DEVELOPMENT AND APPLICATION OF THE 3-ELECTRODE MAG HIGH-SPEED HORIZONTAL FILLET WELDING PROCESS

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ABSTRACT

In the shipbuilding industry, welding efficiency without deteriorating weld quality has been desired to, as a consequence of the recent increase in the amount of shipbuilding and the size of ship hulls. Especially, an innovation in the welding efficiency and weld quality in horizontal fillet welding is a more important issue, because the amount of horizontal fillet welding work generally accounts for 70 percent or higher of the total welding work for ship hulls. One of high-speed horizontal fillet welding processes known as "Twin Tandem One Pool process" has been used in actual fabrication. However, the maximum welding speed of the twin tandem one pool process is approximately 1.5 m/min. In order to increase welding speed and welding quality of the twin tandem one pool process, the authors have employed an additional filler wire positioned between the two wires of the twin tandem one pool process. The additional wire carries DC-EN currents, opposite to DC-EP currents for the main welding wires, thereby reducing arc interference and arc blow at high currents. With this new technique, the authors have improved the stability of the weld pool formation at high currents. Consequently, horizontal fillet welding at a speed of 2.0 m/min on primer-coated steel plates has been achieved with excellent bead appearance, shape, and porosity resistance. Recently, this new process has just been installed in actual shipbuilding and it is confirmed that it truly contributes to improve welding efficiency and minimize repair time.

IIW-Thesaurus keywords: Filler materials; Fillet welds; Horizontal position; Molten pool; Porosity; Process parameters; Speed.

1 Introduction

Horizontal fillet welding plays an important role in shipbuilding and bridge construction. Especially, in shipbuilding, the ratio of horizontal fillet weld length to the total weld length accounts for approximately 70 %. Therefore, it is vital to improve both the welding speed and weld quality in horizontal fillet welding.

At present, the twin tandem one pool process is widely used as a horizontal fillet welding process that can achieve a maximum welding speed of about 1.5 m/min. A schematic diagram of the twin tandem one pool process is shown in Figure 1. In this process, a set of two wire electrodes is positioned in tandem on both sides of the web plate of a fillet joint, and the two wire electrodes deposit one weld pool. As compared to the twin-single-electrode process whose maximum welding speed is about 0.8 m/min, the twin tandem one pool process provides higher welding speeds and excellent porosity resistance. In shipbuilding and bridge construction, it is now satisfactorily used to produce horizontal fillet welds with a leg length of 5 to 6 mm at a welding speed of 1.2 up to 1.3 m/min.

With the twin tandem one pool process, for improving the present maximum welding speed, it is necessary to use higher welding currents (i.e., higher deposition rates). However, when the welding current of the leading wire exceeds 500 A, crucial arc interference occurs because both the leading and trailing wires use DC-EP polarity. This arc interference prevents stable formation of the weld pool, which results in poor bead appearance and shape, less porosity resistance, and increasing spatter.

2 Configuration of three-electrode MAG welding process

The three-electrode MAG welding process (advanced MAG process) has newly been developed to improve weld defects caused by the arc interference and the arc

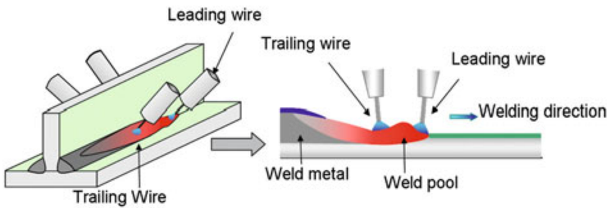

Figure 1 – Schematic diagram of twin tandem one pool process

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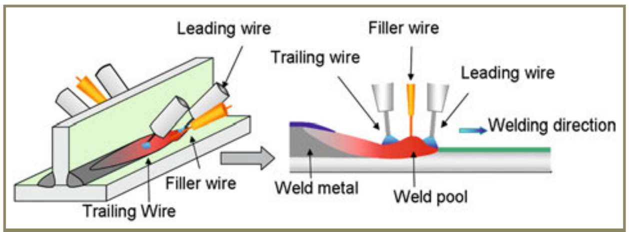


