FLUX-CORED WIRE FOR $Ar-CO_2$ MIXED GAS SHIELDED ARC WELDING

BACKGROUND

Technical Field

[0001]

The present invention relates to a flux-cored wire for $Ar-CO_2$ mixed gas shielded arc welding which provides excellent welding workability in all-position welding when steel used for a steel structure or the like is welded and weld metal having excellent characteristics such as low-temperature cracking resistance, low-temperature toughness, and fracture toughness (hereinafter, referred to as CTOD).

Related Art

[0002]

As a flux-cored wire used for gas shielded arc welding using steel as a material to be welded, for example, a rutile type flux-cored wire or a basic flux-cored wire is known. Welding using the basic flux-cored wire can reduce an oxygen amount of weld metal, and therefore the weld metal has excellent low-temperature toughness and CTOD characteristic. However, welding using the basic flux-cored wire has poorer welding workability in all-position welding than welding using the rutile type flux-cored wire, and therefore is not often used generally.

[0003]

On the other hand, gas shielded arc welding using the rutile type flux-cored wire provides extremely excellent

welding efficiency and welding workability in all-position welding, and therefore is applied in a wide range of fields such as shipbuilding, bridges, oceanic structures, and steel frames.

[0004]

However, the rutile type flux-cored wire is obtained by filling a flux mainly including a metal oxide such as TiO_2 into a steel outer skin, and therefore weld metal has a large amount of oxygen and does not easily obtain low-temperature toughness.

[0005]

In addition, in these flux-cored wires, an amount of diffusion hydrogen is larger than that in a solid wire due to moisture included in a raw material of the flux or moisture absorption while the wire is stored. Therefore, there is a risk of low-temperature cracking of weld metal. It is necessary to perform preheating at about 100°C when a thick steel plate is welded. This reduces a welding efficiency.

[0006]

Various developments have been performed for a rutile type flux-cored wire of low-temperature steel. For example, JP 2009-61474 A discloses a technology for obtaining weld metal having excellent low-temperature toughness by reducing an oxygen amount of the weld metal while an amount of slag acting on welding workability is maintained by adding an alloy component which changes into a slag component during welding. However, in the technology described in JP 2009-61474 A, a shielding gas is CO2, and therefore the oxygen amount of the weld metal increases, sufficient low-temperature toughness or

CTOD value is not obtained, and low-temperature cracking resistance is not taken into account even though high-temperature cracking resistance is secured.

[0007]

JP 2008-87043 A also discloses a technology for obtaining weld metal having excellent low-temperature toughness. However, MgO added for reducing an oxygen amount of weld metal makes an arc unstable during welding, generates a large amount of spatters, and makes welding workability poor. In the technology disclosed in JP 2008-87043 A, low-temperature cracking resistance is not particularly taken into account.

[0008]

JP 2009-248137 A discloses a rutile type flux-cored wire which provides excellent workability in all-position welding and weld metal having excellent low-temperature toughness. However, in the technology disclosed in JP 2009-248137 A, stabilization of low-temperature toughness is not sufficiently studied, and therefore an excellent CTOD value is not obtained disadvantageously.

[0009]

JP 9-277087 A discloses a technology for obtaining excellent low-temperature toughness both in welding and in a heat treatment after welding by limiting contents of Nb, V, and P in a wire. However, also in the technology described in JP 9-277087 A, workability in all-position welding or a CTOD value is not sufficient disadvantageously.

SUMMARY

[0011]

The present invention has been achieved in view of the above-described problems. An object of the present invention is to provide a flux-cored wire for Ar-CO_2 mixed gas shielded arc welding which provides excellent welding workability in all-position welding when steel used for a steel structure or the like is welded and weld metal having excellent low-temperature cracking resistance, low-temperature toughness, and CTOD characteristic.

[0012]

The present inventors have variously made studied a rutile type flux-cored wire for gas shielded arc welding using an Ar-CO_2 mixture as a shielding gas in order to obtain excellent welding workability in all-position welding and weld metal having stable low-temperature toughness at -60°C, an excellent CTOD value at -30°C, and excellent low-temperature cracking resistance.

[0013]

As a result, the present inventors have found that it is possible to obtain excellent welding workability in all-position welding and weld metal having excellent low-temperature toughness and CTOD value by forming the wire of a metal oxide mainly including TiO_2, a slag component including a fluorine compound containing Na and K, an optimum alloy component, and a chemical component containing a deoxidizer. In addition, the present inventors have found that

it is possible to improve low-temperature cracking resistance also in weld metal having relatively high strength by eliminating a seam in a steel outer skin by welding a joint of the molded steel outer skin.

