Materials and Design 34 (2012) 412–426

Contents lists available at SciVerse ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Some studies on weld bead geometries for laser spot welding process using finite element analysis

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ARTICLE INFO

Article history:
Received 14 January 2011
Accepted 2 August 2011
Available online 22 August 2011

Keywords:
Lasers
Welding
Thermal

ABSTRACT

Nd:YAG laser beam welding is a high power density welding process which has the capability to focus the beam to a very small spot diameter of about 0.4 mm. It has favorable characteristics namely, low heat input, narrow heat affected zone and lower distortions, as compared to conventional welding processes. In this study, finite element method (FEM) is applied for predicting the weld bead geometry i.e. bead length (BL), bead width (BW) and depth of penetration (DP) in laser spot welding of AISI 304 stainless steel sheet of thickness 2.5 mm. The input parameters of laser spot welding such as beam power, incident angle of the beam and beam exposure time are varied for conducting experimental trials and numerical simulations. Temperature-dependent thermal properties of AISI 304 stainless steel, the effect of latent heat of fusion, and the convective and radiative aspects of boundary conditions are considered while developing the finite element model. The heat input to the developed model is assumed to be a three-dimensional conical Gaussian heat source. Finite-element simulations of laser spot welding were carried out by using Ansys Parametric Design Language (APDL) available in finite-element code, ANSYS. The results of the numerical analysis provide the shape of the weld beads for different ranges of laser input parameters that are subsequently compared with the results obtained through experimentation and it is found that they are in good agreement.

1. Introduction

Nowadays, laser spot welding is widely recognized as an important modern joining technology, especially in the field of industrial manufacturing applications. The nature of the laser beam enables it to be irradiated on a very small spot on the substrate material, allowing the beam to achieve high power density. This type of welding process is particularly useful in cases where the localized heating is required. The advantages of using laser welding over other conventional welding technologies are the generation of high weld bead depth-to-width ratio, low distortion, narrow Heat Affected Zone (HAZ), reliability and low heat input [1]. Hence, it is widely employed in welding applications requiring high quality and precision, including electronic components, spaceflight and aviation, automobile, medical treatment, etc. During the laser spot welding process, a high energy laser beam (10^5–10^6 W/cm^2) quickly melts the surface of a workpiece material. The beam ionizes the melted material and the available material under the beam partly evaporates leaving a hole named as ‘keyhole’ and creates a plasma plume. The plasma plume expands to a variable extent, depending on the laser beam features, process input parameters and the surrounding atmosphere.

In fact, austenitic stainless steels are often welded using high energy laser beams in industrial processes which produces good metallurgical bonding, high production rate and increases high automation possibilities. Especially, the laser spot welding of AISI 304 austenitic stainless steel is used in several areas, including electronics, medical instruments, home appliances, automotive and specialized tube industry. These types of stainless steels have many characteristics like high resistance to corrosion, low thermal conductivity and high stability at elevated temperatures. In addition to that, the above mentioned steel is a superior absorber of laser light. The quality of the weld and the weld bead dimensions of laser spot welds produced by using a Continuous Wave (CW) Nd:YAG laser welding depends on various input parameters such as beam power, welding speed, beam incident angle, beam exposure time and beam density distribution. The main challenge for the manufacturer is to characterize and specify the laser weld input parameters for a given product. This is usually done by trial and error where the knowledge and experience of engineers/machine operator plays a major role. Further, the weld is inspected to determine the standards specification. Traditional trial and error approaches based on conducting actual experimental welding trials have encountered many difficulties to optimize the laser welding process parameters [2].

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doi:10.1016/j.matdes.2011.08.005

Table 1
Chemical Composition of AISI 304 stainless steel.

Component	C	Cr	Fe	Mn	Ni	P	S	Si
wt.%	0.055	18.28	66.34	1.00	8.48	0.029	0.005	0.6

Weld bead dimensions (depth of penetration, bead length and bead width) are the primary requirement of laser welding, since strength and final shapes are often critical measures of quality. The weld bead geometry can be predicted for different process input parameters from the temperature distribution plots and it is difficult to measure the temperature field of welding, especially in the high energy density process.

As the laser beam impinging on the substrate material (workpiece) over a very short span of time, the workpiece is subjected to very rapid heating and cooling cycles. Every point in the spot weld experiences a complex series of thermal cycles during the passage of the laser beam. This makes the condition quite complicated for analytical modeling techniques. Therefore, the numerical model is the preferred option for simulating these thermal cycles for the combination of laser input parameters. The latest advancement in computing technology and numerical techniques is that the numerical simulations have begun to take a realistic method for the prediction of laser welding parameters for a specific product. The simulations based on FEM are very useful in predicting the weld pool shape and dimensions from the thermal simulation results at an early stage of product design [3].

