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Analysis and control of edge effects in laser bending

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ABSTRACT

Laser forming is a spring back free and non-contact forming technique. The process requires no hard tooling or external forces. Bending is achieved by plastic deformation induced by thermal stresses resulting from rapid nonlinear thermal cycles. Laser bending has the potential to deal with materials which are either extremely difficult or impossible to bend mechanically. Numerical and experimental investigations are presented to advance the understanding of the edge effects in the straight line laser bending process under TGM. More insights into the causes of the edge effects are obtained from the numerical results of temperature, bending angle and plastic strain. A total of six varying velocity scanning schemes of numerical and experimental investigation are carried out. It is evident that scanning schemes significantly influence the bending angle distribution along the scan line. In an attempt to reduce the edge effects, the influence of varying velocity scanning schemes has been investigated. The results show that the combination of acceleration and deceleration scanning schemes can minimize the edge effects. By comparing these varying velocity scanning schemes, the staircase varying velocity scanning scheme reduces the edge effects greatly.

1. Introduction

Laser forming that requires no mechanical contact has its origins in sheet bending for ship construction. Laser forming provides a means of processing materials in a novel manner, which would be difficult or impossible using conventional manufacturing methods. Laser forming can use combinations of straight and curve scan lines to produce three dimensional formed components. Laser forming is of significant value to industries that previously relied on expensive stamping dies and presses for prototype evaluations, which include aerospace, automotive, shipbuilding and microelectronics [1,2]. Laser forming has been a subject of investigation in the past for many researchers. Application of laser heat source for sheet bending was first attempted by Namba [3,4]. Based on the temperature field generated by the laser scan, Vollertsen proposed three different mechanisms to describe how the metal sheet is formed during a laser forming process [5]. They are named as temperature gradient mechanism (TGM), buckling mechanism (BM) and upsetting mechanism (UM). Nowadays, some numerical models [6–10] and analytical models [11–15] have been built in order to improve the understanding mechanisms and prediction. However, due to the changing mechanical restraint and the temperature distribution, the laser forming process is asymmetrical about the scan line and the bending angle is not constant along the scan line, causing the edge effects [16]. Bao and Yao [17] also considered the curved bending edge as the edge effects. Theoretical analysis by Mucha et al. [18] showed that thickness in the bending edge region increases due to thermal contraction under TGM, and the bending edge of the plate is visibly curved due to thermal contraction in the scanning direction. Numerical and experimental attempts have been made by Bao and Yao [19] to study the edge effects under BM. By comparison of different scan velocities, the non-uniform peak temperature along the scan path caused the bending edge to curve, which led the bending angle variation to occur along the scanning direction. Magee et al. [16] showed that the actual profile of bending angle was dependent on the laser processing parameters employed, as well as the material properties. Attempts have been made to reduce the edge effects by empirically varying traveling velocity along the scan path. However, the numerical analysis of varying velocity scan is not involved and it is impossible to design the scan velocity distribution along the scan line to largely reduce the edge effects.

This paper presents numerical and experimental investigations aimed at advancing the understanding of the edge effects in the straight line laser bending process under TGM. Numerical results provide more insights into the causes of the edge effects. The effects of scanning velocity and scan line position on edge effects are investigated. In order to reduce the edge effects, some varying velocity scanning schemes are proposed. The effects of scanning schemes on bending angle distribution along scan line

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are examined using numerical simulation and experiment. A finite element model for analyzing varying velocity scan is constructed, taking into account temperature dependent thermal and mechanical properties. The varying velocity scan schemes are investigated to minimize the edge effects.

2. Mechanism of the edge effects

The computer simulation of laser forming problems is a complicated process because it involves many variables such as heat flux of the laser beam, temperature distribution in the plate elements, changes in material properties and the influence of thermal strains on the plate deformations. The process generally includes three distinct components: the modeling of laser beam, the transfer of heat from the laser beam to the plate and the response of the plate. The primary objective to conduct such analyses is to determine the plastic deformations of the plate and corresponding residual stresses developed during and after the laser scanning. In order to calculate the thermo-structural coupled field with large plastic deformation, an indirect coupled-field analysis (i.e., two sequential analyses) is performed, because the heat produced due to plastic deformation is very small and can be ignored [20]. A transient thermal analysis was first carried out to determine temperature distribution which was then input as a body load for the stress analysis to determine the bending angle. Laser beam was modeled as a moving heat flux using area sector approach [21]. ANSYS APDL language was used

