COMPUTER-AIDED IDENTIFYING REMOVAL PROCEDURE FOR POST-WELDING DISTORTION OF STIFFENED PLATE PANELS (REPORT-1)-CHARACTERISTICS OF REMEDIAL STRAIN

Ahmed M. Rashwan and Yehia A. Abed El-Nasser
Naval Architecture & Marine Engineering Department, Faculty of Engineering,
Alexandria University, Alexandria, Egypt.

ABSTRACT

Welding deflection of stiffened plate panels is an inevitable distortion in fabricating the ship hull plating. This kind of undesired out-of-plane distortion can be removed through creating counter-distortion by a proper removal process. To have an efficient distortion removal process, using the flame straightening method, necessary information about appropriate heating positions and heating conditions are required in advance. Most of these information can be obtained from the counteracting strain field producing the necessary counter-distortion. This paper is devoted to study the characteristics of the counteracting strain which is called here the remedial strain. The counter-distortion for a plate panel is determined by simple simulation for the welding deflection. Then the counteracting strain, i.e. the remedial strain, can be obtained from that counter-distortion. The practicable type of the remedial strains, bending and/or inplane, that can be created by the flame straightening method have been discussed. The relation between the welding deflection shape and the remedial strain has been clarified. The effects of the plate dimension and the maximum deflection on the remedial strain are examined. The finite element method is employed for this purpose.

Keywords: Welding deflection, Distortion removal process, Remedial strain, Finite element method.

1. INTRODUCTION

It is well known that the deflection due to the welding process is an inevitable distortion in fabricating stiffened plate panels of ship's hull. This kind of undesired distortion deteriorates the compressive strength of plates as well as the smoothness of the hull surface. There are different techniques that can be applied to remove undesired distortion such as the flame-heating, the vibratory stress-relieving, and the electromagnetic-hammer techniques [1]. The flame heating technique, which is called the flame straightening method, is the most common distortion removal technique applied in shipyards.

The undesired post-welding distortion of stiffened plate panel can be removed by creating counter-distortion using proper distortion removal process. When the flame straightening method is used as a removal process, plastic deformation producing counter-distortion is created. For this purpose, information about the heating position and heating condition producing the necessary counter-distortion should be known in advance. Most of these information can be determined from the counteracting strain field which produces the necessary counter-distortion. However, the heating process is considered a complex one due to the nonlinear behaviour of the plate material during the heating and cooling cycles. It needs many years of experience that are normally required from skilled craftsman for distortion removal. In order to provide a recover for skill, different techniques can be made such as simulation technique using finite element method. However, available information about the straightening process for stiffened plate panels is too little [1-2].

Utilizing the facility of the great advance in the computer technology, computer-aided identifying removal procedure for welding deflection of stiffened plate panels can be achieved. As a first step, this paper is devoted to study the characteristics of the counteracting strain field which produces the necessary counter-deflection. It is called here the remedial strain. The counter-distortion for a plate panel is determined by simple simulation for welding deflection. Then, the remedial strain field can be obtained for this distorted plate. The practicable type of the remedial strains, bending and/or inplane, that can be obtained using the flame straightening method is discussed. The relation between the welding deflection shape and the necessary remedial strain to be given to the distorted plate has been clarified. The influences of the plate dimension and the maximum deflection on the remedial strain are examined. For this purpose, the finite element method is employed.

2. ANALYSIS OF REMEDIAL STRAIN

2.1. *Source of welding deformation*

During welding, the region near the weld line is affected by the heat input through the molten weld metal and transient thermal stress and deformation occur in the weldment. After completing the welding process, post-welding deformation and residual stress take place in the stiffener and the plate. As a result from the heating and cooling cycle, compressive plastic strain in the heat affected zone (HAZ), as shown in Figure (1), is produced. The created compressive plastic strain in the plate is the main source for the welding deformation of the plate panel. Therefore, the ideal situation to remove the post-welding distortion is to produce an opposite plastic strain at the same position. That means, tensile component of plastic strain eliminating the compressive plastic strain must be produced at the same position. In this case, the deformation as well as the residual stress of the stiffened plate panel, due to the welding process, intuitively will disappear. However, producing such tensile plastic strain distribution at HAZ cannot be achieved using any available techniques. Thus, to remove the welding deformation another counter-loading should be obtained through the known counter-deformation. This trend is commonly applied in removing the excessive distortion using any available process.

