# Tandem Electron Beam Welding (Report V)†

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**Abstract**

*The role of the second electron beam in Tandem Electron Beam Welding was studied. The second beams of various power against the first beam power of 3, 6 and 9kW were impinged into the beam hole of the first beam with a very small crossing angle (~ 8°). Bead crosssections of each case were analysed for root porosities, fluctuations of penetration depth and root radii. In each case, there was an optimum power of the second beam, and the optimum power ratio of these two beams was about 10%.*

*In order to clearify the reason of the optimum power ratio, the welding process was observed dynamically by Transmission X-ray method. High speed movie films were analysed for the depth, width and shape of beam hole. It was found that the shape and stability of the beam hole changed with the power of the second beam, and the most stable beam hole was achieved with the above power ratio.*

**KEY WORDS:** (Electron Beam Welding) (Tandem) (Beam Hole) (Dynamic Observation)

## 1. Introduction

Electron beam welding can utilize an extreamely higher energy density beam than ordinary welding methods. Therefore, it can be applied to the high speed welding of thin plates, or the deep penetration welding of thick plates, which cannot be welded by ordinary methods. However, it is also well known that the beam's high energy density causes certain defects such as humping in high speed welding and spiking and porosity in deep penetration welding.It is difficult to suppress these defects by using an ordinary single electron beam without sacrificing welding speed and penetration depth. In order to overcome these difficulties, we have proposed Tandem Electron Beam Welding method, which uses two electron beam at once. In this method, while the first beam is used as an ordinary high energy density beam, the second beam is used as a controlling beam for the molten metal flow or beam hole shape. In this way the disadvantages caused by ordinary high energy density beam welding have been overcome[1),2)].

In this report, the fundamental parameters in Tandem Electron Beam Welding are discussed, with the aim of reducing power consumption. The second beam was impinged into the beam hole of the first beam at a very small crossing angle, which was reported previously[3)]. Its power was varied against the power of the first beam of 3,6 and 9kW to find the optimum ratio between the first and the second beam. From the bead analysis, the optimum power ratio was determined to be 10% in our experimental conditions. In order to find the reason of this optimum level, the beam hole during the actual welding process was observed dynamically by Transmission X-ray method. High speed movie films taken by this method were analysed to find the optimum ratio.

## 2. Tandem Electron Beam Welder

**Figure 1** shows a schematic diagram of Tandem Electron Beam Welder. There are two electron beam systems in this machine. Maximum acceleration voltage of each electron gun is 60kV and total maximum power is 12kW. The first beam impinges into the specimen perpendicularly. The second beam is deflected by the beam deflector-2 towards the first beam and again focused by the focusing lenz 2-2. Then it impinges into the beam hole of the first beam with a small crossing angle (~8°). In present experiment, these two beams cross on the surface of the specimen, which is the most efficient condition reported previously[3)].

Al 5083 of 12mm width, 40mm thickness and 300mm

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length was used for the specimen, since welding defects occur frequently in this material and it is easy to observe the behaviour of the beam hole by Transmission X-ray method.

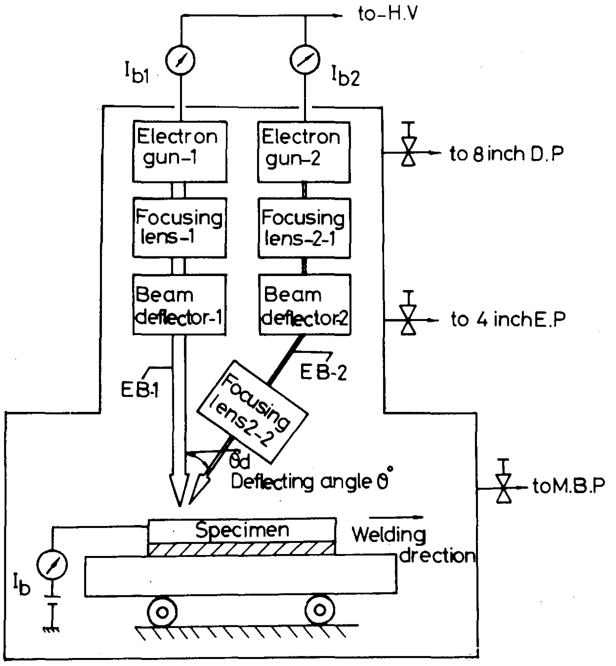


Fig. 1 : Tandem Electron Beam Welder.

