-class high tensile steel and stable and excellent toughness at a low-temperature range in particular and has excellent welding workability such as excellent arc stability, a superior bead appearance/shape, and a small amount of

spatter to be generated.

[0010]

The gist of the present invention includes a flux-cored wire for gas-shield arc welding of high tensile steel that is formed by filling of flux into a steel sheath, the flux-cored wire containing the following compositions in total of the steel sheath and the flux, by mass % with respect to the total mass of the wire:

C: 0.08 to 0.16%;

Si: 0.3 to 0.75%;

Mn: 1.2 to 2.1%;

Cu: 0.15 to 0.45%;

Ni: 0.8 to 3.0%;

Cr: 0.35 to 0.65%;

Mo: 0.2 to 0.6%; and

Ti: 0.04 to 0.30%, and

wherein the flux-cored wire further contains the following compositions in the flux, by mass % with respect to the total mass of the wire:

the total amount of fluorine compound in terms of an F conversion value: 0.01 to 0.1%;

SiO₂: 0.01 to 0.2%; and

the total amount of Na compound and K compound in terms of a Na₂O conversion value and a K₂O conversion value: 0.02 to 0.15%, and

a value of Pts expressed by the following Formula (1) is 0.8 to 1.2, and the remainder is Fe in the steel sheath,

an Fe content in an iron powder and an iron alloy powder, and inevitable impurities.

[0011]

In addition, a seam is eliminated from the steel sheath in such a manner that a joint of the formed steel sheath is welded.

[0012]

Furthermore, the amount of lubricating oil to be fed onto a wire surface is 0.2 to 1.0 g per 10 kg of the wire.

[0013]

$$Pts = [C] + [Si]/7 + [Mn]/5 + [Cu]/7 + [Ni]/20 + [Cr]/8 + [Mo]/2 + [Ti]/5 \dots \text{Formula (1)}$$

wherein each of [C], [Si], [Mn], [Cu], [Ni], [Cr], [Mo], and [Ti] indicates mass % of each of C, Si, Mn, Cu, Ni, Cr, Mo, and Ti with respect to the total mass of the wire.

[0014]

According to the flux-cored wire for gas-shield arc welding of high tensile steel according to the invention, it is possible to provide a flux-cored wire for gas-shield arc welding of high tensile steel in which the welding workability is excellent to ensure the strength of 780 MPa class, for example, the arc stability is excellent, the bead appearance/shape is superior, and the amount of spatter to be generated during the welding is small, so that a high-quality weld metal having stable and high toughness at the low-temperature range and not having

defects can be obtained.

DETAILED DESCRIPTION

[0015]

In order to solve the above problems, the present inventors examined in detail compositions of a flux-cored wire for gas-shield arc welding which, in gas-shield arc welding of 780 MPa-class high tensile steel, had excellent welding workability and could form a weld metal capable of having appropriate strength and obtaining stable and high toughness even at a low temperature range of -60°C .

[0016]

As a result, the inventors find that an arc is stabilized and the amount of spatter to be generated is reduced when the total amount of a fluorine compound in terms of an F conversion value, an Na compound in terms of a Na_2O conversion value, and a K compound in terms of a K_2O conversion value is appropriately adjusted and a bead appearance/shape is excellent when a trace of SiO_2 is contained.

[0017]

In addition, the inventors find that a wire feeding property is stabilized and thus the arc can be further stabilized when an appropriate amount of feeding lubricant is contained in a surface of the wire.

[0018]

Moreover, the inventors find that appropriate

strength and stable low-temperature toughness are achieved at the same time when the content of each of C, Si, Mn, Cu, Ni, Cr, Mo, and Ti is appropriately adjusted.

[0019]

The flux-cored wire for gas-shield arc welding of high tensile steel according to the invention can be obtained by a synergistic effect due to single existence and coexistence of each composition, but reasons for adding and limiting each of the compositions will be described below. In the following description, chemical compositions of the flux-cored wire are expressed by mass % which is a ratio to the total mass of wire, and the mass % will be described simply as "%".

[0020]

[Total amount of C contained in steel sheath and flux: 0.08 to 0.16%]

C is an essential element for improving strength of a weld metal by solid solution strengthening. However, when the content of C is less than 0.08%, it is not possible to obtain the strength of the weld metal. On the other hand, when the content of C exceeds 0.16%, the strength of the weld metal excessively increases and thus toughness deteriorates. In addition, weld-crack sensitivity increases. Accordingly, the total amount of C contained in the steel sheath and the flux is set to be 0.08 to 0.16%. The composition C can be contained in the steel sheath and can be additionally added from the flux in the form of

metal powders, alloy powders and the like.

