Title	Tandem Electron Beam Welding (Report IV) : Analysis of Beam Hole Behaviour by Transmission X-ray Method(WELDING PHYSICS, PROCESSES AND INSTRUMENTS)
Author(s)	Arata, Yoshiaki; Abe, Nobuyuki; Abe, Eiichi
Citation	Transactions of JWRI. 1982, 11(1), p. 1-5
Version Type	VoR
URL	https://doi.org/10.18910/5087
rights	
Note	

Tandem Electron Beam Welding (Report IV)†

— Analysis of Beam Hole Behaviour by Transmission X-ray Method —

Yoshiaki ARATA*, Nobuyuki ABE and Eiichi ABE*****

Abstract

Dynamic behaviour of beam hole during Tandem Electron Beam welding has been observed by transmission X-ray method. X-ray images of the beam hole filmed by a high speed movie camera have been analyzed. Stability of beam hole is discussed with connecting the incident position and angle of the second electron beam against the first beam. For deep penetration welding in Tandem Electron Beam welding, the second beam which impinges into the beam hole of the first beam with small incident angle is more effective than other conditions.

KEY WORDS: (Electron Beam Welding) (X-ray Analysis) (Behaviour of Beam Hole) (Stability)

1. Introduction

Electron beam welding method has the fundamental advantage that it utilizes a high energy density beam. It can be utilized in the fields where ordinary arc welding cannot be applyed such as in high speed welding for thin plates or in deep penetration welding for thick plates. However, the paticular welding defects such as humping for high speed welding and spiking and porosity for deep penetration welding frequently occur in these fields. Although beam oscillation method has been developing to suppress such defects, it is difficult to suppress such defects without any disadvantage by ordinary single electron beam welding.

The authors have been studying Tandem Electron Beam (TEB) welding method, which utilizes two electron beams at a time in order to suppress the welding defects effectively. In case of humping in high speed welding, by impinging the second beam to a proper position with controlling molten metal flow, such defects were suppressed completely[1]. In case of spiking in deep penetration welding, by impinging the second beam into the beam hole made by the first beam with setting the power ratio between the first and the second beam to a proper value, such defects were also suppressed[2].

Observation of beam hole during electron beam welding were performed first by Tong and Giedt[3]. They took X-ray photographs of the beam hole by a flash X-ray source. Bryant[4] also took a series of X-ray photographs by ultra high voltage pulsed X-ray source. Weber et al.[5] observed the X-rays emitted from the beam hole by pin-hole camera method, and analysed them to discuss the formation mechanism of spiking. In previous paper[6], the authors filmed beam hole X-ray images by an X-ray converter and a high speed movie camera. Analysing these high speed movie films, formation mechanism of spiking, suppression mechanism of spiking by TEB method or beam oscillation method were revealed. The comparison between two method was also discussed.

In present paper, in order to clearify the optimum condition of TEB welding method in deep penetration welding, especially, a proper incident position and angle of the second beam to the first beam, the dynamic behaviour of the beam hole has been observed by transmission X-ray method.

2. Experimental Apparatus

Figure 1 shows the block diagram of TEB welder. It has two electron guns, whose maximum output power are each 6 kW (60 kV, 100 mA). Each electron beam has own focusing lens and deflection system. Moreover, the second electron beam has the additional movable second deflection system, which can deflect the second beam in various angles and impinge it into various positions on the specimen.

Schematic diagram of the experimental apparatus is shown in **Fig. 2**. X-rays emitted from an X-ray tube pass through the specimen. They come into the X-ray converter and are converted to visible images. These images are filmed by the high speed movie camera. The X-ray tube is an industrial type with maxmum output current of 4 mA at 160 kV_p. Its focusing area

† Received on March 31, 1982

* Professor
** Research Instructor
*** The Tokyo Metropolitan Research Institute of Industrial Technology

Transactions of JWRI is published by Welding Research Institute of Osaka University, Ibaraki, Osaka, Japan

