Correlation of Brittle Fracture Strength and Chevron Notched Charpy Impact Test Results.

S. Kanazawa, K. Minami, K. Miya and S. Sato;
Product and Development Laboratories, Nippon Steel Corp.

1. Introduction

Recently large scale welded structures have been planned to be constructed as a result of remarkable progress of steel making and welding technic. But the possibility of brittle fracture is increasing in number as the welded structures become larger and therefore some means of preventing fatal accidents have to be developed. In other words, a better method to evaluate a fracture toughness of structural steel has to be investigated for that purpose. A large plastic constraint of the welded structures can not be reproduced with conventional through-notch specimens, but if chevron notch is used at the notch tip this notch would give a very large plastic constraint, by making it possible to simulate actual situation. From such a viewpoint chevron notched tensile plate specimen and bend specimen are tested and it is concluded that transition temperature of chevron notch is higher than that of usual through-notch.[1]

In this report relations between dynamic COD[2] and absorbed energy of chevron notched charpy specimen, and crack arrest characteristics K_c of welded fusion line and absorbed energy of charpy specimen are discussed. Crack arrest test of welded fusion line has not been successful using welded ESSO [3] Specimen to obtain K_c value of bonded part because of residual compression stress at notch tip. But if the chevron notch is machined to the initiation part to make brittle crack go along the bonded part, it is possible to get K_c value of bonded part. This chevron notched ESSOtype specimen is named NSC specimen and is proposed here as a modified testing method.

2. Experiment

2.1 Material

Mild steel, HT-60 and HT-80 are used. The chemical composition and mechanical properties are shown in Table 1 and Table 2 respectively.

2.2 Test Method

In Fig.1 dimensions of dynamic COD and modified ESSO specimen (called hereafter NSC specimen) are shown. Notch geometries of both specimens are chevron notches. A dummy notch method whose notches are assumed to act the same mechanical behavior until fracture applied to the dynamic COD test and dynamic COD value is measured from unfractured notch by microscope. Crack arrest characteristics K_c value of welded fusion line is obtained from the NSC specimen. A brittle crack is started by impact from the notch root which is cooled to about -110°C and go into the higher temperature region to stop at the point where energy balance was satisfied.

3. Test results and discussion

In Fig.2 the relations between dynamic COD and absorbed energy is shown for mild steel, HT-60 and HT-80. Here, σ_y and Φ_d are yield stress at the test temperature and dynamic COD respectively, and $\sigma_y \times \Phi_d$ is nearly equal to energy to initiate crack dynamically. The relation of absorbed energy and $\sigma_y \cdot \Phi_d$ is determined from the figure as follows;

$$
\begin{aligned}
{}_cE &= 0.50\ \sigma_y \cdot \Phi_d \quad (M.S)\\
{}_cE &= 0.32\ \sigma_y \cdot \Phi_d \quad (HT\text{-}60) \qquad (1)\\
{}_cE &= 0.22\ \sigma_y \cdot \Phi_d \quad (HT\text{-}80)
\end{aligned}
$$

where ${}_cE$ is converted into unit of kg-mm/mm^2 by dividing it by cross sectional area of 75 mm^2. Eq.(1) is converted as follows:

$$
\begin{aligned}
{}_cE &= 6.7 \times 10^{-3}\ \sigma_y \cdot \Phi_d \quad (M.S)\\
{}_cE &= 4.3 \times 10^{-3}\ \sigma_y \cdot \Phi_d \quad (HT\text{-}60) \qquad (2)\\
{}_cE &= 2.7 \times 10^{-3}\ \sigma_y \cdot \Phi_d \quad (HT\text{-}80)
\end{aligned}
$$

It is apparent from Eq.(2) that the energy necessary to initiate crack is extremely small in comparison with total absorbed energy. Therefore the absorbed energy of charpy impact test is only consumed to form brittle fractured-surface or shear fractured-surface. For the purpose of normalization, substituting the yield stress at room temperature of each steel instead of σ_y in Eq.(1), the following relation is obtained irrespective of tensile strength level of steel used.

$$ {}_cE = 16.7\ \Phi_d \qquad (3) $$

This relation implies that steel which is tough and has higher impact value gives higher dynamic COD value if chevron notched charpy specimen is used. The same result as the case of chevron notch may be expected on the usual through-notch, but the absolute values of dynamic COD from the chevron notch may be expected to be smaller than those of usual notch considering the amount of plastic constraint at notch root of both notches.