[0014]

That is, the gist of the present invention exists in a flux-cored wire for Ar-CO_2 mixed gas shielded arc welding obtained by filling a flux into a steel outer skin, including, in terms of % by mass with respect to a total mass of the wire, as a total in the steel outer skin and the flux, 0.03 to 0.08% of C, 0.1 to 0.6% of Si, more than 1.26% to 2.5% of Mn, 0.01 to 0.5% of Cu, 0.5 to 1.5% of Ni, 0.05 to 0.5% of Ti, 0.002 to 0.015% of B, and 0.05% or less of Al, and further including, in terms of % by mass with respect to the total mass of the wire, in the flux, 4 to 8% of a Ti oxide in terms of TiO_2 in total, 0.1 to 0.6% of a Si oxide in terms of SiO_2 in total, 0.02 to 0.3% of an Al oxide in terms of Al_2O_3 in total, 0.1 to 0.8% of Mg, 0.05 to 0.3% of a fluorine compound in terms of F in total, 0.05 to 0.3% of one kind or two kinds of Na and K in the fluorine compound in terms of Na and K in total, 0.05 to 0.2% of one kind or two kinds of Na_2O and K_2O in total, and 0.2% or less of a Zr oxide in terms of ZrO_2 in total, the balance being Fe in the steel outer skin, iron powder, a Fe component of iron alloy powder, and inevitable impurities.

[0015]

In addition, the gist of the present invention exists in a flux-cored wire for Ar-CO_2 mixed gas shielded arc welding

characterized in eliminating a seam in the steel outer skin by welding a joint of the molded steel outer skin.

[0016]

According to the flux-cored wire for Ar-CO_2 mixed gas shielded arc welding of the present invention, excellent welding workability in all-position welding is obtained, and weld metal having excellent low-temperature toughness at -60°C, an excellent CTOD value at -30°C, and excellent low-temperature cracking resistance is obtained. Therefore, according to the present invention, it is possible to improve a welding efficiency and a quality of the weld metal.

BRIEF DESCRIPTION OF DRAWING

[0017]

FIG. 1 illustrates a groove shape in a joint test used in Examples of the present invention.

DETAILED DESCRIPTION

[0018]

Hereinafter, compositions of components of the flux-cored wire for Ar-CO_2 mixed gas shielded arc welding according to an embodiment of the present invention, contents thereof, and a reason for limiting the compositions will be described. The content of each component will be represented by % by mass with respect to a total mass of the wire. The % by mass will be represented simply by %.

[0019]

[C: 0.03 to 0.08% as a total in steel outer skin and flux]

C contributes to stabilizing an arc during welding and improves strength of weld metal. However, when the content of C is less than 0.03%, the arc cannot be stabilized, and desired strength of the weld metal cannot be obtained sufficiently. When the content of C is more than 0.08%, C remains in the weld metal excessively, and therefore the strength of the weld metal becomes higher to reduce low-temperature toughness. Therefore, the content of C is set to be from 0.03 to 0.08% as a total in the steel outer skin and the flux. C can be added from metal powder, alloy powder, or the like in the flux in addition to a component included in the steel outer skin.

[0020]

[Si: 0.1 to 0.6% as a total in steel outer skin and flux]

Si partly becomes weld slag during welding, and thereby improves an appearance or a shape of a weld bead and contributes to improving welding workability. However, when the content of Si is less than 0.1%, the appearance or the shape of the weld bead cannot be improved sufficiently. When the content of Si is more than 0.6%, Si remains in the weld metal excessively to thereby reduce low-temperature toughness of the weld metal. Therefore, the content of Si is set to be from 0.1 to 0.6% as a total in the steel outer skin and the flux. Si can be added from metal Si or alloy powder such as Fe-Si or Fe-Si-Mn in the flux in addition to a component included in the steel outer skin.

[0021]

[Mn: more than 1.26% to 2.5% as a total in steel outer

skin and flux]

Mn remains in the weld metal to thereby increase strength, low-temperature toughness, and a CTOD value of the weld metal. However, when the content of Mn is less than or equal to 1.26%, these effects cannot be obtained sufficiently. When the content of Mn is more than 2.5%, Mn remains in the weld metal excessively, and therefore the strength of the weld metal becomes excessively high to thereby reduce low-temperature toughness and a CTOD value of the weld metal. Therefore, the content of Mn is set to be from more than 1.26% to 2.5% as a total in the steel outer skin and the flux. Mn can be added from metal Mn or alloy powder such as Fe-Mn or Fe-Si-Mn in the flux in addition to a component included in the steel outer skin.

[0022]

[Cu: 0.01 to 0.5% as a total in steel outer skin and flux]

Cu makes a structure of the weld metal finer and increases low-temperature toughness and strength. However, when the content of Cu is less than 0.01%, these effects cannot be obtained sufficiently. When the content of Cu is more than 0.5%, the strength of the weld metal becomes excessively high to reduce low-temperature toughness. Therefore, the content of Cu is set to be from 0.01 to 0.5% as a total in the steel outer skin and the flux. Cu can be added from metal Cu or alloy powder such as Cu-Zr or Fe-Si-Cu in the flux in addition to a Cu plating component formed on a surface of the steel outer skin.

[0023]

[Ni: 0.5 to 1.5% as a total in steel outer skin and flux]

Ni improves low-temperature toughness and a CTOD value of the weld metal. However, when the content of Ni is less than 0.5%, this effect cannot be obtained sufficiently. When the content of Ni is more than 1.5%, high-temperature cracking is easily generated in the weld metal. Therefore, the content of Ni is set to be from 0.5 to 1.5% as a total in the steel outer skin and the flux. Ni can be added from metal Ni or alloy powder such as Fe-Ni in the flux in addition to a component included in the steel outer skin.

