Weld Distortion of Disk Shaped Joint by Electron Beam Welding†

Yoshiaki ARATA*, Fukuhisa MATSUDA and Naohiko YOKOSHIMA*****

Abstract

Recently electron beam welding process is often used for precise welding processes because of the feature that there is less distortion than other conventional fusion welding processes. Therefore it is believed that the studies of weld distortion on welded joints by this process is important. For this reason the authors researched the thermal distortion of welded joints shaped as a disk or a ring which were welded concentrically in various conditions of welding heat input and plate thickness. In a part of the research on distortion, the angular change was obtained by measuring the two marked points which were set on both sides of the weld seam before welding. The authors evaluated the angular change by using the parameter which was determined by accelerating voltage, beam current, welding speed and plate thickness.

1. Introduction

Recently electron beam welding process is often used for precise welding processes because of the feature that there is less distortion than other conventional fusion welding processes. However, concerning the amounts of distortion and angular change of welded joints with electron beam process, there are few reports so far though it is believed that the data on weld distortion are important for practical use. Especially, in the field of gear assembly the demand of electron beam welding has increased at present. In this welded joint, allowable distortion and angular change for welding is very small in level because the gear is almost completed. Therefore, to investigate the applicability of electron beam welding process in this field it is very important to know the amounts of weld distortion and angular change of the welded joints with electron beam.

For this reason the authors investigated the thermal distortion of welded joints, shaped as a disk or a ring similar to a gear which were welded concentrically in various conditions of welding heat input and plate thickness.

The authors investigated the distortion and the angular change in the following view-points.

(1) Differences between two types of welded joints of pressed in I-butt and bead-on-plate.
(2) Dependence on difference of location measured along the weld seam.
(3) Deformation in circularity of disk shaped welded joint.
(4) Dependence on change of weld heat input.

In the case where gears (especially shoulder gear) or flanges are welded with electron beam, the direction of the beam is usually parallel to axial direction of welded work which is rotated around the center of the rotation axis. Therefore the joint configuration in this research was simulated in the above, that is, the electron beam welding was performed in the concentric fashion around the center of the rotation axis. Then the distortion and the angular change on either side of the welding bead was measured after welding.

In measurements of the distortion, contact-balls were set to show the distance of marked points on either side of the welding seam before welding, and the change of the length between the two contact-balls before and after the welding were measured using the contact meter.

2. Welding Apparatus and Materials Used

All welding beads were performed without filler, metal using the machine of maximum power of 15 kW, 30 kV of maximum accelerating voltage and 500 mA of maximum beam current, which was made by JEOL.

The material which was used in this research is plain commercial carbon steel plate, SS41, of 10, 20 and 30 mm thickness, the ultimate strength which shows about 41 to 43 kg/mm^2.

3. Experimental Results

3.1 Distortion

Figure 1 shows the difference of distortion between the pressed on I-butt weld and the bead-on-

† Received on July 25, 1973 (IIW Doc. IV-115-73)
* Professor
** Associate Professor
*** Komatsu Mfg. Co., Ltd.

