The University of Osaka
Institutional Knowledge Archive

Title	Mechanical Behaviors in Very Thick Welded Joint from Stress Relief Annealing Estimated by A Simple Specimen(Mechanics, Strength & Structural Design)
Author(s)	Nakacho, Keiji; Ueda, Yukio
Citation	Transactions of JWRI. 1989, 18(2), p. 259-265
Version Type	VoR
URL	https://doi.org/10.18910/10667
rights	
Note	

Mechanical Behaviors in Very Thick Welded Joint from Stress Relief Annealing Estimated by A Simple Specimen†

Keiji NAKACHO* and Yukio UEDA**

Abstract

A simple specimen for multipass butt welded joint of very thick plates was developed in this study to obtain the stresses and creep strains near the finishing few beads from stress relief annealing, where cold cracks and SR cracks might be produced. Approximate distributions of the stresses and creep strains can be calculated by a theoretical analysis or measured by an experiment, using the simple specimen. This method can make CPU time in the analysis very short and can make labor in the analysis or the experiment very little.

Moreover, the above approximate magnitudes of maximum stresses and strains are somewhat larger than the ones of the original joint, and so the cracks may be produced more easily in the simple specimen rather than in the original joint. Accordingly, the simple specimen is suitable for a cracking test.

KEY WORDS : (Simple Specimen) (Stress Relief Annealing) (Multipass Butt Welded Joint) (Stress) (Creep Strain) (SR crack) (Mechanical Behavior)

1. Introduction

The demand for a large capacity in nuclear reactors and chemical plants requires the use of high quality thick plates for a pressure vessel which is one of the main structural components of these plants. In the usual process of the construction, multipass welding and stress relief annealing (SR treatment) are utilized. These kinds of treatments may produce cold cracks and/or SR cracks. For this reason and others, information about transient and residual stresses produced by welding and SR treatment is very important.

To obtain the stresses, two kinds of methods are used, that is, an experiment and a theoretical analysis. In the case of very thick plates which are welded with many welding passes, it takes much labor to perform the experiment or it takes much CPU time to perform the analysis with a computer.

The authors had developed a simple specimen to save the time and labor[1]. Paying attention to the fact that cold cracks appear mainly at the weld metal and HAZ of the finishing few beads where large tensile residual stresses including the maximum are produced, the simple specimen for multipass butt welding was developed to obtain the stresses near the region. SR cracks appear at the almost same region. Thence, in this study, the same kind of simple specimen is used and the applicability for SR tretment is investigated.

2. Specimens and Conditions of Analysis

2.1 Simple Specimen

From the previous studies[2]-[4] on residual stresses of multipass butt welding, it was presumed that the residual stresses near the finishing bead are induced almost only by the finishing few welding passes. Based on the characteristic, a simple specimen like the one shown in **Fig.1(b)** was developed, and using the specimen, the almost same stress distributions as the original specimen were obtained in the weld metal and HAZ of the finishing few beads[1]. But the stress distributions in the other regions around there are different large or small. It may affect the changes of the stress distributions (the behavior of stress relief) near the finishing few beads during SR treatment after welding.

In this study, the same kind of simple specimen is used. The changes of the welding residual stresses during SR treatment are analyzed and the applicability of the simple specimen for SR treatment is examined. Moreover, the material and welding conditions are different between Ref.1) and this study, and so the applicability of the specimen for multipass welding is investigated more widely.

2.2 Specimens for analysis

Two long plates of 100 mm thickness and 195 mm width are welded with 10 mm groove width by multipass

(a) Standard specimen   (b) Simple specimen

Fig. 1 Specimens for analysis.

