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A STUDY OF CRACK DEPTH EFFECT AND SCATTERING ON FRACTURE TOUGHNESS IN THREE POINT BEND COD SPECIMENS

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ABSTRACT

Fracture toughness obtained under the same experimental conditions has the following two characteristic features: fracture toughness has the dependency of crack depth and shows a large scatter even though the same geometrical shaped specimens were applied to the tests, which derives from the sencitivity of micro structures of steel. Quantificational evaluation of these phenomena is performed by applying strain rate-temperature parameter in the fracture process zone (R_γ), which is the function of strain rate and temperature, as the evaluation parameter. Postulating that fracture toughness is a function of R_γ, it makes clear that there is no crack depth effect, namely the plastic constraint effect, on fracture toughness and that the scattering on fracture toughness decreases considerably. Moreover, the possibility which the dimensionless parameter derived from R_γ may be the universal parameter to characterize fracture toughness is indicated.

KEYWORDS

fracture toughness, scattering, crack depth effect, plastic constraint, strain rate, R prameter, three point bend COD spceimen

INTRODUCTION

Fracture toughness is affected by the crack depth, especially, in case that plastic zone grows large before the fracture generating. This phenomenon is known as the plastic constraint effect on fracture toughness.Although the explanation that the geometrical difference of specimen shapes generates this phenomenon is stated in many reports, it is difficult to quantify the phenomenon by applying this concept.

Some fracture parameters, e.g. T stress [1] and Q parameter [2], enable to describe the plastic constraint effect. Both parameters are, however, not practical ones to discuss the criteria of fracture because it is also difficult to identify a critical value at fracture generating.

By using the local approach which Weibull stress is the parameter to characterize this concept, clevage fracture strength could be estimated [3]. Moreover, Weibull stress was applied to explain many problems concerning fracture toughness, e.g. scattering [4], crack depth effect [5] and strain rate effect [6]. However, physical meaning of the shape parameter in the definition of Weibull stress has not been clear

yet. Identfying the precise stress/strain fields are a significant in order to calculate all the parameters mentioned above. Change of the strain rate in the vicinity of a crack tip caused by strain concentration affects the stress/strain fields considerably, because the constitutive relation of materials is a function of strain rate. Considering the strain rate effect on stress/strain fields is, therefore, necessary to identify the precise fields even though static loading condition. In most of analyses based on the local approach, strain rate effect on the stress/strain fields was ignored to calculate Weibull stress.
Authors [8] had shown that fracture toughness is the function of R parameter defined in Eqn. 1 [7] in fracture process zone.

$$R = T \ln(A/\dot{\varepsilon}) \tag{1}$$

where T: temperature [K], A: frequency factor (= 10^8 [s^{-1}]), $\dot{\varepsilon}$: strain rate [s^{-1}]. R parameter in fracture process zone denotes R_γ in the following sections. R_γ is a candidate to quantify the plastic constraint effect on fracture toughness, because a degree of the plastic constraint is directly reflected on the stress/strain fields in fracture process zone.
Large scattering exists in fracture toughness derived under the same experimental condition. This is one of a typical tendency on fracture toughness. Authors postulated that scattering of fracture toughness is caused by the difference of strain rate distribution in fracture process zone, because a certain scattering of pre-crack length in fracture toughness test specimens must remain even though the precracking condition was the same. Scattering of the strain rate in fracture process zone is ignored to evaluate fracture toughness in conventional methods in which fracture toughness is seemed as only function of ambient temperature. Large scattering of fracture toughness could be explained by applying R_γ as the characteristic parameter to control the brittle fracture.
Above the points of view, two types of three point bend COD spceimens which have different crack depth were used to clarify the crack depth effect on fracture toughness quantitatively. In addition, the scattering of fracture toughness caused by a little difference of initial crack depth was investigated by using COD specimens which precracking condition was the same.

FRACTURE TOUGHNESS TEST

Fracture toughness tests were performed in accordance with BS5762 [9].Three point bend COD specimens were made of mild steel (SM400B), which chemical composition and material properties are shown in Table 1.

