TECHNICAL NOTE

Study on the Brittle Fracture of Welded Beam-to-Column Connections†

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Abstract

It was reported that the brittle fracture in plastic range at room temperature took place in the full scale tests of wide flange beam-to-column connections of which the thickness of column flanges were from 40mm to 60mm[1)2)]. It is very important to analyze this phenomenon, because the wide flange of heavy steel section is generally used in the construction of multi-story buildings.

In this paper, the COD testing of welded beam-to-column connection with plate thickness 38mm (1½") is dealt with.

KEY WORDS: (Brittle Fracture) (Structural Members) (Buildings)

1. Introduction

It is the ultimate purpose in structural engineering to design structures reasonably and safely, and it is also one of the most important problem for the designers. Up to now, many conventional design methods have been proposed and put into practice. The major one is the allowable stress design method, i.e. the elastic design method. In this method, we introduce the safety factor (ν) and restrict it to a certain value. Then by the following equation, i.e. the ultimate strength $/\nu$ = design strength (= allowable stress), we define the allowable stress.

In such a way, we should check the safety of structures. It is noted, however, that the ultimate strength of actual structures is not uniform because of the variation of the strength of materials and the uncertainty of constructions, and the reversible equation, that is, the design strength (= allowable stress) x ν = the ultimate strength, exists no more.

Furthermore, in structural design, we do not take into consideration of defects in structures. The defects would exist in structures and be considered to have a great influence upon the strength of structures. In such a case, the usual conventional design method becomes invalid. Where the defects exist in materials the member easily yields around them. As the result, the crack initiates and it propagates the whole structure. At the present time, the fracture mechanics is commonly used to analize such structures with cracks. The fracture mechanics is the most available method for the brittle fracture of steel structure.

The brittle fracture became most important since about 1940, when the welding was widely used in steel construction. Since the brittle fracture of Hasselt Bridge (in Belgium), a lot of welded structures had collapsed in winter.

In general, the following conditions are considered in brittle fracture;

(1) development of local yielding zone at crack tip
(2) initiation of brittle microcrack
(3) propagation of brittle crack

The former two conditions are usually satisfied where defects exist in structures. The last condition, however, is not satisfied in general, because the brittle fracture depends upon the material properties, the temperature and the strain energy of steel member. Whether the brittle crack propagates or not depends upon the various factors mentioned above. The following factors seem to have influence upon brittle fracture;

(1) material properties (grade of steel, change of material properties by welding, anisotropy of rolled steel, etc.)
(2) temperature (transition temperature)
(3) constraint intensity of plastic deformation (plane strain, dimensions of members, etc.)

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(4) residual stresses (by rolling and welding, etc.)

The brittle fracture is caused by superposition of these factors, and it is necessary to make clear how these factors affect on the brittle fracture. The former two factors can be estimated by the test of small specimen, but the latter two cannot be done by it, and they should be estimated by the test of large scale specimen. Therefore the authors examine the fracture toughness of welded beam-to-column connection of heavy steel section.

At first stage we focused our attention on the former two factors, that is, (1) material properties and (2) temperature, and carried out the COD testing of small scale specimen which is little affected by the latter two factors.

2. Experiment

As mentioned above, the test pieces are the COD specimens which are similar to welded beam-to-column connection. The COD specimens are those regarded as a part of welded joint at which the flange plate of beam is connected to the flange of column.

Three types of specimen were provided for COD testing. "A type specimen" is the one perpendicular to rolled direction, that is, specimen of through thickness direction. "B type and C type specimens" are those of rolled direction. These specimens were devided in five kinds by the location of crack tip as following;

(1) A.B specimen (basemetal specimen of through thickness direction)
(2) A.H specimen (H.A.Z. specimen of through thickness direction)
(3) B.D specimen (deposited metal specimen of rolled direction)
(4) B.H specimen (H.A.Z. specimen of rolled direction)
(5) C specimen (base metal specimen of rolled direction)

These specimens are shown in **Fig.1**. The grades of steel employed in this experiment are SS41 and SM50YB, and the material properties are listed in **Table.1**. These specimens were welded by means of CO_2 + Ar gas shielded semi-automatic welding. The temperature range in this experiment was from −50°C to 20°C and test temperatures were −50°C, −20°C, 0°C and 20°C. COD test was carried out by three point bending according to DD19 of British Standards[3]. The experimental results between the force signal and the displacement gage output were plotted on an autographic X-Y recorder. Loading was made by means of the servo pulser of 10tons capacity with the closed loop system. The test was controlled by the actuator piston stroke of the servo pulser and the rate of piston stroke was about 0.2mm/sec. The loading configulation is shown in **Fig.2**.

