

DESCRIPTION

COATED ARC WELDING ELECTRODE

5 Technical Field

[0001]

The present invention relates to a coated arc welding electrode in which a coating agent is applied onto a steel core wire.

10

Background Art

[0002]

In welding sites such as shipbuilding and building, a coated arc welding electrode having excellent welding workability has hitherto been developed so as to efficiently work. For example, inventions as recited in Patent Documents 1 and 2 are published. Patent Document 1 recites technology in which electrode burning resistance is improved by containing of prescribed SiO_2 in reduced ilmenite without causing deterioration of welding workability. Patent Document 2 recites technology in which excellent effect is exerted on welding workability, particularly vertical upward welding, by containing of prescribed C in a steel core wire.

20

[0003]

25 Patent Document 1: JP 2003-311478 A

Patent Document 2: JP 2002-321090 A

Summary of Invention

Problems to be Solved by the Invention

5 [0004]

However, these inventions have the following problems in welding work. In welding work in all positions, poor fitness, poor bead shape and the like are likely to occur and there is a need to adjust bead shape, thus requiring much labor and cost. In order to solve these problems, there is a need to develop a coated arc welding electrode which enables satisfactory fitness between a base material and welded metal at the time of welding, and satisfactory bead shape of weld metal. Patent Document 1 gives consideration to bead shape, but does not recite fitness at the bead end. Patent Document 2 makes no study on fitness at the bead end.

[0005]

The present invention has been made in view of the above problems. Namely, an object of the present invention is to provide a coated arc welding electrode which enables satisfactory welding workability and is particularly excellent in fitness at the bead end, and also enables satisfactory bead shape.

25 Means for Solving the Problems

[0006]

A first coated arc welding electrode according to the present invention is a coated arc welding electrode in which a coating agent is applied onto a steel core wire, wherein a
5 coating ratio of the coating agent is 20.0 to 55.0% by mass based on the total mass of the welding electrode; wherein the coating agent contains, based on the total mass of the coating agent: a titanium oxide material in a particulate form: 15.0 to 60.0% by mass, SiO_2 in terms of Si: 4.0 to
10 14.0% by mass, Al_2O_3 in terms of Al: 0.1 to 3.5% by mass, at least one metal carbonate selected from the group consisting of CaCO_3 , MgCO_3 and BaCO_3 in terms of CO_2 : 1.0 to 15.0% by mass, C: 0.01 to 1.0% by mass, Mn: 0.1 to 15.0% by mass, and a Na compound in terms of Na and a K compound in terms of K
15 in total: 1.0 to 8.0% by mass; wherein the titanium oxide material has the composition containing, based on the total mass of the titanium oxide material: TiO_2 : 58.0 to 99.0% by mass, Si: 2.5% by mass or less, Al: 3.0% by mass or less, Mn: 5.0% by mass or less, Fe: 35.0% by mass or less, Mg: 5.0% by
20 mass or less, and Ca: 2.0% by mass or less; and wherein an oxide composed of at least one of Ti, Fe, Mn, Al and Si exists on a particle surface of the titanium oxide material, and also the oxide satisfies the inequality expression: $1 \leq \text{Al} + \text{Si} \leq 10$ where Al and Si, each denotes an atomic
25 percentage.

[0007]

With such configuration, welding workability is improved by defining a coating ratio of the coating agent. In components of the coating agent, welding workability is improved by defining the titanium oxide material, the viscosity of the slag is adjusted and also an arc force is enhanced by defining the amount of Si, and arc stability and viscosity of the slag are increased by defining the amount of Al. Welded metal is protected and also the viscosity of the slag is enhanced by defining the amount of CO₂, the strength of weld metal is improved and also the arc force is maintained by defining the amount of C. Weld metal is deoxidized and also the strength is adjusted by defining the amount of Mn, and arc stability is improved by defining the total amount of Na and K.

[0008]

In components of the titanium oxide material, bead shape becomes satisfactory by defining the amount of TiO₂, and the viscosity of the slag is adjusted by defining the amounts of Si, Al and Mn. A decrease in melting point is suppressed by defining the amount of Fe, and the amount of generation of spatters is suppressed by defining the amounts of Mg and Ca. Furthermore, the melting point of the titanium oxide material becomes moderate and bead shape becomes satisfactory, and also fitness is improved by defining atomic

percentages of Al and Si.

[0009]

A second coated arc welding electrode according to the present invention is a coated arc welding electrode in which
5 a coating agent is applied onto a steel core wire, wherein a coating ratio of the coating agent is 20.0 to 55.0% by mass based on the total mass of the welding electrode; wherein the coating agent contains, based on the total mass of the coating agent: a titanium oxide material in a particulate
10 form: 2.0 to 20.0% by mass, metallic Si in terms of Si and SiO₂ in terms of Si in total: 4.0 to 14.0% by mass, metallic Al in terms of Al and Al₂O₃ in terms of Al in total: 0.1 to 3.5% by mass, at least one metal carbonate selected from the group consisting of CaCO₃, MgCO₃ and BaCO₃ in terms of CO₂:
15 5.0 to 30.0% by mass, at least one metal fluoride selected from the group consisting of CaF₂, BaF₂, AlF₃, LiF and Na₂SiF₆ in terms of F: 0.5 to 15.0% by mass, C: 0.01 to 0.7% by mass, and a Na compound in terms of Na and a K compound in terms of K in total: 1.0 to 8.0% by mass; wherein the
20 titanium oxide material has the composition containing, based on the total mass of the titanium oxide material: TiO₂: 58.0 to 99.0% by mass, Si: 2.5% by mass or less, Al: 3.0% by mass or less, Mn: 5.0% by mass or less, Fe: 35.0% by mass or less, Mg: 5.0% by mass or less, and Ca: 2.0% by mass or less; and
25 wherein an oxide composed of at least one of Ti, Fe, Mn, Al,

and Si exists on a particle surface of the titanium oxide material, and also the oxide satisfies the inequality expression: $1 \leq Al + Si \leq 10$ where Al and Si, each denotes an atomic percentage.

5 [0010]

With such configuration, welding workability is improved by defining a coating ratio of the coating agent. In components of the coating agent, welding workability is improved by defining the titanium oxide material, the
 10 viscosity of the slag is adjusted and also the arc force is enhanced by defining the amount of Si, and arc stability and viscosity of the slag are increased by defining the amount of Al. Welded metal is protected, the amount of diffusible hydrogen is decreased, and also the viscosity of the slag is
 15 enhanced by defining the amount of CO_2 . The viscosity of the slag is adjusted to improve welding workability by defining the amount of F. The strength of weld metal is improved and also the arc force is maintained by defining the amount of C, and arc stability is improved by defining the total amount of
 20 Na and K.

[0011]

In components of the titanium oxide material, bead shape becomes satisfactory by defining the amount of TiO_2 , and the viscosity of the slag is adjusted by defining the
 25 amounts of Si, Al and Mn. A decrease in melting point is

suppressed by defining the amount of Fe, and the amount of generation of spatters is suppressed by defining the amounts of Mg and Ca. Furthermore, the melting point of the titanium oxide material becomes moderate, bead shape becomes
5 satisfactory, and also fitness is improved by defining atomic percentages of Al and Si.

[0012]

A third coated arc welding electrode according to the present invention is the coated arc welding electrode
10 according to the above 2, wherein the coating agent may contain, based on the total mass of the coating agent: Mn: 1.0 to 7.0% by mass, and also contains: at least one selected from the group consisting of: metallic Ti in terms of Ti: 0.2 to 2.0% by mass, a B compound in terms of B: 0.02 to 0.3% by
15 mass, Ni: 0.5 to 10.0% by mass, Cr and Mo in total: 0.1 to 3.0% by mass, and Al and Mg in total: 0.1 to 2.0% by mass.

[0013]

With such configuration, in components of the coating agent, the strength and toughness of weld metal are improved
20 by containing of a specific amount of Mn. The strength and toughness of weld metal are improved by containing of a specific amount of at least one selected from the group consisting of metallic Ti; B compound; Ni, Cr and Mo in total; and Al and Mg in total.

25 [0014]

A coated arc welding electrode according to the present invention is the coated arc welding electrode according to the above 3, wherein the coating agent may contain, based on the total mass of the coating agent: a Li compound in terms of Li: 0.01 to 1.0% by mass.

[0015]

With such configuration, in components of the coating agent, moisture absorption resistance of the coating agent is improved by containing of a specific amount of a Li compound.

[0016]

A fourth coated arc welding electrode according to the present invention is the coated arc welding electrode according to any one of the above 1 to 3, wherein the coating agent may contain, based on the total mass of the coating agent: ZrO_2 in terms of Zr: 0.1 to 7.0% by mass.

[0017]

With such configuration, in components of the coating agent, the concentration of arcs generated and gross of a bead surface are improved and also fitness of weld metal to a base material is improved by containing of a specific amount of ZrO_2 .

Effects of the Invention

[0018]

According to the present invention, it is possible to

maintain satisfactory welding workability in all positioned welding and to obtain particularly satisfactory fitness at the bead end and satisfactory bead shape. Particularly, vertical weldability is excellent. It is also possible to achieve securing of toughness at low temperature and an improvement in strength by adjusting the content of a specific element. It is also possible to make an attempt to improve moisture absorption resistance of a coating agent and to improve the concentration of arcs generated and gross of a bead surface by adjusting the content of a specific element.

Description of Embodiments

[0019]

Embodiments of the present invention will be described in detail below.

Here, in the following embodiments, "metallic Si" means one or more of "pure metallic Si" and "alloyed Si(s)". Similarly, "metallic Al" means one or more of "pure metallic Al" and "alloyed Al(s)", and "metallic Ti" means one or more of "pure metallic Ti" and "alloyed Ti(s)". For example, when simply referred to as Mn, it means the amount in terms of Mn including all Mn(s) such as pure metal, alloys, compounds (i.e. metallic Mn, Mn oxide, etc.), and the like.

"Oxide" means one or more of "single oxide(s)" and "composite oxide(s)". The "single oxide" means, for example,

an oxide of Ti alone (TiO_2) in the case of Ti, and "composite oxide" means both an oxide formed by aggregation of a plural kinds of these single oxides, and an oxide containing a plurality of metal components such as Ti, Fe, and Mn. The state where this oxide exists on a surface of particles of a titanium oxide material includes the case where the surface of particles is in a state of an oxide.

[0020]

<<First Embodiment>>

The first embodiment relates to a lime-titania type or titania type coated arc welding electrode.

The coated arc welding electrode of the present invention is a coated arc welding electrode in which a coating agent is applied onto a steel core wire, and a coating ratio of the coating agent based on the total mass of the welding electrode (i.e. mass of the coating agent based on the total mass of the welding electrode) is defined. This coating agent contains, based on the total mass of the coating agent, a titanium oxide material, SiO_2 in terms of Si, Al_2O_3 in terms of Al, at least one metal carbonate selected from the group consisting of CaCO_3 , MgCO_3 and BaCO_3 in terms of CO_2 , C, Mn, and total amount of a Na compound in terms of Na and a K compound in terms of K, in a specific amount.

[0021]

Furthermore, titanium oxide material has the

composition containing, based on the total mass of the titanium oxide material, TiO_2 , Si, Al, Mn, Fe, Mg and Ca in a specific amount, and an oxide composed of at least one of Ti, Fe, Mn, Al, and Si exists on a particle surface of the titanium oxide material, and also the oxide satisfies the inequality expression: $1 \leq \text{Al} + \text{Si} \leq 10$ where Al and Si, each denotes an atomic percentage.

It is possible to use, as the steel core wire, for example, SWY11 defined in JIS G 3523.

10 [0022]

A description will be made on the coating ratio of coating agent, the reason for limitation of components, and the reason for limitation of a titanium oxide material defined in the present invention.

15 [0023]

[Reason for Limitations of Coating Ratio of Coating Agent and Components]

<Coating Ratio of Coating Agent: 20.0 to 55.0% by mass>

When the coating ratio of a coating agent is less than 20.0% by mass, prescribed workability is not obtained because of too small amount of the coating agent. Meanwhile, when the coating ratio exceeds 55.0% by mass, slag coverage increases to cause deterioration of workability, particularly deterioration of fitness. Therefore, the coating ratio of the coating agent is set at 20.0 to 55.0% by mass. In the

coating agent, organic substances having the effect of improving coatability and inevitable impurity elements exist.

[0024]

<Titanium Oxide Material in Particulate Form: 15.0 to 60.0%
5 by mass>

Satisfactory welding workability, particularly satisfactory fitness and bead shape can be obtained by using, as a TiO_2 source, a titanium oxide material in which the composition of the oxide is optimized, as mentioned below.

10 When the content of the titanium oxide material is less than 15.0% by mass based on the total mass of the coating agent, welding workability deteriorates, thus failing to obtain satisfactory fitness and bead shape. Meanwhile, when the content of the titanium oxide material exceeds 60.0% by mass,
15 the slag melting point increases and the slag is quickly solidified when weaving is performed. Whereby, weld metal is formed along the manipulation, resulting in formation of a scale-like bead. Therefore, the content of the titanium oxide material in a particulate form is set at 15.0 to 60.0%
20 by mass. More preferably, the content is 35.0 to 55.0% by mass. When the content is set within the above range, appropriate slag melting point and viscosity are obtained, and also satisfactory bead shape and fitness are obtained in vertical welding.

