# THE CRITICAL CONDITION FOR DUCTILE/ BRITTLE TRANSITION IN IMPACT NOTCH–BEND TEST

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## ABSTRACT

The instrumented impact tests of standard Charpy V–notch specimens of a low–carbon steel over a temperature range from 223K to 353K were carried out. It is shown that as in slow notch–bend, the characteristic cleavage stress $Sc_0$ [Yao et al., 1984] also plays a controlling role in critical condition for ductile / brittle transition in impact notch–bend test.

## KEYWORDS

Low–temperature brittleness, cleavage, ductile / brittle transition, instrumented impact test, Charpy V–notch specimens

## INTRODUCTION

There have been extensive researches on the low–temperature brittleness of structural steels (Knott, 1973; Ritchie et al.,1973; Krafka et al.,1980; Yao et al., 1984). The general features of the ductile / brittle transition in slow notch–bend are illurstrated in Fig.1. It was demonstrated that at the temperature $T_c$, which has been named the "characteristic transition temperature of brittleness", the fracture load ($P_f$) reaches a minimal value and the ductile / brittle transition occurs, i.e. the plastic deformation ($\Delta_f$) becomes macroscopically measurable when test temperature is higher than $T_c$ (Li and Yao, 1987; Huang and Yao, 1989; Lei and Yao, 1991a). The primary studies also showed that the temperature $T_c$ is determined by the following equation (Li and Yao, 1987):

$$Q_{max} \cdot \sigma_y(T_c) = Sc_o \tag{1}$$

Where $Sc_0$ is the characteristic cleavage stress (Yao et al., 1984), $\sigma_y(T_c)$ is the yield strength at $T_c$ and $Q_{max}$, the geometrical factor which is approximately equal to 1.96 for standard Charpy V–notch impact specimens (10 × 10 × 55mm) and 2.37 for specimens with a crack or a crack–like notch, respectively (Lei, 1992).

This paper is arranged to investigate whether the above mentioned critical condition for ductile / brittle transition is still valid in impact condition.

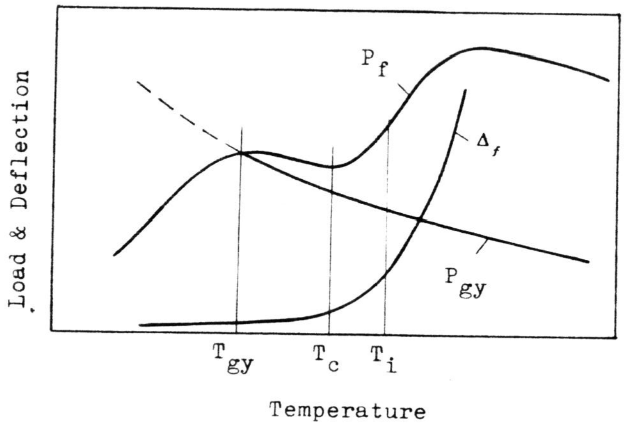


Fig.1. Schematic temperature dependence of fracture behavior of structural steels in slow notch–bend ($P_{gy}$–general yielding load of notch–section; $P_f$–fracture load; $\Delta_f$–deflection before fracture)

## EXPERIMENTAL PROCEDURES AND RESULTS

The material used was a C–Mn steel 16Mn with 0.17wt percent carbon and 1.48wt percent manganese. It was annealed at 1523K for 1 hour. Two sets of series–temperature plain–tension tests with strain rates $5.55\times 10^{-4}$ / sec and $1.10\times 10^{0}$ / sec were carried out. The results had been shown in (Lei and Yao, 1991b). It was concluded that the strain rate has little effect on the characteristic cleavage stress $Sc_0$, which is approximately equal to 743 MPa for both sets of tension test.

Instrumented impact tests of standard Charpy V–notch specimens (ASTM E–23) were carried out at temperatures from 223K to 353K and the main results are shown in Fig.2.



The fracture behavior of Charpy V–notch specimens is similar to that in slow notch–bend and can be characterized by dividing the whole temperature range into four: A. ductile fracture; B. mixed fracture; C. cleavage after general yielding of notch–section; D. cleavage before general yielding. It can been seen that at a definite temperature $T_c = 253K$ the fracture load ($P_f$) reaches a minimal value in combination with a steep transition of the absorbed energy, i.e. the ductile / brittle transition occurs at this temperature.

