Influential Factors Affecting Inherent Deformation during Plate Forming by Line Heating (Report 4) – The Effect of Material Properties

Adan Vega
School of Mechanical Engineering, Technological University of Panama, Panama
Yoshihiko Tango, Morinobu Ishiyama
IHI Engineering, Marine, Showa, Kure, Japan
Sherif Rashed, Hidekazu Murakawa
Joining and Welding Research Institute, Osaka University, Ibaraki, Osaka, Japan

ABSTRACT

A 3-D thermal-elastic-plastic finite element analysis is performed to investigate the influence of temperature dependent material properties on prediction of inherent deformation due to line heating when numerical analysis by FEM is used. First, the temperature dependent material properties are defined. Variation with different degree was introduced and the resulting inherent deformation is then compared. Meanwhile, the other properties and process parameters are kept unchanged. Accordingly, the influence of various material properties on inherent deformation is revealed and discussed. It is found that the temperature dependent material properties play a key role on prediction of inherent deformation. Finally, conclusions of this numerical study are outlined.

KEY WORDS: Line heating; inherent deformation; thermal and physical properties; mechanical properties; numerical analysis; FEM.

INTRODUCTION

The plate forming using gas torch, induction heating or more recently laser heating is one of the most important forming processes actually used in shipyards. However, the line heating process is far to be fully automated, causing delays in the production line. The main reason of this is due to the fact that the relation between applied heat and final plate deformation, the key to automate the process, is too complicated to analyze by using simple mechanical models. In order to find a relation between these two parameters, it is necessary to consider other influential factors affecting the process such as the geometry of the plate, the cooling condition, the location of the heating line, multi-heating lines, heat-induced curvature, residual stresses and inter-heating temperature [Vega et al. (2007), Vega et al. (2008), Vega (2009)]. The authors aim to propose a practical and accurate method to predict deformation of actual size plates such as those used in shipbuilding. As a fundamental component of this method, a line heating inherent deformation database is necessary. This inherent deformation database besides being mainly dependent on primary factors such as the plate thickness, the speed of heat source and the heat input, it also takes into account secondary factors such as the geometry of the plate, the cooling condition, the location of the heating line, multi-heating lines, heat-induced curvature, residual stresses, and inter-heating temperature. Here, it is to be noted that the influences of these secondary factors are not so simple that they can be related to the inherent deformation in a simple manner. Also, it is difficult to obtain these influences by experiments because of the large scatter in test results. In fact, the thermal and physical material properties (heat transfer coefficient, specific heat, thermal conductivity, and density), and mechanical properties (Young’s modulus, yield stress, thermal expansion coefficient, Poisson’s ratio, strain hardening, etc.) are also important parameters affecting the inherent deformation. These parameters are temperature-dependent, and their variations with temperature differ greatly. It is also usual that the same material presents variation on material properties. On the other hand, the contributions of different material properties to the forming process are also different. Therefore, it is hard to find out the guidelines for selecting the above properties from experiments for a given material.

It is indeed necessary to understand the relationship between material properties and inherent deformation in order to develop an inherent deformation database. To achieve this, it is necessary to perform numerical simulation of the line heating process. Using FEM, the line heating process can be precisely simulated. Meanwhile, we can conveniently study the influence of material properties on inherent deformation of steel plates formed by line heating. Many publications in welding simulation considering the influence of material properties on transient temperature fields, residual stress and distortion exists (e.g. Wikander et al. (1994), Zhang et al. (2008), Lindgren (2001), Zhu and Chao (2002), etc.). However, in line heating simulation the amount of information is small or inexistent. Yanjin, Sheng, Guoqu, and Yiguo (2005) investigated the influence of material properties on the laser-forming process of sheet metals. They established a 3D coupled thermo-mechanical FEM to study the relation between bending angle and material properties. In order to study the influence of individual material property on the laser-forming process of sheet metal, the material property to be studied is assumed temperature independent during the welding process while the other properties are assumed temperature dependent. They concluded that the material properties significantly influence the bending angle. In their analysis, which is done using small thin carbon steel plate models (40 mm x 20 mm x 2 mm), the influence of material properties on other components of plate deformation, such as the transverse and longitudinal shrinkage is not discussed.