Evaluation of Fracture Toughness by Master Curve Approach Using Miniature Specimens

Background

The fracture toughness Master Curve *[1] gives a universal relationship between the median of fracture toughness and temperature in the ductile-brittle transition temperature region of ferritic steels such as reactor pressure vessel (RPV) steels. The Master Curve approach specified in the ASTM standard theoretically provides the confidence levels of fracture toughness in consideration of the inherent scatter of fracture toughness. CRIEPI has conducted a series of fracture toughness tests for typical Japanese RPV steels with various specimen sizes and shapes, and has ascertained that the Master Curve method can be well applied to the specimens with thickness of 0.4-inches or larger *[2]. Considering the possible application of the Master Curve method coexistent with the present surveillance program for operating RPVs, the utilization of miniature specimens which can be taken from broken halves of surveillance specimens is quite important for efficient determination of the Master Curve from limited volume of the materials concerned.

Objectives

The purpose of this study is to investigate the applicability of miniature specimens to determine the fracture toughness curve of RPV steels based on the Master Curve approach;

Principal Results

1. Fracture toughness tests using miniature C(T) specimens

Fracture toughness tests were conducted for typical Japanese RPV steels, SFVQ1A forging and SQV2A plate materials, using the miniature C(T) specimens with the thickness of 4 mm (see Fig. 1) following the procedure of the ASTM standard shown in Fig. 2. The differences in test temperature, evaluation method, and specimen size did not affect the Master Curves, and the fracture toughness indexed by the reference temperature *[3], To, obtained from miniature C(T) specimens were consistent with those obtained from standard and larger C(T) specimens (see Fig. 3).

2. Number of data required to determine valid reference temperature

The relation between test temperature and the estimated number of data required to determine valid To was arranged as shown in Fig. 4. A valid To could be determined with realistic number of miniature C(T) specimens, less than ten, if the test temperature was properly selected to be lower than To by 10 to 50℃. In contrast, alternative miniature specimens, sub-size precracked Charpy V-notch specimens, required much more data to determine valid To.

Thus, the Master Curve approach using miniature C(T) specimens could be an effective method to determine the fracture toughness curve of RPV steels.

Future Developments

Based on the series of results, the Master Curve evaluation procedure will be incorporated into a relating national standard.

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Reference

N. Miura, et al., 2009, “Evaluation of Fracture Toughness by Master Curve Approach Using Miniature Specimens”, CRIEPI Report Q08025 (in Japanese)

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*1：The variation of the fracture toughness for ferritic steels in the transition range can be described by the Weibull distribution based on the weakest link theory. Consequently the relation between the median of fracture toughness and temperature can be expressed by an inherent curve.

*2：N. Miura, et al., 2008, “Applicability of Small Specimens to the Evaluation of Master Curve Fracture Toughness for Japanese Reactor Pressure Vessel Steels”, CRIEPI Report Q07304 (in Japanese).

*3：The temperature corresponding to the fracture toughness of 100 MPa-m$^{1/2}$ on the Master Curve. The reference temperature is a unique index to identify the location of the Master Curve.

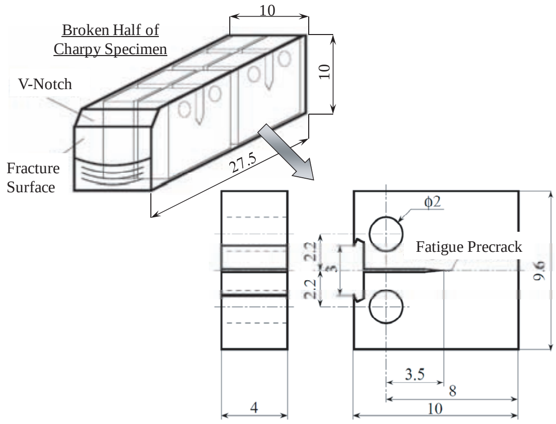


Fig.1 Orientation and configuration of miniature C(T) specimens [size in mm]

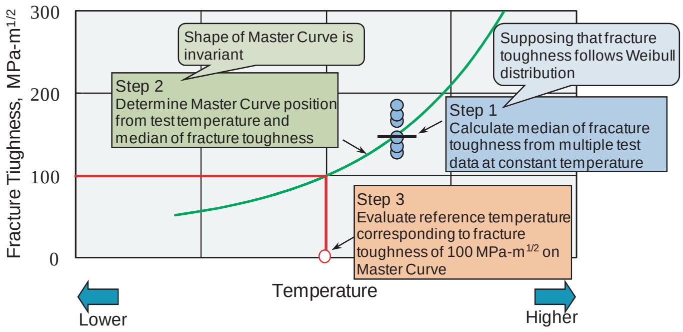
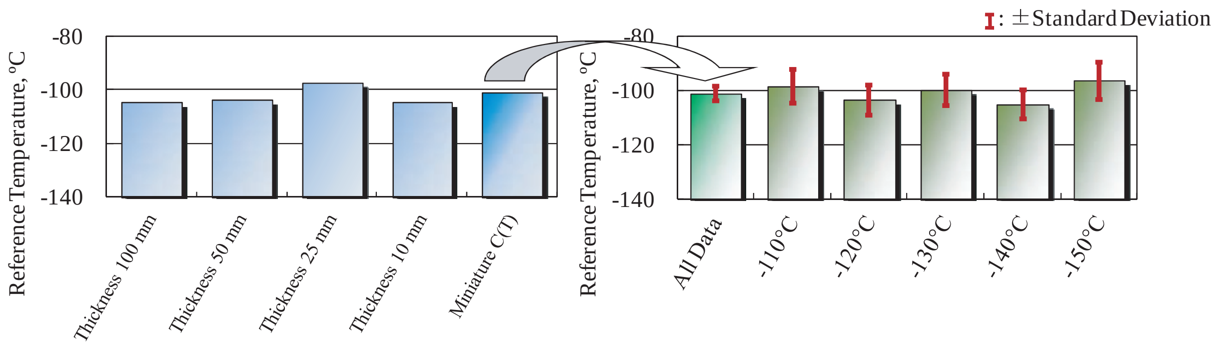


Fig.2 Evaluation procedure of reference temperature based on ASTM standard



Effect of specimen size on To
[Data with thickness of 100 to 10 mm referred from previous study]

Effect of test temperature and evaluation method on To
[Based on miniature C(T) results]

Fig.3 Comparison of reference temperature, To (SFVQ1A forging, C(T) specimens)

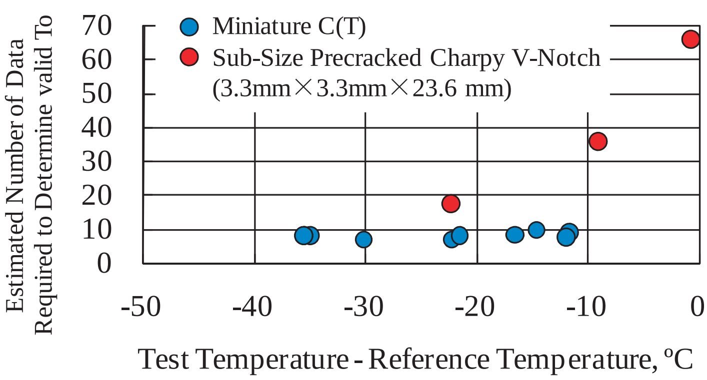


Fig.4 Estimated number of data required to determine valid To