Mechanical Properties on Electron Beam Welds of Constructional High Tension Steels (Report Ⅳ) †

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Abstract

The effects of bead width and hardness difference between the electron-beam weld and the base metal on the transition temperature for fracture mode (Trm) in Charpy impact ductility test were studied in this investigation by using HT50 and 80 constructional high tensile steels. The remarkable conclusion are as follows:

(1) *The impact strength of the weld metal is not depended on the variation of a_b parameter.*
(2) *Moreover with an increase of weld heat input or notch depth for Charpy test specimen, the Trm tends to be raised.*
(3) *With an increase of the annealing temperature, the T_{rm} tends to be raised in general.*
(4) *The impact strength for HT50 and 80 weld metals was not depended on the variation of the hardness of the weld metal except for the HT50 weld with 650°C annealing.*
(5) *The T_{rm} tends to be raised with an increase of bead width ratio, or with a decrease of hardness difference ratio.*
(6) *Isothermal lines for the T_{rm} more than 100°C were made clear by the two parameters of the bead width ratio and the hardness difference ratio.*

1. Introduction

Some results of the mechanical properties of electron-beam welds such as hardness distribution, tensile-, bend-, impact- and fatigue-properties were reported in the two previous reports[1),2)]. Therefore the mechanical properties were almost made clear. However the authors had an attention concerning the impact properties of the weld metal whose bead width was narrower. That is to say, the impact values of these weld metals exceed those of the respective base metal in the temperature higher than the specific temperature.

Then the authors indicated in the previous report[3)] about the specific temperature that a transition phenomenon of the fracture mode occurred at the specific temperature, that is, the fracture occurred in the weld metal in the temperature lower than and crooked to the HAZ and/or the base metal in the temperature higher than. The authors called this specific temperature, at which the fracture mode in Charpy impact specimen changes, the transition temperature for fracture mode (T_{rm}) in the previous report[3)].

Moreover in the previous report[3)], the effect of the weld heat input on the T_{rm} in Charpy impact test was partly clarified. As a result of the report, the T_{rm} is closely related to both the bead width and the difference in the hardness of base and weld metals, and has the tendency to rise with an increase of the bead width or with a decrease of the hardness difference. Then, in this report, the authors have treated about the detailed behavior of the T_{rm} for impact properties by using HT50 and 80 steels. Namely, by the various combinations of the weld heat input and a_b parameter, three different welding conditions were selected to have three different bead widths (narrow, middle and wide bead widths).

Moreover the effects of the notch depth and the weld heat input on the T_{rm} were systematically investigated. Moreover some of the welds were suitably heat-treated in order to reduce the hardness difference between base and weld metals, and the effects of the hardness variation of weld metal on the impact properties were studied. Furthermore, the behaviors of impact properties for the welds in various a_b parameters were also examined. Finally, by the use of the two parameters (bead width and hardness difference ratio in the welds), the limit of the desirable T_{rm} which exceeds 100°C was fixed for the electron-beam welds of HT50 and 80 steels.

2. Experimental Procedure

2.1 Materials used

The materials used in this investigation are HT50 and 80 steels which are widely used in the constructional bridges and buildings. The former is not heat-treated, and the latter is quenched and tempered materials. The chemical compositions of these two types of high tension

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Table 1 Chemical compositions of HT50 and 80 steels used.

(wt%)

Composition / Steel	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	Ceq*
HT50	0.16	0.47	1.39	0.017	0.015	–	–	–	–	–	0.41
HT80	0.13	0.30	0.86	0.013	0.004	0.22	0.87	0.52	0.42	0.04	0.52

*: Ceq = C + 1/6 Mn + 1/24 Si + 1/40 Ni + 1/5 Cr + 1/4 Mo + 1/14 V (JIS G 3106)

steels are listed in **Table 1**. The carbon equivalent (Ceq) of HT50 and 80 steels is 0.41 and 0.52, respectively. The plate thickness of these steels is 25mm.

2.2 Welding procedures and conditions

High vacuum type-EB welder, conventional low voltage type (30KV-500mA, 15KW in maximum), was employed in this investigation. Welding for all materials was performed with one pass bead-on-plate welding method. Any oxide and scale on plate surfaces was completely machined along welding direction and in advance of electron-beam welding, all of test plates were completely de-magnetized and plate surfaces were made clean with degreasing regent.

In this experiment, all of welding were performed with 300mA or 400mA beam power. From the test results of the slope-welding method[4], the focal length (D_F) of each beam power was fixed to be 257mm for 300mA and 244mm for 400mA. It is often observed that 25mm thick plates were burnt through due to the large weld heat input, in case of which welding was performed by means of the stacking of respective two plates.

There are two series of welding conditions adopted in

Table 2 Welding conditions in various a_b parameters.

Beam power (KV-mA)	Welding speed (cm/min)	Weld heat input (KJ/cm)	a_b parameter (D_O/D_F) (D_F = 257 mm)
30–300 (9KW)	36	15	0.75, 0.9, 1.0
30–300 (9KW)	18	30	1.1, 1.2, 1.4

this investigation. **Table 2** shows the one series of welding conditions in which a_b parameter (D_O/D_F, D_O: Objective distance, D_F; Focal length) is varied for the various six levels for two different weld heat inputs

Table 3 Welding conditions in various weld heat inputs.

Designation of welding condition	Beam-power (KV-mA)	Welding speed (cm/min)	Weld heat input (KJ/cm)	a_b parameter (D_O/D_F)
N	30–300 (9KW)	45	12	0.75 (D_F = 257 mm)
M	30–300 (9KW)	18	30	1.0 (257)
W	30–400 (12KW)	18	40	1.2 (244)

(15 and 30KJ/cm). The specimen size in this case is 150mm in width and 500mm in length. **Table 3** shows the other series of welding conditions in which the weld heat input is selected for the different three levels (12, 30 and 40 KJ/cm). In order to obtain the reasonable variation of weld bead width, the a_b parameter to each weld heat input is determined to be 0.75, 1.0 and 1.2, respectively. Each designation of welding condition means that the respective bead width is narrow, middle and wide sizes. The specimen size in this case is 80mm in width and 500mm in length.