Figure 2 – Schematic diagram of advanced MAG process

blow that are induced by increasing the welding current in the twin tandem one pool process [1]. Figure 2 shows a schematic diagram of the advanced MAG process, and Figure 3 shows the basic location of the welding torches. In advanced MAG process, a filler wire is placed additionally as the third electrode between the leading and trailing wire electrodes in the twin tandem one pool process [2]. The filler wire is heated by applying a DC-EN current. The magnetic field generated by the current applied to the filler wire reduces the arc interference between the leading and the trailing wires (both wires are connected to DC-EP polarity), thereby stabilizing the weld pool. Furthermore, the addition of the filler wire gives an effect of cooling the weld pool, and thereby the viscosity of the weld pool increases, and in turn the weld pool can be stabilized. In advanced MAG process, the weld pool is more stabilized than with the twin tandem one pool process, even at higher speed welding (e.g., 2.0 m/min) with higher currents. Consequently, good porosity resistance and good bead appearance and shape can be obtained at a welding speed as high as 2.0 m/min. In this research, the advanced MAG process was compared for some items to the twin tandem one pool process in which the locations of the welding torches were kept as usual (same as those shown in Figure 3 but without the filler wires).

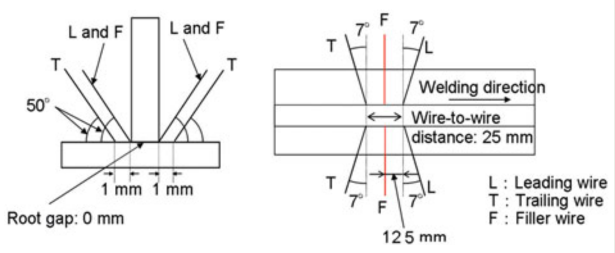


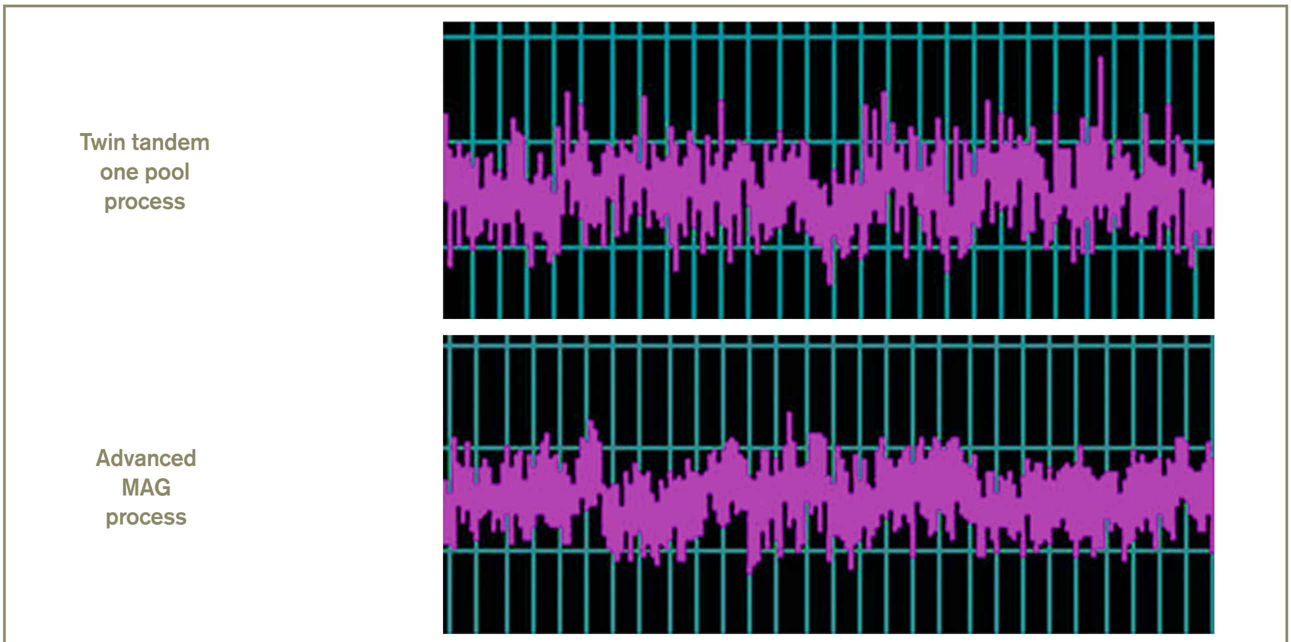
Figure 3 – Location of welding torches of advanced MAG process

The flux-cored wire with a diameter of 1.6 mm especially designed for the advanced MAG process but conformed to JIS Z 3313 T49J0T1-0CA-U was used in this research. This wire offers higher electrical resistance, hence higher Joule heat, thereby enabling the use of a lower current in order to obtain the same volume of deposited metal as with a conventional wire using a higher current. The capability of using relatively low currents makes it possible to reduce the arc interference. Furthermore, this wire is designed by optimizing the amounts of slag formers and deoxidizing agents so that it secures good porosity resistance in high-speed welding. As for the filler wire, a solid wire specially designed for the advanced MAG process with a diameter of 1.2 mm was used.