## 3. Bead Analysis

**Figure 2** shows examples of the transverse and cross sections of the bead welded with various power ratios. Figure 2(a) shows the transverse and cross sections of the bead of a single 9kW electron beam. Those sections of Tandem Electron Beam where the second beam is 0.6, 0.9 and 1.2kW are shown in Fig. 2(b), (C) and (d), respectively. It can be seen that the bead is sound in the case of the 0.9kW beam, but there are many defects in the beads of the other beams.

The bead analysis of these cross sections are shown in **Fig. 3**. The upper figure of Fig. 3 shows the root radii, the middle the fluctuation of penetration depth, and the lower the number of porosities. "f=50Hz" represents the oscillation frequency of the second beam. In present experment, the diameter of the first beam is 0.8mm while that of the second beam is 0.4mm. The second beam enlarged to the size of the first beam by beam oscillation is more effective than the beam without oscillation. It is obvious that there is an optimum power of the second beam which gives the largest root radius, the smallest fluctuation of penetration depth and no porosity. It is about 0.9kW when the power of the first beam is 9kW.

The same analysis were performed for the first

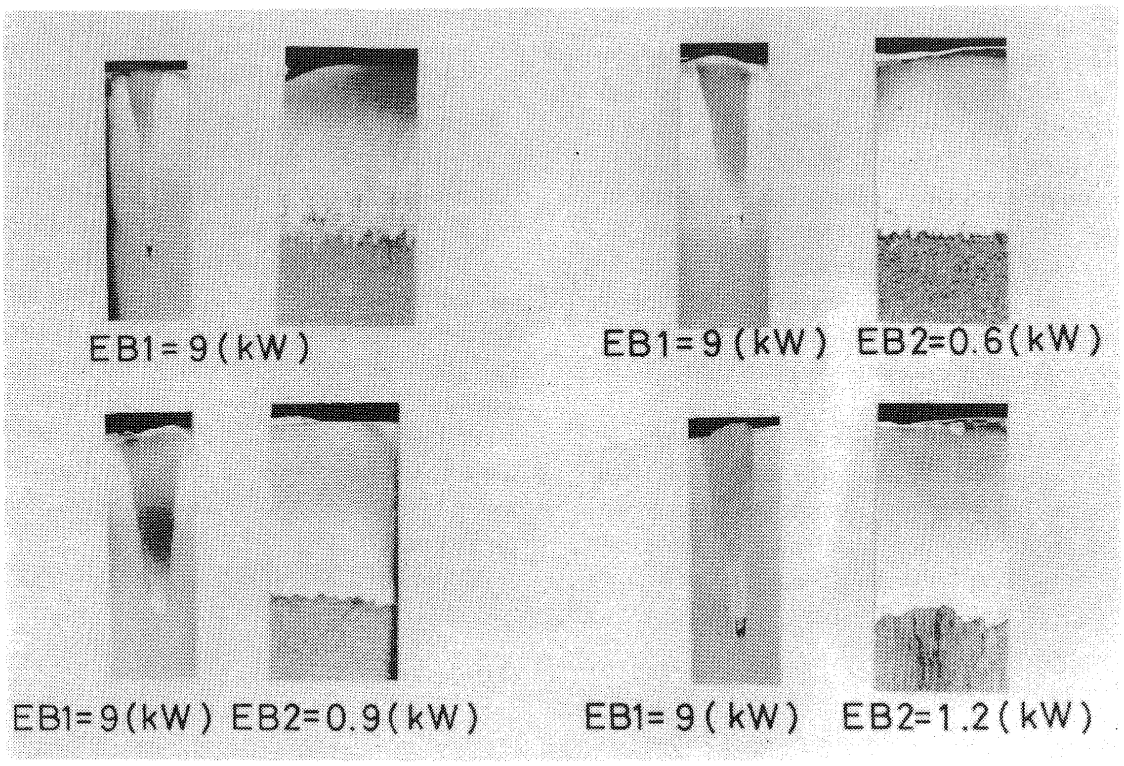


Fig. 2 : Transverse and cross sections of beads of single and Tandem Electron Beam Welding with various power ratios of first and second beam.

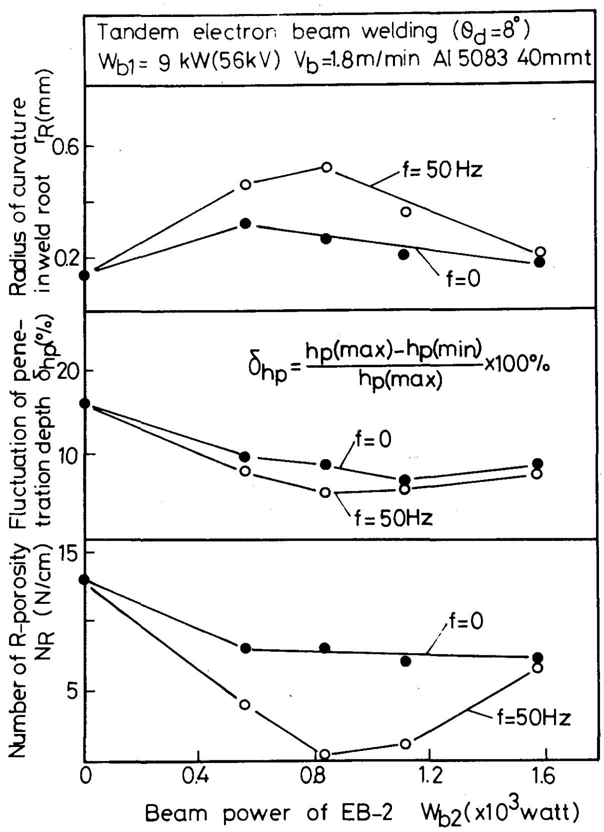


Fig. 3 : Results of bead analysis for the 9kW first beam.

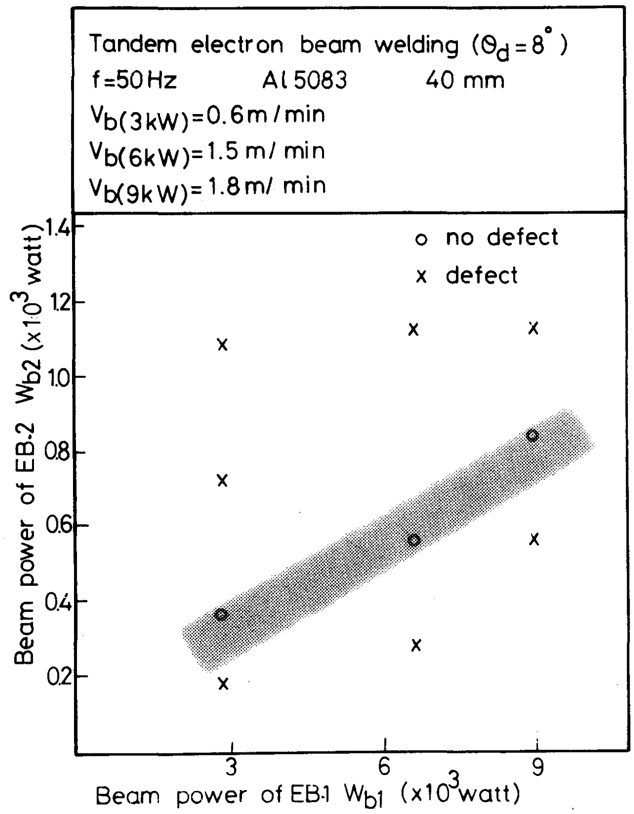


Fig. 4 : Summary of bead analysis.