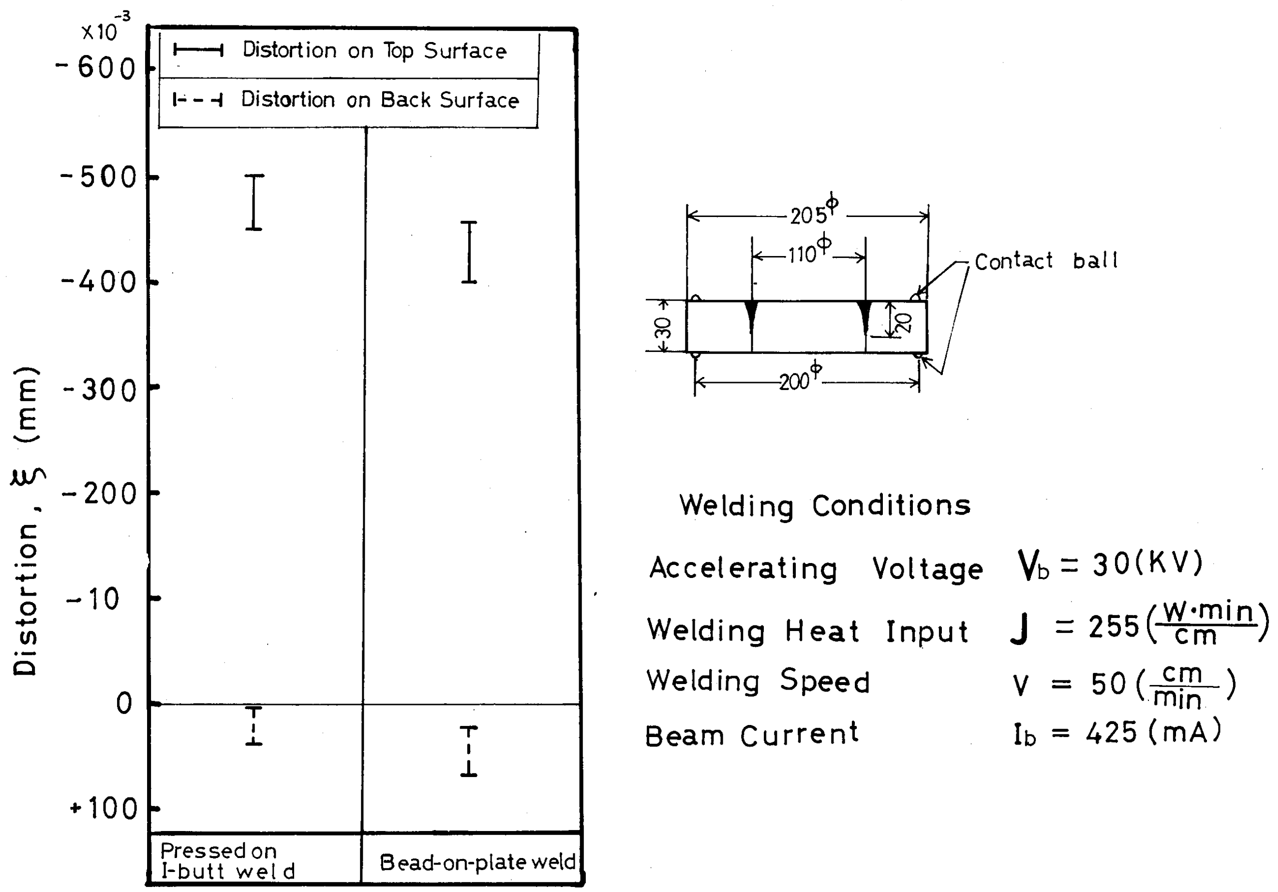


Fig. 1. Comparison of distortions in pressed on I-butt weld and bead-on-plate weld.

plate weld. It is obtained by measuring the length between the two contact-balls on the top surface and the back surface before and after welding. The welding condition is also shown in Figure 1.

According to it, in every test piece, the distortion on the top surface is shrinkage, and that of the back surface is expansion. The expansion on the back surface occured by the bending force which exist in the direction of plate thickness when electron beam is applied to the top surface. The shrinkage distortion was less in bead-on-plate weld than in pressed on I-butt weld, but there were little differences between the two distortions. Therefore the subsequent experiments were all done using the bead-on-plate type welding.

Figure 2 shows the five relations between the location on the electron beam weld seam (which are pointed out by the numbers 1-5, 2-6, 3-7 and 4-8) and the amount of distortion. Five weld beads were welded under the same welding condition. For every weld bead the maximum and the minimum values of the distortion occured at the diameter through the starting point of weld seam (1-5) and at the diameter perpendicular to the one (3-7), respectively.

Figure 3 shows the relations between the difference of the maximum distortion, ξ max and the minimum, ξ min, and welding bead input for different thickness of plate. In this figure, the value of, ξ max or ξ min was obtained by taking the average distortions on the top surface and the back surface of location 1-5 or 3-7, respectively.

The difference of distortion, that is, deformation in circularity of disk shaped joint, increased with an increase in weld heat input for three curves. However, when the weld heat input is large enough, it seems that the deformation in circularity of welded joint keeps a constant or decreases slightly in case of 30 mm thick plate.

Figure 4 and **Figure 5** show the relations between the distortion and the welding heat input on the disk and the ring shaped welded works, respectively. In these figures the data were obtained by measuring the distance of the two marked points of 200 mm length. It was clear from those figures that the distortions on the top surface (which was one side of the surface applied with electron beam) increased in proportion to the welding heat input, but on the back surface, the distortion rapidly increased over a certain welding heat input. A value of welding heat input at which such phenomena occurred was increased with an increase in the plate thickness. The reason in the above phenomena is considered to be