3 Performance of three-electrode MAG welding process

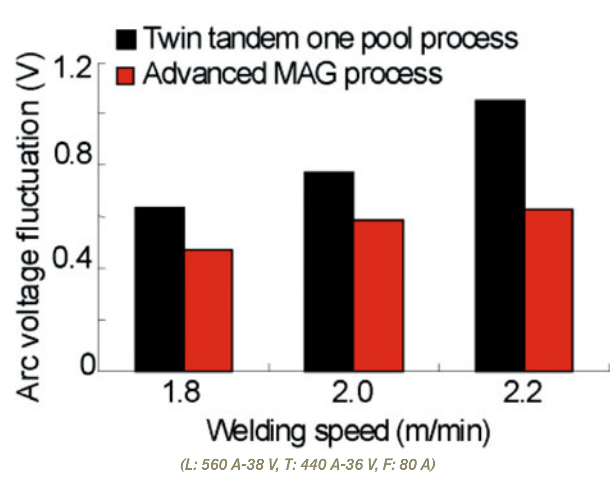
3.1 Effects of the inserted filler wire

Figure 4 shows typical fluctuations in the arc voltage of the trailing wire measured to evaluate the weld pool stability. It is obvious in this figure that the fluctuation of arc voltage waveform with the advanced MAG process is relatively smaller than that with the twin tandem one



(L: 560 A-38 V, T: 440 A-36 V, F: 80 A; Travel speed: 2.0 m/min).

Figure 4 – Effect of welding process on arc voltage profile



(L: 560 A-38 V, T: 440 A-36 V, F: 80 A)

Figure 5 – Effect of welding speed on arc voltage fluctuation

pool process. This phenomenon can be attributed to the stable contour of the weld pool provided by inserting the filler wire. That is, the arc length fluctuates less due to the stable weld pool contour, thereby reducing the arc voltage fluctuation.

Figure 5 shows a comparison of the arc voltage fluctuations (standard deviations of arc voltage measurements) with the advanced MAG and twin tandem one pool processes at welding speeds of 1.8, 2.0, and 2.2 m/min. As observed in this figure, the weld pool generally becomes unstable as the welding speed increases; however, arc voltage fluctuation at a welding speed of 2.2 m/min with the advanced MAG process is less than that at a welding speed of 1.8 m/min with the twin tandem one pool process.

We also observed the behaviour of the weld pool captured with a high-speed camera. Figure 6 shows the weld pool with both the twin tandem one pool and advanced MAG processes. The weld pool of the advanced MAG process is more stable than that of the twin tandem one pool process.

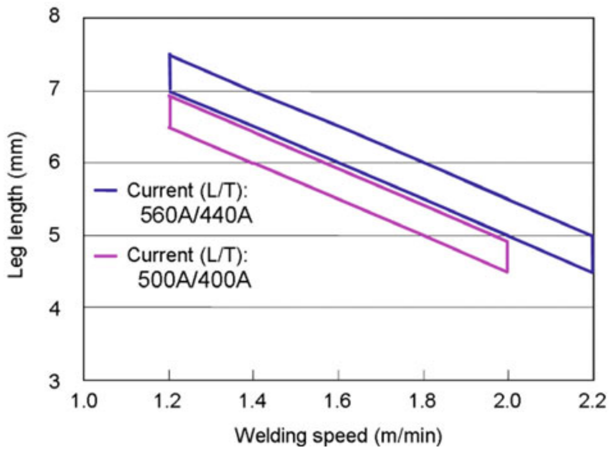
3.2 Proper welding conditions in three-electrode MAG welding process

Figure 7 shows the proper ranges of welding speeds and leg lengths with the advanced MAG process. The optimum welding speeds range from 1.2 to 2.2 m/min. The optimum leg lengths range from 4.5 to 7.5 mm. Figure 8 shows the typical fillet weld bead appearance and shape obtained by the advanced MAG process at a welding speed of 2.0 m/min.

