Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 130 (2015) 948 – 955

Procedia Engineering

www.elsevier.com/locate/procedia

14th International Conference on Pressure Vessel Technology

Redistribution of Residual Stress Field in the Weld Joint Due to Laser Shock Processing

X.L. Wei[a,b], X. Ling[a,b,*]

[a]Jiangsu Key Laboratory of Process Enhancement and New Energy Equipment Technology, Nanjing 210009, China
[b]School of Mechanical and Power Engineering, Nanjing Tech University, Nanjing 210009, China

Abstract

In this paper, residual stress and plastic damage in the welded joint processed by laser shock processing are investigated. Plastic damage during laser shock processing (LSP) is modeled combined with Gurson-Tvergaard-Needleman (GTN) plastic damage constitutive equations. In order to verify the FEA model, benchmark simulations are performed and verified with available experimental results. Results show that predicted residual stresses agree well with the experimental data. It is very interesting that welding tensile residual stress can be modified and changed into compressive residual stress due to laser shock processing. Simulations reveal that void volume fraction (VVF) referring to ductile damage of materials is approximately constant and decaying sharply at the edge of the impact zone in radial direction. A point can be noted that the magnitude of surface void volume fraction (VVF) increases with increasing power density.

Peer-review under responsibility of the organizing committee of ICPVT-14

Keywords: Laser shock processing; Welding; Residual stress; Plastic damage; Finite element analysis.

1. Introduction

White [1] used high-energy pulsed lasers to generate shock waves and plastic deformation in metallic targets for the first time, with the development of confined ablation modes extended by Anderholm [2]. Laser shock processing emerges to be a competitive technology as a method of imparting compressive residual stresses into the surface of metals to improve fatigue life and corrosion resistance in the past several decades. Compared with the traditional

* Corresponding author. Tel.: +86 25 83243112; fax: +86 25 83600956.
E-mail address: xling@njtech.edu.cn

1877-7058
Peer-review under responsibility of the organizing committee of ICPVT-14
doi:10.1016/j.proeng.2015.12.247

surface enhancement techniques such as shot peening, the advantages of LSP include high magnitude of compressive residual stress, deeper plastic deformation layer, increased control in application and reduced microstructural damage [3].

Many investigations have concentrated on experimentally determining mechanical effects including residual stress field and surface morphology significantly enhancing the fatigue life and corrosion resistance abilities of metals [4-10]. During a LSP process, it is very difficult to monitor and investigate the dynamic responding process as well as residual stress in the target by means of experimental approaches. In addition, it is not enough using an analytical model to describe the complex process. In this case, the finite element analysis (FEA) method can be applied to simulate the LSP process for the further exploration and development of the LSP process of materials. Braisted and Brockman [11] used finite element analysis techniques to predict the residual stress induced by laser shock processing. Arif [12] investigated a finite difference algorithm to simulate propagation of stress wave in the material. Ding and Ye [13] applied finite element analysis to predict the development, magnitude and distribution of residual stress induced by multiple LSP impacts. Hu et al. [14] developed a 3-D simulation and only single and multiple laser shocks were performed. Peyre et al. [15] presented a 2-D FEA model to calculate the residual stresses induced by laser shock processing in stainless steels. Warren et al. [16] investigated the effects of parallel multiple laser-material interaction on the stress and strain distributions during LSP. Wu et al. [17] developed a physics-based model for LSP with femtosecond laser pulses, which showed that fs-LSP could produce much higher pressure than LSP with nanosecond laser pulses (ns-LSP) and generate a compressive layer with a thickness up to ~100 μm. Achintha and Nowell [18] presented an eigenstrain model of the residual stresses generated by LSP. However, there are few researches for predicting the residual stress field and plastic damage induced by LSP in the welded joint.

In this paper, a 3-D FEA model is presented to predict residual stresses and plastic damage in welded joint induced by LSP. In this investigation, a thermal elasto-plastic analysis is performed to evaluate the residual stresses for the GATW process. Then, residual stresses redistribution and plastic damage induced by laser shock processing are discussed.

2. Finite element modeling

2.1. Thermal and mechanical analysis of welding

Welding simulation is carried out in a sequentially coupled thermal stress analysis. First, the transient thermal analysis is applied to obtain the temperature history. The FE model with dimensions of 80×80×6 mm is applied in the thermal analysis, shown in Fig. 1. In this research, the double ellipsoid heat source developed by Goldak et al. [19] is adopted. The energy input rate and welding speed are defined as 2520 W and 2 mm/s, respectively. The moving heat source is modeled by a user subroutine in ABAQUS. Second, the mechanical analysis is conducted using the temperature history as a thermal load to determine the welding residual stress and deformation. The FE model of mechanical analysis is the same as that of thermal analysis, except for the boundary conditions and the element type.

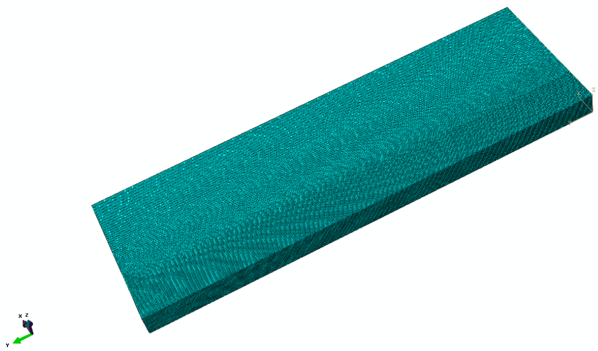

Fig. 1. 3D finite element model.