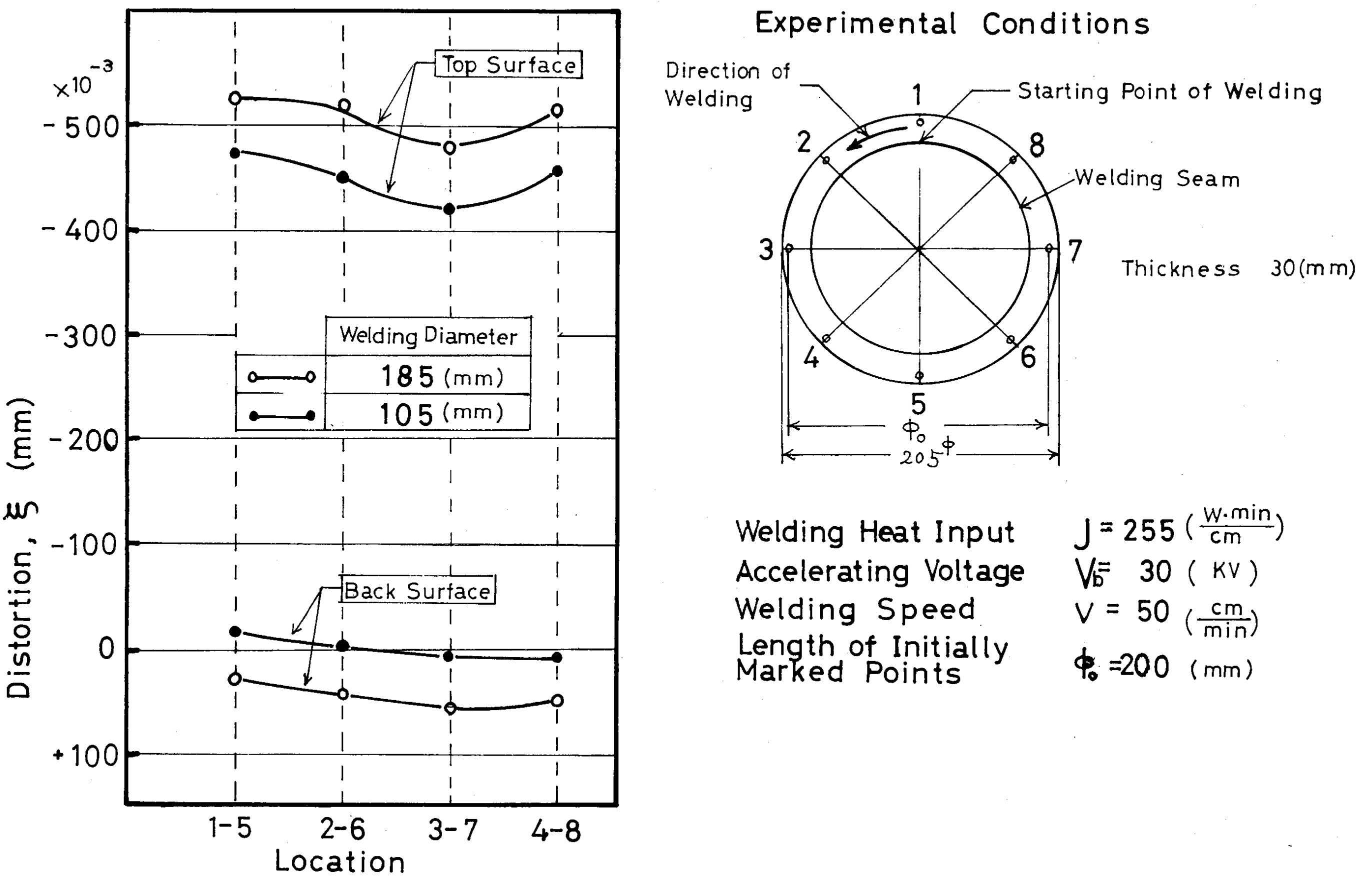


Fig. 2. Comparison of distortion with location of a weld seam by electron beam welding.

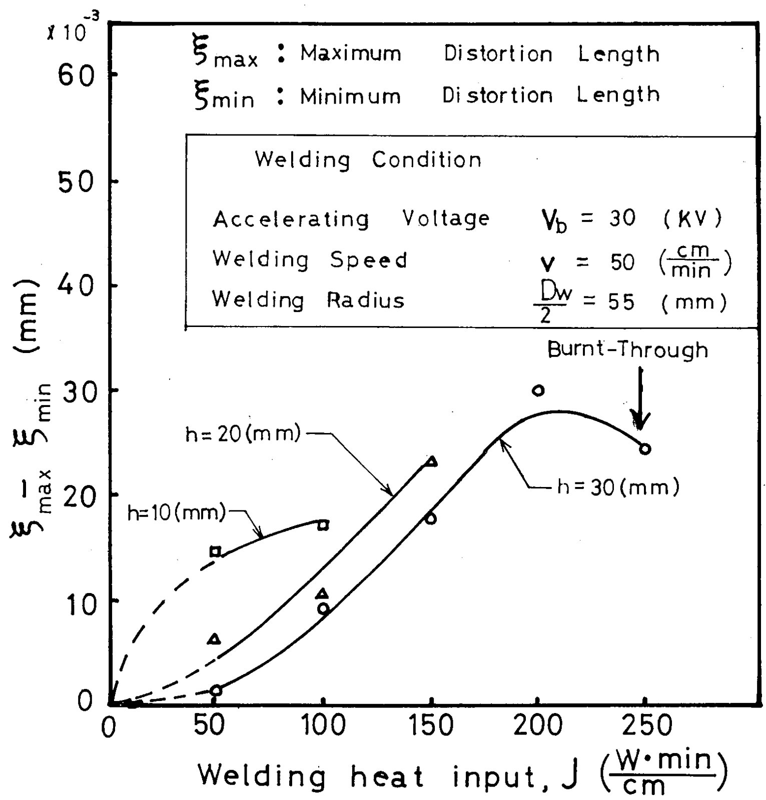


Fig. 3. Relations between the deformation in circularity and welding heat input on ring shaped welded works.