2.3 Heat treatment of weld metal

Two kinds of post heat treatment are given to some of plates welded with N-welding condition in Table 3 in order to reduce the hardness of weld metal. Namely, they are annealed with 450°C x 1 hr, or with 650°C x 1 hr.

2.4 Method for study of impact properties

Impact test was performed with Charpy V-notch specimen, the notch depth of which was successively changed, and the all specimens were notched at the center of the weld metal. The capacity of impact test machine was 50kg-m in maximum. Testing temperatures were firstly selected for six levels, –80, –60, –40, –15, 0°C and room temperature (15 ~ 30°C) in this examination to make the rough estimate of T_{rm}. Two test specimens were tested for each testing temperature. After that, the additional study was done in order to decide the exact temperature for the T_{rm}. For the welds with the welding conditions of Table 2 in which a_b parameter was varied, the test specimens were machined from 3mm under the plate surface, and the impact tests were performed with standard Charpy 2mm V-notch specimens.

Nextly, in case of the welds with the welding conditions of Table 3, in which the weld heat input was varied for the three levels with respective constant a_b parameter, the V-notch depth was successively changed from 1mm through 6mm to 10mm squared specimens. Moreover 15mm squared specimens were additionally made by way of trial in M-and W-welding conditions for

HT50 welds, the V-notch depth of which was 2 or 4mm. Furthermore, the V-notch depth in the heat treated specimens was selected to be 2, 4 or 5mm to 10mm squared. The combination between each welding condition and the test specimens prepared for various notch depths to 10mm square was shown in **Table 4**. The machined location for the test specimens for the N-, M- and W- welding conditions was 3, 4 and 5mm under plate surface, respectively. The respective machined location was determined in order to remove the snake head of electron-beam weld bead and to have parallel walled portion in bead within test specimens after macro-etching in cross-sectional welds.

Table 4 Combination between welding conditions and test specimens prepared for various notch depths to 10 mm square.

	V-notch depth to 10 mm squared specimen		
	12 (KJ/cm)	30 (KJ/cm)	40 (KJ/cm)
As weld	1, 2, 3, 4, 5, 6	1, 2, 3	1, 2
450°C annealing	2, 4, 5	–	–
650°C annealing	2, 4, 5 (mmV)	–	–

3. Bead Shape and Hardness Examinations

All of the electron-beam welded joint of HT50 and 80 steels were X-ray inspected. As the result, very small porosity could be partly observed in them, however reffering to Japan Industrial Standard Specification (JIS Z 3104-1968), most of them were allowable in the first class for synthetic grade.

Photo. 1 shows the macro-photographs for cross-sectional HT80 welds of 30KJ/cm weld heat input in various a_b parameters. The penetration depth was about 27mm in maximum at $a_b = 0.9$. With an increase of a_b parameter, the bead width is gradually tended to turn from wedge shaped type to wine cup shaped type. These tendencies were irrespective of the difference of materials. The bead shapes of 15KJ/cm weld heat input was similarly varied to those of 30KJ/cm. **Fig. 1** shows the variation of the bead width at 2,7 and 10mm inward depth from plate surface in various a_b parameters for HT80 welds of 30KJ/cm weld heat input. In the bottom part of this figure the simple sketch of the bead and its penetration depth are shown. At 2mm inward depth, the bead width showed minimum width of about 7mm at $a_b = 1.0$. Also in the variation at 7mm depth, it showed the discontinuous

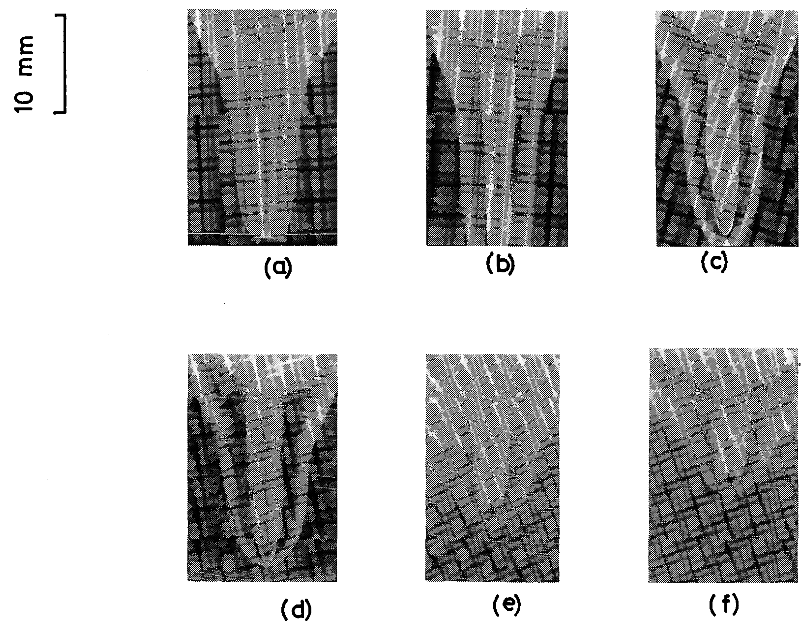

Photo. 1 Marco-photographs for cross-sectional HT80 welds of 30KJ/cm weld heat input in various a_b parameters.

