Development Of Low Heat Input Welding Method To Protect Back Coating Film From Heat Damage

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Steel chimney stack shells with thinning caused by local corrosion are repaired using spliced joints. However, if workers do conventional repair welding, back coating film is damaged by heat input and needs repainting which causes increased costs. Therefore it was developed a low heat input welding method protect back coating film from heat damage using high speed robot welding. Because it is not possible to measure the backside temperature directly during welding, the authors developed a system to guarantee backside temperature when using the low heat input welding method. Backside temperature is guaranteed by using surface temperature data obtained from the thermal sensor attached to the torch tip of the welding robot. This method is applied to steel chimney repair welding at thermal power plants.

Key Words:  MAG Welding, Robot Welding, Low Heat Input, Temperature Guarantee, Coating Film

1. Introduction

Ironworks and electric power plants are often constructed near coastal areas. The stack shells of steel chimneys and exhaust stacks located on site are sometimes corroded by sea salt particles. Stack shells can thereby buckle from insufficient strength due to attrition of thickness, or flue gas can be discharged from opened holes if thinning from corrosion progresses. When thinning and apertures are found at an inspection, they are repaired using spliced joint welding. In spliced joint repair welding of chimney stack shells, since it is high working place, workers carry out repairs using scaffolding or gondola equipment. Coating or lining is applied to the inside surface of the stack shell for corrosion prevention. If welding is carried out without heat input management, the backside temperature becomes higher than the coating or lining heat resistance temperature and burn. In this case, repairs in the form of re-painting or re-lining the inside surface of stack shell are needed, consuming much labor and cost to set up scaffolding. In a nuclear power plant exhaust stack which cannot be accessed inside, repair work on the inside surface of a stack shell is impossible.

The authors therefore developed a welding method whereby the backside coating film is not damaged even if workers weld the surface of the stack shell. Specifically, it uses a low voltage welding power source and welds at high speed using a robot to reduce heat input as much as possible. In addition, in consideration of the local construction environment (outdoor, high altitude), a wind resistant nozzle which enables welding in strong winds of up to 10m/s is developed. Furthermore a system is developed to measure the surface temperature during welding and monitor whether heat input is proper. It was confirmed that joint strength was sufficient, and back coating film sound. As a demonstration test, this method was applied in actual repair welding of a steel chimney in a steelworks and was confirmed to be effective.

2. Low heat input welding system

2.1 Devise configuration

The principle of low heat input is based on high speed welding and a low voltage welding power source. To facilitate it, a light weight, small, multiple-joint robot and a low voltage MAG welding power source are used. The appearance and device configuration of the welding system are shown in Fig. 1 and 2. The welding system used in this study consists of a digital inverter-controlled low sputtering MAG welding source, a compact welding robot, a wind resistant nozzle, a large flow meter for MAG gas, and a small thermal sensor. Because the welding speed is approximately 100 cm/min using a robot, and the arc voltage is about 80% lower than in the case of using a conventional welding power supply, the heat input per pass is reduced to prevent back coating film from heat damage. The welding robot body weighs 31 kg and its electric power output is less than 80 W, so a safety fence around the robot is unnecessary. The welding wire is a low sputtering solid wire for carbon steel suitable for the low current range and the shielding gas is a metal active gas (80% Ar, 20% CO₂). The torch tip of the robot is equipped with a wind resistant nozzle as shown in Fig. 3. With usual MAG welding carried out in high places such as a chimney, faster wind speed compared to near the ground causes the shielding gas to scatter and defects in weld beads, but by using a wind resistant nozzle it became possible to weld better under strong winds of up to 10m/s. The torch tip has a small thermal...
sensor attached making it possible to measure the surface temperature distribution in real time during welding. It is thereby possible to manage the interpass temperature and perform the backside temperature guarantees to prevent damage to back coating film. The base on which to set the robot is fixed to the stack shell by small diameter stud bolts as shown in Fig. 4. Welding time for each stud bolt is about 0.5 seconds and it has been confirmed that the back coating film isn’t damaged thanks to low heat input. Because the robot is fixed to the stack shell by way of the base, the robot can weld even if the stack shell is vibrating in the wind. While this welding method requires advance instruction, the touch sensor enables this worker instruction time to be shortened. A laminated welding program to reduce defects in multipath welding is developed. Thus it is possible to create the full path of a robot welding program after only one instruction session.

