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Numerical modeling of laser welding process of NiTi shape memory alloy

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Abstract

Shape memory alloys (SMAs) are currently used in several applications due to their unique characteristics such as shape memory effect and superelasticity. The usage of NiTi shape memory in complex structures is limited due to the inadequacy of laser joining processes in minimizing the thermal effect on the SME and SE behaviors. In fact, laser welding of SMAs is a challenging process based on the specific behavior of the material in different temperatures and stresses conditions. The aim of the present study is to investigate the reliability and the consistency of a finite element model to predict thermo-mechanical behavior induced by the laser welding. Effects of the heat source distribution, laser power and scan speed on the temperature changes are investigated. Accordingly, the transient temperature distributions and bead dimensions of the welded NiTi plates during welding will be predicted. The numerical model is utilized to predict both the fusion and the heat affected zone. Obviously, achieving the optimum laser parameters has a significant influence on the quality of welded parts so that the HAZ dimension will be reduced, consequently improving the weldability. Simulation results demonstrate a good agreement with experimental temperature distributions, which were recorded by a thermocouple during the welding process. The thermal effect on the weld geometries was also comparable with the experimental results. Indeed, the control of laser parameters can effectively improve the mechanical and functional behavior of the NiTi welded component.

Keywords: Laser welding; Shape memory alloy; NiTi; Finite element method

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1. Introduction

NiTi shape memory alloy (SMA) is widely used in industrial applications because of its unique functional properties, including shape memory effect (SME) and superelasticity (SE) (Elahinia et al., 2014). The transformation mechanism of SMAs is caused by the phase transformation from martensite to austenite, which can be activated by temperature, stress or magnetic fields (Mehrpouya and Bidsorkhi, 2016, Elahinia, 2015). Poor workability of NiTi alloys by conventional methods is due to their high ductility and work-hardening (Mehrpouya et al., 2017). Therefore, an appropriate joining method can enhance the possibility of achieving complex shape components (Oliveira et al., 2017). Laser welding is an economic method for joining NiTi alloys but it is still challenging, since having an acceptable joint strength is not the only requirement. Also, the shape memory response and superelasticity of the joint can be changed by the heating process (Oliveira et al., 2015). Controlling laser parameters allows to obtain better results from laser processes (Gisario et al., 2016b, Gisario et al., 2016a). Indeed, these parameters have a direct influence on the size of heat affected zone (HAZ) and fusion zone (FZ). Hence, finding optimum parameters and developing an appropriate technique can reduce HAZ and FZ regions, and consequently improve the weldability of NiTi alloy. This paper investigates a numerical model to predict the temperature distribution for laser welding of NiTi alloy based on various laser parameters.

2. Finite element modeling

The welding simulation was carried out by ABAQUS 6.11 software using DFLUX code for thermal distribution analysis (Huang et al., 2011). The physical dimension and properties are taken from laser welding of Ni54.7Ti shape memory sheets, performed by a diode laser. Figure 1 shows a multi-layer mesh for two pieces of NiTi sheets which are positioned in front of each other. As shown, the mesh geometry is dense in the laser path for achieving a more accurate result in this region. The temperature distribution resulting from laser welding modeling is exhibited in figure 2, in the middle of the workpiece, along a laser pass when laser power and scan speed are 500 W and 5 mm/s, respectively. As visible, FZ and HAZ geometries are characterized by specific temperature values along the laser path. Therefore, it is possible to investigate FZ and HAZ dimension based on various laser parameters with this FE model.

