

DESCRIPTION

LOW-HYDROGEN TYPE COATED ARC WELDING ELECTRODE

Technical Field

5 [0001]

The present invention relates to a low-hydrogen type coated arc welding electrode in which a steel core wire is coated with a low-hydrogen type coating flux. More particularly, the present invention relates to technology in which moisture absorption resistance of a low-hydrogen type coated arc welding electrode is improved.

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Background Art

[0002]

15 To improve moisture absorption resistance of a coated arc welding electrode, various studies have hitherto been made (see Patent Documents 1 to 4). For example, Patent Document 1 proposes a coated arc welding electrode in which a grass powder is mixed in a coating flux. Patent Documents 2 to 4 propose coated arc welding electrodes in which an aqueous silicate solution of alkali metal is used as a fixing agent of a coating flux.

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Prior Art Documents

Patent Documents

25 [0003]

Patent Document 1: JP 48-34295 B

Patent Document 2: JP 48-65133 A

Patent Document 3: JP 50-14556 A

Patent Document 4: JP 59-38878 A

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Summary of Invention

Problems to be Solved by the Invention

[0004]

10 However, application of aforementioned conventional technologies to a low-hydrogen type coating flux may cause a problem that fixability of the coating flux and welding workability deteriorate. Particularly, there has been required an ultra-low-hydrogen type coated arc welding electrode in which the amount of diffusible hydrogen in the thus obtained weld metal

15 is 4 ml/100 g or less, the coated arc welding electrode having excellent moisture absorption resistance, and satisfactory fixability of a coating flux and welding workability.

[0005]

20 Thus, it is a main object of the present invention to provide a low-hydrogen type coated arc welding electrode which can improve moisture absorption resistance without causing deterioration of fixability of a coating flux and welding workability.

Means for Solving the Problems

25 [0006]

The low-hydrogen type coated arc welding electrode according to the present invention is a low-hydrogen type coated arc welding electrode in which a steel core wire is coated with a coating flux, wherein the coating flux includes: metal carbonate (in terms of CO₂): 8 to 25% by mass, metal fluoride (in terms of F): 2 to 15% by mass, at least one of TiO₂, ZrO₂ and Al₂O₃: 2 to 10% by mass in total, SiO₂: 3 to 12% by mass, Si: 1 to 7% by mass, Mn: 1 to 8% by mass, a Li compound (in terms of Li): 0.03 to 0.7% by mass, and at least one of a Na compound (in terms of Na) and a K compound (in terms of K): 1.0 to 3.5% by mass in total, with the balance being Fe and inevitable impurities, wherein the coating flux has the composition that satisfies a numerical formula 1 below when [Li] denotes the content of a Li compound (in terms of Li), [Na] denotes the content of a Na compound (in terms of Na), and [K] denotes the content of a K compound (in terms of K), and wherein a coating ratio of the coating flux is in a range of 22 to 45% by mass. The coating ratio as used herein is a value calculated by (mass of coating flux/total mass of welding electrode) × 100.

[0007]

[Equation 1]

$$2. 0 \leq (1.22 \times [\text{Na}] + 1.49 \times [\text{K}]) / [\text{Li}] \leq 35 \quad \dots \quad (1)$$

[0008]

The coating flux may be regulated to C: 0.1% by mass or less.

The coating flux may contain Ti: 0.2 to 2.0% by mass.

The coating flux may contain a B compound (in terms of B):
0.02 to 0.3% by mass.

The coating flux may contain Ni: 0.5 to 10% by mass.

5 The coating flux can also contain at least one of Cr and
Mo: 0.1 to 3% by mass in total.

The coating flux can also contain at least one of Al and
Mg: 0.2 to 2% by mass in total.

10 Meanwhile, the steel core wire can be formed, for example,
from a mild steel or a low alloy steel.

Effects of the Invention

[0009]

15 According to the present invention, it is possible to
realize a low-hydrogen type coated arc welding electrode which
has excellent moisture absorption resistance, and also has
satisfactory fixability of a coating flux and welding
workability.

20 Mode for Carrying Out the Invention

[0010]

Mode for carrying out the present invention will be
described in detail below. The present invention is not limited
to embodiments that will be described below.

25 [0011]

The low-hydrogen type coated arc welding electrode according to the embodiment of the present invention is a low-hydrogen type coated arc welding electrode in which a steel core wire is coated with a coating flux including: metal carbonate (in terms of CO₂): 8 to 25% by mass, metal fluoride (in terms of F): 2 to 15% by mass, at least one of TiO₂, ZrO₂ and Al₂O₃: 2 to 10% by mass in total, SiO₂: 3 to 12% by mass, Si: 1 to 7% by mass, Mn: 1 to 8% by mass, a Li compound (in terms of Li): 0.03 to 0.7% by mass, and at least one of a Na compound (in terms of Na) and a K compound (in terms of K): 1.0 to 3.5% by mass in total, with the balance being Fe and inevitable impurities, wherein the coating flux has the composition that satisfies a numerical formula 2 below, and wherein a coating ratio of the coating flux is in a range of 22 to 45% by mass.

[0012]

[Equation 2]

$$2. 0 \leq (1.22 \times [\text{Na}] + 1.49 \times [\text{K}]) / [\text{Li}] \leq 35 \quad \dots \quad (2)$$

[0013]

In the above-mentioned numerical formula 2, [Li] denotes the content of a Li compound (in terms of Li), [Na] denotes the content of a Na compound (in terms of Na), and [K] denotes the content of a K compound (in terms of K).

[0014]

(Coating flux)

[Coating ratio of coating flux based on total mass of welding electrode: 22 to 45% by mass]

A coating ratio (%) of a coating flux in a coated arc welding electrode is calculated by (mass of coating flux/total mass of welding electrode) $\times$ 100. When the coating ratio of the coating flux is less than 22% by mass, the content of N and the amount of hydrogen in weld metal increase and toughness and crack resistance of weld metal deteriorate, due to lack of shielding. Meanwhile, when the coating ratio of the coating flux exceeds 45% by mass, arc length increases to generate arc breaking. Therefore, the coating ratio of the coating flux is set in a range of 22 to 45% by mass.

