International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 27, No. 2, June 2017, pp. 210–215; https://doi.org/10.17736/ijope.2017.hj26

http://www.isope.org/publications/publications.htm

Simplified Evaluation of Brittle Crack Arrest Toughness in Heavy-thick Plate by Combined Small-scale Tests

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To develop a simplified evaluation method for brittle crack arrest toughness in a heavy-thick plate, the correlation between large-scale tests (such as the ESSO test) and small-scale tests (such as the Naval Research Laboratory (NRL) drop-weight test and the Charpy V-notch impact test) was investigated. It was found that the Nil-Ductility Transition Temperature (NDTT) obtained by the NRL drop-weight test at the surface layer and the fracture appearance transition temperature (vTrs) obtained by the Charpy V-notch impact test at the quarter thickness position have a high correlation with brittle crack arrest toughness. A simplified evaluation equation for arrest toughness was suggested by the combination of the results of the small-scale tests. It was confirmed that the developed equation can be applied to various steels independent of the chemical composition and the manufacturing process.

INTRODUCTION

To prevent severe damage by brittle crack propagation in ship structures, brittle crack arrest toughness is required in heavy-thick steel plates applied to large container ships (Nippon Kaiji Kyokai, 2009). Usually, evaluations of the brittle crack arrest toughness are performed by large-scale tests such as the ESSO test. Recently, the evaluation test methods of the brittle crack arrest toughness of materials were carefully investigated by a committee of The Japan Welding Engineering Society (Kawabata et al., 2014; Shimada et al., 2014; Kaneko et al., 2014; Handa et al., 2014), and a standard of the ESSO test method was established (The Japan Welding Engineering Society, 2014). However, these tests may not be suitable for quality assurance tests for mass-produced steel plates because the testing cost is considerably high and these tests are tedious. Additionally, a large-scale experimental facility possessing more than 1,000-ton loading capacity is required to conduct these tests. Therefore, an alternative simple test method to evaluate the brittle crack arrest toughness in heavy-thick steel plates needs to be developed.

Previously, the correlation between large-scale crack arrest tests and small-scale tests was investigated by several institutes and researchers. The Iron and Steel Institute of Japan, which consists of Japanese steel makers and research institutes, investigated the correlation between the double tension crack arrest test and the Charpy V-notch impact test (The Iron and Steel Institute of Japan, 1982). Although they established an estimation equation of the arrest toughness using the energy transition temperature, the accuracy of the estimation was inadequate. Smedley and Wiesner demonstrated that the Naval Research Laboratory (NRL) drop-weight test could be the most practical small-scale test method for the evaluation of the arrest toughness (Smedley, 1989; Wiesner et al., 1993; Wiesner, 1996). Other researchers also indicated the usefulness of the NRL drop-weight test as a simplified arrest test method (Otani et al., 2003; Fukui et al., 2003; Ishikawa et al., 2012; Funatsu et al., 2012). However, these studies were mainly intended for relatively thin plates; therefore, investigations of arrest toughness in heavy-thick plates and their simplified evaluation method by small-scale tests are limited. Additionally, the evaluation position in the thickness direction is particularly significant in heavy-thick plate because the steel plates produced by the Thermo-Mechanical Control Process (TMCP) usually have microstructural variations in the thickness direction, and they have considerable effects on the arrest property.

In the present study, we conducted a number of large-scale tests (ESSO tests) and small-scale tests (NRL drop-weight tests and Charpy V-notch impact tests) by using heavy-thick steel plates with various kinds of chemical composition, thickness, and mechanical properties. The correlations between the results of the ESSO tests and the small-scale tests were investigated. With respect to crack arrest phenomena in heavy-thick plates, a preferable combination of small-scale tests, which can evaluate arrest toughness, was selected. Finally, a simplified evaluation equation for arrest toughness was suggested by the combination of the results of the small-scale tests.

Received August 10, 2015; updated and further revised manuscript received by the editors August 31, 2016. The original version (prior to the final updated and revised manuscript) was presented at the Twenty-fifth International Ocean and Polar Engineering Conference (ISOPE-2015), Kona, Hawaii, June 21–26, 2015.

KEY WORDS: Shipbuilding steel, heavy-thick plate, brittle fracture, brittle crack arrest toughness, high-strength steel, ESSO test, simplified evaluation.