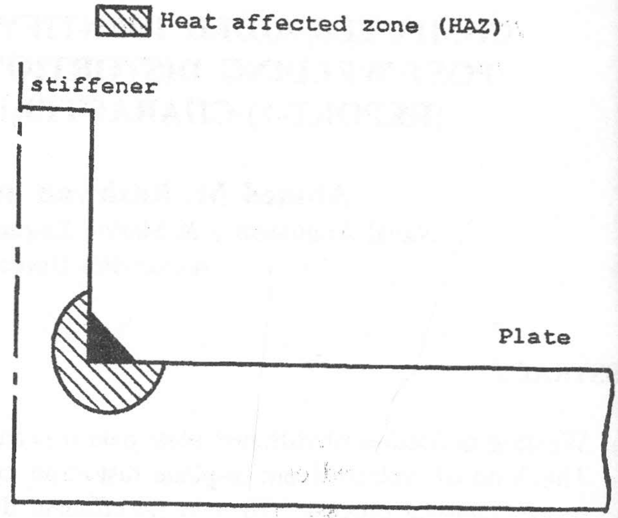


Figure 1. Schematic representation for the heat affected zone HAZ.

2.2. *Application of counter-deformation*

To discuss the counter-deformation, the welding deformation should be known at first. However, making prediction for the post-welding deformation of plate panel needs a thermo-mechanical analysis which is rather time consuming. Consequently, it is convenient to get the plate deformation through similar kind of loading for the plastic strain to examine the counter-deformation. This can be obtained by applying an initial strain to a flat plate in the proper position. Since the heat affected zone is located at the edges of the plate panel, the positions for the applied initial strain are assumed to be located as shown in Figure (2). When the initial strain is applied to the flat plate, then the plate will deform to a certain deformation shape. This simply simulates the deformation of plate due to the influence of an internal loading which is similar to that of the welding process. Instead of applying opposite strain to that of the initial strain in the same previous position, counter-deformation, which is equal in magnitude to that obtained previously but in opposite direction, is applied to the deflected plate. This means that the plate is forced to deform in the opposite direction until the deformation is vanished. Thus, the strain produced in a flat plate deformed to the desired counter-deformation is considered to be the required remedial strain. This simulation is performed using elastic-perfect-plastic plate finite element code with large deformation [3]. The material behaviour of the plate is assumed to be elastic throughout the analysis.

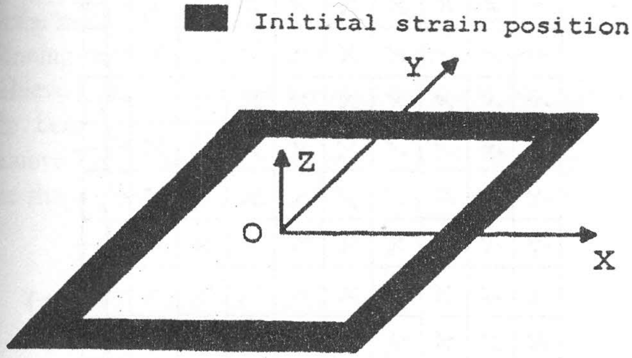


Figure 2. Position for assumed initial strain.

2.2.1. *Example model*

A simply supported square plate of dimensions 1000X000XS mm is considered to examine the characteristics of the remedial strain. The initial strain is applied to the plate in the equal strips, shown in Figure (2). The effective plastic strains due to the welding process are compressive components in *x* and *y* directions with negligible influence of the plastic shear strain. The distribution of each component through the thickness depends on the dimensions of stiffened plate panel as well as the welding conditions. For simplicity, the components of the initial strain are assumed to be equal with negative megnitude and to have a uniform distribution in x and y directions for the considered stripes. On the other hand, the distribution through the thickness is assumed to be linear.