(a) Restraint condition A   (b) Restraint condition B
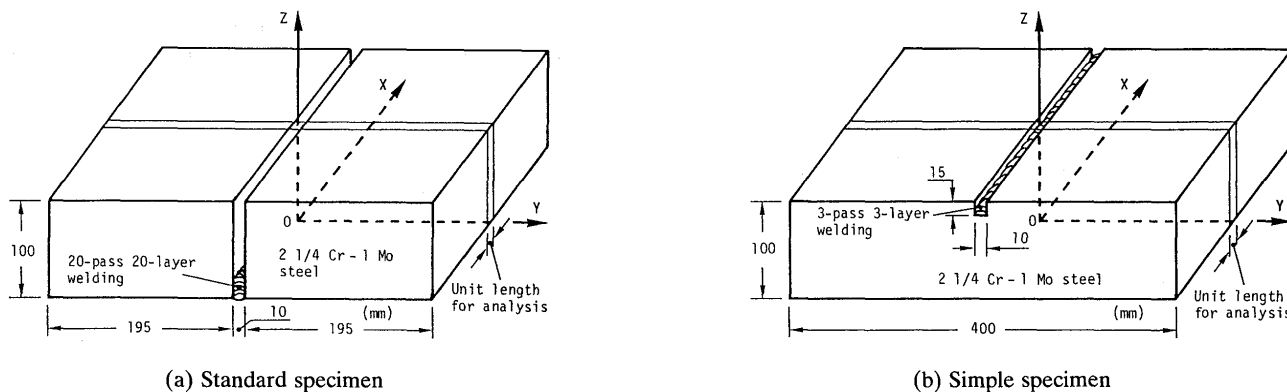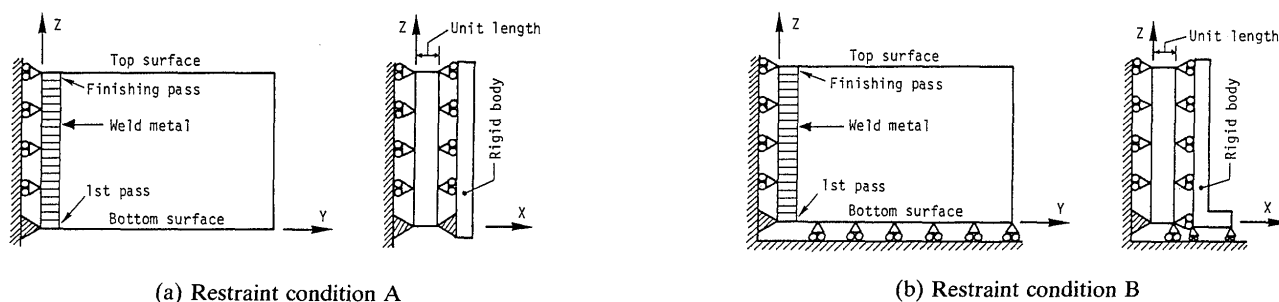
Fig. 2 Restraint conditions of specimens.

welding. The welding method is narrow gap arc welding and 20-pass 20-layer. This welded joint is called "standard specimen" and shown in **Fig.1(a)**. The "simple specimen" has the same dimensions as the standard specimen but the groove is processed only near the top surface and 3-pass welding is performed as shown in Fig.1(b). The material of the specimens is ASTM A336F22(2 1/4Cr-1Mo steel) and the wire used for welding is US521AxMF29A(made by Kobe Steel Co., Ltd.). Their physical and mechanical properties are indicated in Refs.2), 3) and 4), with the chemical compositions.

2.3 Conditions of welding and stress relief annealing

The welding conditions for all welding passes are the same, that is, the heat input is 35,000 J/cm and the heat efficiency is 0.9. The preheating and interpass temperatures are 200 °C.

The conditions of stress relief annealing for the welded specimens are as follows. The heating rate is 30 °C/hr. The heating maximum temperature is 650 °C, and at the temperature the specimen is held for 1 hour.

