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# Effects of Initial Imperfections on Out-of-Plane Deformation and Residual Stress Produced by Welding †

**You Chul KIM*, Jeong Ung PARK**, Yasumasa NAKANISHI***, Izumi IMOTO*** and Kohsuke HORIKAWA******

**Abstract**

*In this paper, the effects of initial imperfections (deflection and residual stress), which are necessarily produced when the steel plates are manufactured, on the out-of-plane deformation and residual stress generated by welding were elucidated from the results of the large deformation thermal elastic-plastic FEM modeling.*

*Residual stress, which was generated when the steel plates were manufactured, did not influence the out-of-plane deformation and residual stress produced by welding. However, initial deflection largely influenced the out-of-plane deformation produced by welding. When the temperature history was the same, transient deflection became a maximum at the same time irrespective of the initial deflection shapes. When the initial deflection shape was concave, the out-of-plane deformation became small near the weld line. However, the out-of-plane deformation in the perpendicular direction to the weld line depended on the initial deflection shapes. On the other hand, the out-of-plane displacement generated by welding when initial deflection wound in the welding direction became the smallest. As result, the out-of-plane deformation remained large because initial deflection remained as it was. When initial deflection wound in the direction perpendicular to the weld line, the out-of-plane deformation largely served to maintain the initial deflection shape. The distribution of residual stress and plastic strain generated by welding was affected by the initial deflection shapes. However, the magnitude was not largely affected.*

**KEY WORDS**: (Welding deformation)(Out-of-plane deformation)(Residual stress)(Plastic strain) (Initial imperfection)(FEM modeling)

## 1. Introduction

It has been known that the deformation and residual stress generated by welding influence the accuracy in manufacturing steel constructions and the various kinds of strength. So, it is necessary that the deformation and residual stress generated by welding can be predicted before welding, and that a system to control or to prevent them is constructed. This problem, with the reduction of skilled workers in manufacture, became one of the most important problems to be solved in the process of construction of welding structures.

In this paper, the effects of initial imperfections (deflection and residual stress), which are necessarily produced when the steel plates are manufactured, on the out-of-plane deformation and residual stress generated by welding are elucidated.

First, initial imperfections generated when the steel plates are produced are assessed. This is achieved by three-dimensional inherent stress analysis after non-conformable strain (inherent strain) is randomly distributed on the whole plate. Then, butt welding of the plate with initial imperfections obtained by three dimensional inherent stress analysis is modeled by thermal elastic-plastic FEM analysis of large deformations. Based on the analyzed results, the effects of initial imperfections on the out-of-plane deformation and residual stress produced by welding are elucidated.

## 2. Initial Imperfections with Steel Plate Manufacture

**Figure 1** shows the model for analysis. The plate length(L) is 600(mm), width(B) is 600(mm), and thickness(h) is 6(mm). Mild steel is assumed as the

† Received on December 8,1997
* Associate Professor
** Graduate Student
*** IHI Co., Ltd.
**** Professor
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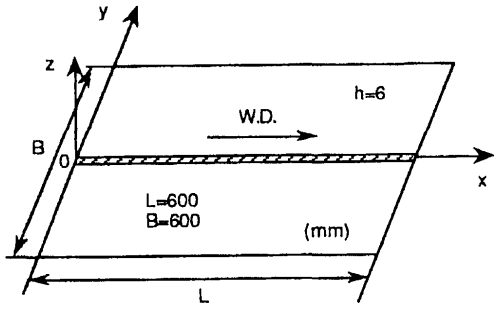