The deformation of the plate due to applying the assumed initial strain is computed using the FEM. From symmetry, only one quarter is considered in the computation and the mesh division employed is shown in Figure (3). The computed deflection surface due to applying the initial strain is shown in Figure (4). It can be noted from this figure that the obtained deflection shape along x and y axes is typical due to applying equal components of initial strain in the strips. When the distorted plate is forced to deform in the opposite direction until the deformation is vanished, the strain field in the plate becomes zero except the existing initial strain in the strips. This is done by applying forced lateral displacement which is proportional to the displacement at each node in an incremental manner.

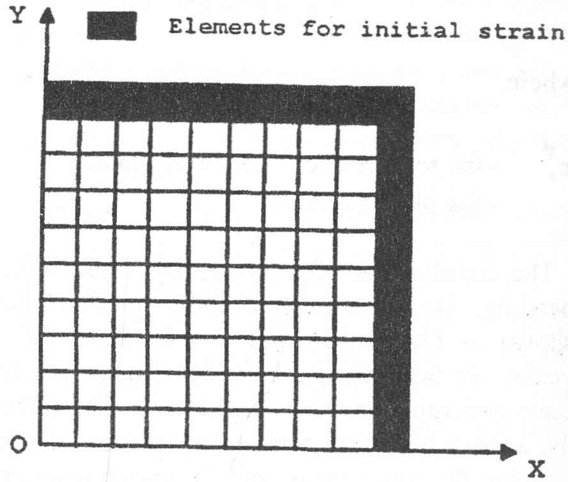


Figure 3. Mesh division (one quarter).

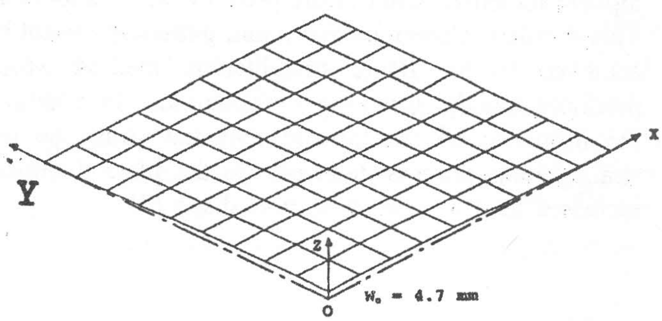


Figure 4. Defection shape of distorted plate due to assumed initial strain.

In this process, the opposite components of the displacements, *u* ,*v* and *w*, computed previously are used as the counter-deformation. Thus, the remedial strain for the distorted plate can be determined by forcing the flat plate to deform to the required counter-deformation. The computed strain inherent for this counter-deformation is the required remedial strain.

2.2.2. *Bending and inplane remedial strains*

Two types of the remedial strain, bending (ε_r^b) and inplane (ε_r^m) can be determined at any point in the plate domain according to the following equations:

$$\varepsilon_r^m = \frac{1}{t}\int_{-t/2}^{t/2} \varepsilon_r^T dZ$$

$$\varepsilon_r^b = \varepsilon_r^T - \varepsilon_r^m \qquad (2)$$

where,

ε_r^T =the total remedial strain at point.
t =the plate thickness.

The distributions of the remedial strain, inplane and bending, are determined for the previous model as shown in Figures (5) and (6). In these figures, the vectors of the principal remedial strains are drawn to scale according to their magnitudes. The direction of the arrow's head for each vector, in-and-out directions, refers to the compressive and the tensile components of the remedial strain, respectively. It is clear from figure 5 that, outside the initial strain position, the tensile inplane remedial strain is the predominant component. This tensile inplane remedial strain generally cannot be achieved by the flame straightening method which produces mainly shrinking deformation. In addition, the influence of the inplane remedial strain on the straightening process decreases as the plate thickness increases for the same distortion shape [3].

