# 결함 평가에서 용접 잔류응력 분포의 영향

## Effect of Residual Stress Distributions in Defect Assessment

이세환*, 이형연*, 김종범*, 이재한*
* 한국원자력연구소

**ABSTRACT** Weld residual stresses can be a major concern in structural integrity assessments such as a nuclear power plant. In this paper, detailed weld residual stress analyses were presented for a typical multi-pass weld of pipe-butt weld and plate T-butt weld. The calculated residual stress distributions were compared with those of the measured data and recommended profiles in R6 and BS7910. Defect assessment which is based on the stress intensity factor (SIF) calculations was carried out for a plate T-but weld with cracks considering the weld residual stress distributions.

## 1. Introduction

The residual stresses are unavoidable in welding process, and the effects of these stresses on welded structures cannot be disregarded. Thermal stresses are generated during welding due to the non-uniform temperature distribution around the joint. As the temperature of the base metal increases, the yield strength decreases and the thermal stresses increase. It is well known that the tensile residual stresses have a bad influence on the structural integrity such as a fatigue strength and fracture toughness, etc[1-2].

For the present study, the residual stresses after welding for a pipe-butt and plate T-butt weld were determined by the finite element method. A transient thermal and elasto-plastic mechanical analyses with an axis symmetric two-dimensional model were performed with the commercial software program ABAQUS [3]. Heat flow in welding process was evaluated by a non-linear transient analysis. The results of numerical analysis for the residual stresses in multi-pass butt weld were compared with those of the measurements data and recommended code profiles which is defined by analytical methods.

Linear elastic fracture mechanics parameter of stress intensity factor (SIF) is widely used in the characterization of materials properties and failure assessment procedures in the presence of a crack. The SIF has been determined by using a Green's function method in conjunction with the finite element analysis for a T-butt weld[4].

## 2. Residual Stress Distributions

In this study, two shapes of weldments, plate T-butt and pipe-butt, are investigated using the recommended codes and finite element method.

### 2.1 R6 and BS7910 Procedures

#### 2.1.1 Plate T-butt weld

R6 procedures recommended two approaches for defining the transverse residual stress profiles, depending on the available welding conditions [5]. If the detailed welding conditions are unknown then polynomial functions provided in the R6 can be used. The BS7910[6] provides two profiles of transverse residual stress distributions. The first profile is a polynomial function representing an upper bound fit based on the experimental data and it is shown in equation (1).

$$\sigma_R^T = \sigma_Y[0.97 + 2.3267(y/W) - 24.125(y/W)^2 + 42.485(y/W)^3 - 21.087(y/W)^4] \quad (1)$$

where, $\sigma_R^T$ : transverse residual stress, $\sigma_Y$ : material yield stress, W : thickness

### 2.1.2 Pipe-butt weld

The through-thickness transverse residual stress profile for circumferential pipe-butt weld is recommended three different polynomials depending on the heat input energy in R6 and BS7910. The residual stress distributions are given below equations in (2-a, b, c) as a functions of y/W and (q/v)/W, where y is distance from the bore, W is pipe thickness, q is welding heat input and v is a torch travel speed.

For, low heat input, $(q/v)/W \leq 50$ J/mm$^2$

$$\sigma_R^T = \sigma_Y[1 - 6.80(y/W) + 24.30(y/W)^2 - 28.68(y/W)^3 + 11.18(y/W)^4] \quad (2\text{-a})$$

Midium heat input, $50 < (q/v)/W \leq 120$ J/mm$^2$

$$\sigma_R^T = \sigma_Y[1 - 4.43(y/W) + 13.53(y/W)^2 - 16.93(y/W)^3 + 7.03(y/W)^4] \quad (2\text{-b})$$

High heat input, $(q/v)/W > 120$ J/mm$^2$

$$\sigma_R^T = \sigma_Y[1 - 0.22(y/W) - 3.06(y/W)^2 + 1.88(y/W)^3] \quad (2\text{-c})$$

## 2.2 Finite Element Analysis

### 2.2.1 Procedures of FE Analysis

Two-dimensional analyses for all residual stress analysis model were carried out in order to reduce calculation time by considering the symmetries of the essential features. The temperature dependent material properties and annealing for a melting were used in the thermal and mechanical analyses. The multi-pass weld has been assumed to a lumped pass by grouping several weld passes into a layer.

### 2.2.2 FE Model and Analysis Results

Fig.1 shows the detailed FE mesh generation and applied thermal and mechanical boundary conditions for a plate T-butt weld model in thermal analysis. A two-dimensional and half symmetric model with respect to the center-line of upper plate was chosen in finite element analysis.

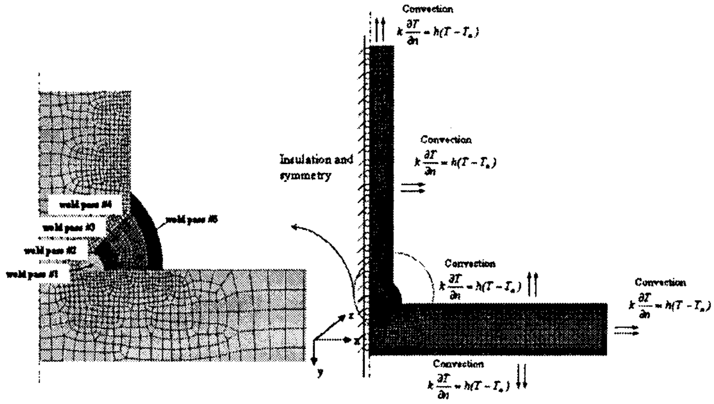


Fig. 1 Detailed FE model for plate T-butt weld

In Fig.2, a two-dimensional, axi-symmetric model with respect to the pipe center line and half-symmetric about the weld center line for a pipe-butt weld was presented.