beam power of 3 and 6kW. These results are summalized in **Fig. 4**. The abscissa is the power of the first beam and the ordinate is the power of the second beam. Circles represent the bead with no defects and crosses represent that with defects. It can be seen that the optimum power ratio is about 10% under our experimental conditions.

## 4. Experimental Apparatus of "Transmission X-ray method"

In order to find why there is an optimum power ratio, we observed beam hole behaviour under welding dynamically[3),4)]. The diagram of the experimental system is shown in **Fig. 5** schematically. X-rays are emitted from the X-ray tube on the right side of Fig. 5 at 80kVp, 4mA. These X-rays pass through the specimen under welding and enter the input screen of the X-ray image converter. In this converter, X-ray images of the beam hole are converted to visible images on the output screen. These visible images are filmed by a 16mm high speed movie camera. The filming rate is 100 frames per second. Since so-called "beam hole X-rays" emitted from the specimen under electron beam welding decreases the image quality of beam hole images,a proper absorber was used to avoid this undesirable radiation.

## 5. Film Analysis

Reproductions of this high speed movie are shown in **Fig. 6**. Figure 6(a) shows the beam hole of a 9kW single electron beam. Figure 6(b), (c) and (d) show Tandem Electron Beam Welding where the power of the second beam is 0.6, 0.9 and 1.2kW, respectively. It is clearly seen that the shape and stability of the beam hole vary with the power of the second beam.

In order to see the fluctuation of the beam hole clearly, these reproductions are analysed against the horizontal length of the beam hole at 0,30,50 and 80% of penetration depth in **Fig. 7**.The parameters are most stable when the power of the second beam is 0.9kW (Fig. 7(c) ).

In order to clarify the dependence of these fluctuations on the power of the second beam, the average value and the standard deviation of those parameters are plotted against the second beam power. It can be clearly seen in **Fig. 8** that the lower part of the beam hole enlarges with the power of the second beam and that the stability also increases with the power of the second beam. However, at 1.2kW, the lower part of the beam hole again decreases in size and stability.

This fact is summalized in **Fig. 9** against various

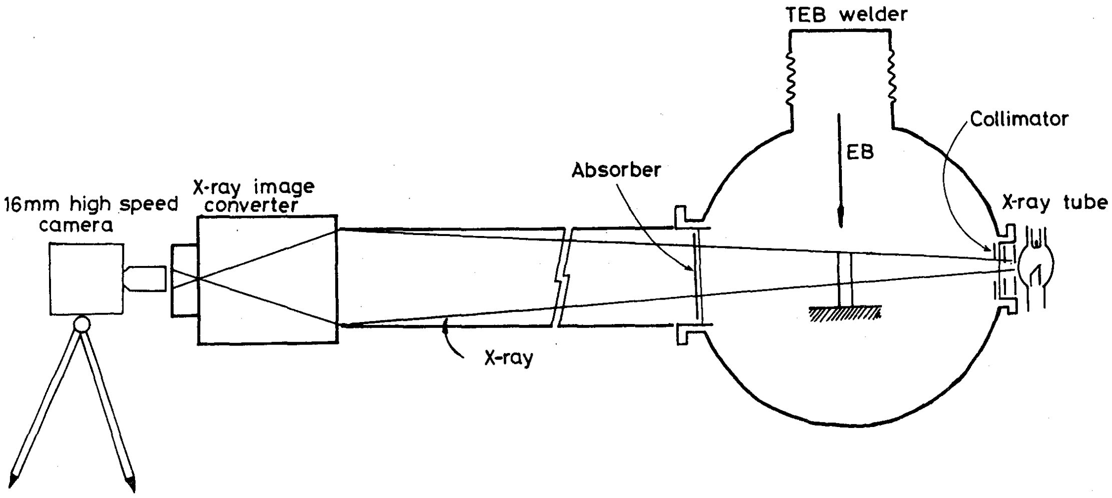


Fig. 5 : Schematic diagram of experimental apparatus of "Transmission X-ray method".