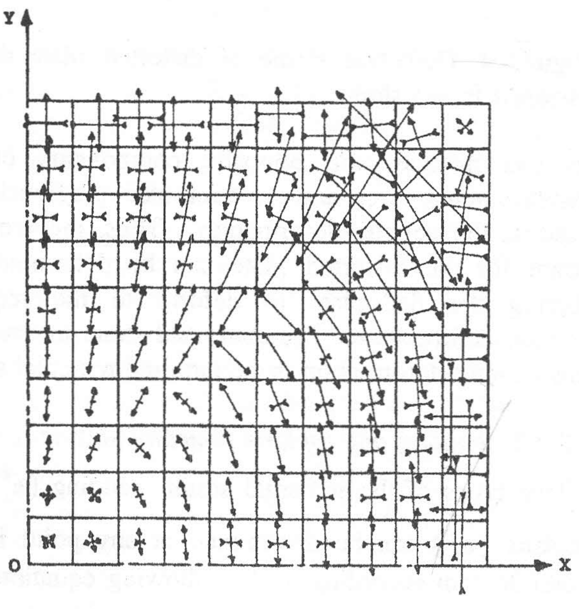


Figure 5. Inplane remedial strain distribution due to counter-deformation.

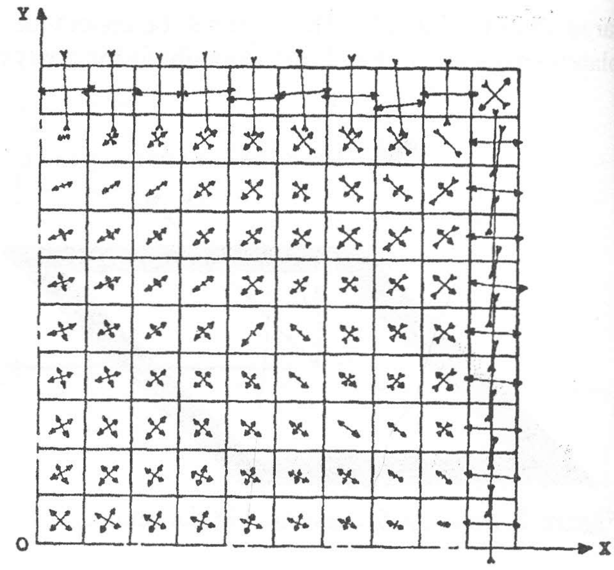


Figure 6. Bending remedial strain distribution due to counter-deformation.

On the other hand, for the bending remedial strain, the heating process must be applied on the convex side of the plate surface to remove the bending distortion. Hence, the bending remedial strain can be considered as the practicable type of remedial strain which can be applied to remove the excessive deflection of stiffened plate panels when the flame straightening method is used. This conclusion is in agreement with the real practice of the flame straightening method. When the plate buckles due to the welding process, the flame heating technique cannot be applied to remove buckling distortion. This is because dominant tensile component of the inplane remedial strain is necessary to eliminate this kind of distortion.

2.3. *Application of deflection shape*

As long as the bending remedial strain is considered the practicable one in the removal process, the shape of welding deflection, only the displacement in z direction, can be used to get it. The previous plate model is used to examine the usefulness of this procedure. The plate is forced deformed to the same deflection shape achieved by the initial strain. The computed bending remedial strain distribution using the deflection shape is shown in Figure (7). It is obvious that the computed bending remedial strain is exactly the same as that obtained from applying the initial strain shown in Figure (6) except a slight change in the strips. Therefore, although only the shape of welding deflection is used, the resulting bending remedial strain is the same. This agrees with the real practice of plate forming in which the same deflection shape can be achieved using different forming methods [4]. Thus, the bending remedial strain which is necessary to remove excessive deflection can be obtained using only the shape of welding deflection.

