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Citation	Transactions of JWRI. 1975, 4(2), p. 197-203
Version Type	VoR
URL	https://doi.org/10.18910/4355
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Underwater Butt Welding of Mild Steel with Water Curtain Type CO_2 Arc Welding Method †

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Abstract

Existing wet process with stick electrode has the limitation that reliable welds can not be obtained. To improve this problem, the authors have been development water curtain type underwater CO_2 arc welding, which consist of dual nozzle, that is, shielding gas flosws out from inner nozzle, and curtain water flows out cylindrical from outer nozzle. Materials used were 4.5, 6, 20, 40mm thick mild steel. By this method, single pass and multi pass butt welding were carried out in the fresh water. Successful results were obtained both in tensile test and bending test.

1. Introduction

International interest has been arosed in development and utilization of ocean which covers 70 per cent of the earth and it resources. Some of them such as development of offshore gas and oil field, utilization of ocean space, fisheries' multiplication, large offshore construction and mineral resources mining in the sea bottom etc. are going to be developed, while the others are remained as the coming industry. But it is evident that the development will be watched with interest in the near of future.

For answer to this time, development of the necessary apparatuses and research promotion of tecnology are regarded as important for basic technologies, one of which is welding technology. In practice, the welding capable on land is not taken trouble to do under water, but as the constructions are enlarged, their type is increased and the served period is prolonged, the parts of the construction will be welded under water. Also it is anticipated that the chance of the underwater welding will increase in case of temporary repair caused by ship's collision, unexpected accident, corrosion etc..

2. Water Curtain Type Co_2 Arc Welding Method

2.1. Characteristics of CO_2 arc welding as underwater welding method

For underwater welding, as well known, there are two method, "dry" and "wet" method. The advantage of the former is that the excellent joint quality can be obtained, but this method is very expensive, because the water tight chamber is necessary correspond to each construction. In the latter method, on the other hand, the welder puts on the diving suit and strike the arc directly under water. This wet method with stick electrode has the limitation that the reliable welds can not be easily obtained, because the welds is affected with diver-welder's skill and includes the blowholes owing to dissolved water.

In the period of ocean development, a new underwater welding method is expected to solve these problems. For underwater welding, the following conditions are requested.

(1) Inexpensive welding equipment and low welding cost
(2) Decrease of electrical hazard
(3) 20cm/min welding speed at least
(4) Possibility of welding in all positions
(5) Reliable weldability
(6) Easy operation
(7) Good visibility
(8) To support oneself by one hand and to weld by another hand, because of no-gravity in the water
(9) Possibility of automatic welding

The authors developed the underwater CO_2 arc welding method with water curtain as the welding method which comparatively satisfied the conditions above mentioned.

3. Principle of the Water Curtain Type Underwater CO_2 Arc Welding Method

This method, as shown in Fig. 1, consists of dual shielding nozzle. Shielding gas flows out from the inner

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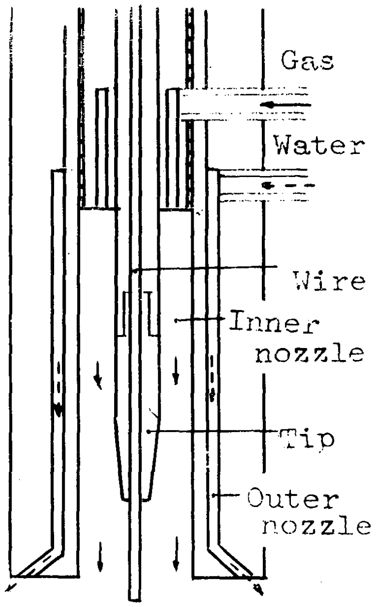


Fig. 1 Schimatic of water curtain type nozzle used in this method.