2.4 Restraint conditions of specimens and method of analysis

As the restraint condition of specimen, two conditions are adopted as shown in **Figs.2(a) and (b)**. In restraint condition A, no external restraint is loaded on the specimen. In restraint condition B, longitudinal bending deformation (rotation around Y-axis) and angular
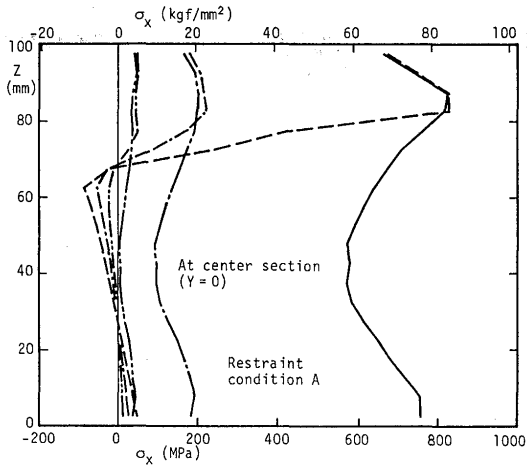
distortion (rotation around X-axis) are restricted. These restraint conditions are the two extreme restraint conditions for actual butt joint. On the other hand, the length of the specimen is sufficient long, and in such a case it is rational to assume that any YZ-plane in the specimen except near the both ends is allowed to move, remaining a plane (plane deformation). Based on the assumption, three-dimensional stress state is realized in thermal elastic-plastic-creep analysis.

The thermal elastic-plastic-creep analysis is performed by applying the finite element method, whose theory was developed by the authors[5),6)]. The analysis as a plane deformation needs only the same memory capacity and CPU time as two-dimensional analysis. In the analysis, the material properties of 2 1/4Cr-1Mo steel and the weld metal are necessary. They are shown in Refs.2), 3) and 4). The welding stresses of the specimen and the changes of them during SR treatment are analyzed continuously.
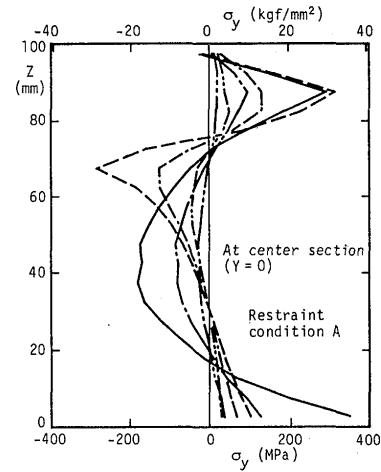
3. Analytical Results and Discussion

Cold cracks and SR cracks are produced in the weld metal and HAZ of the last few welding passes, being largely caused by longitudinal stress σ_x or transverse stress σ_y. So, attention is focused mainly on these regions and stress components.
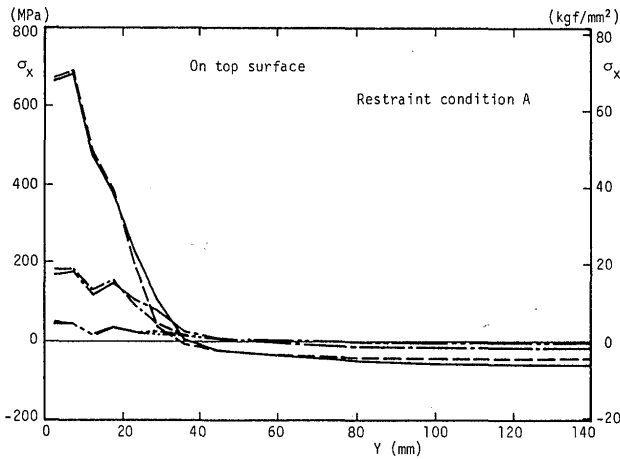
The analytical results for the standard spcimen and the simple specimen are shown and compared in Figs.3 to 7. **Table 1** shows the meanings of various kinds of lines in
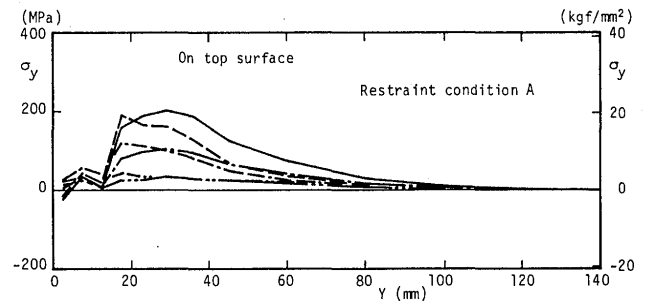
(a) Longitudinal stresses at center section

(b) Transverse stresses at center section

(c) Longitudinal stresses on top surface

(d) Transverse stresses on top surface

Fig. 3 Transient and residual stresses during welding and stress relief annealing under restraint condition A.