2.2 Plate repair welding procedure using a low heat input welding method

The test bodies used in the experiments are shown in Fig. 5. The lower plate is 300 mm × 300 mm × 9 mm, and the piled plate is 150 mm × 150 mm × 9 mm. The steel species is SS400 and the corner part is 50R for better weldability. The weld line is shown by a red line in Fig. 6 and the welding position is flat, vertical downward, and overhead. The backside of the test body is coated with tar epoxy paint, a low heat resistant coating material used in chimneys. With this method, multi pass welding is necessary in order to achieve a low heat input. In the case of a lap fillet weld 9 mm thick, welding is done in 6-7 passes. The pass sequence in the case of 6 passes is shown in Fig. 7. The necessary leg length is 6 mm and with the pass sequence welding defects such as lack of fusion are considered less likely to occur. The welding conditions are shown in Table 1. Welding conditions in each path are the same, with only the aim position changing. In this method tack welding is also performed by a robot so as not to damage the back coating film.
3. Weld and coating film performance test

3.1 Weld bead cross section

The cross section macrostructure test results of the weld beads created in 6 passes using the developed method and in 1 pass using the conventional method (CO₂) are shown in Fig. 7. The solid line is the base material boundary before welding and the dotted line is the boundary of the heat affect zone after welding. It is seen that the weld bead created using the developed method has shallow penetration and very little heat input. The bead toe is smooth so stress concentration is unlikely to occur. Sufficient throat thickness is obtained by multi pass welding. In order to confirm that it had sufficient joint strength, a specimen was subjected to a tensile test (JIS Z 3131) as shown in Fig. 8. The results are shown in Table 2. In the case of the developed method, the fracture position is in the base material and sufficient strength is obtained.

3.2 Bead appearance

Weld beads obtained using the developed method are shown in Fig. 9, and using the conventional method in Fig. 10. Figure 9 is 6-pass and Figure 10 is 1-pass. Comparing the two cases, it is seen that very good bead appearance is obtained by using the developed method. As shown in Fig. 11, welding is also possible when not dealing with rounded corners. It is possible to weld various shapes of plates.

3.3 Wind resistance performance

In this method, the wind resistant nozzle is fitted to the torch tip of a welding robot and it is possible to weld in windy outdoor conditions using a high shielding gas flow rate. In order to confirm the wind performance of the method, welding experiment is performed in strong wind. Plate welding was performed indoors in crosswinds of 7.5m/s generated by a blower. The results are shown in Fig. 12. In the case of not using the wind nozzle (shielding gas flow rate of 20l/min), many blowholes occurred and bead appearance was bad. On the other hand, in the
case of using a wind resistant nozzle (high shielding gas flow rate) good welding was done despite the strong winds. By using the wind resistant nozzle even under strong wind of up 10 m/s, it was confirmed that it is possible to weld. Because a wind speed of 10 m/s is a reference value at which on-site work at high elevations is canceled\(^1\), the wind resistance performance was considered sufficient.

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3.4 Coating film performance test

Coating film performance tests were carried out on specimens welded using this method. The cross-cut test (JIS K 5600-5-6) was done on a 9 mm thick specimen (SS400) whose back surface was coated with tar epoxy paint to confirm the adhesion of the coating film after welding. The results of comparing 6-pass and 3-pass are shown in Table 3. In the 3-pass welding, the amount of heat input per pass increased, thus the back coating film peeled off in the cross-cut test. Because 6-pass welding is low heat input welding, the back surface coating film did not peel and wasn’t damaged. The welding using this method was 6-pass on 9 mm thick base material and there were no problems with the adhesion of the backside coating.

The salt spray test (JIS Z 2371) was carried out on the same welding test specimen, and the backside corrosion resistance was evaluated.

The salt spray test was carried out for 240 hours in a NaCl aqueous solution of 50 g/ℓ (pH 6.5-7.2). A comparison of results in the case of 6-pass and 3-pass welding is shown in Table 4. In the case of 3-pass creation with its large heat input, it is seen that the back surface coating film is corroded and damaged along the weld line. On the other hand, in the case of 6 passes, there is no corrosion of the weld back surface coating. Before the corrosion test, a cutter was used to purposely score the base material with X-shaped marks, which showed corrosion after the test. From the above results, in the case of 6-pass welding of 9 mm base material, it can be said that there is no problem with the corrosion resistance of the back surface coating film after welding.