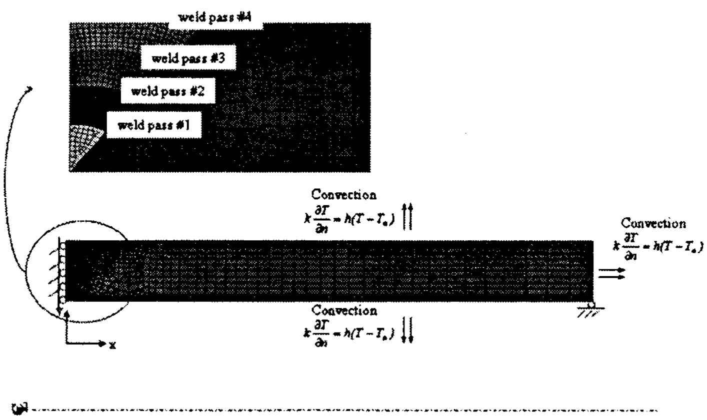


Fig. 2 Detailed FE model for plate T-butt weld

The results of transverse residual stress distributions along the thickness direction are shown in Fig.3, which shows the normalized transverse residual stress at weld toe to the bottom surface. From the profiles, the FE result appears to be in good agreement with the experimental dataset[7], and it is clear that the distributions of R6 and BS7910 are very conservative than those of FE and measured data.

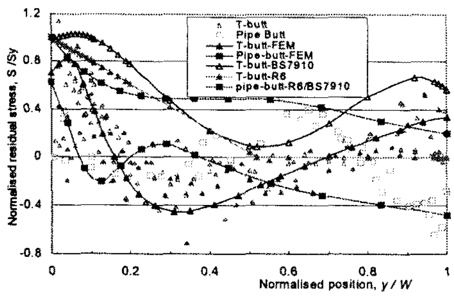


Fig.3 Residual stress distributions

## 3. Stress Intensity Factor

The calculation of the stress intensity factors for the plate T-butt weld has been accomplished using a FE analysis with cracked model in conjunction with the Green's function. The FE models with a specific crack length (a/w) of 0.1-0.5 were applied for a SIF calculations. The SIFs results for the R6, BS7910 and FE results are shown in Fig.4. The SIFs from the R6 and BS7910 distribution are more conservative than those for the FE result.

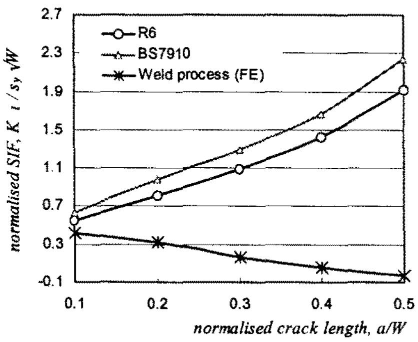


Fig. 4 Comparison of the SIFs results

## 4. Conclusions

The weld residual stress analyses were carried out for a T-butt and pipe-butt weld using detailed finite element analyses. The FE result of the transverse residual stress distributions were considerably less conservative than the recommended residual stress profiles from the R6 and BS7910.

The conservatism of the recommended residual stress distributions from the current life assessment procedures were quantified based on the SIF calculations.

## Acknowledgments

This study was supported by the Korean Ministry of Science & Technology through its National Nuclear Technology Program.

## References

1. R. Thumser, J. W. Bergmann, M. Vormwald : Residual Stress Fields and Fatigue Analysis of Autofrettaged Parts, International Journal of Pressure Vessels and Piping, 79 (2002), 113-117
2. D. H. Bae, I. S. Sohn, and J. K. Hong : Assessing the Effects of Residual Stresses on the Fatigue Strength of Spot Welds, Welding Journal, (2003), 18s-23s
3. ABAQUS, Standard User's Manual. Hibbit, Karlsson and Sorensen, Inc., v.6.4, 2004
4. H. Y. Lee, F. R. Biglari, R. Wimpory and K. M. Nikbin : Treatment of Residual Stress in Life Assessment Procedures, Engineering Fracture Mechanics, 73 (2006), 1755-1771
5. British Energy Generation Ltd : Assessment of the Integrity of Structures Containing Defects, R6 Rev. 4. British Energy Generation Ltd, 2001
6. British Standard Institution : Guide on methods for assessing the acceptability of flaws in metallic structures, BS7910: 1999, British Standards Institution, London, UK. 2000
7. H. Y. Lee, J. B. Kim, J. H. Lee and K. M. Nikbin : Comprehensive Residual Stress Distribution for a Plate and Pipe Components, J. of Mech. Sci. and Tech., 20(3) (2006), 335-344.