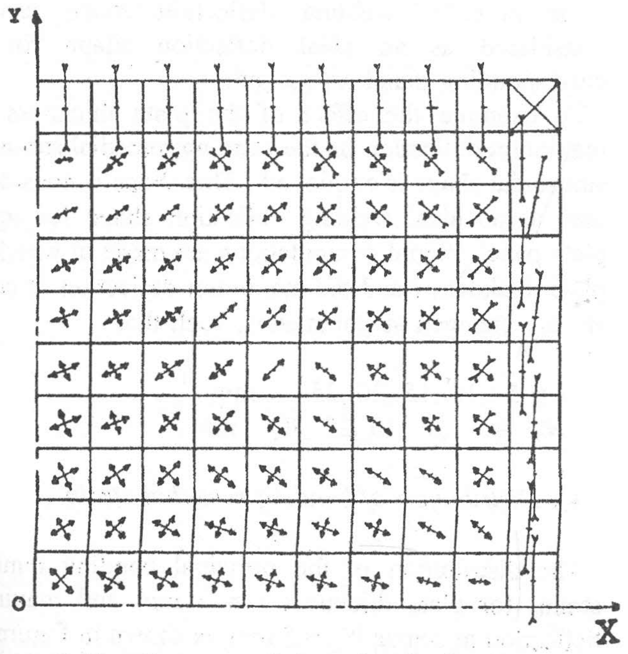


Figure 7. Bending remedial strain distribution due to deflection shape.

3. SHAPES OF WELDING DEFLECTION

As mentioned previously, the shape of welding deflection is of primary importance in computing the necessary bending remedial strain. It depends mainly on the distribution and magnitude of the plastic strain created in the heat affected zone in the plate during the welding process. The created plastic strain during the welding process depends mainly on the following three factors:

i) welding conditions such as the heat input power, type and size of electrode, size of fillet weld or weight of deposited metal and number of passes.

ii) dimensions of plate panel, such as the plate thickness *t* and aspect ratio of the panel a/b, the mechanical and the thermal properties of the material such as yield stress, young's modulus and thermal diffusivity.

iii) constraint conditions, including the welding sequence, size, shape and arrangement of restraining members, etc. Consequently, the welding deflection shape of stiffened plate will depend mainly on the previous mentioned factors too. Although the mechanism of welding deflection of stiffened plate has been established, a precise prediction for the welding deflection shape of plate panels is considered a protracted computing time.

Several measurements were carried out to investigate the characteristics of post-welding deflection of plate panels for ship's hull [5-9]. From the analysis for the measurements it was concluded that the deflection shape of plate panels can be classified according to the plate aspect ratio into four shapes. These four shapes are ranging from sinusoidal to multiwave pattern such that [9]:

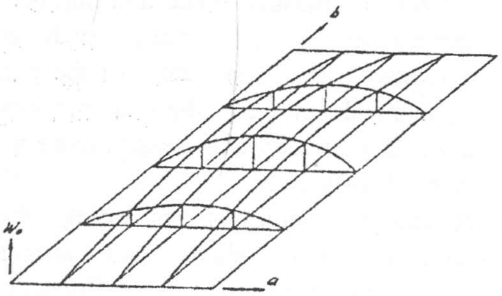
a- *Sinusoidal shape for plates with small aspect ratios* a/b = 1 ~ 1.41 with one lobe along the breadth and the length as shown in Figure (8-a).

b- Dished shape for a/b = 1.41 ~ 2.45 with one lobe in breadth, as shown in Figure (8-b).

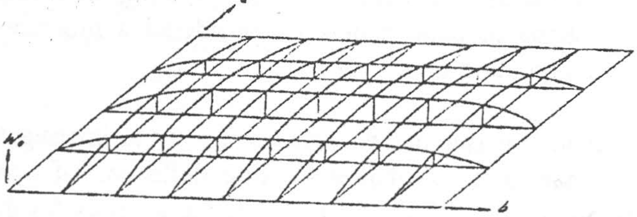
c- Horse shape for a/b = 2.45 ~ 3.46 as shown in Figure (8-c).

d- Multiwave shape for a/b > 3.46 which is dominant in length direction as shown in Figure (8-d).

