A Literature Review On Laser Beam Welding Processes

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Abstract- *Laser welding is a high speed welding process, capable of automated production of consistent quality welds. Compared with many other arc welding processes, fewer passes or higher welding speeds can be used, with lower usage of welding consumables. With proper optimization of welding procedures, full advantage can be taken of the low heat input nature of laser welding for a wide variety of materials, producing welds with acceptable hardness and toughness properties. This paper reviews the various notable works in field of laser welding and magnifies on the effect of various laser welding parameters on the mechanical properties and the microstructure.*

Keywords- laser beam welding, Co2 laser,

I. INTRODUCTION

Laser Beam Welding:

Laser beam welding (LBW) produces coalescence with the heat from a laser beam impinging on the joint. Filler metal occasionally may be used, but the process is primarily used autogenously. Laser is an acronym for light amplification by stimulated emission of radiation. A laser is a device that uses an optical resonating system incorporating a crystal or gas medium and reflective mirrors or focusing lenses to amplify and synchronize light waves into a coherent beam. Coherence of the beam is produced by stimulated electronic or molecular transitions to lower levels of energy. The laser emits this concentrated beam as energy that can be focused on the weld joint or cutting site and applied as heat to make the weld or cut. The engineering disciplines involved in laser beam material processing include laser mechanics, optics, fluid dynamics, and materials science. The first laser was introduced in 1960. It used a ruby crystal electrically excited (pumped) by a flashlamp to produce a laser beam. By the late 1960s, the beam was successfully performing the first laser material processing application: the drilling of diamond dies used in wire drawing. Solid-state lasers of this type produce only short pulses of light energy at repetition frequencies limited by the heat capacity of the crystal. Consequently, even though individual pulses exhibit instantaneous peak power levels in the megawatt range, pulsed ruby lasers are limited to low average power output levels. They have largely been replaced by continuous wave (CW) solid-state lasers, many of which use neodymium-doped, yttrium aluminum garnet (Nd:YAG) crystal rods to produce a continuous, monochromatic beam output in the average power range of 0.5 kilowatt (kW) to 4 kW. Other lasers use carbon dioxide (CO2) and other gases as the lasing medium, with output power ranges of 0.5 kW to 45 kW. Among laser material-processing applications, cutting is the most common, with many types of machines used in industrial production systems worldwide. It is estimated that laser cutting and related equipment for drilling, trimming, machining, scribing, and laser transformation hardening represent well over 50% of industrial laser installations. Laser beam welding is widely used for the high-quality welds required by the automotive, aerospace, shipbuilding, pipeline, and air conditioning industries. Examples of other applications are

The fabrication and hermetic sealing of relay containers, cases for electronic, medical, and other devices, and the production of aluminum tubing. Many of the laser techniques associated with welding, cutting, marking, and surfacing processes also are associated with other industries. Different types and power levels of lasers are used for industrial, medical, construction, and office applications. In medicine, lasers are used for welding and cutting applications such as eye repair welding and self-cauterizing surgical cutting and repairing. In offices around the world laser printers use laser surfacing techniques to apply dry ink to paper; in plastics-painting applications lasers are used to prepare the surface for better adhesion. It is not unusual to hear typical welding terms applied to many uses of lasers in non-traditional applications. This chapter is devoted to the fundamentals of the laser beam welding and cutting processes, modes of operation, and equipment. Other topics include laser

Beam welding operating systems, applications, joint design and preparation, weld quality, and the economics of using these processes. Similar information is presented for laser beam cutting, drilling, and related processes. The chapter concludes with a discussion on safety issues specific to laser beam operations and the safety codes that must be followed to provide the best working environment where lasers are in use.

Working principle of laser beam welding:

Laser welding operates in two fundamentally different modes: conduction limited welding and keyhole welding. The mode in which the laser beam will interact with the material it is welding will depend on the power density of the focused laser spot on the work piece. Conduction limited welding occurs when the power density is typically less than 105W/cm2. The laser radiation is absorbed only at the surface of the material and does not penetrate into the material. Therefore, conduction limited welds exhibit a high width to depth ratio.