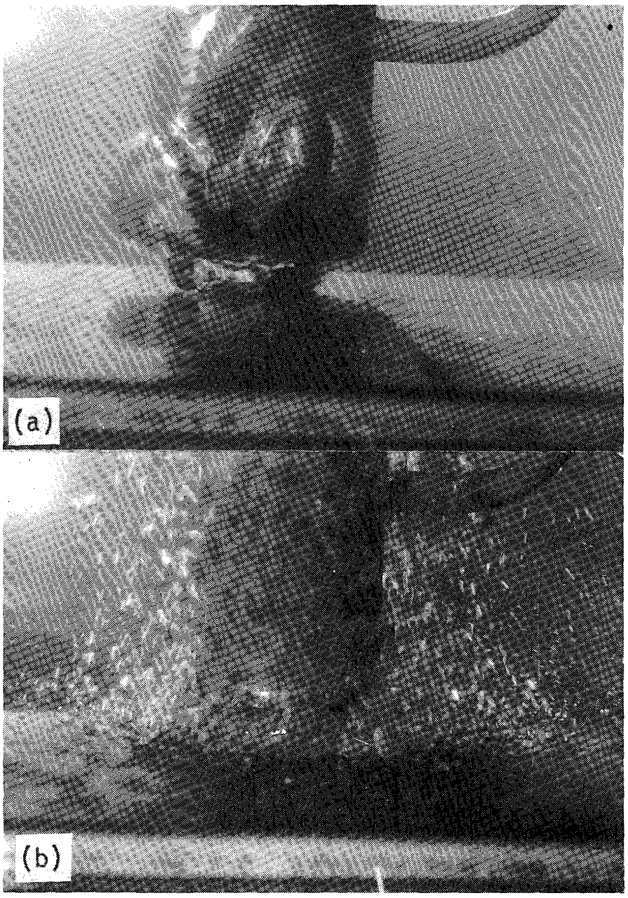


Fig. 2 Shielding condition underwater.
(a) Without water curtain. (b) With water curtain.

nozzle in the same manner as the conventional CO_2 arc welding method, and curtain water flows out annularly from outer nozzle which prevents the escape of inner gas and improves the gas shielding effect under water. Reliable welds can be obtained by this nozzle.

Fig. 2(a) shows the condition that only CO_2 gas flows without curtain water. The gas escapes from the near of nozzle as large babbles, which resulted in the narrow shielding area. In the condition of the same CO_2 flow rate, however, if the water curtain was used, as shown in Fig. 2(b), it is recognized that the gas babbles change small and the shielding area becomes wider.

4. Effect of Water Curtain

4.1. Observation by use of two-dimensional model

To make the observation of this shielding effect easy, we devised a two-dimensional model and took pictures of it by means of ten-times multiplex exposures and then examined the changing condition of CO_2 gas shielding distance. Fig. 3(a) shows the case of no water curtain being used, where it is observed that reaching distances of shielding gas are short on the average. In addition, the changing range is very wide, and sometimes water is pushed back up to the nozzle tip. Fig. 3(b) shows the case where water curtain was used and the water flow angle θ was set at 45°. It is observed that the larger the angle θ is, the shorter the reaching

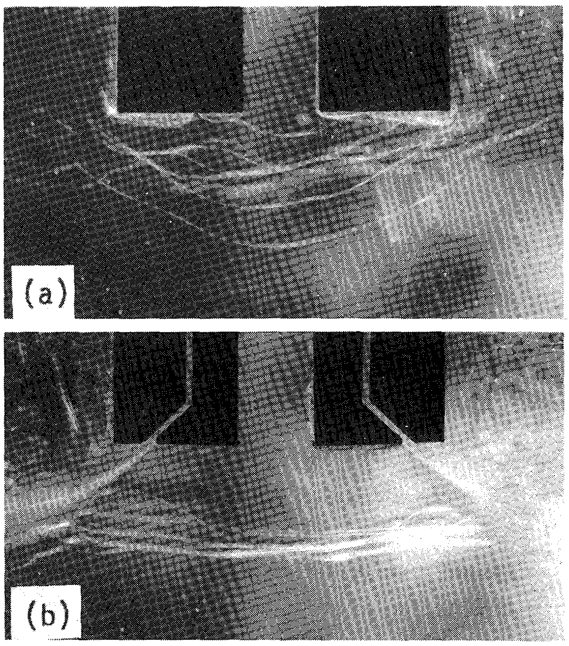


Fig. 3 Observation of shielding effect by two dimensional model
(a) Without water curtain. (b) With water curatin.

distance become, but the narrower the changing range become.

The effect by use of this water curtain can be said as follows: If there is no water curtain, CO_2 gas intermittently escapes from the side just close to the nozzle, taking the form of large bubbles. The moment CO_2 escapes, water is pushed back up to there. If there is water curtain, however, it becomes hard for CO_2 to escape, and even if it could escape in the form of small bubbles, contineously away from the nozzle, thust this makes the changing range narrow.