**Fig. 1** Model for analysis.

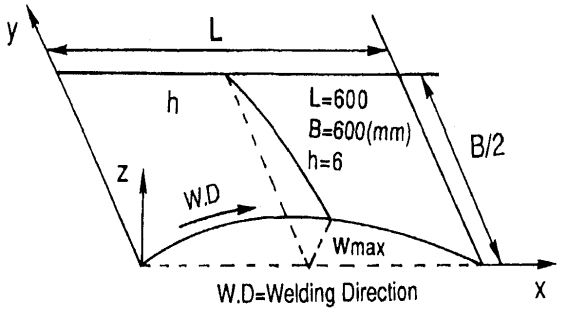
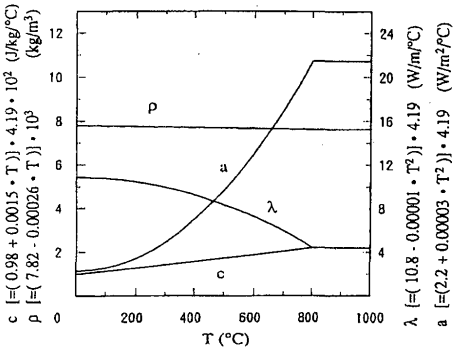
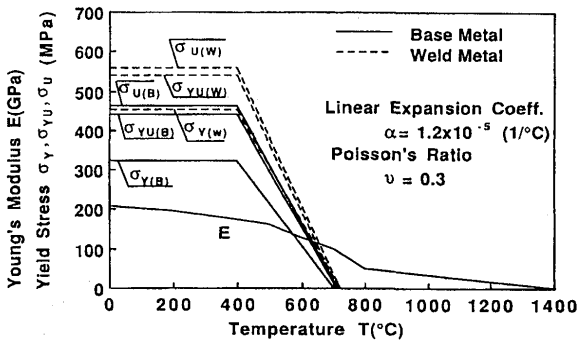



**Fig. 3** Out-of-plane deformation by rolling.

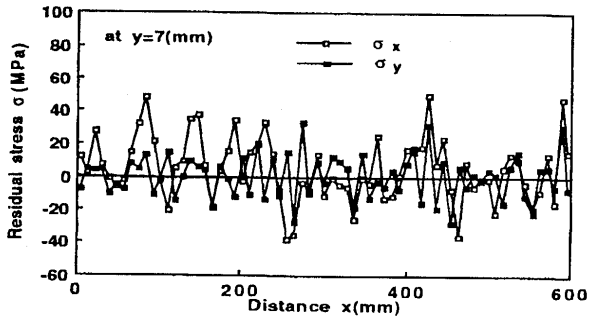



(a) Physical constants.




(b) Mechanical properties.

**Fig. 2** Materials properties.



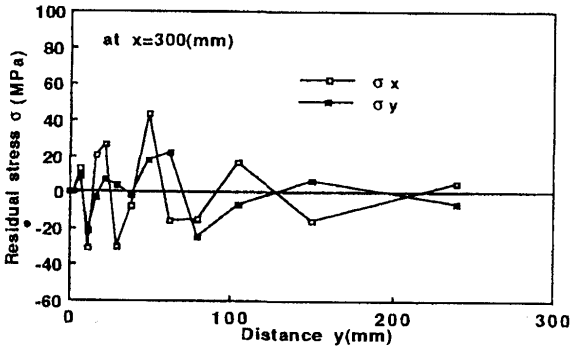




**Fig. 4** Residual stress produced by rolling.

material. **Figure 2** shows the temperature dependence of thermophysical constants and of mechanical properties.

Initial deflection and residual stress (hereinafter called initial stress) produced by steel plate manufacture are assessed by three-dimensional inherent stress analysis. Non-conformable strain is randomly distributed over the whole plate. **Figures 3** and **Fig. 4** show the assessed initial deflection and initial stress. Moreover, the magnitude of non-conformable strain is given so that the maximum of initial deflection and the maximum of initial stress become 5(mm) [1] and 50(MPa) [2], respectively.

## 3. Effects of Initial Stress on Out-of-Plane Deformation and Residual Stress Produced by Welding

In butt welding of the plates with initial deflection (Fig.3), thermal elastic-plastic FEM analysis is done, both in the case that initial stress is considered (Fig.4), and in the case that it is ignored. Then, the effects of initial stress on out-of-plane deformation and residual stress produced by welding are elucidated.

### 3.1 Model and temperature distribution

Welding is performed in the x-direction of the center of the model with an I-groove (Fig.1). Welding

condition are that heat input (Q) is 1140(J/mm) and welding speed(v) is 3(mm/s).

