Numerical Simulation of Brittle Crack Propagation and Arrest in Steels Considering Shear-Lip Formation

Shuji Aihara¹, Kazuki Shibanuma¹ and Tetsuya Namegawa²

¹ Dept. Systems Innovation, Graduate School of Engineering, The University of Tokyo, Bunkyo, Tokyo, Japan.
² The University of Tokyo, presently Nippon Steel & Sumitomo Metal Corporation

ABSTRACT

A model for simulating brittle crack propagation and arrest in steel plates is presented. The model considers the influence of shear-lips formed on a fracture surface acting as crack closure force and that of a loss of plane strain condition at a propagating crack-tip with increasing dynamic stress intensity factor. The latter effect depends not only on the stress intensity factor but also on crack velocity. The model was applied to temperature-gradient crack arrest tests and ultra-wide duplex crack arrest test. The model successfully explained anomalous crack arrest toughness under excessively high applied stress in the temperature gradient tests and crack arrest at stress intensity factor far above crack arrest toughness in the ultra-wide duplex tests.

KEY WORDS: Brittle fracture; fracture mechanics; dynamic crack propagation; crack arrest toughness; crack arrest testing; high-strength steel.

INTRODUCTION

Prevention of brittle crack propagation as well as crack initiation is essentially important for ensuring double integrity in such steel structures as large containerships and offshore structures. Brittle crack initiation is prevented by controlling welding defects and fatigue cracks by repeated load during service and by selecting steel plates and welding consumables having high toughness, together with proper welding conditions. On the other hand, brittle crack propagation must be prevented by adopting steel plates with high crack arrest toughness of base metal, together with proper crack arrest design. Nippon Kaiji Kyokai published the guidelines on Brittle Crack Arrest Design, (Nippon Kaiji Kyokai, 2009), in which fundamental procedures for preventing brittle crack propagation in containership hull structures are presented. The guideline also addresses a testing method to measure brittle crack arrest toughness using temperature-gradient tests.

In what follows, The Japan Welding Engineering Society has published a standard testing method for brittle crack arrest toughness, $K_{ca}$, using temperature-gradient crack arrest specimens, WES 2815 (2014), see Fig.1(a). The standard provides a testing method to obtain $K_{ca}$ from applied stress, $\sigma_{app}$ and arrest crack length, $a$, $K_{ca}$ at crack arrest temperature, $T$, is given by the next equation, where, $W$ is specimen width.

$$K_{ca} = \sigma_{app} \sqrt{\frac{\pi a}{\pi a}} \left[ \frac{2W}{\pi a} \tan \left( \frac{\pi a}{2W} \right) \right]^{1/2}$$

The standard specifies testing conditions, including specimen configurations, impact energy limit, applied stress limit, etc, precisely. Among these variables, allowable range of the applied stress is one of the important points in the standard because non-conservative test results might be derived if the applied stress is excessively high (Aihara, Watabe, Shibanuma, Inoue, Koseki, 2012).

![Fig.1 Crack arrest specimens.](image)

![Fig.2 Discrepancy of crack arrest toughness values derived from standard and ultra-wide specimens.](image)