25 [0025]

<Amount of SiO_2 in terms of Si: 4.0 to 14.0% by mass>

SiO_2 serves as a viscosity modifier of the slag, and also has the effect of increasing an arc force. When the amount of SiO_2 in terms of Si is less than 4.0% by mass based on the total mass of the coating agent, the effect of serving as the viscosity modifier is not sufficiently exerted and deterioration of bead shape is caused. Meanwhile, when the amount of SiO_2 in terms of Si exceeds 14.0% by mass, removability of the slag drastically deteriorates to cause deterioration of workability. Therefore, the amount of SiO_2 in terms of Si is set at 4.0 to 14.0% by mass.

[0026]

<Amount of Al_2O_3 in terms of Al: 0.1 to 3.5% by mass>

Al_2O_3 enables an increase in arc stability and the viscosity of the slag, and serves as the slag forming agent. When the amount of Al_2O_3 in terms of Al is less than 0.1% by mass based on the total mass of the coating agent, arc stability and viscosity of the slag are not sufficiently obtained. Meanwhile, when the amount of Al_2O_3 in terms of Al exceeds 3.5% by mass, the amount of the slag produced increases and also slag removability deteriorates, thus causing deterioration of welding workability. Therefore, the amount of Al_2O_3 in terms of Al is set at 0.1 to 3.5% by mass.

[0027]

<Amount of at least one Metal Carbonate selected from Group

consisting of CaCO_3 , MgCO_3 and BaCO_3 in terms of CO_2 : 1.0 to 15.0% by mass>

A metal carbonate is decomposed by arc heat to generate a CO_2 gas. The metal carbonate has the effect of decreasing partial pressures of H_2 and N_2 gases in arc atmosphere by a CO_2 gas to protect welded metal. It also has the effect of increasing the viscosity of the slag. When the amount of the metal carbonate in terms of CO_2 is less than 1.0% by mass based on the total mass of the coating agent, pits and blowholes are generated due to lack of CO_2 gas shielding. Meanwhile, when the amount exceeds 15.0% by mass, deterioration of workability is caused by a decrease in arc. Furthermore, the viscosity of the slag excessively increases, and thus the molten metal is likely to hang down and fall down to form a projected bead, and also undercut is generated. Therefore, the amount of the metal carbonate in terms of CO_2 is set at 1.0 to 15.0% by mass.

[0028]

<C: 0.01 to 1.0% by mass>

C is an element controlling the strength of weld metal, and is also needed to maintain an arc force by reacting with oxygen. When the content of C is less than 0.01% by mass based on the total mass of the coating agent, no effect is exerted, leading to weak arc spraying. Meanwhile, when the content of C exceeds 1.0% by mass, arc spraying becomes too

strong, leading to the generation of numerous sputters and non-uniform bead shape. Therefore, the content of C is set at 0.01 to 1.0% by mass. More preferably, the content is 0.05 to 0.5% by mass. When the content is set within the
5 above range, appropriate arc force is obtained and arc becomes stable.

[0029]

<Mn: 0.1 to 15.0% by mass>

Mn is needed for deoxidation and strength control of
10 weld metal. When the content of Mn is less than 0.1% by mass based on the total mass of the coating agent, blowholes are generated due to lack of deoxidation. Meanwhile, the content of Mn exceeds 15.0% by mass, crack resistance deteriorates due to excess strength. Therefore, the content of Mn is set
15 at 0.1 to 15.0% by mass. More preferably, the content is 3.5 to 12.0% by mass. When the content is set within the above range, defect resistance (blowhole resistance, crack resistance) becomes satisfactory.

[0030]

20 <Total Amount of Na Compound in terms of Na and K Compound in terms of K: 1.0 to 8.0% by mass>

Na and K have high effect of improving arc stability. When the total amount of a Na compound in terms of Na and a K compound in terms of K is less than 1.0% by mass based on the
25 total mass of the coating agent, it is impossible to

sufficiently obtain the effect. Meanwhile, when the total amount of a Na compound in terms of Na and a K compound in terms of K exceeds 8.0% by mass, peel-off preventiveness and electrode burning resistance of the coating agent deteriorate.

5 Therefore, the total amount of a Na compound in terms of Na and a K compound in terms of K is set at 1.0 to 8.0% by mass.

[0031]

<Balance: Fe and Inevitable Impurities>

10 Balance of the whole coating agent of the coated arc welding electrode contains Fe and inevitable impurities. The coating agent can contain, in addition to the above-mentioned components of the coating agent, small amounts of MgO as a tuning agent for deoxidation, and Ni, Cr, Sb, and the like for the purpose of improving corrosion resistance of
15 weld metal. These elements do not exert an influence on the object of the present invention. The coating agent contains a trace amount of an alkali metal compound of an element other than the above elements.

[0032]

20 [Reason for Limitation of Components of Titanium Oxide Material]

<TiO₂: 58.0 to 99.0% by mass>

TiO₂ plays an important role of supporting weld metal. In vertical welding, when the content is less than 58.0% by
25 mass, bead hangs down because of insufficient amount of slag.

Meanwhile, when the content of TiO_2 exceeds 99.0% by mass based on the total mass of the titanium oxide material, the slag is quickly solidified because of too high melting point, leading to a decrease in pool size at the time of welding.

5 Therefore, it becomes difficult to maintain a constant molten pool shape when weaving is performed in vertical welding, leading to non-uniform bead shape. Therefore, the content of TiO_2 is set at 58.0 to 99.0% by mass. Generally, if the titanium oxide material has high content of TiO_2 , the melting
10 point increases, thus being suited for vertical welding. If the titanium oxide material has low content of TiO_2 , it is suited for fillet welding.

[0033]

<Si: 2.5% by mass or less, Al: 3.0% by mass or less, Mn: 5.0%
15 by mass or less>

Oxides (single oxide or composite oxide) and carbonates of Si, Al and Mn are added so as to adjust the viscosity of the slag. However, oxides and carbonates of Si, Al and Mn sources are not generally added by using a titanium oxide
20 source, but added in a flux by using other raw materials (for example, silica sand, alumina, manganese carbonate, manganese dicarbonate, etc.). When the contents of Si, Al and Mn in the titanium oxide source based on the total mass of the titanium oxide material increase, an influence is exerted on
25 mechanical properties and the viscosity of the slag.

Therefore, the content of Si is set at 2.5% by mass or less, the content of Al is set at 3.0% by mass or less, and the content of Mn is set at 5.0% by mass or less. Although each content may be 0% by mass, as mentioned below, there is a
5 need for atomic percentages of Al and Si on a particle surface of the titanium oxide material to satisfy the inequality expression: " $1 \leq \text{Al} + \text{Si} \leq 10$ ", and thus it is indispensable to contain at least either one of Al and Si.

[0034]

10 <Fe: 35.0% by mass or less>

When the content of Fe in oxides and carbonates increases, the melting point decreases, and thus the molten metal is likely to hang down. Therefore, in general, the content of Fe is preferably higher in the material for fillet
15 welding, whereas, the content of Fe is preferably lower in the vertical welding material. In order to use as a titanium oxide source, or raw materials for both fillet welding and vertical welding, there is a need for the content of Fe to set at 35.0% by mass or less based on the total mass of the
20 titanium oxide material. The content may be 0% by mass.

[0035]

<Mg: 5.0% by mass or less, Ca: 2.0% by mass or less>

Since the titanium oxide material is produced from natural raw materials (rutile, ilmenite, lucoxine), the
25 titanium oxide material of the present invention inevitably

contains impurities such as Mg and Ca (including oxides and carbonates). However, since sputters increase when Mg and Ca are contained in a large amount, it is necessary that the content of Mg is set at 5.0% by mass or less and the content of Ca is set at 2.0% by mass or less, based on the total mass of the titanium oxide material. The content may be respectively 0% by mass.

In components of the titanium oxide material, the titanium oxide material may contain, as inevitable impurities, for example, C, Nb, V, and the like in the following amounts, C: 0.30% by mass or less, Nb: 0.30% by mass or less, and V: 0.30% by mass or less. The components and numerical values are not limited to those mentioned above.

[0036]

<Oxide composed of at least one of Ti, Fe, Mn, Al, and Si exists on Particle Surface of Titanium Oxide Material>

This oxide satisfies the inequality expression: " $1 \leq \text{Al} + \text{Si} \leq 10$ ". More preferably, atomic percentages of Al and Si satisfy the inequality expression: " $1.5 \leq \text{Al} + \text{Si} \leq 6$ ". Namely, it is indispensable that at least one oxide of Al and Si exists. More preferably, atomic percentages of Ti, Fe, Mn and O satisfy the inequality expression: " $1 < \text{Ti}/(\text{Fe} + \text{Mn}) \leq 100$ ", or " $\text{O}/(\text{Fe} + \text{Mn}) \leq 100$ ".

As mentioned above, these definitions can be formulated, for example, by the following method. After producing a

titanium oxide material, oxides and carbonates of Fe, Mn, Al, Si, Mg and Ca are added, followed by firing (sintering) at the temperature at which a surface of the titanium oxide material is slightly melted. The firing temperature is set at about 800 to 1,300°C, although it varies depending on the amount of oxygen in the titanium oxide material and firing method, and the titanium oxide material is sintered in a rotary kiln or a batch furnace, together with raw materials to be added.

[0037]

There is a need for a surface state of titanium oxide material particles to satisfy the following numerical formulas 1 to 3 calculated from surface analysis results in accordance with a prescribed analysis method. Namely, in energy dispersive X-ray spectroscopy (EDX), about 1 g of a raw material is disposed on a carbon tape (C tape) stuck on an aluminum stand. After randomly selecting 5 particles having an area (rectangular region measuring 10 μm $\times$ 10 μm) of a comparatively flat material surface on which no foreign substance exists (adheres) when observed under high magnification (about 2,000 times), an atomic ratio of one field was measured per each particle. With respect to the measurement results of 5 points, the values of the following numerical formulas 1 to 3 are determined and then an average of the values of the numerical formulas is determined. This

measuring method enables evaluation of the titanium oxide material of the present invention.

[0038]

Numerical formula 1: $(x = \text{Al} + \text{Si})$

5 Numerical formula 2: $(y = \text{Ti}/(\text{Fe} + \text{Mn}))$

Numerical formula 3: $(z = \text{O}/(\text{Fe} + \text{Mn}))$

[0039]

10 In the numerical formula 1, x is 1 to 10. The amounts of Al and Si based on the amount of TiO_2 exert an influence on the melting point of the titanium oxide material. When the value x of the numerical formula 1 is between 1 and 10, there is no difference in bead shape. When the value x exceeds 10, the melting point of the titanium oxide material decreases to form projected bead upon vertical welding.

15 Meanwhile, when the value x is less than 1, bead shape becomes non-uniform because of too high melting point of the titanium oxide material. Furthermore, fitness deteriorates. Therefore, the value x is set at 1 to 10 and, when the value x is 1.5 to 6, bead exhibits satisfactory fitness.

20 [0040]

In the numerical formula 2, y is preferably more than 1 and 100 or less. The amounts of Fe and Mn based on the amount of TiO_2 exert an influence on the melting point of the titanium oxide material. When the value y is 1 or less,

25 since the amount of Ti is low, and the amounts of Fe and Mn,

each having low melting point, increase, the melting point of the titanium oxide material decreases and weld metal is likely to hang down, thus forming projected bead. Meanwhile, when the value y exceeds 100, the melting point of the titanium oxide material increases and the slag is quickly solidified. Therefore, it becomes difficult to control the molten pool shape, resulting in poor bead shape. Therefore, the value y is preferably more than 1 and 100 or less.

[0041]

The value z of the numerical formula 3 is preferably 100 or less. When the value z exceeds 100, the amount of oxygen in weld metal excessively increases, leading to a decrease in viscosity. Therefore, bead is likely to hang down in vertical welding to form projected bead. Therefore, the value z is preferably set at 100 or less.

[0042]

<<Second Embodiment>>

A second embodiment relates to a low-hydrogen type coated arc welding electrode.

The coated arc welding electrode of the present invention is a coated arc welding electrode in which a coating agent is applied onto a steel core wire, and a coating ratio of the coating agent based on the total mass of the welding electrode is defined. This coating agent contains, based on the total mass of the coating agent, a

titanium oxide material in a particulate form, metallic Si in terms of Si and SiO_2 in terms of Si in total, metallic Al in terms of Al and Al_2O_3 in terms of Al in total, at least one metal carbonate selected from the group consisting of CaCO_3 , MgCO_3 and BaCO_3 in terms of CO_2 , at least one metal fluoride selected from the group consisting of CaF_2 , BaF_2 , AlF_3 , LiF and Na_2SiF_6 in terms of F, C, and a Na compound in terms of Na and a K compound in terms of K in total, in a specific amount.

