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Automatic Control of Horizontal Narrow Gap Welding (Report I)†
– Algolithm for Automatic Selection of Optimum Welding Condition –

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Abstract

The investigation and the trial manufacture on the automatic control system were made automatically to set up the optimum welding conditions corresponding to the change in the groove width of the joint, for the purpose of the automatic control of the horizontal narrow gap welding by the high-peak pulsed MIG welding method.

Especially, even in case of the change in the groove width of the joint, the consideration is given to set up the optimum welding conditions to have satisfactory bead configuration and constant bead height, and the algorithm for these control was established. Moreover, an automatic control device making use of micro-computer was manufactured as experiment, and the effectiveness of this control method was demonstrated by the experiment with the device.

KEY WORDS: (Automatic Control) (Computation) (Process Parameter) (MIG Welding) (Narrow Gap Welding)

1. Introduction:

The narrow gap welding has recently attracted attention in heavy section steel plates with such merits that a joint can be welded as it is gas-cut requiring no edge preparation and that a square groove requires smaller amount of deposit metal than a single bevel groove, single-V groove, etc. resulting in less consumpting of filler wire. Especially, the horizontal narrow gap welding is useful when structures are under field-assembly, and one or two studies have been made concerning it.[1] In the horizontal welding, the pulsed MIG welding (high-peak pulsed MIG welding) having high peak can be thought advantageous for the horizontal narrow gap welding in its arc concentration, penetration into side walls.[2),3)] However, only a few of the high-peak pulsed MIG welding have been put to practical use, and no appropriate welding conditions have been clarified yet.

Furthermore, in arc welding, the accuracy of the joint preparation is not generally been guaranteed because of size errors in gas-cutting and assembling. Especially in the square narrow gap welding, inaccuracy in the groove width will have influence much upon the welding result.

From such points of view, the authors tried not only to clarify appropriate welding conditions of the horizontal narrow gap welding by the high-peak pulsed MIG welding, but also to automatically detect change in the groove width, to automatically set up the welding conditions matching with its groove width, and to develop an automatic controlled welder with which satisfactory results are obtained. In the present paper, consideration of necessary input data on automatic setting up the welding conditions is made as a result of the various welding experiment, predicting on a computer control. In addition, it was described that the features of an algorithm and a device which manufactured by way of trial, for the automatic control.

2. Procedures of Welding Experiment:

The welding experiment was carried out under the following conditions to acquire the causal relation between welding conditions and welding results in the high-peak pulsed MIG welding.

Multi-layer welding of two passes in one layer was applied to mild steel (SS41) of 16 (mm) in its thickness with solid wire of 1.2 (mm) in its diameter, taking the mixed gas of 25 (l/min) (CO_2 20 (%), Ar 80 (%)) as a shielding gas. The torch vertical angle is –5(°) in the lower weld and +5 (°) in the upper weld, and welding was carried out in the order of lower and upper.

As the supply source, a high-peak pulsed MIG welder (AIRCOMATIC Pulsed-Arc Power Source, AIRCO

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Company, average output current, 300 (A), peak voltage of 72 (v) when no loading, and 45 (v) of base voltage) were applied in the reversed polarity. In the experiment, for the purpose of reducing the controlled variable, the welding voltage is fixed to 70 (v) at peak and 28 (v) at base with the welding current and the welding speed changed in the range of 180 to 280 (A) and 10 to 85 (cm/min) respectively. An example of welding current and voltage oscillogram during welding is shown in **Photo. 1**. As is seen in this oscillogram of welding current, the

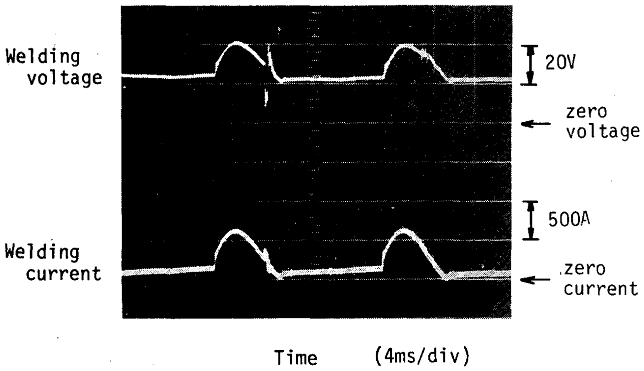

Photo. 1 Oscillogram of welding current and voltage in high-peak pulsed welding.

peak current reached more than five times the base current, being said of a high-peak pulse. In the following experiment, the average current was changed with the ratio of the peak and the base current kept constant.

With the groove width standardized at 12 (mm), and taking account of a change of ± 3 (mm), a weld bead configuration was obtained under various welding conditions at 9, 12, and 15 (mm).

3. Welding Result and Quantitative Fixation of Each Parameter:

When the groove width changes, the bead height will naturally change if welding takes place without changing the conditions. If the welding conditions are changed to adjust the bead height, the bead configuration will sometimes change, being not appropriate to the multi-layer welding. This tendency is remarkable for the welding of two passes in one layer. Then, it was carried out on the basis of the experimental data to quantitatively fix the welding conditions of keeping the constant bead height and of assuring the satisfactory bead configuration.

3.1 Quantitative Fixation of Bead Height:

As shown in the sample sketch of **Fig. 3**, the height obtained by uniformalizing the bead surface at the stage where welding of two passes in one layer is finished is defined as the amount of actual measurement h_{av} of the bead height. An equation this bead height (the calculation amount is defined as h.) is given is derived as follows:

Assuming the value of deposit metal per unit hour of two passes in one layer to be V (mm^3/min) and the welding speed to be v (mm/min) respectively, the bead sectional area S (mm^2) is given in Equation (1).

$$S = V/v \qquad \cdots\cdots \quad (1)$$

Assuming deforming amount of base metal in the groove width which will generate during welding to be ε (mm), S is given as Equation (2). (See **Fig. 1**)

$$\begin{aligned} S &= (W + W')\,h/2 \\ &= Wh - \varepsilon h^2/2d \end{aligned} \qquad \cdots\cdots \quad (2)$$

where

W: Initial groove width
h: Bead height
W': Groove width after deformation
d: Plate thickness

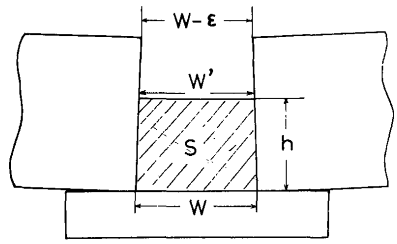

Fig. 1 Scheme to define bead height (h) when base metal is deformed.

