Influential Factors Affecting Inherent Deformation during Plate Forming by Line Heating (Report 5) – The Effect of Water Cooling

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ABSTRACT

In plate forming by line heating the usage of water as a cooling source is common. However, the relationship between water-cooling and plate deformation is not well established. This reduces the possibility of automating the process. In order to solve this problem, the influence of the rate of cooling on inherent deformation is first examined. Then, the inherent deformation produced by line heating is studied in detail. Finally, the relationship between inherent deformation and heating condition is recorded into an inherent deformation database. This database can be used to directly predict inherent deformation due to line heating and therefore enable the automation of the process.

KEY WORDS: Line heating; water-cooling; inherent deformation; heat transfer coefficient; database; edge effect; FEM.

INTRODUCTION

In plate forming by line heating, water-cooling is usually used due to its effectiveness in increasing plate deformation. However, the mechanism of forced cooling such as water cooling is highly complex and it is not fully understood. Therefore, it is necessary to create a method to predict the influence of water-cooling on plate deformation and therefore, enable the usage of automatic machines.

Although there have been many papers reporting the line heating method, very few papers are dealing with the effect of water cooling on deformation of plates due to line heating, [e.g. Satoh, Matsu, Terai and Iwamura (1970), Jang, Kim, Ha and Lee (2005), Ji, Yujun, Zhuoshang, Yanping and Jun (2006), Ha and Jang (2007)]. Not a clear relationship between water-cooling and deformation of plates due to line heating has been found yet. Various attempts have been made to understand the mechanism of heat transfer in pool boiling (the key to explain the influence of water-cooling on line heating process), [e.g. Davidson and Schueler (1960), Han and Griffith (1965), Mikic and Rohsenow (1969), Judd and Hwang (1976), Haramura and Katto (1983), Liu and Wang (2001), Wu, Yang and Yuan (2002), etc.]. However, the calculation of the convection coefficient is a difficult problem and cannot be described by using a single relationship.

The objective of this paper is to develop a method to predict the heat induced deformation due to line heating when water-cooling is used. To achieve this objective, a 3-D thermal-elastic-plastic finite element analysis is performed. First, based on a new method to measure heat transfer coefficient proposed by [Osawa, Sawamura, Ishiyama, Tango and Sugimoto (2008)], the effect of water-cooling on inherent deformation is studied. It has been demonstrated the effectiveness of water-cooling in improving the plate forming by line heating. Furthermore, the relations between heat induced deformation and influential factors such as the heat input, the speed of the heating source and the plate thickness are investigated and recorded into an inherent deformation database. Finally, conclusions of this numerical study are outlined.

SIMULATION OF THE LINE HEATING PROCESS

Method of analysis

Thermal and mechanical analyses were undertaken using a proprietary finite element code, based on the iterative substructure method (ISM). This approach aims to reduce the computational time for complex thermal-elastic-plastic analyses by separating the model into regions which is linear or weakly nonlinear and which is highly nonlinear. An iterative approach is used to ensure the compatibility and the equilibrium between the linear and nonlinear regions. Further details may be found in Nishikawa, Serizawa and Murakawa (2005).

The thermo-mechanical behavior in plate forming by line heating is analyzed using uncoupled formulation. However, the uncoupled formulation considers the contribution of the transient temperature field to stresses through thermal expansion, as well as temperature-dependent thermo-physical and mechanical properties. The solution procedure consists of two steps. First, the temperature distribution history is computed using transient heat conduction analysis. Second, the transient temperature distribution history obtained from the heat conduction analysis is employed as a thermal load in a subsequent mechanical analysis. Stresses, strains and displacements are then evaluated.