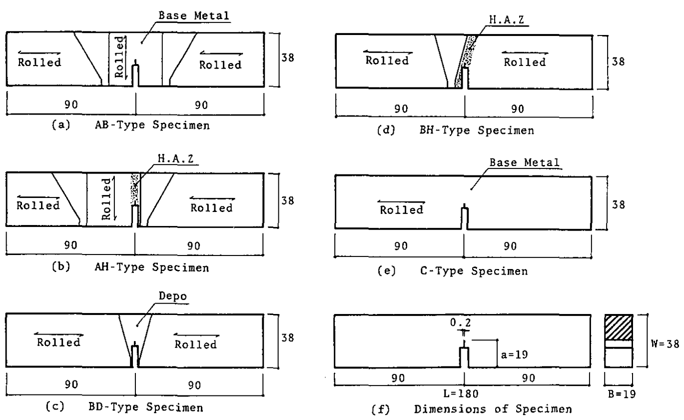

Fig. 1 COD Test Specimen for Bending (in mm)

Table 1 Mechanical Properties

Specimen	Yield Stress (Kg/mm^2)	Ultimate Strength (Kg/mm^2)	Elongation (%)
SS41 (Rolled)	28.8	48.6	-
SM50YB (Rolled)	39.8	57.7	26.1

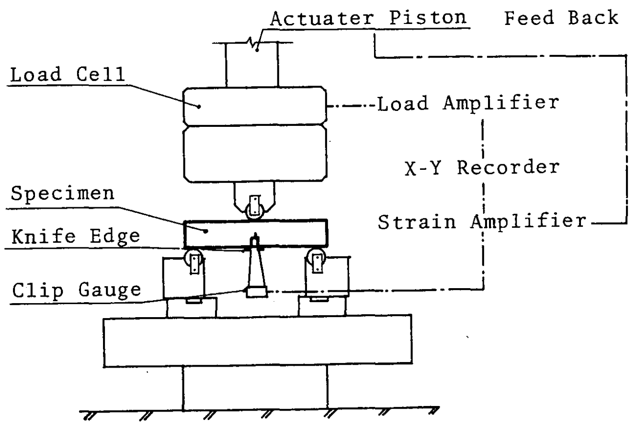

Fig. 2 Loading Configulation

3. Experimental results

The hardness test was carried out before loading by means of Rockwell B hardness testing. The test results are shown in **Fig.3~4**. The hardness of deposited metal contains the highest value of the three in SS41, but in SM50YB that of H.A.Z. is the highest. The hardness of base metal is the lowest in both grades. The hardness of

