Elongation Capacity of Welded Joints in Beam-Column Connections†

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Abstract

In The Great Hanshin-Awaji Earthquake Disaster, "the general yield brittle fractures" were observed in beam-column connections of steel building frames. In this research we describe some experimental results using cruciform butt specimens welded by different types of welding consumable. The specimens are modeled on a cruciform joint by taking out the part of the beam-flange to column-flange connection. The purpose of this research is to examine the occurrence condition of the general yield brittle fracture and its elongation capacity. From the results, we also mention the fracture toughness value and heat-input remits of welding to keep enough elongation capacity in beam-column connections

KEY WORDS: (Damage due to Earthquake) (Steel Structures) (Welded Joints)(Cruciform Joints) (Beam-Column Connection) (Brittle Fracture)

1. Introduction

In The Great Hanshin-Awaji Earthquake Disaster, fractures were observed in beam-column connections of steel building frames. In steel buildings, the beam-column connections are usually made by welding. These parts have the largest load, so that they become the most important part of the frame. The fractures are divided into two types, either due to insufficient strength or to brittle fracture. The former type was found in comparatively older buildings. It is assumed that these were welded according to the old design standards.

However the latter type of damage occurred in connections welded according to the present design standards. It was ascertained by marks of local buckling, peeling of paint or mill scale and Luders's lines, that these fractures occurred after large deformations. In this context, these are regarded as

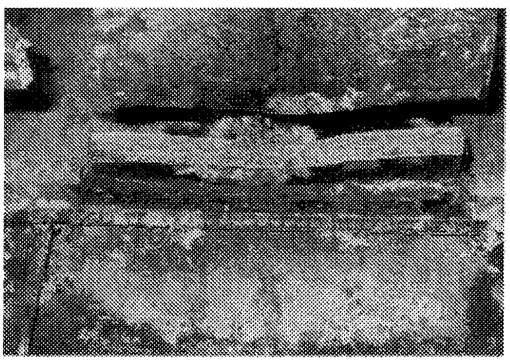

Fig.1 Brittle fracture in base metal from toe of the scallop[2)]

Fig.2 Brittle fracture at heat-affected zone[2)]

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"general yield brittle fractures", because they fractured at stress concentration points or discontinuous points of shape after absorption of seismic energy.[1] As the fracture was maybe caused by the hardness of the metal, so it differs from "the low stress brittle fracture", which hardly absorbs seismic energy. More studies are needed about the influencing [3] factors of general yield brittle fracture and about the energy absorption capacity required for these structures.

Typical modes of brittle fracture in beam-column connections are divided as follows.[2]

(Mode-A) Brittle fractures in the base metal at beam-flanges, starting from the toe of the weld access hole (scallop) in the web. **(Fig. 1)**

(Mode-B) Brittle fractures in the base metal, heat-affected zone or weld metal of welded connections, starting from the backing strip or the end tab. **(Fig. 2)**

It is considered that the mechanical properties of the base metal and the detail of the scallop, the backing strip and the end tab have substantial effects on the Mode-A and Mode-B forms of fracture. It was reported that the plastic deformation capacity of beam-column connections became large following improvement of detail of the scallop.

As well as the above influencing factors, it can be considered that the mechanical properties of the weld metal have substantial effects in Mode-B. In this research we describe bi-axial loading test results using cruciform butt specimens. The purpose of this research is to clarify the occurrence condition of the general yield brittle fractures and its elongation capacity. From the results, we also mention the fracture toughness value and heat-input remits of welding to keep enough elongation capacity in beam-column connections.

2. Occurrence Condition of Brittle Fracture[3), 4)]

The specimens for this research are shaped as shown in **Fig.3** and **Fig.4**. These specimens are modeled on a cruciform joint and lib butt joint by taking out the part of the beam-flange to column-flange connection. In the specimens, butt welds are at the crossover point of flanges, which appears to be the most critical zone for fracture. Single bevel groove and full penetration are used to make the cruciform butt weld.