Eliminating S from Equations (1) and (2), Equation (3) is given.

$$\varepsilon h^2/2d - Wh + V/v = 0 \qquad \cdots\cdots \quad (3)$$

By using Eq. (3) the bead height h will come to be controlled with ε , v and V taken as parameters if the information on the groove width W is obtained. In this connection, since deforming amount ε and the value of deposit metal V are subject to change depending upon the restraint condition of the base metal and the welding conditions, it is necessary to take measurement of them within the working welding conditions.

As a result of the experiment, it is found about ε = 1 (mm) against each conditions, thus ε is fixed in 1 (mm). V will be fixed with the welding current as shown in **Fig. 2**.

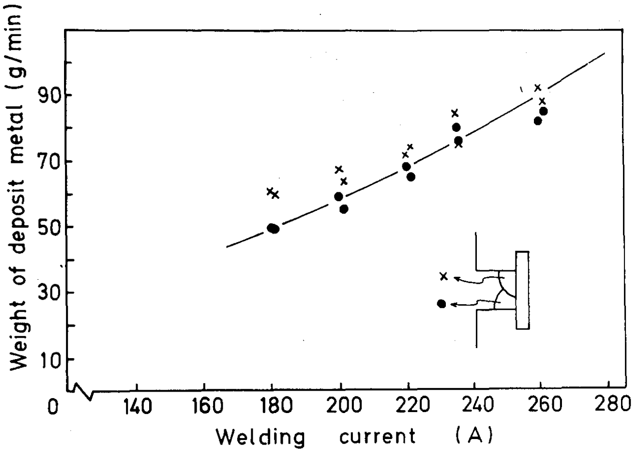

Fig. 2 Relation between welding current and weight of deposit metal.

Shown in solid lines in Fig. 3 is an example of the calculated results of each h, for various welding current, against W = 9, 12 and 15 (mm) from Eq. (3) with the plate thickness d = 16 (mm). The actually amount h_{av} corresponding to the calculated amount is shown in plot in **Fig. 3**. The calculated amount and the actual measured amount are in satisfactory agreement as such.

Therefore, a groove width information is once obtained, it becomes possible to have the accurate estimation of the bead height against the given welding current, welding speed, and plate thickness by using Eq. (3).

The method of the automatic measurement of the groove width will be described in the next paper.

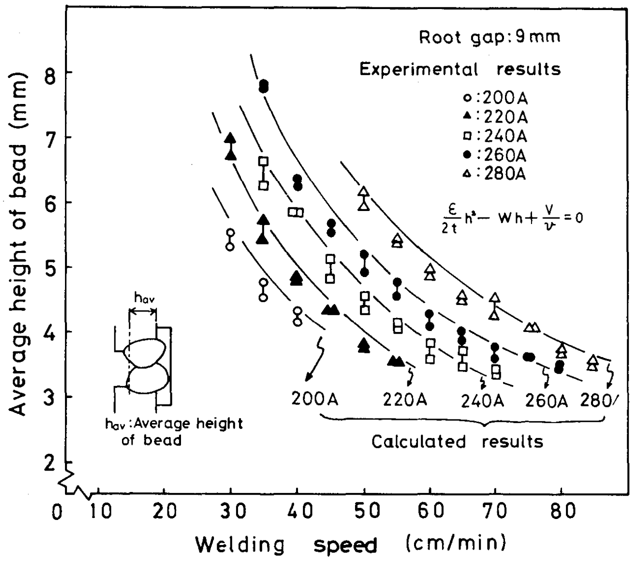

Fig. 3 Relation between bead height and welding speed for various welding currents.
- experimental result (h_{av})
— calculated result (h)

3-2 Quantitative Fixation of Penetration Depth into Side Walls:

The amounts of P_1 and P_2 of the sample sketch of **Fig. 4** are defined as the penetration depth into side walls. The measurement result of $(P_1 + P_2)/2$ is shown in Fig. 4.

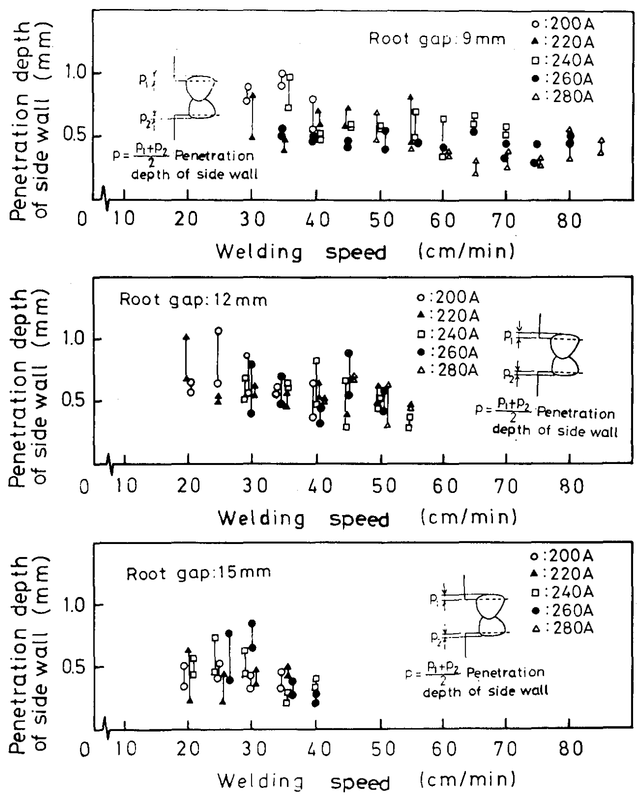

Fig. 4 Relation between welding speed and penetration depth of side wall for various welding currents.

According to the result, there is a tendency that the penetration depth into side walls becomes smaller when the welding speed becomes higher, but it is not so remarkable. In addition, no clear influence due to change of the welding current and groove width is admitted. These can be thought as one of the features of the high-peak pulsed welding.

From the above fact, it has been found that nearly fixed amount of penetration into side walls was obtained irrespective of the welding conditions. This is therefore taken of no special consideration as a controlled variable.

3-3 Quantitative Fixation of Bead Configuration:

In the multi-layer welding, the configuration of lower beads will influence upon the bead formation of the following layer. Investigation was therefore made on the bead configuration. In consideration of the welding of the following layer, the conditions to obtain the satisfactory bead configuration are summarized in the following three items:

1) Few unevennesses (flatness factor)
2) Large contact angles of bead and base metal, and of lower bead and upper bead (smoothness factor)
3) Approximate symmetry in the configuration of lower bead and upper bead (symmetry factor)

For various welding conditions, the above three items were evaluated from its cross section of weld, the bead configuration was classified, and arranged by the welding current and welding speed, whose result is shown below.