**Figure 5** shows one example of temperature distributions obtained by non-steady state heat conduction analysis. The same temperature history is used in thermal elastic-plastic stress analysis for all models considered in this research.

### 3.2 Effects of initial stress on out-of-plane deformation produced by welding

**Figure 6** shows the results of thermal elastic-plastic stress analyses. Whether initial stress exists or not, the out-of-plane displacements produced by welding coincide with each other. It is apparent that initial stress does not influence the out-of-plane deformation produced by welding.

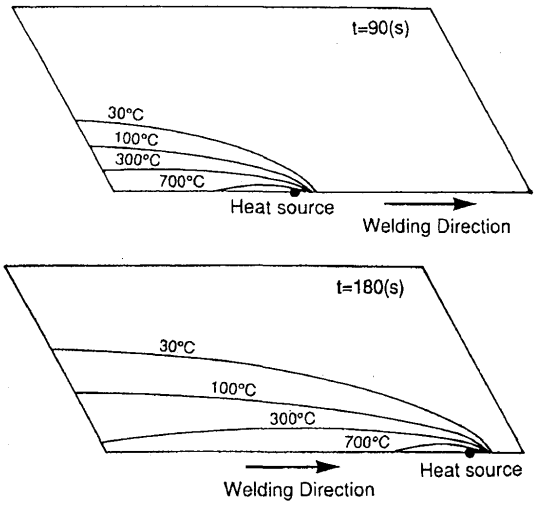



**Fig. 5** Temperature distributions.

### 3.3 Effects of initial stress on residual stress produced by welding

In butt welding, as shrinkage is consistently generated in the direction perpendicular to the weld line, the stress component $\sigma_y$ in this direction is small. Therefore, only the direction of the weld line is observed.

**Figure 7** shows the stress component $\sigma_x$ in the direction of the weld line. As the neighborhood of the weld line is heated to a high temperature and melted by welding, initial stress is at once released. Then, because stress is newly generated during the process of cooling and generates residual stress at room temperature, the neighborhood of the welded joint is not influenced by the initial stress. Contrary to this, although the plate is influenced by initial stress just as it is in the inner part of the plate far from welded line, initial stress does not influence residual stress produced by welding because the magnitude of initial stress is small.

From the above, it is apparent that initial stress, which is generated when steel plates are manufactured, does not influence the out-of-plane deformation and residual stress generated by welding.