In Fig.3 the temperature dependences of K_c values of fusion line are shown by parametering heat input of electro gas welding. The case of heat input 99000 J/cm is obtained by welding X-groove and that of 189000J/cm is obtained by welding V-groove. The K_c-$10^3/T$ relation in Fig.3 shows that crack arrest characteristics K_c becomes smaller when the heat input is lar-

ger. The K_c value may be formally calculated from the absorbed energy of charpy specimen with G_c value concept(strain energy release rate) which is obtained as the absorbed energy per unit area. Namely,

$$ K_c = \sqrt{E\ G_c} \qquad (4) $$

It is sure from the test results of dynamic COD that the absorbed energy of charpy specimen is almost converted into the energy for fracture surface formation and there is no temperature gradient in the specimen. And so G_c from the absorbed energy of charpy specimen represents the mean value of energy for fracture surface formation at some strain rate.[4] It is apparent from the figure that there is good correlation between $(K_c)_C$ from the charpy specimen and $(K_c)_B$ from the NSC specimen, and the relation is represented as follows;

$$ (K_c)_B = 0.5\ (K_c)_C \qquad (5) $$

The relation is very useful because K_c value may be obtained from the charpy test of which validity is $-40°C < T < +20°C$. In Photo.1 a position of crack arrest is shown for example. It is apparent that crack stops along the fusion line.

4. Conclusions

The following conclusions are derived from the results of dynamic COD test and crack propagation-arrest test of bonded part using the chevron notch.

(1) The relation of dynamic COD and absorbed energy is ${}_cE = 16.7\ \Phi_d$.

(2) A brittle crack which is started from the chevron notch propagates along a fusion line of weld and arrests at the same position and so K_c values of bonded part can be assessed using NSC specimen.

(3) $(K_c)_B$ values of bonded part from NSC specimen and $(K_c)_C$ values of bonded part from chevron notched charpy specimen are related with the equation $(K_c)_B = 0.5\ (K_c)_C$.

5. References :

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2. G.N. Fearnehough & R.W. Nichols :
International Journal of Fracture Mechanics. Vol.4, No.3 (1968).

3. H. Kibara, T.Yoshida & H. Oba :
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Table.1 Chemical Composition

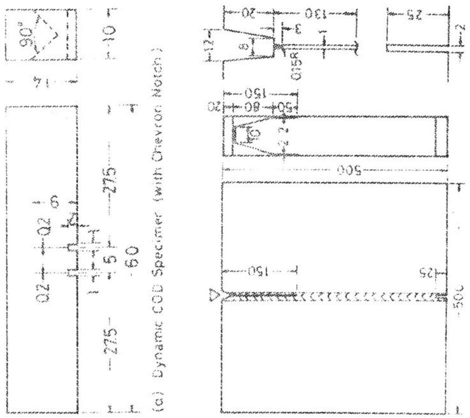
Steel	C	Si	Mn	P	S	Cu	Mo	Ni	Nb	Ti	V
M.S	0.11	0.23	0.98	0.022	0.009	—	—	—	—	—	—
HT-60[1)]	0.16	0.38	1.25	0.009	0.020	0.28	—	0.26	—	—	0.034
HT-60[2)]	0.11	0.22	1.48	0.013	0.006	—	—	—	—	0.02	—
HT-80	0.15	0.35	1.45	0.019	0.005	0.06	0.63	—	0.035	—	—

Table.2 Mechanical Properties

Steel	σ_Y. kg/mm^2	σ_B. kg/mm^2	vTrs. °C
M.S	33.0	44.8	-30
HT-60[1)]	52.0	63.5	-45
HT-60[2)]	57.0	66.0	-41
HT-80	76.0	82.5	-57

HT-60[1)] is for Dynamic COD Test.