Table 1 Notation in Figs. 3~7

Time \ Specimen	Standard specimen	Simple specimen
As welded	——————	— — — — — —
At 575°C of heating stage	——— - ———	— —·—— ·——
After 1 hr. holding at 650°C	——— ·· ———	— —··—— —··—

these figures. They are common in Figs.3 to 7. **Figures 3 and 4** show the changes of the stress distributions during welding and SR treatment. Figure 3 is in the case of restraint condition A, while Fig.4 is in the case of restraint condition B. The (a) and (b) in these figures represent the distributions of σ_x and σ_y at the center section(Y=0). The (c) and (d) represent the distributions on the top surface(Z = 100 mm). **Figure 5** shows the distributions of equivalent creep strain $\overline{\varepsilon}^{\,c}$ at the center section produced during SR treatment. **Figures 6 and 7** represent the distributions of total strain increments $\Delta\varepsilon_x$ and $\Delta\varepsilon_y$ at the same section and same time as $\overline{\varepsilon}^{\,c}$, which are the changes of total strains during SR treatment.

3.1 Welding residual stresses

Welding residual stresses are indicated by solid lines for the standard specimen and broken lines without a dot for the simple specimen in Figs.3 and 4. For both restraint conditions and stress components, welding residual stresses near the finishing few beads obtained by using the simple specimen show the almost same distributions as the standard specimen. Especially, the magnitudes and locations of maximum tensile stresses of σ_x and σ_y almost agree between them. This result corresponds with the one in the study shown as Ref.1), whose material, sizes of the specimen, welding conditions etc. are different from those of this paper. These facts confirm that the welding residual stresses near the finishing few beads are produced only by the last few wedling passes, in most cases.

