Title	Residual stress measurement of large-bore stainless steel pipe with butt-welded joints by inherent strain method
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Citation	Transactions of JWRI. 2010, 39(2), p. 65-67
Version Type	VoR
URL	https://doi.org/10.18910/9331
rights	
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Residual stress measurement of large-bore stainless steel pipes with butt-welded joints by inherent strain method†

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KEY WORDS: (Welding residual stress) (Austenitic stainless steel) (Butt-welded joint) (Inherent strain method) (Large-bore pipe) (Three-dimensional stress distribution)

1. Introduction

The inherent strain method [1] is a destructive technique to measure the residual stress accurately by cutting up the welding structure to be measured. The residual stress is represented by Eq.(1) using inherent strain:

$$\{\sigma\} = [D][H^*]\{\varepsilon^*\} \tag{1}$$

where $\{\sigma\}$ is residual stress, $\{\varepsilon^*\}$ is inherent strain, $[D]$ is the matrix between elastic stress and strain, and $[H^*]$ is the elastic response matrix between inherent strain and elastic strains.

The measurement strain $\{m\varepsilon\}$ is obtained by cutting the welding structure. $\{\sigma\}$ is obtained by substituting the most probable value $\{\hat{\varepsilon}^*\}$ calculated by Eq.(2) to Eq.(1).

$$\{\hat{\varepsilon}^*\} = \left([H^*]^T [H^*]^{-1}\right)[H^*]^T \{{}_m\varepsilon\} \tag{2}$$

The inherent strain method using functional form [2], in which the inherent strain distribution was represented by the function, enables accurate measurement in spite of fewer measurement points because the distribution of inherent strain $\{\varepsilon^*\}$ is represented by the appropriate function.

In this study, the inherent strain method using functional form was applied to welded pipe joints. The measurement strain was measured at 90° from the welding start position and then, the residual stress distribution was calculated assuming that the strain distribution spread uniformly in the circumferential direction. Here, the third order polynomial function was assumed as an appropriate function for inherent strain distribution. However, the appropriate function of inherent strain distribution has not been clarified for a large-bore and heavy-walled welded pipe joint. Therefore, six kinds of functions were examined to represent the distribution appropriately.

$$\varepsilon^{*f}_{k}(\zeta,\xi) = \sum_{i=1}^{N}\sum_{j=1}^{N} A_{ijk}\left(1-\frac{\zeta}{Z_k}\right)^i\left(1-\frac{\xi}{R_k}\right)^j \tag{3}$$

$$\begin{aligned}\varepsilon^{*f}_{k}(\zeta,\xi) &= A_{1k}\left(1-\frac{\zeta}{Z_k}\right)\left(1-\frac{\xi}{R_k}\right)\\ &+\sum_{i=1}^{N}\sum_{j=1}^{N} A_{ijk}\cos\left((2i-1)\frac{\pi\zeta}{2Z_k}\right)\cos\left((2j-1)\frac{\pi\xi}{2R_k}\right)\end{aligned} \tag{4}$$

Here $\varepsilon^{*f}_{k}(\varsigma,\xi)$ is the inherent strain distribution, ζ, ξ, Z_k, R_k are local coordinates, A_{1k}, A_{ijk} are coefficients of inherent strain distribution, N=1,2,3 and k=0,1,2,3,4.

2. Test Pieces

Two kinds of test pieces welded in a butt joint were used: 300A welded pipe joint made of SUS316L with an outer diameter of 318.5mm and thickness of 33.3mm; and 500A welded pipe joint made of SUS316 with an outer diameter of 508.0mm and thickness of 50.0mm. The welding current and voltage were from 63 to 180 A and 20 V, respectively. Tungsten inert gas (TIG) welding was done without fixing the ends from 0° to 180°.

3. Results and Discussion

Figures 1 and 2 show the residual stress distributions for circumferential and axial stress on the inner and outer sides in the 0° - 180° cross section. A different bore changes the distributions of compressive and tensile stress. This is why the residual stress distribution is more complicated due to the change in magnitude of the bending deformation because the magnitude of thermal expansion and the shrinkage are different in the circumferential direction as the bore and wall thickness are each made larger.