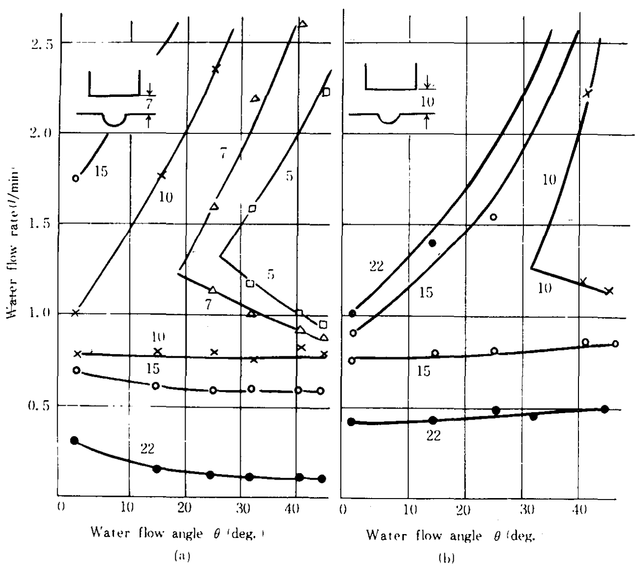


Fig. 4 Relation between water flow angle and water flow rate.

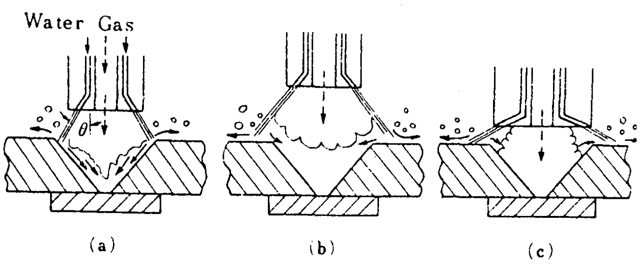


Fig. 5 Effect of water flow angle on shielding.

4.2. Shielding condition

Figure 4 shows the shielding effect of molten pool by use of the two-dimensional model. Numbers entered in the Figures show gas flow rate, and the flow rate between the upper and the lower limits evidences the range to insure a suitable shielding result. That is, if the curtain water flow rate is less than the lower limit, surrounding water enter the molten pool, and if it is more than the upper limit, the curtain water reflects from the base metal and then goes into the molten pool. It is therefore necessary to select a proper shielding gas flow rate associated with the water flow angle.

In actual welding, and normally in case of thin plates butt welding, angle θ is 30° to 60°, curtain water flow rate is 5 to 10 ℓ/min, and shielding gas flow rate is 40 to 60 ℓ/min. In case of thick plates, it is necessary to make edge preparation in order to obtain a good penetration. For, as shown in Fig. 5(a), if curtain water flow angle θ is small, the curtain water reflects from the groove face and then goes into the molten pool. To prevent this, that is, to prevent the water from the grooved face, it is necessary either to position a torch high as shown in Fig. 5(b) or to make the angle θ large as showin in Fig. 5(c). However, in case of (b), because the distance up to the root face is long, therefore the shielding effect becomes poor. So, we after all have to employ the method (c).

5. Experimental Result and Discussion

5.1 Experimental apparatuses and materials

Figure 6 shows the apparatuses used for the experiment where welding was made 30cm depth under water.

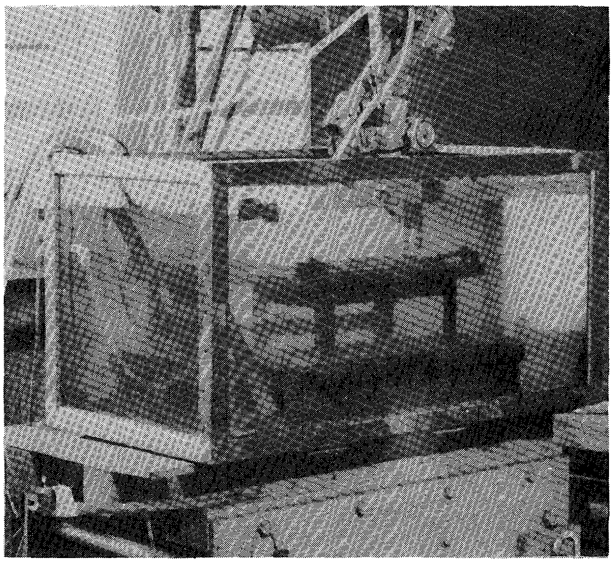


Fig. 6 Welding apparatus used in this experiment.

