

ELECTROSLAG WELDING METHOD AND ELECTROSLAG WELDING APPARATUS

Technical Field

[0001]

An aspect of the present invention relates to an electrosag welding method and an electrosag welding apparatus.

Background Art

[0002]

Recently, in the fields of shipbuilding and industrial machinery, plate thickness tends to increase as the size of each of structures increases. Vertical welding of these structures has been performed by highly efficient electrogas arc welding. However, there are problems for a welding operator on working environment such as arc radiant heat, fumes, sputter, etc. Further, there reveals another problem that as the plate thickness increases, shielding performance deteriorates to thereby degrade mechanical performance of a welded portion, etc.

[0003]

As a solution to these problems, there is electrosag welding which uses Joule heat of molten slag as a heat source. In the electrosag welding, an exposed arc is not used for melting a wire and matrix, but heat is generated inside the molten slag to thereby melt a wire and a matrix. Accordingly, arc radiant heat is not generated and generation of fumes or sputter is also reduced. Thus, working environment is improved. In addition, weld metal is shielded from the atmosphere by the molten slag. Therefore, shielding gas is not required. A shielding effect is not degraded even when plate thickness increases. Nitrogen or the like present in the atmosphere can be effectively prevented from invading the molten metal regardless of the plate thickness. Accordingly, mechanical degradation of the weld metal is also not occurred.

[0004]

On the other hand, in the electrogas arc welding, it is possible to monitor a molten pool and a penetration state of a matrix. In the electrosag welding, a molten

pool and a molten portion of the matrix are covered with the molten slag, so that it is impossible to check a penetration state of the matrix. Unless bead is visually observed after the solidified slag covering the bead is broken by a hammer etc., it is impossible to check whether good penetration has been obtained or not.

[0005]

In addition, the good penetration is important not only in view of whether failure in penetration occurs or not but also in view of the fact that the mechanical properties of the weld metal depends on the degree of the penetration. That is, chemical components of the weld metal are determined by chemical components of the welding wire, chemical components of the matrix, and a penetration ratio. Since the chemical components of the welding wire are different from the chemical components of the matrix, the chemical components of the weld metal change when the penetration ratio changes. This affects the mechanical properties of the weld metal. Therefore, it is important to perform welding while making the penetration ratio as constant as possible.

As the factors which may affect the penetration, examples thereof include welding current, welding voltage, wire protrusive length, etc. In addition thereto, examples of the factors may include slag bath depth in the case of the electroslag welding. The welding current, the welding voltage, the wire protrusive length, etc. are parameters which can be managed easily. However, it is difficult to measure the slag bath depth, and thus, it is difficult to control the slag bath depth.

[0006]

Here, for example, a vertical electrogas welding apparatus is disclosed in Patent Document 1 as conventional electrogas arc welding. The vertical electrogas welding apparatus performs welding upwards while feeding a flux-containing wire to a groove extending in an up/down direction z of a steel plate which is erected substantially vertically. The vertical electrogas welding apparatus includes a carriage and a weaving means. The carriage includes a first electrode, a second electrode, and a travelling drive motor. The tip of the first electrode enters the groove. The second electrode enters the groove at a position closer to an opening side of the groove in a plate thickness direction x of the steel plate than the tip of the first electrode. The carriage can move up along the groove. The weaving means is supported on the

carriage. The weaving means drives the first and second electrodes to weave in the plate thickness direction x.

[0007]

In Patent Document 1, the following description is made. That is, molten metal is formed inside the groove with the advance of welding. Further, molten slag is accumulated on the molten metal. The surface of the molten slag rises to thereby reduce the protrusive length of the wire protruded from a welding torch. When a current value between a power supply circuit and the vertical plate increases to be higher than a predetermined value, a moving-up instruction is issued to the carriage. Further, a slidable copper backing plate covering the opening of the groove moves up with the advance of welding. In accordance with this, the molten slag on the molten pool successively flows between the slidable copper backing plate and weld bead so as to be solidified on the weld bead. In this manner, the molten slag is consumed.

[0008]

For example, a nonconsumable nozzle-type two-electrode electrosag welding method is disclosed in Patent Document 2 as conventional electrosag welding. In the nonconsumable nozzle-type two-electrode electrosag welding method, in a groove formed to be surrounded by backing plates and matrixes, welding is performed by two electrodes simultaneously. The nonconsumable nozzle-type two-electrode electrosag welding method includes the steps of: simultaneously weaving electric power feeding nozzles of the two electrodes in the same direction as an arrangement direction of the two electrodes, and suspending the electric power feeding nozzles in an end portion of the groove and in the vicinity of a central portion of the groove so that the relation $W_c < W_m < W_h$ can be established among current energy W_m during weaving the electric power feed nozzles, current energy W_h during suspension in the end portion of the groove, and current energy W_c during suspension in the vicinity of the central portion of the groove; and further driving the electric power feeding nozzles to rise so that the protrusive length of the welding wire can be kept long enough to set a welding current at a target current value.

[0009]

In addition, in Patent Document 2, the following description is made. That is, welding is performed in the groove surrounded by the backing plates and the

matrixes on all its four sides. Flux containing manganese dioxide is added at the start of the welding so that the depth of a slag bath during the welding can be 15 mm.

Citation List

Patent Documents

[0010]

[Patent Document 1] JP-A-H10-118771

[Patent Document 2] JP-A-H05-42377

Summary of Invention

Technical Problem

[0011]

In comparison with the electrogas arc welding, the electroslag welding has characteristics that arc radiant heat is not generated, generation of fumes or sputter is also reduced, etc. However, in the conventional electroslag welding, welding is performed with the electrodes hung down from above the groove surrounded by the steel plates on all its four sides. Therefore, slag is not consumed so that appropriate slag bath depth can be maintained. However, as the size of each of the matrixes increases, workability deteriorates and the size of the matrix which can be welded is limited depending on the size of each nozzle. Therefore, the electroslag welding is generally, for example, applied to welding of a construction steel material having a length of several meters. On the other hand, if a carriage is used to slide the backing plate as in the electrogas arc welding, welding can be performed on a larger matrix. In this case, welding is not performed in a groove surrounded by steel plates on all its four sides. Consequently, slag may flow between the slidable backing plate and weld bead, and may be consumed.

