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A study on an efficient prediction of welding deformation for T-joint laser welding of sandwich panel PART I : Proposal of a heat source model

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ABSTRACT: *The use of I-Core sandwich panel has increased in cruise ship deck structure since it can provide similar bending strength with conventional stiffened plate while keeping lighter weight and lower web height. However, due to its thin plate thickness, i.e. about 4~6 mm at most, it is assembled by high power CO_2 laser welding to minimize the welding deformation. This research proposes a volumetric heat source model for T-joint of the I-Core sandwich panel and a method to use shell element model for a thermal elasto-plastic analysis to predict welding deformation. This paper, Part I, focuses on the heat source model. A circular cone type heat source model is newly suggested in heat transfer analysis to realize similar melting zone with that observed in experiment. An additional suggestion is made to consider negative defocus, which is commonly applied in T-joint laser welding since it can provide deeper penetration than zero defocus. The proposed heat source is also verified through 3D thermal elasto-plastic analysis to compare welding deformation with experimental results. A parametric study for different welding speeds, defocus values, and welding powers is performed to investigate the effect on the melting zone and welding deformation. In Part II, focuses on the proposed method to employ shell element model to predict welding deformation in thermal elasto-plastic analysis instead of solid element model.*

KEY WORDS: Sandwich panel; Laser welding; Heat transfer analysis; Thermal elasto-plastic analysis.

INTRODUCTION

Application of sandwich panel has been recently increasing in shipbuilding. The sandwich panel have proven to have many advantages over traditional plates; low weight, modular prefabrication, decrease of labor demand. The panels are used in production of walls, decks, bulkheads, staircases and deckhouses on the ships. One of the popular uses is a vehicle deck in RoPax vessel or an upper deck in cruise ship due to the merits of ship stability, crashworthiness and noise & vibration. I-core sandwich panel is composed of two face sheet plates and web plates (called cores) welded perpendicular to the face sheet plates as depicted in Fig. 1. CO_2 laser welding is utilized for welding web plates to face sheet plates due to its merits of narrow heat affected zone, small welding deformation, and deep penetration capability. However, even if CO_2 laser welding induces less welding deformation than other conventional welding methods, the deformation level is still not negligible in the sandwich panel assembled by quite thin plates of 3-5 *mm* thickness.

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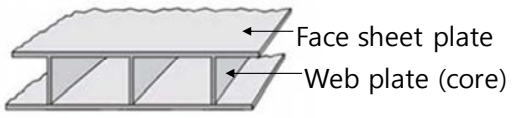

Fig. 1 Shape of I-core sandwich panel.

Web plate is welded to face sheet plate by shooting laser on the face sheet plate at the joint of the face sheet plate and the web plate. The laser penetrates the face sheet plate and reaches upper part of the web plate and the molten zone joins as it cools down. The area where heat energy is imposed is completely different from fillet welding using conventional arc welding method. The resultant welding deformation is much less than the fillet welding due to smaller heat input. Fig. 2 simply shows the procedure of making I-core sandwich panel with one core.

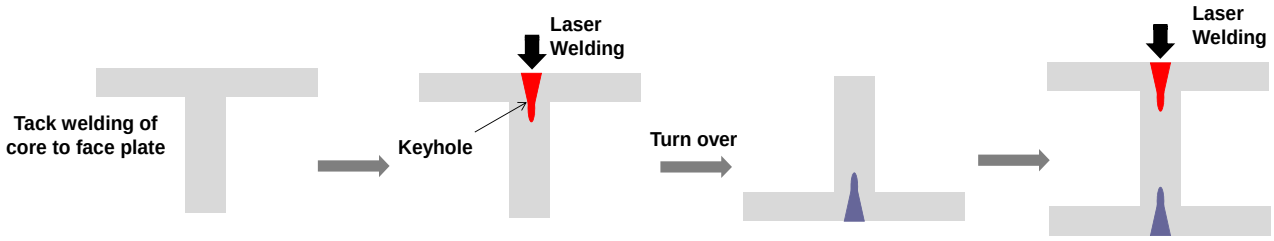

Fig. 2 Process of sandwich panel production with laser welding.

Assumption of a proper heat source in a thermal elasto-plastic analysis is essential to the correct prediction of welding deformation. Meanwhile, researches on the heat source model of laser welding has been focused on only butt welding and any model for T-joint has not been reported. Existing researches on laser welding can be divided into two groups. One is related to the estimation of keyhole shape formed during the welding process and the other one is the assumption of heat source model. As representative studies on the estimation of keyhole shape, Cho and Na (2006) employed a ray-tracing method and Pablo and Guillermo (1997) took into account ever-changing shape which seems to 'hook' according to laser processing of materials. In order to observe transient keyhole shape inside the material, a few methods were suggested (Bardin et al., 2005; Arata et al., 1976; Jin et al., 2002). The initial research of laser heat source is limited to the assumption of line heat source through material depth (Rosental, 1941; Swift-Hook and Gick, 1973). Because of the difficulty in observing how deeply the material is penetrated, those researches could not consider the changes of penetration depth versus heat source power and welding velocity. As efforts to predict the shape of heat affected zone, 2D heat flux equations for low power welding have been proposed (Mazumder and Steen, 1980; Zacharia et al., 1989). However, such a 2D Gaussian distribution heat source model cannot appropriately represent deep penetration of high power heat source. As an improvement, Lee et al. (2005) proposed heat source with laminated Gaussian distribution. It also has deficiency in developing a correct temperature gradient through thickness. Additionally these heat sources don't provide any consideration of defocus effect.

This study proposes a simple volumetric heat source model of laser welding for I-core sandwich including the defocus phenomenon. For a verification of the proposed model, heat transfer analysis and thermal elasto–plastic analysis using solid element model are performed to investigate heat distribution in the thickness direction and the resultant welding deformation, respectively. Both analysis results are compared with experimental results for heat transfer analysis and thermal elasto-plastic analysis. A parametric study for different laser powers, welding speeds, and defocus values is carried out to identify their influences on welding deformation and melting zone size through a series of heat transfer analyses and thermal-elasto plastic analysis. The melting zone size can be used as an indicator of weldability of the T-joint. This study utilizes commercial finite element analysis program, ANSYS version 13.0.

PROPOSAL OF HEAT SOURCE

Keyhole phenomenon occurred by laser welding

Keyhole phenomenon which is shown Fig. 3 is one of main characteristics of the laser welding. When power density of