Optimization of Welding Materials and Conditions for High Speed Submerged Arc Welding of Spiral Pipe*

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Synopsis
Spiral pipe mill in which submerged arc welding is made immediately after pipe forming limits the productivity by the welding speed. The higher welding speed is restrained by occurrence of inner bead defects such as undercutting and concave shape.

The high speed spiral welding techniques including development of new flux and determination of proper welding parameters were established by laboratory simulation tests.

By applying these techniques to actual spiral pipe mill, it became possible to obtain 4 m/min in welding speed.

I. Introduction
Spiral pipe manufacturing process is advantageous in several aspects for the production of large diameter pipe. The spiral welded pipes with their outside diameters ranging from 600 to 2 540 mm and wall thickness of up to 25.4 mm are successfully used for pipe pile as well as line pipe.

In spiral pipe production, formed pipe undergo the inside and outside submerged arc welding immediately after spiral forming. Its productivity is entirely influenced by the welding speed. The process is characterized by welding on inclined surface, which brings easily about weld defects. In order to increase welding speed, it is necessary to develop welding flux and to select proper welding conditions to overcome the weld defects peculiar to spiral welding.

This paper first deals with high speed welding techniques established by laboratory simulation test including development of new spiral welding flux, and then their successful application to actual spiral mill production to reach 4 m/min of welding speed for 9 mm thick pipe wall.

II. Features of Spiral Pipe Welding
A flow of spiral pipe mill is given in Fig. 1. Coiled material is straightened by roll leveller and the tail and front ends of the coils are welded by either tandem SAW or tandem MIG-SAW from one side. Side cutting and bevelling is done by side trimmer to ensure that the bevelled edges have a smooth surface. Preforming the strip edges with prebend roll has proved to be the best method to minimise peaking. The pipe is formed into a spiral by a three-roll bending system. The formed pipe is simultaneously welded inside and outside by tandem SAW (DC-AC). After the welded pipe is subjected to nondestructive testing, it is cut into a certain length.

Since spiral welding is done on inclined surface continuously varied, the bead geometry has the following characteristics:

(1) Inner Bead Shape
As inner welding is performed by the electrode position illustrated in Fig. 2, the position directly under arc corresponds to uphill welding and the final solidifying position to downhill. Accordingly, inner weld has inevitably concave bead shape and easy occurrence of undercutting.

(2) Outer Bead Shape
Outside welding is characterized by downhill for the arcing position and uphill for the final solidifying position, which results in a convex, so called two step bead.

High speed spiral welding causes the above undesired bead geometry and undercutting. These properties are strongly influenced by welding flux and

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welding parameters. Since the defects of outer bead can be removed by adjustment of electrodes position, it is not too much to say that high welding speed of spiral pipe depends upon controlling of the defects of inner bead such as concave shape and undercutting.

III. Development of High Speed Welding Flux

1. Simulation Test on Plate

In order to select and develop high speed welding flux, it is necessary to establish the test method to evaluate easily occurrence of inner bead defects such as concave shape and undercutting. Tandem SAW was done on plate with the various inclined angles according to the welding condition shown in Table 1. Figure 3 gives the test results of undercutting and degree of concave within a range of -2°~6° of inclined angle using a conventional spiral welding flux. The macrosections are shown in Photo. 1. Increased gradient causes less undercutting and more concave. From this tendency, the characteristics of spiral welding flux can be evaluated as follows:

- **Undercutting**: Undercutting ratio (%) of weld bead on the flat plate (gradient 0°)
- **Concave**: Concave depth (mm) of weld bead at 5° downhill

2. Evaluation of Fluxes in Terms of Undercutting and Concave Shape

The above simplified test was applied to commercially available fluxes to clarify their characteristics on inclined surface. The test results are summarized in Fig. 4. Group A is for ordinary flux used for flat welding, while group B has high MnO to improve the resistance to undercutting. Group C is characterized by high MnO and either high Al2O3 or MgO, TiO2, resulting in an improved resistance to undercutting and concave. The properties of flux to be still more developed are shown by an arrow.

