§21. Development of the R Curve Fracture Toughness Test of Round Bar with Circumferential Notch by Using Hardening Curves of Each Virtual Crack Length

Kasaba, K. (Univ. Toyama), Nishimura, A.

1. Introduction

Standardized test methods of plain strain fracture toughness K_{IC} and elastic-plastic fracture toughness J_{IC} are time-consuming and expensive. *R* curve by which a material resistance to a crack growth is expressed is required to be obtained in standardized test methods. On the other hand, a convenient new test method, named *J* evaluation on tensile test (JETT) of round bar with circumferential notch, has been proposed to evaluate the fracture toughness of tough materials. In this research of the previous year, the *R* curve of aluminum A2017-T4 alloy were obtained by JETT specimens, and it was found that the crack growth length before a fracture was about 50 μm, corresponding to two or three of grain size of this material. Giovanola JH et al.[1] showed from their quantitative fracture surface analysis that an infinitesimal crack growth was observed both before the maximum load of JETT, P_{max}, and before definite point of J_{IC} of ASTM standardized test. Therefore the load at which crack growth initiates in JETT specimen is almost the same with P_{max}. The meaning of this P_{max} as a fracture toughness parameter and its appropriate non-dimensional conversion for canceling the size effect of a round bar are discussed in this research.

2. New fracture toughness parameter.

Fig.1 shows σ_{NTS} - d_c/b curves of aluminum A2017-T4 alloy with various *a*/*R*(notch/radius) where $\sigma_{NTS}(=P/\pi b^2)$ is notch tensile stress, $b(=R-a)$ is ligament radius, and d_c is a displacement due to a notch. In this figure, for example, 816-6 shows a/R=0.86 and R=6. Tensile strength of this material, σ_{UTS}, is 430MPa, so that the larger stresses than σ_{UTS} could be applied to a ligament of specimens. A larger *a*/*R* specimen shows larger $(\sigma_{NTS})^{max}/\sigma_{UTS}$ than small *a*/*R* specimen. $(\sigma_{NTS})^{max}$ has been tried to be used as one of fracture toughness parameters[2]. However it doesn't contain an idea of *J* integral, elastic-plastic energy release rate, but it relates to stress triaxiality on the whole ligament.

In a comparison of σ_{NTS} at the same d_c/b among specimens with different configurations, the smaller *a*/*R* of a specimen, the larger σ_{NTS} under small d_c/b. The tendency is, however, inverted under large d_c/b. These are well shown by FEM results of the inset in Fig.1. Therefore in the case of low toughness material like this A2017, an acceptable d_c/b is small and small *a*/*R* specimen(for example 504-6) shows lower J_Q. On the contrary, in the case of high toughness material like manganese steel(SM steel), large *a*/*R* specimen (for example 750-6) shows lower J_Q. These tendencies are indicated by the slope of the curves in Fig.2(later shown).

Since an initial crack growth in JETT specimen is observed at near P_{max}, J_Q can be defined at P_{max}. Virtual crack growth of 1mm on an axsymmetric section corresponds to a crack growth surface of $2\pi b$ mm^2. If the necessarily damage zone for a fracture is dominated by the length on an axsymmetric plane, l_c, an energy release proportional to $2\pi b l_c$ is needed to a specimen. Therefore not J_Q but J_Q/b is appropriate to index a fracture toughness of a round bar, because a size effect of J_Q about a circumferential notch root length $2\pi b$ is canceled in the latter parameter. Fig.2 shows experimental $(\sigma_{NTS})^{max}/\sigma_{UTS}$ - $J_Q/b\sigma_{0.2}$ of A2017 and magnesium steel(SM). Critical $J_Q/b\sigma_{0.2}$ under the same strain constraint state, for example $(\sigma_{NTS})^{max}/\sigma_{UTS}$ =1.8 is supposed to be defined as one of the fracture toughness parameters in this research. That of A2012 (J_{IC} =10kJ/m^2) was 0.051 and that of SM steel(J_{IC} =275kJ/m^2) was 0.18. These data have a possibility for a relative comparison of fracture toughness of the materials, however J_{IC} of each material cannot be obtained by conversion of them. More toughness tests data of various materials are needed to verify this consideration.

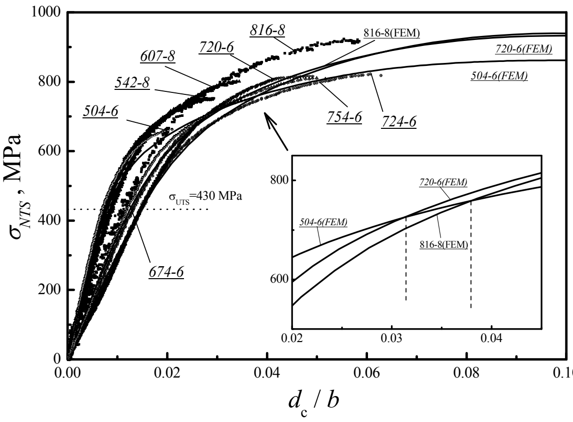

Fig.1 σ_{NTS} vs. d_c/b of A2017-T4 (Experimental and FEM).

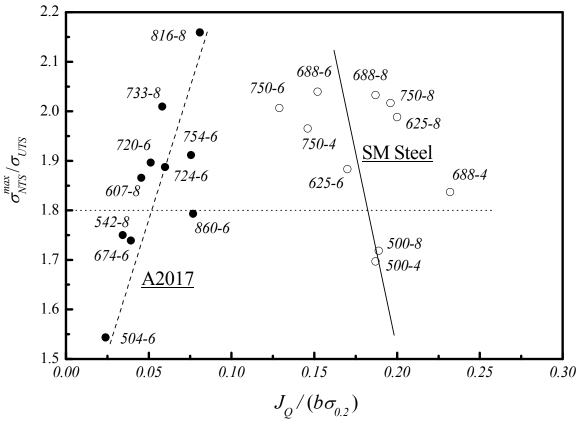

Fig.2 $(\sigma_{NTS})_{max}/\sigma_{UTS}$ vs. $J_Q/b\sigma_{0.2}$ of A2017 and manganese steel.

1) Giovanola JH et.al, E Fracture Mech 59:117-136,1998
2) ASTM E602-03,Annual book of ASTM standards, 2010