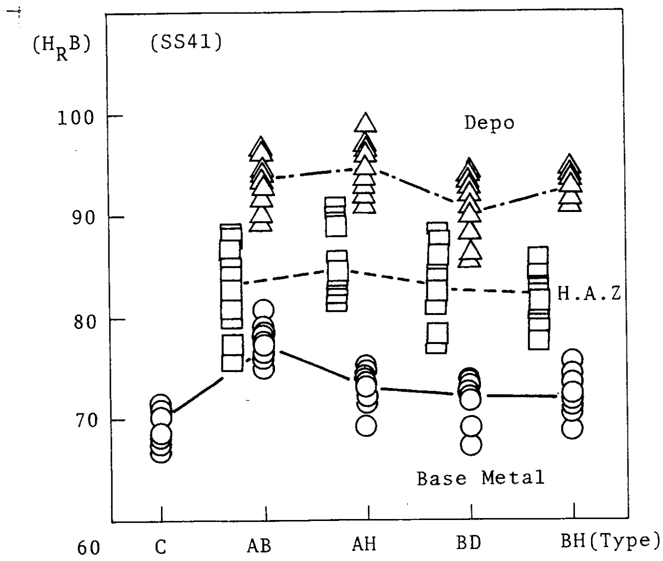

Fig. 3 Distribution of Rockwell B Hardness

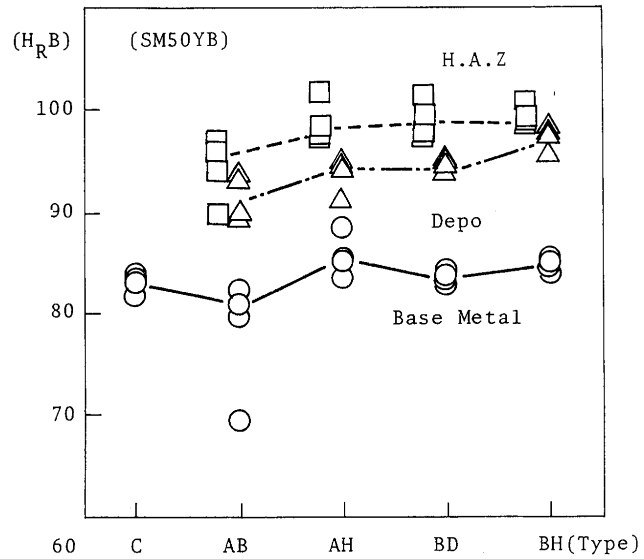

Fig. 4 Distribution of Rockwell B Hardness

SM50YB of high tensile strength is higher than that of SS41. These results are generally concerned with the fracture toughness, that is, the hardness of materials is closely related to the embrittlement of materials by welding.

Fig.5~6 show the COD values plotted against temperatures. The COD values were obtained from the applied force / displacement records. In DD19 of British Standards, it is pointed out that the detection is described in detail. However, it is difficult to employ this method, and in this experiment, as a rule, the clip gage displacement at the first attainment of a maximum load was regarded as the critical displacement without the case of the obvious falling of the applied load. The critical clip gage displacement was converted to the critical crack tip COD (Φ) value by using the following equations.

i) $V_c \geqq 2\gamma\sigma_y W(1-\nu^2)/E$

$$\Phi = \frac{0.45(W-a)}{0.45W+0.55a+Z}\left[V_c - \frac{\gamma\sigma_y W(1-\nu^2)}{E}\right]$$

ii) $V_c < 2\gamma\sigma_y W(1-\nu^2)/E$

$$\Phi = \frac{0.45(W-a)}{0.45W+0.55a+Z}\left[\frac{V_c^2 E}{4\gamma\sigma_y W(1-\nu^2)}\right]$$

The COD values,Φ(=δc),are shown in **Fig.5~6** as the calculated results. The COD value of the base metal of rolled direction is the highest and that of base metal of through thickness direction is the lowest and that of the others exists between the two values. "C specimen" of rolled direction contains enough toughness and stable crack