[0021]

[Total amount of Si contained in steel sheath and flux Si: 0.3 to 0.75%]

Si is added for the purpose of deoxidation of a weld metal. When the content of Si is less than 0.3%, deoxidation of the weld metal becomes poor and thus toughness deteriorates. On the other hand, when the content of Si exceeds 0.75%, it is not possible to obtain stable toughness at a low temperature. Accordingly, the total amount of Si contained in the steel sheath and the flux is set to be 0.3 to 0.75%. The composition Si can be contained in the steel sheath and can be additionally added from the flux in the form of a metal Si and alloy powders such as Fe-Si or Fe-Si-Mn.

[0022]

[Total amount of Mn contained in steel sheath and flux: 1.2 to 2.1%]

Mn is added for ensuring toughness of a weld metal and improving strength of the weld metal. When the content of Mn is less than 1.2%, the strength of the weld metal deteriorates and the toughness thereof may not be sufficiently ensured. On the other hand, when the content of Mn exceeds 2.1%, it is not possible to obtain stable low-temperature toughness of the weld metal. Accordingly, the total amount of Mn contained in the steel sheath and the flux is set to be 1.2 to 2.1%. The composition Mn can

be contained in the steel sheath and can be additionally added from the flux in the form of a metal Mn and alloy powders such as Fe-Mn or Fe-Si-Mn.

[0023]

[Total amount of Cu contained in steel sheath and flux: 0.15 to 0.45%]

Cu has a precipitation strengthening effect, lowers a transformation temperature, and refines the structure, resulting in stabilizing toughness. When the content of Cu is less than 0.15%, it is not possible to obtain stable toughness at a low temperature. On the other hand, when the content of Cu exceeds 0.45%, precipitation embrittlement occurs and thus the toughness deteriorates. In addition, hot cracking is likely to occur. Accordingly, the total amount of Cu contained in the steel sheath and the flux is set to be 0.15 to 0.45%. The composition Cu can be contained in the steel sheath and a fraction of Cu plating, which is performed on the surface of the steel sheath, and can be additionally added from the flux in the form of a metal Cu and alloy powders such as Fe-Si-Cu.

[0024]

[Total amount of Ni contained in steel sheath and flux: 0.8 to 3.0%]

Ni has effects of lowering a transformation temperature to refine the structure and improving strength without deteriorating toughness when being formed in a weld metal as a solid solution. When the content of Ni is less

than 0.8%, it is not possible to sufficiently obtain the effect of preventing the deterioration of toughness. On the other hand, when the content of Ni exceeds 3.0%, a grain boundary embrittles and thus the toughness deteriorates. Accordingly, the total amount of Ni contained in the steel sheath and the flux is set to be 0.8 to 3.0%. The composition Ni can be contained in the steel sheath and can be additionally added from the flux in the form of a metal Ni and alloy powders such as Fe-Ni.

[0025]

[Total amount of Cr contained in steel sheath and flux: 0.35 to 0.65%]

Cr has effects of lowering a transformation temperature to refine the structure and improving toughness. When the content of Cr is less than 0.35%, it is not possible to sufficiently obtain these effects. On the other hand, when the content of Cr exceeds 0.65%, a weld metal is significantly hardened and thus toughness deteriorates. Accordingly, the total amount of Cr contained in the steel sheath and the flux is set to be 0.35 to 0.65%. The composition Cr can be contained in the steel sheath and can be additionally added from the flux in the form of a metal Cr and alloy powders such as Fe-Cr.

[0026]

[Total amount of Mo contained in steel sheath and flux: 0.2 to 0.6%]

Similarly to Ni and Cr, Mo has effects of lowering a

transformation temperature to refine the structure and improving toughness. When the content of Mo is less than 0.2%, it is not possible to sufficiently obtain these effects. On the other hand, when the content of Mo exceeds 0.6%, it is not possible to obtain stable toughness at a low temperature. Accordingly, the total amount of Mo contained in the steel sheath and the flux is set to be 0.2 to 0.6%. The composition Mo can be contained in the steel sheath and can be additionally added from the flux in the form of powders of a metal Mo.