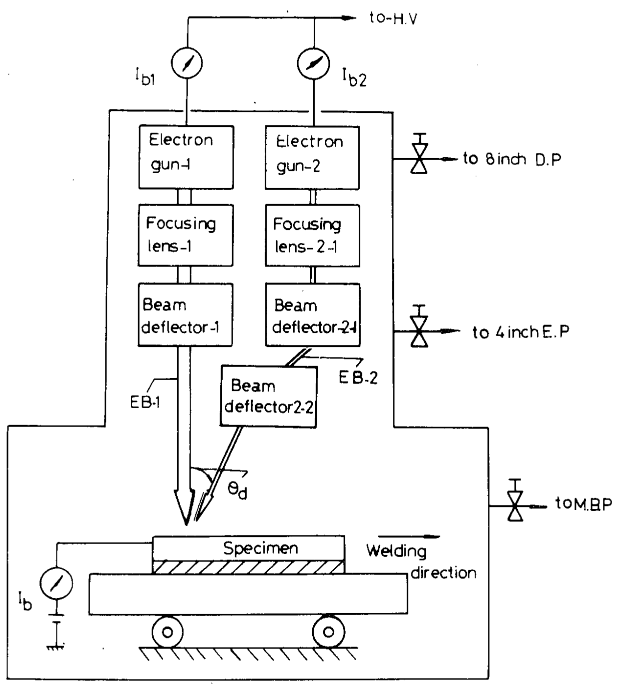


Fig. 1 Block diagram of TEB welder.

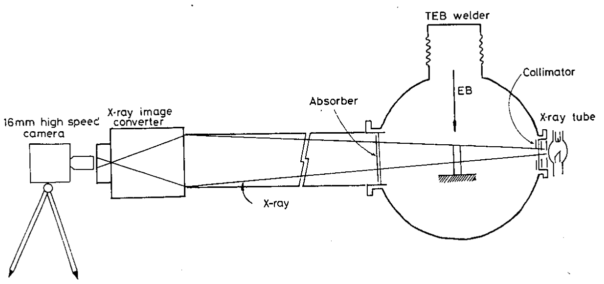


Fig. 2 Schematic diagram of experimental apparatus.

is 0.4×0.4 mm. In order to suppress scattered X-rays by the specimen which decreases the sharpness of X-ray images, three collimeters are inserted between the X-ray tube and the specimen. These collimeters expose only the local part of the specimen to the X-rays, where the beam hole is formed. The beam hole X-rays which caused by the interaction between electrons and metal are emitted from the specimen during electron beam welding. These X-rays also decrease the sharpness of X-ray images. In this experiment, in order to reduce these beam hole X-rays, the accerelation voltage of the electron beam is decreased to 36 kV, as low as possible voltage in our machine. Furthermore, brass foil of 0.2 mm thickness is added behind the observation window as an absorber to avoid these undesired X-rays. 5083 alminum alloy of 12 mm thickness is used for the specimen, because the amount of beam hole X-rays is smaller, the beam penetration depth is larger and the penetration of X-rays is easier than other materials. Distance between the specimen and the X-ray converter is about 2 m and that of the X-ray tube and the specimen is about 40 cm. Therefore, the image is enlarged about 5 times. In order to protect from scattered X-rays, the X-ray tube and a flight tube are shielded by lead. The spacial resolution at the X-ray converter is about 20 lp/cm in present experimental condition. The filming rate of the high speed movie camera is 100 fps. Colour positive films of ASA 400 sensitivity is used on 4 times overdevelopment condition.

3. Results and Discussion

Incident positions of the second beam are classified into three types as shown in **Fig. 3**. In Type A, the second electron beam (EB-2) impinges at the back of the beam hole of the first electron beam (EB-1). In Type B, EB-2 impinges into the beam hole of EB-1. In Type C, EB-2 impinges in front of the beam hole of EB-1. The shapes of beam holes change with types of incident positions. **Figure 4** shows the typical shapes. These photographs are taken on the conditions where TEB can suppress the spiking effectively[2] (incident angle=15°, current of EB-1=60 mA, current of EB-1=50 mA). On the condition of Type A, there exist two independent beam holes. On the condition of Type B, one beam hole which has wide opening and two roots is formed. On the condition of Type C, one beam hole is formed.

Fluctuations on each type are shown in **Fig. 5**. On the condition of Type A, two beam holes behave as independent beam holes. On the condition of Type B, one root caused by EB-1 fluctuates strongly but another

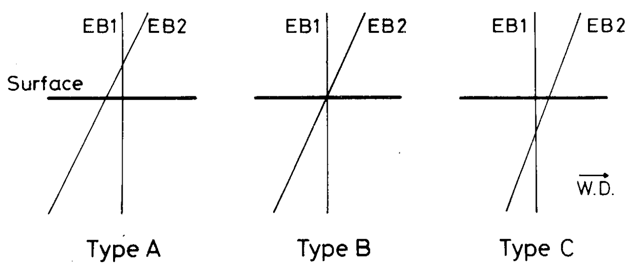


Fig. 3 Types of incident beam position.