[0015]

[Metal Carbonate (in terms of CO₂): 8 to 25% by mass]

Metal carbonate has the effect of decreasing the amounts of N and hydrogen in weld metal. However, when the amount of metal carbonate in the coating flux is less than 8% by mass in terms of CO₂, the amount of hydrogen in weld metal exceeds 4 ml/100 g, and also the amount of N excessively increases, thus failing to obtain satisfactory crack resistance and toughness. Meanwhile, when the amount of metal carbonate in the coating flux exceeds 25% by mass in terms of CO₂, it becomes difficult to perform vertical welding due to excess viscosity of the slag. Therefore, the content of metal carbonate (in terms of CO₂) is set in a range of 8 to 25% by mass based on the total mass of the coating flux.

[0016]

The amount of metal carbonate in the coating flux is preferably set at 11% by mass or more in terms of CO_2 , and more preferably 16% by mass or more, from a viewpoint of decreasing the amount of hydrogen and the amount of N in weld metal.

Meanwhile, the amount of metal carbonate is preferably set at 22% by mass or less in terms of CO_2 so as to decrease slag viscosity and to further improve welding workability. Specific examples of metal carbonate to be mixed in the coating flux include CaCO_3 , MgCO_3 and BaCO_3 .

[0017]

[Metal Fluoride (in terms of F): 2 to 15% by mass]

Metal fluoride has the effect of adjusting the viscosity of the slag to thereby improve welding workability. However, when the amount of metal fluoride in the coating flux is less than 2% by mass in terms of F, bead shape deteriorates due to excess viscosity of the slag. Meanwhile, when the amount of the metal fluoride in the coating flux, exceeds 15% by mass in terms of F, arc becomes unstable. Therefore, the content of metal fluoride content (in terms of F) is set in a range of 2 to 15% by mass based on the total mass of the coating flux.

[0018]

The content of metal fluoride in the coating flux is preferably set at 4% by mass or more from a viewpoint of an improvement in bead shape, and is preferably set at 10% by mass

or less from a viewpoint of stabilizing arc. Specific examples of metal fluoride to be mixed in the coating flux include CaF_2 , BaF_2 , AlF_3 and LiF .

[0019]

5 [TiO₂, ZrO₂, Al₂O₃: 2 to 10% by mass in total]

TiO₂, ZrO₂ and Al₂O₃ serve as a slag-making agent. However, when the total content of TiO₂, ZrO₂ and Al₂O₃ is less than 2% by mass based on the total weight of the coating flux, the viscosity of the slag decreases, leading to deterioration of bead shape. Therefore, at least one of TiO₂, ZrO₂ and Al₂O₃ is mixed in the amount of 2% by mass or more in total.

[0020]

Meanwhile, when TiO₂, ZrO₂ and Al₂O₃ are excessively added, the slag transforms into a glassy state, leading to deterioration of slag removability. In the low-hydrogen type coated arc welding electrode according to the present embodiment, the total content of TiO₂, ZrO₂ and Al₂O₃ is set at 10% by mass or less based on the total mass of the coating flux.

[0021]

20 The total content of TiO₂, ZrO₂ and Al₂O₃ in the coating flux is preferably set at 3% by mass or more from a viewpoint of a bead shape, and is preferably set at 8% by mass or less from a viewpoint of slag removability. There is no need to mix all of TiO₂, ZrO₂ and Al₂O₃, and the above-mentioned effect is obtained by mixing at least one in the coating flux.

[0022]

[SiO₂: 3 to 12% by mass]

SiO₂ serves as a binder and a slag-making agent. However, when the amount of SiO₂ in the coating flux exceeds 12% by mass based on the total mass of the coating flux, the slag transforms into a glassy state, leading to deterioration of slag removability. Meanwhile, when the amount of SiO₂ in the coating flux is less than 3% by mass based on the total mass of the coating flux, it is impossible to obtain the effect as a binder. Therefore, the content of SiO₂ is set in a range of 3 to 12% by mass based on the total mass of the coating flux. The amount of SiO₂ in the coating flux is preferably set at 4% by mass or more from a viewpoint of improving the binder effect, and is preferably set at 9% by mass or less from a viewpoint of slag removability.

[0023]

It is possible to add, as the slag-making agent to be mixed in the coating flux, MgO and CaO, in addition to the above-mentioned acidic oxide, for the purpose of adjusting the viscosity. It is also possible to use, as the binder, potassium silicate, sodium silicate, and the like. It is preferred to substantially not contain silicates containing crystallization water, for example, mica, talc and sericite, since the silicates containing crystallization water increase the amount of hydrogen in weld metal.

[0024]

[Si: 1 to 7% by mass]

Si serves as a deoxidizing agent and can be added in the form of alloy components, for example, Fe-Si and Fe-Si-Mn. When the content of Si is less than 1% by mass based on the total mass of the coating flux, insufficient effect as the deoxidizing agent is exhibited. Meanwhile, when the content exceeds 7% by mass, the viscosity of molten metal increases, thus causing deterioration of welding workability, for example, deterioration of fitness to a base material. Therefore, the content of Si is set in a range of 1 to 7% by mass based on the total mass of the coating flux. The content of Si as used herein does not include Si included in the above-mentioned SiO₂.

[0025]

[Mn: 1 to 8% by mass]

Mn is an element that serves as a deoxidizing agent, like Si mentioned above, and is also effective to improve toughness of weld metal. Mn can be added to the coating flux in the form of metallic Mn, Fe-Mn, and the like. When the content of Mn is less than 1% by mass based on the total mass of the coating flux, blowholes are generated due to lack of deoxidation. Meanwhile, when the content of Mn exceeds 8% by mass based on the total mass of the coating flux, the viscosity of molten metal tends to decrease to form projected bead, leading to deterioration of welding workability. Further, the content of Mn is set in a range of 1 to 8% by mass based on the total mass of the coating flux.

The amount of Mn in the coating flux is preferably set at 2% by mass or more taking toughness of weld metal into consideration, and is preferably set at 5% by mass or less from a viewpoint of improving welding workability.

5 [0026]

[Li compound (in terms of Li): 0.03 to 0.7% by mass]

Li has the effect of improving moisture absorption resistance of the coating flux and is generally added in water glass. When the amount of a Li compound in the coating flux is less than 0.03% by mass in terms of Li, it is impossible to obtain the effect of improving moisture absorption resistance.

Meanwhile, when the amount of a Li compound in the coating flux exceeds 0.7% by mass in terms of Li, moisture absorption resistance is improved, however, performances as a lubricant in the coating step of the coating flux deteriorate due to a decrease in viscosity of water glass, leading to difficulty in coating operation. Meanwhile, when the amount of a Li compound exceeds 0.7% by mass, the fixing strength decreases, so that the coating flux is likely to be fallen away after coating and cracks are likely to be caused during drying.