[0027]

[Total amount of Ti contained in steel sheath and flux: 0.04 to 0.30%]

Ti acts as a deoxidizer and forms a fine Ti oxide in a weld metal to improve toughness of the weld metal. When the content of Ti is less than 0.04%, it is not possible to obtain stable toughness at a low temperature. On the other hand, when the content of Ti exceeds 0.30%, the amount of Ti formed in the weld metal as a solid solution becomes larger and thus the toughness deteriorates. Accordingly, the total amount of Ti contained in the steel sheath and the flux is set to be 0.04 to 0.30%. The composition Ti can be contained in the steel sheath and can be additionally added from the flux in the form of a metal Ti and alloy powders such as Fe-Ti.

[0028]

[Total amount of fluorine compound contained in flux:

0.01 to 0.1% in terms of F conversion value]

A fluorine compound has an effect of concentrating and stabilizing an arc. However, when the total amount of fluorine compound is less than 0.01% in terms of the F conversion value, it is not possible to obtain this effect. On the other hand, when the total amount of fluorine compound exceeds 0.1% in terms of the F conversion value, the arc becomes rough and unstable and thus the amount of spatter to be generated becomes larger. Accordingly, the total amount of fluorine compound contained in the flux is set to be 0.01 to 0.1% in terms of the F conversion value. The fluorine compound can be added from the flux in the form of fluorite, sodium fluoride, potassium fluoride, lithium fluoride, magnesium fluoride, potassium silicofluoride or the like, and the F conversion value is the total amount of F to be contained therein.

[0029]

[Amount of SiO_2 contained in flux: 0.01 to 0.2%]

SiO_2 makes compatibility of a bead toe excellent to make a bead appearance/shape excellent. When the content of SiO_2 is less than 0.01%, the compatibility of the bead toe becomes poor and the bead appearance/shape becomes poor. On the other hand, when the content of SiO_2 exceeds 0.2%, the amount of oxygen to be contained in the weld metal becomes larger and thus low-temperature toughness deteriorates. In addition, since the amount of slag on the bead surface increases, it is necessary to remove the slag

in the multi-layer welding. Accordingly, the amount of SiO_2 to be contained in the flux is set to be 0.01 to 0.2%. The SiO_2 can be added from the flux in the form of silica sand or a solid component such as water glass made of sodium silicate and potassium silicate.

[0030]

[Total amount of Na compound and K compound contained in flux: 0.02 to 0.15% in terms of Na_2O conversion value and in terms of K_2O conversion value]

The Na compound and the K compound have a soft and stable arc. When the total amount of Na compound and K compound is less than 0.02% in terms of the Na_2O conversion value and in terms of the K_2O conversion value, the arc becomes unstable and a large amount of spatter is generated. On the other hand, when the total amount of Na compound and K compound exceeds 0.15% in terms of the Na_2O conversion value and in terms of the K_2O conversion value, the arc becomes strong in reverse and a large amount of spatter is generated. In addition, the compatibility with the bead toe becomes poor and thus a bead appearance/shape becomes defective. Moreover, the amount of slag on the surface of the bead increases, and thus it is necessary to remove the slag in multi-layer welding. Accordingly, the total amount of Na compound and K compound contained in the flux is 0.02 to 0.15% in terms of the Na_2O conversion value and in terms of the K_2O conversion value. The Na compound and K compound can be added from the flux in the form of

potassium feldspar, a solid component such as water glass made of sodium silicate and potassium silicate, or a powder of sodium fluoride, potassium silicofluoride or the like.

[0031]

[Pts: 0.8 to 1.2]

An estimation value Pts in the following Formula (1) is expressed by regression coefficients of other compositions based on a coefficient of [C] set to 1 when a multiple regression analysis is performed by setting the content of C, Si, Mn, Cu, Ni, Cr, Mo, and Ti (mass % to total mass of wire) as an independent variable and strength and toughness of the weld metal as a dependent variable, and the estimation value Pts of the strength and toughness of the weld metal is calculated based on the compositions of a flux-cored wire by Formula (1) described above. When the content of C, Si, Mn, Cu, Ni, Cr, Mo, and Ti is 0.8 to 1.2 by the Pts of the following Formula (1), it is possible to obtain the weld metal having stable toughness, which is good at a low temperature, while ensuring strength. When the Pts is less than 0.8, the strength of the weld metal is reduced. On the other hand, when the Pts exceeds 1.2, the strength of the weld metal becomes higher and thus stable low-temperature toughness is not obtained.