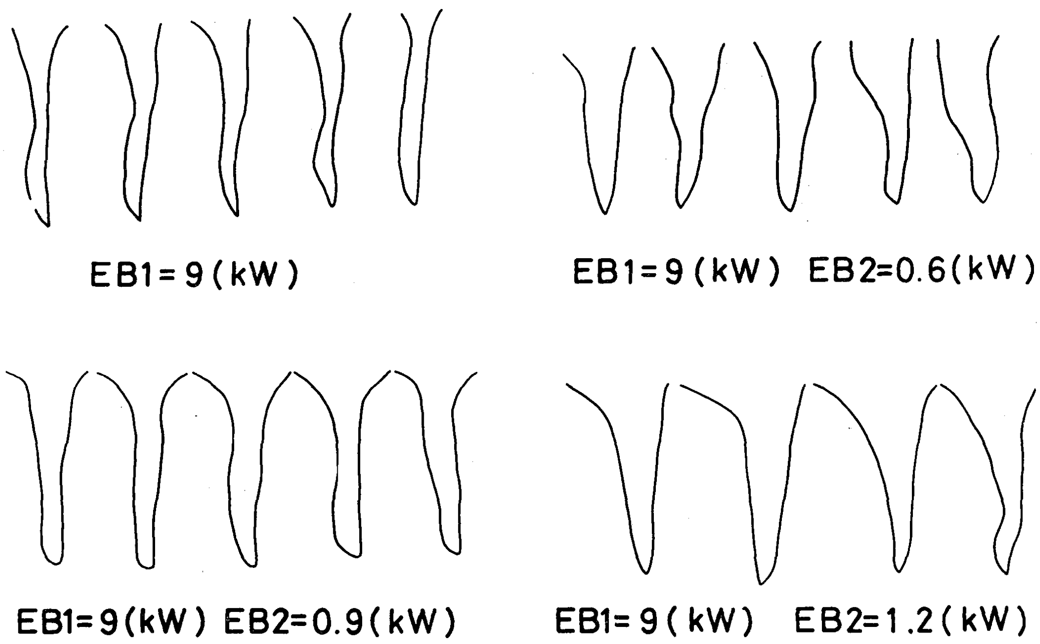


Fig. 6 : Reproductions of high speed film for the 9kW first beam.

power of the first beam. The abscissa is the power of the first beam. The ordinate is the power of the second beam. The shape and stability of the beam hole are classified into 3 types. When the power of the second beam is smaller than the optimum level, the beam hole is narrow and unstable. When the power is at the proper level, the beam hole becomes wide from top to bottom and the behaviour is stable. However,when the power is grater than the optimum level, although the upper part of the beam hole remains large, the lower part becomes narrow. The behaviour of beam hole becomes unstable. This stable region corresponds to the region revealed by bead analysis. It is concluded that the second beam enlarges the beam hole from top to bottom and stabilizes the shape of the beam hole.