[0012]

Therefore, when the slidable backing plate is used for the electroslag welding, flux for compensating a consumed part of the slag has to be added from above to keep the slag bath depth as constant as possible, in order to secure good penetration. Basically, when flux corresponding to the consumed part is added, the slag bath depth can be kept constant. However, as the groove width increases, the bead width

increases to thereby lead to the increase in the consumption amount of the slag. In addition, when the flow of the slag changes due to the temperature of the backing plate, the consumption amount of the slag also changes. Further, when a gap between the backing plate and the matrix changes or welding speed changes, the consumption amount also changes.

[0013]

In this manner, in the electroslag welding using the slidable backing plate, the consumption amount of slag changes due to various factors, and thus, it is necessary to change the added amount of flux. However, it is difficult to measure the slag bath depth. Therefore, a welding operator has no choice but to change the added amount by his/her observation and estimation. Therefore, it depends on the welding operator's skill and insight, and thus, it is very difficult to keep the slag bath depth at a predetermined depth to thereby make penetration good. In addition, change of penetration may cause welding defects and also adversely affect mechanical properties of weld metal.

According to the aforementioned methods disclosed in Patent Documents 1 and 2, when the electroslag welding using a slidable backing plate is performed, the depth of a slag bath changes to thereby affect penetration or mechanical properties of weld metal. Accordingly, the electroslag welding is excellent in welding workability, but unfortunately it is not applicable to welding of a structure with a long welding line.

[0014]

An object of an aspect of the present invention is to perform welding while keeping the depth of a slag bath at a predetermined depth in electroslag welding using a slidable backing plate, so that it is possible to secure good penetration and prevent mechanical properties of weld metal from being degraded.

Technical Solution

[0015]

Under such a situation, an aspect of the present invention provides an electroslag welding method, including: feeding a flux to a slag bath in electroslag welding so that a length of a welding wire from a tip of a contact tip to the slag bath is equal to a predetermined length; adjusting a travelling speed of a travelling carriage

having a welding torch and a slidable backing plate so that a predetermined relation between a welding current and a reference current value is satisfied; and performing welding while keeping a depth of the slag bath at a predetermined depth.

[0016]

From the other point of view, an aspect of the present invention provides an electroslag welding apparatus, including: a welding torch having a contact tip that feeds electric power to a welding wire; a slidable backing plate; a travelling carriage having the welding torch and the slidable backing plate; a travelling carriage controlling device; a slag bath detector; a flux feeding device; and a flux feed controlling device;

wherein: the slag bath detector is configured to detect a slag bath when the slag bath rises to a position of a predetermined length from a tip of the contact tip; in order to make a length of the welding wire from the tip of the contact tip to the slag bath equal to the predetermined length, the flux feed controlling device is configured to control the flux feeding device so as to stop feeding a flux when the slag bath detector detects the slag bath, and so as to feed the flux when the slag bath detector does not detect the slag bath; the travelling carriage controlling device is configured to control a travelling speed of the travelling carriage so that a predetermined relation between a welding current and a reference current value determined in accordance with a wire feeding speed is satisfied; and the electroslag welding apparatus is capable of performing welding while keeping a depth of the slag bath at a predetermined depth.

In addition, the travelling carriage controlling device may be configured to control so as to increase the travelling speed of the travelling carriage when the welding current is larger than the reference current value as the predetermined relation and so as to decrease the travelling speed of the travelling carriage when the welding current is smaller than the reference current value as the predetermined relation.

In addition, the slag bath detector may be configured to detect a welding voltage when a detection terminal of the slag bath detector comes into contact with the slag bath, thereby detecting the slag bath.

In addition, the slag bath detector may be configured to process the detected welding voltage by a filter having a time constant half to twice a weaving period, thereby determining whether the slag bath has been detected or not.

In addition, the detection terminal may be connected to the welding torch.

In addition, the slag bath detector may be configured to apply a voltage to a detection terminal of the slag bath detector from a DC power supply through a resistor to detect the slag bath based on a fact that the voltage of the detection terminal drops down when the detection terminal comes into contact with the slag bath.

In addition, the slag bath detector may have a photosensor and may be configured to detect light from the slag bath to detect the slag bath.

In addition, the flux feeding device may be configured to feed a flux by a valve driven by a solenoid.

In addition, the flux feeding device may be configured to feed a flux by a screw driven by a motor.

In addition, when the wire feeding speed is changed, the reference current value may be automatically changed based on a predetermined function expressing a relation between the wire feeding speed and the reference current value.

In addition, the reference current value may be determined depending on a kind of the welding wire based on the function predetermined in accordance with the kind of the welding wire.

Advantageous Effects of Invention

[0017]

In an aspect of the present invention, it is possible to perform welding while keeping the depth of a slag bath at a predetermined depth in electrosag welding using a slidable backing plate, so that it is possible to secure sound penetration to thereby prevent mechanical properties of weld metal from being degraded.

Brief Description of Drawings

[0018]

FIG. 1 shows an example of the schematic configuration of an electrosag welding apparatus in an embodiment of the present invention.

FIG. 2 is a view of the electrosag welding apparatus shown in FIG. 1 as seen from a direction of an arrow T.

FIG. 3A shows correlation between the depth of a molten slag bath, the length of a welding wire, a welding current, and the width of penetration.