10 [0043]

Furthermore, the titanium oxide material has the composition containing, based on the total mass of the titanium oxide material, a specific amount TiO_2 , Si, Al, Mn, Fe, Mg and Ca; and an oxide composed of at least one of Ti, Fe, Mn, Al and Si exists on a particle surface of the titanium oxide material, and also the oxide satisfies the inequality expression: $1 \leq \text{Al} + \text{Si} \leq 10$ where Al and Si, each denotes an atomic percentage.

It is possible to use, as the steel core wire, for example, SWY11 defined in JIS G 3523.

20 [0044]

A description will be made on the coating ratio of coating agent, the reason for limitation of components, and the reason for limitation of a titanium oxide material defined in the present invention.

[0045]

[Reason for Limitation of Components of Coating Ratio of Coating Agent]

<Coating Ratio of Coating Agent: 20.0 to 55.0% by mass>

5 When a coating ratio of the coating agent is less than 20.0% by mass, prescribed workability is not obtained because of too small coating ratio of the coating agent. Meanwhile, when the coating ratio exceeds 55.0% by mass, slag coverage increases to cause deterioration of workability, particularly
10 deterioration of fitness. Therefore, the coating ratio of the coating agent is set at 20.0 to 55.0% by mass. In the coating agent, organic substances having the effect of improving coatability and inevitable impurity elements exist.

[0046]

15 <Titanium Oxide Material in Particulate Form: 2.0 to 20.0% by mass>

 Satisfactory welding workability, particularly satisfactory fitness and bead shape can be obtained by using, as a TiO_2 source, a titanium oxide material in which the
20 composition of the oxide is optimized, as mentioned below. When the content of the titanium oxide material is less than 2.0% by mass based on the total mass of the coating agent, welding workability deteriorates, thus failing to obtain satisfactory fitness and bead shape. Meanwhile, when the
25 content of the titanium oxide material exceeds 20.0% by mass,

the slag melting point increases and the slag is quickly solidified when weaving is performed. Whereby, weld metal is formed along the manipulation, resulting in a scale-like bead. Therefore, the content of the titanium oxide material in a particulate form is set at 2.0 to 20.0% by mass. More preferably, the content is 5.0 to 15.0% by mass. When the content is set within the above range, appropriate slag melting point and viscosity are obtained, and also satisfactory bead shape and fitness are obtained in vertical welding.

[0047]

<Total Amount of Metallic Si in terms of Si and SiO₂ in terms of Si: 4.0 to 14.0% by mass>

Metallic Si and SiO₂ serve as a viscosity modifier of the slag, and also have the effect of increasing an arc force. When the total amount of metallic Si in terms of Si and SiO₂ in terms of Si is less than 4.0% by mass based on the total mass of the coating agent, the effect of serving as the viscosity modifier is not sufficiently exerted, thus causing deterioration of bead shape. Meanwhile, when the total amount of metallic Si in terms of Si and SiO₂ in terms of Si exceeds 14.0% by mass, removability of the slag drastically deteriorates to cause deterioration of workability.

Therefore, the total amount of metallic Si in terms of Si and SiO₂ in terms of Si is set at 4.0 to 14.0% by mass.

[0048]

<Total Amount of Metallic Al in terms of Al and Al_2O_3 in terms of Al: 0.1 to 3.5% by mass>

5 Metallic Al and Al_2O_3 enable an increase in arc stability and the viscosity of the slag, and serve as the slag forming agent. When the total amount of metallic Al in terms of Al and Al_2O_3 in terms of Al is less than 0.1% by mass based on the total mass of the coating agent, arc stability and viscosity of the slag are not sufficiently
10 obtained. Meanwhile, when the total amount of metallic Al in terms of Al and Al_2O_3 in terms of Al exceeds 3.5% by mass, the amount of the slag produced increases and also slag removability deteriorates, thus causing deterioration of welding workability. Therefore, the total amount of metallic
15 Al in terms of Al and Al_2O_3 in terms of Al is set at 0.1 to 3.5% by mass.

[0049]

<Amount of at least one Metal Carbonate selected from Group consisting of CaCO_3 , MgCO_3 and BaCO_3 in terms of CO_2 : 5.0 to
20 30.0% by mass>

A metal carbonate is decomposed by arc heat to generate a CO_2 gas. The metal carbonate has the effect of decreasing partial pressures of H_2 and N_2 gases in arc atmosphere by a CO_2 gas to protect welded metal. It also has the effect of
25 increasing the viscosity of the slag. When the amount of the

metal carbonate in terms of CO_2 is less than 5.0% by mass based on the total mass of the coating agent, pits and blowholes are generated due to lack of CO_2 gas shielding.

Meanwhile, when the amount of the metal carbonate in terms of CO_2 exceeds 30.0% by mass, deterioration of workability is caused by a decrease in arc. Furthermore, the viscosity of the slag excessively increases, and thus the molten metal is likely to hang down and fall down to form a projected bead, and also undercut is generated. Therefore, the amount of the metal carbonate in terms of CO_2 is set at 5.0 to 30.0% by mass. More preferably, the amount of the metal carbonate is 10.0 to 25.0% by mass. When the amount is set within the above range, the effect of a shielding gas is enhanced, leading to satisfactory fitness.

[0050]

<Amount of at least one Metal Fluoride selected from Group consisting of CaF_2 , BaF_2 , AlF_3 , LiF and Na_2SiF_6 in terms of F: 0.5 to 15.0% by mass>

A metal fluoride is a component which is capable of obtaining satisfactory welding workability by adjusting the viscosity of the slag. When the amount of the metal fluoride in terms of F is less than 0.5% by mass based on the total mass of the coating agent, bead shape deteriorates because of too high viscosity of the slag. Meanwhile, when the amount of the metal fluoride in terms of F exceeds 15.0% by mass,

arc becomes unstable, undesirably. Therefore, the amount of the metal fluoride in terms of F is set at 0.5 to 15.0% by mass based on the total mass of the coating agent. More preferably, the amount is 3.0 to 10.0% by mass. When the amount is set within the above range, slag removability becomes particularly satisfactory.

[0051]

<C: 0.01 to 0.7% by mass>

C is an element controlling the strength of weld metal, and is also needed to maintain an arc force by reacting with oxygen. When the content of C is less than 0.01% by mass based on the total mass of the coating agent, no effect is exerted, leading to weak arc spraying. Meanwhile, the content of C exceeds 0.7% by mass, arc spraying becomes too strong, leading to the generation of numerous sputters and non-uniform bead shape. Therefore, the content of C is set at 0.01 to 0.7% by mass. More preferably, the content is 0.03 to 0.2% by mass. When the content is set within the above range, appropriate arc force is obtained and arc becomes stable.

[0052]

<Total Amount of Na Compound in terms of Na and K Compound in terms of K: 1.0 to 8.0% by mass>

Na and K have high effect of improving arc stability. When the total amount of a Na compound in terms of Na and a K

compound in terms of K is less than 1.0% by mass based on the total mass of the coating agent, it is impossible to sufficiently obtain the effect. Meanwhile, when the total amount of a Na compound in terms of Na and a K compound in terms of K exceeds 8.0% by mass, peel-off preventiveness and electrode burning resistance of the coating agent deteriorate. Therefore, the total amount of a Na compound in terms of Na and a K compound in terms of K is set at 1.0 to 8.0% by mass.

The Na compound also includes the above-mentioned Na_2SiF_6 .

[0053]

<Balance: Fe and Inevitable Impurities>

Balance of the whole coating agent of the coated arc welding electrode includes Fe and inevitable impurities. The coating agent can contain, in addition to the above-mentioned components of the coating agent, a small amount of Ce, La, and the like as a tuning agent for deoxidation, and Nb, V, and the like as a strength adjustor of weld metal. These elements do not exert an influence on the object of the present invention. The coating agent contains a trace amount of an alkali metal compound of an element other than the above elements.

It is also possible to contain, as inevitable impurities, for example, B, Ni, Mo, Cr, and the like in the following amounts; B: less than 0.02% by mass, Ni: less than

0.5% by mass, Mo: less than 0.1% by mass, and Cr: less than 0.1% by mass. The components and numerical values are not limited to those mentioned above.

[0054]

5 [Reason for Limitation of Components of Titanium Oxide Material]

Since the reason for limitation of components of a titanium oxide material in second embodiment is the same as in the first embodiment, the description is omitted here.

10 [0055]

<<Third Embodiment>>

A third embodiment relates to a coated arc welding electrode which is excellent in toughness at low temperature and strength. In the third embodiment, the coating agent
15 contains, based on the total mass of the coating agent, a specific amount of Mn, and also contains a specific amount of at least one selected from the group consisting of metallic Ti in terms of Ti, B compound in terms of B, Ni, Cr and Mo in total, and Al and Mg in total, in the coated arc welding
20 electrode of the second embodiment.

These elements have common effect in a sense that mechanical properties (toughness, strength) are improved.

[0056]

<Mn: 1.0 to 7.0% by mass>

25 Mn has the object of securing of the strength and

deoxidation and is important in a sense that excellent toughness is obtained. When the content of Mn is less than 1.0% by mass based on the total mass of the coating agent, sufficient strength and toughness are not obtained.

5 Meanwhile, when the content of Mn exceeds 7.0% by mass, hardenability of weld metal increases to cause deterioration of toughness. Therefore, when Mn is added, the content of Mn is set at 1.0 to 7.0% by mass.

[0057]

10 <Amount of Metallic Ti in terms of Ti: 0.2 to 2.0% by mass>

Metallic Ti is a deoxidizing element and is also effective to improve the strength of weld metal. The metallic Ti is effective to form a fine spherical oxide, thus refining of the structure of weld metal. When the amount of metallic Ti in terms of Ti is less than 0.2% by mass based on the total mass of the coating agent, it does not exert sufficient effect of improving deoxidizability and the strength of weld metal. Meanwhile, when the amount of metallic Ti in terms of Ti exceeds 2.0% by mass, since the amount of Ti in the weld metal excessively increases, the strength and hardness excessively increases to cause deterioration of toughness. Therefore, when metallic Ti is added, the amount of metallic Ti in terms of Ti is set at 0.2 to 2.0% by mass.

25 [0058]

<Amount of B compound in terms of B: 0.02 to 0.3% by mass>

B has the effect of improving toughness of weld metal by refining a weld metal structure. When the amount of a B compound in terms of B is less than 0.02% by mass based on the total mass of the coating agent, the effect is not exerted. Meanwhile, when the amount of B compound in terms of B exceeds 0.3% by mass, B is excessively precipitated at grain boundaries of weld metal to cause deterioration of toughness due to a decrease in strength in a crystal interface. Therefore, when the B compound is added, the amount of B compound in terms of B is set at 0.02 to 0.3% by mass.

[0059]

<Ni: 0.5 to 10.0% by mass>

Ni is an element for enhancing the strength and toughness. When the content of Ni is less than 0.5% by mass based on the total mass of the coating agent, prescribed effect cannot be obtained. Meanwhile, when the content of Ni exceeds 10.0% by mass, toughness deteriorates since the strength of weld metal excessively increases. Therefore, when Ni is added, the content of Ni is set at 0.5 to 10.0% by mass.

[0060]

<Total Amount of Cr and Mo: 0.1 to 3.0% by mass>

Cr and Mo have the effect of improving the strength of

weld metal. When the total amount of Cr and Mo is less than 0.1% by mass based on the total mass of the coating agent, the effect of improving the strength is not obtained. Meanwhile, the total amount of Cr and Mo exceeds 3.0% by mass, 5 hardenability excessively increases and also carbides are formed to cause deterioration of toughness. Therefore, when at least one of Cr and Mo is added, total amount of Cr and Mo is set at 0.1 to 3.0% by mass.

[0061]

10 <Total Amount of Al and Mg: 0.1 to 2.0% by mass>

Al and Mg are strong deoxidizing agents and have the effect of improving toughness due to a decrease in the amount of oxygen of weld metal. When the total amount of Al and Mg is less than 0.1% by mass based on the total mass of the 15 coating agent, the effect of improving toughness is not obtained. Meanwhile, when the total amount of Al and Mg exceeds 2.0% by mass, arc becomes unstable and the amount of generation of spatters increases, and also the viscosity of the slag decreases to cause poor slag removability. 20 Therefore, when at least one of Al and Mg is added, the total amount of Al and Mg is set at 0.1 to 2.0% by mass.

[0062]

In the third embodiment, the coating agent may further contain, based on the total mass of the coating agent, a 25 specific amount of a Li compound in terms of Li.

<Amount of Li Compound in terms of Li: 0.01 to 1.0% by mass>

Li serves to improve moisture absorption resistance of a coating agent. When the amount of a Li compound in terms of Li is less than 0.01% by mass based on the total mass of the coating agent, the effect of improving moisture absorption resistance is not obtained. Meanwhile, when the amount of a Li compound in terms of Li exceeds 1.0% by mass, an internal gas cannot be removed thus generating dry cracks. Therefore, when a Li compound is added, the amount of a Li compound in terms of Li is set at 0.01 to 1.0% by mass.