3.3 Porosity resistance in three-electrode MAG welding process

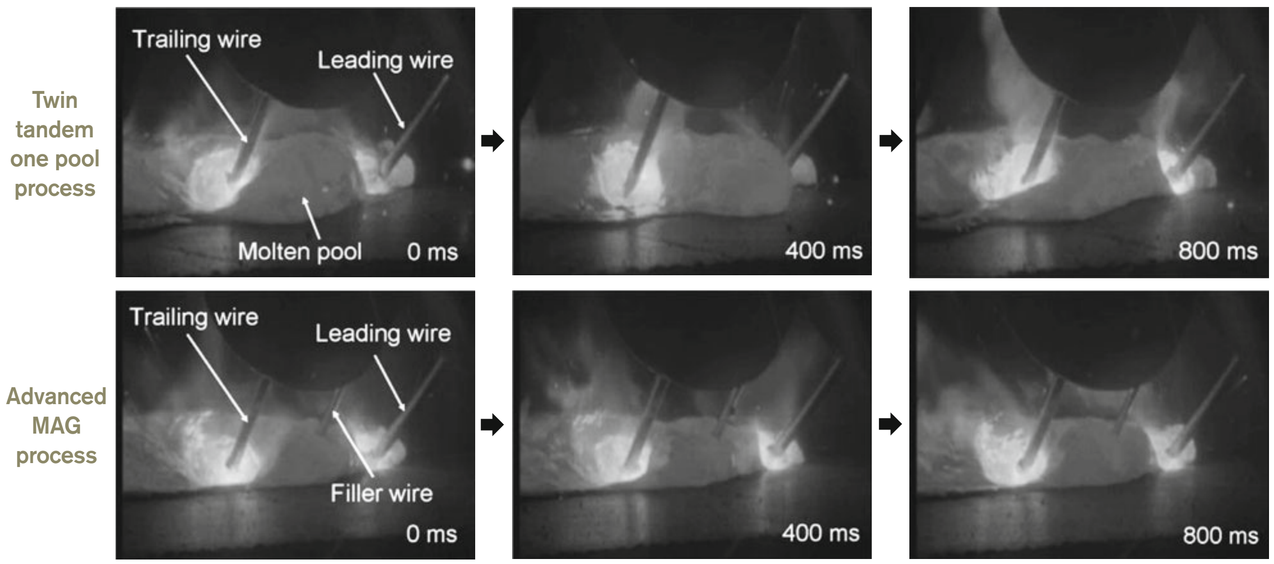
Figure 9 shows test results of the porosity resistance of fillet welds at welding speeds of 1.6, 1.8 and 2.0 m/min. To evaluate porosity resistance, the number of pits and the generation ratio of worm-tracking porosity on the weld bead surface were investigated.

For the test plates, JIS G 3106 SM490A steel was used. The dimensions of each plate were 12 mm in thickness,



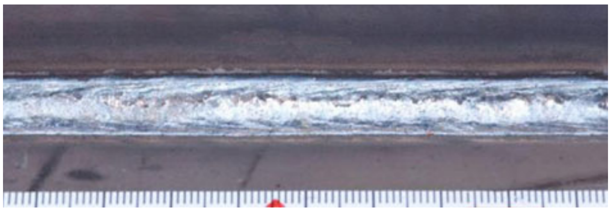
(F: 80 A; Filler wire feed rate: 2.0 m/min).

Figure 7 – Leg length as a function of welding speed

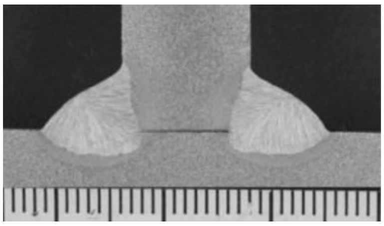


(L: 560 A-38 V, T: 440 A-36 V, F: 80 A; Travel speed: 2.0 m/min)

Figure 6 – Comparison of molten puddle stability (captured by high-speed video; 360 Hz)



a) Bead appearance



b) Cross-sectional bead shape

(L: 560 A-38 V; T 440 A-36 V; F: 80 A; Travel speed: 2.0 m/min; Base metal surface: Inorganic zinc primer coating).