FIG. 3B shows correlation between the depth of a molten slag bath, the length of a welding wire, a welding current, and the width of penetration.

FIG. 3C shows correlation between the depth of a molten slag bath, the length of a welding wire, a welding current, and the width of penetration.

FIG. 4 shows a configuration example of a molten slag bath detector.

FIG. 5 shows an example of a welding voltage distribution on the surface of a molten slag bath.

FIG. 6A shows an example of a welding voltage distribution on the surface of the molten slag bath when a welding torch is weaved in a plate thickness direction.

FIG. 6B shows an example of a welding voltage distribution on the surface of the molten slag bath when the welding torch is weaved in the plate thickness direction.

FIG. 6C shows an example of a welding voltage distribution on the surface of the molten slag bath when the welding torch is weaved in the plate thickness direction.

FIG. 7 shows a configuration example in which a filter circuit is provided in the molten slag bath detector shown in FIG. 4.

FIG. 8 shows an example of a welding voltage waveform in the case of no filter circuit.

FIG. 9 shows an example of a welding voltage waveform in the case of using a filter circuit.

FIG. 10 is a view for explaining an example of a configuration in which a detection terminal is connected to a welding torch.

FIG. 11 shows another configuration example of the molten slag bath detector.

FIG. 12 shows another configuration example of the molten slag bath detector.

FIG. 13A shows a configuration example of a flux feeding device.

FIG. 13B shows the configuration example of the flux feeding device.

FIG. 14 shows another configuration example of the flux feeding device.

FIG. 15 shows comparison results between the case where the slag bath was not controlled and the case where the slag bath was controlled in the embodiment.

FIG. 16 is a table for explaining the influence of the depth of the slag bath on welding.

Description of Embodiment

[0019]

An embodiment of the present invention will be described below in detail with reference to the accompanying drawings.

<Configuration of Welding Apparatus>

First, an electrosag welding apparatus 100 in the embodiment will be described. FIG. 1 shows an example of the schematic configuration of the electrosag welding apparatus 100 in the embodiment. In FIG. 1, a direction designated by an arrow Z is referred to as upward in a vertical direction (up/down direction), a direction designated by an arrow X is referred to as rightward in a plate thickness direction (left/right direction), and a direction moving perpendicularly to the paper of the drawing from the back toward the front is referred to as frontward in a horizontally lateral direction Y. FIG. 2 is a view of the electrosag welding apparatus 100 shown in FIG. 1 as seen from a direction of an arrow T. That is, FIG. 2 is a view looking the electrosag welding apparatus 100 from above. However, a welding torch 4, a flux feeding device 14, a flux feed controlling device 15, a travelling carriage 16, a travelling carriage controlling device 17, etc. which will be described later are omitted in FIG. 2.

[0020]

As shown in FIG. 1, the electrosag welding apparatus 100 in the embodiment includes a stationary copper backing plate 1, a slidable copper backing plate 2, the welding torch 4, a molten slag bath detector 13, the flux feeding device 14, the flux feed controlling device 15, the travelling carriage 16, and the travelling carriage controlling device 17.

[0021]

In the electrosag welding apparatus 100, the stationary copper backing plate 1 is disposed on the back side of a groove and the slidable copper backing plate 2 is disposed on the front side of the groove. Here, a backing material made of heat-resistant ceramics may be used in place of the copper backing plate 1 on the back side.

In addition, the slidable copper backing plate 2 on the front side is a copper backing plate which slides in the up/down direction. The slidable copper backing plate 2 is water-cooled. Any substitute for copper may be used as the slidable copper backing plate 2.

[0022]

The welding torch 4 supplies a welding wire 6 with a welding current 8 fed from a welding power supply (not shown) to weld a welding matrix 3. In addition, the welding torch 4 has a contact tip 5. The contact tip 5 guides the welding wire 6 and feeds the welding current 8 to the welding wire 6.

[0023]

The molten slag bath detector 13 detects the position of a molten slag bath 7.

The flux feeding device 14 adds flux 12 to the molten slag bath 7. The flux 12 is melted to turn into molten slag. Therefore, when the flux 12 is added, the amount of the molten slag bath 7 increases.

The flux feed controlling device 15 controls operation of the flux feeding device 14 so as to adjust the amount of the flux 12 to be added to the molten slag bath 7.

[0024]

The travelling carriage 16 includes the slidable copper backing plate 2, the welding torch 4, the molten slag bath detector 13, the flux feeding device 14, the flux feed controlling device 15, and the travelling carriage controlling device 17 and moves upward (in the direction designated by the arrow Z). That is, the travelling carriage 16 moves integrally with the slidable copper backing plate 2, the welding torch 4, the molten slag bath detector 13, the flux feeding device 14, the flux feed controlling device 15, and the travelling carriage controlling device 17. Accordingly, relative positional relations between them are unchanged. Since the travelling carriage 16 can move up, welding can be performed in the upward direction.

The travelling carriage controlling device 17 increases or decreases travelling speed of the travelling carriage 16 to thereby control operation of the travelling carriage 16.

[0025]

The welding wire 6 is fed from the contact tip 5 of the welding torch 4 into the groove surrounded by the welding matrix 3, the copper backing plate 1 and the slidable copper backing plate 2, and then delivered into the molten slag bath 7 formed inside the groove. The welding current 8 flows from the welding wire 6 into a molten metal 9 through the molten slag bath 7. On this occasion, Joule heat is generated due to the welding current 8 flowing into the molten slag bath 7 and resistance of the molten slag bath 7, and welding can advance while the welding wire 6 and the welding matrix 3 are melted.