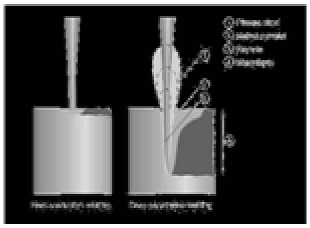

Fig. 1: Types of Welds

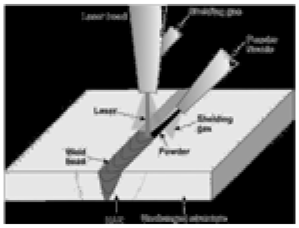

Fig. 2: Schematic of Laser Welding

Laser welding is more usually accomplished using higher power densities, by a keyhole mechanism. When the laser beam is focused to a small enough spot to produce a power density typically > 106-107 W/cm2, the work piece surface vaporizes before significant quantities of heat can be removed by conduction. The focused laser beam penetrates the work piece and forms a cavity called a 'keyhole', which is filled with metal vapor or ionized metal vapor (plasma). This expanding vapor or plasma contributes to the prevention of the collapse of the molten walls of the keyhole in to this cavity. Furthermore, the coupling of the laser beam to the work piece is improved dramatically by the formation of the keyhole. Deep penetration welding is then achieved by traversing the keyhole along the joint to be made (or moving the joint with respect to the laser beam) and results in welds with a high depth to width. Under the action of vapor pressure and surface tension, the molten material at A the leading edge of the keyhole flows around the cavity created by the beam to the back, and solidifies to form the weld. This action leaves a top bead with a chevron pattern, which points towards the start of the weld.

Advantages:

Laser beam welding has numerous advantages over other processes; however, it also has several limitations that should be considered when selecting the welding process for a particular application.

The major advantages include the following:

- Heat input is close to the minimum required to fuse the weld metal. Heat-induced distortion of the workpiece and metallurgical effects in the heat-affected zone (HAZ) are minimized;
- Single-pass laser beam welding procedures have been qualified for metals up to 3.2 mm (1.25 in.) thick, although more typically joints up to 19 mm (0.75 in.) may be welded. This reduces the time needed to weld thick sections and reduces or eliminates the need for welding wire and elaborate joint preparation;
- Electrodes are not required to conduct current to the workpiece, thereby eliminating electrode contamination, indentation, or damage from the high currents used in other welding processes;
- Tool wear is essentially eliminated because LBW is a non-contact process;
- Laser beams are readily focused, aligned, and directed by optical elements, permitting welding in areas not easily accessible by other processes and allowing the laser to be conveniently located relative to the workpiece or redirected around tooling and obstacles in the workpiece;
- The process allows workpiece with internal volumes to be hermetically welded to leave a vacuum or a controlled atmosphere in the finished product;
- The laser beam can be focused on a small area, permitting the joining of small, closely spaced components with extremely small welds;
- A wide variety of materials and many combinations of different types of materials can be welded, including those with dissimilar physical properties, such as electrical resistance, and several that are electrically insulating;
- The laser can be readily mechanized for automated, high-speed welding, including the use of computer numerical controls (CNC) or computer controlled welding;
- Welds in thin metal and small-diameter wire are less susceptible to incomplete fusion than arc welds;

- Laser welds are not influenced by the presence of magnetic fields, as are arc welds and electron beam welds;
- No vacuum is required and no X-rays are generated;
- Aspect ratios (depth-to-width ratios) on the order of 10:1 are attainable when a keyhole weld is made by forming a cavity in the metal; and
- The laser beam can be transmitted to more than one workstation using beam-switching optics, which allows beam timesharing.

Limitations:

Compared to other welding methods, laser beam welding has certain limitations, including the following:

- Joints must be accurately positioned laterally under the laser beam and at a controlled position with respect to the laser beam focal spot;
- When weld surfaces must be mechanically forced together, the clamping mechanism must ensure that the final joint position is accurately aligned with the laser beam impingement point;
- The maximum joint thickness is somewhat limited, as weld penetrations greater than 19 mm (0.75 in.) generally are considered impractical for LBW production applications;
- The high reflectivity and high thermal conductivity of some metals, such as aluminum and copper alloys, may adversely affect weld ability with the laser;
- When performing moderate-to-high-power laser beam welding, appropriate plasma and plume control devices must be employed to ensure that welds are reproducible;
- Lasers tend to have low energy conversion efficiency;
- As a consequence of the rapid solidification characteristic of laser beam welds, some weld porosity and brittleness can be expected in many common engineering alloys; and
- Laser equipment and fixturing costs may be high

II. LITERATURE REVIEW

P. Sathiya, K. Panneerselvam, R. Soundararajan [1] showed that Laser welding input parameters play a very significant role in determining the quality of a weld joint. The joint quality can be defined in terms of properties such as weld bead geometry, mechanical properties and distortion. Therefore, mechanical properties should be controlled to obtain good welded joints. In this 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. Full factorial design was used to carry out the experimental design. Artificial Neural networks (ANN) program was developed 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). The developed ANN model is suitably integrated with optimizing algorithms like GA to optimize the welding parameters. For the optimized welding parameters of GA, the laser welding joints were processed. Joints exhibit better quality. 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.