[0063]

Here, in the first to third embodiments, the coating agent may further contain in a specific amount of ZrO_2 in terms of Zr based on the total mass of the coating agent.

<Amount of ZrO_2 in terms of Zr: 0.1 to 7.0% by mass>

ZrO_2 has the effect of improving concentration of arcs generated and gross of a bead surface. ZrO_2 also enables an improvement in fitness of weld metal to a base material.

When the amount of ZrO_2 in terms of Zr is less than 0.1% by mass based on the total mass of the coating agent, it is impossible to sufficiently obtain effects such as arc concentration, gross of a bead surface, and fitness of weld metal to a base material. Meanwhile, when the amount of ZrO_2 in terms of Zr exceeds 7.0% by mass, the slag thus generated becomes dense to cause deterioration of removability.

Therefore, when ZrO_2 is added, the amount of ZrO_2 in terms of Zr is set at 0.1 to 7.0% by mass (the value of a trace amount of ZrO_2 contained in the titanium oxide material is also included. Namely, the amount of ZrO_2 in terms of Zr is the total amount including the balance in the titanium oxide material).

[0064]

Next, a method for producing a titanium oxide material and a method for producing a coated arc welding electrode will be described.

<<Method for producing Titanium Oxide Material>>

[0065]

The method for producing a titanium oxide material mainly includes two methods such as a firing method and a melting method. The amount of Fe increases when using the firing method, while the amount of Fe decreases when using the melting method. Raw materials for fillet welding (the content of Fe is preferably higher) and vertical welding (the content of Fe is preferably lower) are separately produced by properly using the production method and the titanium raw material.

[0066]

First, the firing method will be described. Regarding raw materials, natural rutile, lucoxine and ilmenite can be used as Ti sources. The content of Ti of each raw material

decreases in order of rutile, lucoxine and ilmenite, and these raw materials can be properly used according to physical properties of the objective titanium oxide material, and used as a mixture. Generally, it is preferred that raw materials having high Ti content are used for vertical welding and raw materials having low Ti content are used for fillet welding. In the case of application, in order to use raw materials with a lesser content of foreign substances, gravity/magnetic/flotation separation is performed for the purpose of concentration of the titanium oxide material and reduction of impurities. Oxides (including composite oxide) and carbonates of Si, Al, Fe, Mn, Mg, Ca and the like can be used (added) as Si, Al, Fe, Mn, Mg and Ca sources. Here, the composite oxide is advantageous for the surface reaction since it has low melting point as compared with the single oxide and carbonates, thus making it possible to react at lower temperature.

[0067]

In the firing method, examples of the firing furnace is a rotary kiln or a batch furnace, and preferably a rotary kiln in which raw materials uniformly come in contact with each other, taking effective reaction between a Ti oxide source and other oxides or carbonates into consideration. In the batch furnace, when firing temperature becomes 1,200°C or higher, it is highly possible that the whole mixed raw

material having a decreased melting point is entirely or partially sintered and solidified, thus requiring extra operations such as coarse crushing, fine crushing and sieving (in this order) of the sintered and solidified titanium oxide material, which leads to an increase in cost. With respect to the firing atmosphere, it is considered that titanium nitride (melting point of $3,000^{\circ}\text{C}$) as a nitride of titanium is formed in the air atmosphere at high firing temperature. Therefore, it is recommended that the firing atmosphere is CO atmosphere, and a CO gas is easily generated by the addition of a C source to the firing raw materials. When ilmenite is used as a Ti source, a large amount of the C source is added so as to increase an apparent melting point of ilmenite, thus reducing an oxidized Fe component constituting ilmenite of an ilmenite particle surface. Namely, the composition of the ilmenite particle surface is shifted to the direction of natural rutile from ilmenite to increase the melting point of the ilmenite particle surface. At this time, there is no need to reduce ilmenite particle to nearly central portion.

[0068]

Next, the melting method will be described. Regarding the raw material, low-cost natural ilmenite can be used as the Ti source. It is also possible to use rutile or lucoxine. In the case of application, in order to use raw materials with a lesser content of foreign substances,

gravity/magnetic/flotation separation is performed for the purpose of concentration of the titanium oxide material and reduction of impurities. Oxides (including composite oxide) and carbonates of Si, Al, Fe, Mn, Mg, Ca and the like can be used (added) as Si, Al, Fe, Mn, Mg and Ca sources. Here, the composite oxide is advantageous for the surface reaction since it has low melting point as compared with the single oxide and carbonates, thus making it possible to react at lower temperature.

10 [0069]

The melting method can be performed by mixing ilmenite and other raw materials (oxides, carbonates) as well as a deoxidizing agent (C source) (it is possible to form into pellets), followed by heating to 1,800 to 2,000°C in an arc furnace or a high-frequency furnace. Whereby, oxidized Fe in ilmenite is reduced into a molten state. Because of its low melting point, Fe aggregates at the lower portion of the furnace, while an oxide composed of Ti, Si, Al, Mn, Fe, Mg, Ca and other impurities is formed at the upper portion of the furnace. It is also possible to use, in addition to an arc furnace, a high-frequency furnace, and the like, an electric furnace.

20 [0070]

The oxide thus obtained is subjected to coarse crushing, fine crushing and grading of grains in this order so as to

form a solvent material. Here, according to properties (bead shape) to be determined of the welding material, and use for vertical welding or fillet welding, a Fe portion having a low melting point (lower portion) and an oxide portion having a high melting point (upper portion) may be used as a mixture, or an intermediate layer (having a melting point between a melting point of the upper portion and that of the lower portion) may be used.

[0071]

In the case of the firing method and the melting method, C and S in the deoxidizing agent may sometimes remain in the titanium oxide material. Since these impurities exert an adverse influence on quality of the welding material, there is a need to perform a post-treatment (pickling or firing treatment) which varies depending on the kind of impurities.

[0072]

In the melting method, since valence (oxidation degree) of Ti in the atmospheric air in the oxide does not become stable, firing may be sometimes performed in the atmospheric air (CO reductive atmosphere during melting) so as to make valance of Ti to be tetravalence (crystal structure of TiO_2) which is the most stable state.

[0073]

After producing the titanium oxide material using the above-described firing method and melting method, oxides and

carbonates of Fe, Mn, Al, Si, Mg and Ca may be added, followed by firing (sintering) so that the surface of the titanium oxide material is slightly melted if there is a need to adjust trace elements such as Fe, Mn, Al, Si, Mg and Ca existing on the surface. The firing temperature is set at about 800 to 1,300°C, although it varies depending on the amount of oxygen in the titanium oxide material and firing method, and the titanium oxide material is sintered in a rotary kiln or a batch furnace, together with raw materials to be added. Fe, Mn, Al, Si, Mg and Ca are likely to be oxidized and, therefore, they may be added as metal.

[0074]

<<Method for Producing Coated Arc Welding Electrode>>

The coated arc welding electrode of the present invention is produced by applying the above-mentioned coating agent around a steel core wire so that a coating ratio of 20 to 55% by mass is attained by a binder such as water glass typified by sodium silicate and potassium silicate, using a conventional welding electrode coater, followed by appropriate (lime-titania type or titania type: 70 to 250°C, low-hydrogen type: 350 to 550°C) firing for removal of moisture. It is possible to use, as the steel core wire, for example, SWY11 defined in JIS G 3523

[0075]

As described above, according to the present invention,

it is possible to obtain satisfactory welding workability by using a titanium oxide material in which the composition of the oxide is optimized. In the titanium oxide material, form of existence of Ti, Fe, Mn, Al, Si and O on a particle
5 surface is controlled, thus making it possible to simultaneously satisfy the appropriate melting point of slag and molten metal, and viscosity and the amount of oxygen, and to ensure satisfactory fitness and bead shape.

In order to ensure toughness at low temperature and
10 strength, it is possible to obtain a coated arc welding electrode having improve toughness at low temperature and strength by adding a specific amount of Mn, and adding a specific amount of at least one selected from the group consisting of metallic Ti in terms of Ti, B compound in terms
15 of B, Ni, total of Cr and Mo, and total of Al and Mg. It is also possible to obtain a coated arc welding electrode in which moisture absorption resistance of the coating agent is improved, by adding a specific amount of a Li compound in terms of Li. It is also possible to obtain a coated arc
20 welding electrode in which arc concentration, gross of a bead surface, and fitness of weld metal to a base material are improved, by adding a prescribed amount of ZrO_2 in terms of Zr.

25 Examples

[0076]

In order to describe the effects of the present invention, a description will be made below by making a comparison between Examples falling within the scope of the present invention and Comparative Examples departing from the scope of the present invention.

[0077]

In the present Examples, Tables 1 and 2 illustrate those about titanium oxide materials, Table 3 illustrates the results thereof, and Table 4 illustrates the compositions of coated arc welding electrodes used. In Table 1, samples Nos. 13 to 16 corresponding to Comparative Examples in Table 2 are mentioned as "Comparative Examples". Here, the titanium oxide materials generally contain impurities such as Si, Al, Mn, Fe, Mg, Ca and the like, and each of components TiO_2 , Si, Al, Mn, Fe, Mg and Ca in Table 1 is within a general range. Therefore, there are not provided Comparative Examples in which contents of these components are equal to or more than upper and lower limits.

Tables 5 to 18 illustrate those about coated arc welding electrodes and, for example, Table 5 corresponds to a first embodiment, Table 6 corresponds to a second embodiment, and Table 7 corresponds to a third embodiment. For example, samples Nos. 1-1 to 1-24 in Tables 5 to 7 are those in which

a titanium oxide material of No. 1 in Tables 1 and 2 is used (details will be mentioned below).

[0078]

First, a method for producing a titanium oxide material, which is a test material, will be described. As mentioned above, the method for producing a titanium oxide material mainly includes two methods such as a firing method and a melting method. The amount of Fe increases when using the firing method, while the amount of Fe decreases when using the melting method. Raw materials for fillet welding (the content of Fe is preferably higher) and vertical welding (the content of Fe is preferably lower) were separately produced by properly using the production method and the titanium raw material.

[0079]

First, the firing method will be described. Regarding raw materials, natural rutile, lucoxine and ilmenite were used as Ti sources. These raw materials were properly used according to physical properties of the objective titanium oxide material, and used as a mixture. In the case of application, in order to use raw materials with a lesser content of foreign substances, gravity/magnetic/flotation separation was performed for the purpose of concentration of the titanium oxide material and reduction of impurities.

Oxides (including composite oxide) and carbonates of Si, Al,

Fe, Mn, Mg and Ca were used (added) as Si, Al, Fe, Mn, Mg and Ca sources.

[0080]

In the firing method, a rotary kiln was used as a firing furnace. CO atmosphere was employed as the firing atmosphere. The C source was added to the firing material.

[0081]

Next, the melting method will be described. Regarding the raw material, low-cost natural ilmenite was used as the Ti source. In the case of application, in order to use raw materials with a lesser content of foreign substances, gravity/magnetic/flotation separation was performed for the purpose of concentration of the titanium oxide material and reduction of impurities. Oxides (including composite oxide) and carbonates of Si, Al, Fe, Mn, Mg and Ca were used (added) as Si, Al, Fe, Mn, Mg and Ca sources.

[0082]

In the melting method, ilmenite and other raw materials (oxides, carbonates) as well as a deoxidizing agent (C source) were mixed, and the mixture was heated to 1,800 to 2,000°C in an arc furnace to reduce oxidized Fe in ilmenite, resulting in a molten state. Because of its low melting point, Fe aggregates at the lower portion of the furnace, while an oxide composed of Ti, Si, Al, Mn, Fe, Mg, Ca and other impurities was formed at the upper portion of the

furnace.

[0083]

The oxide thus obtained was subjected to coarse crushing, fine crushing, and grading of grains in this order
5 so as to form a solvent material.

In order to remove impurities such as C and S in a deoxidizing agent, pickling and firing treatments were performed as a post-treatment.

[0084]

10 After producing a titanium oxide material, in order to adjust trace elements existing on a surface, such as amounts of Fe, Mn, Al, Si, Mg and Ca, oxides and carbonates of Fe, Mn, Al, Si, Mg and Ca were added, followed by firing (sintering) so that a surface of the titanium oxide material is slightly
15 melted. The firing temperature was set at about 800 to 1,300°C, and the titanium oxide material was sintered in a rotary kiln, together with additive raw materials.

The bulk compositions of titanium oxide material Nos. 1 to 16 are shown in Table 1. In the table, the symbol "-"
20 shows that the component is not included.