[0026]

As the welding advances, the molten metal 9 is cooled to turn into a weld metal 10. A part of the molten slag bath 7 becomes a molten slag layer formed between the copper backing plate 1 and the weld metal 10 and a molten slag layer formed between the slidable copper backing plate 2 and the weld metal 10. The molten slag layers are cooled to turn into solidified slag 11. In this manner, a part of the molten slag bath 7 turns into the solidified slag 11 covering surfaces of bead. Accordingly, the molten slag bath 7 is consumed as the welding advances. Therefore, depth L_s of the molten slag bath 7 decreases. In order to compensate the decreased part of the molten slag bath 7, the flux 12 to be melted to turn into the molten slag bath 7 has to be added additionally.

[0027]

The amount of the solidified slag 11 covering the surfaces of the bead varies depending on the width of each bead or the width of the welding groove. In addition, the amount of the solidified slag 11 also varies depending on the close contact degrees or the cooling states of the copper backing plate 1 and the slidable copper backing plate 2. Therefore, the amount of the solidified slag 11 is not constant. The amount of the flux 12 to be added in order to keep the depth L_s of the molten slag bath 7 constant also has to be changed. However, since the depth L_s of the molten slag bath 7 is unknown, the depth L_s of the molten slag bath 7 varies when the added amount of the flux 12 is not appropriate.

[0028]

Therefore, in the embodiment, control for making the depth L_s of the molten slag bath 7 constant is performed. Here, the term “constant” is not limited to the case

where the depth Ls of the molten slag bath 7 is always one value but may also include the case where the depth Ls of the molten slag bath 7 indicates a value within a fixed range in consideration of an error. That is, the depth Ls of the molten slag bath 7 is controlled to be kept at a predetermined depth.

[0029]

A first requirement for making the depth Ls of the molten slag bath 7 constant is as follows. That is, control is made so that a welding wire length Ld (hereinafter referred to as dry extension Ld) between the tip of the contact tip 5 and an upper surface of the molten slag bath 7 can be equal to a predetermined length. In addition, a second requirement for making the depth Ls of the molten slag bath 7 constant is as follows. That is, the travelling carriage controlling device 17 controls the travelling speed of the travelling carriage 16 so that a predetermined relation between the welding current 8 and a reference current value which is predetermined in accordance with wire feeding speed is satisfied, that is, the reference current value and the welding current 8 can be equal to each other.

[0030]

<Requirements for Making Depth of Molten Slag Bath Constant>

First, the first requirement for making the depth Ls of the molten slag bath 7 constant will be described.

When the molten slag bath detector 13 does not detect the molten slag bath 7, that is, when the molten slag bath detector 13 which is disposed on/above an upper portion of the slidable copper backing plate 2 is not in contact with the upper surface of the molten slag bath 7, the flux feed controlling device 15 controls the flux feeding device 14 so as to add the flux 12. On the other hand, when the molten slag bath detector 13 detects the molten slag bath 7, that is, when the molten slag bath detector 13 which is disposed on/above the upper portion of the slidable copper backing plate 2 comes into contact with the upper surface of the molten slag bath 7, the flux feed controlling device 15 controls the flux feeding device 14 so as to stop adding the flux 12. In this manner, the flux feeding device 14 adds the flux 12 to adjust the depth Ls of the molten slag bath 7 so that the molten slag bath detector 13 detects the molten slag bath 7.

[0031]

Here, the welding torch 4, the slidable copper backing plate 2, and the molten slag bath detector 13 are all mounted on the travelling carriage 16. Even when the travelling carriage 16 moves, the relative positional relations between them are unchanged. Therefore, the distance between the tip of the contact tip 5 and the molten slag bath detector 13 is also unchanged. When the molten slag bath 7 rises to the position of the predetermined length (that is, the position of the molten slag bath detector 13) from the tip of the contact tip 5, the molten slag bath detector 13 detects the molten slag bath 7. The flux feed controlling device 15 controls the added amount of the flux 12 so that the molten slag bath 7 is detected by the molten slag bath detector 13. Accordingly, the distance between the tip of the contact tip 5 and the upper surface of the molten slag bath 7, that is, the dry extension L_d , can be controlled to be equal to the predetermined length.

[0032]

Next, the second requirement for making the depth L_s of the molten slag bath 7 constant will be described.

FIGs. 3A to 3C each shows correlation between the depth of the molten slag bath 7, the length of the welding wire 6, the welding current 8, and the width of penetration. Here, assuming that the depth L_s of the molten slag bath 7 changes to hold the relation $L_{s1} > L_{s2} > L_{s3}$, as shown in FIGs. 3A to 3C, in the state in which the dry extension L_d has been controlled to be equal to the predetermined length, the length of the welding wire 6 soaked in the molten slag bath 7 (hereinafter referred to as wet extension L_w) changes substantially proportionally to hold the relation $L_{w1} > L_{w2} > L_{w3}$, and the penetration width L_m changes to hold the relation $L_{m1} < L_{m2} < L_{m3}$. On the other hand, when the value of the welding current 8 is indicated as I_w , the relation between the welding current I_w and the wire feeding speed V_w is expressed as the following mathematical formula (1).

[0033]

[Mathematical Formula 1]

$$I_w = \left(\frac{K1 \times V_w}{K2 + K3 \times L_d + K4 \times L_w} \right)^{1/2} \quad (1)$$

[0034]

In the mathematical formula (1), $K1$ to $K4$ are constants determined based on the diameter, structure and material of the welding wire 6.

[0035]

Further, under the condition that the dry extension L_d is controlled to be equal to the predetermined length by the flux feed controlling device 15, as shown in the aforementioned first requirement, in the state in which welding is being performed with the wire feeding speed V_w set constant, the mathematical formula (1) is expressed as the following mathematical formula (2).