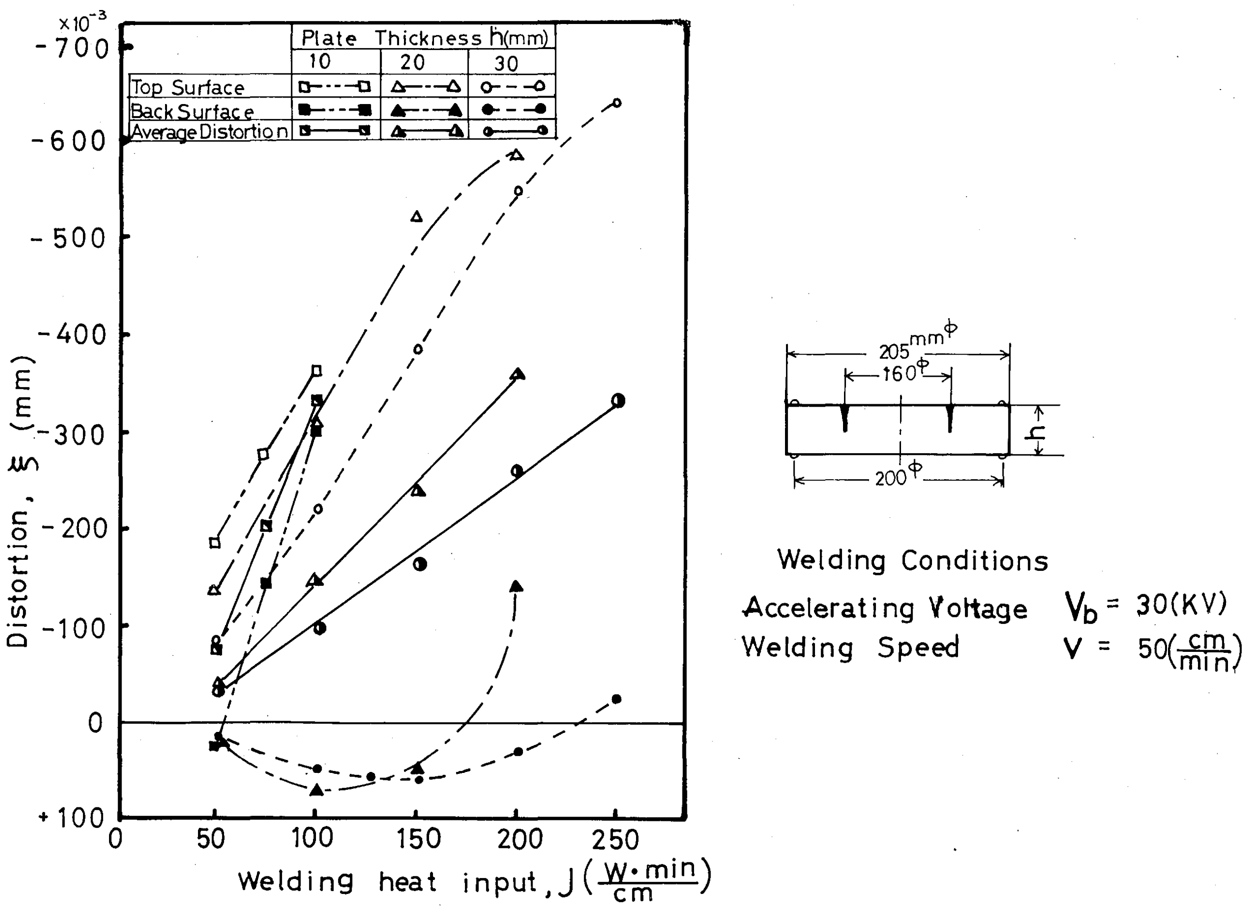


Fig. 4. Relations between distortion and welding heat input on disk shaped welded works for three plate thicknesses.

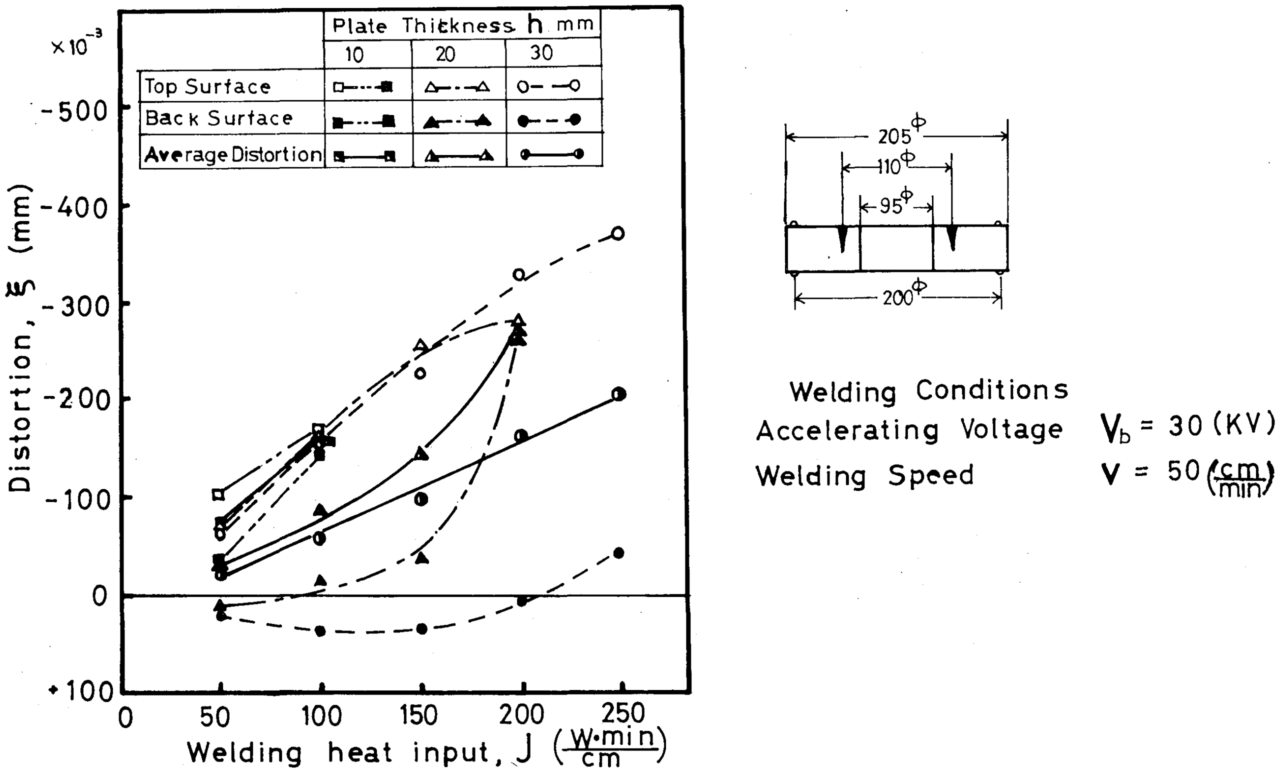


Fig. 5. Relations between distortion and welding heat input on ring shaped welded works for three plate thicknesses.

caused by the penetration depth closing on the plate thickness. Consequently, in case of burnt-through bead, there is little difference between the distortion on the top and the back surfaces.

