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

Yoshiaki ARATA*, Fukuhisa MATSUDA**, Yutaka SHIBATA***, Shigeomi HOZUMI***, Yoshihisa ONO*** and Shouichiro FUJIHIRA****

Abstract

Schenk type bending fatigue properties of electron-beam welds with square-butt joint for commercial high tension steels (HT—50, 60 and 80) of 25 mm thick plates were investigated in this paper. In this investigation two electron-beam welders (conventional high voltage and low voltage types) were used.

The fatigue limits of all the welds showed satisfactorily adequate values which corresponded to those of base metal. Consequently, it was concluded that Schenk type bending fatigue properties of electron-beam welds for HT—50, 60 and 80 steels were sound enough.

There were no remarkable relations between the weld heat input within the range of 7.5 KJ/cm to 20 KJ/cm and the fatigue limit, however the fatigue limit of weld with 100°C preheating showed merely low value as compared with that without preheating for each steel. Therefore, the fatigue limit of welds tended to a little rise with an increase of the hardness of weld metal.

1. Introduction

There are few data[1), 2), 3)], so far, concerning the mechanical characteristics of electron-beam welds of constructional high tension steels and its weldability is still unknown. Then, in this investigation, the authors aimed to make clear the mechanical properties of electron-beam welds of HT—50, 60 and 80 steels. Some results of the mechanical properties of electron-beam welds such as hardness distribution, tensile, bend and impact properties were reported in the previous report[4)]. It was recognized that the results of these mechanical tests except some impact properties of HT—50 steel would be satisfied with the practical use for many fields of application.

However, the fatigue properties were not so clarified for electron-beam welds of these high tension steels. Then, in this report, the authors mainly treated about the fatigue properties of the welds of these steels. Namely, S-N curves were obtained to evaluate the fatigue properties of electron-beam welds by means of Schenk type bending test. Subsequently these S-N curves of welds were compared with those of respective base metal. Furthermore, the relations between the fatigue limits and the weld heat input or the hardness of weld metal were discussed here.

2. Experimental Procedure

2.1 Materials used

The materials used in this investigation are HT—50, 60 and 80 steels which are widely used in the constructional bridges and buildings. The chemical composition of these high tension steels are listed in **Table 1.** HT—50 steel has no heat treatment and HT—60 and 80 steels have quenched and tempered.

Table 1. Chemical composition of HT—50, 60 and 80 steels.

(wt.%)

Composition / Steel	C	Si	Mn	P	S	Ni	Cr	Mo	V	Ceq*
HT—50	0.18	0.43	1.54	0.027	0.021	0.028	0.019	0.002	0.004	0.46
HT—60	0.13	0.32	1.32	0.015	0.013	0.025	0.012	tr	0.030	0.37
HT—80	0.13	0.29	0.85	0.016	0.008	0.98	0.48	0.39	0.023	0.50

*: $Ceq = C + \frac{1}{6}Mn + \frac{1}{24}Si + \frac{1}{40}Ni + \frac{1}{5}Cr + \frac{1}{4}Mo + \frac{1}{14}V$ (JIS Z 3106)

† Received on Dec. 18, 1974

* Professor
** Associate Professor
*** Katayama Iron Works, Ltd.
**** Co-operative Researcher (1974), Katayama Iron Works, Ltd.

treatments. 25 mm thick plates of these steels were square-butt welded with electron-beam welding process.

2.2 Welding Condition

Two machines of high vacuum type-EB welder, conventional high voltage type (150 KV—40 mA, 6 KW) and low voltage type (30 KV—500 mA, 15 KW), were used in this investigation.

Welding for all materials was performed with one pass or two passes method without and with 100°C preheating under the joint profile of butt type as shown in **Fig. 1.** The size of each specimen before welding is 200 mm in width, 500 mm in length and 25 mm in thickness. The welding conditions used on various materials are tabulated in **Table 2.**

The beam power of respective EB-welder was constant at 5 KW for high voltage type or 7.5 KW for low voltage type, and the welding speed was varied for two levels, respectively. Furthermore, the effect of preheating was also examined for each welding speed. Welding was performed for one pass-welding in case of the large weld heat input, while in case of the small weld heat input it was performed for two passes-welding with respective electron-beam welder.

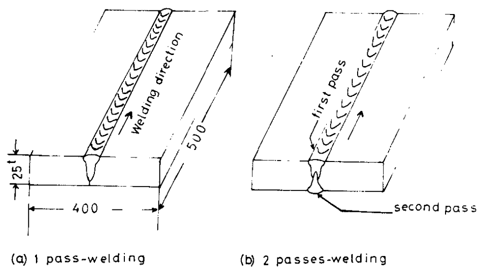


Fig. 1. Dimension of specimen.

