International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 21, No. 1, March 2011, pp. 75–80

http://www.isope.org/publications

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 and Morinobu Ishiyama
IHI Engineering, Marine, Showa, Kure, Japan

Sherif Rashed* and Hidekazu Murakawa*
Joining and Welding Research Institute, Osaka University, Ibaraki, Osaka, Japan

A 3D thermal-elastic-plastic finite element analysis is performed to investigate the influence of temperature-dependent material properties on the 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 a different degree was introduced, and the resulting inherent deformation 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 predicting inherent deformation. Finally, the conclusions of this numerical study are outlined.

INTRODUCTION

For plate forming using a gas torch, induction heating or, more recently, laser heating is one of the most important forming processes actually used in shipyards (Vega et al., 2007). However, the line heating process is far from being fully automated, causing delays in the production line. The main reason is that the relation between applied heat and final plate deformation, the key to automating the process, is too complicated to analyze by using simple mechanical models (Vega et al., 2008). In order to find a relation between these 2 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, 2009).

We 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. Besides being mainly dependent on primary factors such as the plate thickness, the speed of heat source and the heat input, this inherent deformation database 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 the 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 common for the same material to present variations on material properties. The contributions of different material properties to the forming process are also different. Hence, it is hard to discover 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 the finite element method (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.

Much published material in welding simulation considers the influence of material properties on transient temperature fields, residual stress and distortion (e.g. Wikander et al., 1994; Zhang et al., 2008; Lindgren, 2001; Zhu and Chao, 2002). However, in line heating simulation the amount of information is small or nonexistent. Yanjin, Sheng, Guoqun 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 to be temperature-independent during the welding process, while the other properties are assumed to be temperature-dependent. They concluded that the material properties significantly influence the bending angle. In their analysis, which is done by using small, thin carbon steel plate models (40 mm × 20 mm × 2 mm), the influence of material properties on other components of plate deformation—such as the transverse and longitudinal shrinkage—is not discussed.

*ISOPE Member.

Received August 5, 2009; revised manuscript received by the editors November 3, 2010. The original version (prior to the final revised manuscript) was presented at the 19th International Offshore and Polar Engineering Conference (ISOPE-2009), Osaka, June 21–26, 2009.

KEY WORDS: Line heating, inherent deformation, thermal and physical properties, mechanical properties, numerical analysis, finite element method (FEM).