A DC 500A welder with constant voltage characteristic and reversed polarity is employed.

For welding wires, both 1.2mm diam. solid wire and 2.4mm diam. flux cored wire for non gas shielded welding were used. For shielding gases, Ar and CO_2 were selected, and O_2 were mixed to them for the purpose of softening the welds. Materials used for the experiment were 3.2, 4.5, 6, 20 and 40mm thick mild steel. In welding, it is difficult to prevent coming water from the backside to root face, in case of thin plate, a backing plate is provided as showin in Fig. 7(a), and in case of thick plate edge preparation and welding sequence as shown in Fig. 7(b).

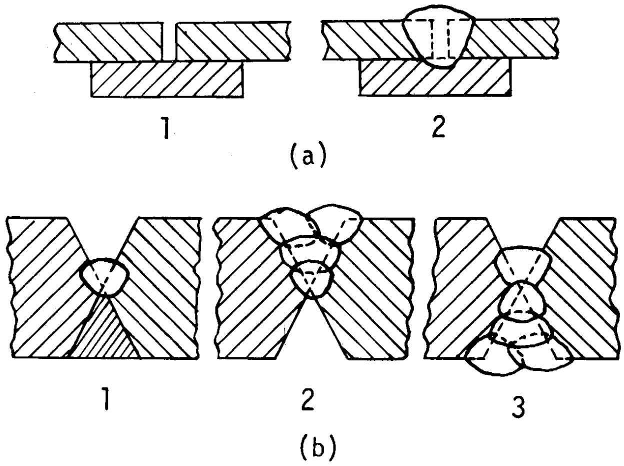


Fig. 7 Welding preparation and welding sequence.

5.2 Observation by use of oscillograph

Figure 8 shows oscillogram of welding current and arc voltage when bead-on-plate welding was done in the condition of 180A current, 30V voltage, welding speed of 20cm/min and 30ℓ/min CO^2 flow rate, and (a) shows the

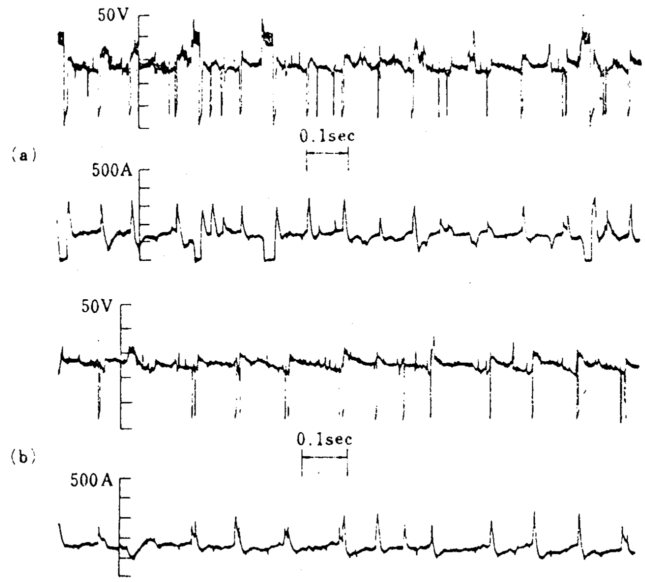


Fig. 8 Oscillogram of arc voltage and welding current during underwater welding.
(a) Without water curtain. (b) With water curatin.

case of no water curtain being used, while (b) shows the case where of 3ℓ/min water curtain flow rate was used, and the other conditions were remained as same. Molten particles undergo regularly a short- circuiting transfer the current increases and at the same time the voltage reduces. The other hand, when no water curtain is used, the current becomes to zero irregularly owing to arc vanishing. This means that CO_2 shielding is insufficient and water enters the arc column occasionally. That is because the arc voltage, when water enters, increases remarkably and exceeds the no load voltage of this welder, even in case of the arc length being good enough to sustain the arc in CO_2. If water curtain is used, however, the arc not go out thanks to perfect shielding with CO_2 and no water entering the arc column.

