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

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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

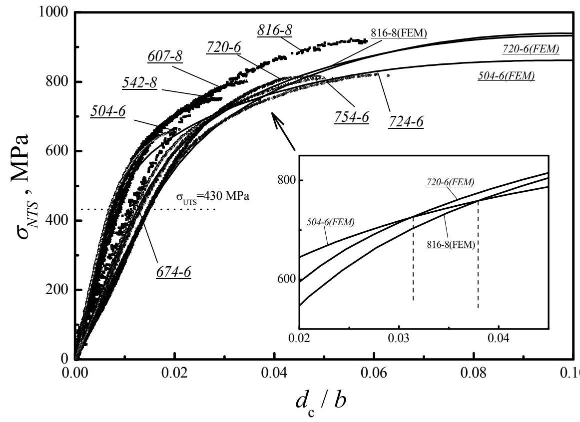

Fig.1 σ_{NTS} vs. d_c/b of A2017-T4 (Experimental and FEM).

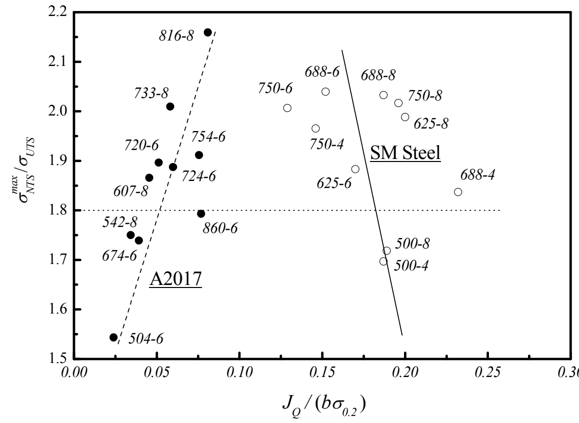

Fig.2 $(\sigma_{NTS})_{max}/\sigma_{UTS}$ vs. $J_Q/b\sigma_{0.2}$ of A2017 and manganese steel.

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 $2\pi bl_c$ 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.

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