Offset method for determination of lower-bound fracture toughness in the transition temperature region

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ABSTRACT

The fracture toughness K_{JC} values of small specimen in the transition temperature region were analyzed to confirm the offset method standardized by JSPS 129 Committee. The offset method is a very useful method for the determination of lower-bound fracture toughness K_{JCi} of material especially in the lower shelf temperature region where the stable crack growth is smaller than about 0.2 mm. The K_{JCi} values obtained from the offset method showed a good agreement with the K_{IC} value of large specimens per ASTM E399 and the K_{JCi} values from the fractography method standarized by JSPS 129 Committee.

KEY WORDS

Elastic plastic fracture, Fracture toughness, Transition region, J-integral,Testing Technique

INTRODUCTION

The J_{IC} testing method of JSME S001 and ASTM E813 using small specimens can measure the fracture toughness of materials in the upper shelf temperature region. However, in the transition temperature region, the J_{IC} testing method has a problem, that is, the large scatter of the measured fracture toughness(1-3). In the other hand, the K_{IC} testing method of ASTM E399 is useful in the transition temperature region, but the measure of K_{IC} values requires large specimens which leads to the large amount of testing cost and manufacturing cost of the specimen.

Recently, Japan Society for the Promotion Science (JSPS) 129 Committee (chairman, Takeo Yokobori)proposed the standaraized testing methods to obtain the lower-bound fracture toughness in the transition temperature region using small specimens which consists of the fractrography method based on the observation of fracture surface of the specimens and the simplified offset method(4-5). This study is the background study of the offset method recommended by JSPS 129 Committee.

TEST METHOD

The materials used in this study are A508 Cl.3 and A533B nuclear pressure vessel steels of which the mechanical properties are shown in Table 1. Both steels were used for the international cooperative round robin tests by JSPS 129 Committee and MPC(Material Properties Council). The A533B steel is the material that the impurities elements were

Table 1 Mechanical properties of the steels used.

Steels	σ_{YS}(MPa)	σ_{TS}(MPa)	El.%	R.A.(%)	FATT(K)	NDTT(K)	CVN-us(J)
A508C1.3	456	599	24.8	75.9	258	243	245
A533B	504	692	20.2	52.0	323	-	70
A470	644	766	23.8	63.0	271	-	165

controlled by which the toughness was reduced(4-5). For the comparison of the fracture toughness between the offset method and K_{IC} tests method, the A470 Ni-Cr-Mo-V steel (Table 1) for turbine rotors was used.

The specimens used are 0.5T-CT, 1T-CT, 2T-CT, 4T-CT and 6T-CT specimens with 20% side grooves. Fatigue precracks of a_o/W=0.50 ~ 0.65 (a_o : precrack length,W : specimen width) were ntroduced under JSME S001 and ASTM E813. The specimens were fractured by strain controlled loading. The number of specimens used were more than five at the same test temperatures.

J-integral were culculated from the load-strain curve at the loading point, and converted to the fracture toughness using the equation.

$$K_{JC}=[J_C/(1-\gamma^2)]^{1/2} \qquad (1)$$

where E is the Young's modulus and γ is Poisson's ratio.

FRACTURE TOUGHNESS IN THE TRANSITION TEMPERATURE REGION

Figure 1 shows the test results of the fracture toughness of A508 Cl.3 steel obtained by the Japanese laboratories (4-5), and Figure 2 shows the test results of fracture toughness of A533B steel obtained by authors . The large scatter of fracture toughness K_{JC} values are observed in both steels, especially in the higher temperature region. And also, the scatter becomes larger as the specimens size is smaller. Figure 3 shows the fracture process of specimens. When the specimen with fatigue crack is loaded, with increasing the load, the