The study of thermal cycles in welding was initially attempted using both analytical and numerical methods. The elementary welding heat source models were based mostly on Rosenthal's solutions [4]. He proposed a mathematical model for a moving heat source under the assumptions of quasi-stationary state and concentrated point heating in three dimensional analyses. Ehlen et al. [5] investigated how the weld pool shape during laser welding is influenced by Marangoni convection. They studied the different types of weld pool dynamics that can occur in laser welding systems for different welding powers. They also calculated the transient distribution of temperatures, phase fractions, flow velocities, pressures and concentration of alloying elements in the melt and two solid phases for a stationary laser welding process. The penetration depth, nugget size and bead width of laser spot welds on AISI 304 stainless steel were studied by Chang and Na [6] using

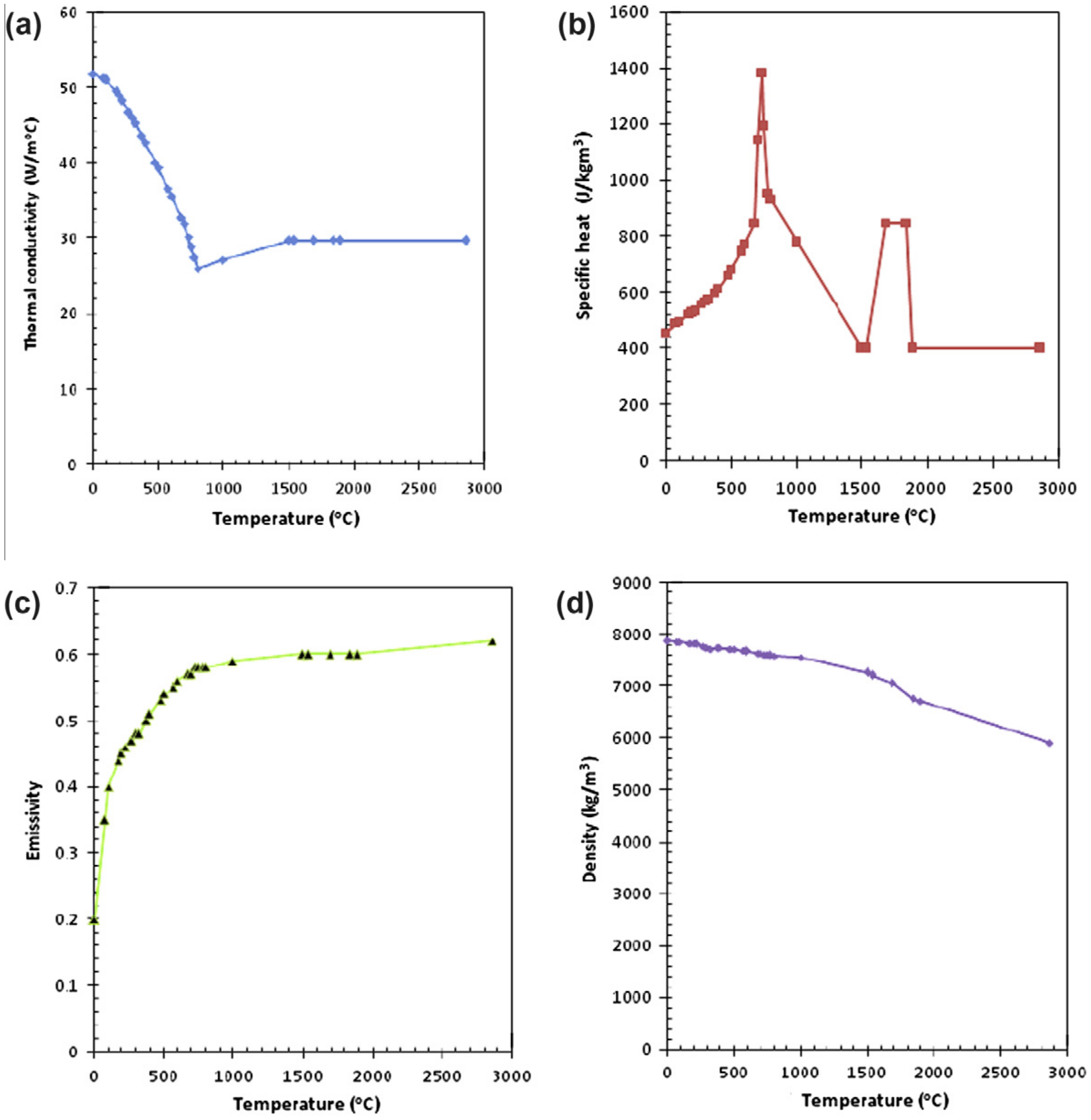

Fig. 1. (a)–(d) Variation of thermo-physical material properties of AISI 304 SS.