JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Review on Laser Beam Welding

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Abstract*: In industries, lasers are used in wide variety of processes like bending, cutting or welding. The welding process is performed using high heat source of laser beam which facilitates deep and narrow welds which are very useful in welding automotive parts. The current research studies the various researches conducting in the field of laser welding using experimental and numerical methods. The strengths and limitations of different laser beam process and welds are also discussed.*

Key Words: Laser beam, welding

1. INTRODUCTION:

Lasers are now being used in the automotive industry to produce seam or stitch welds, as alternatives to conventional resistance spot welding, which are used extensively for attaching auto-body panels to sub-assemblies. The advantages of laser welding over resistance spot welding result from the smallness of the laser spot size, the large penetration depth of the weld into the material and the requirement that only singlesided access to the workpiece is necessary. Further, the equipment used to carry out the welds can be easily adapted to new vehicle program changes, unlike that used for resistance spot welding [1]. Potential benefits realized by the application of laser welding include reduced flange widths, increased structural strength and high-speed automated processing. Traditionally CO2 lasers have been used for auto body applications. Recent advances have been made with Nd:YAG lasers, which are now capable of producing beam powers of more than 2 kW or more through a fibre optic cable. This is particularly useful for robotic operations, where it is necessary to manipulate the laser beam about a stationary part. Lasers are also used in the manufacture of tailored blanks, where suitably prepared sheet metal, including differing thickness and material combinations, are butt welded together prior to being pressed into the finished shape. This results in considerable cost and weight savings and increases structural rigidity [2].

2. LITERATURE REVIEW

Lampa et al. [3] used a series of point sources with an enhanced value of the thermal conductivity in the upper part of the weld region to account for the Maragoni flow in the weld pool, which increases lateral thermal transport and thereby causes a widening of the weld pool. The strength of the 'line' source was assumed to decrease linearly with depth and a larger value for the conductivity was used at the top. The strengths of the point sources were calculated to match the experimental weld profiles. The inclusion of the Maragoni effect is important for predicting the penetration depth. This thermocapillary flow has a diminishing influence on the heat distribution in the weld zone as the welding speed is increased, the effect becomes insignificant for speeds greater than 4 m/min (66 mm/s).

Steen et al. [4] used Rosenthal's line source solution with a point source on the top surface to model the broadening of the weld in the upper layer. The results were used to model experimental weld shapes.

Akhter et al. [5] used the solution for a moving point source to derive a solution for a line source, where the source strength varies along the length of the line. This solution was used to model the shape of the fusion zone.

Resch et al.[6] also used Rosenthal's solution for a point source and integrated over a line of point sources.

Hilton et al. [7] calculated the temperature distribution using an analytical solution to the heat conduction equation and determined the weld pool profile from the shape of the melting isotherm. The keyhole radius, as a function of depth down the weld, could also be calculated.

Tsai and Kou [8] used the line source solution but with a strength which obeyed Beer Lambert's law, so the power absorbed at a depth z is given by

$$-\frac{dI}{dz} = q(z) = \beta I_o e^{-\beta z}$$

where β is the absorption coefficient and Io is the power of the beam at z=0. They provided an analytical solution for this case, however, which did produce a widening of the weld shape near the top, but the broadening was less than that observed experimentally. Beer Lambert's law describes a cross-section for energy absorption which remains constant throughout the depth of the material. Tsai and Kou then go on to introduce a modified version of Beer Lambert's law in which the cross-section does not remain constant with depth:

$$-\frac{dI}{dz} = q(z) = \beta\left(I_o - \int_0^z \gamma \, dz\right) e^{-\beta z} + \gamma$$

If γ=0 then Beer Lambert's law is recovered. When γ =I_0/g=constant, then it is equivalent to a uniform line source. They consider the case of a constant value for γ and produce an analytical solution. Increasing β or decreasing γ resulted in more power being absorbed near the top of the weld.

Metzbower et al. [9] used the results of Tsai and Kou to model the shape of the fusion zone. Calculations of the thermal profile at the centre of the weldment gave the cooling time from 800 to 500 deg. as being about 1.6 seconds for a 12 kW CO2 laser with a spot size of 3.56 mm and a travel speed of 11 mm/s and a He shielding gas. A conductivity of 31 W/m/K was used. The calculated cooling curves were essentially identical for distances of up to 1mm from the centre of the weld.

Lankalapalli et al. [10,11] used a 2-d analytical solution to the problem of heat flow from a cylindrical heat source to solve the problem of a 3-d conical shaped heat source (the keyhole). As the keyhole is conical, the amount of heat absorbed per unit depth decreased with depth. Heat losses from the top and bottom surfaces were ignored and heat conduction in the z-direction was neglected. The temperature distribution was obtained by integrating the 2-d solution over the depth of the keyhole. The strength of the heat source with depth was expressed in terms of the Péclet number (va/2"), where v is the speed, a the radius of the keyhole and " the thermal diffusivity. A semi-empirical expression for the keyhole size was given in terms of the Péclet number and weld width for low-carbon steels. The penetration of the weld was used as an initial estimate of the depth of the keyhole line source. The equation for the temperature distribution was evaluated to obtain the evaporation and melting isotherms which gave the keyhole and weld shapes. The temperature distribution was used to relate the temperature on the bottom surface with the penetration depth. Calculated depths were compared with experimental penetration depths for bead-on-plate welds on AISI 1020 cold rolled steel (low C steel) of thicknesses 0.6-1cm.4-5.3kW Rofin Sinar 6000 laser; welding speeds 2-3.4cm/s. Good agreement was obtained for most welds, although in some cases the depths were overestimated by up to 25%. The measured temperature was a function not only of penetration but also factors such as weld bead width, welding speed and measurement location. The source of errors included assumed keyhole shape, fluid flow in the molten pool, latent heat effects, sensor-sample distance and alignment.