Figure 6 shows the penetration depth versus the welding heat input which was obtained for 30 mm thick plate.

Figure 7 shows the same relation on ring shaped material obtained by measuring the distance of two marked points near the inner edge, 10 mm in length. The data were shown as the average distortion.

The distortions in the above are included in the angular change. Therefore discussions on angular change of welded joint are described in the following.

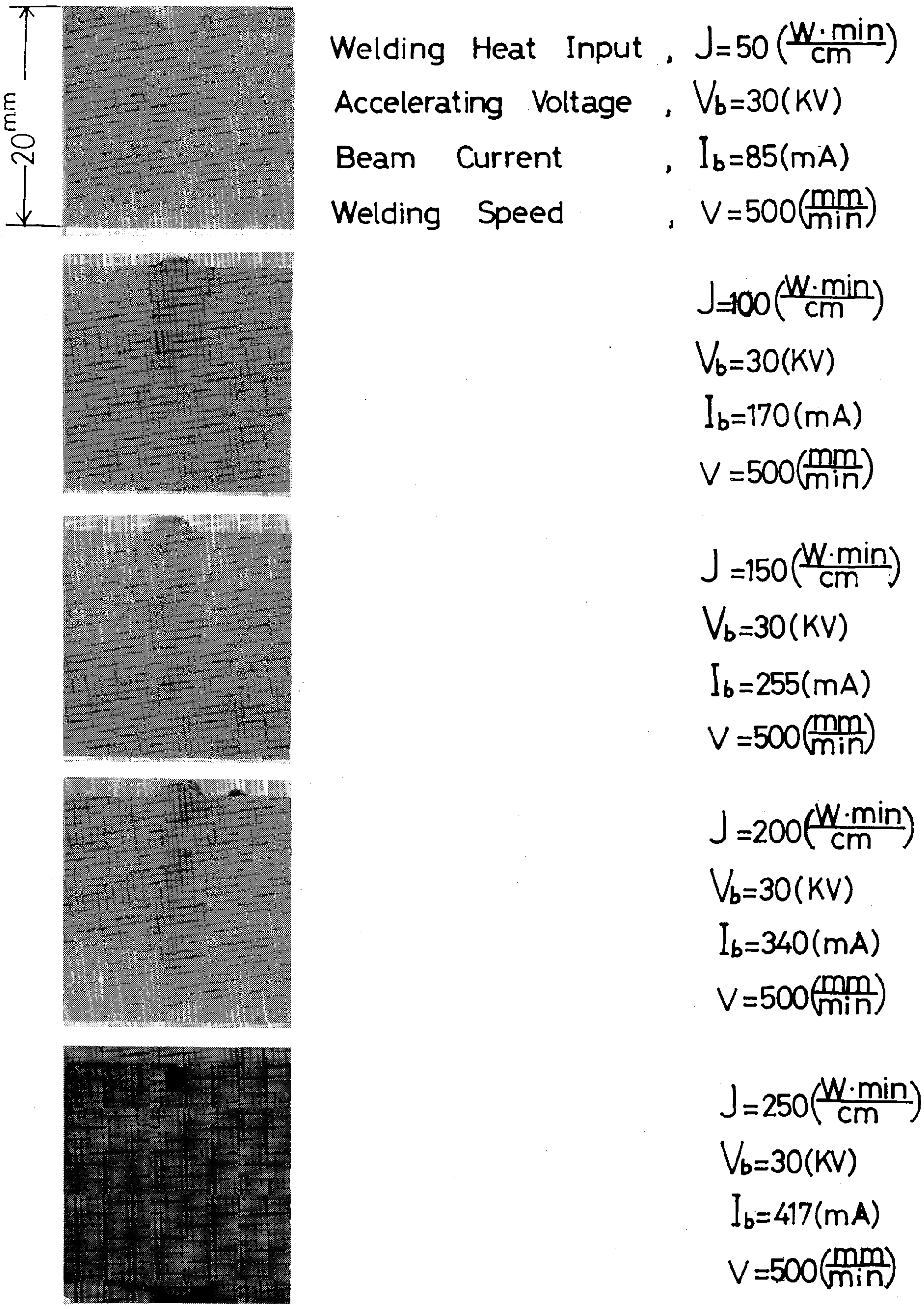


Fig. 6. Shape of weld penetration versus welding variables.