3-3-1 Flatness Factor:

The satisfactory flatness factor leads to the low probability of the generation of defects and lack of fusion in the bead forming of the following layer. **Figure 5** shows the result of 3-staged classification of the flatness factor of the bead surface, where the difference of the bead height d (mm) in the sample sketch of the Figure was measured and classified with $d < 2$ symbolized as ○, z $2 \leqq d < 4$; △, and $d \geqq 4$; x. As a general tendency,beads of good flatness factor are obtained in the low current and high speed region.

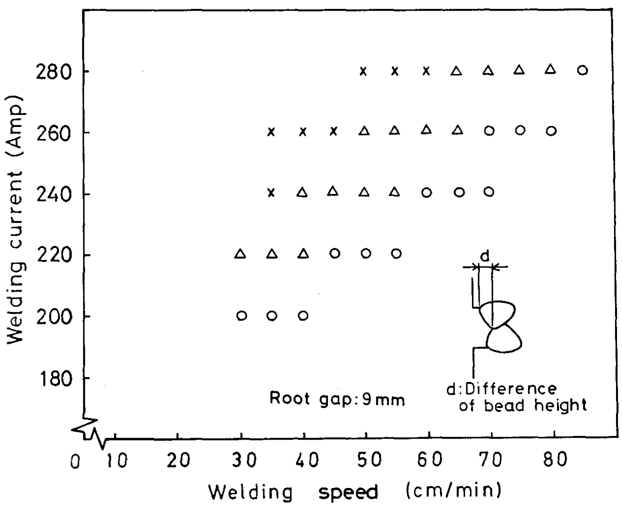

Fig. 5 Classification of bead configuration by flatness factor.

3-3-2 Smoothness Factor:

The contact angles that base metal and bead, and lower bead and upper bead have, relate to the liquidity of deposit metal, and have great influence upon the lack of fusion of the following layer bead. The angles θ_1, θ_2 and θ_3 of the sample sketch of **Fig. 6** are measured and classified in such manner that one having less than two acute angles is figured ○, one having two acute angles △, and one having three acute angles x. The result is shown in Fig. 6, where good smoothness factor is obtained in the low welding current region.

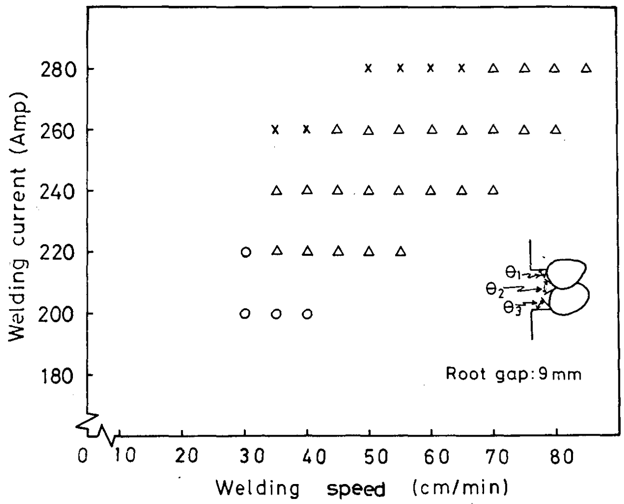

Fig. 6 Classification of bead configuration by smoothness factor.

3-3-3 Symmetry Factor:

This item is necessary when a welding of two passes in one layer is carried out. It is hard to be said of good situation that the change of the lapping position of upper and lower beads according as the welding conditions will lead to change in the bead formation of the following layer. In addition, the symmetry factor is necessary from the appearance of the final bead. Therefore, a/a+c shown in the sample sketch of **Fig. 7** is measured and classified with $a/a+c < 0.65$ symbolized as ○; $0.65 < a/a+c < 0.75$; △ and $a/a+c > 0.75$; x. The result is shown in Fig. 7, where beads of satisfactory symmetry are obtained in high speed region.

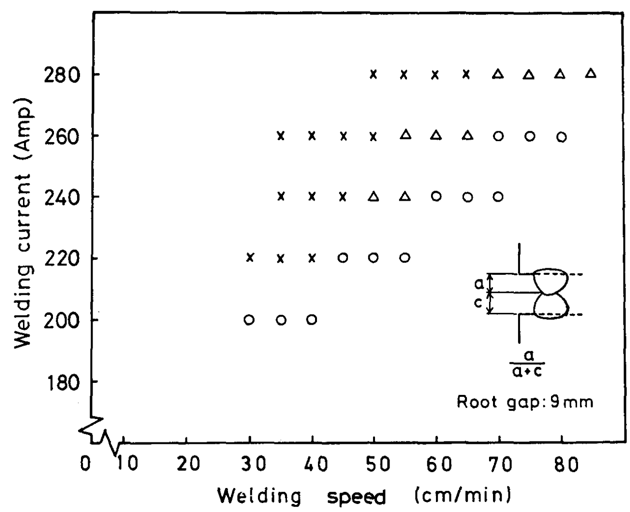

Fig. 7 Classification of bead configuration by symmetry factor.

3-3-4 General Assessment:

A classification of the bead configuration is obtained in connection with the flatness factor, smoothness factor, and symmetry factor, whose summarization is obtained in **Fig. 8** where the symbols stand for the flatness factor

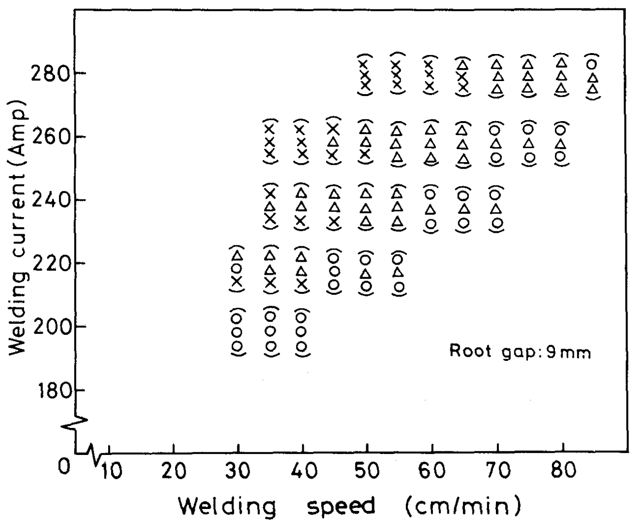

Fig. 8 Synthetic classification of bead configuration by flatness, smoothness and symmetry factors.

smoothness factor, and symmetry factor from the top in each point. Taking an example of a groove width of 9 (mm), similar figure has also been obtained in the groove widths of 12 (mm) and 15 (mm). Using this figure, the space region of the welding speed and the welding current where the satisfactory bead configuration can be obtained. Now, if the region of ○ or △in the flatness factor and the region of ○ both in the smoothness factor and the symmetry factor are defined as the region of satisfactory bead configuration, these regions can be given as some closed region of current and speed space concerning each groove width. If the current and speed are fixed within this region, sound bead configuration can be obtained.