$$\text{Pts} = [\text{C}] + [\text{Si}]/7 + [\text{Mn}]/5 + [\text{Cu}]/7 + [\text{Ni}]/20 + [\text{Cr}]/8 + [\text{Mo}]/2 + [\text{Ti}]/5 \dots \text{Formula (1)}$$

wherein, each of [C], [Si], [Mn], [Cu], [Ni], [Cr], [Mo], and [Ti] indicates mass % of each of C, Si, Mn, Cu,

Ni, Cr, Mo, and Ti with respect to the total mass of wire.
[0032]

The flux-cored wire of high tensile steel for gas-shield arc welding according to the invention has the remainder being Fe in a steel sheath, an iron powder to be added for the purpose of composition adjustment, an Fe content in an iron alloy powder such as Fe-Si, Fe-Mn, or Fe-Ti alloy, and inevitable impurities.
[0033]

A trace amount of Al of the inevitable impurities is essentially contained during steel making of the steel sheath. However, since the Al forms non-metal inclusion in the weld metal, thereby deteriorating toughness, the total amount of Al contained in the steel sheath and the flux is preferably small and is limited to 0.01% or less. P and S are elements to deteriorate toughness of the weld metal, and thus each of the total amounts of P and S contained in the steel sheath and the flux are preferably 0.020 mass % or less.
[0034]

Regarding N, the amount of N formed as a solid-solution in the weld metal is essentially reduced to stably improve toughness of the weld metal, and the total amount of N contained in the steel sheath and the flux is set to be 0.01% or less.
[0035]

Moreover, although a flux filling ratio is not

particularly limited, it is preferably 8 to 20% with respect to the total mass of the wire from the viewpoint of productivity.

[0036]

[Eliminate seam of steel sheath by welding joint of formed steel sheath]

The flux-cored wire for the gas-shield arc welding of the high tensile steel according to the invention has a structure in which the steel sheath is formed into a pipe shape and the flux is filled therein. The types of wires are roughly classified into a wire having a seamless steel sheath obtained by welding of a joint of the formed steel sheath and a wire having a seam steel sheath obtained in such a manner that a joint is not welded to the steel sheath. In the invention, the wire of either of cross-sectional structures can be employed, but the wire having the seam steel sheath is necessary to use a raw material having low moisture content because cold cracking easily occurs when the strength of the weld metal becomes higher. On the other hand, since the wire having the seamless steel sheath can be subjected to a heat treatment for the purpose of reducing the total amount of hydrogen contained in the wire and moisture absorption of the flux is not generated in this wire after the production, the wire having the seamless steel sheath is more preferred since the amount of diffusible hydrogen of the weld metal is reduced and cold cracking resistance can be improved.

[0037]

[Lubricating oil to be fed onto wire surface: 0.2 to 1.0 g per 10 kg of wire]

By Lubricating oil to be fed onto the wire surface, a wire feeding property becomes excellent in the case of semiautomatic welding in particular, and an arc is stable to reduce the amount of spatter to be generated and to prevent the occurrence of welding defects. When the amount of lubricating oil to be fed onto the wire surface is less than 0.2 g per 10 kg of the wire, the wire feeding property becomes poor, the arc is unstable, and thus the amount of spatter to be generated becomes larger. In addition, slag inclusion defects easily occur. On the other hand, when the amount of lubricating oil to be fed onto the wire surface is more than 1.0 g per 10 kg of the wire, the wire slips in a feeding roller, the arc is unstable, and thus the amount of spatter to be generated becomes larger. In addition, the amount of diffusible hydrogen of the weld metal becomes larger and cold cracking easily occur.

[0038]

The lubricating oil to be fed may be any of animal and vegetable oils, mineral oils, or synthetic oils. Examples of the animal and vegetable oils to be used may include a palm oil, a rapeseed oil, a castor oil, a pig oil, a beef oil, and a fish oil; and examples of the mineral oils to be used may include a machine oil, a turbine oil, and a spindle oil. Examples of the synthetic oils to be

used may include a hydrocarbon-based oil, an ester-based oil, a polyglycol-based oil, a polyphenol-based oil, a silicon-based oil, and a fluorocarbon-based oil. Moreover, the lubricating oil to be used may include sulfur-containing lubricating oils of one or two or more of sulfurized fat and oil, sulfurized ester, sulfurized fatty acid, or sulfurized olefin in which sulfur is contained in at least one base oil of fat and oil or ester.