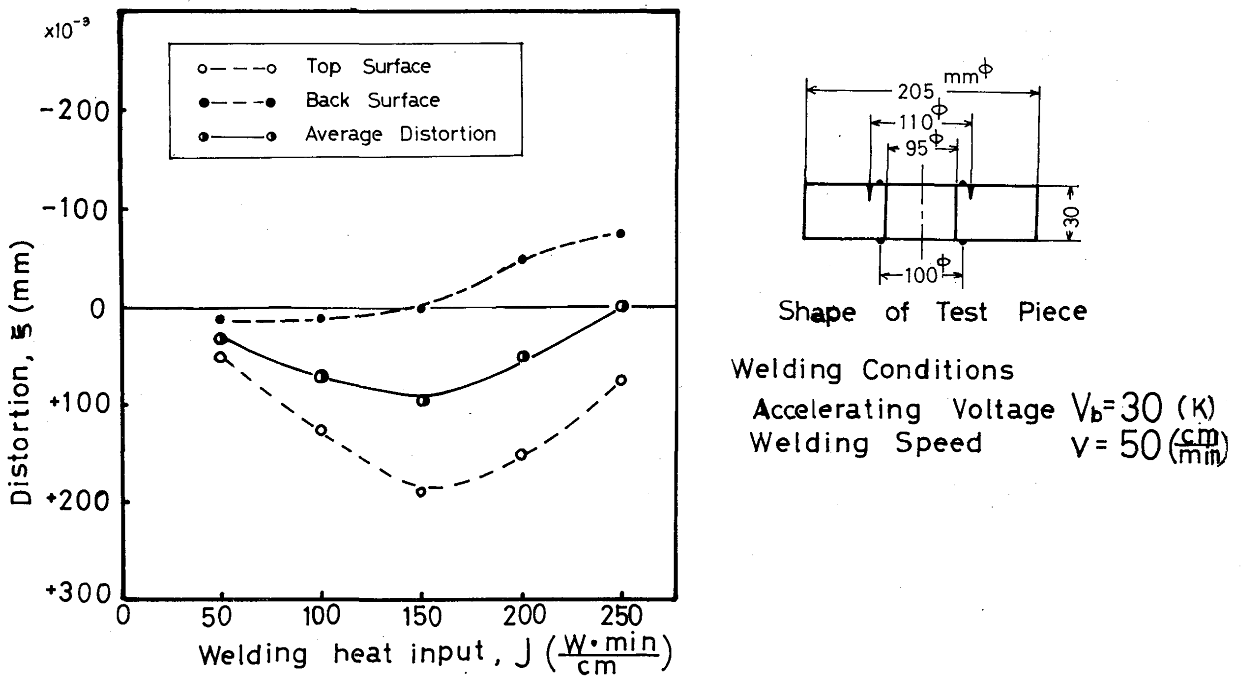


Fig. 7. Relations between distortion of inner diameters and welding heat input on ring shaped welded works.

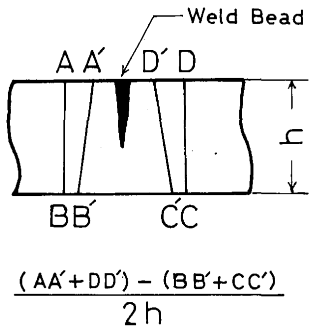
3.2 Angular Change

In case of concentric welding seam for disk or ring shaped welded work, angular change except aforementioned distortion occurs.

In the gear which is welded with electron beam, especially the angular change is a serious problem, for this angular change exerts a detrimental influence upon involute curve and lead error.

Therefore, the authors evaluated the angular change, the values of which were determined by measuring the difference of the distortion of the two marked points before and after welding, where length of marked points on both sides of the weld seam is 20 mm. Thus angular change, δ, was defined as shown in Figure 8.

In **Figure 8,** points A, B, C and D show the locations at initially marked points and A′, B′, C′ and D′ show the points after welding.



$$\delta = \frac{(AA'+DD') - (BB'+CC')}{2h}$$

Fig. 8. Definition of angular change.

According to the aforementioned definition, angular change was obtained against welding heat input on ring and disk shaped welded works. The results are shown in **Figure 9** and **Figure 10,** respectively. As a result of the experiment, when welding heat input was comparatively small, angular change increases for every plate thickness with an increase of welding heat input. Then, in some value of welding heat input, Qm, which depends on thickness of material, angular change showed the maximum value. The reason that the maximum angular change appears at the appropriate value to welding heat input, Qm, is explained as follows. That is, angular change is strongly influenced by the differences of temperature distribution and width of melted zone between the top surface and the back surface of the plate and also bending rigidity of work during and immediately after the welding.

The temperature rise near the weld seam and the width of melted zone on the top surface increases with an increase of welding heat input as shown in Figure 6. Therefore, the bending force to make angular change increases. Meanwhile, the rigidity of work which is opposite to angular change decreases with an increase of penetration depth of weld bead. Therefore, under this circumstance the above mentioned angular change will be increased by increasing weld heat input.

However, in the weld bead, the penetration which is close to the back surface or the burnt-through bead,

