A NUMERICAL STUDY OF PARAMETERS GOVERNING AN INHERENT DEFORMATION DATABASE OF PLATES FORMED BY LINE HEATING

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INTRODUCTION

An automatic plate bending process which has been successfully used in ship plates forming was proposed by [1]. However, to fully automate this process and minimize the work and re-work, accuracy improvements are necessary.

As an overall strategy to improve the accuracy of the forming process, the authors pay attention to those factors which may influence the inherent deformation of plates formed by line heating. In order to identify those factors, we numerically analyze the inherent deformation produced by single heating lines and compare it with that obtained by different combination of multi-heating lines under different heating and cooling condition and applied over plates with different geometries. Based on acknowledge obtained from this study, the influential factors on inherent deformation are identified and its influence clarified.

LINE HEATING INHERENT DEFORMATION

Generally, plate deformation is classified into longitudinal shrinkage (δ_{xx}), transverse shrinkage (δ_{yy}), longitudinal bending (θ_{xx}) and transverse bending (θ_{yy}). These four components of inherent deformation can be determined as follows,

$$\delta_{xx} = \int \varepsilon_{xx}^{p} dydz / \mathrm{h} \tag{1}$$

$$\delta_{yy} = \int \varepsilon_{yy}^{p} dydz / \mathrm{h} \tag{2}$$

$$\theta_{xx} = \int \varepsilon_{xx}^{p} (z - \mathrm{h}/2)/(\mathrm{h}^3/12) dydz \tag{3}$$

$$\theta_{yy} = \int \varepsilon_{yy}^{p} (z - \mathrm{h}/2)/(\mathrm{h}^3/12) dydz \tag{4}$$

Where h is the plate thickness.

PREDICTION OF INHERENT DEFORMATION THROUGH FEM

In order to create an accurate inherent deformation database, it is important to evaluate the effect of each influential factor on prediction accuracy. However, the influences of these factors are not so simple that they can be linearly related. Also, it is difficult to obtain these influences by experiments because of the large scatter in test results. It is necessary to understand the relationship between applied heat, influential factors, and plate deformation in order to develop a fully automated line heating. To achieve this, numerical simulation of the line heating processes is indeed necessary. Using FEM, the line heating process can be precisely simulated. Meanwhile, we can conveniently study the influence of above mentioned factors on plate deformation. On the other hand, thermal-elastic-plastic FEM requires very long computation time and large memory. To overcome this problem, an in-house three dimensional thermal elastic-plastic finite element code based on an iterative substructure method [2] is employed in this research.

INFLUENTIAL FACTORS AFFECTING INHERENT DEFORMATION

Heat-induced deformation is affected by many complex and uncertain factors that make it difficult to obtain accurate predictions required by automatic forming systems. In order to identify important factors affecting inherent deformation, first let us analyze the example of analysis results shown in Figure 1 which presents the inherent transverse shrinkage distribution along the heating line.

A primary factor influencing inherent deformation is the *heating method*. The four components of inherent deformation are strongly related to variables such as the heat input, size of the heating zone and the heating source speed. Inherent deformation almost proportionally increases with the heat input and decreases with the heating source speed. *Cooling method* is another important factor. Inherent deformation is directly dependent on the rate of cooling. Rate of cooling can be increased by using water leading to an increase of transverse shrinkage and a slight decrease of longitudinal shrinkage. The location and area of application of water cooling affects all 4 components of inherent strain. Also, increasing the rate of cooling, the variation on inherent deformation along the heating line decreases.

As shown Fig. 1, inherent transverse shrinkage varies along the heating line. At and near both the entrance and the exit edges (regions L_1 and L_3), inherent deformation is smaller than that in the middle region of the plate (L_2). The same tendency can be observed in the other three components of inherent deformation. The variation of inherent deformation at and near the edges from the maximum inherent deformation near the middle of the plate is another important factor known as the *edge effect*. When the same heating line is applied close to one side of the plate, the inherent deformation becomes smaller. This variation of inherent deformation is called the *side effect*.

The region (L_2) showed in Fig.1, increases in the case of a larger plate while L_1 and L_3 only slightly changes. As shown Figure 2, in the case of short plates, L_2 almost disappears and the inherent deformation at center becomes smaller as the plate becomes shorter. This decrease of inherent deformation is called the *plate length effect*. In large plates, L_2 is large and this effect becomes negligible. In a similar way, in narrow plates the inherent deformation decreases with plate width. This decrease of inherent deformation is called the *plate width effect*. Both, plate length effect and plate width effect depend on plate edge restraint and are observed only in small plates.

The transverse shrinkage distribution shown in Fig. 1 is obtained from the analysis of a 40 mm thick plate. With a smaller plate thickness, the inherent deformation increases. These variations are called the *plate thickness effect*.

The total inherent deformation after two or more heating lines is not a simple addition of that produced by each heating line when applied alone. It is observed when the second heating is applied at the same position of the first heating line (overlapped heating) or when the second heating line is applied in the transverse direction of the first heating line (crossed heating). In these three cases, the inherent deformation produced by the second heating line is greatly affected by the residual stresses produced by the first heating line. In this paper, the difference of the final inherent deformation from the simple summation of the inherent deformation of two heating lines in each of these three cases is called, the *effect of parallel heating lines*, the *effect of overlapped heating lines* and the *effect of crossed heating lines* respectively. Figure 3 shows an example of the effect of crossed heating line on inherent transverse shrinkage. In the case of multiple heating lines, the *heating sequence* also influences the inherent deformation.

In additional to the above mentioned influential factors, the inherent deformation is affected by the residual stresses produced by the cutting process and by the initial curvature of the plate. A summary of above mentioned factors is presented in Tab. 1. A more complete explanation of these influential factors is given in [3, 4 and 5].

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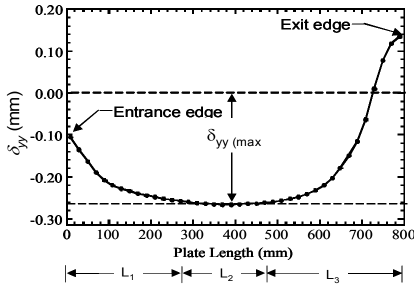

Figure 1: Distribution of inherent deformation

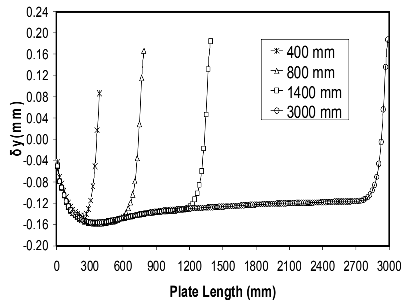

Figure 2: Influence of plate length

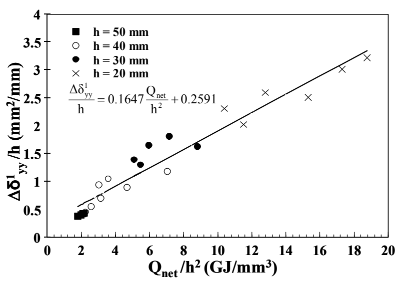

Figure 3: Influence of crossed heating lines

Table 1: Influential factors on inherent deformation

Heating Condition	**Cooling Condition**	**Plate Geometry**
-Heat Input -Torch Speed -Torch Size	-Air Cooling -Water Cooling -Other Methods	-Plate Length -Plate Width -Plate Thickness
Multiples Heating	**Location of Heating**	**Others**
-Overlapped -Parallel -Crossed	-Entrance Plate Edge -Exit Plate Edge -Side Plate Edge	-Residual Stresses -Initial Curvature -Material Properties