(a) a_b=0.75 (b) 0.9 (c) 1.0 (d) 1.1 (e) 1.2 (f) 1.4

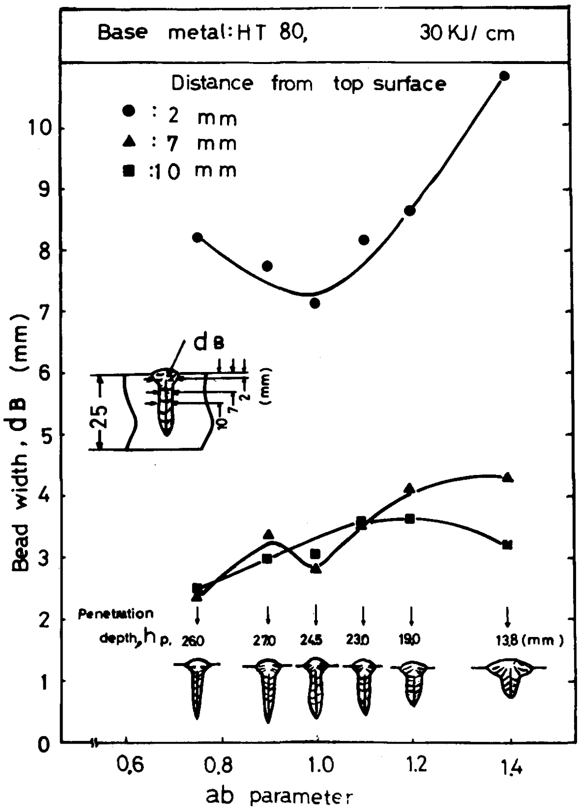

Fig. 1 Variation of bead width for HT80 welds of 30KJ/cm weld heat input in various a_b parameters.

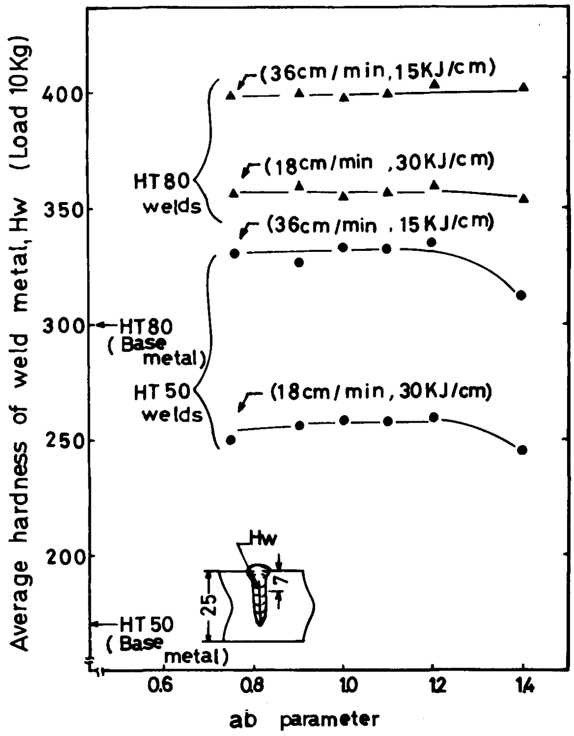

Fig. 2 Relation between a_b parameter and average hardness of weld metal (H_W) for HT50 and 80 welds.

variation at $a_b = 1.0$. It was caused by a little difference of bead shape. Namely, the bead shape at $a_b = 1.0$ had the constricted part just at 7mm depth. **Fig.** 2 shows the relation between the a_b parameter and the average hardness of weld metal (Hw) at 7mm inward from surface for HT50 and 80 welds. The hardness of welds was measured by using Vickers hardness tester with 10kg load. The hardnesses of the weld metal showed nearly constant value to the variation of a_b parameters. However, the hardnesses for $a_b = 1.4$ in HT50 welds seems to be somewhat decreased as compared with those for the other a_b parameters. It seems mainly to be related to the variation of the vaporization of Mn element in the weld metal during electron-beam welding due to the difference in molten puddle shape.

Photo. 2 shows the typical example of HT50 welds for

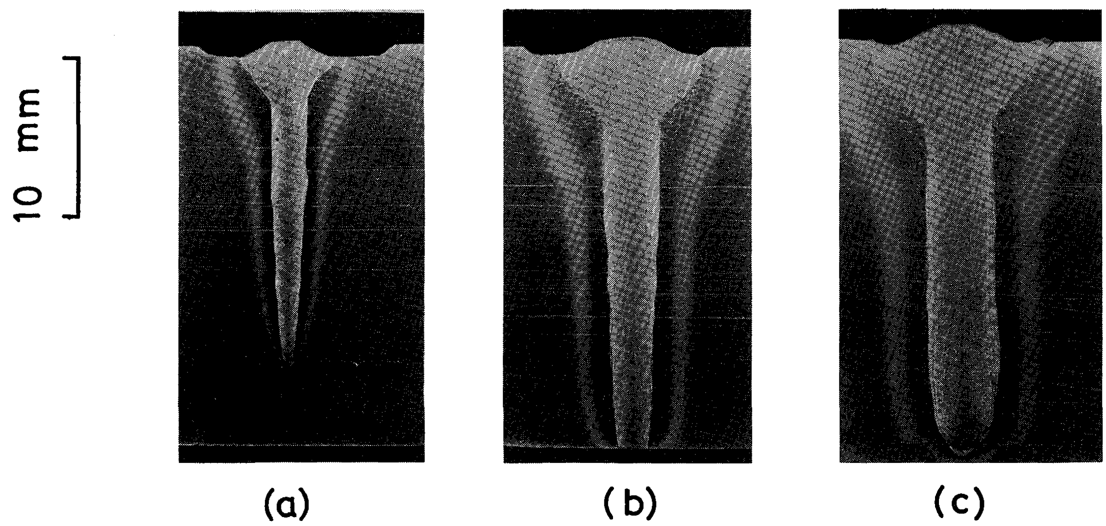

Photo. 2 Typical example of HT50 welds for different three weld heat inputs.

(a) 12KJ/cm, $a_b = 0.75$ (b) 30KJ/cm, $a_b = 1.0$ (c) 40KJ/cm, $a_b = 1.2$

the different three weld heat inputs (12 30 and 40KJ/cm), the bead width of which is varied to be narrow, middle and wide in size, respectively. The relations between the weld heat input and the penetration depth or the bead width are shown in **Fig. 3**. The measured point in the bead width for 12, 30 and 40KJ/cm weld heat inputs is at 8, 9 and 10 mm inwards from plate surface, respectively. Each position corresponds to the center of Charpy specimens machined.