4. Automatic Selection Method of Optimum Welding Conditions:

4-1 Basic Consideration

In case of change in the groove width, an automatic selection method of welding conditions that constant bead height is maintained and that satisfactory bead configuration is obtained was considered on assuming the utilization of a computer, a result of which is shown below:

Even in case of change in the groove width , the conditions obtained from Eq. (3) which the bead height is constant are arranged by groove width, welding speed, and welding current, being shown in **Fig. 9**. The hatching portion shows two curved surfaces of the condition that the bead height h is kept at 3 and 6 (mm) respectively and curved surface groups corresponding to various kinds of bead heights such as $3 < h < 6$ between two curved surfaces and $h < 3$ and $h > 6$ (mm) in their outer regions.

On the other hand, if the region of satisfactory bead configuration mentioned above is arranged in same coordinate system, it will be as shown in **Fig. 10**. (this domain of conditions of satisfactory bead configuration is defined as DCSBC.) The portion of the solid of Fig. 10 which is cut by one curved surface of Fig. 9 will become

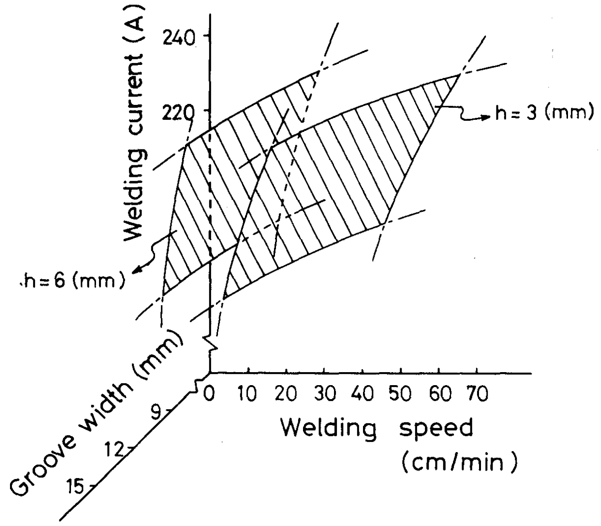

Fig. 9 Example of curved surface which express welding conditions that give constant bead height.

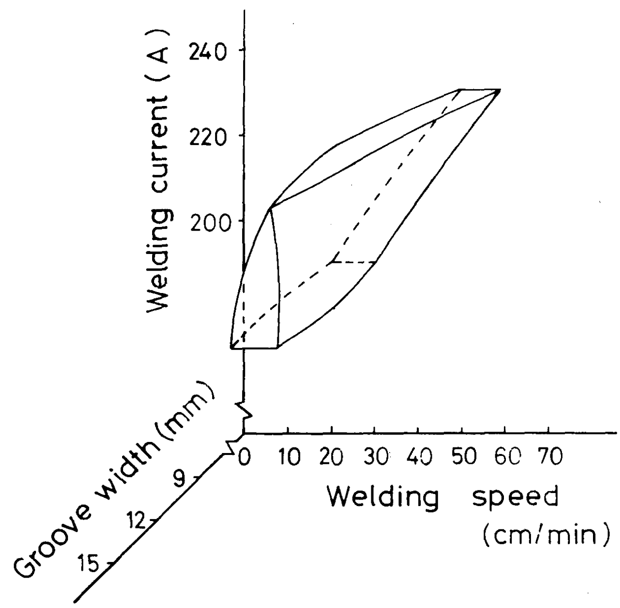

Fig. 10 Three dimensional domain of welding conditions that give the satisfactory bead configuration.

the curved surface with which the bead height will be constant and the bead configuration will be better conditioned. If this curved surface is projected to the co-ordinate axis of the groove width, and its spreading is bigger than the changing extent of the groove width of the joint appropriate welding conditions will be given to that joint making use of that curved surface. In addition, if it is smaller, appropriate welding conditions will not be given to all the groove widths of the joint in its bead height, accordingly, it will be necessary to modify the curved surface of Fig. 10 and to change the bead height. In case of no conditions that will satisfy the changing extent of the groove width of the joint in spite of making use of any curved surface of Fig. 9, the solid of Fig. 10 will be extremely small, i.e. the definition in the region of satisfactory bead configuration in Item 3-3-4 is too severe, resulting in necessity of changing the difinition.

It is concluded that, taking Eq. (3) and the domain of bead configuration as the input data into the computer, and obtaining the information on the change in the groove width of the joint making use of some sensor, the automatic selection of welding conditions can be carried out by the internal calculation of the above operation by means of the computer. The welding conditions are given by setting both of the welding current and welding speed for each groove width. In these welding conditions, giving the optimum welding conditions to each groove width one by one is available by giving priority to change in either of welding current or welding speed, and these approach are described at the next.

4-2 Consideration for Algorithm

For example, the DCSBC is shown in **Fig. 11(a)** with a co-ordinate system of groove width – welding speed – welding current. Shown in **Fig. 11(b)** is the conditions which can be obtained from Eq. (3) in the same co-ordinate system and which can constantly keep the bead height even in case of the change in the groove width. Curved surface A gives the welding conditions where the bead height is kept at a (mm) and curved surface B at b (mm), being a > b. These curved surfaces are hereinafter called "the curved surface for constant bead height".

