A Review of Laser Welding Process for Thin Steel Sheets

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Abstract:
This paper describes a variety of fundamental research results of laser welding of thin steel sheets which the authors have recently performed. Laser welding will be a vital joining technique for thin steel sheets with their increasing applications in aerospace, aircraft, automotive, electronics and other industries. In this review the research and progress in laser welding of thin steel sheets are critically reviewed from different perspectives. Basically two types of industrial lasers, carbon dioxide (CO2) and neodymium-doped yttrium aluminum garnet (Nd: YAG), have been used to weld the thin steel sheets. Some important laser processing parameters and their effects on weld quality are discussed.

Keywords: *Full factorial design (FFD), Laser welding, Mechanical properties, Optimization, Steel sheets*

1. Introduction

Laser Beam Welding (LBW) is a modern welding process used to join multiple pieces of similar and dissimilar metal through the use of a laser beam. Laser welding is based on the interaction of laser light with matter. In general, laser is focused on the material surface and is partially absorbed. The first step in laser welding is laser absorption. The absorbed energy is transferred into bulk material by conduction. The laser energy absorbed by the material starts to heat and melts the material. The melting material will solidify instantly to form a weld. Due to its wide variety of application an experimental investigation and prediction of the process is of utmost important. In this paper influence of various input parameters on the varieties of output parameters related to laser welding process is reviewed.

2. Literature Review

P. Sathiya, K. Panneerselvam and R. Soundararajan (2012) have worked on optimal design for laser beam butt welding process parameter using artificial neural networks and genetic algorithm for super austenitic stainless steel. In that study, the weld bead geometry such as depth of penetration (DP), bead width (BW) and tensile strength (TS) of the laser welded butt joints made of AISI 904L super austenitic stainless steel were investigated. They have used full factorial design to carry out the experimental design. They have developed Artificial Neural networks (ANN) program in Matlab software to establish the relationships between the laser welding input parameters like beam power, travel speed and focal position and the three responses DP, BW and TS in three different shielding gases(Argon, Helium and Nitrogen). The established models were used for optimizing the process parameters using Genetic Algorithm (GA). Optimum solutions for the three different gases and their respective responses were obtained. They have also conducted Confirmation experiment to validate the optimized parameters obtained from GA. The good agreement between the theoretically predicted (GA) and experimentally obtained tensile strength, depth of penetration and bead width confirms the applicability of these evolutionary computational techniques for optimization of process parameters in the welding process.

M.s.w glowski, K. kwieciski, K. krasnowski and R. jachym (2009) have studied the Characteristics of Nd: YAG laser welded joints of dual phase steel. They have presented the examination results of microstructure, mechanical properties, fatigue strength and residual stresses of Nd: YAG laser welded joints in dual phase HDT580X steel. In the investigation, the microstructures have been studied by optical and scanning microscopy. Mechanical properties have been analyzed by tensile, bend and hardness tests. Additionally fatigue tests and residual stress measurements were carried out. The results revealed that the HDT 580X steel was characterized by good laser weldability. The tensile strength of welded joints was at the same level as that of the base metal. They have concluded that the laser welding parameters were appropriate to obtain sound welds. They have indicated that it was possible to achieve good quality welds by the application of proper welding parameters.

A. Ruggiero, L.Tricarico, A.G.Olabi and K.Y.Benyounis (2011) have investigated Weld-bead profile and costs optimization of the CO2 dissimilar laser welding process of low carbon steel and austenitic steel AISI316. The effect of laser power(1.1–1.43kW), welding speed(25– 75 cm/min) and focal point position(- 0.8 to - 0.2 mm) on the weld-bead geometry (i.e. weld-bead area, A; upper width, Wu; lower width, Wl and middle width, Wm) and on the operating cost C was investigated using response surface methodology (RSM).They have used Box– Behnken design for experimental plan; linear and quadratic polynomial equations for predicting the weld-bead width references were developed. The results indicate that the proposed models predict the responses adequately within the limits of welding parameters being used. They have used regression equations to find optimum welding conditions for the desired geometric criteria. They have concluded that the welding speed is the parameter that most significantly influences the main weld bead dimensions.