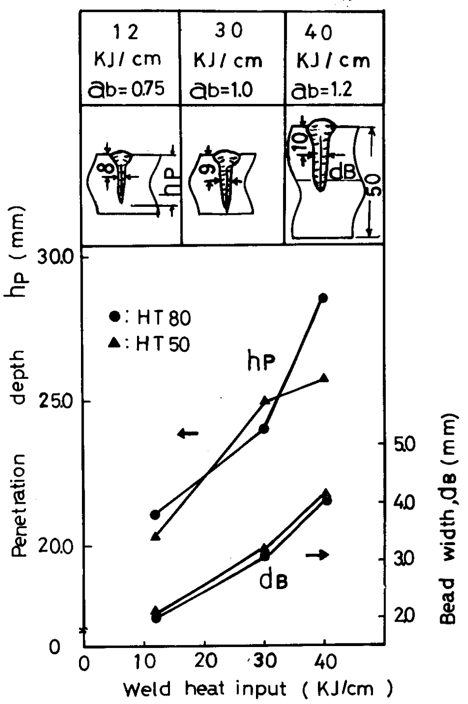

Fig. 3 Relation between weld heat input and penetration depth or bead width.

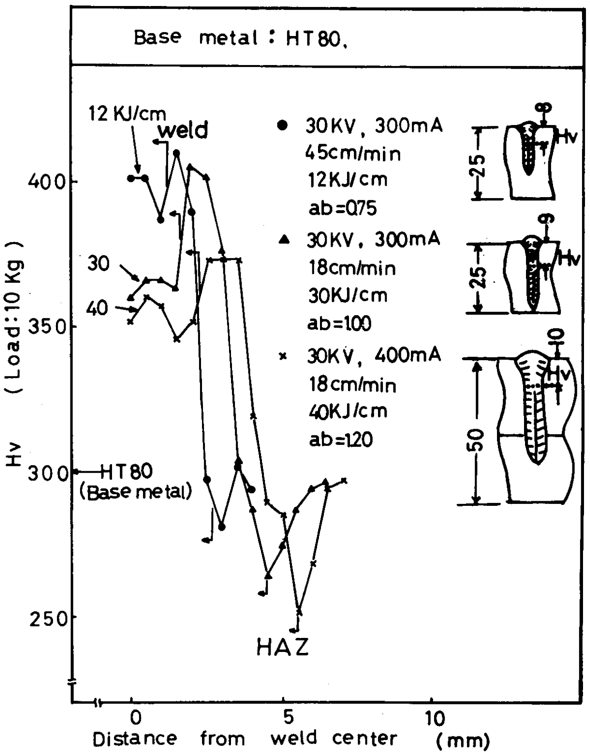

Fig. 4 Vickers hardness distributions of HT80 welds in various weld heat inputs.

Fig. 4 shows the Vickers hardness distributions of HT80 welds in various weld heat inputs. The softened zones are observed in respective distribution. The minimum hardness of softened zone in 40KJ/cm weld heat input showed the lowest value of all of them. This difference of the minimum hardness is considered to be related to the cooling rate for respective weld heat input. **Fig. 5** shows the relation between the weld heat input and

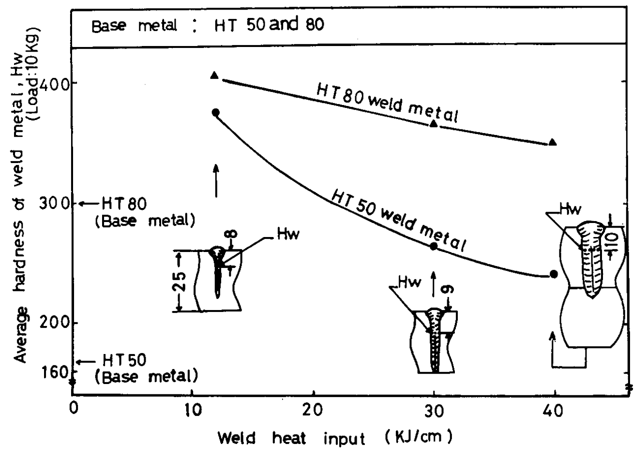

Fig. 5 Relation between weld heat input and average hardness of weld metal (H_W).

the average hardness of weld metal (Hw) for HT50 and 80 welds. Hw tends to be decreased with an increase of the weld heat input regardless of the difference of materials. **Table 5** shows the variation of average hardness in the heat treated-base and -weld metals concerning the welds of 12KJ/cm weld heat input. In case of HT50, the hardness of as-received base metal tended to be a little decreased by the two heat treatments, and the hardness of the weld metal always showed higher value than that of respective base metal. However, in case of HT80, the hardnesses in base and weld metals were remarkably lowered by 650°C annealing, and they showed nearly equal.

Table 5 Variation of average hardness of heat treated-base and weld metals.

(Load; 10 kg)

		HT50		HT80	
		H_W	H_B	H_W	H_B
Weld heat input: 12 KJ/cm	As weld	375	170	405	300
	450°C annealing	300	165	330	300
	650°C annealing	200	145	206	208

H_W; Average hardness of weld metal (VHN)
H_B; Average hardness of base metal (VHN)

4. Impact Properties

As stated previously, the value of impact strength usually showed the different levels even at the same testing temperature due to the difference in the fracture mode for Charpy specimens. Its specific testing temperature is named the transition temperature for fracture mode (T_{rm}). The following is mentioned about the results of the study for the T_{rm} of HT50- and 80-welds.

4.1 Effect of a_b parameter on Trm

As shown in Fig. 2, the hardnesses in the weld metal showed nearly constant regardless of the variation of a_b parameter. Then it is regarded as the variation of bead width. As an example, the transition temperature curves for HT50 welds of 15KJ/cm weld heat input in different three a_b parameters are shown in Fig. 6. The average hardness of weld metal (Hw) in each weld is constant at about 335 (VHN).