Phanikumar et al. [12] modelled the welding procedure in a weld between dissimilar metals by considering the melting and mixing of the fluid forming the weld pool when a gaussian heat input was applied to the join between the workpieces. The coupled continuity, momentum, energy and mass-fraction equations along the boundary were solved numerically. Radiative and convective heat losses on the top and side surfaces were taken into account. Heat transfer occurred at the interface due to the different heat capacities and temperature gradients. Convection caused a heat flow to occur to move hot fluid to the cooler outer edges of the weld pool. The computations were carried out for a stationary spot welding and agreed qualitatively with experimental results from a weld between a piece of Ni and Cu.

Kar et al. [13] obtained numerical solutions of the equation governing heat conduction and fluid/gas movement at the solid/liquid and liquid/gas interfaces. They considered conservation of energy and mass and fluid convection in the model to obtain values for the free surface velocity, the keyhole depth and the weld width and depth. They concluded that the temperature gradient is higher in the trailing edge side of the keyhole.

Dowden et al. [14] also considered fluid flow around the keyhole and also showed that at the rear of the keyhole a considerable drop in temperature can occur. For some metals, including iron, the temperature may not be far off the freezing temperature.

Resch et al. [15] used the solution for a moving point source at radius R (from Rosenthal):

$$T(x,y,z)=T_a+\frac{q}{2\pi kR}\exp\left[-\frac{v}{2\kappa}(\xi+R)\right] \qquad \xi=x-vt \qquad R=\sqrt{\xi^2+y^2+z^2}$$

where is the thermal diffusivity, is the velocity of the point source and is the ambient temperature. This equation was used to calculate the temperature field of an extended source by integrating over a series of point sources of specified strength along a path down to a depth equal to the penetration depth. As the penetration depth was not known, an algorithm was used to carry out the calculations iteratively to provide a self-consistent value for the final depth of the laser beam. The material properties were assumed to be constant. The calculations were carried out numerically using the algorithm and a mesh for welds in 2 mm thick mild steel at a speed of 3 m/min (50 mm/s) with an absorption coefficient of 0.3. A 500 W beam produced a penetration of 0.5mm with 3-d heat conduction. At 1.5kW the transition from conduction to keyhole welding occurred with a penetration of 1.7mm. 3-d conduction occurred at the bottom of the weld, but conduction was almost planar in the upper region. A deep keyhole was produced for a 2kW beam; the result being similar to that from the 2-d heat conduction equation for a moving line source. Plasma arc augmented welding was modelled by superimposing two heat sources: a line source for the keyhole formation by the laser beam and one of decreasing intensity with depth for the heat input from the plasma. This simulates the widening of the melt pool at the top. They also considered twin welding (a laser beam from either side of the workpiece) and showed isotherms for a laterally inclined weld (12 deg.).

Goldak et al. [16] used a finite element analysis for calculating the temperature field and cooling curves. A gaussian distribution of the heat source was assumed which had a double elliptical shape. A comparison of results with experiment and with Rosenthal's heat source calculations gave the following results for the cooling time from 800 to 500 °C.

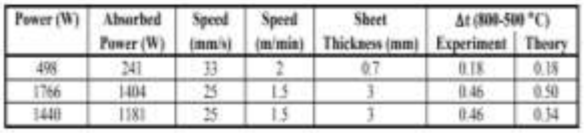
Doong et al. [17] gave the following experimental measurements of the surface temperature of butt welds in AISI 1045 steel and AISI 304 stainless steel using a 2.5kW CO_2 cw laser with a gaussian TEM00 mode laser beam.

Zambon et al. [18] calculated the cooling curves for CO_2 laser welds in stainless steel using an analytical model. Calculations for a weld in a 2.1 mm thick sheet of UNS S 31803 steel with a 3 kW power laser (conductivity=25 W/m/K, diffusivity = 7x10-6 m 2 /s, density=7858 kg/m3 , heat capacity=454.5 J/kg/K) gave a cooling rate of 1950 °C/s at 700 °C, whilst the time to cool from 800 to 500 °C was about 0.2 seconds.

Ion et al. [19] used Rosenthal's solution for a point source moving along a surface and extended it to consider a circular disc source moving along the surface. This did not affect the time taken to cool from 800 to 500 °C.

Grabás et al. [20] used a semi-analytical method for calculating a 3-d temperature field. They produce a solution for a plate of thickness L with a moving gaussian heat source distributed over a depth L'. (Details of the calculations were given elsewhere.) The material properties were assumed to be temperature independent. Some experimental cooling rates were given which showed a temperature increase in the 800 to 500 °C region. The time taken to cool from 800 to 500 °C agreed fairly well with their calculated values as shown in table 3.

Table 3 Experimental and theoretical cooling times for several different laser processing times [20]



Power (W)	Absorbed Power (W)	Speed (mm/s)	Speed (m/min)	Sheet Thickness (mm)	Δt (800-500 °C)	
					Experiment	Theory
498	241	33	2	0.7	0.18	0.18
1766	1404	25	1.5	3	0.46	0.50
1440	1181	25	1.5	3	0.46	0.34

3. CONCLUSION

From the various researches conducted on laser beam welding it is established that the quality of weld joints is significantly affected by laser power and speed of cut. The cooling of weld joints affects the micro structure of welded joints. The numerical solutions and analytical solutions related to weld pool profile and keyhole are presented by various scholars and it's observed that temperature gradient is higher in the trailing edge side of the keyhole specimen.

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