[0085]

[Table 1]

Sample Nos.	Examples	Component of titanium oxide material (% by weight) (balance: inevitable impurities)						
		TiO ₂	Si	Al	Mn	Fe	Mg	Ca
1	Examples	93	0.9	1.0	2.0	1.7	0.2	0.1
2		93	0.4	0.9	1.8	0.8	0.4	0.1
3		90	1.0	0.9	0.7	2.6	0.7	0.2
4		92	0.7	0.8	2.1	1.5	0.2	0.1
5		92	0.9	0.6	0.9	1.9	0.6	0.2
6		92	0.6	0.8	2.0	1.6	0.2	0.1
7		94	0.6	0.9	1.7	1.2	0.2	0.6
8		77	2.3	1.0	0.9	7.1	3.9	0.4
9		92	0.9	0.8	1.4	1.3	0.3	0.1
10		64	0.5	0.6	2.0	27.5	0.1	0.1
11		91	1.0	0.5	0.8	1.7	0.8	0.8
12		87	0.7	0.6	1.7	7.6	0.4	0.1
13	Comparative Examples	98	<0.01	0.7	<0.05	<0.05	<0.05	<0.05
14		79	2.2	1.0	4.9	6.2	1.3	0.2
15		59	0.3	-	0.6	24.6	0.8	0.1
16		67	0.2	1.3	0.5	24.5	0.2	0.2

[0086]

5 Next, an analysis method of an atomic percentage of a particle surface of the titanium oxide material will be described. An analyzer is as follows.

[0087]

(1) First analyzer

10 Apparatus: manufactured by JEOL Ltd.

A WD/ED combined electron probe microanalyzer (EPMA) JXA-8200 is used.

Analysis conditions: accelerating voltage of 15 kv, and irradiation current of 5×10^{-10} A

[0088]

(2) Second Analyzer

Apparatus: manufactured by Hitachi High-Tech Fielding Corporation

5 A scanning electron microscope equipped with EDS, S-3700N, is used.

EDS: GENESIS400 Series, manufactured by EDAX Japan

Analysis conditions: accelerating voltage of 15 kv, and irradiation current of 5×10^{-12} A

10 Analysis was performed using first and second EDX apparatuses, but the same analysis results were obtained in both cases.

[0089]

(3) Quantitative Analysis Method

15 Quantitative analysis was performed by standard-less analysis. A relative intensity ratio of spectra of a standard sample computerized in a computer to the measured spectra was determined, followed by correction calculation so as to make 100% in total.

20 [0090]

The analysis method is as follows. In EDX, about 1 g of a raw material was disposed on a C tape (conductive tape for SEM: carbon double coated adhesive tape, manufactured by Nisshin EM Corporation) stuck on an aluminum stand, and then
25 the raw material was well adhered onto the C tape using a

powder paper, a glass plate, or a micro spoon made of stainless steel. In order to ensure electricity, Os vacuum deposition was applied and, after randomly selecting 5 particles including an area (rectangular region measuring 10 $\mu\text{m} \times 10 \mu\text{m}$) of a comparatively flat material surface on which no foreign substance exists or adheres when observed under high magnification (about 2,000 times), atomic percentage (atomic %) of one field was measured per each particle.

[0091]

10 Analysis conditions: Energy full scale: 20 KeV (10 eV/ch, 2 Kch)

 Effective time: 60 seconds

 Accelerating voltage: 15.0 KV

 Probe current: 5.0×10^{-10} A

15 [0092]

 The calculation method of x, y and z of numerical formulas 1 to 3 described in the surface analysis of the titanium oxide material is as follows. The values of the below-mentioned numerical formula 1 to 3 are determined from the measurement results of the above-mentioned 5 points (points of 5 particles), followed by calculation of an average of x, y and z of 5 points.

[0093]

 In the calculation method of the numerical formulas 2 and 3, an arithmetical mean value of 5 points of denominator

25

and numerator is independently calculated, respectively, and then division is performed using the obtained averages. When the average of the denominator is zero (zero in all 5 points), the values of the numerical formulas 2 and 3 become infinite.

5 [0094]

Analysis results (i.e. EDX analysis results) of an atomic percentage of a particle surface of the titanium oxide material are shown in Table 2. In the table, the symbol “-” shows that the component is not included.

10 [0095]

[Table 2]

Sample Nos.	Examples	Atomic percentage of particle surface of titanium oxide material								
		Ti	O	Fe	Mn	Si	Al	Si+Al	Ti/(Fe+Mn)	O/(Fe+Mn)
1	Examples	33.2	57.6	2.7	2.5	2.7	1.3	4.0	6	11
2		35.8	59.5	0.6	0.7	0.2	3.2	3.4	28	46
3		32.7	64.5	0.7	0.3	0.2	1.6	1.8	33	65
4		43.0	54.9	0.3	0.6	0.8	0.4	1.2	48	61
5		45.3	49.5	0.2	0.3	3.5	1.2	4.7	91	99
6		33.4	57.8	2.5	0.9	0.3	5.1	5.4	10	17
7		37.1	54.6	0.1	0.5	1.6	6.1	7.7	62	91
8		74.9	22.5	0.3	-	1.1	1.2	2.3	250	75
9		43.0	55.0	0.4	0.1	1.3	0.2	1.5	86	110
10		12.8	76.8	0.6	-	4.3	5.5	9.8	21	128
11		74.3	23.6	0.3	0.1	0.9	0.8	1.7	186	59
12		83.1	8.0	0.5	0.3	6.9	1.2	8.1	104	10
13	Comparative Examples	41.1	58.0	0.1	0.1	0.1	0.6	0.7	206	290
14		30.7	55.2	0.2	0.1	7.4	6.4	13.8	102	184
15		1.0	66.0	0.1	0.5	12.8	19.6	32.4	2	110
16		55.0	31.8	0.2	0.1	5.7	7.2	12.9	183	106

[0096]

The evaluation results of a welding test using each titanium oxide material in the coated arc welding electrode

are shown in Table 3. The coated arc welding electrode using the titanium oxide material used in the welding test is produced by using titanium oxide materials shown in Tables 1 to 3, and each amount of components other than the titanium oxide material is as shown in Table 4 below. Fitness and bead shape in Table 3 were evaluated by the same criteria as in five-rank evaluation with respect to the below-mentioned "welding workability". The welding conditions are also the same as those for the below-mentioned "welding workability".

The method for producing a coated arc welding electrode is also the same as the below-mentioned method.

[0097]

[Table 3]

Sample Nos.	Examples	Atomic percentage of particle surface			Test results		
		Si+Al	Ti/(Fe+Mn)	O/(Fe+Mn)	Fitness	Bead shape	Comprehensive evaluation
1	Examples	4.0	6	11	4	4	4
2		3.4	28	46	4	4	4
3		1.8	33	65	4	4	4
4		1.2	48	61	3	4	3
5		4.7	91	99	4	4	4
6		5.4	10	17	4	4	4
7		7.7	62	91	3	4	3
8		2.3	250	75	4	3	3
9		1.5	86	110	4	3	3
10		9.8	21	128	3	3	3
11		1.7	186	59	4	3	3
12		8.1	104	10	3	3	3
13	Comparative Examples	0.7	206	290	2	1	1
14		13.8	102	184	2	2	2
15		32.4	2	110	2	2	2
16		12.9	183	106	2	2	2

[0098]

[Table 4]

Type	Coating ratio of coating agent (% by mass)	Components of coating agent (% by weight) (balance: Fe and inevitable impurities)						
		Titanium oxide material	SiO ₂	Al ₂ O ₃	Metal carbonate	C	Mn	Na+K
Coated arc welding electrode	33.2	15.3	4.0	1.6	2.0	0.90	3.5	3.3

5 [0099]

Regarding comprehensive evaluation, the case where both fitness and bead shape are rated "4" was rated "4", and the case where either one is rated "4" and the other one is rated "3", or the case where both of them are rated "3" was rated "3". Regarding comprehensive evaluation, the case where both fitness and bead shape are rated "2" was rated "2", or the case where either one was rated "1" was rated "1".

10

[0100]

<<Method for Producing Coated Arc Welding Electrode>>

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20

The welding electrode of the present invention was produced by applying the above-mentioned coating agent around a 4.0 mm steel core wire, so that a coating ratio of 20 to 55% by mass is attained, by a binder such as water glass typified by sodium silicate and potassium silicate, using a conventional welding electrode coater, followed by appropriate (lime-titania type or titania type: 70 to 250°C,

low-hydrogen type: 350 to 550°C) firing for removal of moisture. SWY11 defined in JIS G 3523 was used as the steel core wire.

[0101]

5 The component compositions of coated arc welding electrodes are shown in Table 5 to 18. In the table, those departing from the scope of the present invention are indicated by underlining the numerical value or the like. In the table, the symbol "-" shows that the component is not
10 included.

"SiO₂", "Al₂O₃" and "metal carbonate" respectively mean "amount in terms of Si", "amount in terms of Al" and "the amount of at least one metal carbonate selected from the group consisting of CaCO₃, MgCO₃ and BaCO₃ in terms of CO₂",
15 and "Na + K" means "total amount of a Na compound in terms of Na and a K compound in terms of K".

"SiO₂ + Si", "Al₂O₃ + Al" and "metal fluoride" respectively mean "total amount of metallic Si in terms of Si and SiO₂ in terms of Si", "total amount of metallic Al in
20 terms of Al and Al₂O₃ in terms of Al" and "amount of at least one metal fluoride selected from the group consisting of CaF₂, BaF₂, AlF₃, LiF and Na₂SiF₆ in terms of F".

"Metallic Ti", "B compound", "Li compound" and "ZrO₂" respectively mean "amount of metallic Ti in terms of Ti",
25 "amount of B compound in terms of B", "amount of a Li

compound in terms of Li", and "amount of ZrO_2 in terms of Zr".

The same shall apply in Table 4.

[0102]

Here, Tables 5 to 7 illustrate the use of the titanium
oxide material of sample No. 1 in Tables 1 to 3. In this
sample No. 1, "Si + Al" is a more preferable range, and
"Ti/(Fe + Mn)" and "O/(Fe + Mn)" are in a preferable range.

Tables 8 to 10 illustrate the use of the titanium oxide
material of sample No. 7 in Tables 1 to 3. In this sample No.
7, "Si + Al" departs from a more preferable range.

[0103]

In Tables 11 to 13, the titanium oxide material of
sample No. 9 in Tables 1 to 3 is used. In this sample No. 9,
"Si + Al" is within a more preferable range, but "O/(Fe +
Mn)" departs from a preferable range.

Tables 14 to 16 illustrate the use of the titanium
oxide material of sample No. 10 in Tables 1 to 3. In this
sample No. 10, "Si + Al" departs from a more preferable range,
"O/(Fe + Mn)" departs from a preferable range, and also the
content of TiO_2 is rather low.

Tables 17 and 18 illustrate the use of the titanium
oxide material of sample No. 13 in Tables 1 to 3. In this
sample No. 13, "Si + Al" departs from a range, and "Ti/(Fe +
Mn)" and "O/(Fe + Mn)" departs from a preferable range.

[0104]

Tables 5 to 18 respectively correspond to coated arc welding electrodes of a first embodiment (relating to a lime-titania type or titania type coated arc welding electrode), a second embodiment (relating to a low-hydrogen type coated arc welding electrode), and a third embodiment (relating to a coated arc welding electrode which is excellent in toughness at low temperature and strength (mentioned as "low temperature + HT" in the table)).

[0105]

[Table 5]

Corresponding to first embodiment (lime-titania type or titania type)

Examples	Sample Nos.	Coating ratio of coating agent (% by mass)	Components of coating agent (% by mass) (Balance: Fe and inevitable impurities)							
			Titanium oxide material	SiO ₂	Al ₂ O ₃	Metal carbonate	C	Mn	Na+K	ZrO ₂
Examples	1-1	40.0	15.0	4.0	1.6	2.0	0.90	3.5	3.0	-
	1-2	33.0	30.0	14.0	1.2	15.0	1.00	0.1	1.0	-
	1-3	35.0	44.0	8.0	1.4	13.0	0.05	12.0	8.0	-
	1-4	20.0	56.0	9.0	3.5	8.0	0.01	8.0	5.0	-
	1-5	30.0	60.0	11.5	0.1	1.0	0.50	15.0	5.4	-
Comparative Examples	1-6	32.0	<u>10.0</u>	7.0	-	5.0	0.03	0.5	3.7	-
	1-7	44.0	<u>65.0</u>	6.4	<u>3.7</u>	6.0	-	3.0	3.2	-
	1-8	27.0	19.0	<u>3.0</u>	0.9	8.8	0.60	4.0	2.0	-
	1-9	38.0	25.6	<u>15.0</u>	0.8	14.0	<u>1.10</u>	5.6	4.0	-

[0106]

[Table 6]

Corresponding to second embodiment (low-hydrogen type)