[0039]

A shield gas is a mixture of Ar and CO₂, but the amount of CO₂ to be mixed is in the range of 5 to 25 volume % to reduce the amount of oxygen contained in the weld metal. In addition, the flow rate of the shield gas is preferably in the range of 20 to 35 liters/min. so as to achieve defect resistance and to prevent nitrogen from being mixed from the atmosphere.

[Example]

[0040]

The effect of the invention will be described in detail below with reference to Example.

[0041]

Using SPCC defined in JIS G 3141 as a steel sheath (C: 0.01 to 0.05%), after the steel sheath was formed into a U-shape by a forming process, a seamless wire obtained by welding of a joint of the steel sheath and a wire with a gap which is not welded were produced into a tube and were drawn and a palm oil was applied to the surface of the wire,

thereby producing a trial product of a flux-cored wire having various compositions indicated in Table 1. The diameter of the wire was 1.2 mm. The seamless wire obtained by the welding of the joint of the steel sheath was subjected to annealing in the middle of the drawing, but the wire having the joint of the steel sheath was sealed in a vinyl bag and was stored at that state until immediately before welding so as to be dried before the filling of the flux and to prevent moisture absorption of the flux after the wire production.

[0042]

[Table 1]

Class	Mark of wire	Composition of wire (mass %)														Pts	Wire seam	Amount of lubricant to be fed (g/10 kg of wire)	
		Total amount contained in steel sheath and flux								Flux									** Others
		C	Si	Mn	Cu	Ni	Cr	Mo	Ti	*Total amount in terms of F conversion value	SiO ₂	Na ₂ O conversion value	K ₂ O conversion value	Total amount in terms of Na ₂ O conversion value and K ₂ O conversion value					
Inventive Example	W1	0.11	0.39	1.75	0.28	1.76	0.42	0.37	0.09	0.08	0.11	0.02	0.01	0.03	Remainder	0.90	Absence	0.52	
	W2	0.09	0.74	1.32	0.19	2.04	0.39	0.44	0.11	0.01	0.19	0.04	0.08	0.12	Remainder	0.88	Absence	0.27	
	W3	0.10	0.51	2.04	0.16	1.05	0.55	0.36	0.22	0.07	0.05	0.05	0.08	0.13	Remainder	0.95	Absence	0.45	
	W4	0.12	0.64	1.52	0.32	1.58	0.41	0.27	0.08	0.05	0.09	0.11	0.01	0.12	Remainder	0.84	Absence	0.86	
	W5	0.16	0.33	1.63	0.44	0.83	0.52	0.52	0.17	0.01	0.11	0.03	0.06	0.09	Remainder	1.00	Absence	0.72	
	W6	0.08	0.53	1.81	0.22	2.93	0.38	0.45	0.21	0.09	0.16	0.07	0.01	0.08	Remainder	1.01	Absence	1.12	
	W7	0.09	0.48	1.44	0.31	1.69	0.64	0.23	0.16	0.06	0.12	0.04	0.02	0.06	Remainder	0.80	Presence	0.18	
	W8	0.14	0.38	1.57	0.16	0.99	0.44	0.36	0.04	0.04	0.04	0.08	0.03	0.11	Remainder	0.82	Presence	0.17	
	W9	0.13	0.68	1.93	0.15	2.27	0.58	0.57	0.26	0.02	0.13	0.12	0.02	0.14	Remainder	1.16	Absence	0.49	
	W10	0.11	0.47	1.26	0.17	2.94	0.36	0.42	0.29	0.07	0.01	0.05	0.06	0.11	Remainder	0.91	Presence	0.95	
Comparative Example	W11	0.07	0.45	1.58	0.24	1.25	0.45	0.41	0.02	0.03	0.16	0.04	0.03	0.07	Remainder	0.81	Absence	0.66	
	W12	0.17	0.39	1.92	0.29	2.27	0.51	0.39	0.27	0.08	0.11	0.05	0.03	0.08	Remainder	1.08	Absence	0.15	
	W13	0.11	0.22	1.46	0.33	0.98	0.62	0.44	0.23	0.004	0.06	0.02	0.09	0.11	Remainder	0.87	Absence	0.52	
	W14	0.14	0.81	1.88	0.42	2.55	0.53	0.35	0.06	0.12	0.08	0.10	0.02	0.12	Remainder	1.07	Absence	0.43	
	W15	0.09	0.41	1.12	0.18	1.44	0.42	0.51	0.18	0.01	0.11	0.06	0.07	0.13	Remainder	0.81	Absence	1.38	
	W16	0.11	0.52	2.21	0.34	1.85	0.55	0.43	0.22	0.01	0.004	0.04	0.04	0.08	Remainder	1.10	Absence	0.61	
	W17	0.15	0.48	1.49	0.13	2.16	0.46	0.34	0.16	0.05	0.15	0.01	0.005	0.015	Remainder	0.90	Absence	0.75	
	W18	0.12	0.35	1.67	0.49	2.09	0.37	0.29	0.24	0.07	0.01	0.12	0.05	0.17	Remainder	0.92	Absence	0.57	
	W19	0.09	0.51	1.77	0.25	0.73	0.61	0.33	0.09	0.02	0.01	0.04	0.07	0.11	Remainder	0.85	Absence	0.39	
	W20	0.12	0.62	2.01	0.28	3.08	0.52	0.47	0.17	0.05	0.06	0.02	0.03	0.05	Remainder	1.14	Absence	1.62	
	W21	0.13	0.39	1.92	0.19	1.19	0.29	0.56	0.19	0.07	0.15	0.05	0.02	0.07	Remainder	1.01	Presence	0.47	
	W22	0.11	0.65	1.88	0.16	2.07	0.66	0.55	0.28	0.01	0.14	0.03	0.04	0.07	Remainder	1.12	Presence	0.68	
	W23	0.14	0.47	1.64	0.17	2.35	0.41	0.14	0.18	0.09	0.07	0.07	0.05	0.12	Remainder	0.83	Presence	0.88	
	W24	0.10	0.63	1.55	0.35	2.17	0.55	0.68	0.22	0.07	0.08	0.11	0.01	0.12	Remainder	1.11	Absence	0.75	
	W25	0.13	0.51	1.73	0.29	1.91	0.47	0.31	0.32	0.03	0.15	0.03	0.05	0.08	Remainder	0.96	Absence	0.64	
	W26	0.08	0.39	1.56	0.19	1.02	0.37	0.28	0.05	0.05	0.25	0.07	0.01	0.08	Remainder	0.72	Absence	0.58	
	W27	0.15	0.72	2.02	0.18	2.86	0.61	0.54	0.28	0.07	0.05	0.04	0.03	0.07	Remainder	1.23	Presence	0.87	

