CMM 2017

22ND INTERNATIONAL CONFERENCE ON COMPUTER METHODS IN MECHANICS

SEPTEMBER 13-16, 2017, LUBLIN, POLAND

Editors:

Tadeusz Burczyński, Mieczysław Kuczma, Jerzy Warmiński, Jerzy Podgórski, Ewa Błazik-Borowa, Tomasz Lipecki

22^{nd} International Conference on Computer Methods in Mechanics

CMM2017

Short Papers

Editors:
T. Burczyński
M. Kuczma
J. Warmiński
J. Podgórski
E. Błazik-Borowa
T. Lipecki

Lublin, 2017

Cover design
Olga Skoczylas

The short papers have been produced from the electronic materials supplied by Authors without amendments by Editors

Organization of 22nd International Conference on Computer Methods in Mechanics CMM 2017 - task supported in the frame of agreement 697/P-DUN/2017 financed by Minister of Science and Higher Education with funds dedicated for activities promoting science

— —

Organizacja 22nd International Conference on Computer Methods in Mechanics CMM 2017 - zadanie finansowane w ramach umowy 697/P-DUN/2017 ze środków Ministra Nauki i Szkolnictwa Wyższego przeznaczonych na działalność upowszechniającą naukę

ISBN 978-83-7947-264-2

Experimental and numerical investigation on laser-assisted bending of pre-loaded metal plate

Zdzisław Nowak[1] **Marcin Nowak**[1], **Jacek Widłaszewski**[1] **and Piotr Kurp**[2*]

[1] *Institute of Fundamental Technological Research, Polish Academy of Sciences*
Pawińskiego 5B, 02-106 Warsaw, Poland
e-mail: znowak@ippt.pan.pl, nowakm@ippt.pan.pl, jwidl@ippt.pan.pl

[2] *Department of Industrial Laser Systems, Kielce University of Technology*
al. Tysiąclecia Państwa Polskiego 7 , 25-314 Kielce, Poland
e-mail: pkurp@tu.kielce.pl

Abstract

The laser forming technique has an important disadvantage, which is the limitation of plastic deformation generated by a single laser beam pass. In order to increase the plastic deformation one has to repeat the process several times or use the alternative method. To increase the plastic deformation it is possible to add external forces during the laser forming process. In this paper, we investigate the influence of external pre-loads on the laser bending of steel plate. The pre-loads investigated generate bending towards the laser beam. The thermal, elastic-plastic analysis is performed using the commercial nonlinear finite element analysis package ABAQUS. The focus of the paper is to identify how this pattern of the pre-load influence the final bend angle of the plate.

Keywords: laser forming, force-assisted laser bending, thermo-mechanical simulations, FEA

1. Introduction

For the laser bending process without pre-loads, a thermal gradient between the top surface and bottom surface is generated, so that thermal expansion of the material leads to a small bending towards the incident laser beam. In order to improve the deformation magnitude and control the deformation direction, a external load F can be imposed on the metal plate. The bending effect depends on the initial stress state. The buckling of the plate may occur if the compressive pre-stresses are too large. The magnitude of bending is dependent on the applied force F and the distance between the irradiating line and the loading position. The related loading model can be established if one end of the sheet is fixed, and force acts on the other end (shown in Figure 1). In the laser bending under pre-loaded process, the temperature and displacement fields affect each other. So this is a typical coupled thermal-mechanical problem. The computer simulation of laser forming problems is a complicated process. It involves many variables such as the 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. In the present numerical study, the commercial nonlinear finite element code, ABAQUS is used. While compared with the input laser beam energy, the heat generated due to the mechanical deforming process is negligible. Therefore, to simplify the analysis, the laser forming problem herein will be decoupled by two distinct models; the thermal model and the mechanical model. This essentially means that the temperature and the stress fields can be solved separately in the numerical analysis, although the temperature field must be known before the stress field can be determined.

In this paper, the laser bending process of steel plate with pre-loads is studied in detail. The main advantages of this process are: (1) good bending ability, (2) no significant influence on material structure and good surface quality, (3) good repeatability. This process provides a new way for bending plate metals. It also provides a solution for forming many plate metals which are hard to bend by traditional processes because of their hardness.

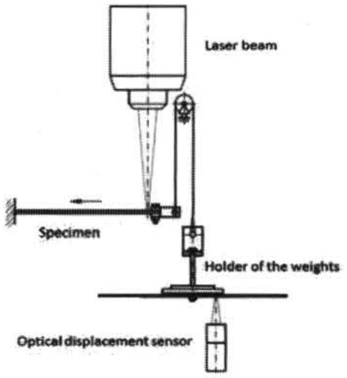

Figure 1: Experimental setup includes the specimen, laser beam, holder of the weights and the optical displacement sensor

2. Laser-assisted bending of pre-loaded plate

Experimental study of the laser-assisted bending process of pre-loaded plate was conducted on specimens made of X5CrNi18-10 (1.4301) stainless steel. The 20 mm wide and 1 mm thick specimens were clamped in a cantilever arrangement, as shown in Figure 1. The initial pre-stress condition was realized with a gravitational load acting on the own mass of the specimen and a set of weights attached to its free end. The holder of the weights could freely rotate with respect to the specimen to provide a constantly vertical load force F. The external force F was applied to the specimen at a distance 175 mm from the fixture, as measured along the initially straight specimen. The following values of the weights were used in a series of experiments: 145 G (1.42 N), 195 G (1.91 N), 245 G (2.40 N) and 295 G (2.89 N). After the specimen had been loaded mechanically by its own weight (gravitational load) and the force F, it was heated with a laser beam moving along longitudinal axis x, starting from the posi-

[1]The research reported herein was supported by a grant from the National Centre for Research and Development (No. PBS3/A5/47/2015).