5.3 Single pass welding

Figure 9 shows the appearance of bead and the result of radiographic inspection of the welds, when closed gap

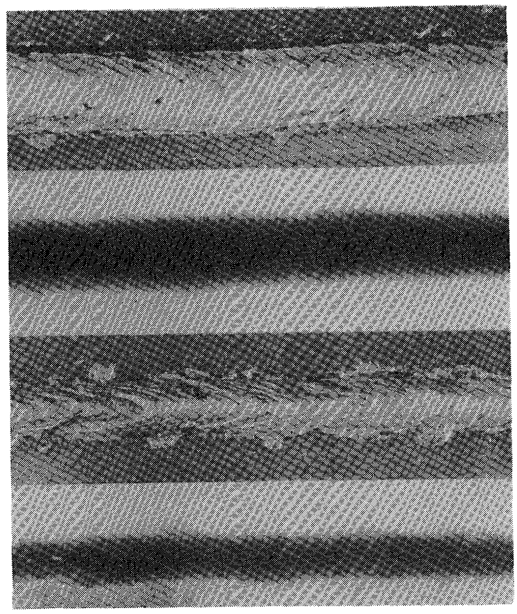


Fig. 9 Effect of welding speed on bead appearance and radiographic inspection (Solid wire used).

welding of 3.2mm thick mild steel plates was done with use of solid wire and in the condition of curtain water flow rate of 3ℓ/min. As seen from (a), blowholes are not present in the condition of the welding speed being less than 30cm/min. If the speed is over the above rate, however, blowholes come to appear as shown in (b). This is because some water remains in the gap and there is not enough time for the water in front of the molten pool to be completely evaporated if the welding speed is too fast.

The problem in case of solid wire used is that blowholes are apt to appear if the welding speed is fast. Therefore flux cored wire was tried. Fig. 10 shows the

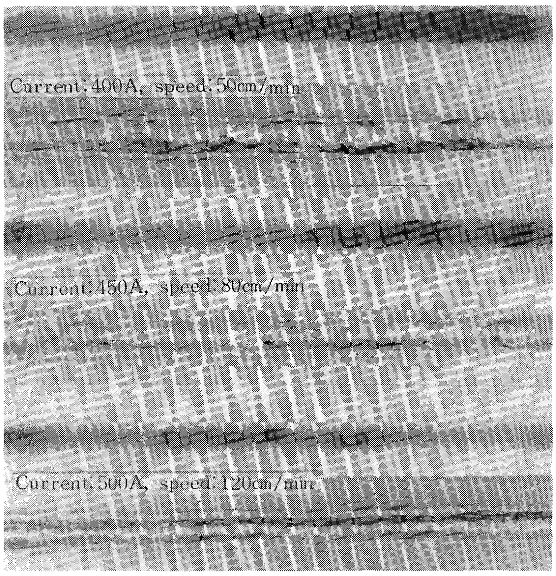


Fig. 10 Effect of welding speed on bead appearance and radiographic inspection (Flux cored wire used).