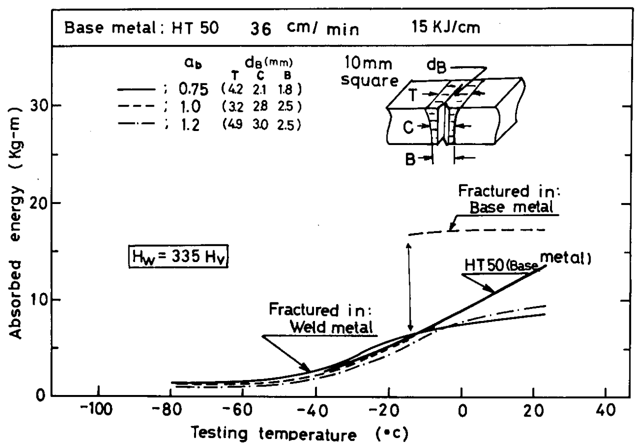

Fig. 6 Transition temperature curves for HT50 welds of 15KJ/cm weld heat input in different three a_b parameters.

The fracture mode separated into two types at $-15°C$ in case of $a_b = 1.0$, however it didn't separate even at 25°C in a_b = 0.75 and 1.2. Namely, the T_{rm} of the weld metal for a_b=0.75, 1.0 and 1.2 was >25, −15 and >25°C. respectively. The average bead widths at the top, center and bottom parts for each test specimen machined are also shown. Juding from this result, it is considered that the top bead width for test specimens has an important influence on the shift of T_{rm} for each weld metal.

Furthermore, the impact strength of the weld metal is little varied by the change of a_b parameters, and its value corresponds to that of base metal. **Fig. 7** shows the transition temperature curves for HT50 welds of 30KJ/cm weld heat input in different three a_b parameters. In this case the fracture always occurred in weld metal even at 100°C. It is due to the increase in the bead width (d_B) and the decrease in Hw in comparison with those of the

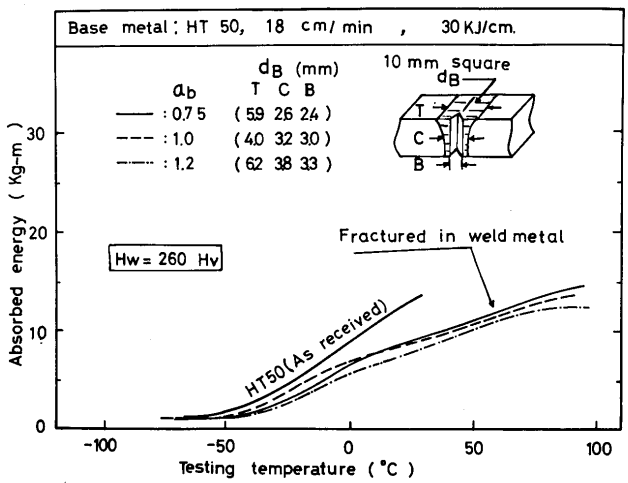

Fig. 7 Transition temperature curves for HT50 welds of 30KJ/cm weld heat input in different three a_b parameters.

welds of 15KJ/cm.

Moreover, the above-mentioned tendencies for HT80 welds were almost similar to those for HT50 welds. However in HT80 welds, the impact strength of weld metal seems to show lower value than that of base metal.

4.2 Effects of weld heat input and notch depth on T_{rm}

Fig. 8 shows the transition temperature curves for

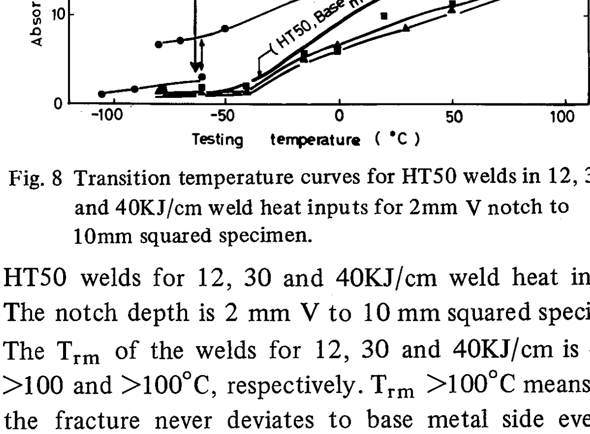

Fig. 8 Transition temperature curves for HT50 welds in 12, 30 and 40KJ/cm weld heat inputs for 2mm V notch to 10mm squared specimen.

HT50 welds for 12, 30 and 40KJ/cm weld heat inputs. The notch depth is 2 mm V to 10 mm squared specimen. The T_{rm} of the welds for 12, 30 and 40KJ/cm is −60, >100 and >100°C, respectively. T_{rm} >100°C means that the fracture never deviates to base metal side even at 100°C testing temperature. With an increase of the weld heat input, all of each bead width at top, center and bottom for test specimens machined are increased and the hardness in weld metal is decreased, and therefore the fracture tends to occur within the weld metal easily. Namely, the T_{rm} of each weld is considered to have the tendency to rise with an increase of the weld heat input.

Furthermore, in case of the result for the 1 mm notch depth to 10 mm squared specimen, the T_{rm} tended to rise with an increase of the weld heat input.

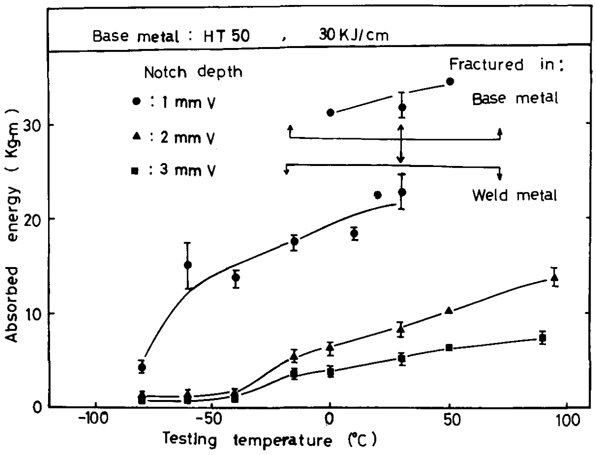

Fig. 9 Effect of notch depth variation to 10mm squared specimen on T_{rm} shift for HT50 welds of 30KJ/cm weld heat input.

