©SNAK, 2015

Int. J. Nav. Archit. Ocean Eng. (2015) 7:157~173
http://dx.doi.org/10.1515/ijnaoe-2015-0012
pISSN: 2092-6782, eISSN: 2092-6790

Welding deformation analysis based on improved equivalent strain method considering the effect of temperature gradients

Tae-Jun Kim[1], Beom-Seon Jang[2] and Sung-Wook Kang[2]

[1]*Hyundai Heavy Industries Co., Ltd*
[2]*RIMSE, Department of Naval Architecture and Ocean Engineering,*
Seoul National University, Seoul, Korea

ABSTRACT: *In the present study, the existing equivalent stain method is improved to make up for its weaknesses. The improved inherent strain model is built considering more sophisticated three dimensional constraints which are embodied by six cubic elements attached on three sides of a core cubic element. From a few case studies, it is found that the inherent strain is mainly affected by the changes in restraints induced by changes of temperature-dependent material properties of the restraining elements. On the other hand, the degree of restraints is identified to be little influential to the inherent strain. Thus, the effect of temperature gradients over plate thickness and plate transverse direction normal to welding is reflected in the calculation of the inherent strain chart. The welding deformation can be calculated by an elastic FE analysis using the inherent strain values taken from the inherent strain chart.*

KEY WORDS: Welding deformation; Inherent strain; FE analysis; Equivalent strain method.

INTRODUCTION

In shipyards, ships are constructed by the block building method. Welding inevitably induces distortion of a block, and this accumulates during the sequential fabrication process. As the block erection step accounts for about one-third of the whole shipbuilding process, the accuracy of a block's shape and size has a close relation to the overall efficiency of production in the shipyard. The welding distortions reduce the fabrication accuracy of ship hull blocks, and decrease productivity, due to the amount of correction work that is required. To increase the precision of fabrication, the welding distortion and the exact distortion margin at every fabrication stage should be estimated, to meet the allowable tolerances of ship hull blocks.

The prediction and control of welding distortions at the design stage has been an essential task for shipyards, to ensure higher quality, as well as higher productivity (Jang et al., 2007). The most widely used method is the thermal elasto-plastic analysis method. This method gives a relatively accurate result. However, it is disadvantageous in computational time, because of the non-linearity of material. In order to overcome the above difficulties, some efficient approaches are needed.

Ha (2007) developed a modified equivalent loading method based on the inherent strain that incorporated hardening effects. The proposed method was applied to calculate the residual stress at the HAZ. Jang et al. (2007) developed the welding distortion analysis method for the stiffened curved plate using equivalent load method based on inherent strain method

Corresponding author: *Beom-Seon Jang*, e-mail: *seanjang@snu.ac.kr*

considering the fabrication sequences. Ha and Rajesh (2009) carried out thermal distortion analysis for Thermo-Mechanical Control Process (TMCP) steel using inherent strain.

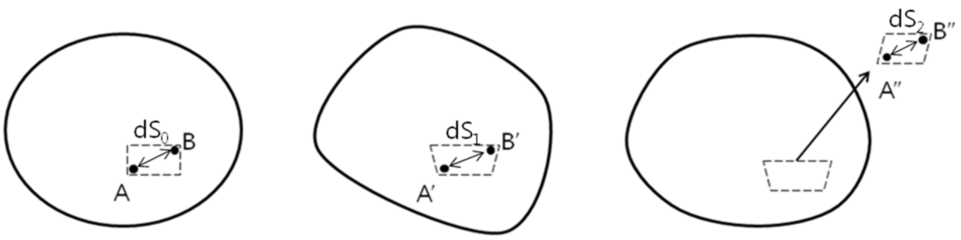
The main purpose of the present study is to propose an efficient approach to predict the welding deformation, based on inherent strain theory, combined with finite element analysis.

EQUIVALENT STRAIN METHOD BASED ON INHERENT STRAIN

Definition of the inherent strain

The inherent strain is defined mechanically as follows: At first, there is a material object that has no stress distribution. When it is under stress by any causes, stress acting on an element of material is accompanied by strains. Then, the stress is released, by cutting out a small part of material; however, residual and irrecoverable strain may still exist. This strain is regarded as the inherent strain.

It can be explained by means of the three material states shown in Fig. 1 (Lee, 1999). The initial state has no stress distribution (Fig. 1 (a)) inside, and the material experiences a stressed condition, caused by phenomena such as thermal strain (Fig. 1 (b)); and the stress is partly released, by cutting a part from the material (Fig. 1 (c)).



(a) Initial state (stress free). (b) Stressed state. (c) Stress released state.

Fig. 1 Definition of the inherent strain.

Based on the above definition, the inherent strain (ε^*) is expressed by subtracting the elastic strain from the total strain,

$$\varepsilon^* = \frac{dS_2 - dS_0}{dS_0} \tag{1}$$

The total strain can be divided into the thermal, plastic, and elastic strains,

$$\varepsilon = \varepsilon^{th} + \varepsilon^{p} + \varepsilon^{e} \tag{2}$$

The inherent strain is defined as the sum of irrecoverable strains, or difference between total strain and elastic strain. (Ha, 2007).

$$\varepsilon^* = \varepsilon^{th} + \varepsilon^{p} = \varepsilon - \varepsilon^{e} \tag{3}$$

Welding analysis based on inherent strain

The distortion and residual stress are computed by elastic analysis, imposing the inherent strain as the initial strain, in the inherent strain method. Inherent strains always remains along the weld bead, and in the nearby zone. It is considered as a source of welding deformation.

The inherent strain is used to two different methods: the equivalent loading method and the equivalent strain method. As for its application, the equivalent strain method (= strain boundary method) is common, and it contains the equivalent loading