If the solid showing the DCSBC is cut by the curved

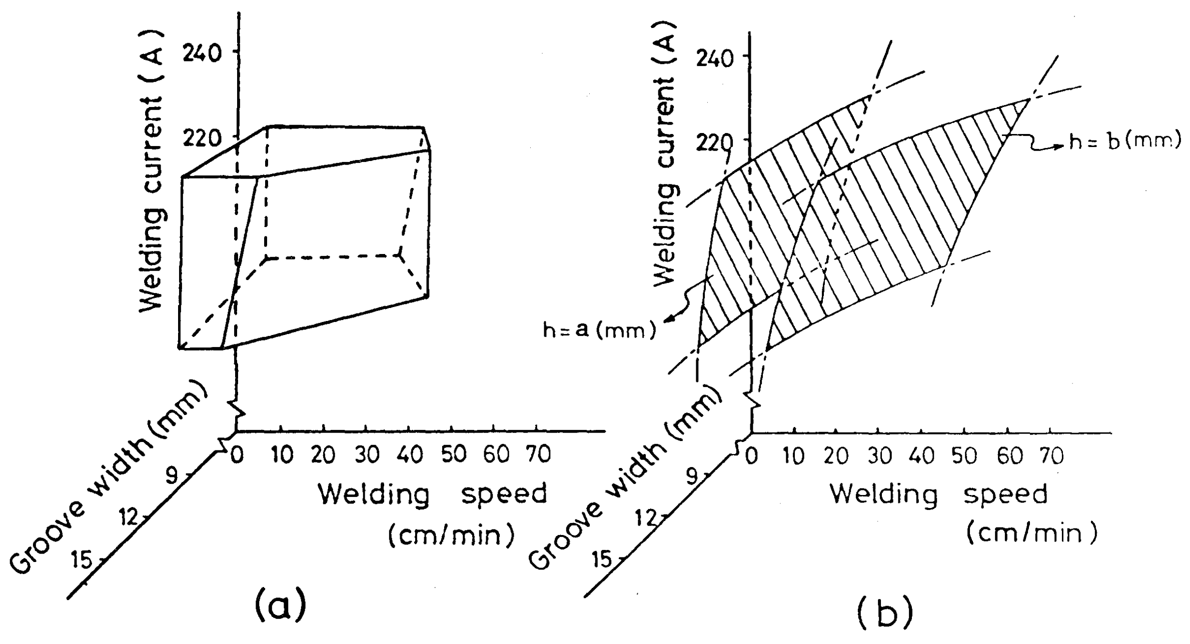

Fig. 11 Curved surface that give the constant bead height and domain that give the satisfactory bead configuration.

surface for constant bead height, the sectional curved surface will indicate the correct welding condtions (various kinds of combination of welding current and speed) corresponding to each groove width. For example, the section of the solid of Fig. 11(a) cut by both curved surfaces of A and B of Fig. 11(b) will be **(a)** and **(b)** of **Fig. 12** respectively. If this cut curved surface is projected to the groove width axis, its spreading is given as W_{a1} - W_{a2} in (a) and W_{b1} - W_{b2} in (b), of Fig. 12. Now, if the changing extent of the groove width of the joint is called W_{r1} - W_{r2} correct welding conditions corresponding to all the changes in the groove width of the joint are given in case of Fig. 12(a). In case of Fig. 12(b), no correct welding conditions will be given between W_{r1} - W_{b1} and between W_{r2} - W_{b2}.

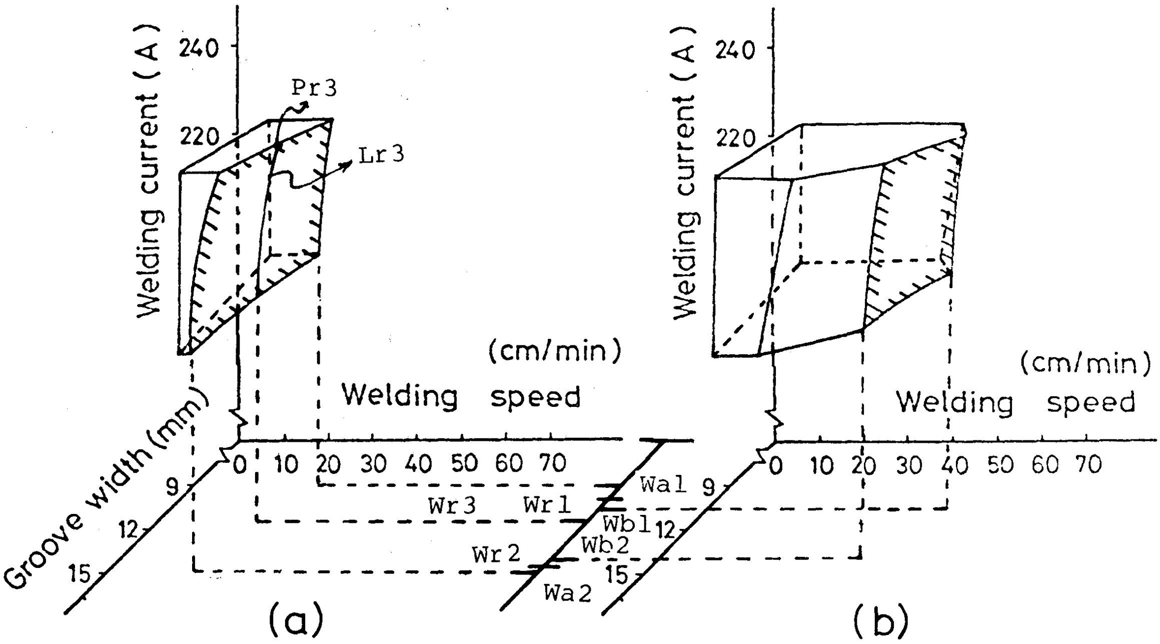

Fig. 12 Cut curved surface and explanation of various symbols,
(a) when the solid of Fig.11(a) was cut by curved surface A of Fig.11(b).
(b) when the solid of Fig.11(a) was cut by curved surface B of Fig.11(b)

Now, if consideration is given to a calculation by the computer, it is necessary to first obtain the changing extent of the groove width of the joint required, and then to fix h so that the cut curved surface will be in the condition of Fig. 12(a) by changing h in various ways. In this case, it is common for h to be given in certain extent, and the selection of greatest h therein (to be defined as h_m) will reduce the welding layer leading to the work efficiency. In addition, if the changing extent of the groove width of the joint failed to be covered in any of h's, it will prove of a excessively small DCSBC having been input, and hence this domain is required to be changed. To meet this, the framing criteria (mentioned in the previous term) of the DCSBC should be loosened a little.

