Suppression Mechanism of Overlapping Defects in High Speed TEB Welding†

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In previous report[1], overlapping defects in high speed electron beam welding at over 0.25 m/sec were suppressed by the Tandem Electron Beam welding method. In this report, the suppression mechanism is discussed using high speed observation of welding phenomena.

Figure 1 shows the experimental setup of the high speed observation system. The first and the second electron beams and a high speed camera are aligned along the welding direction. The first beam impinges perpendicularly on the specimen and the second beam and the high speed camera are each inclined 25 degree from the vertical line. A Xenon short arc lamp is used for illumination and a 200 mm macro lens with 2X rear tele-converter is used for the close-up photography. The magnification is about 1.7 at 1m focal length. The lamp is set at the side window of the vacuum chamber and illuminates the specimen with a beam 45 degrees downward from the horizontal.

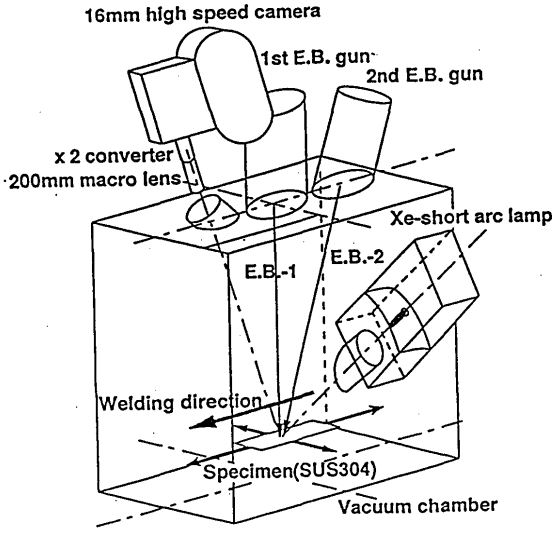

Fig.1 Experimental apparatus for high speed photography.

Figure 2 shows an example of high speed film in single electron beam welding at 0.35 m/sec showing overlapping phenomenon. Welding conditions are V_b=70 kV, I_b=225 mA, a_b=1.0, v_b=0.35 m/sec, and the specimen consists of SUS304 steel plates of 3 mm thickness. The filming rate is 3000 fps. The bright spot at the left end is beam impingement point and the welding direction is the right to the left. It can be seen that the long beam hole is formed and the molten metal is violently ejected away from both sides of the beam hole, solidifying immediately on the cold surface of the specimen.

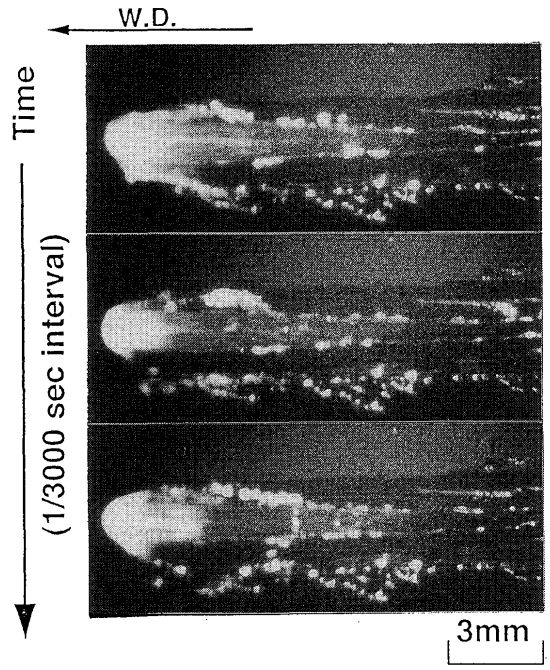

Fig.2.High speed photographs at a welding speed of 0.35m/sec.

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Analyzing this high speed movie, the following mechanism is thought to operate and is shown in **Fig. 3.** When the welding speed is low, the drilling speed of the electron beam is too high compared with welding speed, and the angle of the front wall is nearly vertical. Therefore, the direction of the molten metal flow, (which is affected by the vapor flow perpendicularly to the front wall), is horizontal. There is no molten metal flowing towards outside of the beam hole. Conversely, when the welding speed is high compared with the drilling speed of the electron beam (the energy density of the beam must of course increase), beyond a welding speed of 0.25 m/sec for SUS304 steel plates of 3 mm in thickness, the angle of the beam hole becomes low and the direction of the molten metal flow changes from horizontal to vertical. Therefore, the molten metal is channelled away from both sides of the beam hole by the high speed vapor flow. Furthermore, a high welding speed introduces a low heat input to the specimen around the bead. So, the molten metal immediately solidifies at the cold surface of the specimen. The bulk of the molten metal ejected from the beam hole cannot return to the beam hole and remains as the overlap bead.