Examples	Sample Nos.	Coating ratio of coating agent (% by mass)	Components of coating agent (% by mass) (Balance: Fe and inevitable impurities)							
			Titanium oxide material	SiO ₂ +Si	Al ₂ O ₃ +Al	Metal carbonate	Metal fluoride	C	Na+K	ZrO ₂
Examples	1-10	55.0	2.0	8.0	0.9	30.0	0.5	0.60	3.4	-
	1-11	32.0	20.0	4.0	0.1	25.0	3.0	0.70	1.0	-
	1-12	44.0	15.0	14.0	3.5	18.0	10.0	0.20	8.0	-
	1-13	20.0	13.0	8.7	1.5	10.0	7.4	0.01	2.6	-
	1-14	27.0	7.0	11.3	2.2	5.0	15.0	0.03	5.4	-
Comparative Examples	1-15	33.0	<u>1.2</u>	7.2	<u>—</u>	7.6	3.5	0.02	3.5	-
	1-16	38.1	<u>21.0</u>	6.5	<u>3.8</u>	9.6	4.9	<u>—</u>	6.7	-
	1-17	26.6	16.0	<u>3.3</u>	0.6	12.4	1.3	0.60	2.4	-
	1-18	32.2	15.5	<u>14.8</u>	0.9	14.5	8.0	<u>0.80</u>	4.5	-

[0107]

[Table 7]

Corresponding to third embodiment (low temperature + HT)

Examples	Sample Nos.	Coating ratio of coating agent (% by mass)	Components of coating agent (% by mass) (Balance: Fe and inevitable impurities)														
			Titanium oxide material	SiO ₂ +Si	Al ₂ O ₃ +Al	Metal carbonate	Metal fluoride	C	Na+K	Metallic Ti	B compound	Ni	Cr+Mo	Al+Mg	Mn	Li compound	ZrO ₂
Examples	1-19	34.0	15.1	7.0	0.4	10.0	3.0	0.03	8.0	2.0	0.02	-	0.20	-	2.0	-	-
	1-20	33.0	13.2	8.0	1.2	12.0	3.2	0.05	4.0	-	-	10.0	-	0.6	1.6	-	-
	1-21	37.0	4.9	11.2	2.0	14.0	5.5	0.10	3.0	0.2	0.30	-	-	1.0	1.0	-	-
Comparative Examples	1-22	50.0	4.8	4.0	1.4	9.0	2.9	0.08	2.2	<u>0.1</u>	<u>0.01</u>	-	-	-	2.2	-	-
	1-23	25.0	15.6	6.5	2.1	29.0	11.2	0.40	3.4	-	<u>0.35</u>	<u>10.5</u>	-	-	4.0	-	-
	1-24	40.0	15.2	4.4	1.1	20.0	10.5	0.12	5.6	-	-	-	<u>0.05</u>	-	<u>0.8</u>	-	-

[0108]

[Table 8]

Corresponding to first embodiment (lime-titania type or titania type)

Examples	Sample Nos.	Coating ratio of coating agent (% by mass)	Components of coating agent (% by mass) (Balance: Fe and inevitable impurities)							
			Titanium oxide material	SiO ₂	Al ₂ O ₃	Metal carbonate	C	Mn	Na+K	ZrO ₂
Examples	7-1	55.0	55.0	4.0	0.1	1.0	0.85	0.1	3.3	-
	7-2	30.0	35.0	4.6	1.8	14.0	1.00	6.7	2.1	-
	7-3	25.3	44.0	8.0	1.4	2.5	0.30	12.0	1.0	-
	7-4	22.0	57.0	10.0	2.4	7.6	0.22	8.0	7.0	-
	7-5	34.0	60.0	11.5	3.0	1.0	0.50	3.5	5.4	0.1
Comparative Examples	7-6	20.0	16.0	7.0	2.0	5.0	0.03	-	0.8	-
	7-7	62.0	55.0	6.4	3.0	6.0	0.70	3.0	8.2	-
	7-8	35.6	19.0	5.5	0.9	16.2	0.60	15.5	2.0	7.1
	7-9	18.0	25.6	13.0	0.8	0.8	0.55	5.6	4.0	-

[0109]

[Table 9]

Corresponding to second embodiment (low-hydrogen type)

Examples	Sample Nos.	Coating ratio of coating agent (% by mass)	Components of coating agent (% by mass) (Balance: Fe and inevitable impurities)							
			Titanium oxide material	SiO ₂ +Si	Al ₂ O ₃ +Al	Metal carbonate	Metal fluoride	C	Na+K	ZrO ₂
Examples	7-10	25.0	5.0	6.3	0.9	30.0	15.0	0.32	1.2	-
	7-11	32.0	12.2	4.5	0.5	26.0	12.0	0.44	2.5	-
	7-12	33.0	13.4	14.0	2.1	6.7	9.2	0.15	3.8	-
	7-13	27.0	20.0	8.7	3.5	19.0	5.6	0.01	4.5	-
	7-14	28.6	7.0	11.3	2.2	5.0	9.8	0.08	8.0	-
Comparative Examples	7-15	<u>56.0</u>	3.0	7.0	0.8	12.0	<u>15.5</u>	0.03	3.7	-
	7-16	<u>19.0</u>	4.0	6.4	2.2	<u>4.4</u>	4.8	0.10	3.2	-
	7-17	25.0	12.0	4.5	0.9	<u>31.0</u>	1.2	0.60	<u>8.1</u>	-
	7-18	31.0	11.0	7.0	0.8	14.5	<u>0.4</u>	0.30	<u>0.9</u>	-

[0110]

[Table 10]

Corresponding to third embodiment (low temperature + HT)

Examples	Sample Nos.	Coating ratio of coating agent (% by mass)	Components of coating agent (% by mass) (Balance: Fe and inevitable impurities)														
			Titanium oxide material	SiO ₂ +Si	Al ₂ O ₃ +Al	Metal carbonate	Metal fluoride	C	Na+K	Metallic Ti	B compound	Ni	Cr+Mo	Al+Mg	Mn	Li compound	ZrO ₂
Examples	7-19	31.2	10.4	4.5	1.2	8.7	2.9	0.10	7.9	0.2	0.30	-	-	0.4	4.8	-	-
	7-20	28.0	7.8	8.0	1.3	25.4	12.3	0.06	4.2	0.4	-	0.5	3.0	-	2.0	-	-
	7-21	35.5	4.9	12.5	2.1	26.7	5.5	0.09	3.6	-	-	2.5	-	0.1	7.0	-	-
Comparative Examples	7-22	31.1	15.4	4.3	1.8	25.2	10.2	0.02	2.3	<u>2.2</u>	-	-	<u>3.1</u>	-	1.0	-	-
	7-23	42.0	16.5	5.5	2.3	28.2	10.4	0.21	3.5	-	0.04	2.3	-	-	<u>7.2</u>	-	-
	7-24	39.2	3.8	4.4	2.1	20.0	2.8	0.05	5.1	-	-	-	<u>0.05</u>	<u>0.08</u>	2.5	-	-

[0111]

[Table 11]

Corresponding to first embodiment (lime-titania type or titania type)

Examples	Sample Nos.	Coating ratio of coating agent (% by mass)	Components of coating agent (% by mass) (Balance: Fe and inevitable impurities)							
			Titanium oxide material	SiO ₂	Al ₂ O ₃	Metal carbonate	C	Mn	Na+K	ZrO ₂
Examples	9-1	30.2	15.0	4.0	1.6	2.0	1.00	2.0	2.9	-
	9-2	28.0	60.0	11.0	3.5	15.0	0.35	0.1	1.0	-
	9-3	26.8	48.0	8.0	1.4	12.0	0.23	6.2	7.0	-
	9-4	20.0	36.0	9.0	2.5	8.0	0.75	9.9	4.5	-
	9-5	30.0	22.4	14.0	0.1	1.0	0.50	15.0	8.0	7.0
Comparative Examples	9-6	32.0	25.0	7.0	-	5.0	<u>1.08</u>	0.5	3.7	-
	9-7	44.0	33.3	6.4	<u>4.0</u>	6.0	-	3.0	3.2	-
	9-8	27.0	<u>9.4</u>	<u>3.0</u>	0.9	8.8	0.60	4.0	2.0	-
	9-9	38.0	<u>64.0</u>	<u>15.0</u>	0.8	2.5	0.05	5.6	4.0	<u>0.05</u>

[0112]

[Table 12]

Corresponding to second embodiment (low-hydrogen type)

Examples	Sample Nos.	Coating ratio of coating agent (% by mass)	Components of coating agent (% by mass) (Balance: Fe and inevitable impurities)							
			Titanium oxide material	SiO ₂ +Si	Al ₂ O ₃ +Al	Metal carbonate	Metal fluoride	C	Na+K	ZrO ₂
Examples	9-10	40.2	2.0	4.0	3.5	28.0	0.5	0.70	8.0	-
	9-11	20.0	19.2	4.4	0.1	25.0	3.6	0.45	1.0	-
	9-12	34.6	13.4	13.4	3.2	17.3	10.0	0.10	7.6	-
	9-13	28.0	16.2	8.7	1.5	22.1	7.4	0.02	2.6	-
	9-14	27.0	11.2	11.3	2.9	5.0	15.0	0.20	4.2	7.0
Comparative Examples	9-15	33.0	<u>1.7</u>	7.0	-	12.0	10.8	0.02	3.2	-
	9-16	38.0	<u>20.8</u>	6.4	<u>3.6</u>	9.6	2.7	-	6.6	-
	9-17	25.0	12.0	<u>3.8</u>	0.9	8.8	6.0	0.23	2.1	-
	9-18	31.0	11.0	<u>14.3</u>	0.8	14.5	8.0	<u>0.75</u>	4.2	<u>0.08</u>

[0113]

[Table 13]

Corresponding to third embodiment (low temperature + HT)

Examples	Sample Nos.	Coating ratio of coating agent (% by mass)	Components of coating agent (% by mass) (Balance: Fe and inevitable impurities)														
			Titanium oxide material	SiO ₂ +Si	Al ₂ O ₃ +Al	Metal carbonate	Metal fluoride	C	Na+K	Metallic Ti	B compound	Ni	Cr+Mo	Al+Mg	Mn	Li compound	ZrO ₂
Examples	9-19	28.8	4.8	4.3	2.3	15.4	2.2	0.02	7.3	1.7	0.20	-	0.1	0.1	3.5	-	-
	9-20	29.3	3.0	12.0	1.2	26.7	4.5	0.12	5.4	0.8	0.10	1.2	-	0.5	4.5	-	-
	9-21	35.7	14.8	6.8	2.2	25.2	11.2	0.08	1.6	-	0.08	5.0	-	2.0	1.8	0.01	-
Comparative Examples	9-22	50.0	3.2	4.2	1.2	9.5	2.9	0.10	2.5	<u>0.1</u>	<u>0.01</u>	<u>0.4</u>	-	-	2.3	-	-
	9-23	25.0	17.6	5.5	1.9	26.5	1.8	0.31	3.2	-	-	-	-	<u>2.1</u>	2.8	-	-
	9-24	44.0	4.9	4.3	0.8	21.0	11.2	0.22	7.6	-	-	<u>10.2</u>	<u>3.1</u>	-	4.0	<u>0.005</u>	-

[0114]

[Table 14]

Corresponding to first embodiment (lime-titania type or titania type)

Examples	Sample Nos.	Coating ratio of coating agent (% by mass)	Components of coating agent (% by mass) (Balance: Fe and inevitable impurities)							
			Titanium oxide material	SiO ₂	Al ₂ O ₃	Metal carbonate	C	Mn	Na+K	ZrO ₂
Examples	10-1	39.0	60.0	5.1	0.1	6.0	0.44	0.1	2.2	-
	10-2	22.2	17.0	10.8	3.5	15.0	0.15	15.0	4.3	-
	10-3	29.0	55.0	8.0	1.3	2.5	0.30	3.5	2.5	-
	10-4	37.5	33.0	14.0	2.4	7.6	0.60	12.0	6.8	-
	10-5	34.0	15.0	7.5	3.3	14.0	0.01	5.5	5.4	-
Comparative Examples	10-6	20.0	16.0	<u>3.0</u>	1.7	5.0	0.03	<u>15.8</u>	1.3	-
	10-7	<u>61.0</u>	56.0	12.0	1.1	<u>0.9</u>	0.66	3.0	<u>8.5</u>	-
	10-8	<u>19.0</u>	19.0	9.3	2.9	<u>16.2</u>	0.51	12.1	2.0	-
	10-9	21.0	25.6	8.8	2.0	4.0	0.55	-	<u>0.9</u>	-

[0115]

[Table 15]

Corresponding to second embodiment (low-hydrogen type)

Examples	Sample Nos.	Coating ratio of coating agent (% by mass)	Components of coating agent (% by mass) (Balance: Fe and inevitable impurities)							
			Titanium oxide material	SiO ₂ +Si	Al ₂ O ₃ +Al	Metal carbonate	Metal fluoride	C	Na+K	ZrO ₂
Examples	10-10	25.0	3.0	8.7	3.5	30.0	15.0	0.12	6.5	-
	10-11	32.0	12.2	4.5	0.5	26.0	11.0	0.35	8.0	-
	10-12	33.0	14.9	14.0	1.7	6.7	9.2	0.15	4.3	-
	10-13	27.0	20.0	8.7	3.3	19.0	6.5	0.70	7.6	-
	10-14	28.6	8.0	11.3	2.4	5.0	9.8	0.21	1.0	0.1
Comparative Examples	10-15	<u>55.5</u>	14.3	7.1	0.9	11.0	<u>15.2</u>	0.09	5.6	-
	10-16	<u>19.5</u>	15.6	6.4	2.2	<u>4.8</u>	4.8	0.10	4.4	-
	10-17	25.0	9.0	11.6	2.5	<u>30.7</u>	1.6	0.22	8.5	-
	10-18	31.0	12.2	10.2	0.9	13.5	<u>0.3</u>	0.53	<u>0.8</u>	<u>7.1</u>

