Effect of Plate Thickness on Brittle Fracture Initiation and Arresting Characteristics for Very Thick Plates

By Kazuo Ikeda
Deputy Manager, Structural Engineering Laboratory, Kobe Steel,
Ltd., Doi, Amagasaki, 660, Japan
and Keiichi Komoda
Staff, Ditto.

A killed steel (SM 41) of 50, 100, 150 and 200 mm thick plates rolled from an identical charge was normalized at 910°C for various hours were tested. For comparison, specimens of 150 mm thick were machined at both surfaces equally to reduce the thickness to 100 mm. The chemical compositions and the tensile properties are presented in Table 1.

Table 1 Chemical compositions and tensile properties

Plate Thick. mm	Chemical Compositions %					Tensile Properties		
	C	Si	Mn	P	S	σ_y kg/mm^2	σ_u kg/mm^2	Elong. %
50	0.15	0.27	0.90	0.009	0.016	30	45	36
100	0.14	0.24	0.88	0.009	0.015	29	46	38
150	0.15	0.26	0.91	0.009	0.016	28	47	40
200	0.14	0.26	0.92	0.009	0.015	25	45	40

The deep notch test and the ESSO test with temperature gradient of 0.20°C/mm were employed to evaluate fracture initiation and arresting characteristics of plate, respectively.1)2) The test specimens as shown in Figs. 1 and 2 were pulled in tension in a 3,000 ton test

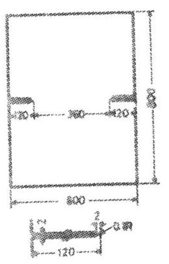

Fig. 1 Deep notch test specimen

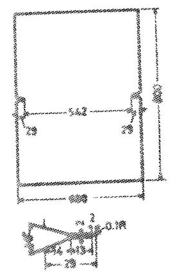

Fig. 2 ESSO test specimen

rig at Structural Engineering Laboratory, Kobe Steel, Ltd., and a 4,000 ton test rig at Ship Research Institute, Ministry of Transport.

In the temperature zone of brittle fracture initiation at low stress levels below general yielding, the following energy condition can be applied:

$$\frac{\pi[f(\gamma)\sigma]^2 c}{E} = 2S_i \tag{1}$$

where $$f(\gamma) = \sqrt{\frac{2}{\pi\gamma}\left(\tan\frac{\pi\gamma}{2}+0.1\sin\pi\gamma\right)} \tag{2}$$

$$\gamma = c/b$$

b is the half breadth of deep notch test specimen and c is the notch length. E is Young's modulus and S_i is the plastics surface energy.

From the arrested crack length, c, in the ESSO test with temperature gradient, the critical stress intensity factor for crack arrest, K_c, can be evaluated by

$$K_c = \sigma f(\gamma)\sqrt{\pi c} \tag{3}$$

where $$f(\gamma) = \sqrt{\frac{2}{\pi\gamma}\tan\frac{\pi\gamma}{2}}, \quad \gamma = c/b \tag{4}$$

b is the breadth of specimen.

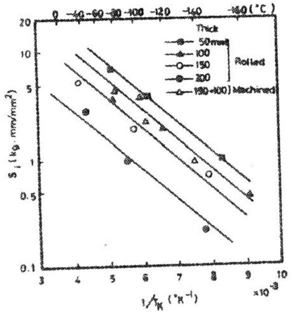

Fig. 3 Plastic surface energy for initiation vs. absolute temperature

From the fracture stress at various temperatures in the deep notch test and Eq.(1), a linear relationship between the logarithm of S_i and the reversal of absolute temperature, $1/T_k$, exists as shown in Fig.3 and expressed by

$$S_i = S_{oi}e^{-2k_i/T_k} \tag{5}$$

where S_{oi} and k_i are the material constants. The inclination of line or k_i is invariable and the effect of plate thickness is found in S_{oi}.

The design stress, σ, is expressed by

$$\sigma = \sigma_y/n \tag{6}$$

where σ_y is the yield stress at room temperature and n is the safety factor.