3.2 Transient and residual stresses, creep strains and total strains during stress relief annealing

The changes of welding residual stresses during stress relief annealing are indicated by broken lines with dots in
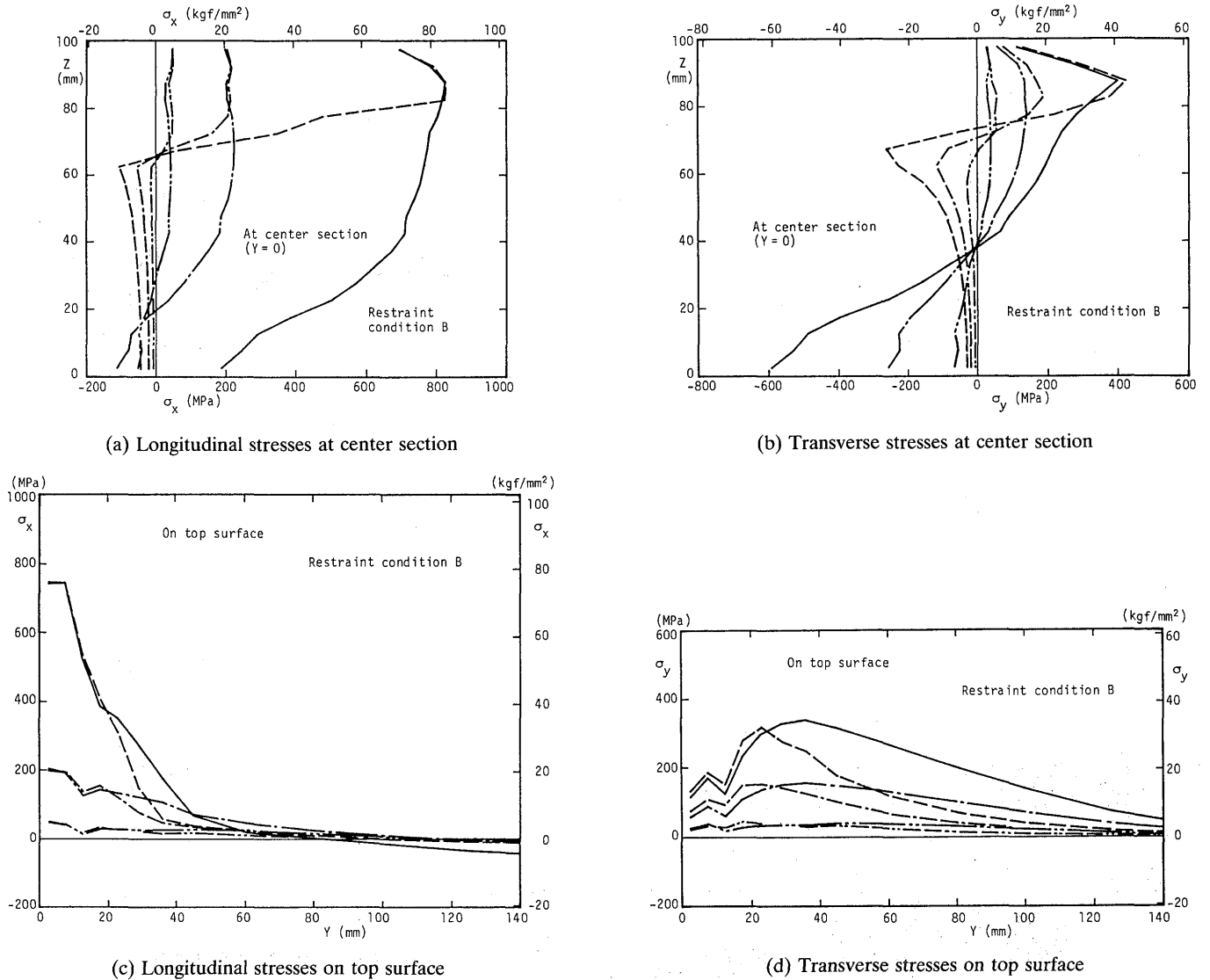
(a) Longitudinal stresses at center section

(b) Transverse stresses at center section

(c) Longitudinal stresses on top surface

(d) Transverse stresses on top surface

Fig. 4   Transient and residual stresses during welding and stress relief annealing under restraint condition B.

Figs.3 and 4. As regards the longitudinal stress σ_x, the largest stress component, near the finishing few beads, the approximate stress to the one in the standard specimen can be obtained by using the simple specimen, for both restraint conditions, like the welding residual stresses. On the other hand, the transverse stress σ_y near its maximum tensile location at the center section becomes different between the two specimens during SR treatment. The stress σ_y in the simple specimen is considerably larger than the one in the standard specimen. The mechanism of the behavior will be considered next.

The decrease of the stresses is considered to be caused mainly by the production of creep strains. Equations (1) and (2) are the relations between the respective components in the multi-axial stress state, during SR treatment.

$$\{\Delta\sigma\} = [D^e]\{\Delta\varepsilon^e\} \tag{1}$$
$$\{\Delta\varepsilon^e\} = \{\Delta\varepsilon\} - \{\Delta\varepsilon^T\} - \{\varepsilon^c\} \tag{2}$$

