Proposal of Rational Determination of Fracture Toughness Lower-Bound Curves by Master Curve Approach

Background

The "Master Curve *1" gives the relation between the median of fracture toughness and temperature in ductile-brittle transition temperature region. The procedure to determine the Master Curve is provided in the current ASTM standard. CRIEPI has conducted a series of fracture toughness tests for typical Japanese reactor pressure vessel (RPV) steels with various specimen sizes and shapes, and has ascertained that the Master Curve approach can be well applied to them. Considering the substitution of the alternative lower-bound curves based on the Master Curve approach for the recursive K_{Ic} curves in the present codes, the statistical characteristic should be well incorporated into the determination of the lower-bound curves. The current ASTM standard provides the procedure to identify the lower-bound curves, however, it is semi-empirically addressed without sufficient consideration on statistical reliability.

Objectives

Thist study aims to propose a rational determination method of fracture toughness lower-bound curves based on the Master Curve approach;

Principal Results

1. Proposal of a rational determination method of lower-bound curves

Lower-bound curve is derived by the following two steps (see Fig. 1);

(a) Determine a confidence limit curve by reducing the Master Curve so that the confidence limit curve can envelop the variation of the fracture toughness, and

(b) Determine a lower-bound curve by shifting the confidence limit curve upward in temperature upon considering the uncertainty of the reference temperature *2.

The current ASTM standard does not take account of the effect of sample size in the determination of the confidence limit curve, and semi-empirically gives the shift adjustment in the determination of the lower-bound curve. By resolving these issues, a new method to determine the rational lower-bound curves was proposed with well-defined meaning on their statistical reliability (see Table 1).

2. Verification of the proposed method

The lower-bound curve based on the proposed methods could conservatively envelop the fracture toughness data for RPV steels (see Fig. 2). Thus the adequacy of the proposed method was verified.

Future Developments

Based on the results, a Master Curve evaluation procedure using less and smaller specimens will be further developed, which can coexist with the present surveillance program.

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Reference

N. Miura, et al., 2008, "Applicability of Small Specimens to the Evaluation of Master Curve Fracture Toughness for Japanese Reactor Pressure Vessel Steels", Technical Report Q07304 (in Japanese)
N. Miura, et al., 2008, "Proposal of Rational Determination of Fracture Toughness Lower-Bound Curves by Master Curve Approach", Technical Report Q07305 (in Japanese)

*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 : 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.

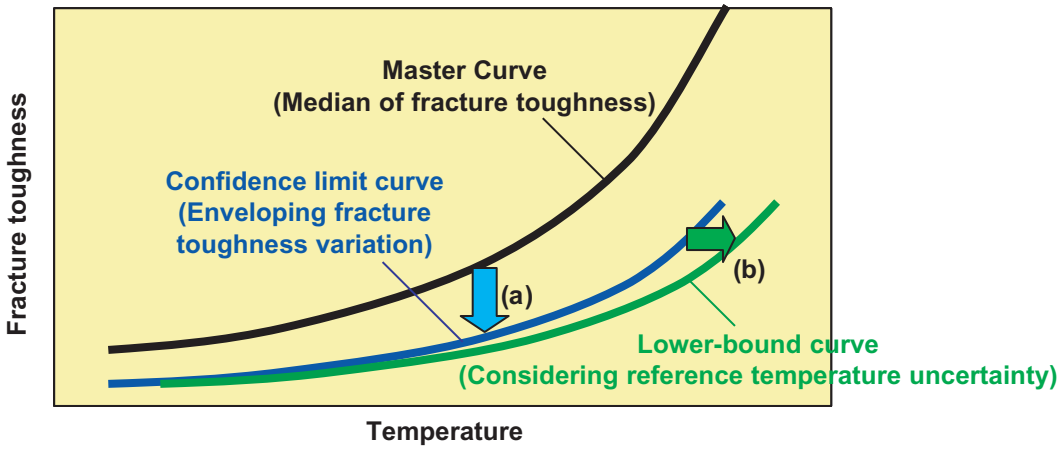

Fig.1 Schematic Derivation of Lower-Bound Curves
—(a) Determine a confidence limit curve by reducing the Master Curve—
—(b) Determine a lower-bound by shifting the confidence limit curve upward in temperature—

Table 1 Comparison of Determination of Lower-Bound Curves
Based on Current ASTM Standard and Proposed Method

	ASTM standard	Proposed method
Confidence limit curve determination	Using constant reducing factor for infinite sample size	Using reducing factor as function of sample size and confidence level
Lower-bound curve determination	Determine semi-empirical shift adjustment	Determine shift adjustment considering statistical distribution of reference temperature

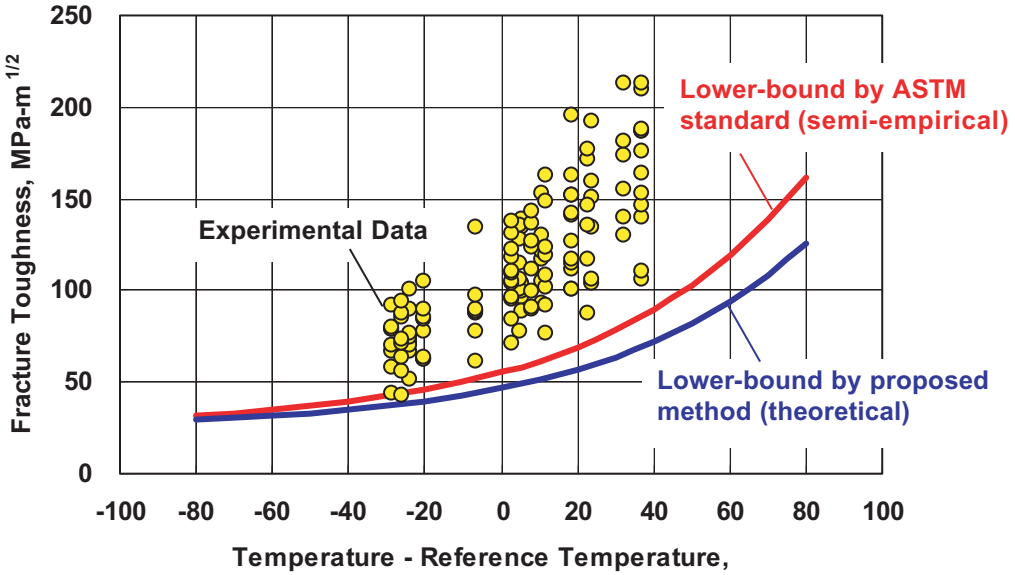

Fig. 2 Typical Comparison between Experimental Fracture Toughness Data and Lower-Bound Curves
—experimental data were obtained from about 100 SFVQ1A specimens with the thickness of 10 to 100 mm—