*: Fluorine compound uses CaF₂, MgF₂, and K₂SiF₆

**: Others are Fe in steel sheath, Fe content in iron powder and iron alloy, and inevitable impurities

[0043]

Using the experimentally produced flux-cored wire, investigation was performed on welding workability, weld-metal performance, and crack resistance.

[0044]

The welding workability and the weld-metal performance were tested by a weld-metal test under welding condition indicated in Table 2 according to JIS Z 3111 using a steel sheet having a thickness of 20 mm as defined in JIS G 3128 SHY685. Arc stability during welding and the welding workability such as spatter occurrence states and a bead appearance/shape were investigated. The wire was fed using a conduit cable having a length of 6 m during welding. In addition, mechanical properties were investigated on a No. A1 tensile test piece and an impact test piece taken from the weld-metal part.

[0045]

Tensile strength of 800 to 920 MPa was evaluated, which was excellent. In addition, toughness was evaluated by a Charpy impact test at a temperature of -60°C, and absorption energy has an average value of 90 J or higher and was a minimum value of 70 J or higher, which were excellent.

[0046]

The crack resistance was tested by a U-groove weld cracking test under the welding conditions indicated in Table 2 according to JIS Z 3257 using a steel sheet having

a thickness of 40 mm as defined in JIS G 3128 SHY685. The presence or absence of crack occurrence of surface crack and cross-sectional crack (five cross-sections) was investigated on test specimens after the elapse of 48 hours from the welding by a penetrating test (JIS Z 2343). These results are collectively indicated in Table 3.