Nextly, **Fig. 9** shows the effect of notch depth variation to 10 mm squared specimen on the shift of the T_{rm} for HT50 welds of 30KJ/cm weld heat input. The T_{rm} of the welds for 1,2 and 3mm V-notch depths was 30, >100 and $>100°C$, respectively. Namely, the T_{rm} of each weld tended to shift to higher temperature with an increase of the notch depth, that is, with a decrease of the remained thickness in the notch bottom for Charpy specimen. Furthermore, the features on the T_{rm}-shift of HT80 welds with the variation of weld heat input and notch depth are almost similar to those of HT50 welds. The relations between the notch depth to 10 mm squared specimen and the T_{rm} for HT50 and 80 welds in various weld heat inputs are shown in **Fig. 10.** As stated in the above, it was found that the T_{rm} for HT50 and 80 weld metal tended to be raised with an increase of the notch

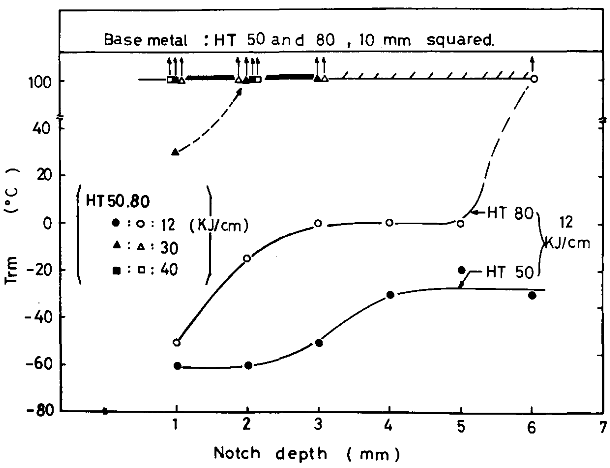

Fig. 10 Relation between notch depth to 10mm squared specimen and T_{rm} for HT50 and 80 welds in various weld heat inputs.

depth or weld heat input. In case of 6mm V-notch to 10mm squared specimen, the T_{rm} for HT50 and 80 welds of 12 KJ/cm weld heat input was -30 and $>100°C$, respectively. This difference in T_{rm} seems to be mainly caused by the respective hardness difference between the base and weld metals. Namely, as the hardness difference in HT50 welds is larger than that of HT80 welds, it is thought that the fracture of HT50 welds easily deviated to base metal side as compared with that of HT80 welds. Furthermore, by using the 15mm squared specimens, the notch depth of which is 2 or 4 mm, the impact tests were done concerning some of HT50 welds of 30 and 40KJ/cm weld heat inputs. As an example, **Fig. 11** shows the effect of notch depth variation to 15 mm squared specimen on the T_{rm}-shift for HT50 welds of 30KJ/cm weld heat input. The features on the T_{rm}-shift for 15 mm squared specimen by the variation of weld heat input or notch depth are similar to those for 10 mm squared. As shown in Fig. 11, the T_{rm} for the welds of 30KJ/cm in 2

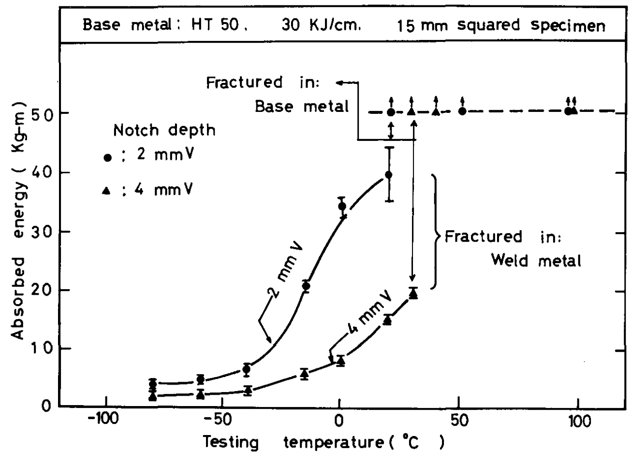

Fig. 11 Effect of notch depth variation to 15mm squared specimen on T_{rm} shift for HT50 welds of 30KJ/cm weld heat input.

and 4 mm V notches was 20 and 30°C, respectively. Moreover the T_{rm} for the welds of 40KJ/cm in 2 and 4 mm V-notches was >100 and $>100°C$, respectively. Furthermore, the T_{rm} for 15 mm squared specimen seemed to show lower temperature than that for 10 mm squared at the same 2 mm notch depth in case of 30KJ/cm weld heat input.

4.3 Effect of heat treatment on Trm

Some of the welds of 12KJ/cm weld heat input were annealed with 450°C x 1 hr or with 650°C x 1 hr in order to reduce the hardness of weld metal. Then, **Fig. 12** shows the comparison of the absorbed energy curves for HT80 welds without and with heat treatment for 2 mm V notch

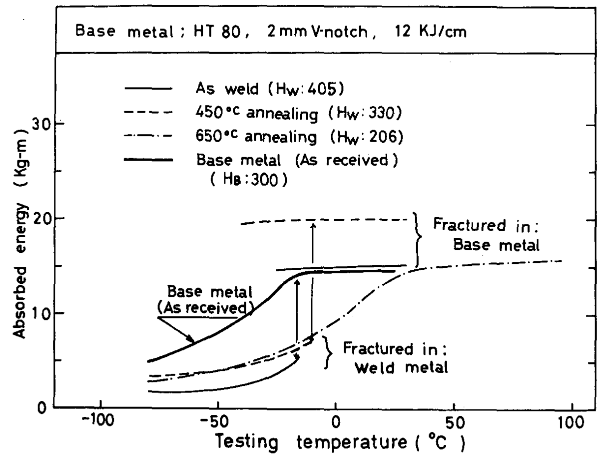

Fig. 12 Comparison of absorbed energy curves for HT80 welds without and with heat treatment for 2mm V notch to 10mm squared specimen.