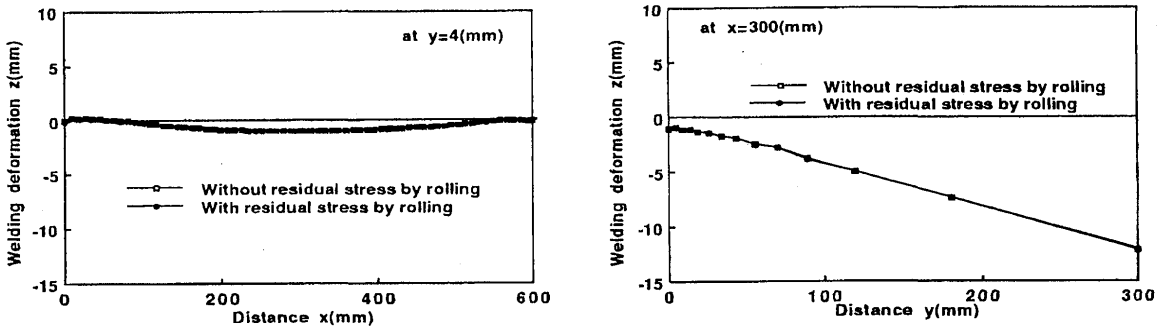



**Fig. 6** Displacement in z-direction produced by welding.

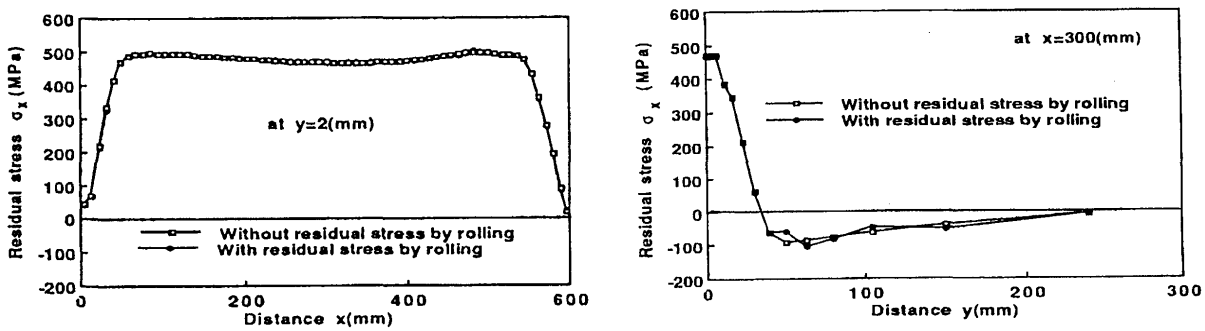



**Fig. 7** Residual stress produced by welding.

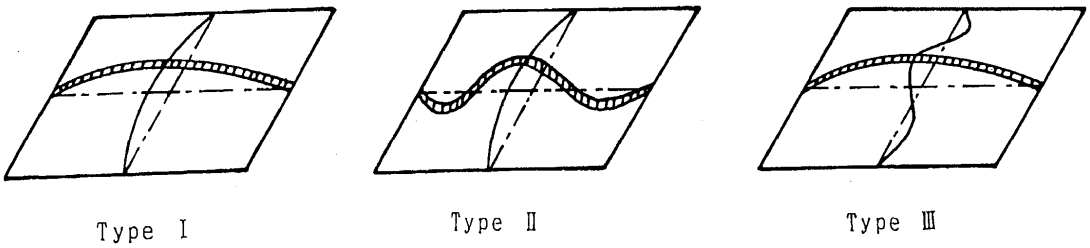
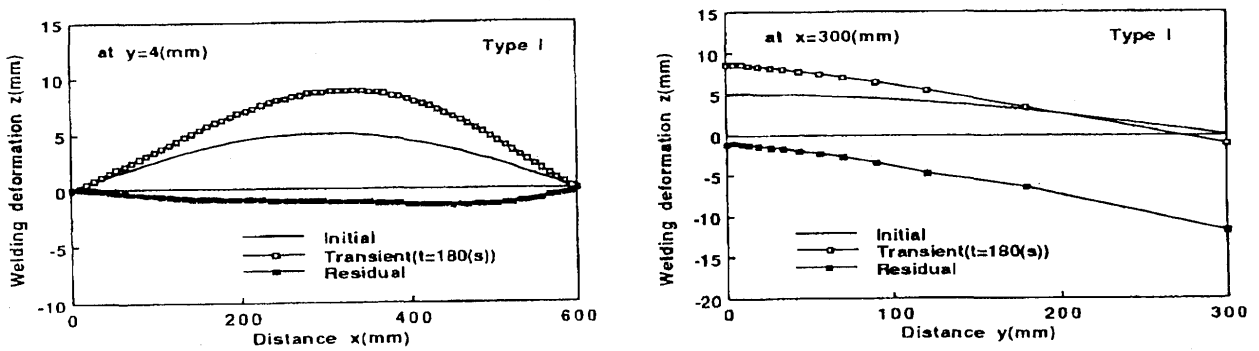
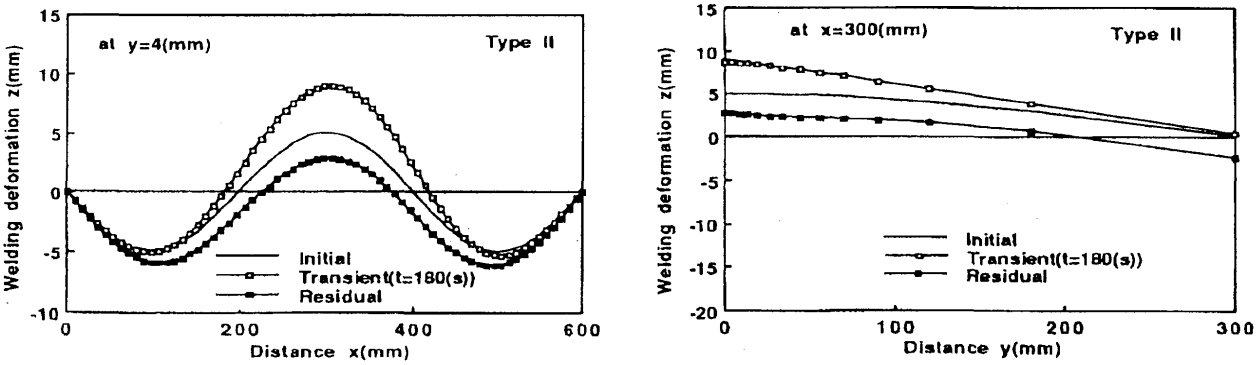