[0047]

[Table 2]

Test item	Sheet thickness (mm)	Groove shape	Welding condition					Shield gas
			Current (A)	Voltage (V)	Speed (cm/min)	Preheating temperature(°C)	Interpass temperature(°C)	
Deposited metal test	20	Gap: 12 mm 45 deg. Groove	270	27	25	100	150	Ar + 20%CO ₂ Flow rate: 25 litters/min.
Weld cracking test	40	Single side 20 deg. U-groove	240	26	22	75	-	

[0048]

[Table 3]

Class	Mark of wire	Welding workability			Deposited metal performance			Result of weld cracking test (presence or absence)	Overall evaluation
		Arc stability	Spatter occurrence state	Bead appearance/shape	Tensile strength (MPa)	Absorption energy (J)			
						Average value	Minimum value		
Inventive Example	W1	Stable	Less	Good	867	95	91	Absence	○
	W2	Stable	Less	Good	849	98	92	Absence	○
	W3	Stable	Less	Good	886	94	85	Absence	○
	W4	Stable	Less	Good	833	107	96	Absence	○
	W5	Stable	Less	Good	902	92	83	Absence	○
	W6	Slightly unstable	Slightly much	Good	907	89	79	Absence	○
	W7	Slightly unstable	Slightly much	Good	801	122	105	Absence	○
	W8	Slightly unstable	Slightly much	Good	814	113	98	Absence	○
	W9	Stable	Less	Good	919	93	78	Absence	○
	W10	Stable	Less	Good	873	96	89	Absence	○
Comparative Example	W11	Stable	Less	Good	787	98	63	Absence	×
	W12	Unstable	Much	Good	935	73	68	Presence of crack in crater	×
	W13	Unstable	Less	Good	851	65	55	Absence	×
	W14	Rough arc	Much	Good	903	96	51	Absence	×
	W15	Unstable	Much	Good	792	69	54	Absence	×
	W16	Stable	Less	Bad	911	97	58	Absence	×
	W17	Unstable	Much	Good	865	101	59	Absence	×
	W18	Strong arc	Much	Good	873	66	58	Presence of crack in crater	×
	W19	Stable	Less	Good	839	63	52	Absence	×
	W20	Unstable	Much	Good	912	59	49	Presence	×
	W21	Stable	Less	Good	901	65	58	Absence	×
	W22	Stable	Less	Good	927	55	49	Presence	×
	W23	Stable	Less	Good	822	54	51	Absence	×
	W24	Stable	Less	Good	908	93	57	Absence	×
	W25	Stable	Less	Good	891	72	66	Absence	×
	W26	Stable	Less	Good	779	54	46	Absence	×
	W27	Stable	Less	Good	945	93	61	Presence	×

[0049]

In Tables 1 and 3, wires marked by W1 to W10 represent Inventive Examples and wires marked by W11 to W27 represent Comparative Examples. Since the wires of Inventive Examples W1 to W5, W9, and W10 appropriately contain: the amount of C, Si, Mn, Cu, Ni, Cr, Mo, and Ti of the flux-cored wire; the total amount of fluorine compound in terms of an F conversion value; SiO_2 ; the total amount of Na compound and K compound in terms of a Na_2O conversion value and a K_2O conversion value; and a Pts value and the amount of lubricant to be fed onto the wire surface, the very satisfactory results were obtained in which an arc became stable, the amount of spatter to be generated was small, the bead appearance/shape was excellent, all of the tensile strength of the deposited metal and the average value and the minimum value of absorption energy were excellent, and cracks hardly occurred.

[0050]

In the wire W6 having a large amount of lubricant to be fed onto the wire surface and the wires W7 and W8 having a small amount of lubricant to be fed, the arc became slightly unstable and the amount of spatter to be generated was also somewhat large.

[0051]

In the wire W11 of Comparative Examples, since the content of C was small, the tensile strength of the deposited metal was low. In addition, since the content of

Ti was small, the minimum value of the absorption energy of the deposited metal was low.

[0052]

In the wire W12, since the content of C was large, the tensile strength of the deposited metal was high and the average value of the absorption energy was low. In addition, the cracks occurred in a crater. Moreover, since the amount of lubricant to be fed onto the wire surface was small, the wire feeding property became poor, the arc became unstable, and thus the amount of spatter to be generated was large.

[0053]

In the wire W13, since the content of Si was small, the average value of the absorption energy of the deposited metal was low. In addition, since the total amount of fluorine compound in terms of the F conversion value was small, the arc became unstable.

[0054]

In the wire W14, since the content of Si was large, the minimum value of the absorption energy of the deposited metal was low. In addition, since the total amount of fluorine compound in terms of the F conversion value was large, the arc became rough and the amount of spatter to be generated was large.

[0055]

In the wire W15, since the content of Mn was small, the tensile strength of the deposited metal and the average

value of the absorption energy were low. In addition, since the amount of lubricant to be fed onto the wire surface was large, the arc became unstable and the amount of spatter to be generated was large.