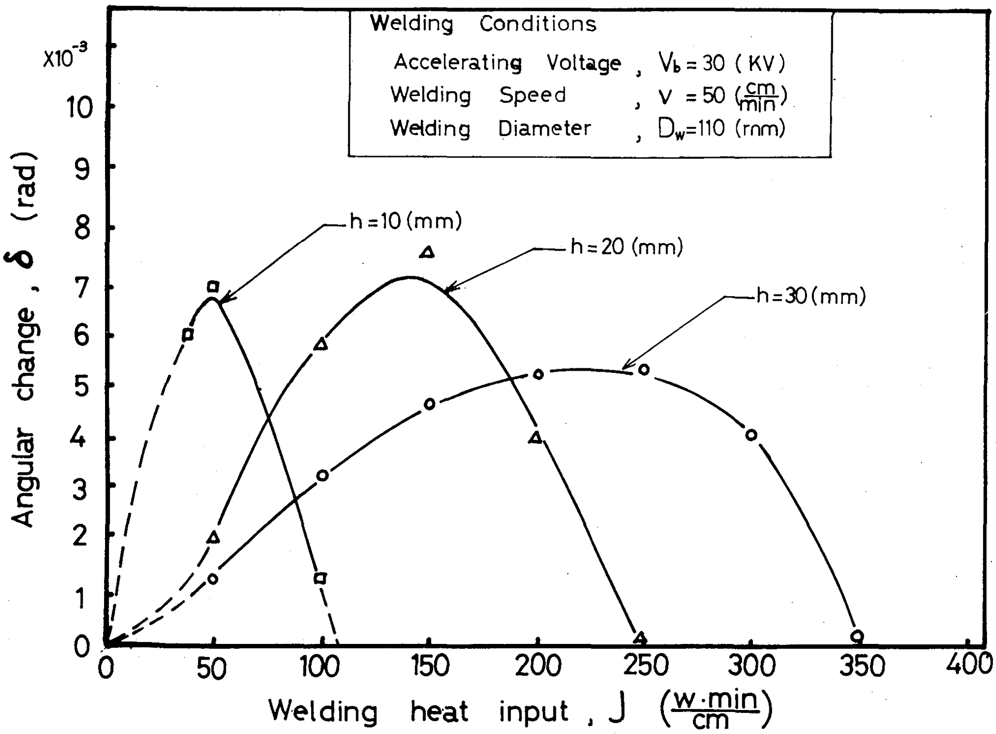


Fig. 9. Relations between angular change and welding heat input on ring shaped material.

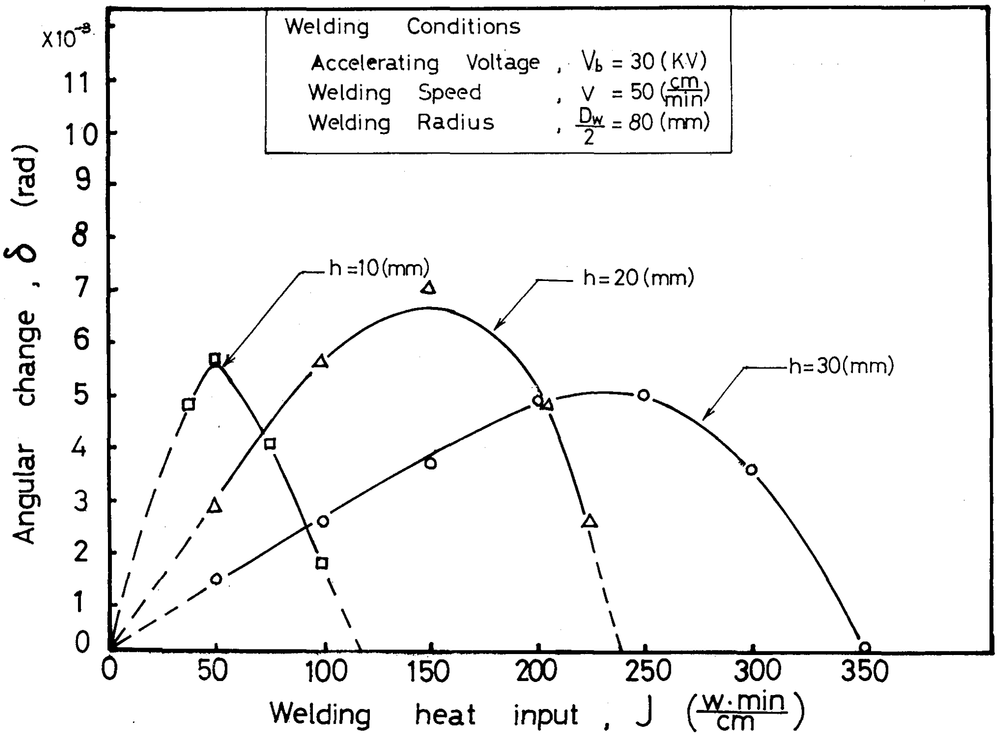


Fig. 10. Relations between angular change and welding heat input on disk shaped material.

the temperature rise near the weld seam and the width of melted zone are almost the same on both surfaces and can be easily understood from Figure 6. In this circumstance the bending force for angular change will disappear.

In Figures 9 and 10 the maximum value of the angular change appeared roughly where the penetration depth is about three fourths of the plate thickness.

Next, it is convenient that angular change which occurs in electron beam welding can be indicated by a certain parameter that represents all the welding variables.

The weld distortion and angular change in coated manual arc welding have been previously researched in terms of the inherent distortion and inherent angular change[1]. According to the research, the inherent angular change, δ_{in}, can be represented as an equation, using a parameter χ, which is equal to $I/h\sqrt{v \cdot h}$, where I is arc current, h is plate thickness and v is welding speed.

$$\delta_{in} = C_1 \cdot \chi^m \cdot \exp(-C_2 \chi) \quad (1)$$

where, C_1 and C_2 are the constants that are determined by characteristic of welding electrode used.

Therefore, the authors thought that the angular change in electron beam welding could be indicative of a certain parameter such as χ. Now, the authors represented the angular change in electron beam welding as to a parameter χ_e, which is equal to $V_b \cdot I_b / h\sqrt{v \cdot h}$, where V_b is accelerating voltage of beam, I_b is beam current emitted and other h and v are as aforementioned.