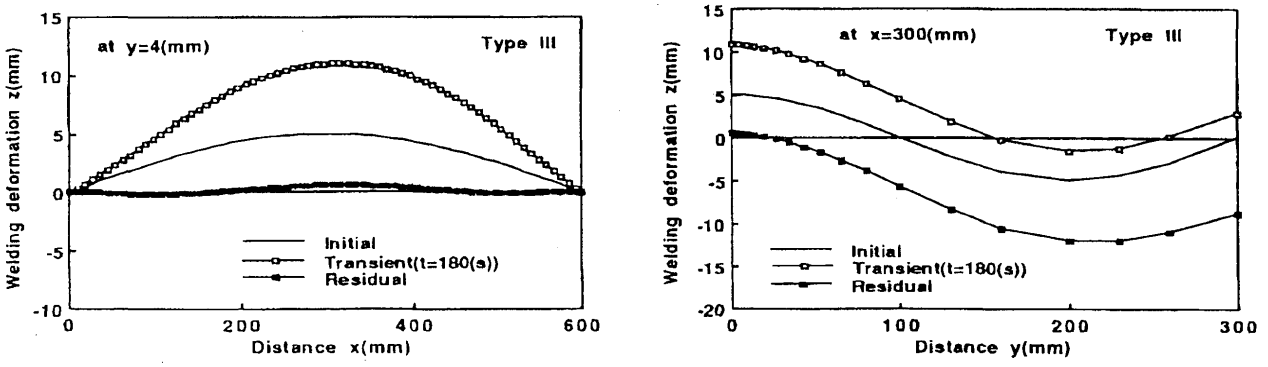

**Fig. 8** Configurations of initial deflection.




(a) Type I




(b) Type II




(c) Type III

**Fig. 9** Out-of-plane deformation produced by welding.

## 4. Effects of Initial Deflection on Out-of-Plane Deformation, Residual Stress and Plastic Strain Produced by Welding

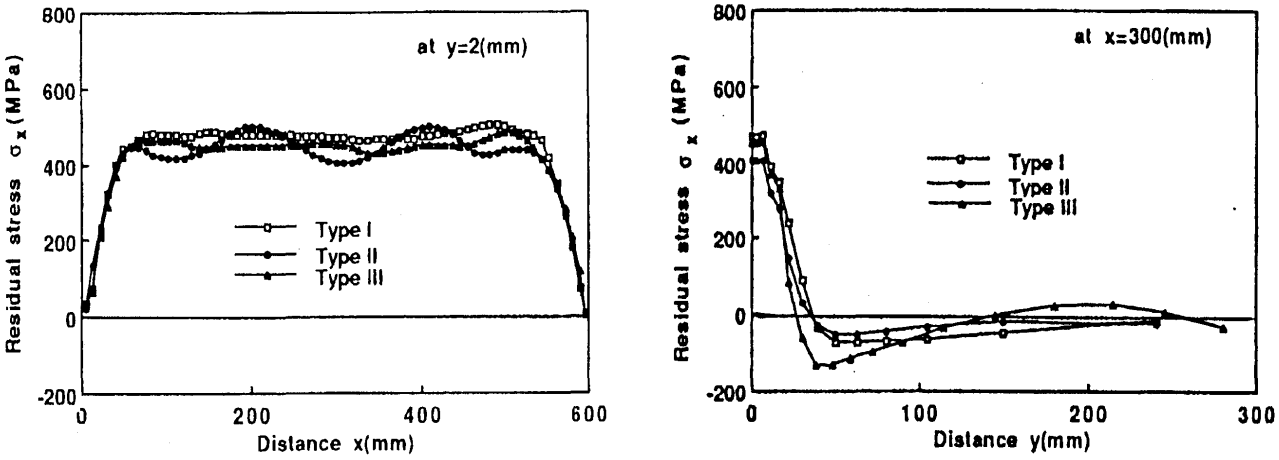
It was known that initial stress, which is necessarily generated when steel plates are manufactured, did not influence the out-of-plane deformation and residual stress produced by welding. So, here, initial stress is disregarded, and with the initial deflection shapes changed, the effects of initial deflection on the out-of-plane deformation, residual stress and plastic strain produced by welding are assessed.