In case of two passes-welding, both the first and the second pass were welded in the same direction, and the second pass was performed without and with 100°C preheating after the raised temperature of the welds due to the first pass welding without or with preheating was fully cooled to room temperature (R·T). 100°C preheating was performed by driving the defocused electron-beam along the welding line, and the preheating temperature, 100°C was ascertained by use of a chromel-alumel thermocouples.

In Table 2, welding conditions, A and C for the one pass-welding were determined by the result of preliminary test, the weld heat input of which was burnt through 20 mm thick steel plate, and welding conditions, B and D for two passes-welding were also selected as the weld heat input to burn through 15 mm thick steel plate. A typical example of macrophotographs of the entire welds for HT—60 steel is shown in **Photo. 1,** which was welded with one pass and two passes by low voltage type EB-welder. The beam

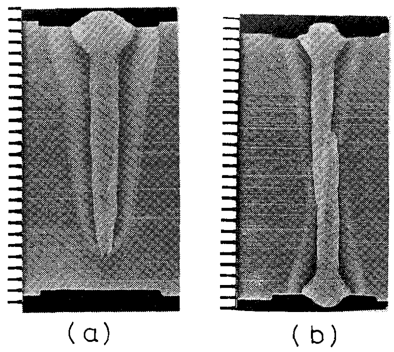


Photo. 1. Macrophotographs of welds for HT—60 steel by use of low voltage type E·B welder.
(a) one pass-welding
(b) two passes-welding

Table 2. Welding conditions used.

Series \ Condition	Beam power (KV—mA)	Welding speed (cm/min)	Weld heat input (KJ/cm)	Preheat temperature (°C)	Welding procedure
D5A, D6A, D8A	150−33≒(5 KW)	15	20.0	R · T	One pass-welding as Fig. 1 (a)
D5B, D6B, D8B	150−33≒(5 KW)	24	12.5	R · T	Two passes-welding as Fig. 1 (b)
D5C, D6C, D8C	150−33≒(5 KW)	15	20.0	100	One pass-welding as Fig. 1 (a)
D5D, D6D, D8D	150−33≒(5 KW)	24	12.5	100	Two passes-welding as Fig. 1 (b)
N5A, N6A, N8A	30−250=(7.5 KW)	30	15.0	R · T	One pass-welding as Fig. 1 (a)
N5B, N6B,VN8B	30−250=(7.5 KW)	60	7.5	R · T	Two passes-welding as Fig. 1 (b)
N5C, N6C, N8C	30−250=(7.5 KW)	30	15.0	100	One pass-welding as Fig. 1 (a)
N5D, N6D, N8D	30−250=(7.5 KW)	60	7.5	100	Two passes-welding as Fig. 1 (b)

Note; D: High voltage type EB-welder
N: Low voltage type EB-welder
5: HT—50 6: HT—60 8: HT—80
A, B, C, D: Welding condition

active parameter a_b (D_0/D_F), was respectively selected for 0.97 and 0.93 in high and low voltage electron-beam welders, the objective distance (D_0) of which was 430 and 280 mm, respectively.

Every square butt joint had a good fit up and did not have any excessive gap by use of the restraint jig and tack welding, and any scale on root faces and plate surfaces was completely eliminated. Furthermore, all of the specimens used were completely de-magnetized and the root faces of joint were made clean by acetone in advance of electron-beam welding.

2.3 Fatigue test

Fatigue tests for the welds for HT—50, 60 and 80 steels were performed by means of Schenk type bending test-machine (max. 4Kg–m, 1800 r.p.m.). The test specimen has two semicircular notches (radius: 5 mm) at both ends of the welds as shown in **Fig. 2.** The specimens were machined from the midst of plate thickness for one pass-welding and of the first bead for two passes-welding. All of specimens were X- ray inspected in advance of fatigue test and the test was done with the defect-free specimens. Ten specimens were usually examined for each welding condition to determine the fatigue properties of the respective weld.

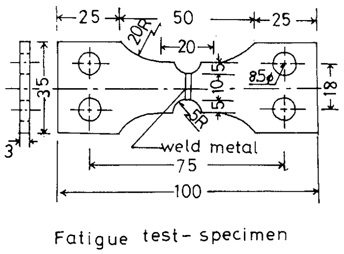


Fig. 2. Dimension of fatigue test specimen.