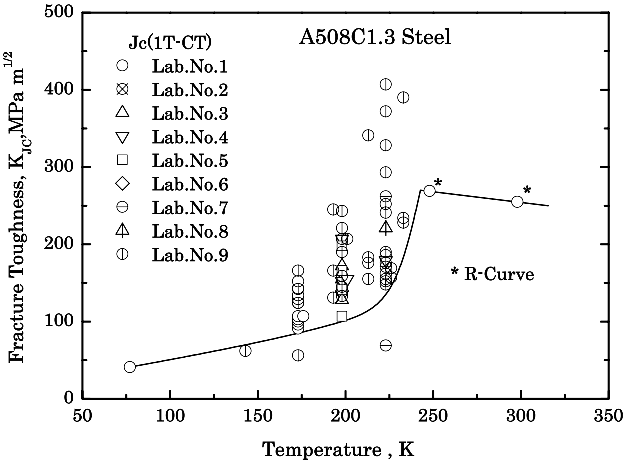

Fig.1 Fracture toughness K_{JC} values as a function of temperature for A508Cl.3 steel.

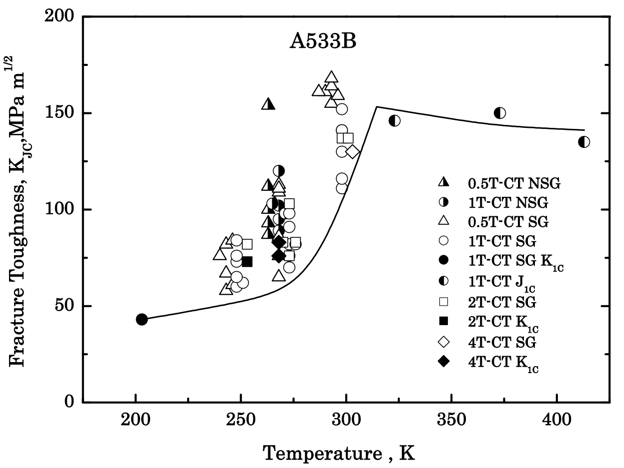

Fig.2 Fracture toughness K_{JC} values as a function of temperature for A533B steel.

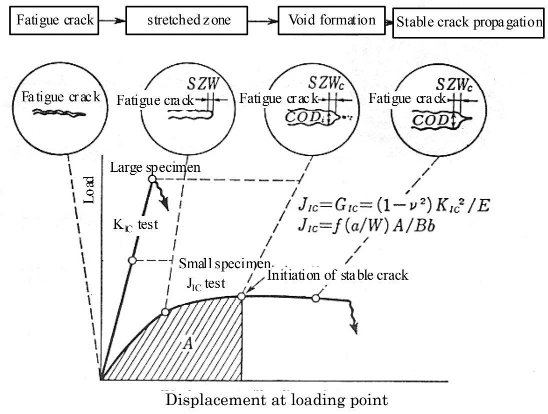

Fig.3 Fracture process around a crack tip.

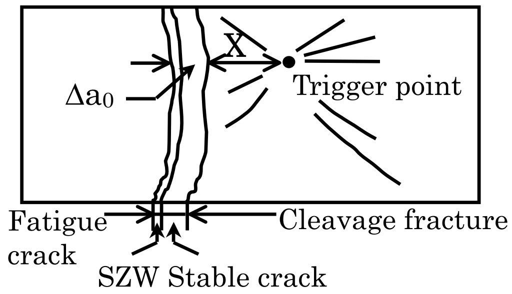

Fig.4 Schematic representation of Δa_o,X and Δa_o+X.