### 4.1 Effects of initial deflection on out-of-plane deformation

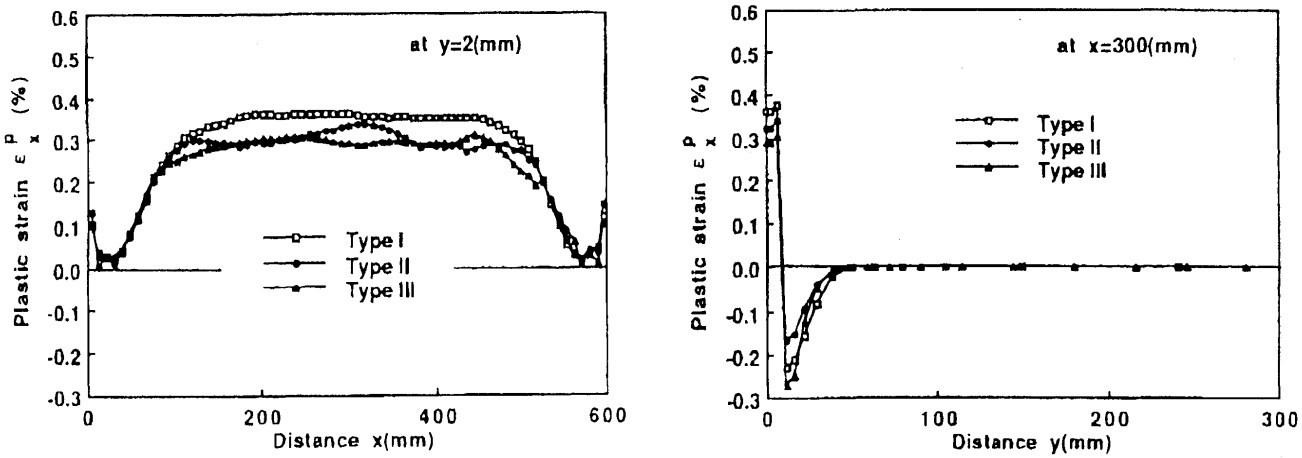
As shown in **Fig. 8**, initial deflection is assumed to exist as three types, with the maximum magnitude of initial deflection of ±5(mm).

**Figure 9** shows transient and residual components of the out-of-plane deformation on the weld line (y=0 (mm)) and at the middle of plate (x=300 (mm)) which are obtained by thermal elastic-plastic FEM analysis with the initial deflection shapes changed (Type I, Type II, Type III). The out-of-plane deformation produced by welding occurs in the direction to extend initial deflection from the beginning of welding to t=180 (s) in which initial deflection becomes a maximum irrespective of the initial deflection shapes. Then, it deforms in the direction to make initial deflection small. Although the initial deflection shapes are different, there is no significant difference in the tendency for deformation, but the magnitude of the out-of-plane deformation is different.

Noting the out-of-plane displacement (the difference between residual deformation and initial deflection) in the direction of the weld line, the tendency of




(a) Residual Stress.




(b) Plastic Strain.