20 [0027]

Therefore, the content of a Li compound content is set in a range of 0.03 to 0.7% by mass in terms of Li based on the total mass of the coating flux. It is possible to use, as a specific example of the Li compound, LiCO_3 and LiF , in addition to Li_2O

to be added to water glass.

[0028]

[Na compound (in terms of Na), K compound (in terms of K): 1.0 to 3.5% by mass in total]

5 Na and K have the effect of ensuring fixability of the coating flux and arc stability. However, when the total amount of a Na compound (in terms of Na) and a K compound (in terms of K) in the coating flux is less than 1.0% by mass based on the total mass of the coating flux, arc becomes unstable and also the fixing
10 strength decreases, so that the coating flux is likely to be fallen away after coating and cracks are likely to be caused during drying. Meanwhile, when the total amount of a Na compound (in terms of Na) and a K compound (in terms of K) in the coating flux exceeds 3.5% by mass based on the total mass of the coating flux, moisture
15 absorption resistance of the coating flux deteriorates.

[0029]

 Therefore, the total amount of a Na compound (in terms of Na) and a K compound (in terms of K) in the coating flux is set in a range of 1.0 to 3.5% by mass. There is no need to mix both
20 a Na compound and a K compound (in terms of K), and the above-mentioned effect can be obtained by mixing any one of them to the coating flux.

[0030]

 [Relation among content of Li compound, content of Na compound,
25 and content of K compound]

In the low-hydrogen type coated arc welding electrode according to the present embodiment, the coating flux has the composition in which a relation among the content of a Li compound (in terms of Li), the content of a Na compound (in terms of Na), and the content of a K compound (in terms of K) satisfies the above-mentioned numerical formula 2. Li, and Na and K have the opposite effect with respect to an influence on the fixing strength and moisture absorption resistance of coating flux. Namely, Li decreases the fixing strength of the coating flux, while it has the effect of improving moisture absorption resistance. In contrast, Na and K have the effect of increasing the fixing strength, while they cause deterioration of moisture absorption resistance.

[0031]

Thus, in the low-hydrogen type coated arc welding electrode according to the present embodiment, the inventors considered that the degree of an influence of these alkali components on the fixing strength and moisture absorption resistance of the coating flux has a correlation with an atomic radius of each element. As a result, the inventors have found that, when an atomic radius of Li is 1, an atomic radius of Na is 1.22 and an atomic radius of K is 1.49, and it is possible to simultaneously evaluate the fixing strength and moisture absorption resistance of the coating flux by a parameter: $(1.22 \times [\text{Na}] + 1.49 \times [\text{K}]) / [\text{Li}]$ where Na + K is placed in the numerator, and Li is placed in the denominator.

[0032]

When $(1.22 \times [\text{Na}] + 1.49 \times [\text{K}]) / [\text{Li}]$ is less than 2.0, the coating flux is excellent in moisture absorption resistance, but the fixing strength of the coating flux decreases. When $(1.22 \times [\text{Na}] + 1.49 \times [\text{K}]) / [\text{Li}]$ exceeds 35, the fixing strength of the coating flux increases, but moisture absorption resistance decreases. Therefore, the parameter $(1.22 \times [\text{Na}] + 1.49 \times [\text{K}]) / [\text{Li}]$ shown in the above-mentioned numerical formula 2 is set in a range of 2 to 35. Taking balance between the fixing strength and moisture absorption resistance of the coating flux into consideration, $(1.22 \times [\text{Na}] + 1.49 \times [\text{K}]) / [\text{Li}]$ is preferably in a range of 5 to 20.

[0033]

[C: 0.1% by mass or less]

When the content of C exceeds 0.1% by mass based on the total mass of the coating flux, hot cracks are likely to occur and high carbon martensite, which causes deterioration of toughness, is likely to occur due to excess amount of C in weld metal. Therefore, the content of C is preferably regulated to 0.1% by mass or less based on the total mass of the coating flux.

[0034]

In the low-hydrogen type coated arc welding electrode according to the present embodiment, it is possible to optionally add one, or two or more component(s) shown below, to the coating flux, in addition to the above-mentioned components.

[0035]

[Ti: 0.2 to 2.0% by mass]

5 Ti is a deoxidizing element and is also an element that is effective to improve the strength of weld metal. Ti also has the effect of forming fine spherical oxide to thereby refine the structure of weld metal. When the content of Ti is less than 0.2% by mass based on the total mass of the coating flux, it is impossible to sufficiently obtain the deoxidizing effect and the effect of improving the strength of weld metal. Meanwhile, when
10 the content of Ti exceeds 2.0% by mass, the amount of Ti in weld metal excessively increases to thereby excessively increase the strength and hardness, thus causing deterioration of toughness of weld metal. Therefore, when adding Ti, the content is set in a range of 0.2 to 2.0% by mass based on the total mass of the coating
15 flux. Ti can be added in the form of Fe-Ti and metallic Ti.

[0036]

[B compound (in terms of B): 0.02 to 0.3% by mass]

20 B is an element that is effective to suppress formation of grain boundary ferrite and has strong hardenability. When the content of B in the coating flux is less than 0.02% by mass in terms of B, it is impossible to obtain the effect of suppressing formation of grain boundary ferrite due to B, leading to coarsening of the metal structure of weld metal. Meanwhile, when the content of B in the coating flux exceeds 0.3% by mass, weld
25 metal exhibits a coarse lath-like structure, thus causing

deterioration of toughness. Therefore, when adding B, the content (in terms of B) is set in a range of 0.02 to 0.3% by mass based on the total mass of the coating flux. B can be added in the form of Fe-B, Fe-Si-B and metallic B.

5 [0037]

[Ni: 0.5 to 10% by mass]

Ni has the effect of enhancing strength and toughness of weld metal and, when a working temperature of a welding member is lower than -40°C , Ni is preferably added so as to achieve the reconciliation between the strength and toughness of weld metal. When the content of Ni is less than 0.5% by mass based on the total mass of the coating flux, it is impossible to obtain the effect of improving toughness of weld metal. Meanwhile, when the content of Ni exceeds 10% by mass based on the total mass of the coating flux, toughness deteriorates due to excessively high strength of weld metal, and also hot cracks are likely to occur during welding. Therefore, when adding Ni, the amount is set in a range of 0.5 to 10% by mass based on the total mass of the coating flux. Ni can be added in the form of metallic Ni, Ni-Mg and Fe-Ni.