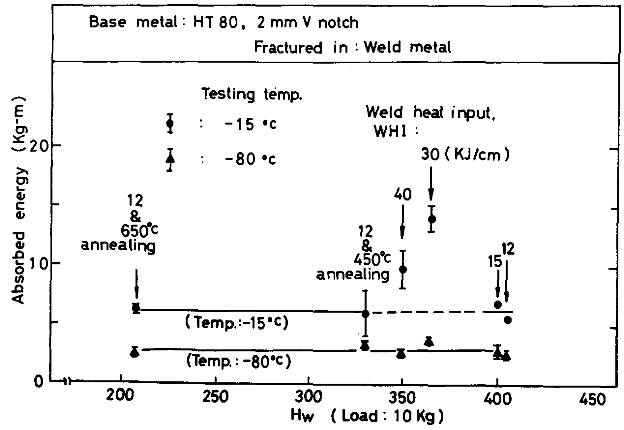

Fig. 14 Relation between average hardness and absorbed energy of weld metal for HT80 welds.

to 10 mm squared specimen. The T_{rm} for as-welds, 450°C and 650°C annealed welds is −15, −10 and > 100°C, respectively. Namely, with an increase in the heat treatment temperature, that is, with a decrease in the hardness of weld metal, the T_{rm} tended to be raised in general.

Also the respective impact strength of the weld metal always showed lower value than that of as-recieved base metal, however the impact strength at low testing temperature seems to be little raised by the heat treatments as compared with that of the as-welds. The tendencies for 4 and 5 mm notch depth specimen are almost similar to those in 2 mm notched. Furthermore, the features on the T_{rm}-shift in HT50 welds with heat treatments had similar tendency to those in HT80 welds, however, the impact strength of weld metal for HT50 welds in case of 650°C annealing showed remarkably higher value than that of the as-weld for HT50.

4.4 Relation between hardness and toughness in weld metal

Figs. 13 and 14 show the relations between the average hardness and the absorbed energy of the weld metal for HT50 and 80 welds by using the testing temperature as the parameter, respectively. The respective absorbed energy was shown in the value obtained by 2 mm V-notch specimen to 10 mm square, the fracture of which occurred within the weld metal. In HT50 welds (Fig. 13), the impact strength of the weld metal without heat treatments was not varied irrespective of the hardness variation, that is, the variation of weld heat input within the range of the authors' experiment. However, concerning the welds with heat treatments, the impact strength of the weld metal of 450°C annealed showed little higher value than that of the as-weld, and especially in 650°C annealed it showed remarkably high value. This will be due to a large change in microstructure of the weld by annealing. On the other hand, in HT80 welds (Fig. 14) the impact strength of the weld metal without and with heat treatments at the testing temperature, −80°C showed almost constant value regardless of the hardness variation of weld metal, according to a rough view. However, at −15°C testing temperature, the impact strength for the weld metal of 30 and 40KJ/cm weld heat inputs showed higher value than that for the others. This is due to the difference in the fracture propagation within the weld metal. Namely, in this case the fracture propagated along the notched location, but at the both sides of the notch for specimens it had a tendency to deviate partly to HAZ side. Therefore, it seems to show higher value. If there is no partial deviation to HAZ side at the both sides of notch, the impact strength is expected to show the similar value to that of the other welds.

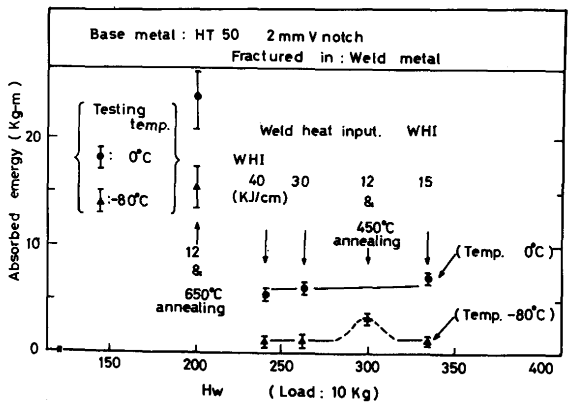

Fig. 13 Relation between average hardness and absorbed energy of weld metal for HT50 welds.

4.5 Settlement of the limit for the desirable T_{rm} higher than 100°C

It was found as stated in 4.4 that the impact strength for the weld metals of HT50 and 80 without and with heat treatments shows almost the same value, irrespective of the hardness variation of the weld metal except for the HT50 welds with 650°C annealing. Therefore, the features of the Trm for the weld metal of each steel were considered to be influenced by the two parameter, that is, the bead width and the hardness difference between base and weld metals. Then the settlement of the limit for the desirable Trm higher than 100°C was done for the weld metals of HT50 and 80 by using the bead width ratio (d_B/h) and the hardness difference ratio (H_w-H_B/H_B).
where, d_B: Bead width in test specimen.
h: Remained thickness of notch bottom for specimen.
H_w: Average hardness of weld metal at the center of specimen.
H_B: Average hardness of base metal.
To know the limit of the Trm higher than 100°C is very important to evaluate the true ductility of the weld metal. If the limit is not obvious, and the standard Charpy specimen is easily adopted to evaluate the ductility of the weld metal having very narrow weld zone and hard in hardness as electron beam or laser weld metals, the true ductility of the weld metal will be lost or confused and sometimes the researcher has an illusion that the ductility of the weld metal become abruptly superior to that of the base metal and also become to be scattered very much in the temperature range higher than the specific temperature (Trm).