In order to increase the front wall angle, the first beam was inclined, and in order to decrease solidification speed, Tandem Electron Beam operation was applied.

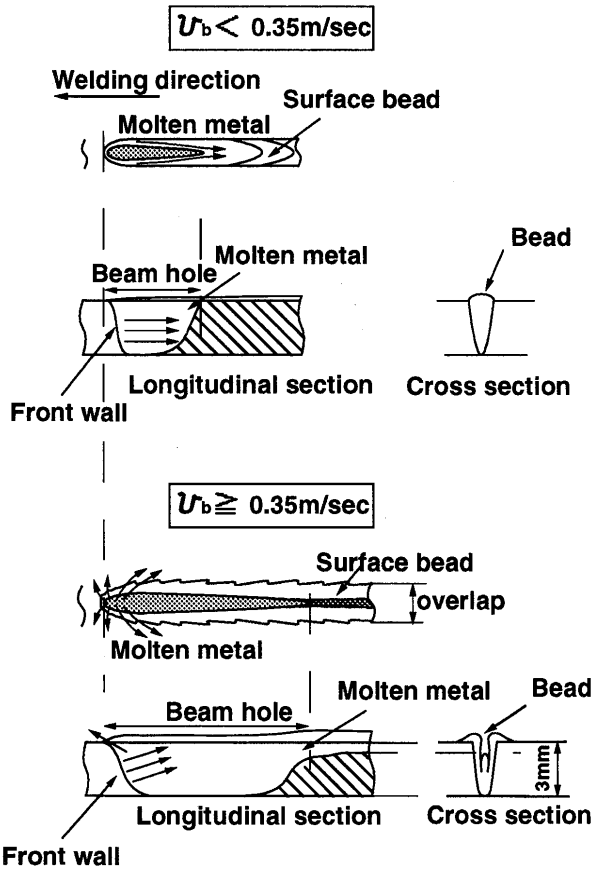

Fig.3 Formation processes of overlapping.

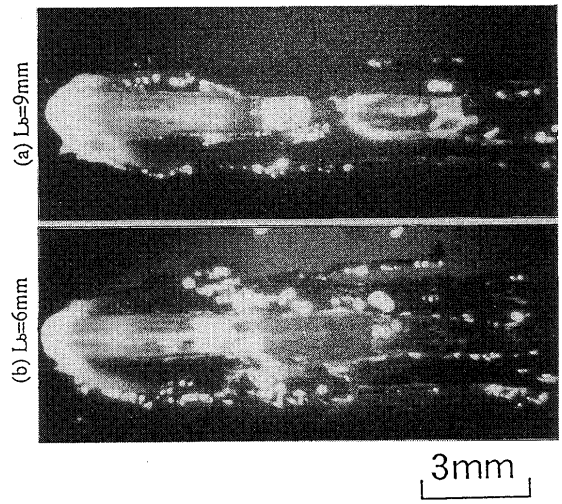

Fig.4.High speed photographs of bead surface in TEB welding.

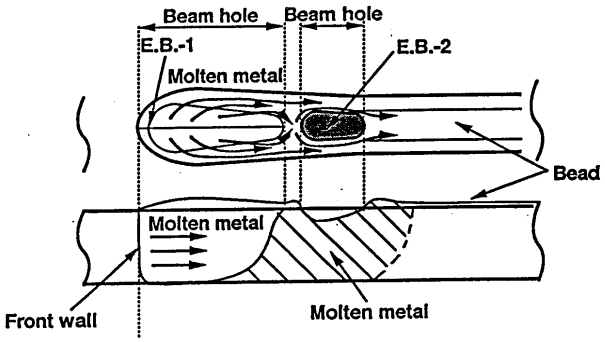

Fig.5 Suppression mechanism of weld defects in high speed TEB welding.

High Speed photographs of the bead surface in Tandem Electron Beam welding at 0.35 m/sec are shown in **Fig.4**. It is seen that the ejection of molten metal is reduced by the inclination of the first beam. The bright spot 9 mm behind of the front of the bead is the second beam impingement point, and a sound bead is formed behind that point.

The suppression mechanism of overlapping defects in high speed TEB welding is thought to be as shown in **Fig.5**. The beam inclination makes the front wall angle vertical, and the molten metal flow becomes horizontal. However, the solidification rate of the molten metal is still too high to form a sound bead. Large cavities remain inside the bead. The second beam impingement, 9 mm behind the first beam, reheats the molten metal at the end of the flow and decreases the solidification speed. Therefore, the inside the bead is filled with metal and a sound bead is obtained.

References

1) M. Tomie, N. Abe and Y. Arata; Trans. of JWRI, 23(1)1984, 103.