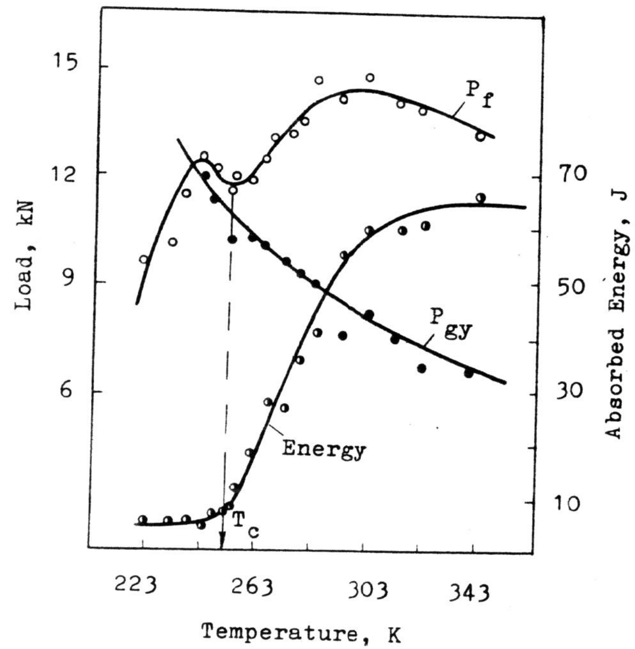


Fig.2. Temperature dependance of fracture behavior of Charpy V–notch specinens in impact ($P_{gy}$–general yielding load; $P_f$–fracture load).

## DISCUSSION AND SUMMARY

The previous work (Yao et al., 1984) stressed that for the onset of cleavage fracture a combined demand of both the critical stress condition and the "effective yield zone" must be satisfied (see Fig.3). On the other hand, a dynamic incremental nonlinear FEM analysis for the Charpy V–notch specimen in impact (which will be reported in detail elsewhere) indicated that the effective strain rate ($\dot{\varepsilon}_{eff}$) does not distribute uniformly below the notch root but steeply drops with the distance from notch root (also see Fig.3). In the "effective yield zone" after general yielding the average value of $\dot{\varepsilon}_{eff}$ is only about $3 \times 10^{\circ}$ / sec (Lei,1992).

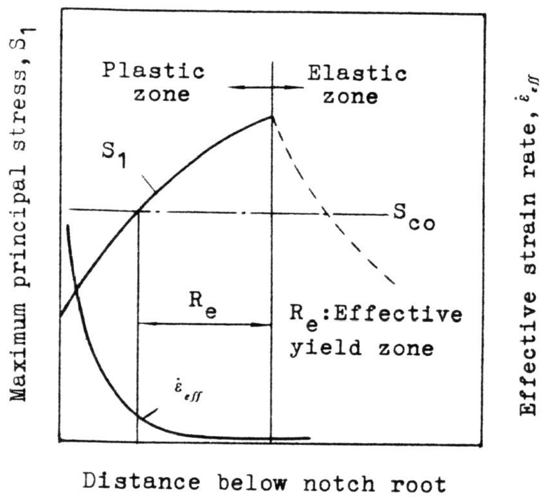


Fig.3. Schematic illustration of the "effective yield zone" ($R_e$) and the distribution of the effective strain rate ($\dot{\varepsilon}_{eff}$) below notch root.

The value of the yield strength in the "eftective yield zone" at the concerned temperature $T_c$ can be deduced by two sets of plain–tension results at $T_c$ with ralatively slow strain rates (see Table.1) according to the following equation (Samanta, 1970; Liu et al., 1990):

$$\sigma_y(T,\dot{\varepsilon}) = A(T) + B(T) ln\dot{\varepsilon} \qquad (2)$$



where $\sigma_y$ $(T,\dot{\varepsilon})$ is the yield strength at any investigated temperature (T) with the strain rate ($\dot{\varepsilon}$), while A(T) and B(T) are both constants for a given temperature.

Table 1 Tested values of yield strength at $T_c$(253K)

| Strain rate, $sec^{-1}$ | $5.55 \times 10^{-4}$ | $5.55 \times 10^{-2}$ |
|---|---|---|
| Yield strength*, MPa | 270 | 328 |

* Average of three measurements.

The calculation based on equation (2) showed that:

$$\sigma_y(T,\dot{\varepsilon})\Big|_{\substack{T=T_c \\ \dot{\varepsilon}=3\times10^{\circ}/sec}} = 383 MPa$$

By using $Q_{max} = 1.96$ (Lei, 1992) and $\sigma_y$ $(T, \dot{\varepsilon}) = 383MPa$ the value of $Sc_0$ can be determined by equation(1):

$$Sc_0 = Q_{max} \cdot \sigma_y(T,\dot{\varepsilon})\Big|_{\substack{T=T_c \\ \dot{\varepsilon}=3\times10^{\circ}/sec}} = 751(MPa)$$

This result well agrees with the tested value—$Sc_0 = 743MPa$ (Lei and Yao, 1991 b). Then it can be concluded that in impact notch–bend test the critical condition for ductile / brittle transition as shown in equation (1) is still valid and that the characteristic cleavage stress $Sc_0$, which is nearly the same even in the impact condition, also plays a controlling role in evaluating the low–temperature fracture behavior.

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