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The Round Robin Test on Normalization Method under Static Loading Conditions

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1. Introduction

It is well known that ferritic steels can display a lower fracture resistance values under rapid loading rates due to Dynamic Strain Aging (DSA) phenomenon.[1,2] In order to consider DSA in application of Leak-Before-Break (LBB) in nuclear power plant. Korean Standard Review Plan (KSRP) 3.6.3-1 on LBB recommends to conduct dynamic loading J-R test for ferritic steel piping material.[3]

While the unloading compliance method is well established for J-R determination, it can not be applied to dynamic loading situation because of the impracticability of unloading at such high rates. Alternatively, the dc-electric potential drop (DCPD) method has been employed for crack length measurements in continuous dynamic loading.[3] However, a severe shortcoming of the DCPD method was encountered in testing ferromagnetic materials with unclear definition of crack initiation point due to spurious potential peaks arising in the early stage of rapid loading[4,5]. Recently, DCPD method was excluded from ASTM Method E1820-99 because of difficulties for application as well as the particular accuracy issue.

The normalization method, developed by Landes et al. [6~10], has no fundamental shortcoming in its application to dynamic fracture tests since only load and load line displacement need to be measured in order to determine J-R curves. In 2001, the normalization method was accepted as ASTM Method E1820-01 for use as a high rate J-R tests. Prior to its approval by ASTM, the High Rate Round Robin was conducted under the coordination of ASTM Subcommittee E08.08.02 for the verification of accuracy and reproducibility in 2000.[11]

In the High Rate Round Robin, however, the results of normalization method could not be compared with any of other well-established methods because no suitable method is available as a reference due to aforementioned difficulties. With the new Annex A15 developed for its implementation added in ASTM Method E1820-01, the need for systematic validation on the consistency of the normalization method with a well-established standard method became apparent. The present work has been conducted to meet this need.

2. Description of the Round Robin Experiments

A106Gr.C nuclear piping steel which is archive material for main steam line pipes of Ulchin Nuclear Power Plants unit 3&4, was used in this round robin. Its chemical composition is shown in Table 1. One inch compact tension (CT) specimens in compliance with ASTM method were machined in TL orientation, and were distributed for this round robin test. Tensile tests were conducted at Seoul National University and test results shown in Table 2, were supplied together with the CT specimens to the round robin participants.

The specimens, tensile data and test procedure were distributed to 13 participants. Each participant received 4 CT specimens without pre-cracking and side-groving. Table 3 shows test matrix for the round robin test. The round robin test was conducted according to ASTM Method E1820-99a and "Draft Annex A15. Normalization Data Reduction Technique" for unloading compliance method and normalization method, respectively.

3. Results and Discussion

Out of 13 initial volunteers, 10 participants finally submitted their test results. All the data were reanalyzed by round robin coordinator, SNU. The J-R curves were compared with each other and, for convenience, all the J_{Ic} values were compared in Figure 1.

J_{Ic} determined by unloading compliance has large deviation of 53 % from the mean value. But, some data are invalidated based on ASTM Method E1820-99a or Draft Annex A15 as a result of reanalysis. When one data that shows severe fluctuation in crack size data is excluded, maximum deviation is reduced to 30 %. J_{Ic} determined by the normalization method with unloading has 60 % maximum deviation for the mean value. This large deviation is observed in some laboratory data that shows excessive deviation of fitted normalization function from tangent line.

It was found that the tangent point positions from final point show very large scatter in normalized load-displacement curves and this make large scatter of J_{Ic} values. In order to find the solution of normalization fitting problem, modified normalization procedure of offset method and linear tangent method are evaluated. This method excludes inconsistent normalization method result but slightly rise the mean values of J_{Ic} compared with unloading compliance method and standard procedure of normalization method. Figure 2 shows that offset method and linear tangent method reduce the deviation of J_{Ic} determined by normalization method.

In order to confirm the true crack length, 4 number of additional specimens were tested by SNU. These specimens were stopped in crack initiation region in 1.57 mm of load line displacement, and broken. Figure

3 shows the optically measured crack length compared with the crack length determined by unloading compliance method and normalization method in same load line displacement region. In two specimens, unloading compliance well measured the crack length but in two other specimens, it overestimated the crack length. In average value, unloading compliance method overestimated the crack length and normalization method underestimated the crack length in crack initiation region, except one data of unreasonable J-R curve shape. But, it is just the results of one laboratory, and round robin showed it is not general trend.