where $\{\Delta\sigma\}$:Stress increment during SR treatment

$[D^e]$:Elastic stress-strain matrix

$\{\Delta\varepsilon^e\}$:Elastic strain increment during SR treatment

$\{\Delta\varepsilon\}$:Total strain increment during SR treatment

$\{\Delta\varepsilon^T\}$:Thermal strain increment during SR treatment

$\{\varepsilon^c\}$:Creep strain produced during SR treatment

In order to discuss the behavior briefly, the term of temperature-dependency of $[D^e]$ and plastic strain increment $\{\Delta\varepsilon^P\}$ are neglected in Eqs.(1) and (2) respectively. The relation between stress increments and creep strains shown above is very complex in the three-dimensional stress state, and so, in this study, the equivalent creep strain $\overline{\varepsilon}^{\,c}$ is used as a representative value of produced creep strains. The distributions of the equivalent creep strain $\overline{\varepsilon}^{\,c}$ at the center section are shown
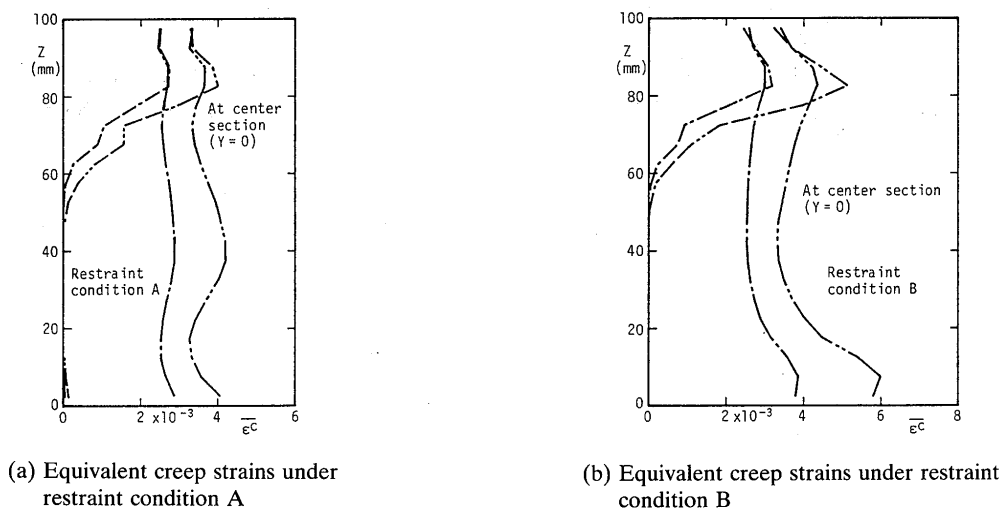
(a) Equivalent creep strains under restraint condition A

(b) Equivalent creep strains under restraint condition B

Fig. 5 Equivalent creep strains at center section during stress relief annealing.

(a) Longitudinal total strain increments

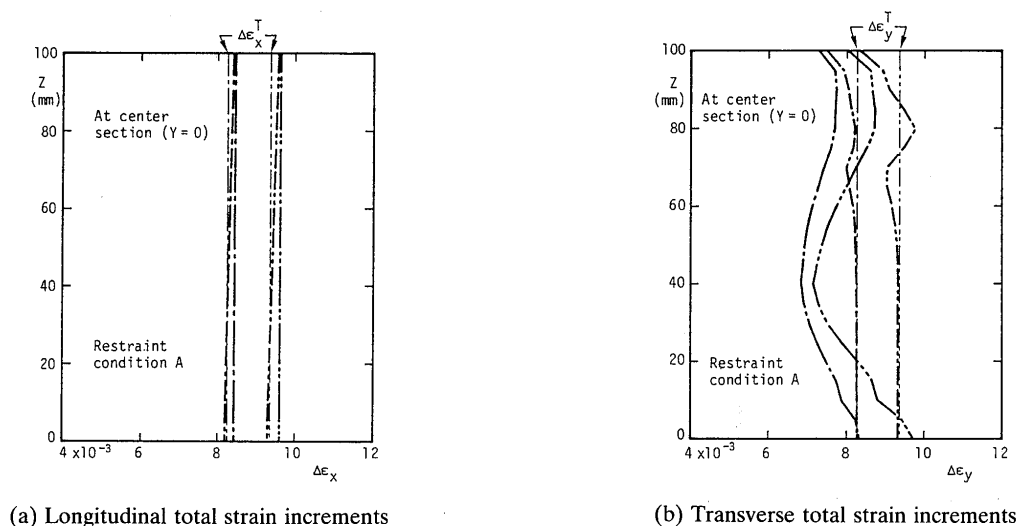(b) Transverse total strain increments

Fig. 6 Total strain increments at center section during stress relief annealing under restraint condition A.