The constitutional peculiarities of spiral welding flux are generally explained as follows:

1) High MnO content to prevent the occurrence of undercutting
2) High flux melting temperature by adding Al2O3 and MgO, resulting in a reduced molten slag layer to restrain the concave geometry
3) Increased arc stability by addition of TiO2 to reduce irregularity of bead

In order to obtain the flux with more excellent spiral weld operative characteristics, 20 kinds of SiO2-MnO base fluxes with various amounts of MgO, Al2O3, ZrO2, CaO, TiO2, FeO were produced experimentally. Their basicities calculated by Boniszewsky's equation range from 0.28 to 1.62.

These laboratory fluxes were produced by melting materials in electric arc furnace followed by dry cooling. The grain size is controlled to be 12×150 mesh.

The above mentioned simulation test was carried out for these fluxes, and their undercutting ratio and concave depth were measured. The test results are summarized in Fig. 5. A ◯ mark gives the properties of a conventionally used spiral welding flux.

No. 5 and No. 9 fluxes gave irregular bead shape along the seam, so that the undercutting and concave properties could not be evaluated. The fluxes re-
presented by solid mark gave pock mark on the bead surface, characterized by CaO (CaF₂) content of more than 10%. No. 12 and No. 13 having high MgO and ZrO₂ respectively showed excellent concave property, but high susceptibility to undercutting. No. 18 among these fluxes was selected as a high speed spiral welding flux with the desired characteristics indicated in Fig. 4. This flux is characterized by MnO/SiO₂=0.7, high Al₂O₃, medium MgO, high TiO₂ and small amount of FeO to possess high melting point and arc stability.

3. Spiral Weld Operative Characteristics and Physical Properties of Flux

It is well known that the physical properties of flux influence bead shape and defect occurrence. These properties of the above 20 fluxes were measured by the following methods.

1) Bulk density: According to JISK 6721-1977
2) Melting point: Spheroidized temperature of flux grain in Ar atmosphere
3) Fluidity: Flow length of 1300 °C melted flux in a grooved plate with an inclined angle.

The clear relationship did not exist between these physical values and undercutting. The relation of flux melting point vs. degree of concave shape is given in Fig. 6. Concave depth decreases with increasing flux melting temperature.

A section of bead longitudinal direction are schematically illustrated in Fig. 7. Degree of concave shape depends mainly upon flow of molten metal during solidifying process, namely, the velocity of molten metal, Vₘ. This velocity is influenced by viscosity and thickness of slag, so that low fluidity and high melting temperature cause less concave shape. Bulk density has the effect of impeding molten metal’s flow by pressing molten metal from the top. The above relationship between depth of concave and physical properties is formulated by regression analysis as follows:

\[ C = 6.3 - 3.3 \times 10^{-3} MP + 1.4 \times 10^{-2} F - 1.2 \times 10^{-1} \sqrt{F} - 0.8 BD \] ..............................(1)

where, \( MP \): Melting point of flux (°C)
\( F \): Fluidity (cm)
\( BD \): Bulk density (g/cm³).

The correlations between calculated and measured concave depth are shown in Fig. 8.

IV. Selection of High Speed Spiral Welding Conditions

1. Full Scale Spiral Welding Simulator

Welding parameters are another dominant factor to control weld geometry and defects. In order to
select proper welding parameters, a full scale spiral welding apparatus to simulate actual spiral mill was used. Figure 9 gives the outline of its apparatus. While a 1.6 m long pipe rotates on a turning roller, tandem SAW touch furnished on the top of manipulator advanced into pipe. Though formed pipe is welded with fixed torch for spiral pipe mill, this apparatus can simulate the actual spiral pipe inner welding with respect to bead formation.

The higher welding speed was examined with particular reference to low arc voltage of trailing torch by setting up the welding speed of 2.0–3.5 m/min based on the present welding conditions for 9, 12, 14, 19 mm thick pipe wall. The newly developed flux mentioned in Chap. III was used for this experiments.

2. Effects of Welding Parameters on Inner Bead Shape

The relationship between welding parameters and bead shape is shown in Fig. 10. Reproduced flux gives the almost same bead profile as the new one for both welding conditions. The weld penetration depth, $P$ is given as a linear function of $(I_1+I_2)/v$ as follows:

$$P = 1.2 + 0.65(\frac{I_1+I_2}{v})$$

where, $I_1$, $I_2$: Current of leading and trailing electrode, respectively (A)
$v$: Travelling speed (cm/min).