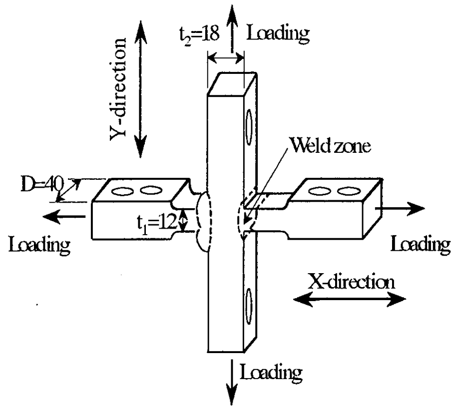


Fig.3 A conception shape of cruciform butt specimen

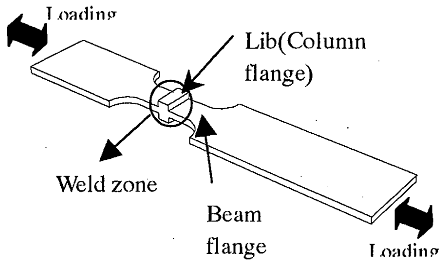


Fig.4 A conception shape of lib butt specimen

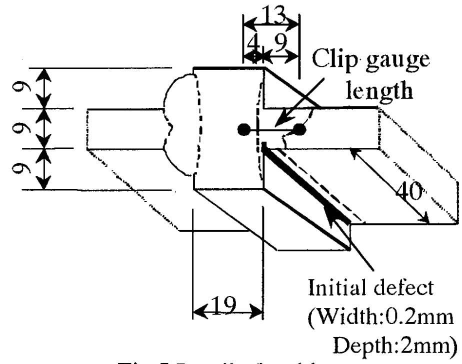
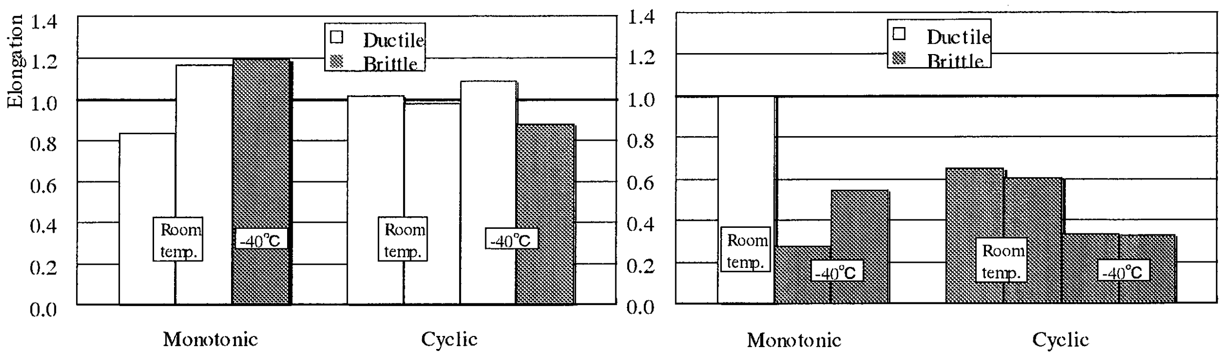


Fig.5 Detail of weld zone of lib butt specimen

Table 1 Condition of brittle fracture

Loading pattern	Specimen Temperature	Charpy absorbed energy of weld metal vE_0		
		≅200 J	≅100 J	15~40 J
Monotonic	Room temp.	0/4	0/1	0/1*
	-40°C	2/3	1/1	5/7
Cyclic	Room temp.	0/4	0/2	4/6
	-40°C	3/6	3/4	4/4

(Number of brittle fracture specimen/ Total number of specimen)
*: Other two specimens are fractured in base metal



(a) $_{V}E_0 ≅ 200J$ (b) $_{V}E_0 ≅ 15 \sim 40J$

Fig.6 Comparison of elongation

After welding, the width of the weld part is narrowed from 40mm to 30 mm. Moreover an artificial notch (Width:0.2mm, Depth:2mm) is added in the thickness direction as an initial defect by electric wire-cut. The detail of the weld zone is shown in **Fig.5**.

The mechanical properties of the weld metal (Charpy absorbed energy at 0ºC: VE0≅200J, 100J and 15~40J), temperature of the specimen (Room temperature and –40ºC), and Loading pattern are varied in this experiment.

The strain rate after yield in a static test is usually from 10^{-4} to 10^{-3}/s. Experiments at strain rates from 10^{-4} to 10^{-3}/s at -40°C can be regarded as the same condition as for strain rates from 6×10^{-3} to 4×10^{-2}/s at 0°C temperature by using this R-parameter.[5),6)]

Table 1 shows the number of brittle fracture specimens and the total number of specimens under several conditions. It can be said that the fracture-surface appearance mainly depends on the specimen temperature and the fracture toughness, regardless of the loading pattern. In particulars the specimen temperature (the strain rate) has substantial effects on the occurrence of brittle fracture. Even if specimens have more than 200J of Charpy absorbed energy at 0ºC, brittle fractures are observed in many specimens. But the brittle fracture-surface ratios tend to decrease in the order of the magnitude of Charpy absorbed energies of the weld metal.