(a) Longitudinal total strain increments
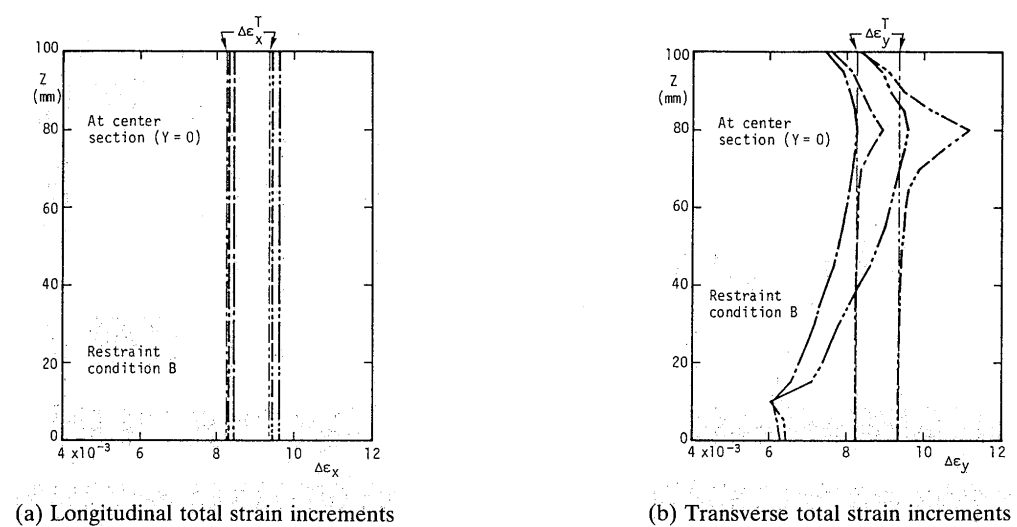

(b) Transverse total strain increments

Fig. 7 Total strain increments at center section during stress relief annealing under restraint condition B.

in Fig.5. The larger the value of the strain becomes, the larger the reduction of stresses becomes generally. In the figure, the larger magnitude of the strain is observed in the simple specimen rather than in the standard specimen, at the noting region. This result disagrees with the tendency of the decrease of stresses. Looking at Eq.(2) again, $\Delta\varepsilon$ and $\Delta\varepsilon^T$ have effect on $\Delta\varepsilon^e$, to add to ε^c. $\Delta\varepsilon^T$ is the same magnitude in the two kinds of specimens, and so $\Delta\varepsilon$ is investigated next.

Figures 6 and 7 show the distributions of $\Delta\varepsilon_x$ and $\Delta\varepsilon_y$ at the center section. $\Delta\varepsilon_x$ is almost the same magnitude as $\Delta\varepsilon_x^T$ and the difference between the two specimens is small in both restraint conditions. On the other hand, the distributions and magnitudes of $\Delta\varepsilon_y$ are largely different between the two specimens. In the half region of the bottom surface side, $\Delta\varepsilon_y$ in the simple specimen is the same magnitude as $\Delta\varepsilon_y^T$, but $\Delta\varepsilon_y$ in the standard specimen is remarkably smaller than $\Delta\varepsilon_y^T$. In the half region of the top surface side, the difference of $\Delta\varepsilon_y$ between the simple specimen and the standard specimen becomes small more or less but the tendency does not change. By the way, $\Delta\varepsilon^e$ in the left side of Eq.(2) has the minus value actually, which means the decrease of stresses in Eq.(1). Therefore, obviously from Eqs.(1) and (2), the larger in plus value $\Delta\varepsilon$ is, the smaller in minus value $\Delta\varepsilon^e$ and $\Delta\sigma$ are. It is considered that this behavior influences the reduction of σ_y significantly. As a result, the reduction of the stress σ_y in the simple specimen become smaller than the one of the standard specimen. The difference of $\Delta\varepsilon_y$ between the two specimens is caused by the difference of the distributions of the welding residual stresses. In the standard specimen, large stresses distribute in the whole center section(XZ-section), and so $\Delta\varepsilon_y$ caused by the stress relief is large not only in the region of the top surface side but also in the region of the bottom side. Integrated $\Delta\varepsilon$ becomes the displacement, and the displacement continues in the solid body unless a crack is produced. So $\Delta\varepsilon_y$ in the half region of the bottom side affects $\Delta\varepsilon_y$ in the half region of the top side. The reverse is also true. As a result, $\Delta\varepsilon_y$ in the region of the top surface side is different between the two specimens.