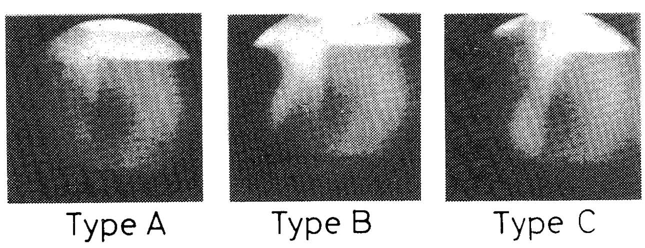


Fig. 4 Photographs of beam hole in each types.

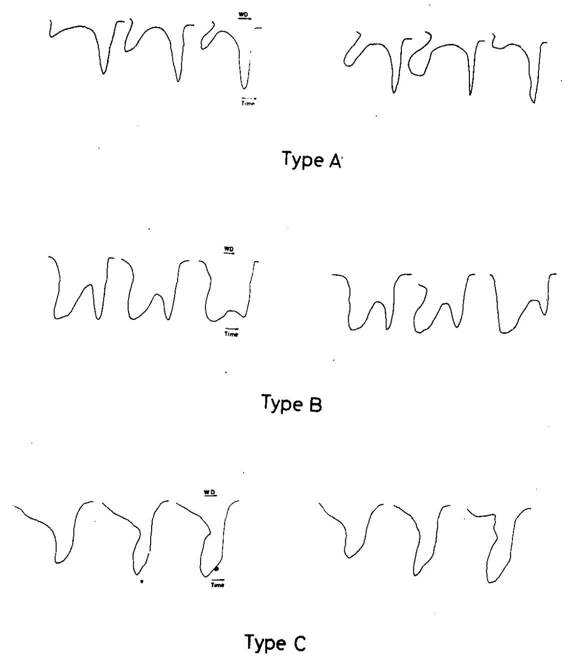
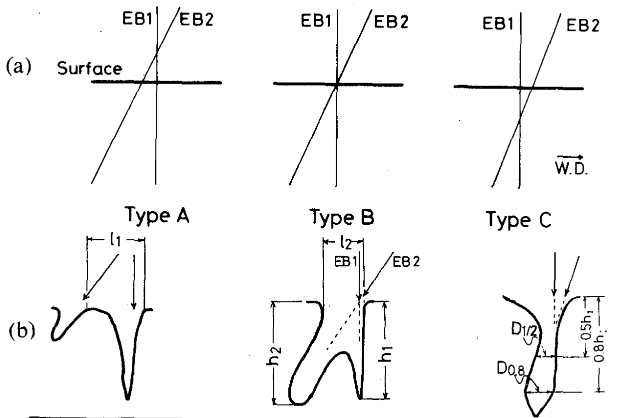


Fig. 5 Reproductions of high speed films in each types.



(c)

Type	h_1	σ_{h_1}	h_2	σ_{h_2}	$D_{1/2}$	$\sigma_{D_{1/2}}$	$D_{0.8}$	$\sigma_{D_{0.8}}$	l_1	σ_{l_1}	l_2	σ_{l_2}
A	14.4	0.9	7.1	2.0	2.3	0.5	1.9	0.7	8.6	0.5	5.6	0.6
B	14.3	1.8	16.3	0.6	8.8	2.4	4.4	0.8	—	—	13.4	0.8
C	16.0	1.9	—	—	4.3	1.4	3.3	0.8	—	—	14.4	1.6

Fig. 6 Film analysis.
(a) Type of incident position
(b) Parameters of analysis
(c) Table of results

one caused by EB-2 slightly fluctuates. On the condition of Type C, the opening and depth of beam hole are large but the beam hole fluctuates as a hole. In order to evaluate the fluctuation of the beam hole on each type quatitatively, a depth of the beam hole, a lengh of the opening of the beam hole, lengthes of the beam hole at a half depth and an 80% depth of the beam hole are measured as shown in **Fig. 6**. As clearly seen in table in Fig. 6, beam holes in Type B are most stable and has largest depth. Although the beam hole in Type C has the largest length of opening