20 [0038]

[Cr, Mo: 0.1 to 3% by mass in total]

Cr and Mo have the effect of increasing the strength of weld metal. However, when the total content of Cr and Mo is less than 0.1% by mass based on the total mass of the coating flux, it is impossible to obtain the effect of improving the strength of weld

metal. Meanwhile, when the total content of Cr and Mo exceeds 3% by mass based on the total mass of the coating flux, hardenability becomes excessive and carbides are generated, thus causing deterioration of toughness of weld metal. Therefore, when adding Cr and Mo, the amount is set in a range of 0.1 to 3% by mass in total based on the total mass of the coating flux. There is no need to add both Cr and Mo, and only either one of them may be added.

[0039]

[Al, Mg: 0.2 to 2% by mass in total]

Al and Mg serve as a strong deoxidizing agent, and have the effect of reducing the amount of oxygen in weld metal to thereby improve toughness. When the total content of Al and Mg is less than 0.2% by mass based on the total mass of the coating flux, it is impossible to obtain the effect of improving toughness of weld metal. Meanwhile, when the total content of Al and Mg exceeds 2% by mass based on the total mass of the coating flux, arc becomes unstable to thereby increase the generation amount of sputters, and also the viscosity of the slag decreases thus causing deterioration of slag removability. Therefore, when adding Al and Mg, the total content of them is set in a range of 0.2 to 2% by mass based on the total mass of the coating flux. There is no need to add both Al and Mg, and only either one of them may be added.

[0040]

[Balance]

Components other than those mentioned above in coating flux, namely, balance include Fe, alkali metal oxide, alkali earth metal oxide and inevitable impurities. Examples of inevitable
5 impurities as used herein include P, S, V, Nb, Sn and Zr.

[0041]

(Steel Core Wire)

Examples of the steel material used in a steel core wire include a mild steel and a low alloy steel.

10 [0042]

As mentioned in detail above, in the low-hydrogen type coated arc welding electrode according to the present embodiment, since the composition of the coating flux, particularly a relation among the content of a Li compound, the content of a Na compound,
15 and the content of a K compound is specified, it is possible to improve moisture absorption resistance without causing deterioration of fixability of the coating flux and welding workability. It is also possible to obtain weld metal in which the amount of diffusible hydrogen is 4 ml/100 g or less, by using
20 the low-hydrogen type coated arc welding electrode according to the present embodiment.

[0043]

Finally, just in case, the inventors would like to additionally mention that the present invention includes the
25 following embodiments.

First embodiment: A low-hydrogen type coated arc welding electrode in which a steel core wire is coated with a coating flux, wherein

the coating flux includes:

5 metal carbonate (in terms of CO_2): 8 to 25% by mass,
metal fluoride (in terms of F): 2 to 15% by mass,
at least one of TiO_2 , ZrO_2 and Al_2O_3 : 2 to 10% by mass in total,

SiO_2 : 3 to 12% by mass,

10 Si: 1 to 7% by mass,

Mn: 1 to 8% by mass,

a Li compound (in terms of Li): 0.03 to 0.7% by mass, and
at least one of a Na compound (in terms of Na) and a K compound
(in terms of K): 1.0 to 3.5% by mass in total, with the balance
15 being Fe and inevitable impurities,

wherein the coating flux has the composition that satisfies
a numerical formula (1) below when [Li] denotes the content of
a Li compound (in terms of Li), [Na] denotes the content of a Na
compound (in terms of Na), and [K] denotes the content of a K
20 compound (in terms of K), and

wherein a coating ratio of the coating flux is in a range
of 22 to 45% by mass.

Second embodiment: The low-hydrogen type coated arc welding
electrode according the first embodiment, wherein the content of
25 C in the coating flux is regulated to 0.1% by mass or less.

Third embodiment: The low-hydrogen type coated arc welding electrode according to the first embodiment or the second embodiment, wherein the coating flux further contains: Ti: 0.2 to 2.0% by mass.

5 Fourth embodiment: The low-hydrogen type coated arc welding electrode according to any one of the first embodiment to the third embodiment, wherein the coating flux further contains: a B compound (in terms of B): 0.02 to 0.3% by mass.

10 Fifth embodiment: The low-hydrogen type coated arc welding electrode according to any one of the first embodiment to the fourth embodiment, wherein the coating flux further contains: Ni: 0.5 to 10% by mass.

15 Sixth embodiment: The low-hydrogen type coated arc welding electrode according to any one of the first embodiment to the fifth embodiment, wherein the coating flux further contains: at least one of Cr and Mo: 0.1 to 3% by mass in total.

20 Seventh embodiment: The low-hydrogen type coated arc welding electrode according to any one of the first embodiment to the sixth embodiment, wherein the coating flux further contains: at least one of Al and Mg: 0.2 to 2% by mass in total.

Eighth embodiment: The low-hydrogen type coated arc welding electrode according to any one of the first embodiment to the seventh embodiment, wherein the steel core wire is formed from a mild steel or a low alloy steel.

Examples

[0044]

The effect of the present invention will be specifically described below by way of Examples and Comparative Examples of the present invention.

In these Examples, using a welding electrode coater, each steel core wire having the composition shown in Table 1 below was coated with a coating flux having composition (composition after sintering) shown in Tables 2 and 3 below, and then sintered at 400 to 500°C for about 1 hour to manufacture the respective low-hydrogen type coated arc welding electrodes of Examples and Comparative Examples. Each coating ratio of the respective welding electrodes of Examples and Comparative Examples is as shown in Tables 2 and 3 below. Balance in the compositions of steel core wires and coating fluxs shown in Tables 1 to 3 below includes Fe and inevitable impurities. The welding electrodes Nos. 1 to 30 shown in Tables 2 and 3 below fall within the scope of the present invention, whereas the welding electrodes Nos. 31 to 48 shown in Table 3 below depart from the scope of the present invention.