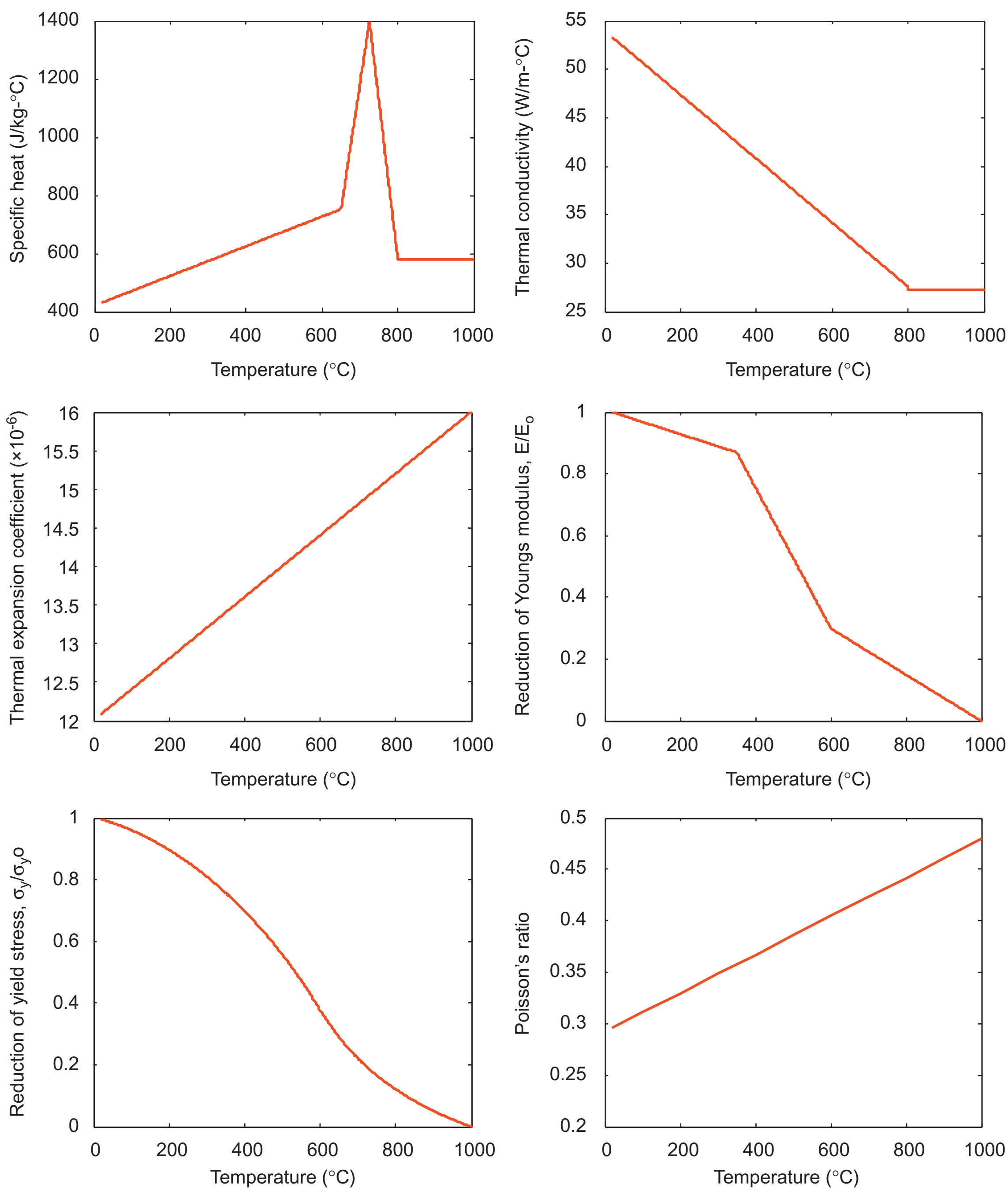

Fig. 1. Thermal and mechanical properties of low carbon steel.