Figure 8 – Typical bead appearance and shape with advanced MAG process

85 mm in width and 600 mm in length for both the web and flange plates. The test plates were coated with inorganic zinc primer, the coating thickness of which was controlled to be 30±5 µm. For evaluating the porosity resistance under such a severe condition that generated gases were difficult to escape from the root of the fillet joint, the lower edge of the web plate was machined evenly to make a close contact with the flange plate surface. As for pits, the mean value of the number of pits on the weld beads on both sides of the web plate was considered as the number of pits for one test cycle . The generation ratio of worm-tracking porosity on one side of the web plate was calculated by Equation (1), and the mean value of the calculated figures on both sides of the web plate was considered as the generation ratio for one test cycle.

$$\Sigma d\,[\mathrm{mm}]/600\,[\mathrm{mm}] \times 100\,[\%] \qquad (1)$$

where

Σd is the total length summed up over the individual worm-tracking porosities occurred in the welding direction on the weld bead surface.

For the number of pits and the generation ratio of worm-tracking porosity on the weld surface, the mean values obtained by three test cycles were used for evaluation.

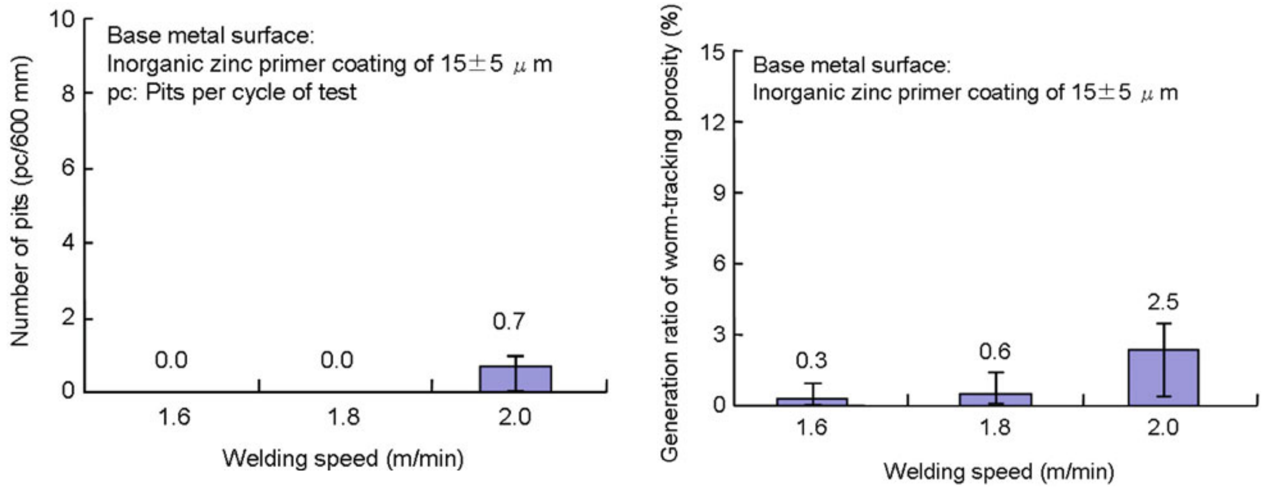
As welding speed increases, the porosity resistance generally tends to decrease; however, the test results can generally be regarded as sufficient porosity resistance in terms of practicality, taking into account the above-mentioned severer test conditions than under actual fabrication conditions.

4 Application in actual shipbuilding

Recently, the advanced MAG process has been introduced in actual shipbuilding in Japan. Figure 10 shows a welding machine equipped with this advanced MAG process. In this application, fillet welded joints with a leg length of 6 to 6.5 mm are obtained at a welding speed of approximately 1.4 to 1.5 m/min. At this speed, the surface of the weld metal is virtually free from pits or wormholes in actual shipbuilding. Therefore it is confirmed that this process truly contributes to improve welding efficiency and minimize repair welding time.

5 Conclusions

It has been confirmed that the advanced MAG process is superior to the twin tandem one pool process in terms of weld pool stability and arc interference resistance in higher-speed horizontal fillet welding at a welding speed of up to 2.0 m/min. With such superior characteristics, the advanced MAG process can provide better porosity resistance as well as consistent bead appearance and shape.



(L: 560 A-38 V; T: 440 A-36 V; F: 80 A)

Figure 9 – Results of porosity resistance tests

1 set of advanced MAG process
Welding speed: 1.5 m/min
Leg length: 6.0 to 6.5 mm

5 sets of advanced MAG process
Welding speed: 1.4 m/min
Leg length: 6.0 to 6.5 mm

Figure 10 – Application to shipyard welding machines

With such improved performances, the advanced MAG process will be able to contribute largely to improve welding speed and weld quality in horizontal fillet welding in shipbuilding and bridge construction.

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