[0045]

[Table 1]

No.	Composition (% by mass)					
	C	Si	Mn	P	S	N
C1	0.05	0.01	0.47	0.003	0.010	0.008
C2	0.06	0.01	0.46	0.003	0.009	0.009
C3	0.05	0.02	0.46	0.003	0.008	0.003
C4	0.09	0.02	0.42	0.003	0.005	0.004
C5	0.06	0.02	0.41	0.002	0.007	0.004
C6	0.08	0.01	0.42	0.004	0.008	0.003
C7	0.06	0.01	0.42	0.005	0.007	0.005
C8	0.07	0.01	0.43	0.005	0.007	0.003
C9	0.08	0.01	0.45	0.003	0.006	0.006
C10	0.01	0.02	0.49	0.007	0.008	0.003

[0046]

[Table 2]

	Sample No.	Core wire No.	Composition of coating flux (% by mass)																Parameter	Coating ratio (% by mass)
			Metal carbonate (in terms of CO ₂)	Metal fluoride (in terms of F)	TiO ₂ +ZrO ₂ +Al ₂ O ₃	SiO ₂	Si	Mn	Li compound (in terms of Li)	Na compound (in terms of Na)	K compound (in terms of K)	Na+K	C	Ti	B compound (in terms of B)	Ni	Cr+Mo	Al+Mg		
Examples	1	C1	21	3.0	4.0	5.5	2.5	3.5	0.48	0.70	0.40	1.10	0.04	< 0.01	< 0.01	1.3	< 0.01	1	3.0	32
	2	C2	20	8.0	6.5	7.0	5.5	2.5	0.04	0.75	0.27	1.02	0.07	0.8	0.12	1.2	< 0.01	1.5	33.4	30
	3	C3	18	10.0	2.5	9.1	4.7	3.2	0.19	1.35	1.20	2.55	0.06	0.5	0.15	< 0.01	< 0.01	0.88	18.4	33
	4	C3	13	2.5	9.0	8.5	3.5	4.5	0.18	1.33	0.62	1.95	0.05	0.6	0.09	1.2	< 0.01	0.96	14.5	35
	5	C3	25	14.0	4.7	7.5	4.1	3.8	0.15	1.32	0.55	1.87	0.05	< 0.01	< 0.01	< 0.01	< 0.01	1.2	16.2	29
	6	C4	15	7.2	4.5	8.2	3.5	3.7	0.21	1.33	0.50	1.83	0.06	0.6	0.09	1.6	< 0.01	0.75	11.5	44
	7	C5	17	6.5	7.2	5.8	2.3	4.3	0.62	1.20	1.50	2.70	0.05	0.7	0.08	< 0.01	< 0.01	1.01	6.0	23
	8	C5	9	5.7	5.1	6.5	1.5	3.6	0.15	1.70	1.60	3.30	0.06	0.8	0.08	1.3	< 0.01	0.75	29.7	29
	9	C3	13	4.3	6.1	7.6	6.3	3.5	0.16	1.35	0.65	2.00	0.08	1.1	0.20	1.2	< 0.01	0.85	15.9	27
	10	C5	18	11.0	5.8	6.5	3.3	1.3	0.11	1.25	0.75	2.00	0.07	0.5	0.15	1.5	< 0.01	1.1	23.9	30
	11	C6	22	3.5	7.2	3.2	5.7	3.1	0.10	1.25	0.30	1.55	0.06	0.2	0.03	1.6	0.4	1.35	20.2	36
	12	C7	11	5.5	4.6	7.3	5.2	6.7	0.09	0.00	1.10	1.10	0.05	< 0.01	< 0.01	8.1	2.3	0.65	17.5	29
	13	C8	20	12.3	5.5	11.3	3.5	4.5	0.11	0.90	0.00	1.10	0.04	0.4	0.11	1.5	< 0.01	0.85	12.7	28
	14	C3	15	6.3	4.3	8.5	4.3	3.6	0.66	0.80	0.40	1.20	0.09	< 0.01	< 0.01	7.2	1.5	0.73	2.4	31
	15	C5	19	8.0	4.1	7.2	3.9	3.7	0.13	1.18	0.70	1.88	0.05	0.6	0.09	1.3	< 0.01	< 0.01	19.7	28
	16	C5	19	7.8	4.1	7.2	3.9	3.7	0.21	1.18	0.70	1.88	0.05	0.6	0.09	1.3	< 0.01	0.95	11.7	28
	17	C5	19	7.9	4.1	7.3	3.8	3.7	0.18	1.22	0.70	1.92	0.05	0.6	0.09	1.3	< 0.01	0.95	14.3	28
	18	C8	20	7.6	4.1	7.3	3.9	3.7	0.12	1.18	0.70	1.88	0.05	0.6	0.09	1.3	< 0.01	0.95	21.6	30
	19	C9	20	7.7	4.1	7.3	3.9	3.7	0.16	1.18	0.70	1.88	0.03	0.6	0.09	1.2	< 0.01	0.95	15.1	30
	20	C8	21	8.1	4.1	7.2	3.8	4.0	0.25	1.22	0.70	1.92	0.05	0.6	0.09	1.3	< 0.01	0.95	10.1	29
	21	C5	11	8.6	3.3	7.5	2.0	3.2	0.17	1.40	0.74	2.14	0.05	1.95	0.08	< 0.01	< 0.01	0.71	16.5	34
	22	C6	18	7.4	4.1	7.8	3.8	3.8	0.23	1.15	0.70	1.85	0.03	0.6	0.09	1.7	0.2	0.95	10.8	30
	23	C5	22	6.7	6.0	6.5	4.5	3.0	0.22	1.16	0.80	1.96	0.03	< 0.01	0.08	5	0.3	0.77	11.8	29
	24	C8	18	7.8	4.0	5.5	3.8	4.3	0.23	1.20	0.84	2.04	0.03	0.4	0.10	3	< 0.01	0.94	11.7	33
	25	C5	17	7.2	3.9	5.8	3.4	3.1	0.18	1.17	0.84	2.01	0.01	0.6	0.10	5.8	0.3	0.92	15.1	29

[0047]

[Table 3]