A summary of the above discussion can be explained as follows. About the longitudinal stress σ_x, the largest stress component, near the finishing few beads, the approximate stress to the one in the standard specimen can be obtained by using the simple specimen, like the welding residual stresses. On the other hand, the transverse stress σ_y near the region becomes different between the two specimens during SR treatment. The stress σ_y in the simple specimen is considerably larger than the one in the standard specimen. The equivalent creep strain $\overline{\varepsilon^c}$ also has the similar tendency to σ_y. That

is, the both magnitudes of stress and creep strain near the maximum location of welding residual stresses are the almost same between the two specimens or somewhat larger in the simple specimen. Accordingly, SR cracks may be produced more easily in the simple specimen rather than in the standard specimen, and so, by using the simple specimen and performing the theoretical analysis or the experiment, the result on safety side can be obtained with very short CPU time and/or a little labor.

4. Conclusion

In this study, a simple specimen for a very thick butt welded joint was examined, which was developed to obtain the distributions of residual stresses and creep strains near the finishing few beads by welding and SR treatment. The achievement is as follows.

Using the simple specimen and performing a theoretical analysis or an experiment, approximate magnitudes and locations of the maximum tensile stresses and creep strains by welding and SR treatment can be found out, which appear usually near the finishing few beads and cause cold cracks and SR cracks. This mathod can make CPU time in an analysis very short and can make labor in an analysis or an experiment very little.

Moreover, the above approximate magnitudes are somewhat larger than the ones in the standard specimen, and so the cracks may be produced more easily in the simple specimen rather than in the standard specimen. Accordingly, the simple specimen is suitable for a cracking test.

References

1) Y. Ueda and K. Nakacho : Simplifying Methods for Analysis of Transient and Residual Stresses and Deformations due to Multipass Welding, Trans. of JWRI, Vol.11, No.1, 1982, pp.95-103, and Quarterly J. of JWS (The Japan Welding Society), Vol.2, No.1,1984, pp.75-82 (in Japanese).

2) Y. Ueda, E. Takahashi, K. Fukuda and K. Nakacho : Transient and Residual Stresses in Multi-Pass Welds, IIW Doc. X-698-73, 1973, and Trans. of JWRI, Vol.3, No.1, 1974, and J. of JWS, Vol.44, No.6, 1975, pp.464-474 (in Japanese).

3) Y. Ueda, E. Takahashi, K. Fukuda, K. Sakamoto and K. Nakacho : Multi-pass Welding Stresses in Very Thick Plates and Their Reduction from Stress Relief Annealing, IIW Doc. X-850-76, 1976, and Trans. of JWRI, Vol.5, No.2, 1976, pp.179-189, and Proc. of Third Int. Conf. on Pressure

Vessel Technology (ASME), Part II, 1977, pp.925-933.

4) Y. Ueda, E. Takahashi, K. Fukuda, K. Sakamoto and K. Nakacho : Mechanical Behavior of Multipass Welded Joint during Stress Relief Annealing, J. of JWS, Vol.47, No.8, 1978, pp.500-506 (in Japanese).

5) Y. Ueda and T. Yamakawa : Analysis of Thermal Elastic-Plastic Stress and Strain during Welding by Finite Element Method, Trans. of JWS, Vol.2, No.2, 1971, pp.90-100, and

IIW Doc. X-616-71, 1971, and J. of JWS, Vol.42, No.6, 1973, pp.567-577 (in Japanese).

6) Y. Ueda and K. Fukuda : Analysis of Welding Stress Relieving by Annealing Based on Finite Element Method, IIW Doc. X-773-75, 1975, and Trans. of JWRI, Vol.4, No.1, 1975, pp.34-45, and J. of JWS, Vol.44, No.11, 1975, pp.902-908 (in Japanese).