[0024]

[Ti: 0.05 to 0.5% as a total in steel outer skin and flux]

Ti makes the structure of the weld metal finer and improves low-temperature toughness and a CTOD value. However, when the content of Ti is less than 0.05%, this effect cannot be obtained sufficiently. When the content of Ti is more than 0.5%, an upper bainitic structure hindering toughness is generated to reduce toughness and the CTOD value. Therefore, the content of Ti is set to be from 0.05 to 0.5% as a total in the steel outer skin and the flux. Ti can be added from metal Ti or alloy powder such as Fe-Ti in the flux in addition to a component included in the steel outer skin.

[0025]

[B: 0.002 to 0.015% as a total in steel outer skin and flux]

A small amount of B added makes the microstructure of the weld metal finer and improves low-temperature toughness and the CTOD value of the weld metal. However, when the content of B

is less than 0.002%, these effects cannot be obtained sufficiently. When the content of B is more than 0.015%, low-temperature toughness and the CTOD value of the weld metal are reduced, and high-temperature cracking is easily generated in the weld metal. Therefore, the content of B is set to be from 0.002 to 0.015%. B can be added from metal B, alloy powder such as Fe-B or Fe-Mn-B, or borax in the flux in addition to a component included in the steel outer skin.

[0026]

[Al: 0.05% or less as a total in steel outer skin and flux]

Al remains in the weld metal as an oxide to reduce the toughness of the weld metal. Particularly when the content of Al is more than 0.05%, the toughness of the weld metal is significantly reduced. Therefore, the content of Al is set to be 0.05% or less. Al is not an essential element but the content thereof may be 0%.

[0027]

[Total content of Ti oxide in terms of TiO_2 in flux: 4 to 8%]

A Ti oxide contributes to stabilizing an arc during welding, improves a shape of a weld bead, and contributes to improving welding workability. In addition, in vertical upward welding, the Ti oxide adjusts viscosity or a melting point of melted slag by being included in weld slag, and prevents melted metal from dripping. However, when a total content of the Ti oxide in terms of TiO_2 is less than 4%, these effects cannot be obtained sufficiently, the arc is unstable, a

generation amount of spatters is large, and the shape of the weld bead is deteriorated. In addition, when the total content of the Ti oxide in terms of TiO_2 is less than 4%, the melted metal easily drips in vertical upward welding. When the total content of the Ti oxide in terms of TiO_2 is more than 8%, the arc is stable and a generation amount of spatters can be reduced. However, the Ti oxide remains excessively in the weld metal to thereby reduce low-temperature toughness. Therefore, the total content of the Ti oxide in terms of TiO_2 in the flux is set to be from 4 to 8%. The Ti oxide is added from rutile, titanium oxide, titanium slag, ilmenite, or the like in the flux.

[0028]

[Total content of Si oxide in terms of SiO_2 in flux: 0.1 to 0.6%]

A Si oxide adjusts viscosity or a melting point of melted slag to improve a slag encapsulation property. However, when a total content of the Si oxide in terms of SiO_2 is less than 0.1%, the slag encapsulation property is deteriorated and an appearance of a bead is poor. When the total content of the Si oxide in terms of SiO_2 is more than 0.6%, a base degree of the melted slag is reduced, and an oxygen amount of the weld metal is thereby increased to reduce low-temperature toughness. Therefore, the total content of the Si oxide in terms of SiO_2 is set to be from 0.1 to 0.6%. The Si oxide can be added from silica sand, zircon sand, sodium silicate, or the like in the flux.

[0029]

[Total content of Al oxide in terms of Al_2O_3 in flux: 0.02 to 0.3%]

An Al oxide adjusts viscosity or a melting point of melted slag during welding to prevent melted metal from dripping particularly in vertical upward welding. However, when a total content of the Al oxide in terms of Al_2O_3 is less than 0.02%, this effect cannot be obtained sufficiently, and the melted metal easily drips in vertical upward welding. When the total content of the Al oxide in terms of Al_2O_3 is more than 0.3%, the Al oxide remains excessively in the weld metal to thereby reduce low-temperature toughness. Therefore, the total content of the Al oxide in terms of Al_2O_3 is set to be from 0.02 to 0.3%. The Al oxide can be added from alumina or the like in the flux.

[0030]

[Mg in flux: 0.1 to 0.8%]

Mg acts as a strong deoxidizer, and thereby reduces oxygen in the weld metal to increase low-temperature toughness and the CTOD value of the weld metal. However, when the content of Mg is less than 0.1%, these effects cannot be obtained sufficiently. When the content of Mg is more than 0.8%, Mg reacts vigorously with oxygen in an arc during welding to increase generation amounts of spatters and fumes. Therefore, the content of Mg is set to be from 0.1 to 0.8%. Mg can be added from metal Mg or alloy powder such as Al-Mg in the flux.

[0031]

[Total content of fluorine compound in terms of F in flux: 0.05 to 0.3%]

A fluorine compound stabilizes an arc. However, when a total content of the fluorine compound in terms of F is less than 0.05%, the arc cannot be stabilized sufficiently. When the total content of the fluorine compound in terms of F is more than 0.3%, the arc is unstable to increase a generation amount of spatters. In addition, when the total content of the fluorine compound in terms of F is more than 0.3%, melted metal easily drips in vertical upward welding. Therefore, the total content of the fluorine compound in terms of F is set to be from 0.05 to 0.3%. The fluorine compound can be added from CaF_2, NaF, LiF, MgF_2, K_2SiF_6, Na_3AlF_6, AlF_3, or the like. The content in terms of F is a total content of F included therein.

