Simulation for Additive Manufacturing
11th –13th October 2017
Munich, Germany

Numerical simulation of laser shock processing effects on residual stresses of Multi-layer butt-welded stainless steel joints

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Key Words: *Butt-welded Joints, Weld Residual Stress, Laser Shock Peening, Numerical Simulation*

Abstract: To investigate the residual stresses variation in Cr13-type low carbon martensitic stainless steel multi-layer butt-welded joints subject to laser shock processing (LSP), LSP simulation is performed with the weld residual stress as the initial status by ABAQUS software. Influences of shock parameters such as laser pulse energy, spot sizes, pulse width, multiple shots and overlapping rate on the residual stress are mainly studied for the purpose of optimizing these laser shock parameters by comparing the residual stress fields before and after LSP processing. The results show that LSP has made the residual stress change from tensile residual stress to high-level compressive residual stress on the stainless steel welded joint surface. Residual stress distributions could be significantly improved by optimizing the processing parameters. The ideal residual stress field without "residual stress hole" could be obtained under the condition of 36 J of laser pulse energy, 2.5 mm of spot radius, 30 ns of pulse width, 3 ~ 4 of shock numbers and 75% of overlapping rate.

Introduction: Cr13-type low carbon martensitic stainless steels are an economical option for the demand of superior mechanical properties and high corrosion resistance. However, higher residual thermal stresses often occur near the weldment due to uneven heating and subsequent rapid cooling in welding process, while such weld residual stresses especially tensile residual stresses may cause crack initiation, accelerate crack propagation, and even finally lead to the fracture of welded structure and disastrous consequences under the combined action of service load and environment [1]. Therefore, it is of great importance to control the magnitude and distribution of the residual stress by LSP technology [2] for improving the resistance to stress corrosion cracking and the service life of these stainless steel welded structure. At present, little effort has been devoted to modeling the role of LSP in performance improvements of stainless steel welded joints after LSP. So, it is necessary to investigate the changes of the residual stress fields before and after LSP through using finite element method.

Results and Discussion: Fig.1(a) shows the welding geometrical model and the sequence of the weld passes, while Fig.1(b) shows the mesh of the 3D finite element model in which the heat source center is moving along the Z direction in welding line. The comparison of weld residual stresses computed in the present paper and measured by Thibault et. al. [3] has been conducted as shown in Fig.2. It is noticed that our simulated results are basicly in good agreement with Thibault's results. Fig.3(a) shows the contours of equivalent stress induced by different overlapping rates. As shown in Fig.3(a), for the 75% overlap case, the center of the laser spot is lapped just on the center of the former spot radius and the maximum compressive residual stress occurs on the center of the spot radius, which just counteracts the influence of the "stress holes". Therefore, the residual stress distribution is more uniform. Fig.3(b) indicates the transverse residual stresses distribution under multiple LSP shots and φ=75% overlapping rate. In the cases of the same laser overlap rate (75%), the average compressive residual stress and depth of compressive stress layer are increased with increasing LSP shots, but their values tend to be constant after 4 laser shots.

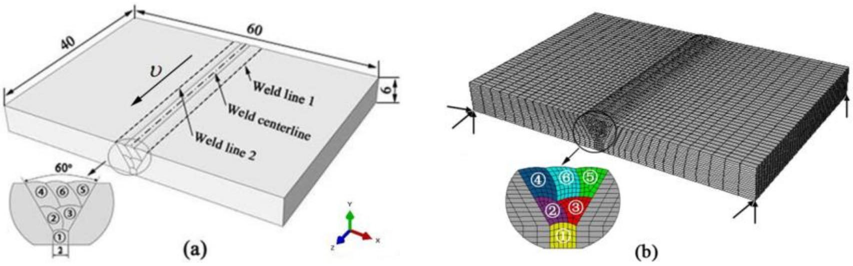

Fig. 1. Analysis model: (a) Geometry model, and (b) 3D finite element model and weld pass locations of the butt-welded joint (all dimensions in "mm").

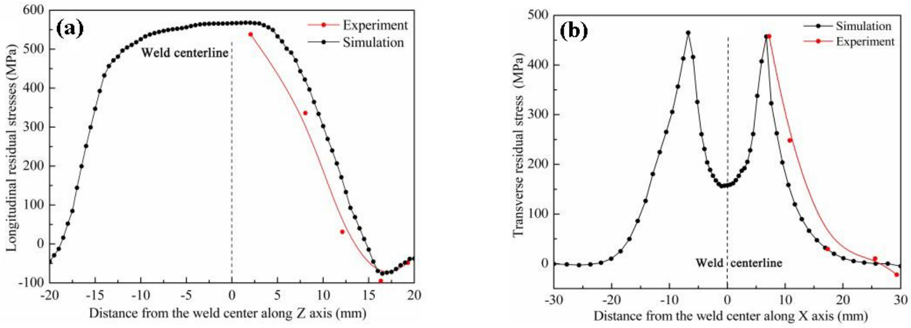

Fig. 2. The comparison of weld residual stresses: (a) longitudinal and (b) transverse residual stresses computed in the present paper and measured by Thibault [3]

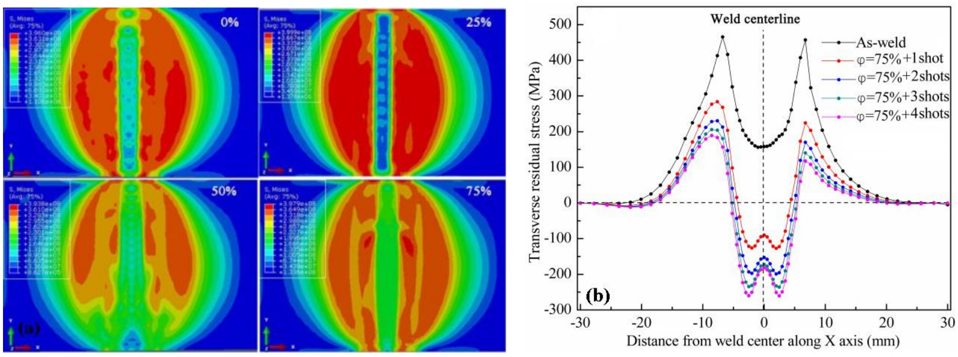

Fig. 3. (a) The contours of equivalent stress under different overlapping rates and (b) transverse stress under multiple LSP shots with the overlapping rate of 75%

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