3. Experimental results

An example of tested specimens for HT—50 steel, the welding condition of which corresponds to D5D in Table 2, is shown in **Photo. 2.** This was fractured through the weld metal, however some of the tested specimens were fractured through the heat-affected zones (HAZ). In neither case did the fracture path propagate to the base metal.

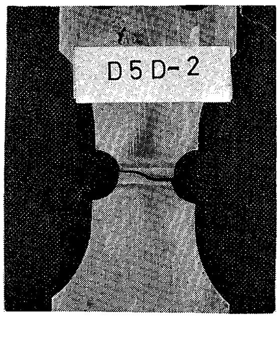
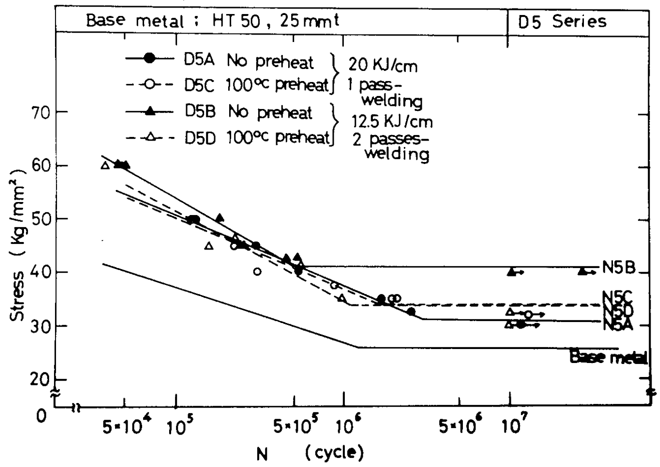


Photo. 2. An example of fatigue tested specimen.

Fatigue properties (S-N curves) of the respective weld and the base metal for HT—50, 60 and 80 steels are shown in **Figs. 3~8,** which are classified by the



Eig. 3. S-N curve for D5 series.

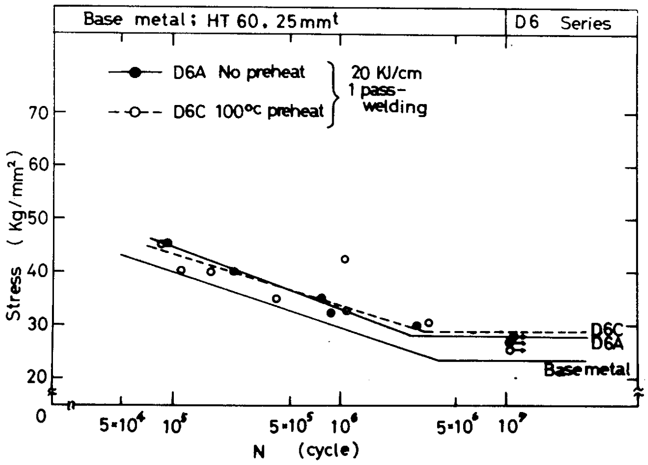


Fig. 4. S-N curve for D6 series.

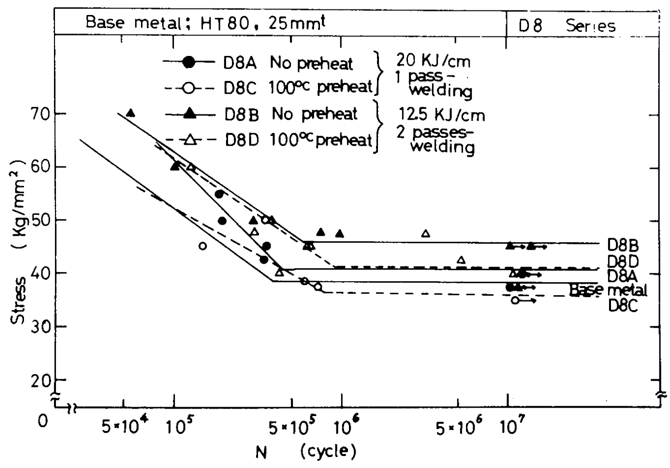


Fig. 5. S-N curve for D8 series.

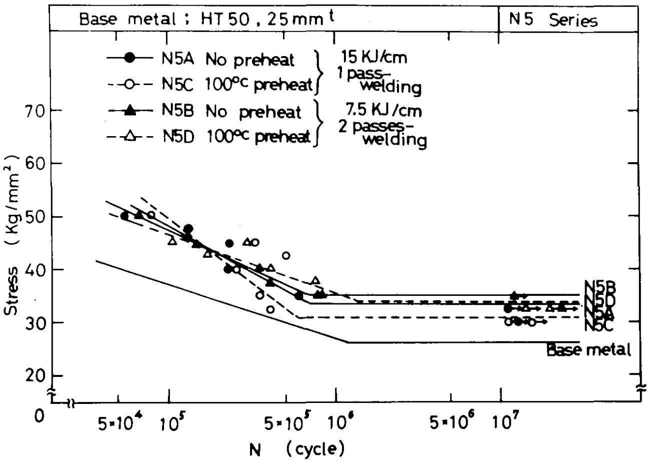


Fig. 6, S-N curve for N5 series.

