Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 25-26, 2012

J estimation method in R6 and RCC-MR A16 under combined primary and secondary stresses

Jeong Soon Park [a*], Jin Ho Lee [a], Seyoung Im [b]
[a] *Korea Institute of Nuclear Safety, 62 Gwahak-ro, Yuseong-gu, Daejeon*
[b] *Korea Advanced Institute of Science and Technology, 291 Daehak-ro, Yuseong-gu, Daejeon*
[*] *Corresponding author: k651pjs@kins.re.kr*

1. Introduction

When both primary stress and tensile secondary stress are present in a cracked component, secondary stress, e.g. thermal stress, also contributes to the crack driving force as primary stress does. Crack driving force for elastic plastic fracture mechanics, J-integral, cannot be easily obtained under the combined primary and secondary stress condition as in the linear elastic fracture mechanics where principle of superposition is applicable since contribution of secondary stress to the J-integral can vary with the load magnitude and resulting plasticity.

Well-known defect assessment procedures in Europe, R6[1] and RCC-MR A16[2], introduce the adjustment factor of their own to consider the plasticity effect on secondary stress and the interaction effect of primary and secondary stress for J-integral estimation.

In this paper, J-integral estimation methods considering plasticity and combined stress effects in R6 and RCC-MR A16 approaches are reviewed. In addition, finite element analyses are performed for cylinders with circumferential defects under tension and radial temperature distribution to quantifying plasticity and stress interaction effects, and to comparing the results with those obtained by using R6 and A16 approaches.

2. J-integral estimation methods

In this section J-estimation methods considering plasticity and combined stress interaction effects in R6 and RCC-MR A16 approaches are described.

2.1 Reference stress method

R6 and RCC-MR A16 both use the reference stress method to estimate J-integral. In the reference stress method, reference stress is defined as

$$\sigma_{ref} = L_r \cdot \sigma_y ,\; L_r = \frac{P}{P_{ref}} \quad (1)$$

σ_{ref} is dependent on how to determine P_{ref}. RCC-MR A16 provides two options to determine σ_{ref}.

2.2 R6 approach

For the secondary stress only, R6 introduces multiplying factor V_o in order to take into account plasticity effects on the secondary stress.

$$J^{s} = \frac{(V_o \cdot K^{S})^2}{E'} \quad (2)$$

For combined primary and secondary stress, R6 procedure adopted two approaches in order to account for interaction effects of primary and secondary stress, one of which uses additive term ρ and the other uses multiplying factor V.

Elastic-plastic J-integral under combined primary and secondary stress can be obtained using V as follows [3]:

$$J^{P+S} = \frac{(K^{P} + V \cdot K^{S})^2}{E'} \left[\frac{E\varepsilon_{ref}}{\sigma_{ref}} + \frac{1}{2} L_r^2 \frac{\sigma_{ref}}{E\varepsilon_{ref}} \right] \quad (3)$$

In the equation (3), ε_{ref} is the reference strain corresponding to the reference stress on the material tensile curve. R6 provides equations to estimate V for the condition where secondary stress is relatively small, and it is called the simplified method. Those equations are dependent on the magnitude of secondary stress and L_r. For large secondary stress, detailed method, $V=\xi \cdot V_o$, using tabulated values of ξ is provided. V=1 means elastic superposition of the K^P and K^S while V=0 indicates secondary stress not contributing to J which means secondary stress being fully relaxed.

2.3 RCC-MR A16 approach

RCC-MR A16 introduces multiplying factor k_{th} in R6 for secondary stress only [4].

$$J_s = J_{el}^{th} \cdot [k_{th}]^2 \quad (4)$$

A16 only considers radial variation in temperature.

Under combined primary and secondary stress, J-integral can be estimated using k^*_{th}

$$J_s = \left[\sqrt{J_s^{me}} + k_{th}^{*} \cdot \sqrt{J_{el}^{th}} \right]^2 \quad (5)$$

In the equation (5), J_s^{me} means corrected J-integral considering plasticity effect.

RCC-MR A16 provides compendiums about stress intensity factors, multiplying factor k_{th} and k^*_{th} for various types of structures and defects.

3. Analysis

3.1 Finite Element Analysis (FEA)

For the present work, several finite element analyses are performed using the general purpose FEA program, ABAQUS.

The material used in FEA is assumed to follow the Ramberg-Osgood relationship and deformation plasticity option is used. Values of elastic modulus (E) and yield stress (σ_y) are chosen as E=200 GPa and σ_y=300 MPa , respectively.

As a loading condition, uniaxial tension and temperature distribution (radial and linear distribution) are considered.