With the above operation, the optimum bead height h_m is obtained, and the cut curved surface indicating correct welding conditions are given by one in number. Then, the welding conditions to obtain h_m is given by various kinds of combinations of welding current and speed. For example, if the groove width is W_{r3}, the welding conditions should prove correct at any points on L_{r3} line of Fig. 12(a). As the method to decide the optimum welding conditions out of this correct welding conditions group, to select the conditions of high current available for high speed welding, for example, a method of selecting P_{r3} point, is considered. But, if the optimum welding conditions are to be decided by this method, it is necessary to change both the welding current and speed every time the groove width of the joint changes, resulting in a littel complication in the control device. Then, it was decided to try a method that either of the change in the welding current or the welding speed is given priority as a method of correlating the groove width and the welding conditions one to one. This can be thought useful not only for the purpose of reducing the manipulating variable, but also from a standpoint that stable welding is possible. Furthermore, since the change in the welding speed can be made by a simpler method, a method of giving priority to the change in the welding speed was adopted in this research. The method is introduced as follows:

If the cut curved surface obtained (Fig. 12(a)) is projected to the plane which the welding current-groove width will make the shadowed portion of **Fig. 13** will be obtained. From this figure, a range of welding current (I_{max} − I_{min} in this case) to cover the changing extent of the groove width of the joint with the constant current is obtained. If the welding current is fixed to some range in this extent, and the welding speed corresponding to each amount of the groove width is obtained from Eq. (3), and control with welding speed becomes available. In this

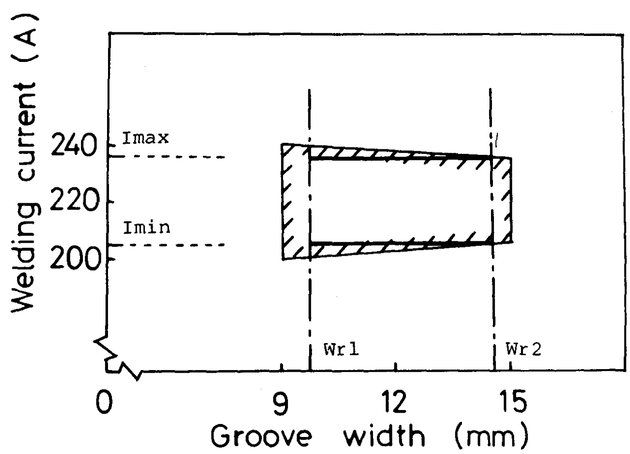

Fig. 13 Region that the cut curved surface Fig.12(a) is projected to the plane of the welding current – groove width, in which constant current is required for control.

case, the welding current is given in some range, but the procedure efficiency will be increased if a high current range where the high speed welding is permitted is selected.

Usually, the optimum welding conditions corresponding to each groove width can be decided according to the above concept, but there will be some cases where the changing extent of the groove width of the joint cannot be covered only by the change in the welding speed depending upon the shape of the cut curved surface. For example, in case the projected figure of the cut curved surface to the plane of current – groove width will make and the changing extent of the groove width of the joint should become as shown in the sample figure of **Fig. 14**, it is hard to cover the changing extent of the groove width of the joint only by the speed change, at the constant current. In this case, considering from the

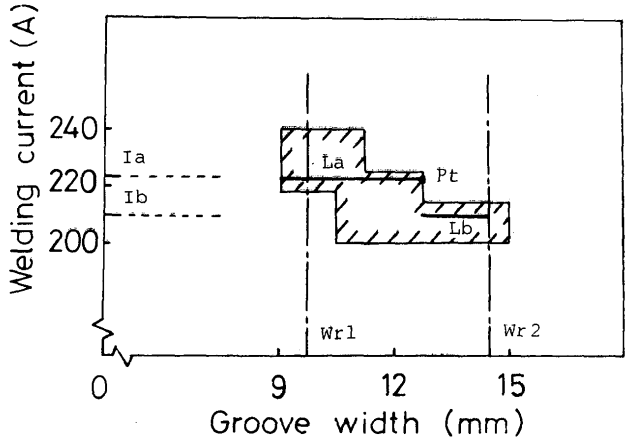

Fig. 14 Region that the cut curved surface is projected to the plane of the welding current – groove width, in which varied current is required for control.

priority basis of welding speed change, a method that the change in the welding conditions will take place along Line L_a of Fig. 14 (fixed by current I_a, and allowing change only in speed), and that the current is changed at Point P_t and then done along Line L_b (fixed by current I_b) will become the setting method of the welding conditions of least numbers of current change. In this method, the lines corresponding to Line L_a are considered on various values of current, the longest one of them in the groove width direction is decided as Line L_a, and then Line L_b is dicided from Point P_t in same operation.

From the above-mentioned investigation, if both the Eq. (3) which constantly keeps the bead height, the DCSBC, and the groove width information of the joint are taken as an input data to the computer, the optimum welding conditions corresponding to the change in the groove width of the joint can be set up by the internal operation of the computer leading to acquisition of the bead height.

4-3 Algorithm for Automatic Setting-up:

To realize the above-mentioned operation, the algorithm that the computer should have is explained as follows:

In the operation of the computer in this method, the search and logical decision in the three dimensional space of groove width – welding speed – welding current will be the main task, and then requires a serial change in the current, groove width, and bead height. In the following explanation, the increase (changed amount) is symbolized as I_s, W_s, and h_s. Experimentally, it has been proved that $I_s = 10$ (A), $W_s = 0.5$ (mm) are reasonable.

From the input data of Eq. (3) and DCSBC and changes in the groove width of the joint required, a method that the maximum amount h_m of the bead height giving correct welding conditions is obtained is flow-charted in **Fig. 15**. In such manner, DCSBC on the plane of certain value of current is considered (Fig. 15 right-side), a point of intersection with the curved line showing the welding conditions of constantly keeping h according to Eq. (3) is calculated, and W_{h1} and W_{e1} of the groove width co-ordinate series are obtained. This operation is effected by changing the current and W_{e1} and W_{h1} are stored in memoty on all such occasions. Upon completion of the examination in the necessary current range, minimum amount W_{e1}' of stored W_{e1} and maximum W_{h1}' of stored W_{h1} are calculated to compare them with W_{r1} and W_{r2} in the changing extent of groove width of the joint. If $W_{e1}' < W_{r1}$ and $W_{h1}' > W_{r2}$ are found, it proves that correct welding conditions to cover the changing extent of the groove width of the joint by that bead height h should exist, and memory storage takes

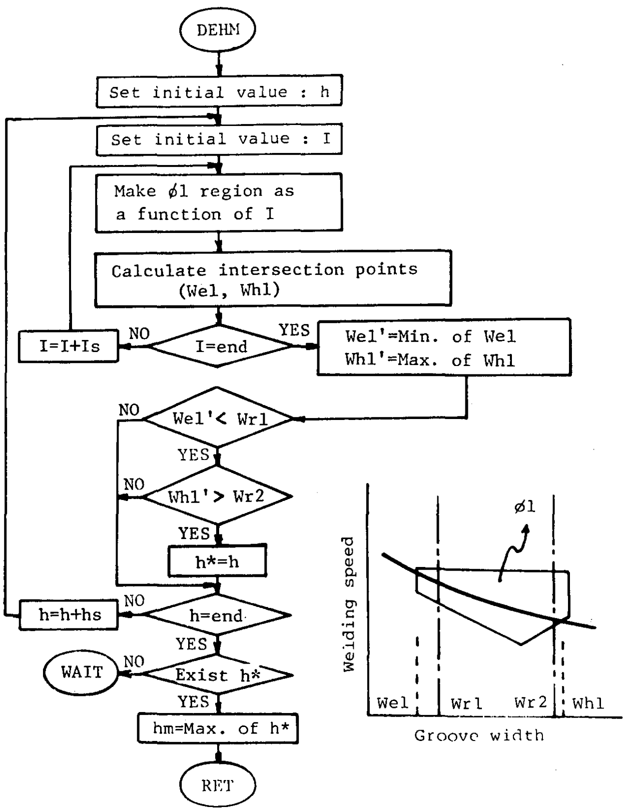

Fig. 15 Flowchart for decision of optimum bead height (h_m).