[0116]

[Table 16]

Corresponding to third embodiment (low temperature + HT)

Examples	Sample Nos.	Coating ratio of coating agent (% by mass)	Components of coating agent (% by mass) (Balance: Fe and inevitable impurities)														
			Titanium oxide material	SiO ₂ +Si	Al ₂ O ₃ +Al	Metal carbonate	Metal fluoride	C	Na+K	Metallic Ti	B compound	Ni	Cr+Mo	Al+Mg	Mn	Li compound	ZrO ₂
Examples	10-19	32.0	8.2	13.4	2.3	25.6	8.4	0.03	8.0	0.7	0.12	1.5	0.1	1.0	4.5	-	-
	10-20	33.4	4.5	5.3	1.6	28.2	5.4	0.19	5.4	-	0.10	5.9	0.4	1.0	2.8	-	-
	10-21	36.8	3.9	7.5	0.7	30.0	6.3	0.09	3.4	-	-	9.0	1.0	0.1	5.0	1.0	-
Comparative Examples	10-22	32.6	15.2	4.0	1.4	9.0	5.7	0.15	2.2	0.08	-	-	-	-	1.3	1.1	-
	10-23	33.4	4.7	6.5	2.1	29.0	4.0	0.40	3.4	-	-	10.1	3.1	-	1.5	-	-
	10-24	25.6	8.9	4.4	1.1	20.0	8.0	0.03	5.6	-	-	-	-	0.05	0.9	-	-

[0117]

[Table 17]

Corresponding to first embodiment (lime-titania type or titania type) (corresponding to Comparative Example No. 13 of titanium oxide material)

Example	Sample No.	Coating ratio of coating agent (% by mass)	Components of coating agent (% by mass) (Balance: Fe and inevitable impurities)							
			Titanium oxide material	SiO ₂	Al ₂ O ₃	Metal carbonate	C	Mn	Na+K	ZrO ₂
Comparative Example	13-1	40.0	15.0	4.0	1.6	2.0	0.90	3.5	3.0	-

[0118]

[Table 18]

Corresponding to second embodiment (low-hydrogen type) (corresponding to Comparative Example No. 13 of titanium oxide material)

Example	Sample No.	Coating ratio of coating agent (% by mass)	Components of coating agent (% by mass) (Balance: Fe and inevitable impurities)							
			Titanium oxide material	SiO ₂ +Si	Al ₂ O ₃ +Al	Metal carbonate	Metal fluoride	C	Na+K	ZrO ₂
Comparative Example	13-2	55.0	2.0	8.0	0.9	30.0	0.5	0.60	3.4	-

[0119]

With respect to the coated arc welding electrodes thus produced, the following tests were carried out. In each test, the conditions were changed so as to correspond to the first
5 embodiment (relating to a lime-titania type or titania type coated arc welding electrode), the second embodiment (relating to a low-hydrogen type coated arc welding electrode), and the third embodiment (relating to a coated arc welding electrode which is excellent in toughness at low
10 temperature and strength (mentioned as "low temperature + HT" in the table)).

[0120]

<<Welding Workability>>

[Corresponding to First to Third Embodiments]

15 Here, bead shape, fitness, arc stability and slag removability were evaluated.

[0121]

(Test Base Material for Confirmation of Welding Workability)

[Corresponding to First to Third Embodiments]

20 A test plate measuring 12 mm in thickness and 400 mm in length made of a rolled steel for welded structure (SM490A) defined in JIS G G3106 was used as a test base material for confirmation of welding workability.

[0122]

25 (Welding conditions)

Welding current: 140 to 160 Amp

Polarity: Alternate current (AC)

Welding position: Vertical

[0123]

5 <Bead Shape>

[Corresponding to First to Third Embodiments]

After subjecting to vertical welding at 140 to 160 Amp, the weld zone was observed, and bead shape was visually evaluated.

10 Evaluation criteria are as follows. Samples rated as "3 to 5" were judged as "Pass".

[0124]

5: Flat and extremely uniform wavy shape

4: Slightly projected to flat, and uniform wavy shape

15 3: Slightly projected, and uniform wavy shape

2: Projected and roughened wavy shape

1: Projected and drastically roughened wavy shape, unstable

[0125]

<Sensory Evaluation Excluding Bead Shape>

20 [Corresponding to First to Third Embodiments]

Fitness, arc stability, and slag removability were evaluated in the following manner. Samples having fitness rated as "3 to 5" were judged as "Pass", while samples having arc stability and slag removability rated as "2 and 3" were
25 judged as "Pass".

[0126]

<Fitness>

5: Very easy to fit, undercut is much less likely to occur

4: Easy to fit, undercut is much less likely to occur

5 3: Easy to fit, undercut is less likely to occur

2: Take a long time to fit

1: Take a long time to fit (poor fitness), undercut is likely to occur

[0127]

10 <Arc Stability>

3: Very stable, no arc breaking occurs

2: Stable, arc breaking scarcely occurs

1: Arc breaking sometimes occurs to easily cause defects such as slag inclusion, or defects are likely to occur

15 [0128]

<Slag Removability>

3: Self-releasing

2: Easy to release by scale hammer

1: Release by scale hammer takes a long time

20 [0129]

<<Mechanical Properties>>

[Corresponding to Third Embodiment]

(Test Base Material for Confirmation of Mechanical Properties)

25 All-weld metal was produced in accordance with JIS

Z3211, and mechanical properties were examined.

A test plate measuring 20 mm in thickness and 300 mm in length made of a rolled steel for welded structure (SM490A) defined in JIS G G3106 was used as a test base material for confirmation of mechanical properties.

[0130]

(Welding conditions)

Welding current: 140 to 170 Amp

Polarity: Alternate current (AC) or Direct current (DC (+))

Welding position: Flat

Preheating/interpass temperature: 90 to 110°C

Lamination method: 7 to 9 layers, two passes for each layer

[0131]

<Tensile Strength, Impact Performance (Impact Value)>

[Corresponding to Third Embodiment]

In accordance with JIS Z3211, tensile strength, Charpy absorbed energy at -60°C (toughness) were evaluated.

Regarding evaluation criteria of the tensile strength, samples having a tensile strength of 671 MPa or more were rated "A", samples having a tensile strength of 520 to 670 MPa were rated "B", and samples having a tensile strength of 519 MPa or less were rated "C". Samples rated as "A" and "B" were judged as "Pass". In the table, only the numerical value is shown.

Regarding evaluation criteria of the toughness, samples

having Charpy absorbed energy of 80 J or more were rated "A", samples having Charpy absorbed energy of 47 to 79 J were rated "B", and samples having Charpy absorbed energy of 46 J or less were rated "C". Samples rated as "A" and "B" were
 5 judged as "Pass". In the table, only the numerical value is shown.

These results are shown in Tables 19 to 32.

[0132]

[Table 19]

10 Corresponding to first embodiment (lime-titania type or titania type)

Nos.		Welding workability			
		Bead shape	Fitness	Arc stability	Slag removability
Examples	1-1	5	5	2	2
	1-2	4	4	2	2
	1-3	5	4	3	2
	1-4	4	4	2	2
	1-5	4	4	3	2
Comparative Examples	1-6	1	1	1	3
	1-7	1	4	1	1
	1-8	1	4	3	3
	1-9	1	4	3	1

[0133]

[Table 20]

Corresponding to second embodiment (low-hydrogen type)

Nos.		Welding workability			
		Bead shape	Fitness	Arc stability	Slag removability
Examples	1-10	4	4	2	2
	1-11	4	5	2	3
	1-12	5	5	3	3
	1-13	5	5	2	3
	1-14	5	5	3	2
Comparative Examples	1-15	1	1	1	2
	1-16	1	4	1	1
	1-17	1	4	2	2
	1-18	1	4	2	1

5 [0134]

[Table 21]

Corresponding to third embodiment (low temperature + HT)

Nos.		Welding workability				Mechanical properties	
		Bead shape	Fitness	Arc stability	Slag removability	Tensile strength (MPa)	Impact value (J)-60°C
Examples	1-19	4	5	3	3	525	79
	1-20	5	5	3	3	670	98
	1-21	4	5	3	3	521	70
Comparative Examples	1-22	4	4	3	2	493	43
	1-23	4	4	2	2	887	20
	1-24	4	4	2	2	500	40

[0135]

[Table 22]

Corresponding to first embodiment (lime-titania type or titania type)

Nos.		Welding workability			
		Bead shape	Fitness	Arc stability	Slag removability
Examples	7-1	5	4	2	2
	7-2	5	4	2	2
	7-3	5	4	3	2
	7-4	4	3	3	2
	*7-5	4	4	2	2
Comparative Examples	7-6	4	3	1	2
	7-7	4	1	2	2
	7-8	1	3	1	1
	7-9	1	1	1	1

- 5 Note) Sample No. 7-5 exhibited improved stiffness, improved arc concentration and satisfactory gross of bead surface as a result of the addition of Zr.

[0136]

[Table 23]

- 10 Corresponding to second embodiment (low-hydrogn type)

Nos.		Welding workability			
		Bead shape	Fitness	Arc stability	Slag removability
Examples	7-10	5	4	2	2
	7-11	5	4	2	2
	7-12	5	4	3	3
	7-13	4	4	2	3
	7-14	5	4	3	3
Comparative Examples	7-15	4	1	1	2
	7-16	1	1	1	1
	7-17	1	3	1	2
	7-18	1	3	1	2

[0137]

[Table 24]

Corresponding to third embodiment (low temperature + HT)

Nos.		Welding workability				Mechanical properties	
		Bead shape	Fitness	Arc stability	Slag removability	Tensile strength (MPa)	Impact value (J)-60°C
Examples	7-19	5	4	3	2	576	80
	7-20	5	4	3	2	692	60
	7-21	4	3	3	3	720	65
Comparative Examples	7-22	4	3	2	2	654	21
	7-23	4	3	2	2	751	40
	7-24	4	3	2	2	500	45

5 [0138]

[Table 25]

Corresponding to first embodiment (lime-titania type or titania type)

Nos.		Welding workability			
		Bead shape	Fitness	Arc stability	Slag removability
Examples	9-1	4	3	2	2
	9-2	4	3	3	2
	9-3	5	4	3	2
	9-4	5	4	3	2
	*9-5	4	4	3	2
Comparative Examples	9-6	1	3	1	2
	9-7	5	4	1	1
	9-8	1	1	2	2
	9-9	1	3	2	1

Note) Sample No. 9-5 exhibited improved stiffness, improved arc concentration and satisfactory gross of bead surface as a result of the addition of Zr.

[0139]

[Table 26]

Corresponding to second embodiment (low-hydrogen type)

Nos.		Welding workability			
		Bead shape	Fitness	Arc stability	Slag removability
Examples	9-10	4	3	2	2
	9-11	4	4	2	3
	9-12	5	5	3	3
	9-13	4	4	2	3
	*9-14	5	5	3	2
Comparative Examples	9-15	1	1	1	2
	9-16	1	4	1	1
	9-17	1	4	2	2
	9-18	1	4	2	1

Note) Sample No. 9-14 exhibited improved stiffness, improved arc concentration and satisfactory gross of bead surface as a result of the addition of Zr.

[0140]

[Table 27]

Corresponding to second embodiment (low temperature + HT)

Nos.		Welding workability				Mechanical properties	
		Bead shape	Fitness	Arc stability	Slag removability	Tensile strength (MPa)	Impact value (J)-60°C
Examples	9-19	4	4	2	2	522	65
	9-20	4	3	3	3	658	80
	*9-21	5	4	3	3	559	104
Comparative Examples	9-22	4	3	2	2	498	41
	9-23	4	3	2	1	630	58
	9-24	4	3	2	2	980	25

Note) Sample No. 9-21 exhibited improved moisture absorption resistance.

[0141]

[Table 28]

Corresponding to first embodiment (lime-titania type or titania type)

Nos.		Welding workability			
		Bead shape	Fitness	Arc stability	Slag removability
Examples	10-1	3	3	3	2
	10-2	3	3	3	2
	10-3	4	4	3	2
	10-4	3	3	3	2
	10-5	3	3	3	3
Comparative Examples	10-6	1	3	2	2
	10-7	3	1	2	2
	10-8	1	1	1	1
	10-9	3	3	1	2

5 [0142]

[Table 29]

Corresponding to second embodiment (low-hydrogen type)

Nos.		Welding workability			
		Bead shape	Fitness	Arc stability	Slag removability
Examples	10-10	3	3	2	2
	10-11	4	4	2	2
	10-12	4	4	3	3
	10-13	3	4	2	3
	10-14	4	4	2	3
Comparative Examples	10-15	3	1	1	2
	10-16	1	1	1	1
	10-17	1	3	1	2
	10-18	1	3	1	1

[0143]

[Table 30]

Corresponding to third embodiment (low temperature + HT)

Nos.		Welding workability				Mechanical properties	
		Bead shape	Fitness	Arc stability	Slag removability	Tensile strength (MPa)	Impact value (J)-60°C
Examples	10-19	4	4	3	3	651	98
	10-20	3	3	3	3	723	104
	*10-21	3	3	3	3	847	80
Comparative Examples	10-22	3	3	3	3	490	40
	10-23	3	3	3	3	1,018	20
	10-24	4	4	3	3	501	35

Note) Sample No. 10-21 exhibited improved moisture absorption resistance.