	Sample No.	Core wire No.	Composition of coating flux (% by mass)																Parameter	Coating ratio (% by mass)
			Metal carbonate (in terms of CO ₂)	Metal fluoride (in terms of F)	TiO ₂ +ZrO ₂ +Al ₂ O ₃	SiO ₂	Si	Mn	Li compound (in terms of Li)	Na compound (in terms of Na)	K compound (in terms of K)	Na+K	C	Ti	B compound (in terms of B)	Ni	Cr+Mo	Al+Mg		
Examples	26	C10	19	6.5	6.2	6.0	5.1	3.8	0.19	1.16	0.85	2.01	0.01	< 0.01	< 0.01	7.8	1.4	0.08	14.3	32
	27	C10	12	6.5	3.8	10.0	3.3	4.5	0.24	1.14	0.90	2.04	0.01	< 0.01	< 0.01	5.8	1.7	0.66	11.5	30
	28	C8	22	8.5	5.8	7.5	3.5	3.9	0.20	1.26	0.76	2.02	< 0.01	< 0.01	< 0.01	2	1.2	0.08	13.1	31
	29	C3	21	6.5	6.0	5.5	1.8	3.7	0.22	1.15	0.80	1.95	0.05	0.1	< 0.01	0.3	< 0.01	0.15	11.9	30
	30	C3	21	6.7	6.1	5.5	1.8	3.7	0.22	1.15	0.80	1.95	0.05	0.1	< 0.01	0.3	< 0.01	0.35	11.9	30
Comparative Examples	31	C8	20	8.5	5.6	6.8	4.0	4.3	0.07	1.30	0.74	2.04	0.04	0.7	0.09	1.5	< 0.01	0.88	37.2	31
	32	C5	21	8.5	5.6	6.8	4.0	4.3	0.60	0.60	0.20	0.80	0.04	0.7	0.09	1.5	< 0.01	0.88	1.7	31
	33	C3	18	18.5	4.5	15.1	3.8	4.3	0.26	1.15	0.85	2.00	0.05	0.8	0.10	6.5	< 0.01	0.95	10.3	28
	34	C5	6	9.2	5.5	7.5	5.2	2.5	0.02	1.15	0.21	1.36	0.05	0.8	0.08	1.7	< 0.01	0.88	85.8	29
	35	C3	28	8.5	6.0	7.5	4.0	3.5	0.10	1.20	0.85	2.05	0.08	0.7	0.08	1.5	< 0.01	0.85	27.3	48
	36	C7	21	7.8	4.1	6.9	3.8	4.0	0.27	1.25	0.70	1.95	0.06	0.8	0.09	1.5	< 0.01	0.88	9.5	20
	37	C3	20	7.9	1.5	2.1	4.0	4.5	0.26	1.15	0.80	1.95	0.06	0.8	0.08	1.7	< 0.01	0.88	9.8	30
	38	C3	21	7.8	12.5	6.9	4.3	4.1	0.15	1.20	0.70	1.90	0.05	0.7	0.08	1.5	< 0.01	0.88	16.7	28
	39	C7	20	7.8	4.1	6.9	8.0	3.5	0.10	1.20	0.74	1.94	0.06	0.6	0.09	1.3	< 0.01	0.95	25.7	29
	40	C7	20	7.8	4.1	6.9	5.5	8.2	0.13	1.20	0.74	1.94	0.06	0.6	0.09	1.3	< 0.01	0.95	20.3	29
	41	C3	20	7.8	4.1	6.9	0.5	0.3	0.10	1.15	0.75	1.90	0.06	0.6	0.09	1.3	< 0.01	0.95	25.2	30
	42	C5	21	7.9	4.1	6.8	3.8	4.0	0.15	2.20	1.45	3.65	0.05	0.6	0.09	1.2	< 0.01	0.95	32.3	30
	43	C8	21	1.5	5.5	8.5	4.1	4.5	0.12	1.15	0.85	2.00	0.04	0.9	0.08	5.1	< 0.01	0.85	23.2	31
	44	C5	20	7.7	3.9	6.2	3.7	2.5	0.76	1.20	0.75	1.95	0.05	< 0.01	0.08	1.6	< 0.01	0.08	3.4	29
	45	C10	19	6.2	6.2	5.4	4.3	3.3	0.19	1.22	0.84	2.06	0.01	2.2	0.35	3.6	< 0.01	0.94	14.6	32
	46	C5	22	6.7	6.0	5.5	4.0	2.3	0.22	1.16	0.80	1.96	0.03	< 0.01	0.08	12	< 0.01	0.77	11.8	29
	47	C8	20	9.4	5.8	6.6	4.2	4.2	0.20	1.15	0.75	1.9	< 0.01	< 0.01	< 0.01	1.7	3.3	0.08	12.4	28
	48	C5	21	7.1	4.1	6.9	3.8	4.1	0.18	1.22	0.60	1.82	0.04	0.6	0.09	1.3	< 0.01	2.5	13.5	28

[0048]

With respect to the respective coated arc welding electrodes of Examples and Comparative Examples manufactured by the above-mentioned method, moisture absorption resistance, mechanical performances, welding workability, fixability of a coating flux, and the amount of diffusible hydrogen in weld metal were evaluated.

[0049]

<Moisture Absorption Resistance>

Moisture absorption resistance was evaluated by the following procedure. That is, a coated arc welding electrode re-dried by heating under temperature conditions at 350°C for 1 hour was exposed in an atmosphere at a temperature 30°C and a relative humidity of 80% for 6 hours, and then the amount of moisture absorbed by a coating flux was measured by the Karl Fischer method (vaporization method). At the time of measurement, heating was performed at 750°C so as to vaporize moisture from the coating flux, and then dry air was introduced into a measuring device as a carrier gas. As a result, a welding electrode having the moisture in the coating flux of 3,000 ppm by mass or less was judged as "good".

[0050]

<Mechanical Properties/Welding Workability>

Using the respective coated arc welding electrodes of Examples and Comparative Examples, welding was performed and

welding workability was evaluated. For your reference, mechanical performances of the thus obtained weld metal were evaluated. In that case, JIS G 3106: 2008 SM490A (20 mm in thickness) was used as a steel plate for welding (base material).
5 Groove shape was 20° V groove and a groove gap was 16 mm. Welding position was flat position, a polarity was alternating current (AC) or direct current electrode positive (DCEP), a welding current was in a range of 150 to 160 A, a welding voltage was in a range of 22 to 23 V, a welding heat input was in a range of 2.0
10 to 2.1 kJ/mm, and a preheating/interpass temperature was in a range of 90 to 110°C. Welding workability as used herein means arc stability, slag removability, and bead shape.

[0051]

To re-dry the coating flux, each welding electrode was
15 heated under temperature conditions at 350°C for 1 hour before welding. Mechanical performances were evaluated by a tensile strength (TS) of weld metal and absorbed energy (vE -20°C) of a Charpy impact test at -20°C, and a welding electrode having a tensile strength of 490 MPa or more and absorbed energy of 90 J
20 or more was judged as "good". Meanwhile, welding workability was organoleptically evaluated by rating scale consisting of four grades (A, B, C and D), and welding electrodes with ratings A and B were judged as "good". These mechanical properties are not essential properties in the coated arc welding electrode of the
25 present invention. Therefore, even though the evaluation

results are not good, no influence is exerted on the effects of the present invention, and it can be said that the effects of the present invention are obtained if other properties are good.