Figures 3 and 4 show the residual stress distribution of the 300A welded pipe joint. The distributions calculated by using two functions with N=3 in Eq.(3) and Eq.(4) are very reliable based on statistical and mechanical standpoints [3]. However, more investigation is needed to determine the most reliable function. Additional functions with various N values are now being examined.

4. Conclusions

The results in this study were summarized as follows:

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† Received on 30 September 2010

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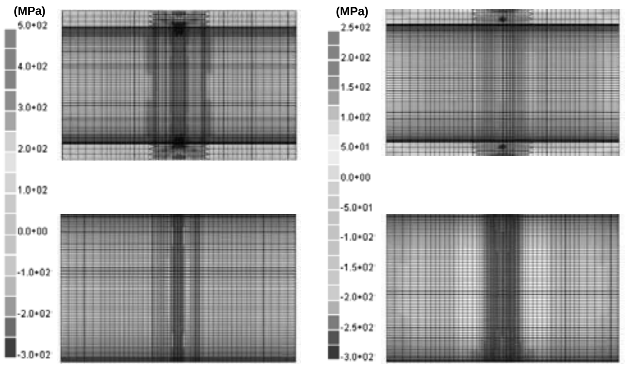
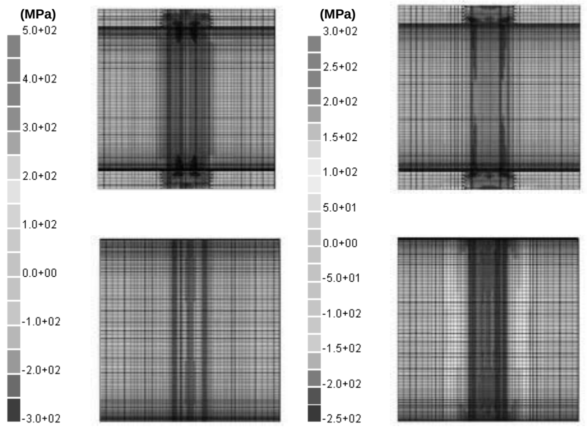
Transactions of JWRI is published by Joining and Welding Research Institute, Osaka University, Ibaraki, Osaka 567-0047, Japan



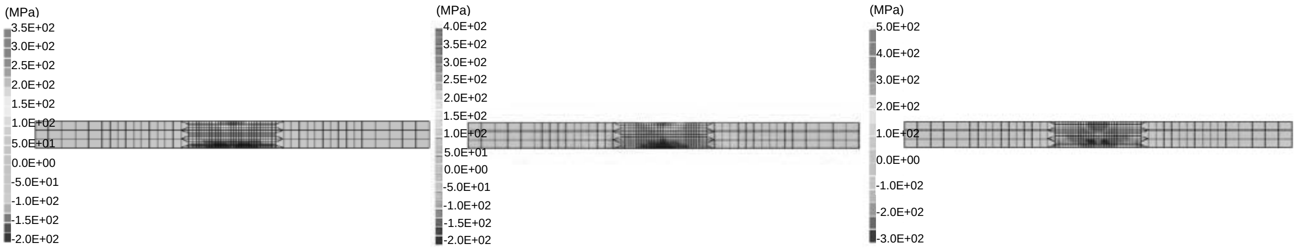
(a) Circumferential stress (b) Axial stress

Fig.1 Residual stress distribution of 300A welded pipe joint (0° - 180° cross section, function with N=3 in Eq.(3)).

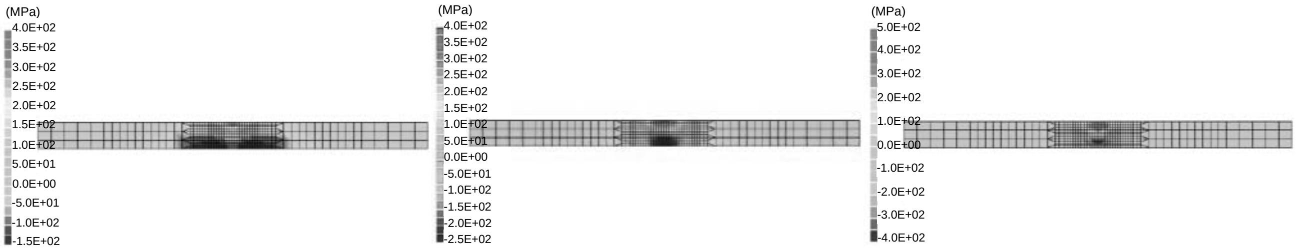


(a) Circumferential stress (b) Axial stress

Fig.2 Residual stress distribution of 500A welded pipe joint (0° - 180° cross section, function with N=3 in Eq.(3)).