5

[0144]

[Table 31]

Corresponding to first embodiment (lime-titania type or titania type)

No.		Welding workability			
		Bead shape	Fitness	Arc stability	Slag removability
Comparative Example	13-1	1	2	2	2

10

[0145]

[Table 32]

Corresponding to second embodiment (low-hydrogen type)

No.		Welding workability			
		Bead shape	Fitness	Arc stability	Slag removability
Comparative Example	13-2	1	2	2	2

[0146]

As shown in Tables 19 to 32, since samples Nos. 1-1 to 1-5, Nos. 1-10 to 1-14, Nos. 1-19 to 1-21, Nos. 7-1 to 7-5, Nos. 7-10 to 7-14, Nos. 7-19 to 7-21, Nos. 9-1 to 9-5, Nos. 9-10 to 9-14, Nos. 9-19 to 9-21, Nos. 10-1 to 10-5, Nos. 10-10 to 10-14, and Nos. 10-19 to 10-21 satisfy the scope of the present invention, satisfactory results were obtained in each evaluation.

[0147]

10 In sample No. 1-6, bead shape and fitness deteriorated because of too small amount of a titanium oxide material. Arc stability deteriorated because of too small amount of Al_2O_3 . In sample No. 1-7, bead shape deteriorated because of too large amount of the titanium oxide material. Slag
15 removability deteriorated because of too large amount of Al_2O_3 . Arc stability deteriorated because of too small amount of C. In sample No. 1-8, bead shape deteriorated because of too small amount of SiO_2 . In sample No. 1-9, slag removability deteriorated because of too large amount of SiO_2 .
20 Bead shape deteriorated because of too large amount of C.

[0148]

In sample No. 1-15, bead shape and fitness deteriorated because of too small amount of a titanium oxide material. Arc stability deteriorated because of too small amount of
25 " $\text{Al}_2\text{O}_3 + \text{Al}$ ". In sample No. 1-16, bead shape deteriorated

because of too large amount of the titanium oxide material.
Slag removability deteriorated because of too large amount of
"Al₂O₃ + Al". Arc stability deteriorated because of too
small amount of C. In sample No. 1-17, bead shape
5 deteriorated because of too small amount of "SiO₂ + Si". In
No. 1-18, slag removability deteriorated because of too large
amount of "SiO₂ + Si". Bead shape deteriorated because of
too large amount of C.

[0149]

10 In sample No. 1-22, strength and toughness deteriorated
because of too small amount of metallic Ti and B compound.
In sample No. 1-23, toughness deteriorated because of too
large amounts of B compound and Ni. In sample No. 1-24,
strength and toughness deteriorated because of too small
15 amounts of "Cr + Mo" and Mn.

[0150]

In sample No. 7-6, blowholes were generated because of
too small amount of Mn, while arc stability deteriorated
because of too small amount of "Na + K". In sample No. 7-7,
20 fitness deteriorated because of too large coating ratio.
Electrode burning was likely to occur because of too large
amount of "Na + K", and also a coating agent was fallen away.
In sample No. 7-8, welding cracks occurred because of too
large amount of Mn. Arc stability and bead shape
25 deteriorated because of too large amount of metal carbonate.

Slag removability deteriorated because of too large amount of ZrO_2 . In sample No. 7-9, welding workability entirely deteriorated because of too small coating ratio. Pits and blowholes were generated because of too small amount of a metal carbonate.

[0151]

In sample No. 7-15, fitness deteriorated because of too small coating ratio. Arc stability deteriorated because of too large amount of metal fluoride. In sample No. 7-16, welding workability entirely deteriorated because of too small coating ratio. Pits and blowholes were generated because of too small amount of a metal carbonate. In sample No. 7-17, arc stability and bead shape deteriorated because of too large amount of a metal carbonate. Electrode burning was likely to occur because of too large amount of "Na + K", and also a coating agent was fallen away. In sample No. 7-18, bead shape deteriorated because of too small amount of metal fluoride. Arc stability deteriorated because of too small amount of "Na + K".

[0152]

In sample No. 7-22, toughness deteriorated because of too large amounts of metallic Ti and "Cr + Mo". In sample No. 7-23, toughness deteriorated because of too large amount of Mn. In sample No. 7-24, strength and toughness deteriorated because of too small amounts of "Cr + Mo" and "Al + Mg".

[0153]

In sample No. 9-6, bead shape deteriorated because of too large amount of C. Arc stability deteriorated because of too small amount of Al_2O_3 . In sample No. 9-7, slag
5 removability deteriorated because of too large amount of Al_2O_3 . Arc stability deteriorated because of too small amount of C. In sample No. 9-8, bead shape deteriorated because of too small amount of SiO_2 . Bead shape and fitness deteriorated because of too small amount of a titanium oxide
10 material. In sample No. 9-9, slag removability deteriorated because of too large amount of SiO_2 . Bead shape deteriorated because of too large amount of a titanium oxide material. The effect due to the addition of Zr was not exerted because of too small amount of ZrO_2 .

15 [0154]

In sample No. 9-15, bead shape and fitness deteriorated because of too small amount of a titanium oxide material. Arc stability deteriorated because of too small amount of " $\text{Al}_2\text{O}_3 + \text{Al}$ ". In sample No. 9-16, bead shape deteriorated
20 because of too large amount of a titanium oxide material. Slag removability deteriorated because of too large amount of " $\text{Al}_2\text{O}_3 + \text{Al}$ ". Arc stability deteriorated because of too small amount of C. In sample No. 9-17, bead shape deteriorated because of too small amount of " $\text{SiO}_2 + \text{Si}$ ". In
25 sample No. 9-18, slag removability deteriorated because of

too large amount of "SiO₂ + Si". Bead shape deteriorated because of too large amount of C. The effect due to the addition of Zr was not exerted because of too small amount of ZrO₂.

5 [0155]

In sample No. 9-22, toughness and strength deteriorated because of too small amounts of metallic Ti, B compound and Ni. In sample No. 9-23, slag removability deteriorated because of too large amount of "Al + Mg". In sample No. 9-24, 10 toughness deteriorated because of too large amounts of Ni and "Cr + Mo". The effect due to the addition of Li was not exerted because of too small amount of a Li compound.

[0156]

In sample No. 10-6, bead shape deteriorated because of 15 too small amount of SiO₂. Welding cracks occurred because of too large amount of Mn. In sample No. 10-7, fitness deteriorated because of too large coating ratio. Electrode burning was likely to occur because of too large amount of "Na + K", and also a coating agent was fallen away. Pits and 20 blowholes were generated because of too small amount of a metal carbonate. In sample No. 10-8, welding workability entirely deteriorated because of too small coating ratio. Arc stability and bead shape deteriorated because of too large amount of a metal carbonate. In sample No. 10-9, arc 25 stability deteriorated because of too small amount of "Na +

K". Blowholes were generated because of too small amount of Mn.

[0157]

In sample No. 10-15, fitness deteriorated because of too large coating ratio. Arc stability deteriorated because of too large amount of metal fluoride. In sample No. 10-16, welding workability entirely deteriorated because of too small coating ratio. Pits and blowholes were generated because of too small amount of a metal carbonate. In sample No. 10-17, arc stability and bead shape deteriorated because of too large amount of a metal carbonate. Electrode burning was likely to occur because of too large amount of "Na + K", and also a coating agent was fallen away. In sample No. 10-18, bead shape deteriorated because of too small amount of metal fluoride. Arc stability deteriorated because of too small amount of "Na + K". Slag removability deteriorated because of too large amount of ZrO_2 .

[0158]

In sample No. 10-22, strength and toughness deteriorated because of too small amount of metallic Ti. Dry cracks occurred because of too large amount of a Li compound. In sample No. 10-23, toughness deteriorated because of too large amounts of "Cr + Mo" and Ni. In sample No. 10-24, strength and toughness deteriorated because of too small amounts of "Al + Mg" and Mn.

In samples No. 13-1 and No. 13-2, bead shape and fitness deteriorated since the value of "Si + Al" in a particle surface of a titanium oxide material is less than the lower limit value.

5 [0159]

While the present invention has been described in detail by way of embodiments and examples, scope of rights thereof should be broadly interpreted based on the description of the scope of claims without being restricted to aforementioned contents. Modification and variation of the contents of the present invention can be broadly made based on aforementioned description .

10

CLAIMS

1. A coated arc welding electrode, a coating agent being applied onto a steel core wire thereof,

wherein a coating ratio of the coating agent is 20.0 to 55.0% by mass based on the total mass of the welding electrode;

wherein the coating agent contains, based on the total mass of the coating agent:

a titanium oxide material in a particulate form: 15.0 to 60.0% by mass,

SiO₂ in terms of Si: 4.0 to 14.0% by mass,

Al₂O₃ in terms of Al: 0.1 to 3.5% by mass,

at least one metal carbonate selected from the group consisting of CaCO₃, MgCO₃ and BaCO₃ in terms of CO₂: 1.0 to 15.0% by mass,

C: 0.01 to 1.0% by mass,

Mn: 0.1 to 15.0% by mass, and

a Na compound in terms of Na and a K compound in terms of K in total: 1.0 to 8.0% by mass;

wherein the titanium oxide material has a composition containing, based on the total mass of the titanium oxide material:

TiO₂: 58.0 to 99.0% by mass,

Si: 2.5% by mass or less,

Al: 3.0% by mass or less,

Mn: 5.0% by mass or less,

Fe: 35.0% by mass or less,

Mg: 5.0% by mass or less, and

Ca: 2.0% by mass or less;

and wherein an oxide composed of at least one of Ti, Fe, Mn, Al and Si exists on a particle surface of the titanium oxide material, and also the oxide satisfies the inequality expression: $1 \leq Al + Si \leq 10$ where Al and Si, each denotes an atomic percentage.

2. A coated arc welding electrode, a coating agent being applied onto a steel core wire thereof,

wherein a coating ratio of the coating agent is 20.0 to 55.0% by mass based on the total mass of the welding electrode;

wherein the coating agent contains, based on the total mass of the coating agent:

a titanium oxide material in a particulate form: 2.0 to 20.0% by mass,

metallic Si in terms of Si and SiO_2 in terms of Si in total: 4.0 to 14.0% by mass,

metallic Al in terms of Al and Al_2O_3 in terms of Al in total: 0.1 to 3.5% by mass,

at least one metal carbonate selected from the group

consisting of CaCO_3 , MgCO_3 and BaCO_3 in terms of CO_2 : 5.0 to 30.0% by mass,

at least one metal fluoride selected from the group consisting of CaF_2 , BaF_2 , AlF_3 , LiF and Na_2SiF_6 in terms of F: 0.5 to 15.0% by mass,

C: 0.01 to 0.7% by mass, and

a Na compound in terms of Na and a K compound in terms of K in total: 1.0 to 8.0% by mass;

wherein the titanium oxide material has the composition containing, based on the total mass of the titanium oxide material:

TiO_2 : 58.0 to 99.0% by mass,

Si: 2.5% by mass or less,

Al: 3.0% by mass or less,

Mn: 5.0% by mass or less,

Fe: 35.0% by mass or less,

Mg: 5.0% by mass or less, and

Ca: 2.0% by mass or less;

and wherein an oxide composed of at least one of Ti, Fe, Mn, Al, and Si exists on a particle surface of the titanium oxide material, and also the oxide satisfies the inequality expression: $1 \leq \text{Al} + \text{Si} \leq 10$ where Al and Si, each denotes an atomic percentage.

3. The coated arc welding electrode according to claim 2,

wherein the coating agent contains, based on the total mass of the coating agent:

Mn: 1.0 to 7.0% by mass, and also contains:

at least one selected from the group consisting of:

metallic Ti in terms of Ti: 0.2 to 2.0% by mass,

a B compound in terms of B: 0.02 to 0.3% by mass,

Ni: 0.5 to 10.0% by mass,

Cr and Mo in total: 0.1 to 3.0% by mass, and

Al and Mg in total: 0.1 to 2.0% by mass.

4. The coated arc welding electrode according to claim 3, wherein the coating agent contains, based on the total mass of the coating agent:

a Li compound in terms of Li: 0.01 to 1.0% by mass.

5. The coated arc welding electrode according to any one of claims 1 to 4, wherein the coating agent contains, based on the total mass of the coating agent:

ZrO₂ in terms of Zr: 0.1 to 7.0% by mass.