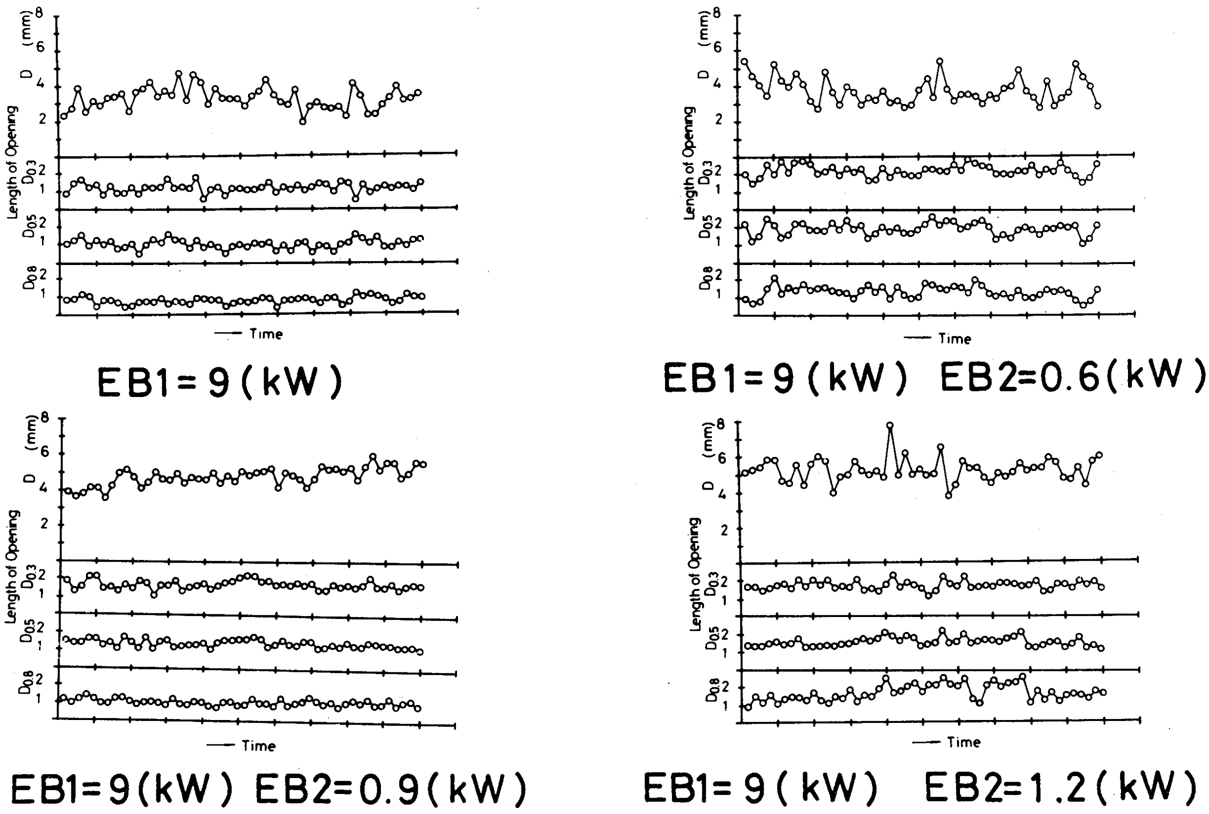


Fig. 7 : Film analysis (1).

