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Reverse analysis of scan strategies for controlled 3D laser forming of sheet metal

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Abstract

Laser forming is an advanced manufacturing technique for the shaping and adjustment of metallic and non-metallic components by controlled laser induced thermal stress. Important advantages of laser forming include the absence of external mechanical tooling, flexibility and potential for automatic control. A large number of relevant two-dimensional laser forming studies have been completed to date. However, for the production of complex 3D shapes, such as ship hull components, airplane fuselages and automotive bodies, two-dimensional laser forming is limited. Therefore, in order to advance process for realistic applications, the investigation of the 3D scanning strategies becomes essential. This includes both in plane shortening and out-of-plane bending. In order to determining the scanning patterns and process parameters for forming any arbitrary 3D shape, numerical simulation is a strong tool to analyse the required stress and strain distribution and related processing parameters. In the presented investigation, the object is to develop optimal irradiation patterns and parameters to form a S275 steel square thin plate to a given generic ship hull shape through finite element simulation and experiment verification. A novel approach was used for the development of scan strategies for controlled 3D laser forming of sheet metal components based on a reverse analysis. A patched modular virtual press tool was employed in a commercial FE package COMSOL Multiphysics to extract the required strain-displacement map to achieve a given shape from a starting condition. The laser processing conditions have then been extracted from the magnitude of strain and displacement of each patch. A closed loop control iterative approach has then been used to ensure part accuracy during experimental verification.

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Keywords: 3D laser forming, FEM simulation, close loop control

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1. Introduction

In laser forming, the deformation of sheet metal is produced by thermal stresses, which are generated by a controlled defocused laser beam scanned over the surface [1,6]. During laser forming, the non-uniform expansion will occur due to the non-uniform thermal stresses; therefore the plastic deformation will be generated when the thermal stresses exceed the yield point of the material [14].The advantages of laser forming include without any external mechanical tooling, flexibility and automatic control. A large number of relevant two-dimensional laser bending studies have been done to date. However, for the production of complex 3D shapes, such as ship and aerospace surfaces, two-dimensional laser forming is limited [1,3,13]. Therefore, in order to advance process for realistic applications, the investigation of the 3D scanning strategies becomes more necessary, which accompanies both in plane shortening and out-of-plane bending [5,9] as seen in Fig.1. In order to determining the scanning patterns and process parameters for forming any arbitrary 3D shape, numerical simulation is a strong tool to analyse the scan strategies and the processing parameters [6,7].

In the presented investigation, the object is to develop optimal irradiation patterns and parameters to form S275 steel square thin plate with the size of 100×100×1.5mm to a representative ship hull shape. The work consists two parts, finite element simulation and experiment verification. The numerical simulation with two models have been developed by using COMSOL Multiphysics 5.2. One is a virtual press tool mechanical model, and the other is a laser heating thermal mechanical model with a step-wise moving Gaussian distribution of heat flux laser beam.

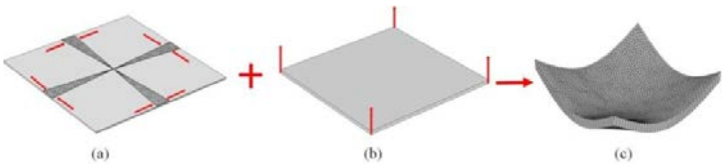

Fig. 1. (a) In-plane shrinkage; (b) Out-of-plane bending; (c) 3D formed shape

2. FEM Simulation

2.1. Determination of the scanning patterns by mechanical model

In the mechanical model, the first step was to decompose the top surface of the initial sheet into a group of sixteen patches with 25 nodal points as shown in Fig.2 (a). The desired shape can be seen in Fig. 2 (b), this is a representative ship hull shape.

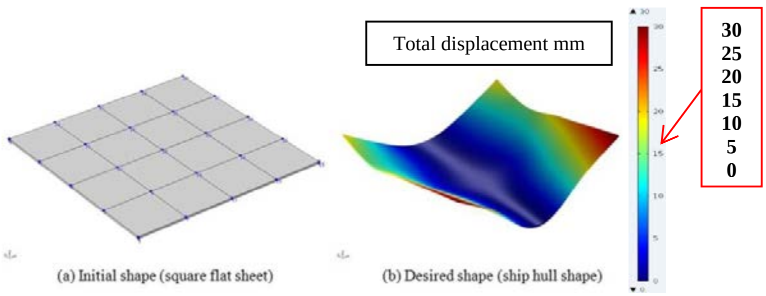

Fig. 2. Definition of the initial shape and desired shape

$$e^I = \frac{1}{h}\int_h^0 e^T \, d_z$$
$$e^B = \frac{1}{h^2}\int_h^0 (e^T - e^I) z d_z \quad (1)$$

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