[0036]

[Mathematical Formula 2]

$$I_w = \left(\frac{K5}{K6 + K4 \times L_w} \right)^{1/2} \quad (2)$$

[0037]

That is, based on the mathematical formula (2), the welding current I_w changes in inverse proportion to the wet extension L_w . When the wet extension L_w increases, the welding current I_w decreases. Since the depth L_s of the molten slag bath 7 is proportional to the wet extension L_w as described above, the welding current I_w when the molten slag bath 7 has appropriate depth L_{s2} is set as a reference current value I_{w2} in advance. When the welding current I_w becomes larger than the reference current value I_{w2} in accordance with the advance of the welding, determination is made as follows: the depth L_s of the molten slag bath 7 becomes smaller than L_{s2} and the penetration width L_m becomes larger than L_{m2} . Therefore, the travelling carriage controlling device 17 increases the travelling speed of the travelling carriage 16. When the travelling speed of the travelling carriage 16 increases, control is made so as to increase a wire protrusive length ($L_d + L_w$) so that the welding current I_w can be decreased to be equal to the reference current value I_{w2} . On the other hand, when the welding current I_w becomes smaller than the reference current value I_{w2} , determination is made as follows: the depth L_s of the molten slag bath 7 becomes larger than L_{s2} and the penetration width L_m becomes smaller than L_{m2} . Therefore, the travelling carriage controlling device 17 decreases the travelling speed of the travelling carriage 16.

[0038]

To describe additionally, the depth L_s of the molten slag bath 7 is first adjusted to be L_{s2} as the predetermined depth, and welding is then started. Moreover, the travelling speed of the travelling carriage 16 is determined in

accordance with the value of the welding current I_w . In accordance with the advance of the welding, a part of the molten slag bath 7 turns into the solidified slag 11 and is consumed. Therefore, the depth L_s of the molten slag bath 7 decreases. When the molten slag bath detector 13 disposed on/above the upper portion of the slidable copper backing plate 2 decreases to a level not in contact with the upper surface of the molten slag bath 7, the flux feed controlling device 15 controls the flux feeding device 14 so as to add the flux 12. The flux 12 is added for a while. Then, the flux feed controlling device 15 controls the flux feeding device 14 to stop adding the flux 12 when the molten slag bath detector 13 detects the molten slag bath 7, that is, when the molten slag bath detector 13 disposed on/above the upper portion of the slidable copper backing plate 2 comes into contact with the upper surface of the molten slag bath 7. Control is made thus so that the distance between the tip of the contact tip 5 and the upper surface of the molten slag bath 7, that is, the dry extension L_d can be equal to the predetermined length. On the other hand, the welding current I_w when the molten slag bath depth is appropriate is set as the reference current value I_{w2} . Therefore, as long as the dry extension L_d is constant by the aforementioned control, the wet extension L_w can be also constant and the depth of the slag bath can be also constant.

[0039]

In this manner, the travelling carriage controlling device 17 controls the travelling speed of the travelling carriage 16 so that the welding current I_w can be equal to the reference current value I_{w2} . Thus, control is made so that the depth L_s of the molten slag bath 7 can be constant to be equal to the appropriate depth L_{s2} . Accordingly, the appropriate penetration width L_{m2} can be obtained. In addition, weld metal having stable mechanical properties can be obtained.

[0040]

In addition, the reference current value I_{w2} is determined as follows. In the electrosag welding apparatus 100, when welding using a certain welding wire 6 is first performed with the wire feeding speed V_w set constant, the dry extension L_d is controlled to be equal to the predetermined length. When welding is performed using some kinds of welding currents I_w , the welding is performed with different wet extensions L_w and different penetration widths L_m . A welding current I_w with

which an optimal penetration width L_{m2} is obtained on this occasion is determined as the reference current value I_{w2} for the wire feeding speed V_w .

[0041]

Next, the wire feeding speed V_w is changed, and an optimal reference current value I_{w2} is obtained similarly. When this is repeated, the reference current value I_{w2} can be obtained as a function of the wire feeding speed V_w . This function (function expressing the relation between the reference current value I_{w2} and the wire feeding speed V_w) is stored in advance in the travelling carriage controlling device 17. When control is made to use an output of a wire feeding speed setter or a detected value of the wire feeding speed to set the reference current value I_{w2} , the reference current value I_{w2} can be set correspondingly to the wire feeding speed V_w . When the wire feeding speed V_w is changed, the reference current value I_{w2} is also changed automatically in accordance with the changed wire feeding speed V_w . Welding can be performed with a wet extension L_w (or the depth L_s of the molten slag bath 7) in which optimal penetration can be obtained automatically.

[0042]

In addition, the welding wire 6 is changed and the aforementioned procedure is performed. In this manner, the reference current value I_{w2} corresponding to the wire feeding speed V_w can be obtained also for each kind of welding wire 6. Here, the reference current value I_{w2} can be obtained based on the function of the wire feeding speed V_w in accordance with each kind of welding wire 6 such as the diameter, structure and material of the welding wire 6, etc. To describe additionally, the function of the wire feeding speed V_w can be determined in accordance with each kind of welding wire 6 and the reference current value I_{w2} can be obtained based on the function for the kind of welding wire 6.

[0043]

<Configuration of Molten Slag Bath Detector>

Next, the configuration of the molten slag bath detector 13 will be described in detail. FIG. 4 shows a configuration example of the molten slag bath detector 13.

As shown in FIG. 4, the molten slag bath detector 13 in the embodiment includes a detection terminal 18, a differential amplifier 19, a contact determination reference signal setter 20, and a comparator 21. The detection terminal 18 is made of

copper which is conductive metal. The detection terminal 18 is generally water-cooled. The detection terminal 18 detects partial voltage of welding voltage when the detection terminal 18 comes into contact with the molten slag bath 7.

[0044]

Upon reception of the voltage of the detection terminal 18 and the voltage of the slidable copper backing plate 2 as inputs, the differential amplifier 19 outputs a difference between the two voltages. Since the slidable copper backing plate 2 is in contact with the welding matrix 3, the voltage of the slidable copper backing plate 2 is equal to the voltage of the matrix 3.