A Ribolla, G.L. Damoulis and G.F. Batalh (2005) have investigated the use of Nd: YAG laser weld for large scale volume assembly of automotive body in white. They have suggested some advantages in laser welding as a variety of benefits over other types of welding. Deep penetration of precise narrow welds, small heat affected zone, low heat input, fast weld times, minimum part distortion, no secondary processing and high repeatability can be mentioned as great advantages. In large scale production, the continuous average power at the work piece delivered by a 4 kW, continuous-wave Nd: YAG laser source can be used for body large scale welding of steel alloys, which is still dependent on surface preparation.

Alexandra P. Costaa, Lui´sa Quintinoa, and Martin Greitmannb (2003) have worked on Laser beam welding hard metals to steel. They have examined Laser beam weldability of hard metals to steel with high power (cw) CO2 laser, (cw) Nd: YAG laser and (pw) Nd: YAG laser. Steel/ hard metal joints, with 2.5 mm thickness, welded by the three laser systems, for comparison. Two different hard metals compositions (K10 and K40) were examined. Power (P), speed (s) and vertical focal point position (f.p.p.) were investigated. To reduce the problem of porosity and crack formation in the hard metal, the parameter, tw, horizontal distance from the beam to the joint was also investigated. Weld bead size, microstructure, bending tests and hardness were evaluated. The welding parameters influence was studied in order to obtain full penetration and high resistant joints. Continuous lasers leads to full penetration, high resistant and low cracking weld joints. The horizontal f.p.p. (tw) is an important parameter to prevent overheating of the hard metal and the risk of crack formation. The vertical f.p.p. is also an important parameter to achieve full penetration and high resistant joints. In fact this process has the overall advantage of producing small beads and HAZ and minimizing residual stresses. Continuous Nd: YAG laser was found to present the best results.

Yang dongxia and Lixiaoyan (2012) has worked on Optimization of weld bead geometry in laser welding with filler wire process using Taguchi's approach. In their work, laser welding with filler wire was successfully applied to joining a new-type Al–Mg alloy. Welding parameters of laser power, welding speed and wire feed rate were carefully selected with the objective of producing a weld joint with the minimum weld bead width and the fusion zone area. Taguchi approach was used as a statistical design of experimental technique for optimizing the selected welding parameters. From the experimental results, they have found that the effect of welding parameters on the welding quality decreased in the order of welding speed, wire feed rate, and laser power. The optimal combination of welding parameters was the laser power of 2.4 kW, welding speed of 3 m/min and the wire feed rate of 2 m/min. Verification experiments have also been conducted to validate the optimized parameters. S/N ratio analysis and ANOVA were used to investigate the influence of process parameters (including laser power, welding speed and wire feed rate) on the upper width, lower width and the fusion zone area. The welding speed is the most significant parameter that influences the weld bead geometry, while wire feed rate has relatively significant effect on the upper width and the fusion zone area.

B.S. Yilbas n, A.F.M. Arif ,B.J. Abdul Aleem (2010) have carried out Laser welding of mild steel sheets under nitrogen assisting gas ambient. They have computed Temperature and stress fields in the welding region through the finite element method. The residual stress developed in the welding region was measured using the XRD technique and the results were compared with the predictions. Optical microscopy and the SEM were used for the metallurgical examination of the welding sites. They have found that von Mises stress attains high values in the cooling cycle after the solidification of the molten regions. The residual stress predicted agreed well with the XRD results. They have found that temperature decay rate in the molten zone was lower than in the solid. That was because of the absorption and dissipation of the laser energy in the molten zone which was generated in the surface region.

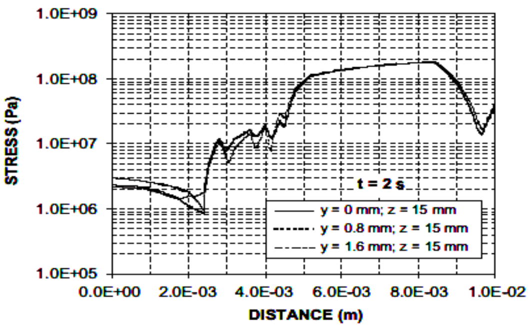

Fig. 1 Von Mises stress distribution along the x-axis at different depths below the surface and for two time periods

K. R. Balasubramanian, G. Buvanashekaran and K. Sankaranarayanasamy (2006) have worked on Mathematical and ANN Modeling of Nd: YAG Laser Welding of Thin SS Sheets. They have investigated Laser welding of Austenitic stainless steel (AISI 304) of thickness 3.0 mm using 2 kW CW Nd: YAG laser. The effect of laser power (0.6-1.4 kW), welding speed (0.8-2 m/min) and shielding gas flow rate (5 -15 l/min) on the weld-bead geometry i.e. depth of penetration (DOP), weld bead width (BW) was investigated.

