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# OBSERVATION OF MICRO-CRACKS BENEATH FRACTURE SURFACE DURING DYNAMIC CRACK PROPAGATION

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**ABSTRACT**

In this study, micro-cracks generated during dynamic crack propagation were investigated for an ESSO specimen and V-notched Charpy specimen. The ESSO test with temperature gradient and the Charpy impact test were conducted for steel for shipbuilding. The macroscopic roughness of the fracture surface increases with increasing temperature. The section beneath the fracture surface generated during dynamic brittle crack propagation was observed using a scanning electron microscope, after cutting with a focused ion beam or grinding. Many micro-cracks can be found beneath the brittle fracture surface in the V-notched Charpy specimen. In the ESSO specimen, which had a macroscopic flat surface, micro-cracks can be detected beneath the main crack propagated in the temperature range from –140°C to –100°C. On the other hand, there were a few micro-cracks beneath the main crack propagated at relatively high temperature, at which the fracture surface was macroscopically rough. The number of micro-cracks in the Charpy specimen is fewer than those in the ESSO specimen at the same temperature. The observations indicated that the correlations of Charpy impact properties with crack arrest performance for the ESSO specimen was inconvincible in terms of the differences in the micro-scale fracture behavior as well as lack of theoretical basis.

**Keywords:** Notched specimen, Brittle fracture, Rapid crack propagation, Cleavage micro-crack, Structural steel

**Highlights**

- Numerous cleavage micro-cracks generated during dynamic brittle crack propagation.
- Micro-crack density in Charpy specimen was similar to that for the ESSO specimen.
- Micro-crack density decreases with increasing temperature for both specimens.

## 1. Introduction

Since brittle crack propagates rapidly, brittle fracture in large-scale structures causes catastrophic damage. The propagation speed recorded by Machida et al. [1] was shown to be higher than 1000 m/s for low carbon steels. The Robertson, ESSO, and double tension tests are used for directly evaluating the crack arrest toughness of steels. The empirical correlation between the results of the Charpy impact test and the ESSO test reported by Feely et al. [2] is that the approximate mean value of the Charpy absorbed energy, at the ESSO brittle fracture temperature, is 41 J for low carbon steels. The 41 J transition temperature is generally used for evaluation of material toughness. Many researchers [3–9] investigated a correlation between Charpy crack arrest force and the temperature at crack arrest toughness $K_a$ = 100 MPa·m$^{1/2}$. The force at the end of unstable crack propagation in a Charpy specimen was determined using an instrumented Charpy testing machine. This is more physically grounded than the conventional 41 J transition temperature. The Charpy crack arrest force showed good correlation with not only nil ductility temperature but also crack arrest performance. These correlations are widely used for evaluation of crack arrest toughness of structural steels. However, the theoretical basis of this correlation is not clear because of lack of the physical background. There are many differences between the ESSO specimen and the Charpy specimen. The size of specimen is quite difference. The loading condition is also difference.

The mechanism of brittle crack propagation has not yet been fully understood. During rapid crack propagation, many micro-scale phenomena occur, such as the initiation of micro-cracks and formations of river patterns and tear ridges. Micro-cracks induce a brittle fracture in structures. Iung and Pineau [9] reported that many cleavage micro-cracks were observed along the brittle crack path. Numerous cleavage micro-cracks were observed underneath the main fracture surface of the Charpy specimen [10-12]. The Micro-cracking induces energy dissipation by generating surfaces. The dissipation energy might affect the brittle crack propagation.