The contact determination reference signal setter 20 outputs a voltage as a reference signal. The voltage is substantially half the voltage which is detected when the detection terminal 18 comes into contact with the molten slag bath 7. For example, an example of a welding voltage distribution on the surface of the molten slag bath 7 is shown in FIG. 5. The detection terminal 18 normally detects a welding voltage of about 6 volts (voltage unit: V). Accordingly, the voltage outputted as a reference signal is set as about 3V which is half the detected welding voltage. When the detection terminal 18 is not in contact with the molten slag bath 7, the welding voltage is not applied to the detection terminal 18. Accordingly, the voltage of the detection terminal 18 is 0 V.

[0045]

The comparator 21 receives an output signal of the differential amplifier 19 and the reference signal of the contact determination reference signal setter 20 as inputs. When the output signal of the differential amplifier 19 is larger than the reference signal of the contact determination reference signal setter 20, the comparator 21 generates a signal of determination that the detection terminal 18 and the molten slag bath 7 come into contact with each other. The generated signal is sent to the flux feed controlling device 15, and the flux 12 is fed and stopped by the flux feeding device 14 and control is made so as to locate the upper surface of the molten slag bath 7 at the predetermined length from the tip of the contact tip 5. Thus, the dry extension L_d is kept at the predetermined length.

[0046]

FIGs. 6A to 6C each shows an example of a welding voltage distribution on the surface of the molten slag bath 7 when the welding torch 4 is weaved in the plate thickness direction. First, the welding voltage distribution shown in FIG. 6B is provided when the welding wire 6 is in the center of the plate thickness. The welding voltage detected by the detection terminal 18 is about 6 V. On this occasion, the welding torch 4 is weaved in order to make penetration in the plate thickness direction uniform. When the welding torch 4 is in the vicinity of the copper backing plate 1, the voltage detected by the detection terminal 18 disposed in the vicinity of the slidable copper backing plate 2 is reduced to about 3 V which is half of 6 V, as shown in FIG. 6A. Conversely, when the welding torch 4 comes to the vicinity of the slidable copper backing plate 2 as shown in FIG. 6C, the welding voltage detected by the detection terminal 18 is higher to be about 12 V.

[0047]

Here, the voltage of the reference signal of the contact determination reference signal setter 20 is set at about 1.5 V, the comparator 21 can properly determine that the molten slag bath 7 and the detection terminal 18 are in contact with each other. Since the value of the reference signal is small, there is also however a possibility that proper determination may be blocked due to the welding state or external noise etc.

In order to prevent the misdetection, the molten slag bath detector 13 may include a filter circuit 22 which is disposed at the rear of the differential amplifier 19 so that the molten slag bath detector 13 can determine whether the molten slag bath 7 is detected or not, based on the welding voltage processed by the filter circuit 22. FIG. 7 shows a configuration example in which the filter circuit 22 is provided in the molten slag bath detector 13 shown in FIG. 4. It is desirable that the filter circuit 22 is set as a filter circuit 22 having a time constant substantially as long as the weaving period of the welding torch 4, that is, about half to twice the period.

[0048]

FIG. 8 shows an example of a welding voltage waveform which is obtained in the case of no filter circuit 22. FIG. 9 shows an example of a welding voltage waveform which is obtained in the case of using the filter circuit 22. Specifically, the waveform shown in FIG. 8 is a welding voltage waveform detected when a filter

having a sampling period of 250 ms is absent. In addition, the waveform shown in FIG. 9 is a welding voltage waveform for a moving average of 27 pieces of data, that is, for a moving average of an interval of 6.75 sec (6750 ms). Here, one scale on the ordinate indicates 3.000 V, and one scale on the abscissa indicates one second (sec). In addition, in the examples shown in FIGs. 8 and 9, the weaving period of the welding torch 4 is 8 seconds. Accordingly, the welding voltage waveform is equivalent to the weaving period of the welding torch 4.

[0049]

As obvious from these welding voltage waveforms, in the case of no filter, the voltage detected by the detection terminal 18 is reduced to about 3 V when the welding torch 4 is in the vicinity of the copper backing plate 1, but the detected voltage reaches about 12 V when the welding torch 4 is in the vicinity of the slidable copper backing plate 2. In addition, the detected welding voltage has a large variation. On the other hand, the welding voltage waveform obtained through the filter is averaged in the range of from 9 V to 12 V. Therefore, when the filter circuit 22 is used, the reference signal for contact determination can be set at 3 V to 6 V, and thus, the risk of misdetection can be reduced largely. Although the example in which a time constant substantially equal to the weaving period is used has been shown here, an effect has been confirmed even with a filter having a time constant which is about half to twice the weaving period.

[0050]

In addition, the detection terminal 18 may be connected to the welding torch 4. FIG. 10 is a view for explaining an example of a configuration in which the detection terminal 18 is connected to the welding torch 4. In the example shown in FIG. 10, the configurations of the differential amplifier 19, the contact determination reference signal setter 20, the comparator 21 and the filter circuit 22 are the same as the configurations shown in FIG. 7, but the detection terminal 18 is connected to the welding torch 4. When the welding torch 4 weaves, the detection terminal 18 also weaves together with the welding torch 4. Accordingly, the detection terminal 18 is always located in the vicinity of the welding wire 6. Therefore, with reference to the welding voltage distributions shown in FIGs. 6A to 6C, a welding voltage of about 24 V can be detected when the detection terminal 18 comes into contact with the molten

slag bath 7. In addition, substantially constant voltage can be detected regardless of the weaving of the welding torch 4. Accordingly, the risk affected by noise etc. is decreased.