Table 1 Chemical composition and material properties (plate thickness = 16[mm])

Chemical composition (Wt%)					Material properties			
C	Si	Mn	P	S	Y.S. [MPa]	T.S. [MPa]	El. [%]	$_vE$ at 0[˚C] [J]
0.15	0.20	1.05	0.009	0.002	299	452	33	260

Two types of the ratio of specimen breadth (W) to initial crack depth (a_0) were equiped for the experiment. One named standard specimen in this paper is that $a_0/W = 0.5$, the other named short cracked specimen in this paper is that $a_0/W = 0.1$. Fracture toughness tests by using standard specimen were performed under three ambient temperatures (-75, -60 and -40 ˚C). These results were investigated to verify the hypothesis which the scattering was caused by the difference of strain rate in fracture process zone. The tests by using short cracked specimen were done only -75 ˚C. By comparing fracture toughness of two types of specimens, crack depth effect on fracture toughness was also investigated. Both tests were performed under constant crosshead speed (about 0.04mm/s), which could be seen as static loading.
Round bar tension test were also performed by collecting test pieces from the same material of COD specimens. Crosshead speed (0.005mm/s) could be recognized as a static loading. Four ambient temperatures (-130, -80,-30 and 25 ˚C) were set under the tests.

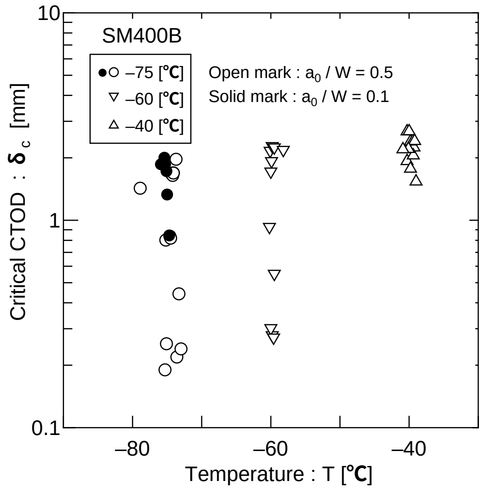

Figure 1 Relationship between ambient temperature and critical CTOD

EXPERIMENTAL RESULTS

Critical CTOD used as fracture toughness was calculated by using the conversion formula in BS5762 [9]. Measured values, mouth COD, crack length etc., at unstable fracture generating were applied to the calculation of fracture toughness, because the strain rate effect on the scattering and crack depth effect of fracture toughness at the moment of brittle fracture generating was highlighted in this paper. Crack length in calculating fracture toughness was equal to the sum of initial length and fibrous crack length grown by stable ductile fracture.
Figure 1 shows the relationship between ambient temperature and fracture toughness derived from the experiments. A noticeable scattering of fracture toughness can be recognized in Fig. 1. Fracture toughness of short cracked specimen shows a large value in the same ambient temprature. This is a same manner of ref.[5].

EVALUATION OF FRACTURE TOUGHNESS BY USING R PARAMETER

To evaluate the scattering and crack depth effect on fracture toughness, R parameter in fracture process zone (R_γ) at brittle fracture generating were calculated by the procedure stated in ref.[10]. Relationship

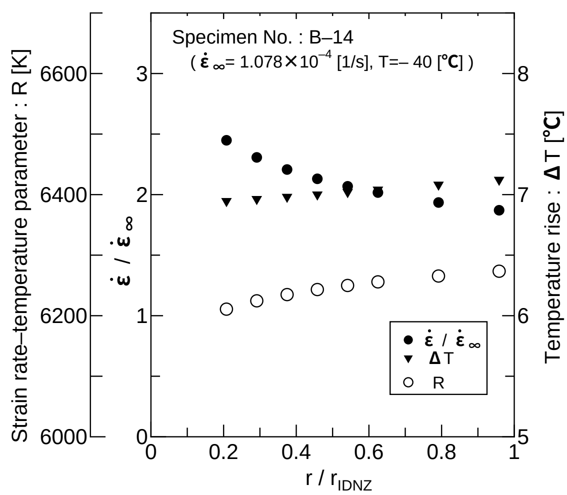

Figure 2 An example of R parameter, strain rate and temperature rise due to plastic work distributions in IDNZ