place with its h taken as h^*. These operation are examined in the previously given bead height range, and the existence of h^* is then examined, and if found existing, the maximum amout is decided to be h_m. If found not existing, the computer offers the instructions to enlarge the DCSBC and stands by.

From the above operation, the value of h_m and the cut curved surface employing the bead height h_m are decided absolutely. Then, a method to set up the welding conditions corresponding one to one to the groove width change of the joint from this cut curved surface is flow-charted in **Fig. 16**. In this operation, W_{e2} and W_{h2} of the point of intersection is calculated by considering the projecting figure of the cut curved surface (Fig. 16, right-side) to the plane of the current groove width and the straight line of constant current of the projecting figure, and then, W_{e2} and W_{h2} are comparison with the changing extent of W_{r1} and W_{r2} of the groove width of the joint. If found $W_{e2} < W_{r1}$ and $W_{h2} > W_{r2}$, constant current control will become available, and storage be made with its current taken as I*. This operation is effected in the current range having been fixed, and existence of I* stored is investigated. If found existing, the maximum amount among them is decided to be I_m. If found not existing, transference of program step is made to the routine where welding current speed change is investigated.

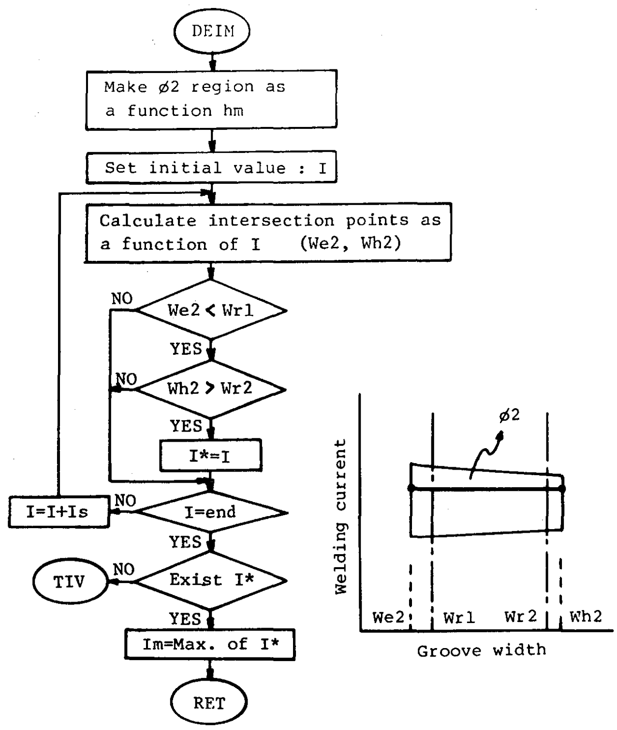

Fig. 16 Flowchart for decision of optimum welding current (I_m), corresponding to the groove width change.

Next, explanation is given to this welding current-speed change routine, whose flow-chart is shown in **Fig. 17**. As in the right-side figure, this shows the case where a straight line of constant current is cut at Point P_t. In this case, the value of W_t, in the groove width co-ordinate, of point P_t on the various values of current is calculated, and

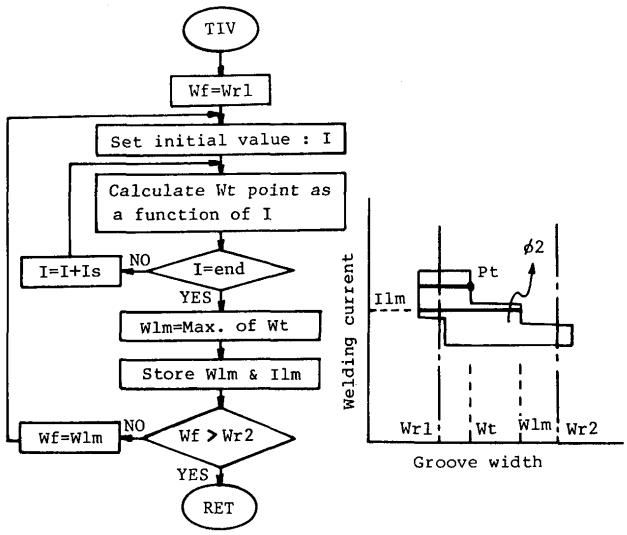

Fig. 17 Flowchart of operation in case that varied welding current is required for control.

the current showing its maximum amount is decided and stored as the working current up to W_t. Subsequently, repeating the same operation from W_t, the current is decided and stored up to the final point W_{r2} of the groove width of the joint. With this, the welding current and its changing point (as the value of groove width) giving the optimum welding conditions with minimum current change are given.

With the above, the optimum bead height h_m and welding current I_m (If it is given in the plural form, its changing point is shown by the value of groove width.) are given by a series of operation. With the h_m and I_m, the optimum welding speed to each required value of groove width of the joint is calculated from Eq. (3) and the results are stored in memory corresponding to the groove width value in the welding direction of the joint. With the above, the automatic setting-up of the optimum welding conditions is finished. These algorithms were coded into symbolic computer-dependent language by means of the assembler program.

5. Automatic Control Experiment:

5-1 Explanation of Device:

A system to carry out automatic control by means of the above mentioned algorithm is manufactured as a trial, it is roughly categorized as follows:

1) Picture-taking system (TV camera, monitor television)
2) Processing system (CPU: i 8080A, ROM: i 1702A, RAM: i 2102)
3) Electrical system (4-channel servo amplifier)
4) Mechanical system (4-axis independent driving mechanism)

The function of each is outlined as follows:

In the picture-taking system, the groove width information indispensable to this algorithm can be automatically obtained by the optical method. Other various kinds of information can be obtained by this system, whose details will be described in the next report. Furthermore, the groove width information can be input manually.