[0051]

<Another Configuration Example of Molten Slag Bath Detector>

Next, another configuration example of the molten slag bath detector 13 will be described. FIGs. 11 and 12 each shows another configuration example of the molten slag bath detector 13.

In the example shown in FIG. 11, the molten slag bath detector 13 includes a detection terminal 18, a DC power supply 23, a resistor 24, a differential amplifier 19, a filter circuit 22, a contact determination reference signal setter 20, and a comparator 21. For example, the DC power supply 23 is a power supply of about 100 V to 200 V. An output of the DC power supply 23 is connected to the detection terminal 18 through the resistor 24. Here, for example, the value of the resistor 24 is 20 k Ω to 500 k Ω .

[0052]

When the detection terminal 18 is not in contact with the molten slag bath 7, no current flows. Accordingly, the voltage of the DC power supply 23 is substantially applied to the detection terminal 18. On the other hand, when the detection terminal 18 comes into contact with the molten slag bath 7, the current flows into the slidable copper backing plate 2 from the detection terminal 18 through the molten slag bath 7. Accordingly, the voltage of the DC power supply 23 drops due to the resistor 24. The voltage of the detection terminal 18 decreases to a part of the welding voltage, that is, to about 3 V to 12 V. The change is determined by the differential amplifier 19, the filter circuit 22, the contact determination reference signal setter 20, and the comparator 21, and then, the molten slag bath 7 is detected. Operations of them are the same as those in the aforementioned method, so that description thereof will be omitted.

According to the method, the voltage of the detection terminal 18 is 100 V to 200 V when the detection terminal 18 and the molten slag bath 7 are not in contact with each other. On the other hand, the voltage of the detection terminal 18 is 3 V to 12 V when the detection terminal 18 and the molten slag bath 7 are in contact with

each other. Since a difference between the two voltages is large, reliable operation can be expected.

[0053]

In the example shown in FIG. 12, the molten slag bath detector 13 includes a photoreceiver 25 and a photoreception determination device 26 as photosensors. The photoreceiver 25 receives light emitted from the surface of the molten slag bath 7. The photoreception determination device 26 determines the time when the light quantity of the photoreceiver 25 reaches a certain level. On the assumption that the determination level of the light quantity has been determined in advance, the angle of the photoreceiver 25 etc. is adjusted, so that adjustment can be made to make the dry extension Ld equal to a target predetermined length. In addition, the determination result is sent to the flux feed controlling device 15, and the flux 12 is fed so as to keep the dry extension Ld constant.

[0054]

To describe additionally, when the photoreception determination device 26 determines that the light quantity of the photoreceiver 25 reaches the certain level, the molten slag bath 7 rises up to the position of the predetermined length from the tip of the contact tip 5. In this case, the dry extension Ld is not larger than the predetermined length. Accordingly, the flux feed controlling device 15 makes control to stop adding the flux 12. On the other hand, when the photoreception determination device 26 determines that the light quantity of the photoreceiver 25 does not reach the certain level, the molten slag bath 7 does not rise up to the position of the predetermined length from the tip of the contact tip 5. In this case, the dry extension Ld is larger than the predetermined length. Accordingly, the flux feed controlling device 15 makes control to add the flux 12.

[0055]

<Configuration of Flux Feeding Device>

Next, the configuration of the flux feeding device 14 will be described in detail. FIGs. 13A and 13B each shows a configuration example of the flux feeding device 14.

As shown in FIG. 13A, when a solenoid 27 in the flux feeding device 14 in the embodiment moves back and forth as designated by an arrow 28, a valve 30 rotates

around a rotary shaft 29, as designated by an arrow 31. Accordingly, a flux feeding nozzle 32 is opened/closed. By the operation, the flux 12 in a flux hopper 33 is fed to the molten slag bath 7.

[0056]

Here, FIG. 13A shows a state in which the flux feeding nozzle 32 is closed. On the other hand, FIG. 13B shows a state in which the flux feeding nozzle 32 is opened. When the flux feeding nozzle 32 is opened, the flux 12 in the flux hopper 33 is fed to the molten slag bath 7 through the flux feeding nozzle 32.

[0057]

<Another Configuration Example of Flux Feeding Device>

Next, another configuration example of the flux feeding device 14 will be described. FIG. 14 shows another configuration example of the flux feeding device 14.

In the flux feeding device 14 in the example shown in FIG. 14, flux 12 is extruded from a flux hopper 33 due to rotation of a screw 35 driven by a motor 34, and fed to a molten slag bath 7 via a not-shown passage.

[0058]

<Examples>

Next, experimental results will be shown and Examples in the embodiment will be described. The embodiment is not limited to the Examples.

In the electroslag welding apparatus 100 shown in FIG. 1, welding using a welding wire 6 having a diameter of 1.6 mm was performed in a 20° V-groove with a plate thickness of 60 mm under the conditions that the wire feeding speed was 15.4 m/min, the welding voltage was 42 V and the reference current value was 380 A. The distance between the tip and the matrix was set at 45 mm. In addition, welding was started at a slag bath depth of 25 mm. Comparison results between the case where the slag bath was not controlled (the conventional method) and the case where the slag bath was controlled in the embodiment after electroslag welding was stable will be shown in FIG. 15. Here, the result in the embodiment will be shown as an Example and the result in the conventional method will be shown as a comparative example.

[0059]

Distances by which the travelling carriage 16 moved up are shown as distances after electrosag welding was stable and evaluation results of “arc occurrence”, “surface bead width” and “penetration” in the respective distances are shown in FIG. 15. As to “arc occurrence”, “B” is indicated for the case where an arc occurred and “A” is indicated for the case where no arc occurred. As to “penetration”, “B” is indicated for the case where there was penetration failure and “A” is indicated for the case where there was no penetration failure. From the results shown in FIG. 15, it is found that when the molten slag bath 7 is controlled, penetration depth is substantially constant and surface bead width does not change largely.