[0032]

[Total content of one kind or two kinds of Na and K in terms of Na and K in fluorine compound in flux: 0.05 to 0.3%]

Na and K in the fluorine compound further reduce oxygen in the weld metal (such a reduction in oxygen cannot be performed only by Mg), and increase the low-temperature toughness and the CTOD value of the weld metal. However, when a total content of one kind or two kinds of Na and K in terms of Na and K in the fluorine compound is less than 0.05%, these effects cannot be obtained sufficiently. When the total content of one kind or two kinds of Na and K in terms of Na and K in the fluorine compound is more than 0.3%, the arc is rough to increase a generation amount of spatters. Therefore, the total content

of one kind or two kinds of Na and K in terms of Na and K in the fluorine compound is set to be from 0.05 to 0.3%. Na and K in the fluorine compound can be added from NaF, K_2SiF_6, Na_3AlF_6, or the like. The content in terms of Na or K is a total content of Na or K included therein.

[0033]

[Total content of one kind or two kinds of Na_2O and K_2O in flux: 0.05 to 0.2%]

Na_2O and K_2O act as an arc stabilizer and a slag forming agent. When a total content of one kind or two kinds of Na_2O and K_2O is less than 0.05%, an arc is unstable to increase a generation amount of spatters, and an appearance of a bead is also poor. When the total content of one kind or two kinds of Na_2O and K_2O is more than 0.2%, slag detachability is poor, and metal easily drips in vertical upward welding. Therefore, the total content of one kind or two kinds of Na_2O and K_2O is set to be from 0.05 to 0.2%. Na_2O and K_2O can be added from a solid component of water glass including sodium silicate and potassium silicate, calcium titanate, sodium titanate, or the like.

[0034]

[Total content of Zr oxide in terms of ZrO_2 in flux: 0.2% or less]

A Zr oxide is added from zircon sand or a zirconium oxide. In addition, a small amount of the Zr oxide is included in a Ti oxide. However, the Zr oxide deteriorates slag detachability. Particularly when the content thereof is more

than 0.2%, the slag detachability is significantly poor. Therefore, the total content of the Zr oxide in terms of ZrO_2 is set to be 0.2% or less.

[0035]

[No seam in steel outer skin]

The flux-cored wire for Ar-CO_2 mixed gas shielded arc welding according to an embodiment of the present invention has a structure obtained by molding a steel outer skin into a pipe-like shape and filling a flux thereinto. The kind of the wire is roughly classified into a wire having no seam in a steel outer skin obtained by welding a joint of the molded steel outer skin, and a wire having a seam in a steel outer skin without welding the joint of the steel outer skin. In the present invention, any kind of wire can be employed. However, the wire having no seam in the steel outer skin is more preferable because the wire having no seam in the steel outer skin can be subjected to a heat treatment for reducing a total amount of hydrogen in the wire, a flux after manufacturing does not absorb moisture, and therefore it is possible to reduce an amount of diffusion hydrogen in the weld metal and to improve low-temperature cracking resistance.

[0036]

The balance of the flux-cored wire for Ar-CO_2 mixed gas shielded arc welding to which the present invention is applied is Fe in the steel outer skin, iron powder added for adjusting components, a Fe component of iron alloy powder such as a Fe-Mn alloy or a Fe-Si alloy, and inevitable impurities. A flux

filling ratio is not particularly limited, but is preferably from 8 to 20% with respect to the total mass of the wire from a viewpoint of productivity.

[0037]

The shielding gas during welding is a mixed gas of Ar-5 to 25% CO_2 for reducing an oxygen amount of the weld metal.

Examples

[0038]

Hereinafter, effects of the present invention will be described specifically with Examples.

[0039]

By using JIS G3141 SPCC for a steel outer skin, the steel outer skin was molded into a U shape in a step of molding the steel outer skin. Thereafter, a wire having no seam obtained by welding a joint of the steel outer skin and a wire having a gap without welding were manufactured into pipe shapes and drawn to experimentally manufacture flux-cored wires having a wire diameter of 1.2 mm and containing various components, indicated in Tables 1 to 4.

[0040]

[Table 1]