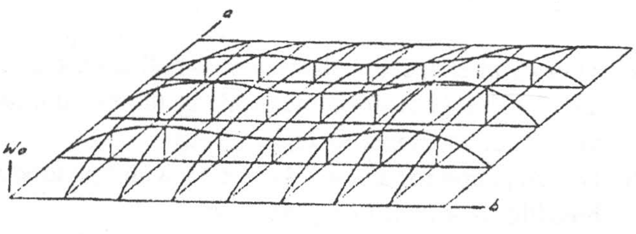
These different shapes nearly covers different parts of the ship's hull such as shell plating, deck plating and hatch covers for product and bulk carriers of different deadweights [9]. However, the magnitude of the maximum deflection will vary according to the plate thickness, the welding condition as well as the condition of constraint.



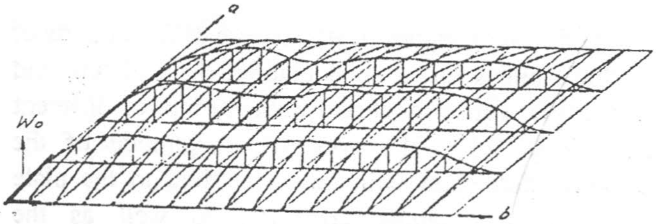
(a) Sinusoidal shape.



(b) Dished shape.



(c) Horse shape.



(d) Multiwave shape.

Figure 8. Shapes of welding deflection of plate panel [9].

4. IDEAL DEFLECTION SHAPE

As a matter of fact, typical shapes for welding deflection will not occur even for the same plate panel dimensions. This is due to the wide range of parameters such as the welding conditions, constraint conditions as well as the welding sequence. There will be a difference in the resulting deflection shape which can be identified for each shipyard. Utilizing the statistical analysis for the measurements of welding deflection shape, the most probable shape for each aspect ratio can be determined. Consequently, this most probable welding deflection shape can be considered as an ideal deflection shape for the corresponding panel aspect ratio.

To examine the effect of the plate thickness and maximum deflection on the bending remedial strain, the sinusoidal shape is employed. This shape is considered here as an ideal welding deflection shape for square plate panel. Serial computations are made in which the plate thickness t and the maximum deflection at center W_o are changed as parameters, such that

$t = 5$,10 ,15 ,20 ,25 mm.
$W_o = 1$,5 ,10 ,20 ,30 mm.

4.1 *Distribution of bending remedial strain*

The distribution of the principal bending remedial strain, for plate thickness $t = 5$ mm and maximum deflection at center $W_o = 5$ mm, is shown in Figure (9). If the plate thickness t is changed while the maximum deflection W_o is kept constant, the distribution of the bending remedial strain will be the same. On the other hand, the magnitude of the bending remedial strain will increase as the plate thickness t increases. This is the well known linear relationship between the bending strain and the plate thickness for constant curvature. This suggests that for a certain plate aspect ratio, the distribution of the bending remedial strain becomes the same for different plate thicknesses. Therefore, a unified heating position layout [3] can be determined for each panel aspect ratio as long as the welding deflection shape is the same. However, in case of thin plates, spot heating technique is used to remove the bending deformation while for thicker plates, heating lines technique is used [1].