**Fig. 10** Distributions of residual stress and plastic strain.

displacement is the same irrespective of the initial deflection shape in the direction of the weld line. However, the magnitude of the out-of-plane displacement is different. The magnitude is smaller in the order, Type II, Type III and Type I. Including the total displacement and the transient state, the magnitude is smaller in the order, Type II, Type I and Type III. When initial deflection winds in the direction of the weld line (Type II), the out-of-plane displacement is small because the direction of the out-of plane displacement is different at the position on the weld line.

On the other hand, noting the out-of-plane displacement in the direction perpendicular to the weld line, the tendency of displacement is different according to the initial deflection shape in this direction. The tendency of displacement in Type I differs from that in Type II and Type III. Type III in which initial deflection winds in the direction perpendicular to the weld line has the out-of-plane displacement maintaining the initial deflection shape in this direction.

From the above, it was confirmed that the initial deflection shapes largely influence the out-of-plane deformation. In Type I, the out-of-plane deformation becomes small near the weld line and large at the free edge of the plate. The out-of-plane displacement in Type II produced by welding is small. However, initial deflection remains as it is, and then, the out-of-plane deformation remains large. In Type III, the out-of-plane deformation becomes small near the weld line, as in Type I. However, it is large at inner parts of the plate.

### 4.2 Effects on residual stress and plastic strain

In welding with no difference of temperature in plate thickness, production factors of deformation, residual stress and plastic strain produced by welding involve expansion and shrinkage in the direction of the weld line and in the direction perpendicular to the weld line. Among them, the expansion and shrinkage in the direction of the weld line are the more important factors. So, residual stress and plastic strain in the direction of the weld line are examined as follows.

*4.2.1 Residual stress*

**Figure 10**(a) shows the stress component $\sigma_x$ in the direction of the weld line. The distribution of residual stress is influenced by the initial deflection shape. However, the magnitude of residual stress is not significantly different.

*4.2.2 Plastic strain*

Figure 10(b) shows the plastic strain component $\varepsilon^p_x$ in the direction of the weld line. It is apparent that $\varepsilon^p_x$ is generated only near the welded joint and its magnitude is not largely affected by the differences of the initial deflection shapes.

Based on these facts, it can be concluded that differences in the initial deflection shapes do not largely influence residual stress and plastic strain generated by welding.

## 5. Conclusion

The effects of residual stress (initial stress), which is produced when steel plates are manufactured, on deformation and residual stress generated by welding were investigated. The results can be summarised as follows:

(1) Initial stress does not influence the out-of-plane deformation generated by welding. On the other hand, in the residual stress generated by welding, the neighborhood of welded joints is not affected by initial stress but the inner part of the plate far from welded joints is affected by initial stress. However, since the absolute value of initial stress is small, it is concluded that initial stress does not influence residual stress generated by welding.

The effects of the initial deflection shapes on the out-of-plane deformation, residual stress and plastic strain were also investigated.

(2) When the temperature history is the same, transient deflection becomes a maximum at the same time irrespective of the initial deflection shapes.

(3) The initial deflection shapes largely influence the out-of-plane deformation generated by welding. When the initial deflection shape was concave (Type I and Type III), the out-of-plane deformation became small near the weld line. However, the out-of-plane deformation in the direction perpendicular to the weld line depends on the initial deflection shapes. On the other hand, the out-of-plane displacement generated by welding when initial deflection winds in the welding direction (Type II) becomes the smallest. The out-of-plane deformation remains large because the initial deflection remains as it is. When initial deflection winds in the direction perpendicular to the weld line (Type III), the out-of-plane deformation occurs and maintains the initial deflection shape.

(4) The distribution of residual stress and plastic strain generated by welding is affected by the initial deflection shapes. However, the magnitude is not large.

### Reference

1) H. Mano, H. Kawabe, K. Masaoka and T. Ito :Statistical Characteristics on the Compressive Ultimate Strength of Deck Panels, Journal of the Kansai Society of Naval Architects, Vol.21, 1990(145-156) (in Japanese).

2) K. Horikawa, K. Isimoto : TMCP steel applied to a bridge, Report of JWRI, 1987 (in Japanese).