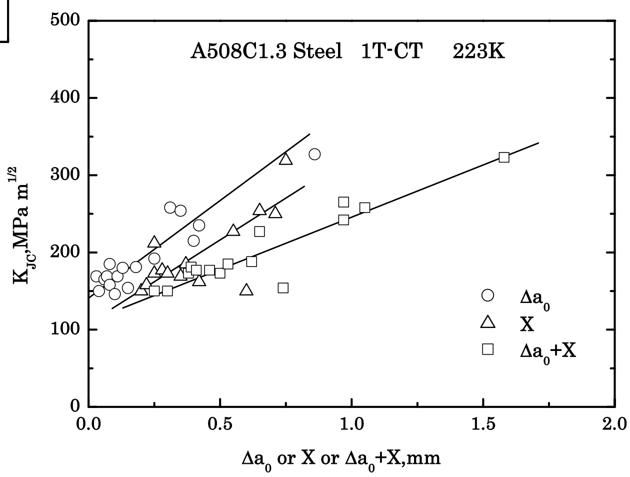

Fig.5 K_{JC} vs.Δa_0, K_{JC} vs.X and K_{JC} vs.Δa_0+X relationships.

crack tip is stretched and becomes blunt. And then, the boids initiates ahead of the stretched zone. During the following loading, the boids are combined, by which the stable crack initiates. After the initiation of stable crack, it grows larger when the load increases. The premature fracture occurs at the weakest point, that is, the trigger point which may be caused by the ununiformity of the material. Therefore, the scatter of the fracture toughness is controlled by the stable crack length, Δa_o, and the distances to the trigger point, X, and /or Δa_o+X (6-7).

The fracture surfaces of the broken specimens were observed using Scanning Electron Microscope (SEM). The stable crack length Δa_o , the distance from the tip of the stable crack front to trigger point X, and Δa_o+X in Fig.4 were measured. Figure 5 shows the relationship between the fracture toughness K_{JC} and Δa_o or X or Δa_o+X. The K_{JC} values show the good relationship with Δa_o, X, Δa_o+X. The scatter of fracture toughness K_{JC} is controlled by the mount of Δa_o, X, and Δa_o+X. This is the background of the fractography method recommended by JSPS 129 Committee.

THE PROPOSAL OF OFFSET METHOD

The offset method proposed in this study is the simplified method to obtain the lowest value of fracture toughness J_{Ci} or K_{JCi}, which is based on the assumption that the slope dJ/da of the elationship between J_C and Δa_o, and /or the slope dK/da of the relationship between K_{JC} and Δa_o, are constant. The test procedure is as follows.

(1) At first, to obtain the J-R curve of the material, the fracture toughness test is conducted in the upper shelf temperature region using unloading compliance method. And the J-R curve shown by the relationship between J-integral and stable crack growth Δa_0 is obtained

(2) The offset line is drawn at the distance of Δa_o=0.2mm in the parallel to the trangent line of R curve from the original point as shown in Fig.6(a). Here, the K-R curve shown by the relationship between K_J and Δa_o can be used instead of J-R curve.

(3) The slope n is detetrmined by drawing the tangent line to R curve at the cross point between the offset line and J-R curve or K-R curve.

(4) And then, at the test temperature in the transition temperature region, the fracture toughness tests are conducted using 6 specimens. The relationship between J_C value at fracture and stable crack growth Δa_o,
or K_C value and Δa_o is obtained.

(5) The obtained six J_C and/ or K_C and Δa_o relationships are plotted as shown in Fig.6(b). And the parallel lines to the slope n are drawn to pass the each data. The smallest value at the cross point between the slope n and the longitudinal lines is defined as the lowest fracture toughness Jci and K_{JCi}.

(6) In the case that the measure of R-curve at the upper shelf temperature can not be conducted, the six test specimens are fractured at the test temperature using unloading compliance method with measuring J-R curve or K-R curve.

(7) The lines of the constant n=400J/m^3 to J-R curve or the lines of the constant n=300 MPa·m$^{1/2}$/mm to K-R curve are drawn to pass the J_C or K_{JC} points of each fractured specimen as shown in Fig.7.

(8) The smallest J_C or K_{JC} value determined by the cross points between these line and longitudinal line is defined as the lowest fracture toughnesses J_{Ci} or K_{JCi}.