G.R. Mirshekari, A.Saatchi, A.Kermanpur, S.K.Sadrnezhaad [2] have shown in their work a comparative study on laser welding of NiTi wire to itself and to AISI304 austenitic stainless steel wire . Microstructures, mechanical properties and fracture morphologies of the laser joints were investigated using optical microscopy, scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), X-ray diffraction analysis (XRD), Vickers micro hardness (HV0.2) and tensile testing techniques. The results showed that the NiTi–NiTi laser joint reached about 63% of the ultimate tensile strength of the as-received NiTi wire (i.e.835MPa) with rupture strain of about 16%.This joint also enabled the possibility to benefit from the pseudo-elastic properties of the NiTi component. However, tensile strength and ductility decreased significantly after dissimilar laser welding of NiTi to stainless steel due to the formation of brittle intermetallic compounds in the weld zone during laser welding. The micro hardness values from the weld zone toward the base metal increased in NiTi–NiTi joint, while it decreased in NiTi–SS joint. In addition, NiTi – NiTi joint was fractured in ductile manner at the weld zone near the fusion line, while brittle failure occurred at the center of the NiTi–SS weld zone.

Lifang Mei, Genyu Chen, Xiang zhong Jin, Yi Zhang, Qiang Wu [3] presented some useful results on deep-penetration laser welding of high-strength galvanized steel sheets, which had been carried out by a self-made CO2 laser unit with maximum power output of 1.5kW.The work pieces of high-strength galvanized automobile steels with thickness of 1.5mm were butt-welded with argon as the shielding gas.

The effects of such factors as laser power, welding speed, focal position, shielding gas and zinc vaporization on the quality of welds are investigated. With the processing parameters optimized and the proper shielding gas used in both co axial and side-blow direction, most of the defects, such as pores, cracks and softening in HAZ, can be avoided in laser welding joints. The microstructure, the hardness distribution and the elemental distribution in the welding joints can be changed due to laser heating and recrystallization. In order to determine the mechanical properties of the welding joints, the static tensile strength was tested. Experimental results indicated that both the strength and micro hardness of welding joints were higher than those of the base metal. The deep punching performance acquired by adopting Ar as shielding gas is better than that acquired by adopting N2 as shielding gas .Meanwhile; the effect of zinc vaporization on welding joints can be effectively controlled by means of blowing side shielding gas. The experimental results indicate that the promising welding quality can be obtained under the chosen condition of taking Ar as shielding gas, laser power P as 1300W, defocusing amount Df as 0.4mm, welding speed v as 1.0 m/min, coaxial-blown shielding gas-flow rate q as 2.5 m3/h, side-blown shielding gas-flow rate q as 1.8 m3/h, and side-blown angle α as 301.

A.G. Olabi, F.O. Alsinani, A.A. Alabdulkarim, A. Ruggiero, L. Tricarico , K.Y. Benyounis [4] investigated dissimilar full-depth laser-butt welding of low carbon steel and austenitic steel AISI316 was investigated using CW 1.5kW CO2 laser. The effect of laser power, welding speed and focal point position on mechanical properties (i.e., ultimate tensile strength, UTS and impact strength, IS) and on the operating cost C was investigated using response surface methodology (RSM). The experimental plan was based on Box–Behnken design; linear and quadratic polynomial equations for predicting the mechanical properties were developed. The results indicate that the proposed models predict the responses adequately within the limits of welding parameters being used a laser power value of 1.1 kW is suggested as an optimum input process value to obtain excellent welded joints produced from austenitic stainless steel AISI316 and low carbon steel. The welding speed is the most effective parameter affecting the main weld bead dimensions as the area and the middle width, and it has to be set right on certain values to make all the responses optimized. Being focal point position fixed around -0.41 mm and laser power on 1.17 kW, setting welding speed on 72.66 cm/min, all the weld bead dimensions come out very reduced as area can be minimized by more 9% and middle width by 14%, spending 20% less money than the first criteria solution cost. Anyway, depending on the desired impact strength value for the specific application, if any, and on how much important and critical are mechanical properties on that, fixing welding speed on 57.93 cm/min, focal point position on -0.35 mm and laser power on 1.30kW, can be more efficient and smart, as it ensures a pretty higher value of ultimate tensile strength (360MPa) and impact strength

Shanmugarajan B., Chary J N. , Padmanabham G., Arivazhagan B. , Shaju K. Albert , Bhaduri A.K. [5] studied Influence of variables such as laser power, welding speed, shielding gas and laser beam mode on microstructure and mechanical properties. Here autogenously bead-on-plate (BoP) laser welding studies were carried out on 3mm thick 304B4 grade stainless steel using a 3.5kW slab CO2 laser. Dye penetrant testing, microstructural analysis, bead geometry measurements, micro hardness survey, and micro structural analysis in both as-weld and post-weld heat treated conditions were carried out. The microstructural and bead geometry analyses of the welds have shown that the welds were free from cracks in the fusion zone (FZ) and also in the heat affected zone (HAZ) for all the welding parameters studied. The Gaussian mode has given a very narrow weld width compared to donut mode. During welding use of helium and nitrogen has reduced the width of the FZ and HAZ. The as-weld micro hardness was more than double the base metal, and the peak hardness was shifted from the center to the fusion boundaries with the increase in heat input. The PWHT has reduced the hardness of both the FZ and HAZ.