[0056]

In the wire W16, since the content of Mn was large, the minimum value of the absorption energy of the deposited metal was low. In addition, since the content of SiO_2 was small, the compatibility of the bead toe became poor and the bead appearance/shape became bad.

[0057]

In the wire W17, since the content of Cu was small, the minimum value of the absorption energy of the deposited metal was low. In addition, since the total amount of Na compound and K compound in terms of the Na_2O conversion value and the K_2O conversion value was small, the arc became unstable and the amount of spatter to be generated was large.

[0058]

In the wire W18, since the content of Cu was large, the average value of the absorption energy of the deposited metal was low. In addition, cracks occurred in the crater. Moreover, since the total amount of Na compound and K compound in terms of the Na_2O conversion value and the K_2O conversion value was large, the arc became strong and the amount of spatter to be generated was large.

[0059]

In the wire W19, since the content of Ni was small, the average value of the absorption energy of the deposited metal was low.

[0060]

In the wire W20, since the content of Ni was large, the average value of the absorption energy of the deposited metal was low. In addition, since the amount of lubricant to be fed onto the wire surface was large, the arc became unstable, the amount of spatter to be generated was large, and cracks occurred in a weld cracking test.

[0061]

In the wire W21, since the content of Cr was small, the average value of the absorption energy of the deposited metal was low. In the wire W22, since the content of Cr was large, the tensile strength of the deposited metal was high and the average value of the absorption energy was low. In addition, since a seam was provided on the steel sheath, cracks occurred in the weld cracking test.

[0062]

In the wire W23, since the content of Mo was small, the average value of the absorption energy of the deposited metal was low.

[0063]

In the wire W24, since the content of Mo was large, the minimum value of the absorption energy of the deposited metal was low.

[0064]

In the wire W25, since the content of Ti was large, the average value of the absorption energy of the deposited metal was low.

[0065]

In the wire W26, since the content of SiO₂ was large, the average value of the absorption energy of the deposited metal was low. In addition, since the Pts is low, the tensile strength of the deposited metal was also low.

[0066]

In the wire W27, since the Pts was high, the tensile strength of the deposited metal was high and the minimum value of the absorption energy was low. In addition, since a seam was provided on the steel sheath, cracks occurred in the weld cracking test.

What is claimed is:

1. A flux-cored wire for gas-shield arc welding of high tensile steel that is formed by filling of flux into a steel sheath, the flux-cored wire containing following compositions in total of the steel sheath and the flux, by mass % with respect to the total mass of the wire:

C: 0.08 to 0.16%;

Si: 0.3 to 0.75%;

Mn: 1.2 to 2.1%;

Cu: 0.15 to 0.45%;

Ni: 0.8 to 3.0%;

Cr: 0.35 to 0.65%;

Mo: 0.2 to 0.6%; and

Ti: 0.04 to 0.30%, and

wherein the flux-cored wire further contains following compositions in the flux, by mass % with respect to the total mass of the wire:

the total amount of fluorine compound in terms of an F conversion value: 0.01 to 0.1%;

SiO₂: 0.01 to 0.2%; and

the total amount of Na compound and K compound in terms of a Na₂O conversion value and a K₂O conversion value: 0.02 to 0.15%, and

a value of Pts expressed by following Formula (1) is 0.8 to 1.2:

$$\text{Pts} = [\text{C}] + [\text{Si}]/7 + [\text{Mn}]/5 + [\text{Cu}]/7 + [\text{Ni}]/20 + [\text{Cr}]/8 + [\text{Mo}]/2 + [\text{Ti}]/5 \dots \text{Formula (1)}$$

wherein each of [C], [Si], [Mn], [Cu], [Ni], [Cr], [Mo], and [Ti] indicates mass % of each of C, Si, Mn, Cu, Ni, Cr, Mo, and Ti with respect to the total mass of the wire, and

the remainder is Fe in the steel sheath, an Fe content in an iron powder and an iron alloy powder, and inevitable impurities.

2. The flux-cored wire for gas-shield arc welding of high tensile steel according to claim 1, wherein a seam is eliminated from the steel sheath in such a manner that a joint of the formed steel sheath is welded.

3. The flux-cored wire for gas-shield arc welding of high tensile steel according to claim 1 or 2, wherein the amount of lubricating oil to be fed onto a wire surface is 0.2 to 1.0 g per 10 kg of the wire.