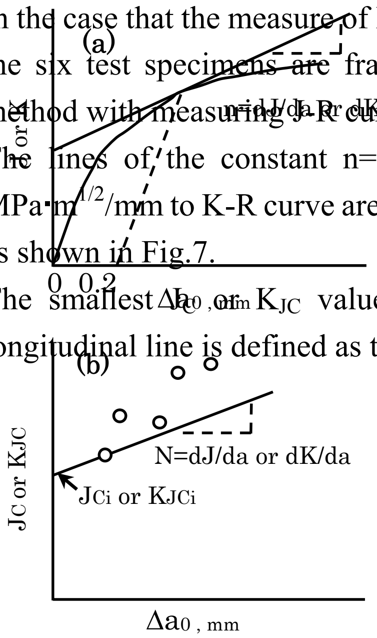

Fig.6 Representation of the offset method using slope n of R-curve.

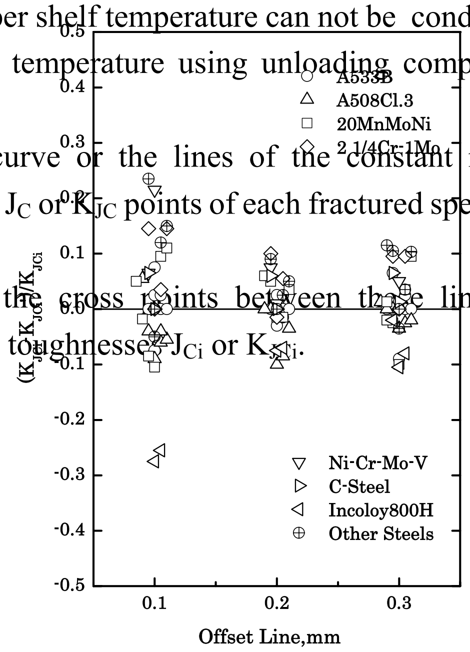

Fig.8 (K_{JCi}-K_{JCi}')/K_{JCi} value at each offset tangent line.

DISCUSSIONS

In the case of the offset method, the slope n must be obtained by drawing the offset line of 0.2 mm in the upper shelf temperature region. Figure 8 shows the accuracy of the obtained fracture toughness, that is, the difference between K_{JCi}' and K_{JCi}, where K_{JCi}' was determined using the mean value of the slope n obtained at the cross point of 0.1, 0.2, 0.3 mm offset lines on K-R curves of 38 materials, and K_{JCi} was obtained from the slope n of each material. The difference between the fracture toughness K_{JCi}' and the fracture toughnesses K_{JCi} of each material is larger than $\pm$10% in the use of the 0.1 mm offset line, and is within $\pm$10% in the use of 0.2 mm and 0.3mm offset lines. In the other hand, according to the observation of the premature fractured specimens, the lengths of stable crack growth Δa_o were less than 0.2 mm. Therefore, the 0.2mm offset line was selected.

In the case that the fracture toughness test in the upper shelf temperature region can not be conducted, the more simplified method using the constant slope n was proposed. This proposal is very useful and very simple because anybody can measure the same fracture toughness K_{JCi} value. Figure 9 shows the slope n decided using 0.2 mm offset lines of 38 materials. To measure the lowest fracture toughness of material,the slopes n should be larger. From Fig.9, n=300 MPa·m$^{1/2}$/mm was selected as the slope which gives larger values more than 90% for K-R curves. And for J-R curves, the corresponding slope n=400J/m^3 was also selected.

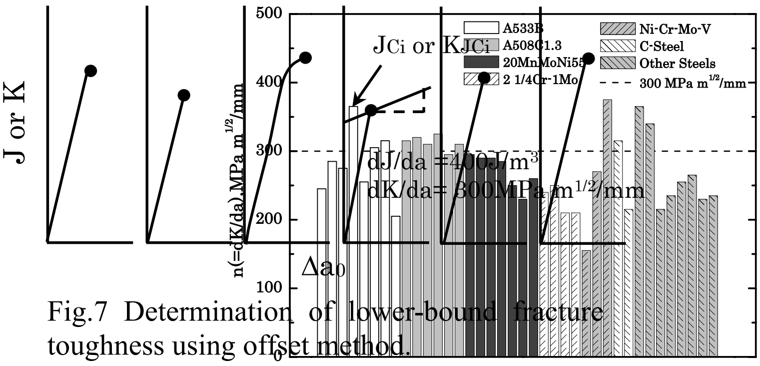

Fig.7 Determination of lower-bound fracture toughness using offset method.

