Studies on Numerical Simulation of Temperature Distribution in Laser Beam Welding of 304L Austenitic Stainless Steel

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ABSTRACT

A numerical simulation of temperature distribution in laser welding of 304L austenitic stainless steel have been investigated in the present research work. A three-dimensional Gaussian conical moving heat source has been implemented in the present numerical simulation using ANSYS software package. Temperature-dependent thermal physical properties of 304L austenitic stainless steel have been considered, which affects the temperature profile in the weldment. The effect of laser welding process parameters, namely, average beam power, welding speed, and laser spot diameter on weld bead geometry have been studied. The temperature distribution obtained from the numerical results at different positions away from the weld line were found to be in good agreement with the experimental results. The shape of the weld pool profile obtained through numerical simulation are in good agreement with the experimental results. Mechanical properties of the welded joint have also been studied. The ultimate tensile strength of the laser welded sample was equal to the base metal 304L austenitic stainless steel.

KEYWORDS
Butt Joint, Heat Source, Laser Welding, Numerical Simulation, Temperature Distribution, Thermocouple

INTRODUCTION

Laser beam welding is a high-power density welding process. It is a widely growing technology comparative to other welding processes because of its smooth, precise and effective operation. It has many advantages over other welding processes as it is very fast process, comparatively less heat affected zone and less distortion of the weldment. Many numerical simulation models have been developed to study the temperature distribution, residual stresses and distortion over the last decade by many researchers, because it is economical as well as time saving. Numerical modelling and simulation have been an evolution in the area of joining of materials as many complex physical phenomena during welding could be easily simulated and used to optimize the welding process parameters. Laser welding is a non-conventional welding process for joining wide range similar and dissimilar materials. Laser welding has wide application in automotive and aerospace industry, which has made it an important area of research over the last decade. Many researchers have been working to determine the temperature distribution and weld bead geometry during laser welding using both analytical and numerical methods.

Rosenthal (1946) developed an analytical method for solving temperature distribution of the welded joint considering point, line or plane heat source. Rosenthal solutions give accurate results.
for peak temperature less than 20 percent of the melting point. Steen et al. (1998) studied analytical modelling for temperature distribution of laser welding using point and line heat source and numerically calculated the weld profiles and compared with experimental weld profiles. They also estimated the ratio of laser power absorbed in the welded region. Line heat source resembles power absorption in keyhole downward and point heat source resembles plasma radiation from the keyhole. Frewin and Scott (1999) studied pulsed laser welding and developed three-dimensional finite element model of heat flow using a subroutine in ANSYS APDL. They investigated the dimensions of heat affected zone and fusion zone and transient temperature profile. Carmignani et al. (1999) investigated the residual stresses and strains in laser welding of austenitic stainless steel 304L sheet of 10mm thickness with maximum laser beam power of 15KW. Numerical simulation of temperature distribution and stress field developed during laser welding have been measured as a function of welding speed using ABAQUS. De et al. (2003) studied the temperature field around the weld pool of laser spot welds for evaluating the dimension of the weld pool. Temperature gradient in and around the weld pool is required for predicting the mechanical properties of the weld which depends on the cooling rate of the welded joint. Numerical simulation of laser beam welding process using a nonlinear heat transfer analysis based on the keyhole formation and coupled with transient thermo-mechanical analysis were studied by Tsirkas et al. (2003). They also studied the phase transformation during laser welding using the continuous cooling transformation diagram. GuoMing et al. (2007) examined the temperature distribution in laser beam welding of stainless steel 304L using finite element analysis simulation software package ANSYS, and observed that as the heat source moves the temperature profile of the workpiece varies with time and space. The temperature gradient of laser beam welding was large, and heat affected zone was small compared to other welding processes. Spina et al. (2007) investigated the numerical simulation of laser welding of AA5083 alloys using finite element method for predicting the thermal and mechanical fields in form of temperature, stress and strain distribution and compared their results with experimental values with good agreement. Sabbaghzadeh et al. (2008) studied the numerical simulation of pulsed laser welding by two different methods namely finite element method and finite difference method for predicting the temperature profiles and weld bead geometry. Both the numerical results were compared with the experimental values and were found in good agreement.

Balasubramanian et al. (2008) numerically evaluated the temperature distribution and weld bead geometry using finite element analysis code SYSWELD for different laser process parameters and compared the results with experimental. They observed that the best optimized laser process parameter for full penetration of the welded joint was beam power of 1250W, laser welding speed of 750mm/min and beam incident angle of 90 degree. Shanmugam et al. (2009) studied the numerical modelling of laser welding of austenitic stainless steel of 2.5mm thickness using ANSYS to determine the temperature profile and shape of molten pool and compared with experimental results with good accuracy. Kazemi and Goldak (2009) studied a 3D FEM using ANSYS to numerically simulate the Nd:YAG laser beam welding of AISI 304L sheet of thickness 4mm, considering the effect of temperature dependent material properties such as thermal conductivity and density. They observed that the Peclet number, thermal conductivity and absorption coefficient of the material are the three parameters which affects the weld geometry. They developed a numerical model using both line and point heat source for better prediction of keyhole weld geometry. Bag et al. (2009) developed 2D axis symmetric, FEM numerical model to study the heat flow in laser spot welding with combined effect of adaptively defined volumetric heat source and surface heat flux. Numerical modelling of conduction-based laser welding can be improved by using adaptive volumetric heat source.

Capriccioli and Frosl (2009) studied and compared three dimensional numerical models for both TIG and laser welding of INCONEL 625 and AISI 316 using birth and death technique in ANSYS for thermal and mechanical simulation. They determined the fusion zone of the welded joint for both TIG and laser welding and compared with experimental values with good agreement. Akman et al. (2009) studied the laser welding of titanium alloy of 3mm thickness with pulsed Nd:YAG laser. They observed the effect of variation of laser process parameters on depth of penetration and
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