Substituting Eqs.(5) and (6) into the Griffith-Orowan energy condition for infinite plate expressed by Eq.(1) where $f(\gamma)$ is unity, one obtains

$$e^{2k_i/T_k} = \frac{2E}{\pi}\cdot\frac{S_{oi}}{\sigma_y^2}\cdot\frac{n^2}{c} \tag{7}$$

The correlations between the brittle fracture initiation temperature and the half crack length in an infinite plate for the safety factor, n, of 2 and 2.5 from Eq.(7) are shown in Fig.4.

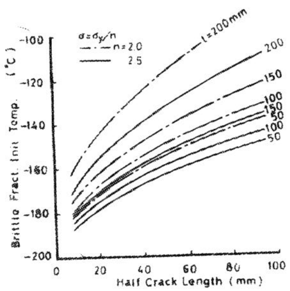

Fig. 4 Brittle fracture initiation temnerature vs. half crack length

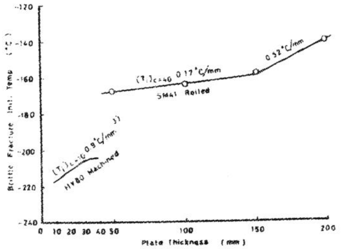

Fig. 5 Brittle fracture initiation temperature vs. plate thickness

Effect of plate thickness on brittle fracture initiation temperature for half crack length of 40 mm, $[T_i]_{c=40}$, at the stress level of $\sigma_y/2.5$ is shown in Fig.5. It is noted that $[T_i]_{c=40}$ increases with plate thicnkess slightly. The data for plate thickness from 15 to 45 mm obtained previously$^{3)}$ are also plotted.

Effect of plate thickness on brittle fracture arresting temperature for crack length of 100 mm at the stress level of $\sigma_y/2$ at room temperature, $[T_a]_{c=100}$, is shown in Fig.6. It is noted that $[T_a]_{c=100}$ increases linearly with plate thickness, and the effect of plate thickness by machining from 150 mm to 100 mm is not so different from that by rolling for the material tested. The data for plate thickness from 15 mm to 200 mm obtained previously$^{3)4)}$ are also plotted.

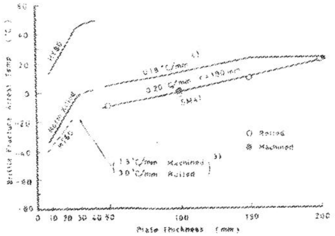

Fig. 6 Brittle fracture arresting temperature vs. plate thickness

The thickness coefficient for fracture arrest based on 30 mm thick plate, $f_a(t)$, in WES-136 is expressed by

$$K_c = f_a(t)K_o(30)e^{k/T_k} \tag{8}$$

where $K_o(30)$ is K_o for 30 mm thick plate.

The thickness coefficient for brittle fracture initiation characteristics, $f_i(t)$, and $f_a(t)$ decrease linearly with increased thickness as shown in Fig.7, and are expressed by the following equations:

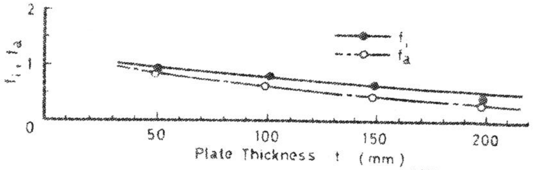

Fig. 7 Thickness effect coefficients for initiation and arrest

$$f_i(t) = 1 - \frac{1}{320}(t-30) \qquad (35 \leq t \leq 200) \tag{9}$$

$$f_a(t) = 1 - \frac{1}{230}(t-30) \qquad (35 \leq t \leq 200) \tag{10}$$

References

(1) K. Ikeda, Y. Akita and H. Kihara, "The Deep Notch Test and Brittle Fracture Initiation," Welding Journal Vol. 46, No.3, (1967) 133-S

(2) Y. Akita and K. Ikeda, "On Brittle Crack Propagation and Arrest-Theoretical and experimental analyses of ESSO test with temperature gradient," I.I.W. Doc. IX-364-63, (1963)

(3) "Study on Prevention of Welded Structures from Brittle Fracture," Report of Iron & Steel Committee, Japan Weld. Eng. Soc. (1962)

(4) K. Kalna, "Investigation of the Size Effect in Brittle Failure," Proc. 3rd Conference on Dimensioning, Budapest (1968)