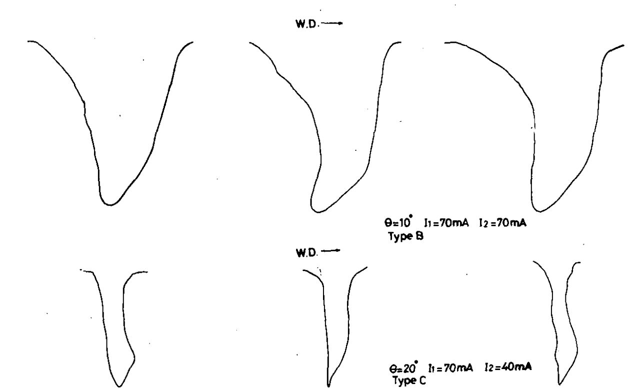


Fig. 7 Reproductions of high speed film in different incident angles.
(a) 10°, Type B, EB–1=70 mA, EB–2=70 mA
(b) 20°, Type C, EB–1=70 mA, EB–2=40 mA

and the depth is not so small, the fluctuation of depth and length of opening is larger than those in Type B.

Therefore it is revealed that as far as incident position is concerned, Type A does not fitted for TEB welding and that Type B is better than Type C at the incident angle of 15°.

On the next step, the relationship between incident angles, positions and beam hole shapes has been studied. Two incident angles (10°, 20°) are examined. **Figure 7** shows the typical shapes of the beam hole in these two incident angles. Upper reproductions show the most stable beam hole obtained on the condition of Type B, 10°, EB-1=70 mA and EB-2=70 mA. The length of opening is very large and the shape is very stable. Lower reproductions show the unstable beam hole obtained on the condition of Type C, 20°, EB-1=70 mA and EB-2=40 mA. The length of opening is small and the shape is very unstable. On this condition, sometimes the image of beam hole could not be seen on the film.

Figure 8 shows the comparison between Type B and Type C for average depth of the beam hole and its standard deviation in case of 10° (a) and 20° (b), for average length of opening and its standard deviation in case of 10° (c) and 20° (d), respectively. In case of the incident angle of 10° (see Fig. 8(a) and (c)), Type B gives larger average depth and length of opening than Type C but standard deviations are nearly the same. On the contrary, in case of the incident angle of 20° (see Fig. 8(b) and (d)), average depth and length of opening are nearly the same in those two incident angles but the standard deviation of depth of Type B is smaller than Type C. On the other hand, for the depth of beam hole (see Fig. 8(a) and (b)), the condition of incident angle of 10° and Type B is superiour than other conditions. For the length of opening