division	wire symbol	component of wire (% by mass)												
		total in steel outer skin and flux								flux				
		C	Si	Mn	Cu	Ni	Ti	B	Al	content in terms of TiO_2	content in terms of SiO_2	content in terms of Al_2O_3	Mg	*content in terms of F
Examples of the present invention	W1	0.05	0.32	2.01	0.21	0.52	0.15	0.0055	0.01	5.56	0.22	0.03	0.28	0.11
	W2	0.08	0.32	1.52	0.35	0.67	0.19	0.0114	0.02	4.87	0.14	0.09	0.38	0.09
	W3	0.06	0.12	2.18	0.24	1.31	0.08	0.0088	0.01	6.59	0.52	0.16	0.54	0.27
	W4	0.04	0.42	2.04	0.02	0.92	0.32	0.0069	-	6.84	0.33	0.21	0.13	0.14
	W5	0.03	0.38	1.85	0.36	1.33	0.32	0.0107	0.03	5.27	0.18	0.07	0.75	0.19
	W6	0.05	0.27	1.45	0.47	0.67	0.24	0.0045	0.02	7.16	0.26	0.11	0.35	0.21
	W7	0.04	0.58	1.91	0.18	0.75	0.22	0.0092	0.03	4.09	0.58	0.23	0.66	0.08
	W8	0.05	0.21	1.94	0.07	1.48	0.09	0.0113	0.02	6.55	0.34	0.15	0.27	0.22
	W9	0.04	0.16	2.46	0.22	0.62	0.11	0.0035	0.01	6.91	0.21	0.26	0.19	0.15
	W10	0.04	0.26	1.48	0.05	0.88	0.46	0.0046	0.03	7.18	0.45	0.09	0.55	0.13
	W11	0.05	0.47	2.01	0.36	1.07	0.07	0.0138	0.01	5.92	0.39	0.17	0.42	0.23
	W12	0.06	0.39	1.61	0.24	1.25	0.17	0.0074	0.04	4.99	0.31	0.22	0.36	0.18
	W13	0.05	0.27	2.05	0.19	0.95	0.22	0.0024	0.01	6.78	0.45	0.07	0.47	0.14
	W14	0.07	0.42	2.12	0.25	1.18	0.05	0.0062	0.02	7.55	0.38	0.12	0.55	0.06

*As a fluorine compound, one kind or two or more kinds of CaF_2, AlF_3, NaF, K_2SiF_6, K_2ZrF_6, and Na_3AlF_6 were used.

[0041]

[Table 2]

division	wire symbol	component of wire (% by mass)								
		flux								seam of wire
		**in fluorine compound			Na_2O	K_2O	total of Na_2O and K_2O	content in terms of ZrO_2	**others	
		content in terms of Na	content in terms of K	total content in terms of Na and K						
Examples of the present invention	W1	0.12	-	0.12	0.04	0.07	0.11	0.05	balance	present
	W2	-	0.08	0.08	0.07	0.08	0.15	0.03	balance	present
	W3	0.21	0.07	0.28	0.04	0.08	0.12	0.04	balance	present
	W4	0.08	0.07	0.15	-	0.06	0.06	0.07	balance	absent

	W5	0.11	0.07	0.18	0.09	0.05	0.14	0.05	balance	absent
	W6	0.15	0.07	0.22	-	0.09	0.09	0.19	balance	present
	W7	-	0.07	0.07	0.07	0.04	0.11	0.02	balance	present
	W8	0.09	0.12	0.21	0.08	0.08	0.16	0.09	balance	present
	W9	0.07	0.09	0.16	0.09	0.09	0.18	0.11	balance	present
	W10	0.07	0.04	0.12	0.06	0.08	0.14	0.13	balance	present
	W11	0.17	0.07	0.24	0.08	-	0.08	0.04	balance	present
	W12	0.11	0.08	0.19	0.06	0.09	0.15	0.03	balance	present
	W13	0.13	-	0.13	0.05	0.11	0.16	0.11	balance	present
	W14	0.06	-	0.06	0.08	-	0.08	0.17	balance	present

**As Na and K in a fluorine compound, one kind or two or more kinds of NaF, K_2SiF_6, K_2ZrF_6, and Na_3AlF_6 were used.
***Others are Fe in a steel outer skin, iron powder, a Fe component of an iron alloy, and inevitable impurities.

[0042]

[Table 3]

division	wire symbol	component of wire (% by mass)												
		total in steel outer skin and flux								total in steel outer skin and flux				
		C	Si	Mn	Cu	Ni	Ti	B	Al	content in terms of TiO_2	content in terms of SiO_2	content in terms of Al_2O_3	Mg	*content in terms of F
Comparative Examples	W15	0.02	0.15	1.35	0.31	1.05	0.21	0.0075	0.02	5.81	0.41	0.08	0.04	0.09
	W16	0.09	0.48	2.08	0.22	0.67	0.43	0.0048	0.03	4.95	0.22	0.15	0.44	0.18
	W17	0.06	0.04	1.56	0.43	1.25	0.15	0.0035	0.01	6.67	0.23	0.37	0.15	0.12
	W18	0.04	0.65	1.94	0.29	0.69	0.25	0.0105	0.04	4.88	0.52	0.22	0.61	0.25
	W19	0.04	0.32	1.26	0.32	0.87	0.16	0.0088	0.05	5.64	0.46	0.14	0.73	0.29
	W20	0.06	0.42	2.57	0.17	1.14	0.42	0.0067	0.01	6.18	0.37	0.07	0.25	0.09
	W21	0.04	0.29	1.31	0.004	1.08	0.18	0.0054	0.02	6.92	0.25	0.13	0.44	0.18
	W22	0.07	0.41	2.13	0.55	1.22	0.41	0.0115	0.05	5.16	0.19	0.23	0.65	0.25
	W23	0.05	0.38	1.95	0.18	0.44	0.13	0.0065	0.03	4.78	0.51	0.11	0.19	0.36
	W24	0.05	0.27	1.76	0.35	1.56	0.22	0.0079	0.01	6.52	0.46	0.25	0.33	0.06
	W25	0.07	0.49	1.92	0.28	0.92	0.02	0.0035	0.02	7.04	0.38	0.19	0.57	0.03
	W26	0.03	0.16	1.35	0.16	0.55	0.56	0.0102	0.04	6.53	0.24	0.25	0.61	0.22
	W27	0.05	0.33	1.96	0.07	1.07	0.18	0.0013	0.01	7.11	0.18	0.01	0.25	0.17
	W28	0.05	0.42	2.02	0.12	0.59	0.29	0.0164	0.02	6.05	0.47	0.21	0.43	0.11
	W29	0.06	0.41	1.95	0.29	1.11	0.08	0.0055	0.08	7.13	0.04	0.17	0.59	0.24
	W30	0.05	0.45	2.04	0.09	0.85	0.19	0.0097	0.03	3.45	0.68	0.09	0.24	0.08
	W31	0.05	0.28	1.68	0.17	1.03	0.31	0.0072	0.02	9.14	0.35	0.22	0.92	0.09