In the processing system, optimum welding conditions corresponding to the groove width of the joint are decided from Eq. (3) and the DCSBC making use of the obtained groove width information, and further its control signal is output. In addition, a whole system is controlled with the processing system.

In the electrical system, various kinds of control signals output from the processing system are amplified, and the mechanical system is driven by them.

In the mechanical system, torch driving is performed, and the position information on each axis in the co-ordinate system is fed back to the processing system. Moreover, it feeds back to the processing system the number of revolutions and revolving speed of the driving motor in the welding direction for the purpose of improving the reliability of the welding travel.

5-2 Experimental Result:

With the above-mentioned device loaded with the algorithm described in Chapt. 2, an automatic control experiment was carried out. Showing an example of the result, the groove width information applied the method of the automatic input by means of the optical method.

Photograph 2 shows the bead appearance and the macro-section of its three points in case a test piece whose groove width changes in a straight line from 9 to 15 (mm) is automatically controlled up to four passes in two layers welding. **Figure 18** shows the progress of the change in the controlled welding speed, which has characteristic change with the automatic control system by the influence of the backlash of the mechanical system,etc.,but it is thought to have full accuracy as the control of the welding. In

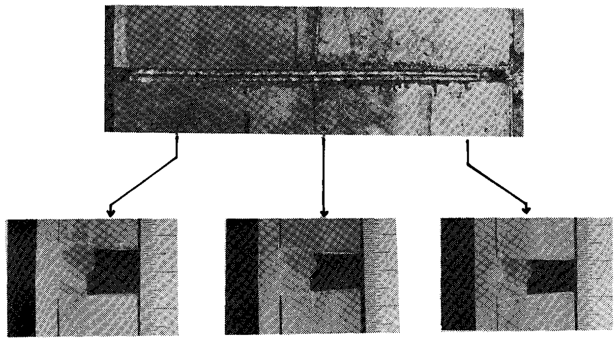

Photo. 2 Bead appearance and weld cross sections which are controlled.

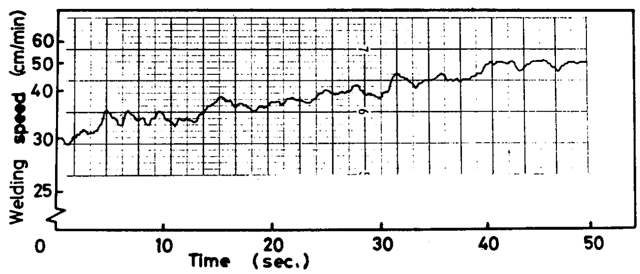

Fig. 18 Osillogram of controlled welding speed.

addition, as seen in Photo. 2, the bead height and the bead configuration are little varied though the groove width has largely changed. In this case, the computer operation resulted in $h_m = 4.5$ (mm) and $I_m = 220$ (A). In this experiment, the change of welding current was conveniently conducted by the preset method in compliance with the operation result of the computer, but control signal from the processing system has been output, and accordingly, if the control device should have current control function, the real time control of the welding current would be possible.

The bead height per layer at each position in the welding direction was measured on the test piece, resulting in **Fig. 19**. Marked ○ shows the case by the automatic control, and the bead height being constantly maintained in the accuracy of within 0.5 (mm). In the figure, the change in the bead height when welding was carried out under the same welding conditions (in case of no control) is shown by the marks × and ●. As compared with the bead on the point of 9 (mm) in the groove width, the bead height on the point of 15 (mm) is changed about 2.5 to 3.0 (mm) per layer. This proves the justifiability of this method.

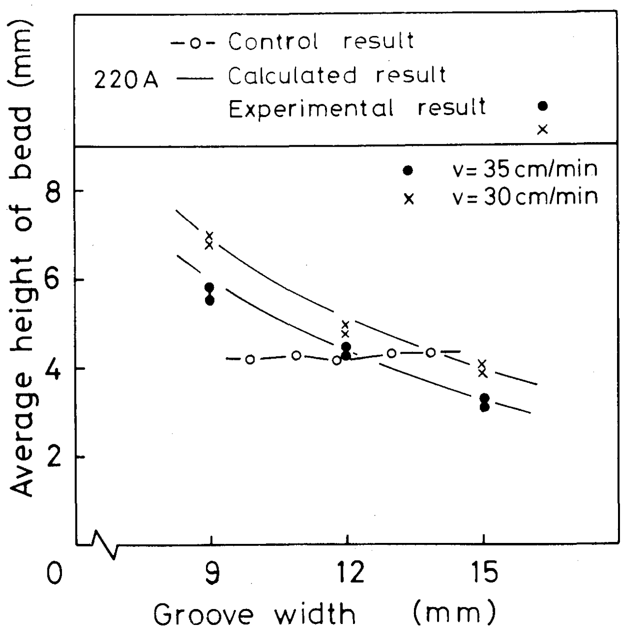

Fig. 19 Relation between groove width and the bead height per layer.
– ○ – with control (I = 220 A const.)
– ●– without control (I = 220 A, v = 35 cm/min. const.)
– × – without control (I = 220 A, v = 30 cm/min. const.)

6. Conclusion

On the purpose of the automatic control of the horizontal narrow gap welding by the high-peak pulsed MIG welding method, the welding experment and the consideration assuming the computer control were given for the automatic selection of the optimum welding conditions corresponding to the change in the groove width of the joint, and an algorithm and an automatic control device making use of micro-computer were manufactured.

The results obtained are summarized as follows:

(1) Bead height can be given by the solution of Eq. (3) of $h^2/2d - Wh + V/v = 0$. Knowing the groove width W, h is given with the welding current and welding speed taken as a parameter.

(2) The bead configuration is evaluated in consideration of the flatness factor, smoothness factor, and symmetry factor, and the domain (domain of satisfactory bead configuration) of the welding conditions from which satisfactory result can be obtained is given by three dimensional closed domain where welding current, welding speed, and groove width are taken as the co-ordinate system.

(3) A process to set up the domain which give the correct welding condition is shown with Eq. (3) giving the bead height and with the domain of satisfactory bead configuration taken as the input of the computer and with these input data laid on top of another in space. This proves to have shown the computerized automatic selection of appropriate welding conditions assuring that the bead height is constant and the bead configuration is turned satisfactory, corresponding to change in the groove width of the joint.

(4) Control algorithm was established basing upon the method of (3) above. This has been performed chiefly by the serial search of the domain of the welding conditions in the three dimensional space of welding speed-welding current-groove width.

(5) An automatic control system making use of the micro computer was manufactured as a trail, an automatic control experiment was carried out with the algorithm of (4) above, and this method was proved effective.

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