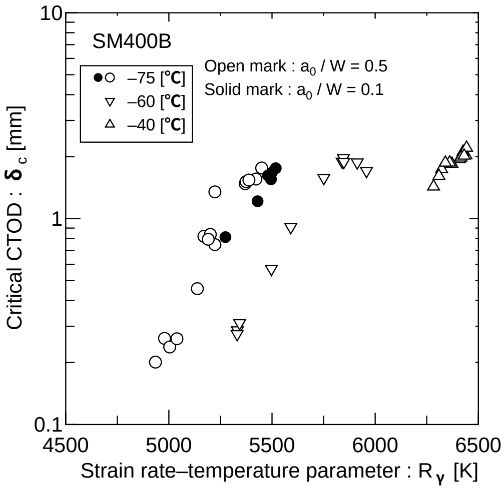

Figure 3 Relationship between R parameter in IDNZ and critical CTOD

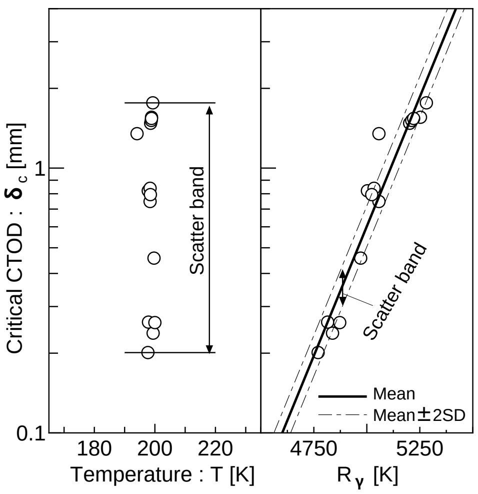

Figure 4 Comparison of R_γ and temperature as a parameter concerning the scattering of fracture toughness

between R parameter and yield stress (σ_Y) of the material had been provided from the round bar tension tests in advance. This relation is shown as follows.

$$\sigma_Y = 106.7 \exp(5607/R) \tag{2}$$

Unit in yield stress is MPa and in R parameter is abosolute temperature.

Figure 2 shows an example of R parameter distribution in IDNZ [11] which can be considered as fracture process zone. Abscissa in Fig. 2 is normalized by the distance from crack tip to the tip of IDNZ (r_{IDNZ}). The value of R parameter at the center of IDNZ was regard as R_γ in this paper, because R parameter in IDNZ keeps a approximately constant distribution at an arbitrary time throughout the loading. The calculation results of strain rate ($\dot{\varepsilon}$) normalized by the nominal strain rate ($\dot{\varepsilon}_\infty$) and of temperature rise (ΔT) due to plastic work are also shown in Fig. 2. Calculation procedure and the definition of nominal strain are explained in ref.[8] and [10]. As a result of the heat conduction, maximum value of ΔT appears in inside region apart from crack tip. This result was in agreement with the measuring result of temperature distribution near crack region [12] qualitatively. Strain rate in IDNZ increases more than about twice comparing with nominal strain rate. The strain rate increasing ratio in IDNZ showed a different value in each specimen.

Figure 3 shows the relationship between R_γ and fracture toughness. The different tendency of the relation can be recognized according to ambient temperature. However, the relation in Fig. 3 under each ambient temperature can be considered as an inherent relation. Comparison of R_γ and temperature as a parameter concerning the scattering of fracture toughness, which test temperature was -75 ℃, is shown in Fig. 4. Bold line and alternative long and short dash lines in the right side of Fig. 4