4. Weld and coating film performance test

4.1 Backside temperature guarantee

During lap fillet welding in a chimney stack shell, it isn’t possible to see the back coating film. Especially, in the stack shell of nuclear power plants, people can’t enter inside the chimney and check the status of the back coating film. Therefore, when low heat input welding is used, a technique by which to confirm that the back coating film isn’t damaged is essential. A countermeasure is necessary to manage the backside temperature in real time during welding and to stop the welding when the heat input becomes excessive for some reason. To manage backside temperature, the temperature of the weld surface is taken as a possible measurement item. In this study, the integrity of the back coating film is guaranteed by measuring the temperature of the weld surface during welding in real time.

4.2 Surface temperature measurement method

In this system, a small, light thermal sensor is attached to the
tip of the torch of the welding robot to measure the surface temperature data of the weld. The specifications of the thermal image sensor used are shown in Table 5. By using the thermal sensor, thermal image data and test data are acquired at a sampling rate of 1 Hz. The thermal sensor has an image capture range of 95 mm × 95 mm and being attached to the tip of the torch always follows the robot’s motion and captures images of the welding position. By adjusting the posture of the welding robot, the temperature of the spliced joint plate can be measured and the interpass temperature can be controlled.

Table 5 Temperature sensor specifications

<table>
<thead>
<tr>
<th>Temperature measuring range</th>
<th>100°C~800°C</th>
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<tr>
<td>Flame time</td>
<td>3 Hz</td>
</tr>
<tr>
<td>Temperature measuring accuracy</td>
<td>0.5°C (at 100°C black body)</td>
</tr>
<tr>
<td>Accuracy</td>
<td>The bigger of ±1%or±3°C</td>
</tr>
<tr>
<td>Detection element</td>
<td>2000 pixel</td>
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<td>Measurement wavelength</td>
<td>center wavelength 10 μm</td>
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<td>View angle</td>
<td>25° × 25°</td>
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<td>Spatial resolution</td>
<td>9.1 mrad</td>
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<td>Focus</td>
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</tr>
<tr>
<td>Mass</td>
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</table>

4.3 Temperature judgment method

From the surface temperature data obtained by the thermal sensor during welding, it is determined whether the amount of heat input is appropriate. Figure 13 shows how the heat input is judged. The length \( L \) (from high temperature point \( T_h \) to low temperature point \( T_l \)) can be calculated using test data. During all welding passes from the start to the end, \( T_h \) is set to be lower than the highest temperature at each data value. \( T_l \) is higher than the maximum temperature of the right end point column. The length \( L \) is point-by-point, connecting all the maximum value pixels of each column from point \( T_h \) to point \( T_l \).

In determining reference value \( L_C \), a cross-cut test (JIS K 5600) and salt spray test (JIS Z 2371) were done to check the soundness of the back coating film after welding. Neither test revealed any problem, showing that using this system managed surface temperature during welding and prevented heat damage.

By comparing \( L \) with reference value \( L_C \), the program judges whether heat input is excessive. If \( L \) is greater than \( L_C \), the program detects excessive heat input and sends a stop signal to the robot controller. The welding robot then stops even if partway through a job.

The value of \( T_h \) and \( T_l \) depends on the thickness of the base plate and welding conditions. The value of \( L_C \) changes with each pass. Figure 6 shows the weld pass sequence of 6-pass lap fillet welding. The thickness of both the base and lap plate is 9 mm. Table 6 shows the values in this case of \( T_h \), \( T_l \), and \( L_C \). \( T_h \), \( T_l \), and \( L_C \) are calculated for each base plate thickness and summarized to a database. Since the weld pass sequence and welding conditions change with the thickness of the base plate, thresholds must be set that meet each set of welding conditions.

5. Conclusions

It is developed a low heat input welding method not to damage backside coating film, using a welding robot. Low heat input welding is achieved using a low voltage power source and a robot which can weld fast. A wind resistant nozzle is developed and it can weld under strong winds of up to 10 m/s. The integrity of the backside coating film was checked using various tests and weld beads were found to have sufficient strength. It is possible to guarantee a certain backside temperature by using surface temperature data acquired by a thermal sensor during welding. Low-heat input welding using this technology can be used not only on chimneys, but on bridges, tanks and other steel structures too.

References
[1] The Ordinance on Industrial Safety and Health - Article 552 (1972)