The concave depth decreases with a decrease in welding speed for a given $(I_1+I_2)/v$ and with decreasing arc voltage of trailing torch.

This effect of lower arc voltage was confirmed by a hammer-blow test which means that plate welded by single SAW is blown down during welding to clarify the behaviour of molten metal. Figure 11 gives the relationship among arc voltage, crater length and amount of molten slag per length. Higher arc voltage gives long crater and increased molten slag, which results in a remarkable fall of molten metal at final solidifying stage.

3. Selection of High Speed Welding Parameters

The following conditions based on lower arc voltage of trailing torch and use of newly developed flux were raised to find the suitable welding parameters:

1) Free from undercutting
2) Concave depth of up to 1.0 mm
3) Weld penetration depth of half of thickness.

The relationships among parameter \((I_1 + I_2)/v\), concave depth and weld penetration depth are shown again in Fig. 12, where weld penetration depth and allowable concave depth taking existence of groove into account are also given. A 19 mm thick plate with groove caused 1.3 mm increase in penetration depth and 0.3 mm decrease in concave depth as compared with bead on plate.

A flow of determination of inner welding parameters for 9 mm wall thickness as an example is given in Fig. 13. This results indicates that 4.5 m/min of welding speed can be achieved for 9 mm wall thickness, provided a developed flux can be used under the proper welding conditions.

V. Application of High Speed Welding Technique to Spiral Pipe Mill

When a new flux is applied to welding spiral pipe mill, one of the dominant parameters to control bead profile is selection of torch position to prevent final weld solidifying point from being situated in the steep inclined position for higher welding speed. Outside welding can select any welding head position because of finishing pipe forming. On the other hand, inside welding limits the head position since welding is done immediately after joining of pipe and plate. By raising plate intake level by 155 mm, a relative head position of 50~60 mm became possible because of joining pipe with plate with enough length from the bottom of pipe.

Figure 14 shows the effect of relative position of welding head on weld penetration depth, inner bead concave depth and outer bead reinforcement height, for a newly developed flux.

These high speed welding techniques including welding flux and welding parameters were applied to actual spiral pipe mill for wall thickness of 9, 12 and 16 mm. The welding conditions and the resultant bead geometry are given in Table 2. The satisfactory bead profiles without undercutting were obtained.

![Fig. 12. Nomograph for determination of welding conditions (Tandem SAW).](image)

![Fig. 14. Effect of relative position of welding head on weld penetration depth, inner concave depth and outer bead reinforcement height.](image)

![Fig. 13. Flow for determination of welding parameters for 9 mm thick pipe wall.](image)
The welding speed newly developed against pipe wall thickness is shown together with the conventional method in Fig. 15. Its speed increases by 165 % and 120 % of the conventional speed for thinner plate and thicker plate respectively, and gives maximum 4.0 m/min for 9 mm wall thickness.

VI. Conclusions

Tests to increase spiral welding speed were carried out, and the following results were drawn.

(1) Main factor to impede higher speed spiral welding is defects of inner bead such as undercutting and concave shape. A simplified test to make SAW bead on inclined surface was established to simulate occurrence of these inner weld defects.

(2) A flux having MnO/SiO2: 0.7, high Al2O3, medium MgO, high TiO2 and small amount of FeO was newly developed as high speed spiral welding flux.

(3) Concave bead depth by the simplified standard test can be formulated by the following physical properties of flux,

\[ C = 6.3 - 3.3 \times 10^{-8} MP + 1.4 \times 10^{-2} F - 1.2 \times 10^{-1} / F - 0.8 BD \]

where, 
MP: Melting point (°C)
F: Fluidity (cm)
BD: Bulk density (g/cm³).

(4) Torch position and low arc voltage of trailing torch among welding parameters are the important factors to obtain satisfactory inner bead shape. By taking these effects into account, the welding conditions suitable for a new flux were rationally established.

(5) Application of the above high speed spiral welding techniques to actual spiral pipe mill proved to get 4 m/min in welding speed for 9 mm thick wall pipe.

REFERENCES