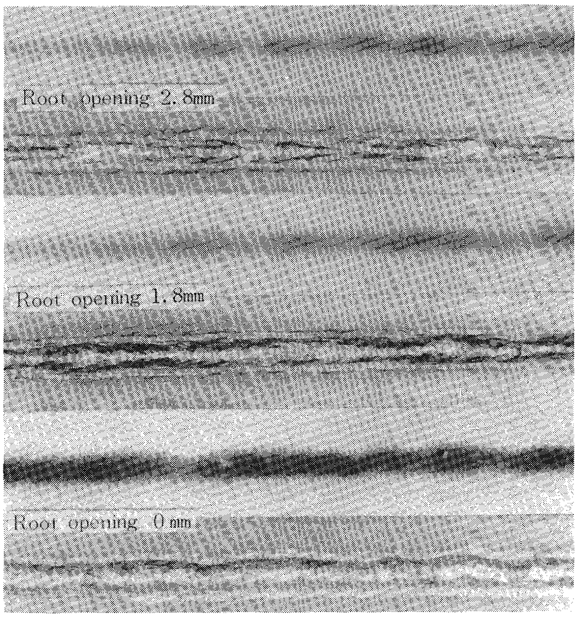


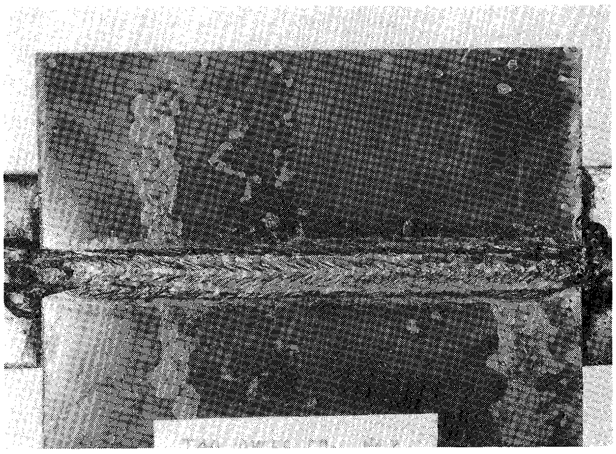
Fig. 11 Effect of root opening on bead appearance and inspection (Flux cored wire used).

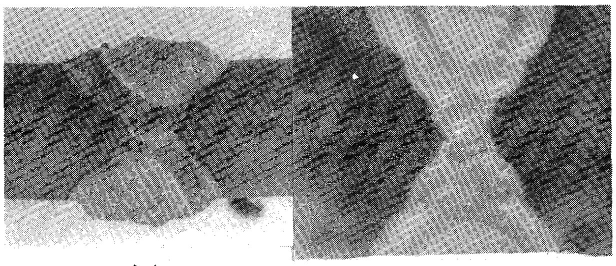
result of radiographic inspection and the appearance of bead of the weld zone when welding was done in over the range of welding speed from 50cm/min to 120cm/min. Needless to say, satisfactory welding can be made in the condition of slow welding speed that is less than 50cm/min. Welding can be made with no problem, even in the condition of 120cm/min speed rate. As plate thickness increases, the gap must be prepared, in order to examine the shielding effect in the like condition, butt welding of 4.5mm thick mild steel plate was done, in which various gap was prepared when both plates were butted against each other. This result is shown in Fig. 11. There occurred no blowhole in case of the gap being zero. And even in case of 2.8mm gap, no blowhole appeared at all.

5.4 Multiple pass welding

Welding speed can be increased up to around 120cm/min in case of flux cored wire being used. But if this wire is applied to automatic welding, however, there arises a problem that slag produced on the bead surface has to be removed at each pass of welding. In contrast, although in case of solid wire being used, it is difficult to make the welding speed faster than 30cm/min, but there is a feature that no slag is produced at all. This feature of slag free is very useful for multiple layer welding.

For a given value of welding current, a higher welding speed requires more numbers of pass, while a lower welding speed allows so less numbers of pass. For this reason, around 20 to 30cm/min welding speed does not create any problem, and the use of solid wire is therefore considered quite adequate. For a thick plate





(a) (b)

Fig. 13 Macrostructure of welds

with an edge preparation made, because of the distance to the root face being fairly long, the curtain water flow rate and the shielding gas flow rate are 6ℓ/min and 50 to 60ℓ/min, respectively, and CO_2 or Ar, or a mixed gas is used.

For both 20mm and 40mm thick plates, 26cm length test pieces were used. After these test pieces were multiple pass welded, hardness and macro test pieces were, mechanically cut off from both ends, and tensile test pieces and bending test pieces from the middle portion. The bending test pieces of 20mm thick were mainly given the face bending test and partly the side bending test. Inversely, however, ones of 40mm thick were mainly given in the side bending test and partly the face bending test. This is because it was necessary, in conducting the bending test, to broaden the width of the test pieces more than the plate thickness in order to prevent buckling.

Fig. 12 shows the welded test pieces whose thickness is 40mm. It is to be noted that a tab plate is attached to the both ends to prevent the bead from its dropping. Fig. 13(a) is the macro-structure when a 20mm thick mild steel plate was welded with a prepared 60° groove angle of 60° and in the condition of 400A current and 40cm/min speed, while (b) is the one of a 40mm thick plate with a prepared 60° groove angle, and this welding was done in seven passes and from both sides. The both cases show good penetration. Fig. 14. shows the hardness distribution of the welds of 40mm thick plate, and in this case CO_2 and CO_2 + O_2 (7 : 3) were used for a shielding gas.