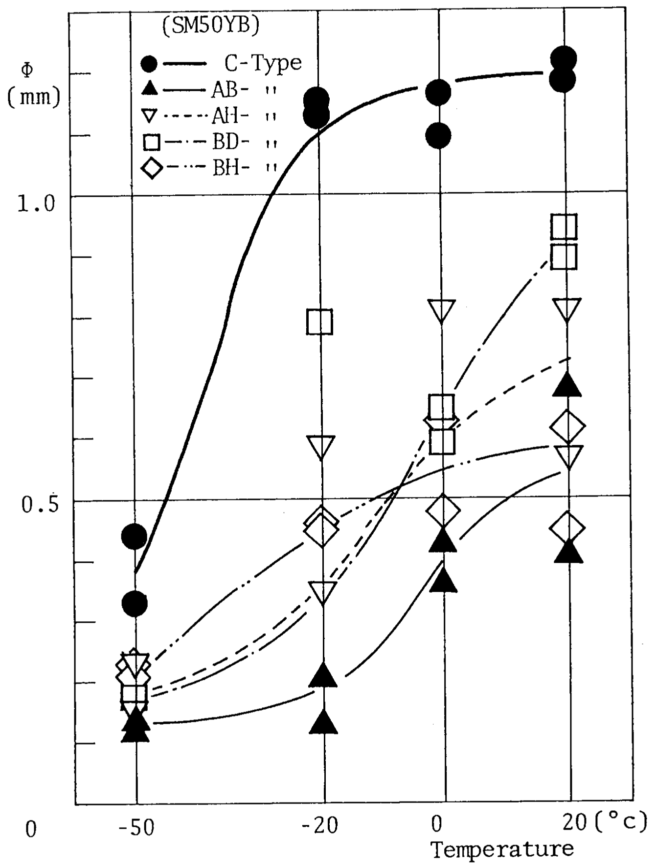

Fig. 5 COD Values V.S Temperature

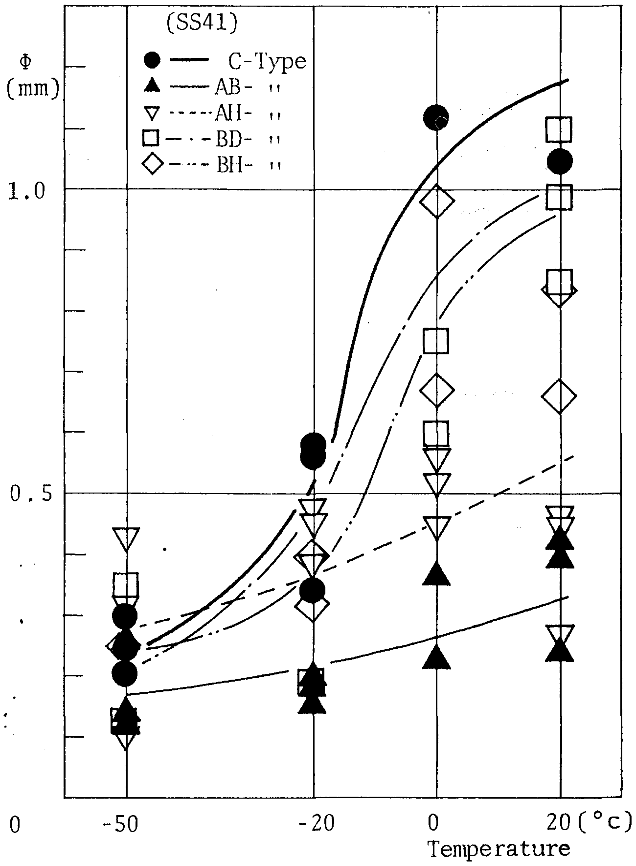

Fig. 6 COD Values V.S Temperature

grows gradually up to fracture. On the contorary, "A.B specimen" of through thickness is easily destroyed by tearing. This phenomenon seems to be concerned with lamellar tearing. The other specimens except the H.A.Z. of through thickness seems to be embrittled by welding.

4. Summary and Conclusion

This experiment was carried out to get the basic conception on the brittle fracture of welded joints of heavy steel section. The basic conception on the fracture toughness obtained from COD testing is described herein concerning with material properties and temperature.

In general the fracture toughness seems to be closely related to the hardness of materials except the case of through thickness direction, and it seems that the COD value may be predicted by the hardness of materials, although the correlation between COD and hardness is unknown at the present stage.

The following conclusions are obtained from the test results.

(1) The difference in the grade of steel has little influence upon the brittle fracture in this case. It seems that there is no distinguished difference in the COD values of base metals.

(2) The base metal of rolled direction contains enough toughness to grow the stable crack. However, the base metal of through thickness is easily fractured by tearing. This phenomenon seems to be closely related to the lamellar tearing, which has received remarkable attention recently[4)5)].

(3) The heat affection by welding embrittles material properties of rolled direction, but it reforms those of through thickness direction on the contrary and the COD value of H.A.Z. is higher than that of base metal.

(4) Further experiment should be carried out to make clear the effects of plastic constraint and of residual stress including the estimation of hardness and lamellar tearing.

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References

1) Ben Kato, et al, "Brittle fracture of heavy steel section" ; Trans. of AIJ, No.156, FEB.1969,pp.1-10 (in Japanese)

2) Ben Kato, et al, "Brittle fracture of heavy steel section (No.II)" ; Trans. of AIJ, No.176, OCT.1970, pp.11-16 (in Japanese)

3) British standards, "Method for Crack Opening Displacement (COD) testing ",DD.19, 1972

4) Toshio Nagao, et al, "Effect of restraint intesity of joint on lamellar tearing (Report 1)" ; Journal of JWS, Vol.45, No.2, FEB.1976, pp.31-39 (in Japanese)

5) Shogo Kanazawa, et al, "On the assessment of lamellar tearing susceptibty", Journal of JWS, Vol.45, No.3, MAR.1976. pp. 72-79 (in Japanese)