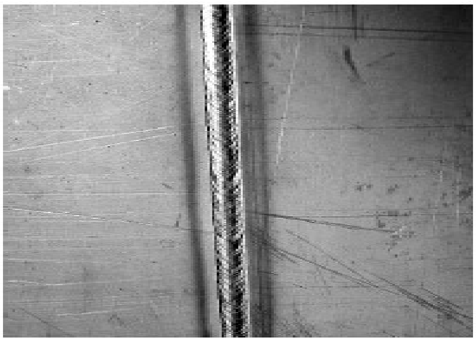

Fig. 2 Laser welded SS sheet

The experiment was designed on three levels Box-Behnken design with replication. Modeling was done using artificial neural network and multiple regression analysis. Comparison of neural network model and multiple linear regression model was made and found that error rate predicted by the artificial neural network was smaller than that predicted by multiple regression analysis in terms of the bead width and depth of penetration.

M. Masoumi, S.P.H. Marashi, M. Pouranvari, J. Sabbaghzadeh and M. J. Torkamany (2009**)** have worked on assessment of the effect of laser spot welding parameters on the joint quality using taguchi method. Laser spot welding is receiving increasing attention as a high speed technique to replace the resistance spot welding method for joining metal sheets in automotive industry. In this investigation laser spot welding was used to join low carbon steel sheets. The relationship between the joint quality and laser spot welding parameters was studied using Taguchi design of experiment method. Taguchi analysis was made to determine the most effective parameters in the investigated range on the quality of laser welded joints. To address this issue, tensile- shear tests were performed on laser spot welded joints. Joint quality and mechanical behavior are evaluated by energy absorption capability of weld before crack initiation. Optimum process parameters in the studied range were found which would ensure the desirable pullout failure mode and thus maximum failure energy.

M.M.A. Khan and L. Romoli (2012) have experimentally investigated the seam geometry, microstructure evolution and microhardness profile of laser welded martensitic stainless steels. They have investigated the effects of energy density on geometry of the weld seam and development of microstructures at various weld zones. Weld resistance at the interface is energy-limited and seam profile only changes from conical to cylindrical after a certain limit of energy input. Microstructures in the fusion zone changes from cellular to columnar dendritic and equiaxed dendritic with increasing energy input. In this study, martensitic AISI416 and AISI440Fse stainless steels were laser welded using different energy input in the range of 21.3 J/mm^2 to 48.9J/mm^2.

Jose´ Roberto Berrettaa and Wagner de Rossib (2007) have investigated the Pulsed Nd: YAG laser welding of AISI 304 to AISI 420 stainless steels. They have studied the influence of the laser beam position, with respect to the joint, on weld characteristics. Specimens were welded with the laser beam incident on the joint and moved 0.1 and 0.2mm on either side of the joint. The joints were examined in an optical microscope for cracks, pores and to determine the weld geometry. The microstructure of the weld and the heat affected zones were observed in a scanning electron microscope. An energy dispersive spectrometer, coupled to the scanning electron microscope, was used to determine variations in (weight %) the main chemical elements across the fillet weld. Vickers microhardness testing and tensile testing were carried out to determine the mechanical properties of the weld.

G. Padmanaban and V.Balasubramanian (2010) has worked on an Optimization of laser beam welding process parameters to attain maximum tensile strength in AZ31B magnesium alloy. An empirical relationship was developed to predict tensile strength of the laser beam welded AZ31B magnesium alloy by incorporating process parameters such as laser power, welding speed and focal position. The experiments were conducted based on a three factor, three level, central composite face centered design matrix with full replications technique. The empirical relationship can be used to predict the tensile strength of laser beam welded AZ31B magnesium alloy joints at 95% confidence level. The results indicate that the welding speed has the greatest influence on tensile strength, followed by laser power and focal position.

Important LBW parameters and their levels.