*As a fluorine compound, one kind or two or more kinds of CaF_2, AlF_3, NaF, K_2SiF_6, K_2ZrF_6, and Na_3AlF_6 were used.

[0043]

[Table 4]

division	wire symbol	component of wire (% by mass)								
		flux								seam of wire
		**in fluorine compound			Na_2O	K_2O	total of Na_2O and K_2O	content in terms of ZrO_2	***others	
		content in terms of Na	content in terms of K	total content in terms of Na and K						
Comparative Examples	W15	0.08	-	0.08	0.05	0.06	0.11	0.06	balance	absent
	W16	0.09	0.07	0.16	0.08	-	0.08	0.07	balance	present
	W17	0.09	0.02	0.11	0.08	0.07	0.15	0.09	balance	absent
	W18	0.12	0.11	0.23	0.09	0.16	0.25	0.04	balance	absent
	W19	0.24	0.12	0.36	0.07	-	0.07	0.08	balance	absent
	W20	0.07	-	0.07	-	0.08	0.08	0.12	balance	present
	W21	0.06	0.09	0.15	0.05	0.08	0.13	0.28	balance	absent
	W22	0.08	0.04	0.22	0.08	0.09	0.17	0.04	balance	present
	W23	0.15	0.13	0.28	0.08	-	0.08	0.05	balance	absent
	W24	0.03	-	0.03	0.04	0.08	0.12	0.06	balance	absent
	W25	-	0.05	0.05	0.07	0.07	0.14	0.11	balance	absent
	W26	0.09	0.09	0.18	-	0.02	0.02	0.12	balance	absent
	W27	0.11	0.02	0.13	0.05	0.11	0.16	0.05	balance	absent
	W28	-	0.08	0.08	0.03	0.06	0.09	0.07	balance	absent
	W29	0.11	0.08	0.19	0.04	0.08	0.12	0.15	balance	absent
	W30	-	0.06	0.06	0.05	0.08	0.13	0.02	balance	absent
	W31	0.06	-	0.06	-	0.08	0.08	0.16	balance	absent

**As Na and K in a fluorine compound, one kind or two or more kinds of NaF, K_2SiF_6, K_2ZrF_6, and Na_3AlF_6 were used.
***Others are Fe in a steel outer skin, iron powder, a Fe component of an iron alloy, and inevitable impurities.

[0044]

For the experimentally manufactured wires, welding workability was evaluated by vertical upward fillet welding using a steel plate defined by JIS G 3126 SLA 365, and mechanical properties were evaluated by a welding cracking test and a deposited metal test. In addition, for some experimentally manufactured wires, a welding joint test was performed by vertical upward welding using a K groove illustrated in FIG. 1 to perform a CTOD test. In this K groove, a groove angle was set to 45°, a groove depth on a surface side was set to 23 mm, and a groove depth on a back side was set to 35 mm. These welding conditions are indicated in Table 5.

[0045]

[Table 5]

test item	welding position	plate thickness (mm)	welding method	shielding gas	groove	current (A)	voltage (V)	welding speed (cm/min)
evaluation of welding workability	vertical upward	12	semi-automatic MAG	Ar-20%CO_2 25 L/minute	T type fillet	210	23	approximately 10
deposited metal test	downward	20	automatic MAG		in conformity with JIS Z 3111	270	29	30
welding cracking test	downward	40	automatic MAG		20° on one side U groove	240	26	22
welding joint test (CTOD)	vertical upward	60	semi-automatic MAG		FIG. 1 (K groove)	190 to 220	21 to 25	19 to 23

[0046]

Evaluation of welding workability by vertical upward welding was performed by examining stability of an arc, generation states of spatters and fumes, an appearance and a shape of a bead, dripping conditions of melted metal, and presence of high-temperature cracking.

[0047]

The welding cracking test was performed in conformity with a U shape welding cracking test method (JIS Z 3157) at a preheated temperature of a test body of 75°C. Presence of surface cracking or cross section cracking (five cross sections) of the test body 58 hours after welding was examined by penetrant testing (JIS Z 2343).

[0048]

The deposited metal test was performed by welding in conformity with JIS Z 3111. Test pieces for a tensile test (No. A1) and an impact test (V notch test piece) were collected from a center part of deposited metal in a plate thickness direction to perform a mechanical test. In evaluation of tensile strength, a test piece having tensile strength of 570 to 680 MPa was evaluated as being excellent. Evaluation of toughness was performed by a Charpy impact test at -60°C. The Charpy impact test was performed repeatedly for each test piece, and a test piece having an average of three absorption energies of 60 J or more was evaluated as being excellent.