Figure 11 shows the angular change using the parameter χ_e. In this experiment parameter χ_e was varied to three stages by changing the beam current under the same accelerating voltage of 30 kV and welding speed of 50 cm/min. In all welding variables diameter of electron beam was always kept the smallest on the work surface by controlling the focusing coil.

All the data that were obtained from three different welding variables approximately indicated a curve as shown in Figure 11.

This relation is similar to the relation between the inherent angular change, δ_{in}, and the parameter, χ, in arc welding.

Therefore the authors evaluated the angular distortion that is the function of the parameter, χ_e, by using the following boundary conditions.

$$\begin{aligned} \delta &= 6.0\times10^{-3} && \text{at } \chi_e = 6.0\times10^3 \\ \delta &= 2.45\times10^{-3} && \text{at } \chi_e = 2.0\times10^3 \\ \frac{\partial \delta}{\partial \chi_e} &= 0 && \text{at } \chi_e = 6.0\times10^3 \end{aligned} \quad (2)$$

As a result, the authors obtained an experimental equation for angular distortion of disk shaped joints with electron beam, which is shown by

$$\delta = 1.2\times10^{-3} \cdot \chi_e^{2.08} \cdot \exp(-0.346 \cdot \chi_e) \quad (3)$$

where, χ_e is $V_b \cdot I_b / h\sqrt{v \cdot h}$

The maximum angular change occurs at about 6×10^3 of χ_e.

4. Conclusions

(1) The shrinkage distortion is less in bead-on-plate weld than in fixed I-butt joint weld, but there is little difference between the two in the case welds of ring and disk shaped work.

(2) The maximum value of the shrinkage distortion occurs at the diameter through the starting point of weld seam, and the minimum value of it occurs at the diameter perpendicular to the diameter through the starting point of weld seam.

(3) The maximum value of the angular change appears where the penetration depth is about three fourths of the plate thickness.

(4) The angular change, δ, which occurs in electron beam welding was represented by the following

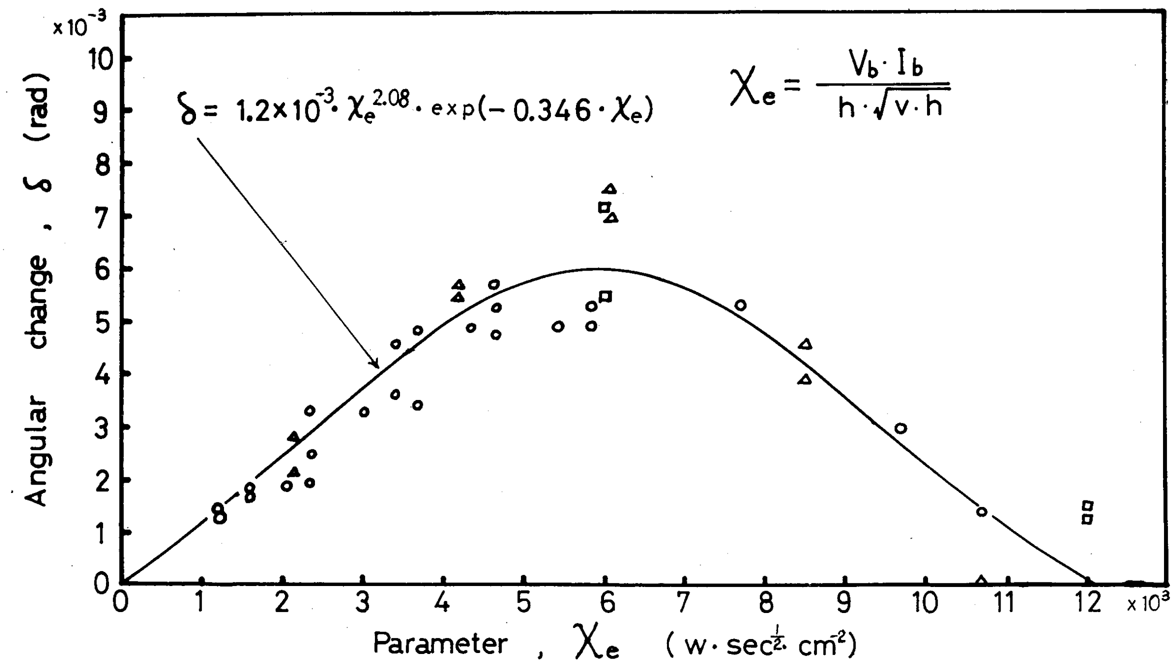


Fig. 11. Angular change versus parameter χ_e.

experimental equation using a parameter χ_e that is defined by accelerating voltage V_b, beam current I_b, welding speed v and plate thickness h.

$$\delta=1.2\times10^{-3}\cdot\chi_e^{2.08}\cdot\exp(-0.346\,\chi_e)$$

$$\chi_e=\frac{V_b I_b}{h\sqrt{v\cdot h}}$$

and the maximum angular change occurs at

$$\chi_e=6.0\times10^{3}\ \left(\frac{\mathrm{w}\cdot\mathrm{sec}^{1/2}}{\mathrm{cm}^2}\right).$$

Acknowledgment

The authors would like to express their gratitude to Dr. Shigetomo Matsui for his advice in this experiment and to Mr. Toshisuke Isoya for his co-operation to publish this paper.

Reference

1) M. Watanabe, K. Satoh: "Welding Mechanics and Its Application" (in Japanese), Asakura Book Store, 1965.