Finite element models are verified since FE elastic stress intensity factors (SIF) are well matched with RCC-MR A16 SIF solutions within 1% for tension condition as shown in Fig. 1.

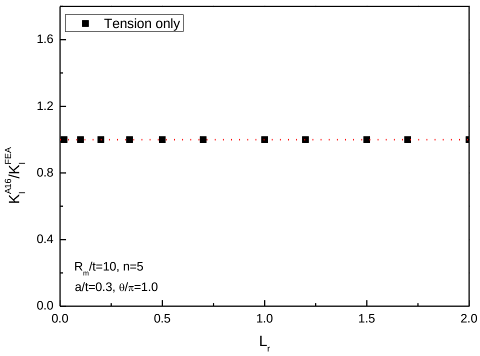

Fig. 1. FEA model verification under tension.

3.2 V_o, k_{th} estimation

Multiplying factors, V_o and k_{th}, are depicted in Fig. 2 for the condition where radial temperature distribution is only considered. V_o is estimated by using FEA while k_{th} is calculated by using the RCC-MR A16 method. To quantify the magnitude of the secondary stress, a non-dimensional parameter, S, is introduced and defined as

$$S = \frac{K^S}{K^P / L_r} \qquad (6)$$

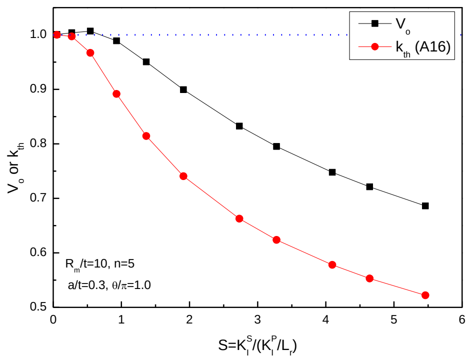

Fig. 2. Multiplying factors (V_o, k_{th}) to take plasticity effect into account under secondary stress only.

For the limiting case S→0, V_o and k_{th} approach to the unity. V_o and k_{th} are generally close to the unity for small value of S while they decrease from the unity as S increases. RCC-MR A16 gives smaller values of elastic-plastic J-integral than FEA under thermal stress only.

For small values of S (S<1), V_o can be greater than the unity, which suggests that small secondary stresses may behave in a similar manner to primary stresses.

3.3 V, k_{th}^* estimation

Multiplying factors for combined primary and secondary loading condition, which are V and k_{th}^*, are obtained and depicted in Fig. 3.

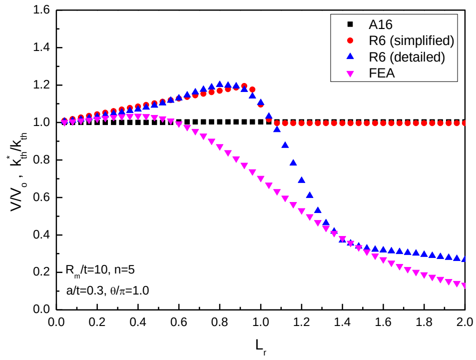

Fig. 3. Normalized multiplying factors (V, k_{th}^*) for combined primary and secondary loading(S=0.27) condition

Values of V from R6 approach (both simplified and detailed method) show conservative values than FEA results for all values of L_r. In addition, R6 simplified method and RCC-MR A16 give overly conservative values at L_r>1. On the other hand, FEA gives larger values than RCC-MR A16 for small values of L_r, which indicates that RCC-MR A16 can be non-conservative and cannot consider interaction effect of primary and secondary stress enough.

3. Conclusions

In this study, multiplying factors to the crack driving force are obtained to consider plasticity effect on secondary stress and interaction effect of primary and secondary stress using FEA and estimation methods provided in R6 and RCC-MR A6. For the condition of secondary stress only, RCC-MR A16 gives non-conservative values than FEA results. For the combined loading condition of primary and secondary stress, R6 approach gives conservative values than FEA results. RCC-MR A16 also gives conservative results for Lr > 1 while it can be non-conservative for small values of primary and secondary stress.

REFERENCES

[1] British Energy Generation Ltd, R6, Assessment of the Integrity of Structures Containing Defects, Revision 4, 2006.
[2] AFCEN, RCC-MR Appendix A16, Guide for Leak Before Break Analysis and Defect Assessment, Edition 2007
[3] T.G.Song, A Method To Estimate Non-linear Fracture Mechanics Parameters under Combined Primary and Secondary Stresses, 2010
[4] B. Drubay et.al., A16: Guide for Defect Assessment at Elevated Temperature, International Journal of Pressure Vessels and Piping 80, p. 499-516, 2003