4. Conclusion

Round robin program was conducted to quantify errors and differences between the normalization method and the unloading compliance method in order to further validate the technique. In this round robin, the characteristics of normalization method were found and the error of it was quantified. The current standard was found to have the problem of fitting difficulty with normalization function, and modified normalization method was proposed.

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Table 1. Chemical composition of the test material, A106Gr.C [wt%]

C	Mn	P	S	Si	Mo	Cr	Cu	V	Ni	Fe
0.24	1.08	0.011	0.011	0.23	0.04	0.09	0.09	0.007	0.11	balance

Table 2. Tensile properties of the test material, A106Gr.C at R.T.(25° C)

	Y.S.[MPa]	U.T.S. [MPa]	Elastic Modulus [GPa]
Specimen 1	336.9	567.2	-
Specimen 2	344.8	569.9	-
Specimen 3	346.4	565.4	-
Mean	342.7	567.5	204

* Y.S. = yield strength * U.T.S. = ultimate tensile strength

Table 3. shows test matrix for the round robin test.

Specimen	Initial crack length	Loading	Analysis
1	$a_0/W=0.5$	With unloading	Unloading compliance & Normalization
2	$a_0/W=0.65$	With unloading	Unloading compliance & Normalization
3	$a_0/W=0.5$	With unloading	Normalization confirmatory test
4 (opt.)	$a_0/W=0.5$	Ramp loading	Normalization

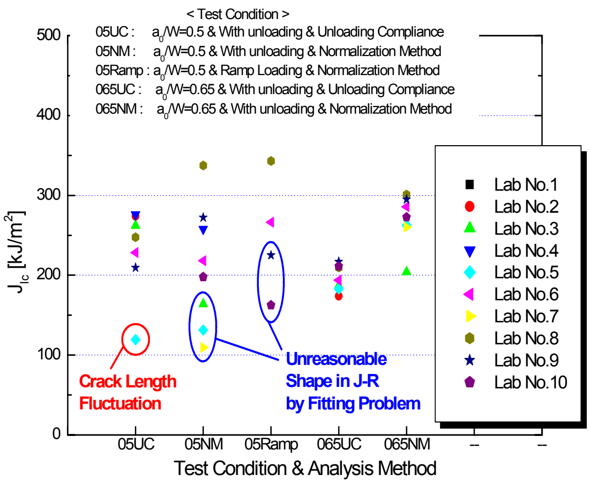

Figure 1. J_{Ic} values determined by reanalysis.

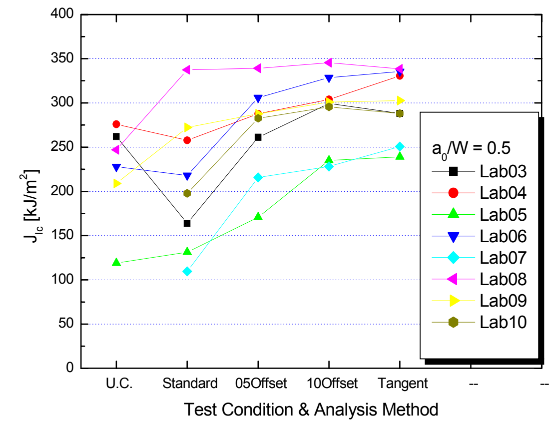

Figure 2. J_{Ic} values determined by unloading compliance method, normalization method standard procedure, and normalization method of offset and linear tangent technique.

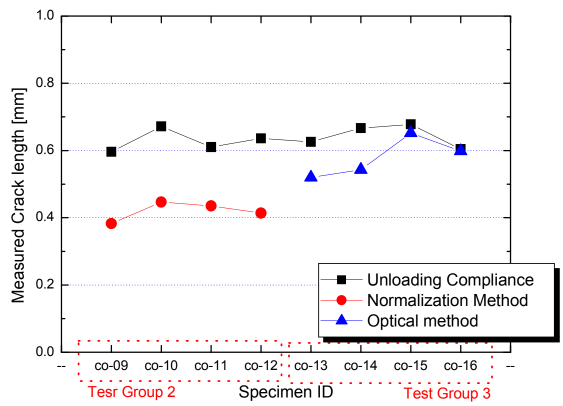

Figure 3. Crack length measurement in crack initiation region by unloading compliance, standard normalization method and optical measurement in fracture surface.