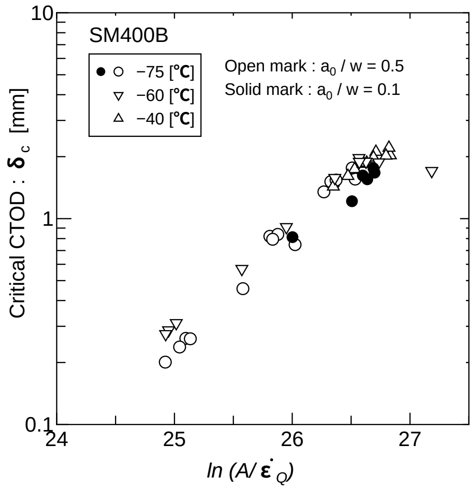

Figure 5 Relationship between dimensionless R parameter in IDNZ and critical CTOD

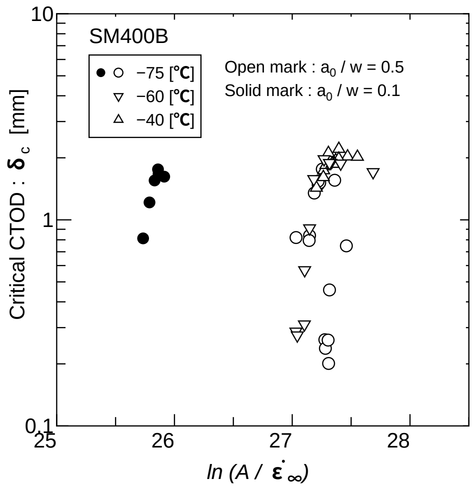

Figure 6 Relationship between dimensionless R parameter, based on nominal strain rate and ambient temperature, and critical CTOD

represent the mean line and $\pm 2SD$ (SD: standard deviation) ones of experimental results respectively. Figure 4 shows that the scattering of fracture toughness can be considerably reduced by using R_γ as a evaluating parameter for fracture toughness. This result indicates that the scattering of fracture toughness originates in the difference of strain rate in fracture process zone due to the difference of initial crack length.

The relationship betwen R_γ and fracture toughness of both standard specimens and short cracked specimens under the same ambient temperature can be seen identical in Fig. 3. Fracture toughness derived from the same ambient temperature can be considered as an inherent function of R_γ regardless of crack depth.

THE NEW PARAMETER CHARACTERIZING FRACTURE TOUGHNESS

An adequate parameter for possessing the universal relation to fracture toughness was studied. The dimensionless parameter (R_0) defined by Eqn. 3 was investigated as a candidate of the parameter.

$$R_0 = \ln(A/\dot{\varepsilon}_Q) \tag{3}$$

where, A: frequency factor ($= 10^8$ [s^{-1}]), $\dot{\varepsilon}_Q$: strain rate in fracture process zone [s^{-1}]. The midpoint in IDNZ was considered as the reference point of $\dot{\varepsilon}_Q$. Figure 5 shows the relationship between R_0

and fracture toughness. It can be recognized that fracture toughness is the inherent function of this parameter. On the othre hand, Figure 6 shows the relationship between the dimensionless parameter derived from substituting nominal strain rate for the term of strain rate in Eqn.3 and fracture toughness. The result in Fig. 6 remains the difference caused by the crack depth and the scattering on fracture toughness.

Figures 5 and 6 insist that the scattering and the crack depth effect, namely the plastic constraint effect, on fracture toughness are caused by the difference of strain rate in fracture process zone. The effect of temperature appears in value for the parameter in Fig. 5 indirectly, because the effect of strain rate and temperature on constitutive equation was considered to identify the stress/strain fields in the vicinity of a crack tip.

Yokobori [13] shows the relationship between activation free energy and applied stress as follows.

$$U \propto \ln(1/\sigma). \tag{4}$$

Comparing the form of Eqn. 3 with Eqn. 4, it can be expected that R_0 has a close relation to activation free energy in fracture process zone.

CONCLUDING REMARKS

Quantificational evaluation for the scattering and crack depth effect on fracture toughness is performed by considering the strain rate effect on fracture toughness. By postulating that fracture toughness is a function of R parameter in fracture process zone, it makes clear that the crack depth effect, namely the plastic constraint effect, and the scattering on fracture toughness can be explained by the difference of strain rate in fracture process zone. Moreover, the parameter defined by Eqn. 3 could be the universal parameter to characterize fracture toughness.

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