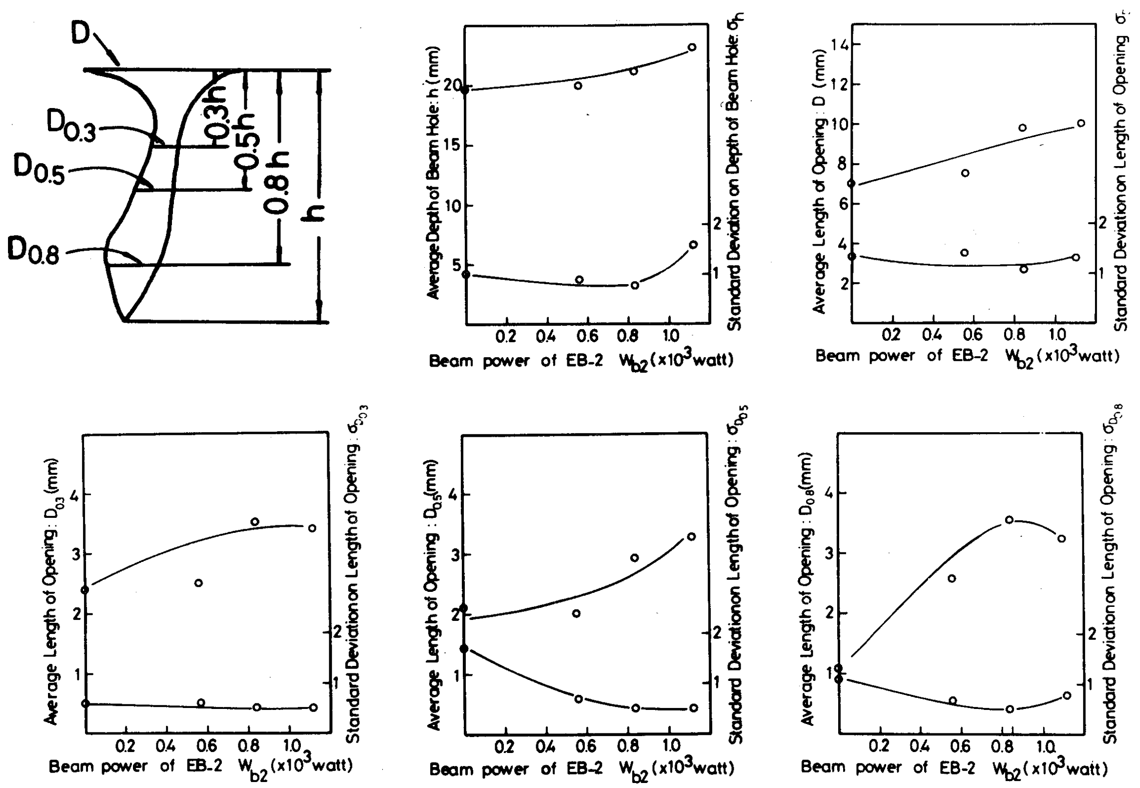


Fig. 8 : Film analysis (2).

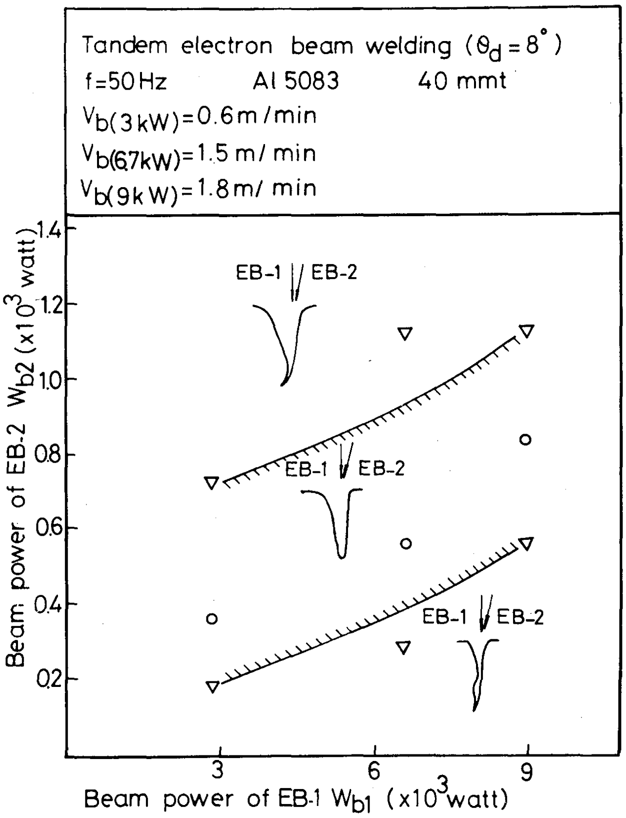


Fig. 9 : Summary of film analysis.

## 6. Conclusion

In Tandem Electron Beam Welding, the incident power of the second beam is very important. The second beam controls the shape of the beam hole and stabilizes the behaviour of the beam hole. In our experiments, the optimum ratio between the first and the second beam is about 10%.


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