HT-60[2)] is for Crack arrest Test.



(a) Dynamic COD Specimen (with Chevron Notch)

(b) Modified ESSO Specimen (with Chevron Notch) — NSC Specimen —

Fig.1 Configurations of Specimen and Notch Details.

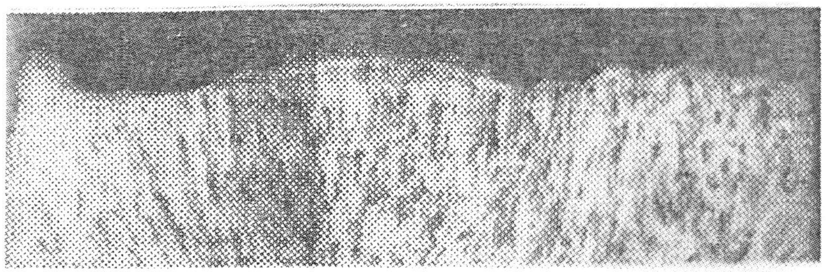


Photo.1 The position of crack arrest.

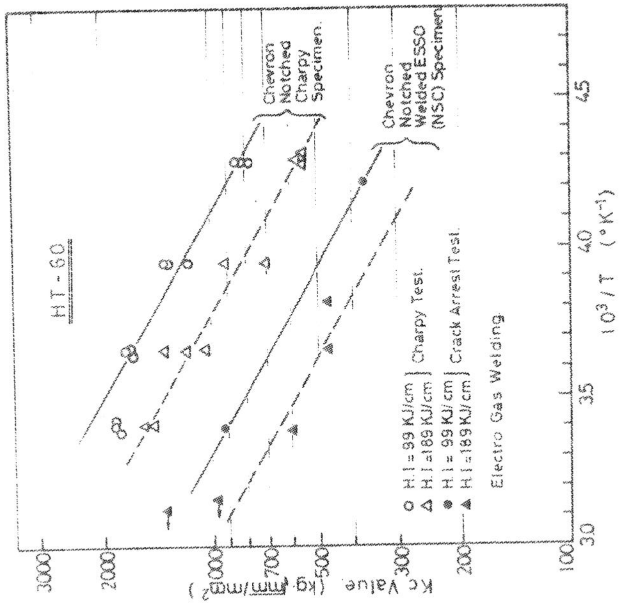


Fig. 3 Relations between Kc and Arrest Temperature for Charpy Test and Crack Arrest Test.

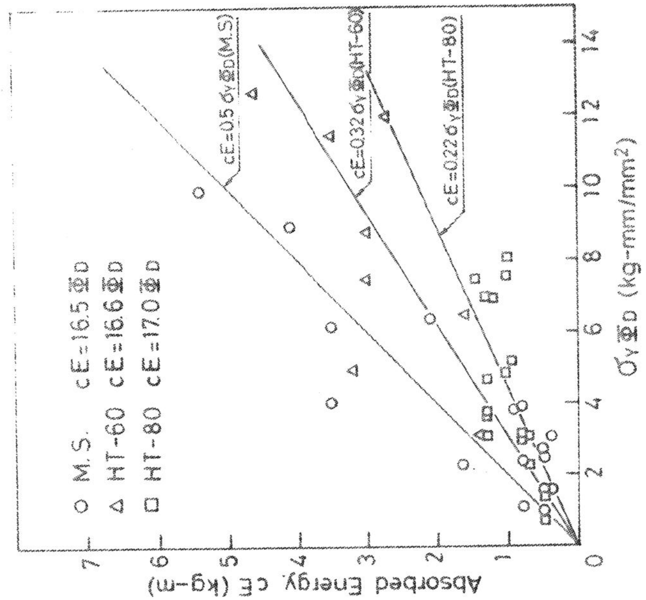


Fig. 2 Relation between cE and $\sigma_Y \Phi_D$