3. Elongation Capacity[3),4)]

Figure 6 shows some examples of comparison of elongation capacity. All values are made dimensionless by the elongation value at room temperature and under monotonic loading. White bars mean that a ductile fracture surface appeared in the specimen and gray bars mean that a brittle fracture surface appeared in the specimen.

In the case of high fracture toughness specimen ($_{V}E_0$≅200J), even if a brittle fracture surface is observed at -40ºC, the elongation capacity does not become small. On the other hand in the case of low fracture toughness specimen (VE0≅15~40J), the elongation capacity become significantly smaller indicated by the changing of fracture-surface appearance from ductile to brittle.

From these results, it can be said that the elongation capacity mainly depends on the fracture toughness of weld metal, regardless of the fracture-surface appearance.

4. Required Fracture Toughness[4)]

It can be accepted if the elongation capacity is enough to absorb all seismic energy in the joint, even if the fracture-surface appearance is brittle. As the

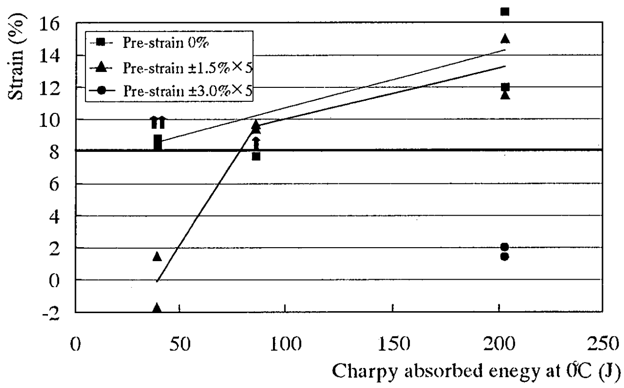


Fig.7 Charpy absorbed energy of weld metal-elongation capacity relationship (-40ºC)

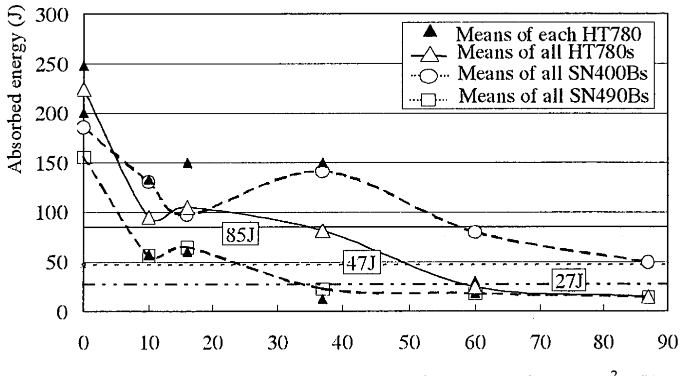


Fig. 8 Comparison between 780N/mm^2 grade steels and mild steels

required elongation, we adopt "8% after cyclic pre-strain, ±1.5% and 5 times".

Figure 7 shows the relationship between Charpy absorbed energy of the weld metal and elongation capacity carried out from the experiments using lib butt specimens.

From these results, 85J of Charpy absorbed energy can be proposed as the required fracture toughness to keep enough elongation capacity in the beam- column connections.

5. Heat-Input Limits[4),7)]

The fracture toughness of steels for building structures may be altered after experiencing the thermal cycles imposed by the welding processes. Many studies have shown that the toughness decrease occurs in the heat affected zone (weld HAZ) of most low alloy steels, include mild steels. So it seems that it is also important to pay attention to the toughness decrease of HAZs, not merely the toughness of the base metal and the weld metal. In this study, the welding heat-input limit to HAZs to keep the required fracture toughness are investigated based on simulated HAZ tests. **Figure 8** shows some examples of relationship between Charpy absorbed energy and equivalent weld heat-input. From these relationships, we propose the heat-input limits for the HAZs of SN400Bs, SN490Bs, HT780s and low yield strength steels to meet the required fracture toughness.

6. Closing Remarks

From some experiments, we clarify the occurrence condition of the general yield brittle fracture and its elongation capacity. Moreover we also propose the required fracture toughness value in welding to keep enough elongation capacity and the required heat-input remits for the HAZ of some steels in beam-column connections.

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