[0060]

Welding results in the case where the electrosag welding apparatus 100 in the embodiment was used to perform welding with the aforementioned wire feeding speed and the slag bath depth was changed will be described. FIG. 16 is a table for explaining the influence the slag bath depth on welding. Evaluation results of “arc occurrence”, “surface bead width”, “penetration” and “toughness” in respective slag bath depths are shown in FIG. 16. As to “toughness”, “A” is indicated for the case where the “toughness” was not smaller than 39 J (Joule) and “B” is indicated for the case where “toughness” was smaller than 39 J under the condition that the temperature was -20°. From the results shown in FIG. 16, it is found that an appropriate slag bath depth in this case is 20 mm to 60 mm. Only one example has been shown here. However, workability changes depending on the flux kind, the wire kind and the welding voltage actually used in welding, and the appropriate slag bath depth also changes.

[0061]

Although the electrosag welding apparatus 100 uses one electrode to perform welding in the embodiment, the electrosag welding apparatus 100 is not limited to such a configuration but may use multiple electrodes to perform welding.

[0062]

Although an aspect of the present invention has been described above using the embodiment, the technical scope of the present invention is not limited to the aforementioned embodiment. It is obvious to those skilled in the art that the present

invention may be changed variously or replaced by any other mode without departing from the spirit and scope of the present invention.

Reference Signs List

[0063]

1: copper backing plate, 2: slidable copper backing plate, 3: welding matrix, 4: welding torch, 5: contact tip, 6: welding wire, 7: molten slag bath, 8: welding current, 9: molten metal, 10: weld metal, 11: solidified slag, 12: flux, 13: molten slag bath detector, 14: flux feeding device, 15: flux feed controlling device, 16: travelling carriage, 17: travelling carriage controlling device, 18: detection terminal, 19: differential amplifier, 20: contact determination reference signal setter, 21: comparator, 22: filter circuit, 23: DC power supply, 24: resistor, 25: photoreceiver, 26: photoreception determination device, 27: solenoid, 28: arrow, 29: rotary shaft, 30: valve, 31: arrow, 32: flux feeding nozzle, 33: flux hopper, 34: motor, 35: screw, 100: electrosag welding apparatus

CLAIMS

1. An electroslog welding method, comprising:
 - feeding a flux to a slag bath in electroslog welding so that a length of a welding wire from a tip of a contact tip to the slag bath is equal to a predetermined length;
 - adjusting a travelling speed of a travelling carriage having a welding torch and a slidable backing plate under a welding condition of a constant wire feeding speed during the welding so that a predetermined relation between a welding current and a reference current value is satisfied; and
 - performing welding while keeping a depth of the slag bath at a predetermined depth.
2. An electroslog welding apparatus, comprising:
 - a welding torch having a contact tip that feeds electric power to a welding wire;
 - a slidable backing plate;
 - a travelling carriage having the welding torch and the slidable backing plate;
 - a travelling carriage controlling device;
 - a slag bath detector;
 - a flux feeding device; and
 - a flux feed controlling device; wherein:
 - the slag bath detector is configured to detect a slag bath when the slag bath rises to a position of a predetermined length from a tip of the contact tip;
 - in order to make a length of the welding wire from the tip of the contact tip to the slag bath equal to the predetermined length, the flux feed controlling device is configured to control the flux feeding device so as to stop feeding a flux when the slag bath detector detects the slag bath, and so as to feed the flux when the slag bath detector does not detect the slag bath;
 - the travelling carriage controlling device is configured to control a travelling speed of the travelling carriage under a welding condition of a constant wire feeding speed during the welding so that a predetermined relation between a welding current

and a reference current value determined in accordance with a wire feeding speed is satisfied; and

the electroslag welding apparatus is capable of performing welding while keeping a depth of the slag bath at a predetermined depth.

3. The electroslag welding apparatus according to claim 2, wherein:
the travelling carriage controlling device is configured to control so as to increase the travelling speed of the travelling carriage when the welding current is larger than the reference current value as the predetermined relation and so as to decrease the travelling speed of the travelling carriage when the welding current is smaller than the reference current value as the predetermined relation.

4. The electroslag welding apparatus according to claim 2, wherein:
the slag bath detector is configured to detect a welding voltage when a detection terminal of the slag bath detector comes into contact with the slag bath, thereby detecting the slag bath.

5. The electroslag welding apparatus according to claim 4, wherein:
the slag bath detector is configured to process the detected welding voltage by a filter having a time constant half to twice a weaving period, thereby determining whether the slag bath has been detected or not.

6. The electroslag welding apparatus according to claim 4, wherein:
the detection terminal is connected to the welding torch.

7. The electroslag welding apparatus according to claim 2, wherein:
the slag bath detector is configured to apply a voltage to a detection terminal of the slag bath detector from a DC power supply through a resistor to detect the slag bath based on a fact that the voltage of the detection terminal drops down when the detection terminal comes into contact with the slag bath.

8. The electroslag welding apparatus according to claim 2, wherein:

the slag bath detector has a photosensor and is configured to detect light from the slag bath to detect the slag bath.

9. The electroslog welding apparatus according to claim 2, wherein: the flux feeding device is configured to feed a flux by a valve driven by a solenoid.

10. The electroslog welding apparatus according to claim 2, wherein: the flux feeding device is configured to feed a flux by a screw driven by a motor.

11. The electroslog welding apparatus according to claim 2, wherein: when the wire feeding speed is changed, the reference current value is automatically changed based on a predetermined function expressing a relation between the wire feeding speed and the reference current value.

12. The electroslog welding apparatus according to claim 11, wherein: the reference current value is determined depending on a kind of the welding wire based on the function predetermined in accordance with the kind of the welding wire.