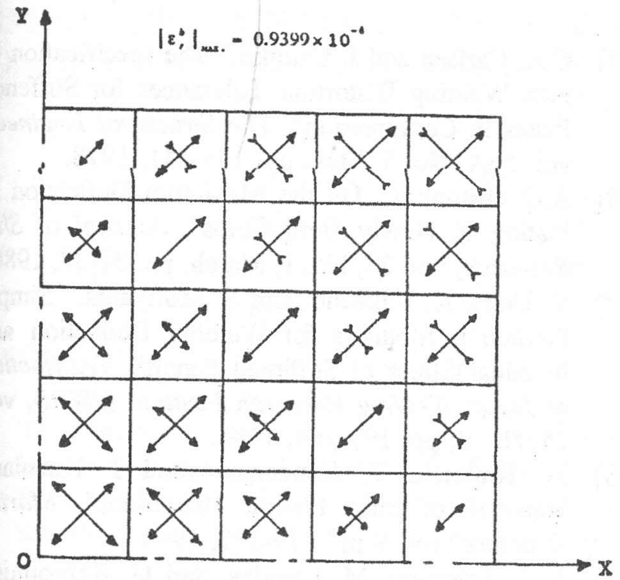


Figure 9. Distribution of bending remedial strain for sinusoidal deflection shape.

4.2 *Effect of maximum deflection*

The effect of the maximum deflection W_0 on the bending remedial strain can be determined from Figure (10). The average of bending remedial strain at the center is plotted against the dimensionless parameter (tW_0/a^2), where a is the length of plate. This parameter is related to the plate bending strain. It is obvious from this figure that as the parameter (tW_0/a^2) increases, the magnitude of the bending remedial strain increases too. In addition, for a given plate thickness t, the distribution of the bending remedial strain remains the same for the different maximum deflection W_0. Thus, regardless of the plate thickness,t, and the magnitude of the maximum deflection, W_0, the bending remedial strain distribution will be the same for constant panel aspect ratio. Consequently, excluding thin plates, unified heating position layout for each aspect ratio can be obtained. On the other hand, the proper heating conditions will depend on the magnitude of the plate thickness and the maximum deflection [3-4], W_0 as well as on the removal process itself.

5. CONCLUSIONS

To have an efficient distortion removal process for the welding deflection of plate panels, it is necessary to determine the proper procedures to be applied to create the counter-deflection. The counter-distortion for plate panel is determined through simple simulation for the welding deflection using the finite element method. Then, the remedial strain field for this distorted panel can be determined. The practicable type of the remedial strains that can be produced by flame straightening method has been clarified. The effects of the plate thickness and the maximum deflection on the characteristics of the bending remedial strain have been examined for a square plate panel. Through the present study, the following conclusions are drawn:

1) To remove excessive welding deflection of plate panels, using the flame straightening method, the bending remedial strain can be considered the practicable remedial strain that can be produced.
2) The necessary bending remedial strain to remove the bending deformation can be obtained using only the shape of welding deflection.
3) In case of different plate thicknesses,t, and different magnitudes of the maximum deflection,W_0, the distribution of the bending remedial strain remains constant for the same plate panel aspect ratio and deflection shape. Thus, excluding thinner plates, unified heating position layout for each panel aspect ratio can be achieved.

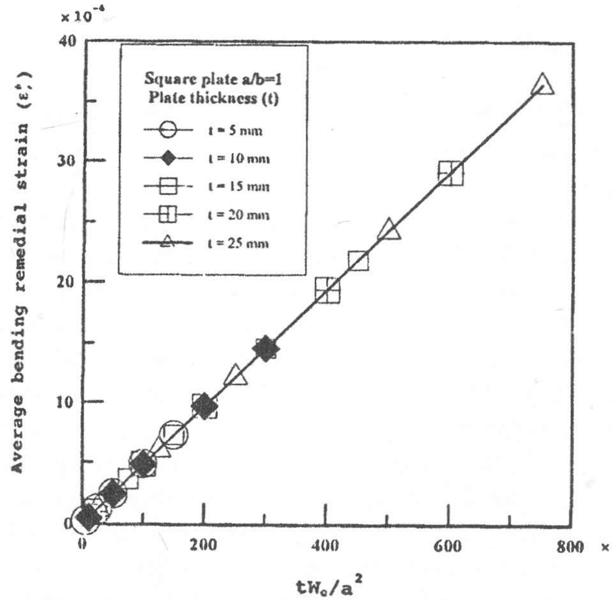


Figure 10. Relation between average bending remedial strain at plate center and tW_0/a^2.

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