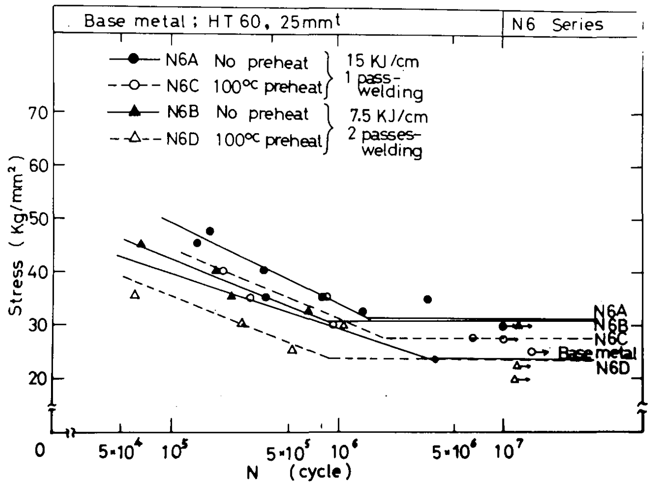


Fig. 7. S-N curve for N6 series.

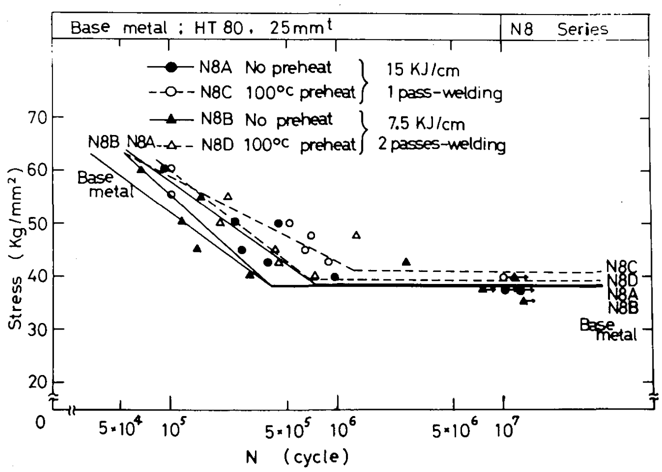


Fig. 8. S-N curve for N8 series.

types of steels and EB-welders used. As shown in those figures, the fatigue limits of all the welds showed adequate values which corresponded to those of base metal. Particularly in case of HT—50 steel, the values of fatigue limit of welds are considerably superior to those of the metal regardless of the difference of EB-welder. Therefore, it is concluded that Schenk type bending fatigue properties of electron-beam welds for HT—50, 60 and 80 steels are satisfactory enough.

Nextly, the relations between weld heat input and the fatigue limit of welds for HT—50, 60 and 80 steels are shown in **Fig. 9.** There were no obvious relations between them within the range of a given weld heat input (7.5 KJ/cm to 20 KJ/cm) for both one pass-and two passes-welding, however it seemed that the fatigue limit of welds with 100°C preheating showed merely low value as compared with that of the welds without preheating at the same weld heat input. **Fig. 10** shows the relation between the fatigue limit and the average hardness of respective weld metal (H_w) which was shown in the previous report. The fatigue limit of the welds for HT—50 and 60 steels tended to be a little increased with an increase of the hardness, while in case of HT—80 steel it had no obvious relation.

Finally the relation between the fatigue limit of welds and the absorbed energies at R·T (20°C) for weld metal is shown in **Fig. 11.** The impact properties of welds examined by Charpy 2 mm-V notch specimens have been discussed in the previous report and also the arrow-signs in this figure indicate the range of absorbed energies due to the difference in the form of fracture path. There are no special relations between them.