[0049]

In the welding joint test, a back side of the K groove

illustrated in FIG. 1 was welded, and then the groove was subjected to back chipping of a radius of 6 mm and a groove angle of 45° from a steel plate surface to a depth of 34 mm, and a surface side was welded. For evaluation of a CTOD value by the welding joint test, a CTOD test piece was collected in conformity with BS (British standard) 5762, and three tests were performed repeatedly at a test temperature of -30°C. A test piece having a minimum CTOD value of 0.5 mm or more was evaluated as being excellent. These results are indicated in Table 6 collectively.

[0050]

[Table 6]

division	wire symbol	test results of welding workability	results of U type cracking test	results of mechanical test			total evaluation
			presence of cracks	TS (MPa)	vE-60 (J)	CTOD value -30°C (mm)	
Examples of the present invention	W1	excellent	absent	605	72	0.81	○
	W2	excellent	absent	636	82	0.64	○
	W3	excellent	absent	626	96	-	○
	W4	excellent	absent	659	84	-	○
	W5	excellent	absent	656	98	0.75	○
	W6	excellent	absent	609	92	0.81	○
	W7	excellent	absent	627	84	-	○
	W8	excellent	absent	604	101	-	○
	W9	excellent	absent	613	87	1.02	○
	W10	excellent	absent	655	82	-	○
	W11	excellent	absent	613	76	-	○
	W12	excellent	absent	611	81	-	○
	W13	excellent	absent	640	86	0.67	○
	W14	excellent	absent	637	75	-	○
Comparative Examples	W15	unstable arc	absent	521	51	0.19	×
	W16	excellent	present	750	54	-	×
	W17	poor appearance and shape of bead	absent	621	48	-	×
	W18	poor slag detachability dripping of metal	absent	656	42	-	×
	W19	a large amount of spatters	absent	535	49	0.24	×
	W20	excellent	present	748	55	0.28	×
	W21	poor slag detachability	absent	539	56	-	×

	W22	excellent	present	747	39	-	×
	W23	unstable arc, a large amount of spatters dripping of metal	absent	582	35	0.17	×
	W24	crater cracking	absent	672	55	0.25	×
	W25	unstable arc	absent	615	37	0.18	×
	W26	unstable arc, a large amount of spatters poor appearance of bead	absent	679	46	0.27	×
	W27	dripping of metal	absent	637	35	0.19	×
	W28	crater cracking	absent	675	41	0.22	×
	W29	poor appearance of bead	absent	632	53	-	×
	W30	unstable arc, a large amount of spatters dripping of metal	absent	647	48	-	×
	W31	a large amount of spatters a large amount of fumes	absent	665	51	-	×

[0051]

Wire symbols W1 to W14 in Tables 1, 2, and 6 represent Examples of the present invention, and wire symbols W15 to W31 in Tables 3, 4, and 6 represent Comparative Examples. The wire symbols W1 to W14 as Examples of the present invention had compositions of components within a range defined in the present invention. Therefore, the wire symbols W1 to W14 had excellent welding workability, no crack in a U type cracking test, and excellent tensile strength and absorption energy in a deposited metal test. That is, the wire symbols W1 to W14 obtained extremely satisfactory results. The wire symbols W1, W2, W5, W6, W9, and W13 which had been subjected to a welding joint test obtained excellent CTOD values.

[0052]

The wire symbol W15 in Comparative Examples included a

small amount of C. Therefore, in the wire symbol W15, an arc was unstable and the tensile strength of deposited metal was low. In addition, the wire symbol W15 included a small amount of Mg. Therefore, in the wire symbol W15, the absorption energy of the deposited metal was low and a CTOD value in the welding joint test was low.

[0053]

The wire symbol W16 included a large amount of C. Therefore, in the wire symbol W16, the tensile strength of deposited metal was high and the absorption energy was low. In addition, in the wire symbol W16, there was a seam in a steel outer skin and the tensile strength of the deposited metal was high, and therefore a crack was generated in a welded part in the U type cracking test.

[0054]

The wire symbol W17 included a small amount of Si. Therefore, in the wire symbol W17, an appearance and a shape of a bead were poor. In addition, the wire symbol W17 included a large amount of an Al oxide in terms of Al_2O_3. Therefore, in the wire symbol W17, the absorption energy of deposited metal was low.

[0055]

The wire symbol W18 included a large amount of Si. Therefore, in the wire symbol W18, the absorption energy of deposited metal was low. In addition, the wire symbol W18 included a large amount of Na_2O and K_2O in total. Therefore, in the wire symbol W18, slag detachability was poor and metal

dripped.

[0056]

The wire symbol W19 included a small amount of Mn. Therefore, in the wire symbol W19, the tensile strength of deposited metal was low and the absorption energy was low. In addition, a CTOD value in the welding joint test was low. Furthermore, the wire symbol W19 included a large amount in terms of Na and K in the fluorine compound. Therefore, in the wire symbol W19, a generation amount of spatters was large.

[0057]

The wire symbol W20 included a large amount of Mn. Therefore, in the wire symbol W20, the tensile strength of deposited metal was high and the absorption energy was low. In addition, in the wire symbol W20, there was a seam in a steel outer skin and the tensile strength of the deposited metal was high, and therefore a crack was generated in a welded part in the U type cracking test. In addition, a CTOD value in the welding joint test was low.