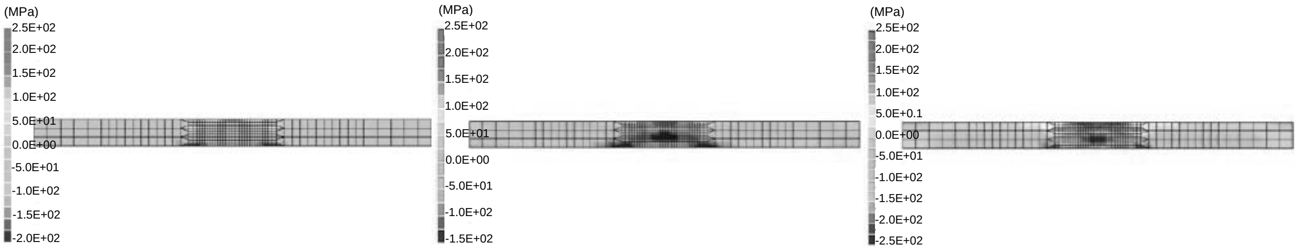


(a) N=1 in Eq.(3) (b) N=2 in Eq.(3) (c) N=3 in Eq.(3)

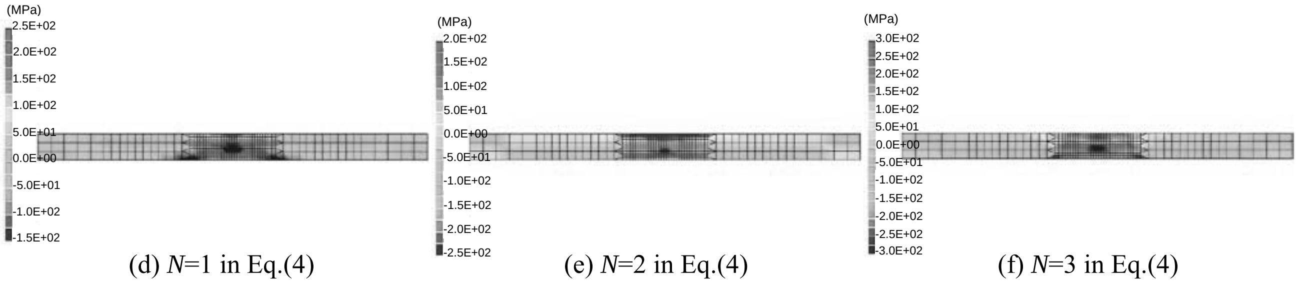


(d) N=1 in Eq.(4) (e) N=2 in Eq.(4) (f) N=3 in Eq.(4)

Fig.3 Circumferential residual stress of 300A welded pipe joint (90° cross section).



(a) N=1 in Eq.(3) (b) N=2 in Eq.(3) (c) N=3 in Eq.(3)



(d) N=1 in Eq.(4) (e) N=2 in Eq.(4) (f) N=3 in Eq.(4)

Fig.4 Axial residual stress of 300A welded pipe joint (90° cross section).

(1) The inherent strain method using functional form was applied to large-bore and heavy-walled stainless steel pipe with butt-welded joint.
(2) The shape of the stress distribution had a more complex change when the bore and thickness were larger.
(3) Six kinds of functions were examined to provide greatly reliable distribution of residual stress.

References

[1] Y. Ueda, K. Fukuda, K. Nakacho and S. Endo: J. Soc. Nav. Archit. Jpn., (1975), pp.499-507.

[2] Y. Ueda and N.X. MA: Quarterly Journal of JWS, 11 (1993), pp.189-195.

[3]K. Nakacho, N. Ogawa and T. Ohta: Quarterly Journal of JWS, 27 (2009), pp.297-306.