

Chapter 8

A Finite Element Study of Buckling and Upsetting Mechanisms in Laser Forming of Plates and Tubes

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ABSTRACT

Laser beam forming has emerged as a viable technique to form sheet metal by thermal residual stresses. Although it has been a subject of many studies, its full industrial application is not yet established. This article aims to complement the existing research in the area of laser forming in order to gain a better understanding of the process. A numerical investigation of laser forming of stainless steel sheets has been carried out and validated experimentally using a High Power Diode Laser (HPDL). Three processing parameters are tested; laser power, beam diameter and plate thickness. Also, laser bending of stainless steel tube is simulated and compared against the published experimental data. The main underlying mechanisms of laser forming are demonstrated through the simulations.

INTRODUCTION

Conventional mechanical bending process for sheet material involves a set of bending die and punch with a sheet material placed in between. During bending, the sheet material is plastically

deformed into the desired shape by the application of forces. This process is generally suitable for mass production. However, for production of rapid prototyping of a few parts, the conventional sheet metal forming processes are often uneconomical due to high cost of dies and the possibility of redesign of the dies in case of design error.

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In recent years laser forming has emerged as a viable technique to form sheet metal by thermal residual stress. The important element in laser forming process is the material which is scanned with a defocused laser beam such that laser-material interaction causes localized heating of the surface without melting. Laser forming idea was first discovered by Kitamura (1983) who successfully bent a 22mm thick steel plates using a 15kW CO₂ laser. Since then many research works have been carried out in this area for applications in aerospace, automotive, shipbuilding, and electronic industries.

There are many advantages of laser forming compared to conventional sheet bending. Among these are design flexibility, production of complex shapes (which is not achievable by conventional methods), forming of thick plates and the possibility of rapid prototyping. Dearden and Edwardson (2003) in their review, described recent developments and techniques of laser forming for both micro and macro scale applications. Recently, Shen and Vollertsen (2009), in their review on laser forming, described many recent developments and new techniques in modelling of laser forming, including analytical models, numerical simulations and empirical models.

High Power Diode Laser (HPDL) has been used widely in laser processing including laser forming. The wide usage of HPDL is generally attributed to its high efficiency, long life and competitive capital and operating costs (Lawrence, Schmidt, & Li, 2001; Pinkerton, 2004). This laser normally produces a rectangular or an elliptical beam shape with various sizes and geometries. The first attempt to use a 2.5kW HPDL to bend mild steel plate was conducted by Lawrence, Schmidt, and Li (2001). Later, Lawrence (2002) compared laser forming using CO₂ laser and HPDL. Casamichele, Quadrini, and Tagliaferri (2007) investigated laser forming of stainless steel and aluminum alloy sheets using a 1.5kW diode laser. Chen, Jeswiet, Bates, and Zak (2008) used a medium power diode laser to bend thinner metal sheets. Guglielmotti,

Quadrini, Santo, and Squeo (2009) performed a mechanical performance test on stainless steel sheets bent by a 1.5kW diode laser.

Modelling of laser beam forming is a complex and demanding task due to its highly non-linear and transient nature. Ju and Wu (1998) have done a comparison between Finite Element Method (FEM) and Finite Difference Method (FDM) simulations on laser forming of sheet metal and studied the temperature fields during the process. Kyrsanidi, Kermanidis, and Pantelakis (1999) have numerically investigated laser forming by Temperature Gradient Mechanism (TGM) with the results validated by a series of experiments. These results were then used by Zhang and Michaleris (2004) in their investigations using Lagrangian and Eulerian formations of the FEM for modelling laser forming process.

Sichun and Zhong (2002) and Yongjun Shi et al. (2007) have numerically investigated temperature gradient mechanism of thin plates irradiated with a straight line laser beam. Chen, Wu, and Li (2004) and Zhang, Guo, Shan, and Ji (2007) have also numerically investigated the deformation behaviour of laser path which is along a curve rather than in a straight line on sheet metal. Hu et al. (2002) investigated the buckling instability of laser sheet forming and concluded that buckling mechanism is activated when there is an insignificant temperature gradient through the thickness.

Tube bending has many applications in many industries for products such as air conditioners, boilers, heat exchangers, tubes, and pipes. Conventional mechanical tube bending has a limitation on minimal bending radius due to material thinning at the extrados (outside arc of the bent tube) (Zhang et al., 2006). To reduce thinning, pressure bending may be adopted. At the intrados, there is a tendency for buckling and wrinkling to occur as a result of the compressive stresses. Mandrels can be used to prevent these defects but this will increase the complexity of the process.

A great advantage of tube laser bending compared to mechanical bending is less ovalization

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