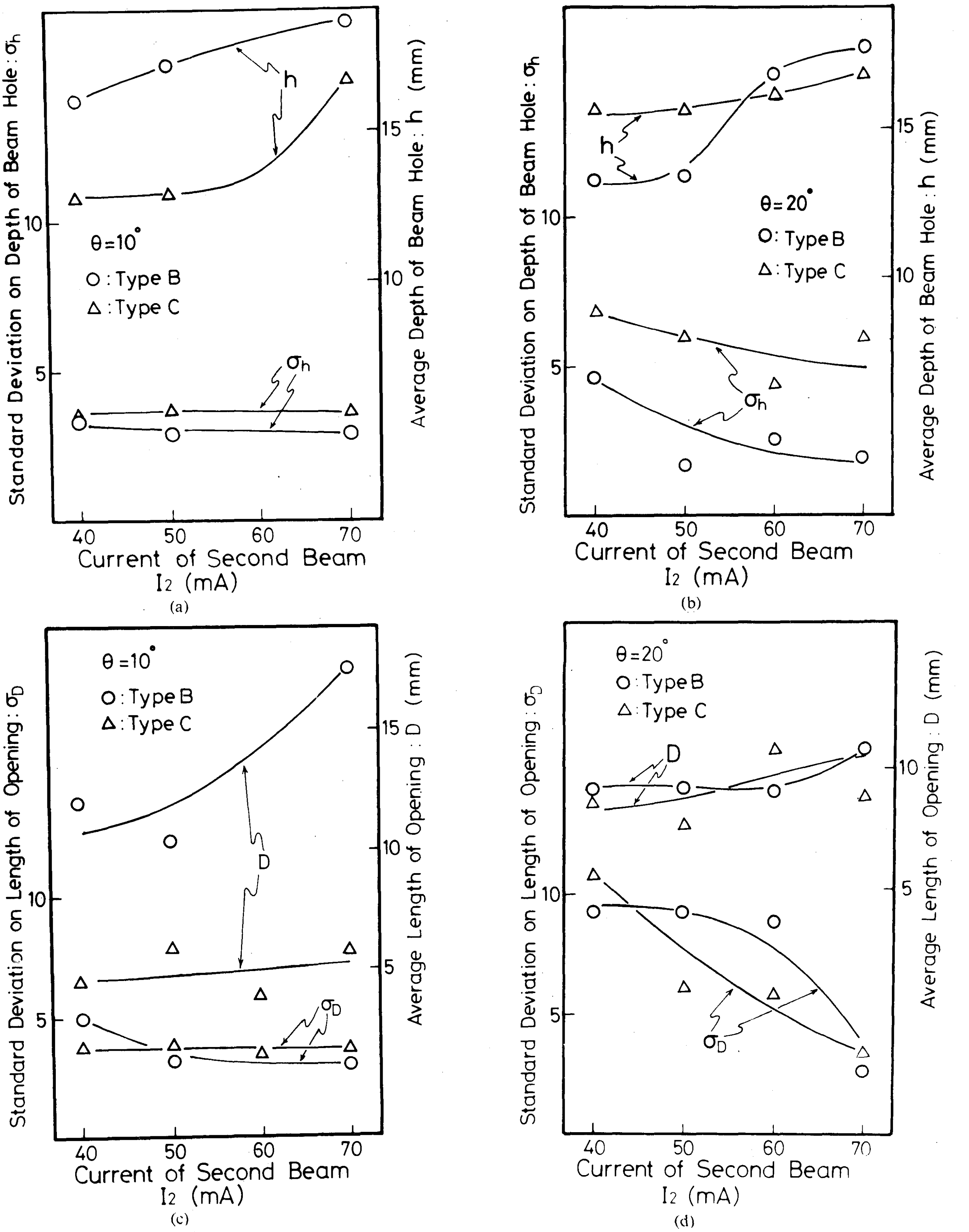


Fig. 8 Results of film analysis.
(a) 10°, average depth of beam hole and its standard deviation
(c) 10°, average length of opening and its standard deviation
(b) 20°, average depth of beam hole and its standard deviation
(d) 20°, average length of opening and its standard deviation

(see Fig. 8(c) and (d)), the condition of incident angle of 10° and Type B gives larger length and stability than other conditions.

In the previous paper[6], the authors have reported that suppression of welding defects in TEB welding is caused by remelting and repairement of the defects by low enrgy density second electron beam. In this experiment, it is found that suppression of welding defects in TEB welding is caused also by stabilization of the beam hole which is originated in broadning of beam hole in the direction of welding. (Transverse bead width is not broadened.) And it is also found that the condition of the small incident angle and Type B is superiour in depth, lenght of opening and their stability than other conditions.

4. Conclusion

Dynamic behaviour of beam hole during Tandem Electron Beam welding was observed by transmission X-ray method. Analysis of high speed film revealed the shape and fluctuation of beam hole.

At three different types of incident position of EB-2 and three different incident angles, shapes and fluctuation of beam hole has been studied. As far as incident position is concerned, Type B (EB-2 impinges into the beam hole of EB-1) gives most stable beam holes. As far as incident angle is concerned, smaller angle is better for stability and depth of beam hole. In TEB welding, it is also found that EB-2 not only remelts the root of beam hole and repaires the defects but also it enlarges the beam hole and increases stability of the beam hole with suppressing the welding defects.

References

1) Y. Arata and E. Nabegata: Tandem Electron Beam Welding (Report I): Trans. JWRI, Vol. 7 (1978), No. 1, pp. 101–109.
2) Y. Arata, E. Nabegata and N. Iwamoto: Tandem Electron Beam Welding (Report II): Trans. JWRI, Vol. 7 (1978), No. 2, pp. 233–243.
3) H. Tong and W.H. Giedt: Radiograph of the Electron Beam Welding Cavity: Rev. Sci. Instrum., Vol. 40 (1969), No. 10, pp. 1283–1285.
4) L.E. Bryant: Flash Radiography of Electron Beam Welding: Materials Evaluation, Vol. 29 (1971), No. 10, pp. 237–240.
5) C.H. Weber, E.R. Funk and R.C. McMaster: Penetration Mechanism of Partial Penetration Electron Beam Welding: W.J., Vol. 51 (1972), No. 2, pp. 90s–94s.
6) Y. Arata, N. Abe and S. Yamamoto: Tandem Electron Beam Welding (Report III): Trans. JWRI, Vol. 9 (1980), No. 1, pp. 1–10.