Figs. 15 and 16 show the result of the settlement of the limit of the Trm higher than 100°C for HT50 and HT80 weld metals, respectively. Also the isothermal line for the T_{rm} from –20 to –40°C was roughly made clear in HT50 weld metal. The figures are represented with the bead width and the hardness difference ratios. The number in the figure shows the T_{rm} in each test. However the T_{rm} for the HT50 welds with 650°C annealing was not included in Fig. 15, as the impact strength showed remarkably high value.

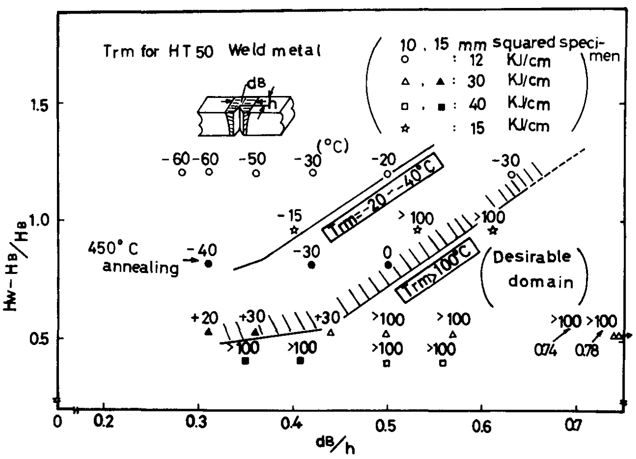

Fig. 15 Settlement of limit of the T_{rm} higher than 100°C for HT50 weld metal.

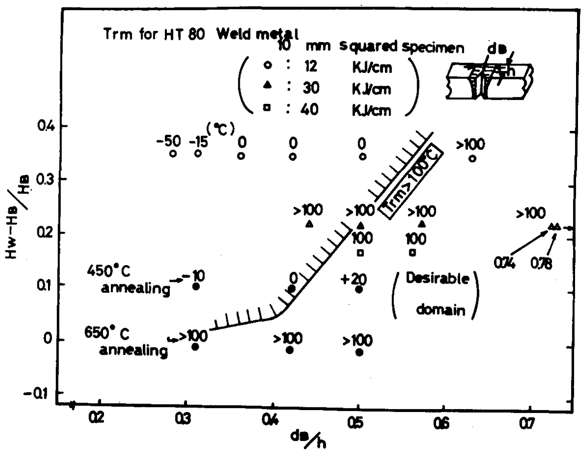

Fig. 16 Settlement of limit of the T_{rm} higher than 100°C for HT80 weld metal.

In each figure the d_B introduced was the bead width at the top surface for specimens, and the $T_{rm} > 100$°C means that the fracture didn't deviate to base metal even at 100°C testing temperature. From this result it is found that the fracture has a tendency not to deviate to base metal if the hardness difference ratio is decreased and/or the bead width ratio is increased. Moreover, in comparison of the result for HT50 welds (Fig. 15) with that for HT80 welds (Fig. 16), the limit of the T_{rm} higher than 100°C for HT80 welds showed in general the lower temperature at the similar hardness difference ratio. This seems to be due to the differrence in the impact strength of the weld metal between them. That is, as the impact strength for HT80 weld metal is higher than that for HT50, the T_{rm} for HT80 welds tends to shift to the lower temperature side.

Then, as an example, taking into consideration about the conventional submerged arc welds, the bead width ratio is extremely large and the hardness difference ratio nearly equals to zero. Therefore, it is found that the fracture never deviated to the base metal as the point for the weld is in the desirable domain for the $T_{rm} > 100$°C in each figure.

5. Conclusion

The effect of individual variation of the bead width and the hardness of weld metal and the notch depth of Charpy test specimen on the transition temperature for fracture mode, T_{rm}, was made clear on the electron-beam welds for HT50 and 80 steels. The results obtained are as follows.

(1) Effect of α_b parameter on the hardness of weld metal and the T_{rm}

(a) The hardness of the weld metal showed a nearly constant value regardless of α_b parameter.

(b) The impact strength of the weld metal is irrespective of the variation of α_b parameter. The impact strength for HT50 welds corresponded to that for base metal, however in HT80 welds it showed lower value than that for base metal.

(c) The top bead width in Charpy test specimen showed an important influence on the T_{rm}-shift in case of the variation of α_b.

(2) Effect of weld heat input or notch depth of Charpy test specimen on the T_{rm}.

(a) The T_{rm} has a tendency to be raised with an increase of weld heat input or notch depth of specimen.

(b) The T_{rm} for 15 mm squared Charpy test specimen showed lower temperature than that for 10 mm squared at the same notch depth.

(3) Effect of heat treatment

(a) With an increase of the annealing temperature, that is, with a decrease of the hardness of the weld metal, the T_{rm} tended to be raised in general.

(b) The impact strength of the weld metal for HT50 welds with 650°C annealing showed remarkably higher value than that of the as-welded.

(c) Except for the HT50 welds with 650°C annealing, the impact strength for HT50 and 80 welds without and with heat treatment was not almost dependent on the hardness variation of the weld metal.

(4) Limit of T_{rm} higher than 100°C

(a) Both of isothermal lines for the $T_{rm} > 100$°C for the weld metal of HT50 and 80 steels were roughly made clear by using the bead width to specimen size ratio and the hardness difference to base metal ratio.

(b) The T_{rm} tends to be raised with an increase of the bead width ratio, or with a decrease of the hardness difference ratio.

(c) The T_{rm} for the weld metal of HT80 steel showed in general lower temperature than that for HT50 weld metal at similar hardness difference ratio.

(d) For the purpose of acquisition of the true ductility of the weld metal which has a narrow bead width and a high hardness. An attension should be paid for the decision in the size of Charpy test specimen. A criterion for decision in the size of Charpy specimen was established for the weld metal for HT50 and HT80 steels in this investigation.

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