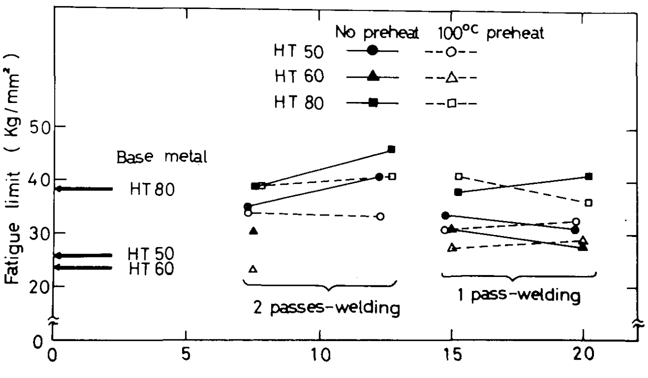


Fig. 9. Relation between fatigue limit and weld heat input for base metal and welded joints of HT—50, 60 and 80 steels.

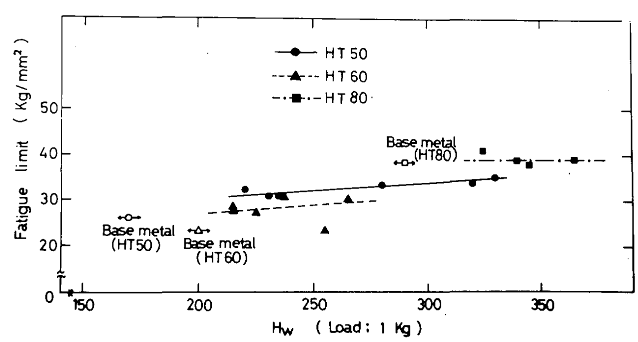


Fig. 10. Relation between fatigue limit and hardness in base and weld metals for HT—50, 80 and 80 steels.

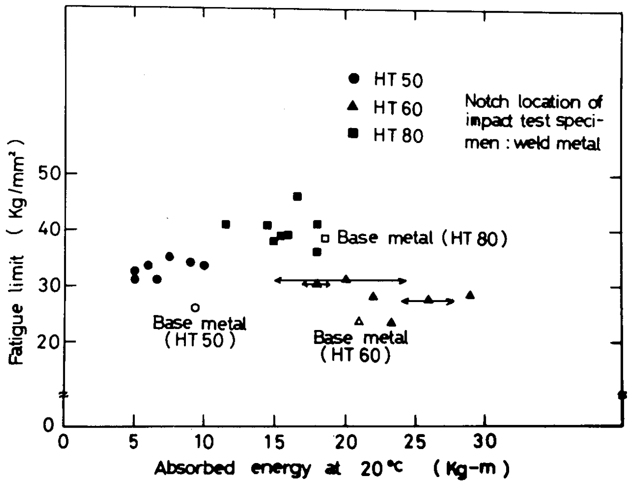


Fig. 11. Relation between fatigue limit and absorbed energy at 20°C for base metal and welded joints of HT—50, 60 and 80 steels.

4. Conclusion

In this report Schenk type bending fatigue properties of electron-beam welds for constructional high tension HT—50, 60 and 80 steels were clarified. The summary of the obtained results is as follows.

(1) The fatigue limits of all welds showed exceedingly adequate values which corresponded to those of base metal regardless of the difference of electron-beam welders. Paticularly, in case of HT—50 steel, the fatigue limits showed higher values than those of the base metal.

(2) Within the range of a given weld heat input (7.5 KJ/cm to 20 KJ/cm) no obvious relations were observed between weld heat input and the fatigue limit of welds. However the fatigue limits tended to be merely lowered by 100°C preheating at the same weld heat input.

(3) It seemed that the fatigue limits of welds were related with the hardness of weld metal. In general the fatigue limits had a tendency to be a little raised with an increase of the hardness except for HT—80 steel.

(4) No obvious relations were observed between the fatigue limit and the absorbed energies at room temperature.

Acknowledgement

Sincere appreciation is expressed to S. Katayama, the graduate student of Welding Department, Osaka University, who kindly assisted us for carrying out the various tests.

References

1) A. J. William et al: "Properties of Electron-Beam Welds in Ultra-High-Strength Steels", 1st International Conference of Electron Ion Beam Science and Technology 1965, 674～712.

2) H. I. Mchenry et al: "Electron Beam Welding of D6AC Steels", Welding Journal, Vol. 45, No. 9, Sep. 419S-425S, 1966.

3) W. P. McGregor et al: "Electron Beam Welding of Thick Sections", AFML-TR-69-198, Aug., 1969.

4) Y. Arata et al: "Mechanical Properties on Electron Beam Welds of Constructional High Tension Steels (Report I)", Trans. of JWRI, Vol. 3, No. 2, p. 59～74, 1974.

5) Y. Arata et al: "Study on Characteristics of Weld Defect and Its Prevention in Electron Beam Welding (Report I)", Trans. of JWRI, Vol. 2, No. 1, p. 103～112, 1973.