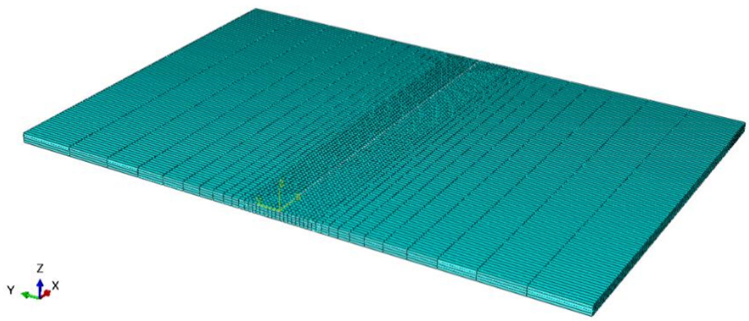

Fig. 1. Mesh geometry

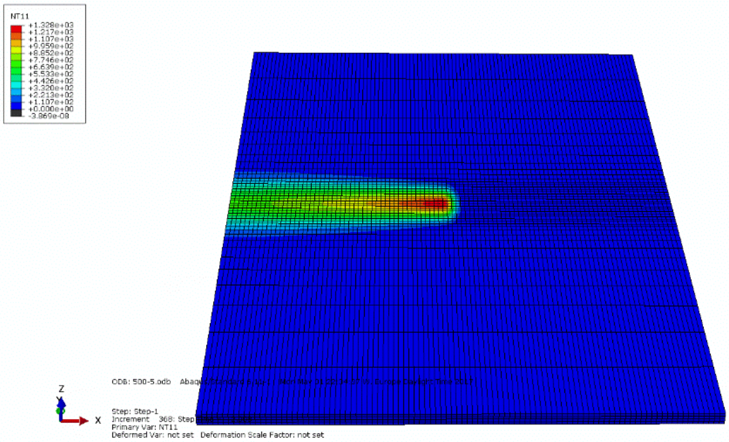

Fig. 2. Temperature distribution on the surface of NiTi sheet when V=5 mm/s and P=500 W

3. Result and discussion

Figure 3 represents a 3D map of the maximum temperature based on various laser parameters including laser power and scan speed. This temperature is recorded by a thermocouple during the experiment, which was embedded under the workpiece, 2 mm from the fusion line, inside the heat affected zone. Although the temperature increases when laser power and scan speed rise, the influence on temperature of laser power is significantly higher. The maximum temperature achieved from the simulation results has a similar trend, as shown in figure 4. The influence of laser power is dramatically higher than scan speed on the stored maximum temperature. Accordingly, the simulation matches with good accuracy the experimental results.

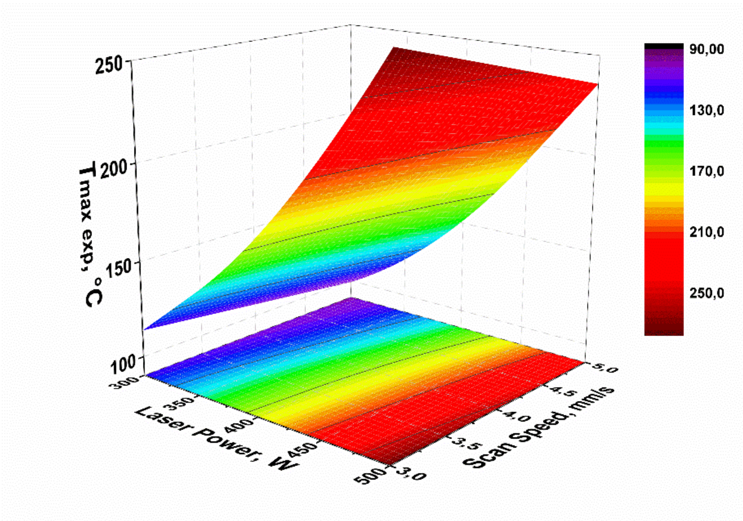

Fig. 3. 3D map of maximum temperature-laser power-scan speed based on experiment results

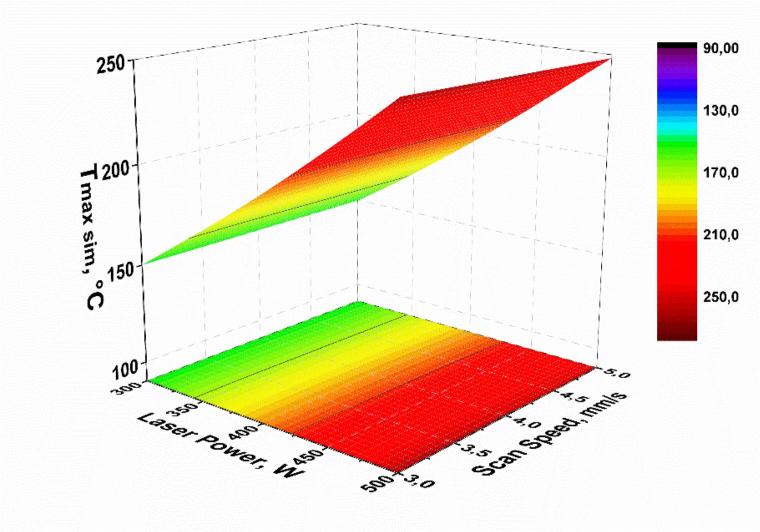

Fig. 4. 3D map of maximum temperature-laser power-scan speed achieved from the simulation results

Finite element modeling was applied to predict the thermal distribution on the surface of NiTi sheets during the laser welding process by varying several laser parameters such as laser power and scan speed. Finding the optimum parameters can improve the laser welding process and, consequently, decrease the FZ and HAZ dimensions. Therefore, the shape memory response of NiTi alloy can be improved by reducing thermal distortions in the welded zone due to laser irradiation. Further studies will investigate the effect of a pre-heating step of the substrate on weldability of NiTi alloy.

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