#	Parameters	Notation	Unit	Levels		
				−1	0	+1
1	Laser power	P	Watts	2500	3000	3500
2	Welding speed	S	m/min	4.5	5	5.5
3	Focal position	F	mm	0	−1.5	−3

Fig. 3 Important LBW parameters

Emel Taban, Eddy Deleu, Alfred Dhooge and Erdinc Kaluc (2009) have investigated the Laser welding of modified 12% Cr stainless steel: Strength, fatigue, toughness, and microstructure and corrosion properties. Recently designed modified 12% Cr stainless steel with 0.01% carbon level still conforming to EN 1.4003 and UNS S41003 grades has been joined by laser welding. Tensile and bend tests, fatigue and toughness testing were carried out while tensile and fatigue fracto graphs were examined. Toughness after the post weld heat treatments at various temperatures was examined. Micro structural investigations, hardness and ferrite content measurements as well as grain size analysis of the weld zones were done. Fairly good strength, ductility and fatigue results were obtained while microstructure–property relationship was explained.

T. Markovitsa and J. Takácsa (2010) have investigated an Edge welding of laminated steel structure by pulsed Nd: YAG laser. The construction of the electric motor components consists of laminated electrical steel structure. Next to the conventional welding the laser welding is an alternative technology to fix the laminated structure. They have analyzed the effect of the laser parameters on the geometry of the welded seam applying a pulsed Nd: YAG laser. They have suggested that Increasing welding speed decreases the sizes of weld geometry at the same energy, the laser pulse energy has a higher effect on the weld bead geometry than on the welding speed, the pulse time and welding speed have a higher effect in ranges of higher pulse energies, the pulse energy, the pulse time and the welding speed influence the width of the weld less than the depth of the weld and in order to increase the welding speed a higher average laser power range has to be applied.

C. B. Reed, K. Natesan, Z. Xu, and D. L. Smith (2009) have investigated **t**he effect of laser welding process parameters on the mechanical and micro structural properties of v-4cr-4ti structural materials. They have conducted a systematic study to examine the use of a pulsed Nd: YAG laser to weld sheet materials of V-Cr-Ti alloys and to characterize the micro structural and mechanical properties of the resulting joints. Deep penetration and defect-free welds were achieved under an optimal combination of laser parameters including focal length of lens, pulse energy, pulse repetition rate, beam travel speed, and shielding gas arrangement. The key for defect-free welds was found to be the stabilization of the keyhole and providing an escape path for the gas trapped in the weld. An innovative method was developed to obtain deep penetration and contamination-free welds. The effort directed at developing an acceptable post weld heat treatment showed that five passes of diffuse laser beam energy over the welded region softened the weld material, especially in the root region of the weld.

Cheolhee Kim, Woongyong Choi, Jeonghan Kim and Sehun Rhee (2008) have examined the Relationship between the Weldability and the Process Parameters for Laser-TIG Hybrid Welding of Galvanized Steel Sheets. They have suggested that When TIG preceding laser-TIG hybrid welding is applied to the lap joint welding of galvanized steel sheets without a gap, good welds without blowholes and bubbles can be obtained. Zinc vaporization and oxidization by heat of the preceding arc before the following laser arrives may remove the defects of the welds. Porosity is the main defect during laser lap welding of galvanized steel sheets. During laser-TIG hybrid welding, the electrode height should be maintained over 2.0mm to prevent damage to the electrode tip. When the weldability was evaluated according to the welding current, travel speed and distance between laser beam and the electrode at a fixed electrode height of 2.0 mm, the main effects of the welding current, and the welding speed were statistically significant. A lower speed welding and a higher welding current showed better weldability.

A. Klimpel and A. Lisiecki (2007) have investigated the Laser welding of butt joints of austenitic stainless steel AISI 321 sheets 0.5 [mm] and 1.0 [mm] thick using a high power diode laser HPDL. They have showed that there is a wide range of laser autogenous welding parameters which ensures high quality joints of mechanical strength not lower than the strength of the base material (BM). The butt joints of austenitic steel AISI 321 sheets welded by the HPDL diode laser at optimal parameters are very high quality, without any internal imperfections and the structure and grain size of weld metal and HAZ is very small and also the HAZ is very narrow and the fusion zone is very regular. They have suggested that the weldability of stainless steels indicate that the basic influence on the quality of welded joints and reduction of thermal distortions has the heat input of welding, moreover the highest quality of welded joints of austenitic stainless steel sheets are ensured only by laser welding.

3. Conclusion

Here, the researchers have explored the number of ways to do the laser welding on different types of materials using varieties of lasers. They have also suggested the various techniques for Design of experiment like as full factorial design, Taguchi method, Box-Behnken design and Response surface methodology. Various approaches for predicting the behavior of the laser welding process are also suggested like using ANN or by neuro fuzzy approach. It was also observed the main important parameters which affect the weld bead geometry.

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