[0058]

The wire symbol W21 included a small amount of Cu. Therefore, in the wire symbol W21, the tensile strength of deposited metal was low and the absorption energy was low. In addition, the wire symbol W21 included a large amount of a Zr oxide in terms of ZrO_2. Therefore, in the wire symbol W21, slag detachability was poor.

[0059]

The wire symbol W22 included a large amount of Cu.

Therefore, in the wire symbol W22, the tensile strength of deposited metal was high and the absorption energy was low. In addition, in the wire symbol W22, there was a seam in a steel outer skin and the tensile strength of the deposited metal was high, and therefore a crack was generated in a welded part in the U type cracking test.

[0060]

The wire symbol W23 included a small amount of Ni. Therefore, in the wire symbol W23, the absorption energy of deposited metal was low and a CTOD value in the welding joint test was low. In addition, the wire symbol W23 included a large amount of a fluorine compound in terms of F. Therefore, in the wire symbol W23, an arc was unstable, a generation amount of spatters was large, and metal dripped.

[0061]

The wire symbol W24 included a large amount of Ni. Therefore, in the wire symbol W24, high-temperature cracking was generated in a crater part. In addition, the wire symbol W24 included a small amount in terms of Na and K in the fluorine compound. Therefore, in the wire symbol W24, the absorption energy of deposited metal was low and a CTOD value in the welding joint test was low.

[0062]

The wire symbol W25 included a small amount of Ti. Therefore, in the wire symbol W25, the absorption energy of deposited metal was low and a CTOD value in the welding joint test was low. In addition, the wire symbol W25 included a small

amount of a fluorine compound in terms of F. Therefore, in the wire symbol W25, an arc was unstable.

[0063]

The wire symbol W26 included a large amount of Ti. Therefore, in the wire symbol W26, the absorption energy of deposited metal was low and a CTOD value in the welding joint test was low. In addition, the wire symbol W26 included a large amount of Na_2O and K_2O in total. Therefore, in the wire symbol W26, an arc was unstable, a generation amount of spatters was large, and an appearance of a bead was poor.

[0064]

The wire symbol W27 included a small amount of B. Therefore, in the wire symbol W27, the absorption energy of deposited metal was low and a CTOD value in the welding joint test was low. In addition, the wire symbol W27 included a small amount of an Al oxide in terms of Al_2O_3. Therefore, in the wire symbol W27, metal dripped.

[0065]

The wire symbol W28 included a large amount of B. Therefore, in the wire symbol W28, high-temperature cracking was generated in a crater part and the absorption energy of deposited metal was low. In addition, a CTOD value in the welding joint test was low.

[0066]

The wire symbol W29 included a large amount of Al. Therefore, in the wire symbol W29, the absorption energy of deposited metal was low. In addition, the wire symbol W29

included a small amount of a Si oxide in terms of SiO_2. Therefore, in the wire symbol W29, a slag encapsulation property was poor and an appearance of a bead was poor.

[0067]

The wire symbol W30 included a small amount of a Ti oxide in terms of TiO_2. Therefore, in the wire symbol W30, an arc was unstable, a generation amount of spatters was large, and metal dripped. In addition, the wire symbol W30 included a large amount of a Si oxide in terms of SiO_2. Therefore, in the wire symbol W30, the absorption energy of deposited metal was low.

[0068]

The wire symbol W31 included a large amount of a Ti oxide in terms of TiO_2. Therefore, in the wire symbol W31, the absorption energy of deposited metal was low. In addition, the wire symbol W31 had a large amount of Mg. Therefore, in the wire symbol W31, generation amounts of spatters and fumes were large.

What is claimed is:

1. A flux-cored wire for Ar-CO_2 mixed gas shielded arc welding obtained by filling a flux into a steel outer skin, comprising;

in terms of % by mass with respect to a total mass of the wire, as a total in the steel outer skin and the flux,

0.03 to 0.08% of C;

0.1 to 0.6% of Si;

more than 1.26% to 2.5% of Mn;

0.01 to 0.5% of Cu;

0.5 to 1.5% of Ni;

0.05 to 0.5% of Ti;

0.002 to 0.015% of B; and

0.05% or less of Al,

and further comprising:

in terms of % by mass with respect to the total mass of the wire, in the flux,

4 to 8% of a Ti oxide in terms of TiO_2 in total;

0.1 to 0.6% of a Si oxide in terms of SiO_2 in total;

0.02 to 0.3% of an Al oxide in terms of Al_2O_3 in total;

0.1 to 0.8% of Mg;

0.05 to 0.3% of a fluorine compound in terms of F in total;

0.05 to 0.3% of one kind or two kinds of Na and K in the fluorine compound in terms of Na and K in total;

0.05 to 0.2% of one kind or two kinds of Na_2O and K_2O in total; and

0.2% or less of a Zr oxide in terms of ZrO_2 in total,

the balance being Fe in the steel outer skin, iron powder, a Fe component of iron alloy powder, and inevitable impurities.

2. The flux-cored wire for Ar-CO_2 mixed gas shielded arc welding according to claim 1, wherein a seam in the steel outer skin is eliminated by welding a joint of the molded steel outer skin.