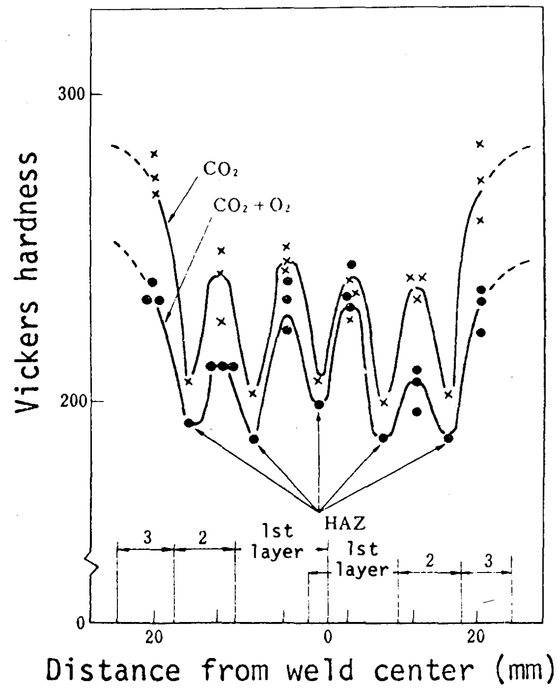


Fig. 14 Hardness distribution of multi-pass welds.

In both cases, because of placing more passes of bead on the preceding bead is heat-affected by following bead, as the result of it, hardness becomes lower. Although the last layer is hard, its hardness is below the Vickers hardness 300, and there is no fear that the properties of the weld zone will be largely affected if the hardness remaines at that value. Adding of O_2 results in lower hardness compared with the case where a no mixing gas is used. When flux cored wire is used, the gas in the vicinity of the weld zone contains the gas produced from the flux; therefore, the O_2 gas has to be added by as much amount as 40% in order to reduce the hardness.

Fig. 15 shows the appearance of bead and the result of radiographic inspection of the welds when 40mm thick plate was welded by use of flux cored wire and the mixed gas of CO_2 and O_2 for a shielding gas. As seen from the figures, there is no defect such as blowholes, cracks or insufficient penetration, and thus a good weld was obtained. Although not shown here, good results were obtained also when no mixing gas, Ar or CO_2 for instance, was used. However, as mentioned later, when solid wire was used, a good result was obtained in case of a 20mm thick plate, but blowholes appeared in case of a 40mm thick plate.

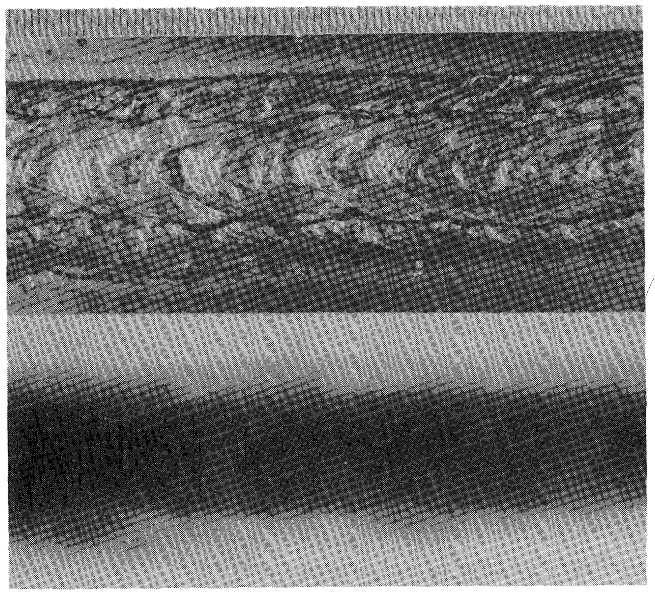


Fig. 15 Bead appearance and radiographic inspection (Thickness 40mm).

5.5 Fracture test

Figure 16 shows the result of the tensile test after the reinforcement was removed from the welds of 20mm and 40mm thick plates. In both cases, CO_2 and the mixed gas of CO_2 and O_2 were used for the shielding gas, and in eigher condition the fracture occurred at the base material and the weld zone thus proved sound. Fig. 17 shows the result of face bending test, and CO_2 and

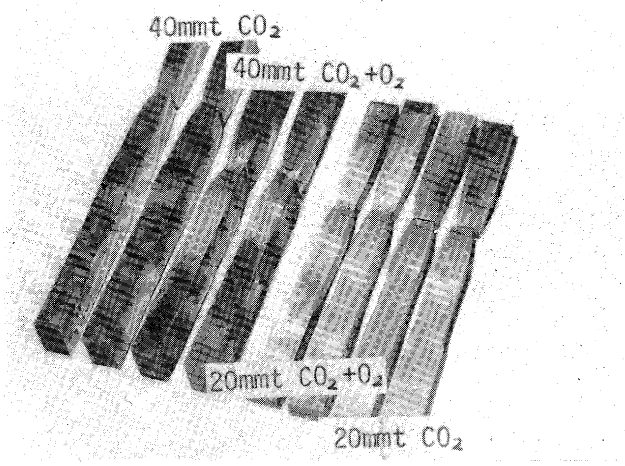


Fig. 16 Results of tensile testing.