MS13

tion x = 150 mm towards the fix end of sample (x = 0). The laser beam was produced by the TRUMPF TruFlow6000 CO_2 laser, which operated in the continuous-wave (CW) mode. The radiation wavelength was 10.6 micro-meters. The applied laser head produced approximately rectangular 20 x 2 mm laser spot on the material surface. Therefore, the laser spot covered the whole width of the laser treated specimen. Laser beam of power 200 W had velocity 200 mm/min (3.33 mm/s) with respect to the specimen. In order to increase coupling of laser power, each specimen was coated with a black paint. Deformation of the specimen was measured using an optical displacement sensor MicroEpsilon LLT1700.

3. Numerical simulations of heating and stress analysis

Numerical simulations were conducted using the finite element method. The influence of the plastic deformation on its temperature and thermal effects due to microstructural changes were neglected for the considered austenitic stainless steel. The thermal-mechanical sequentially coupled quasi-static analysis is conducted in two separate steps:

- determination of temperature field under prescribed heat load and boundary conditions,
- elastic-plastic incremental analysis of stress and strain due to the mechanical load and thermal load, using the calculated temperature field.

One half of the specimen was modeled taking the advantage of its symmetry with respect to the $x - z$ plane for axis $y = 0$, where x is longitudinal and z is the thickness direction z. Symmetry condition in the thermal problem was accounted for by considering the plane of symmetry as adiabatic, whereas heat convection and radiation was allowed on all other surfaces of the model. DC3D8 elements for the thermal problem, and compatible elements C3D8 for mechanical analysis were used. Ten elements were applied in the thickness direction z of the specimen in order to accurately model the bending deformation and any influence of the temperature gradient. Thermal dependence of the following material properties was taken into consideration: thermal conductivity, specific heat, thermal expansion coefficient, Young's modulus, yield stress, Poisson's ratio and density. To achieve possibly high modeling accuracy in this research the yield stress dependence on temperature was based on data presented by Chen and Young [1] for the austenitic stainless steel. Their characteristics were recalculated using the room temperature yield stress value 234 MPa for the steel used in this research. Isotropic strain hardening model was used with the Huber-Mises-Hencky yield criterion. The elastic deformation was described by the Hooke's law. While the laser beam passage from the position x = 150 mm to the position x = 0 took 45 seconds, and experimental measurements were carried out also for several seconds after laser heating was finished, numerical calculations accounted only for 40 s of laser heating to avoid local effects related to the change in heat dissipation conditions close to the specimen fixture.

4. Comparison of results

Figure 2 shows time-runs of the free end deflection of the specimen caused by the application of the moving laser beam, for several cases of the mechanical load F. The presented deflection U is measured in the direction of axis z, starting from the equilibrium position reached after mechanical loading. Similarly, time t is a time, which is equal 0 at the beginning of laser heating. This comparison of experimental and numerical results is regarded as a satisfactory validation of the numerical model.

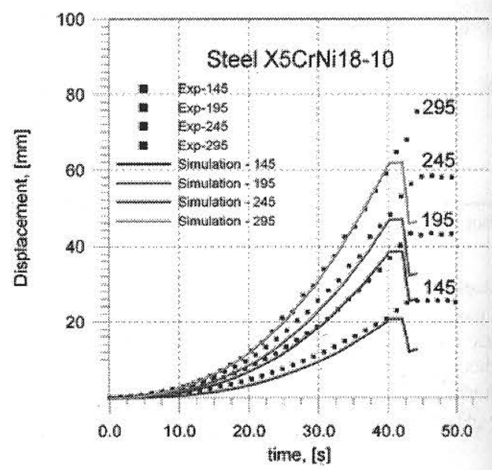

Figure 2: A comparison of the free-end deflection U as measured in experiments and calculated numerically as a function of time for 145 G (1.42 N), 195 G (1.91 N), 245 G (2.40 N) and 295 G (2.89 N) forces.

Hence, numerical simulations are used to get insight into the development of temperature, stress and strain fields during the process of hybrid, thermal and mechanical, acting on the thin-walled plate.

5. Conclusions

Experimental investigations of the hybrid thermo-mechanical processing of thin plates with a laser beam proved the feasibility of mechanically-assisted laser bending with high efficiency. Large bending deformations of plates were achieved after single laser beam pass. Forming performance of plate can be improved significantly under pre-loading. The deformation of the plate results from cumulative effect of the yield stress drop in elevated temperature and the stress field generated by external load.

Calculated numerically deflections of laser-assisted bending of pre-loaded plate are in a good agreement with some experimentally measured values for most of the analyzed load cases. A worst agreement observed in one case may indicate an influence of the variability in the laser energy absorption by this sample.

References

[1] Chen, J. and Young, B., Stress–strain curves for stainless steel at elevated temperatures, *Engineering Structures*, 28, 229–239, 2006.

[2] Simulia, *ABAQUS/Explicit User's Manual*, ver. 6.13, Dassault Systèmes, Providence, USA, 2013.