[0052]

5 <Fixability of Coating Flux>

Fixability of a coating flux was evaluated by the following procedure. That is, first, it was visually observed whether or not cracks are present on a surface of the coating flux, after sintereing. Then, stability of a protective sheath during
10 welding was organoleptically evaluated by rating scale consisting of four grades (A, B, C and D). As a result, welding electrodes with ratings A and B were judged as "good".

[0053]

<Amount of Diffusible Hydrogen>

15 One pass welding was performed by flat position under the conditions of a polarity of AC or DCEP (direct current electrode positive), a welding current in a range of 150 to 160 A, a welding voltage of 22 V, and a welding speed of 180 mm/minute. In that case, a welding atmosphere was an atmosphere at a temperature of
20 20°C and a relative humidity of 10%. To re-dry the coating flux, each welding electrode was heated under temperature conditions at 350°C for 1 hour before welding.

[0054]

The amount of diffusible hydrogen in weld metal obtained
25 by welding was measured by the method in accordance with JIS Z

3118: 2007. As a result, a weld metal in which the amount of diffusible hydrogen is 4.0 ml/100 g or less was judged as "good". The above evaluation results are collectively shown in Table 4 below.

[0055]

[Table 4]

	Sample No.	Amount of hygroscopic moisture (ppm by mass)	Amount of diffusible hydrogen (ml/100 g)	Arc stability	Slag removability	Bead shape	Fixability	TS (MPa)	vE -20°C (J)
Example	1	745	1.8	B	A	A	B	520	98
	2	2832	3.8	A	A	A	A	567	102
	3	1950	2.5	B	B	B	B	541	145
	4	1780	3.1	A	B	B	B	689	100
	5	1870	2.6	B	A	B	B	524	105
	6	2325	3.4	B	B	A	B	683	95
	7	1570	3.6	A	A	A	B	584	92
	8	2855	3.9	A	A	A	A	534	105
	9	1750	3.3	A	A	B	B	598	112
	10	1973	3.8	B	A	A	B	523	91
	11	1850	3.5	B	A	B	B	518	99
	12	1120	3.6	B	A	B	B	870	93
	13	850	3.2	B	B	A	B	625	123
	14	730	1.6	B	A	A	B	825	96
	15	2015	3.5	A	A	A	B	558	110
	16	841	2.4	A	A	A	B	580	210
	17	1236	3.1	A	A	A	B	575	205
	18	2055	1.9	A	A	A	B	570	190
	19	1805	2.4	A	A	A	B	566	200
	20	827	2.0	A	A	A	B	590	180
	21	1920	3.3	A	A	A	B	632	115
	22	902	2.5	A	A	A	B	610	165
	23	873	2.8	A	A	A	B	645	188
	24	1005	2.9	A	A	A	B	630	150
	25	895	2.3	A	A	A	B	661	175
	26	1105	2.7	A	A	A	B	755	120
	27	955	3.1	A	A	A	B	827	130
	28	1735	2.8	A	A	A	B	676	123
	29	1050	3.3	A	A	A	B	465	80
	30	1120	3.1	A	A	A	B	495	97
Comparative Example	31	3115	4.3	A	A	A	A	621	155
	32	550	1.8	D	A	A	D	633	148
	33	855	3.3	C	D	A	B	656	171
	34	8355	6.5	B	A	A	A	677	120
	35	2331	3.8	C	A	D	B	635	155
	36	3850	4.5	A	A	A	B	625	75
	37	845	3.1	A	A	D	C	641	145
	38	1866	3.5	A	C	A	B	773	91
	39	2551	3.6	A	A	C	B	721	95
	40	2100	3.5	A	A	C	B	783	88
	41	2520	3.4	A	A	D	B	523	70
	42	3215	3.7	A	A	A	A	592	158
	43	2250	3.7	A	A	C	B	633	135
	44	783	2.8	A	A	A	D	576	140
	45	902	3.5	A	A	A	B	854	83
	46	890	3.0	A	A	A	B	821	79
	47	1131	3.3	A	A	A	B	863	73
	48	1201	3.5	D	C	B	B	573	105

[0056]

As shown in Table 4, in the welding electrode No. 31, since $(1.22 \times [\text{Na}] + 1.49 \times [\text{K}]) / [\text{Li}]$ exceeds the scope of the present invention in the composition of the coating flux, the welding
5 electrode was inferior in moisture absorption resistance and exhibited a large amount of diffusible hydrogen. Meanwhile, in the welding electrode No. 32, since $(1.22 \times [\text{Na}] + 1.49 \times [\text{K}]) / [\text{Li}]$ does not meet the scope of the present invention in the composition of the coating flux, the coating flux exhibited low fixing
10 strength. Further, since the total content of a Na compound and a K compound does not meet the scope of the present invention, arc became unstable.

[0057]

In the welding electrode No. 33, since metal fluoride
15 exceeds the scope of the present invention in the composition of the coating flux, arc stability deteriorated. Further, since the content of SiO_2 exceeds the scope of the present invention in the composition of the coating flux, slag removability deteriorated. In the welding electrode No. 34, since $(1.22 \times [\text{Na}] + 1.49 \times$
20 $[\text{K}]) / [\text{Li}]$ exceeds the scope of the present invention, and also the content of metal carbonate and the content of a Li compound do not meet the scope of the present invention in the composition of the coating flux, the welding electrode was inferior in moisture absorption resistance and exhibited a large amount of
25 diffusible hydrogen.

[0058]

In the welding electrode No. 35, since the content of metal carbonate exceeds the scope of the present invention in the composition of the coating flux, a bead shape deteriorated.

5 Further, since a coating ratio of the coating flux exceeds the scope of the present invention, arc became unstable. In the welding electrode No. 36, since a coating ratio of the coating flux does not meet the scope of the present invention, the amount of diffusible hydrogen in weld metal increases, thus causing
10 deterioration of toughness of weld metal.

[0059]

In the welding electrode No. 37, since the total content of TiO_2 , ZrO_2 and Al_2O_3 does not meet the scope of the present invention in the composition of the coating flux, a bead shape
15 deteriorated. Further, since the SiO_2 content does not meet the scope of the present invention, fixability deteriorated.