Fig.9 Slope n determined from 0.2mm stable crack growth offset tangent line.

COMPARISON BETWEEN K_{JCi} FROM THE OFFSET METHOD AND K_{IC} OF LARGE SPECIMENS

Fig.10 and Fig.11 show the comparison among K_{JCi} values obtained using the offset method, K_{JCi} values obtained by the fractgraphy method[5)] and the valid K_{IC} values of large specimens per ASTM E399 for A533B steel and A470Ni-Cr-Mo-V steel, respectively.

The K_{JCi} values obtained by the offset method showed a good agreement with K_{JCi} values from

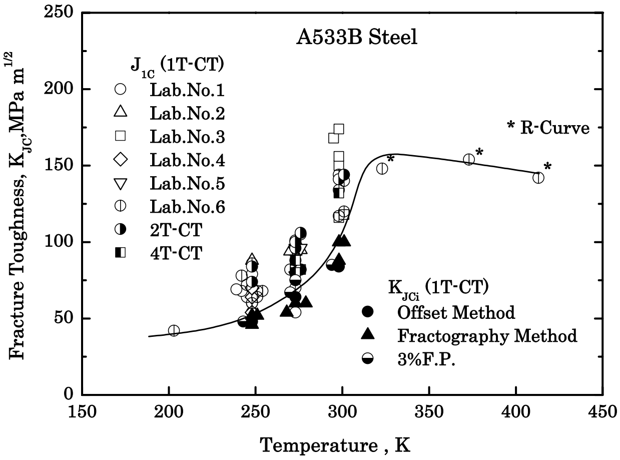

Fig.10 Comparison of K_{JCi} values obtained from the offset method and fractgraphy method and and fractgraphy method and valid K_{JC} values for A533B steel.

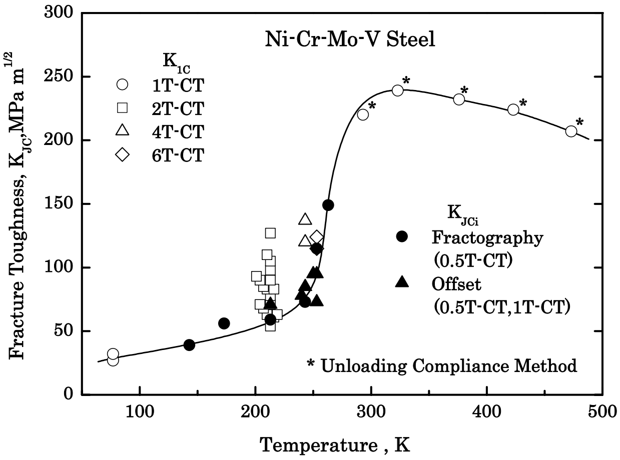

Fig.11 Comparison of K_{JCi} values obtained from the offset method and fractography method and valid KIC values for A470 Ni-Cr- Mo-V steel.

the fractgraphy method and the lowest value of K_{IC} of large specimens. This suggests that the offset method is valid for measuring the lower-bound fracture toughnesses K_{JCi} of materials in the transition temperature region.

CONCLUSION

In this study, the offset method is recommended as one of the standard test methods by JSPS 129 Committee to measure the lower-bound fracture toughnesses K_{JCi} in the transition temperature region using small specimens. The obtained K_{JCi} values using offset method showed a good agreement with the K_{IC} values of large specimens.

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