§20. 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. 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 the tough materials. Since a fracture toughness is defined by the J at which the stable crack growth starts, the onset of the crack growth has to be detected correctly. However to detect the onset is much difficult for JETT specimens, and there are no standard methods to do it. In this research, a method to detect crack growth by using calculated P-d_c curves of the virtual specimens with various crack length was tried.

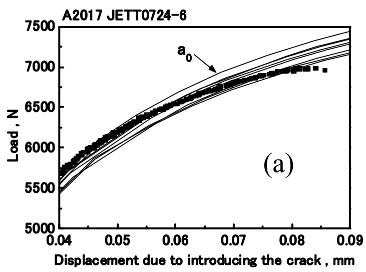
2. Hardening curves of each virtual crack length

Fig.1(a) shows magnified view of P-d_c nonlinear curves of plastic deformation of aluminum A2017-T4 alloy with a/R(notch/radius)= 4.34mm/6.0mm= 0.724. The curve of the specimen with the notch length, a_0, and those of the specimens with notch plus axisymmetric virtual crack length, a_0+5n μm (n=1-10), were calculated by FEM. Using the crack growth lengths given by cross points of the experimental and calculated curves, R curves of this material shown in Fig.1(b) was obtained. In the figure, the result of another specimen, a/R(notch/radius)= 4.04mm /6.0mm = 0.674, is also drawn.

The final crack growth lengths before fracture of less than 50μm correspond to two or three grain size around notch tip of this material. These predicted axisymmetric small crack growths may be nominal one because if a crack grows in an arbitrary site of the circumferential tip, a specimen may be subjected to unaxisymmetric loading afterward. However it is obvious that some fracture event had occurred at the extrapolated J_{in} of around 20 KJ/m^2. Tensile fracture with dimples was observed in only grain boundaries around not only tip area but also axis. That is because precipitations are thought to be segregated in some grain boundaries. Therefore micro voids in many grain boundaries were generated and grew since J_{in}=20 or 22 KJ/m^2 and the following transgranular brittle fracture occurred at J_f(fracture point)=43 or 38KJ/m^2.

3. Calculated stress distribution around tip

Fig.2 shows mode I stress distribution around notch or crack tip. Abscissa in this figure shows distance from tip on the ligament normalized by J. One of the theoretical solutions of stress distribution of an infinite plate with a crack, HRR(dotted line), shows that stress distribution for every loading level can be expressed by a single line to this abscissa. The stress of CT specimen (thin line) is less than that of HRR in this material. The stress distributions at fracture of both specimens, that at J_c=10KJ/m^2 of CT specimen (black square) and that at J_f= 43KJ/m^2 are the same (blue circle). The magnitude of J means an area where high stresses are generated while σ_{yy}/σ_0 means the maximum stress around the tip. The former intrinsic critical value is thought to be necessary condition for ductile fracture, where the latter critical value is for brittle fracture. Because J_{in}=20 or 22 KJ/m^2 of JETT specimen exceeds intrinsic J_c=10KJ/m^2 (from CT specimen), local micro voids can be generated. However the necessary condition of the critical maximum stress was not still fulfilled at J_{in} of JETT specimen. The onset of local (grain boundaries) micro voids, J_{in} ,is not easily defined by another fracture toughness test. Therefore this J_{in} is the special index to this research hardening curves method. More considerations for the effectiveness of J_{in} as alternative index to express the fracture toughness of age hardening materials is needed.



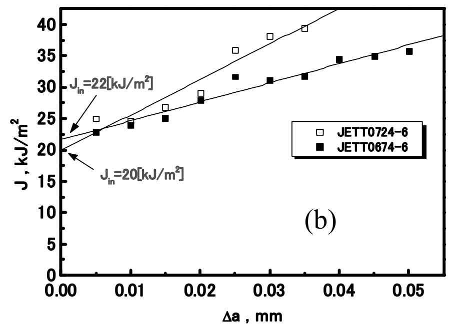


Fig.1 (a) P-dc curves and (b) obtained R curves

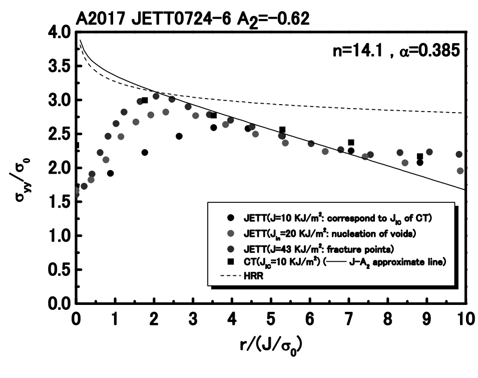


Fig.2 Mode I stress distribution around tip