Meanwhile, in the welding electrode No. 38, since the total content of TiO_2 , ZrO_2 and Al_2O_3 exceeds the scope of the present invention in the composition of the coating flux, slag
20 removability deteriorated.

[0060]

In the welding electrode No. 39, since the content of Si exceeds the scope of the present invention in the composition of coating flux, the viscosity of molten metal increased. In the
25 welding electrode No. 40, since the content of Mn exceeds the scope

of the present invention in the composition of coating flux, the viscosity of molten metal decreased, and a bead shape deteriorated in both cases. Meanwhile, in the welding electrode No. 41, the content of Si and the content of Mn do not meet the scope of the present invention in the composition of the coating flux, blowholes are generated due to lack of deoxidation, and also toughness of weld metal deteriorated.

[0061]

In the welding electrode No. 42, since the total of the content of a Na compound and the content of a K compound exceeds the scope of the present invention in the coating flux, the welding electrode was inferior in moisture absorption resistance. In the welding electrode No. 43, the content of metal fluoride does not meet the scope of the present invention in the composition of the coating flux, the viscosity of the slag increased, thus causing deterioration of a bead shape. In the welding electrode No. 44, since the content of a Li compound exceeds the scope of the present invention in the composition of the coating flux, the fixing strength of the coating flux decreased.

[0062]

Meanwhile, the welding electrode No. 45 exhibited satisfactory moisture absorption resistance, and fixability workability of coating flux and welding. However, since exceeding 2.0% by mass of Ti was added to the coating flux and exceeding 0.3% by mass of a B compound was added, toughness of

weld metal deteriorated. Likewise, the welding electrode No. 46 also exhibited satisfactory moisture absorption resistance, and fixability of coating flux and welding workability. However, since exceeding 10% by mass of Ni was added to the coating flux, toughness of weld metal deteriorated.

[0063]

The welding electrode No. 47 also exhibited moisture absorption resistance, and fixability of the coating flux and welding workability. However, since exceeding 3% by mass of Cr and Mo are added to the coating flux, toughness of weld metal deteriorated. Meanwhile, in the welding electrode No. 48, since exceeding 2% by mass of Al and Mg are added to the coating flux, arc became unstable and also slag removability deteriorated.

[0064]

In contrast, the welding electrodes No. 1 to 30 manufactured within the scope of the present invention had excellent moisture absorption resistance, and also had satisfactory fixability of the coating flux and welding workability. In addition, since the welding electrodes Nos. 1 to 28 and 30 contain a specific amount of one, or two or more element(s) of Ti, a B compound, Ni, Cr, Mo, Al and Mg, mechanical properties of weld metal were excellent as compared with the welding electrode No. 29 having smaller content of these elements.

[0065]

The above results revealed that, according to the present

invention, it is possible to obtain a low-hydrogen type coated arc welding electrode which has excellent moisture absorption resistance, and also has satisfactory fixability of a coating flux and welding workability.

5 [0066]

This application claims priority based on Japanese Patent Application No. 2014-001073 filed on January 7, 2014 in Japan, the disclosure of which is incorporated by reference herein.

CLAIMS

1. A low-hydrogen type coated arc welding electrode in which a steel core wire is coated with a coating flux, wherein

the coating flux comprises:

metal carbonate (in terms of CO_2): 8 to 25% by mass,

metal fluoride (in terms of F): 2 to 15% by mass,

at least one of TiO_2 , ZrO_2 and Al_2O_3 : 2 to 10% by mass in total,

SiO_2 : 3 to 12% by mass,

Si: 1 to 7% by mass,

Mn: 1 to 8% by mass,

a Li compound (in terms of Li): 0.03 to 0.7% by mass, and
at least one of a Na compound (in terms of Na) and a K compound (in terms of K): 1.0 to 3.5% by mass in total, with the balance being Fe and inevitable impurities,

wherein the coating flux has the composition that satisfies a numerical formula (1) below when [Li] denotes the content of a Li compound (in terms of Li), [Na] denotes the content of a Na compound (in terms of Na), and [K] denotes the content of a K compound (in terms of K), and

wherein a coating ratio of the coating flux is in a range of 22 to 45% by mass.

$$2. 0 \leq (1.22 \times [\text{Na}] + 1.49 \times [\text{K}]) / [\text{Li}] \leq 35 \quad \dots \quad (1)$$

2. The low-hydrogen type coated arc welding electrode according to claim 1, wherein the content of C in the coating flux is regulated to 0.1% by mass or less.

3. The low-hydrogen type coated arc welding electrode according to claim 1, wherein the coating flux further contains:
at least one of Al and Mg: 0.2 to 2% by mass in total.

4. The low-hydrogen type coated arc welding electrode according to claim 1, wherein the steel core wire is formed from a mild steel or a low alloy steel.

5. The low-hydrogen type coated arc welding electrode according to any one of claims 1 to 4, wherein the coating flux further contains:

at least one of Cr and Mo: 0.1 to 3% by mass in total.

6. The low-hydrogen type coated arc welding electrode according to any one of claims 1 to 4, wherein the coating flux further contains,

Ti: 0.2 to 2.0% by mass, and

a B compound (in terms of B): 0.02 to 0.3% by mass.

7. The low-hydrogen type coated arc welding electrode

according to any one of claims 1 to 4, wherein the coating flux further contains:

Ni: 0.5 to 10% by mass,
Ti: 0.2 to 2.0% by mass, and
a B compound (in terms of B): 0.02 to 0.3% by mass.

8. The low-hydrogen type coated arc welding electrode according to any one of claims 1 to 4, wherein the coating flux further contains:

Ni: 0.5 to 10% by mass, and
at least one of Cr and Mo: 0.1 to 3% by mass in total.

9. The low-hydrogen type coated arc welding electrode according to any one of claims 1 to 4, wherein the coating flux further contains:

Ni: 0.5 to 10% by mass, and
at least one of Cr and Mo: 0.1 to 3% by mass in total, and
a B compound (in terms of B): 0.02 to 0.3% by mass.

10. The low-hydrogen type coated arc welding electrode according to any one of claims 1 to 4, wherein the coating flux further contains:

Ni: 0.5 to 10% by mass,
at least one of Cr and Mo: 0.1 to 3% by mass in total,
Ti: 0.2 to 2.0% by mass, and

a B compound (in terms of B): 0.02 to 0.3% by mass.