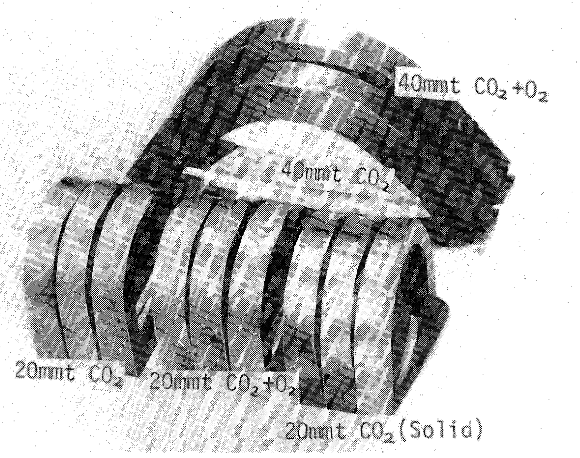


Fig. 17 Results of surface bend testing.

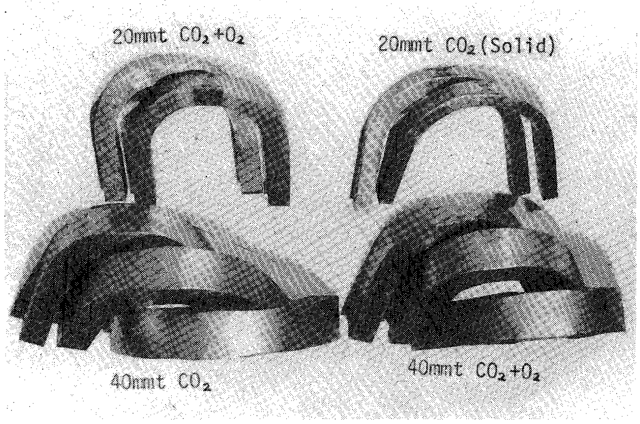


Fig. 18 Results of side bend testing.

the mixed gas of CO_2 aand O_2 were used for the shielding gas.

For a 20mm thick plate, flux cored wire and solid wire were used. And the weld zone passed the 180° bending test also in case of the solid wire being used. Fig. 18 shows the result of side bending test, the width of test piece was cut to 25mm for 40mm thick plate, and to 18mm for 20mm thick plate. The welds passed the 180° side bending test in case of flux cored wire being used. In case of 20mm thick plate, a good result was obtained even when the solid wire was used. However, in case of a 40mm thick plate the solid wire was applied. Although a good result was obtained in the face bend test, a satisfactory result was not yet obtained in the side bend test, that is, a little hair crack was recognized on the first layer surface in 180° bending test. This is because if the plate thickness is thick, the distance from the nozzle to the root surface becomes long and the shielding effect tends to become poor and therefore some blowholes only occur at the first layer of welding.

6. Conclusions

With the curtain water type CO_2 arc welding method, underwater single and multiple pass butt welding of mild steel in down hand position were carried out and the successful results were obtained both in tensile test, needless to say, and bending test. The summary of the results is as follows:

(1) In case of single pass butt welding of thin plate, a little gap is allowable. It is difficult to obtain the excellent results at the welding speed more then 30cm/min in case of using solid wire, but high speed welding such as 120cm/min is possible in case of using flux cored wire.

(2) In the multiple pass welding of thick plate, edge preparation is necessary. In this way, bending test was passed in case of not only 20mm but also 40mm thick plate using flux cored wire. But the slag which was produced in each pass must be removed. On the other hand, in case of solid wire, the slag is not produced at all and time to remove it is saved. While face bending test of 40mm thick plate welds was passed, but blowholes are recognized in initial layer of welds. Therefore a little crack was recognized on surface in 180° side bending test, in case of 20mm thick plate, however, 180° both side and face bending tests were passed.