Mingjun Zhang, Genyu Chen , Yu Zhou, Shenghui Liao [6] examined the effect of the processing parameters on the weld bead geometry and the microstructure and mechanical properties of the optimal joint were investigated. The results show that the focal position is a key parameter in high-power fiber laser welding of thick plates. There is a critical range of welding speed for achieving good full penetration joint. The type of top shielding gas influences the weld depth. The application of a bottom shielding gas improves the stability of the entire welding process and yields good weld appearances at both the top and bottom surfaces. The maximum tensile stress of the joint is 809 MPa. The joint fails at the base metal far from the weld seam with a typical cup–cone-shaped fracture surface. Welding speed, Focal position and shielding gas are the parameters that are studied. The weld depth increases when a top shielding gas is applied in the following order: argon < nitrogen < helium. The application of a bottom shielding gas improves the stability of the entire welding process, yielding good weld appearances at both the top and bottom surfaces.

A. Squillace, U. Prisco, S. Ciliberto, A. Astarita [7] studied the influence of welding speed and laser power on weld quality of 1.6 mm thick Ti − 6Al − 4V sheets autogenously laser beam welded in butt configuration using a Nd-YAG laser. The joint quality was characterized in terms of weld morphology, microstructure and mechanical properties. An under fill defect, controlling the whole weld geometry, was observed both at the weld face and root surface. In dependence of the specific heat input, this defect showed a maximum, which separates two different welding regimes: keyhole welding, at low heat input, and a welding regime where heat conduction around the keyhole is predominant, at high heat input. Influence of the under fill radius on the weld fatigue life was also assessed. Weld morphology is strictly influenced by the welding regime wherein they are produced. The welds under investigation, compared with the base material, reach similar tensile performance with a reduced ductility. Fatigue life of the investigated welds is strongly influenced by the value of the under fill radius. Indeed, the S–N curve tends to move towards region of higher cycles as the value of the under fill radius increases; this means that the fatigue strength of the welded joints can be improved by partially or totally eliminating the under fill. The fatigue fracture initiates and propagates near the lower point of the under fill convexity at the interface between the FZ and the HAZ.

J.K. Honga et al. [8] studied that the CO2 laser welding characteristics of Inconel 718 having two different grain sizes ASTM #4 and #10 under optimum conditions of welding power, welding speed and focused position of the laser and uses pre-heat and post-heat treatment. They analyzed microstructures of HAZ and fused zone using optical microscope and scanning electron microscope (SEM). They suggested that the modified cyclic solution heat treatment showed reduction of micro-fissures.Weichiat Chen et al. studied on CO2 laser welding of hot-dip galvanized steel sheets, were pre-drilled used by pulsed Nd:YAG laser to form vent holes along the weld line. They have established that the using this process with no gap produced welding without defect such as porosity, spatter, and loss of penetration and possible to neglect the difficult to produce a gap between welding plates.

ShurongYu et al. [9] studied the CO2 laser lap welding of dissimilar metals of 5A05 aluminum alloy and ST04Z galvanized steel sheet. The welding quality was tested and analyzed on the basis of microscopic structure, mechanical performance of weld joints. They found that at the time of welding 5A05 aluminum alloy part was melted, but ST04Z sheet part was not melted and fractures occurred in heat-affected zone (HAZ) of 5A05 aluminum alloy.O. VedantAkgun et al. studied on effect of heat treatment on corrosion behaviour of laser surface melted 304L stainless steel at the time of welding. Micro-structural and compositional changes were investigated by the electrochemical behaviours. It was observed that chemical composition rather than micro-structural changes that took place during laser surface melting had a greater effect on corrosion behaviour.

A. k. Lakshminarayanan et al.[10] studied on welding of 409M stainless steel by using 3. 5 kW CO2 laser and evaluated the micro-structural and mechanical properties of weld zone. Base material was observed to have coarse grain structure, whereas welded reason was seen to have fine dendritic structure and equi-axed axial grains of ferrite. Impact toughness of laser welded joint was found to be higher than base metal due to existence of equi-axed and dendritic grain perpendicular to the crack path.

A. Ruggiero et al.[11] investigated the butt welding on the dissimilar metal of low carbon steel and austenitic steel AISI316 with full depth of penetration by CO2 laser. They have also investigated the effect of process parameters on the shape of weld bead geometry using response surface methodology (RSM). They have proposed that the optimal welding combination would minimize the middle width, the weld-bead area and the cost.

Hideki Hamatani et al.[12] studied the CO2 laser welding of mild steel SS45 with a thickness of 0.8, 2.0, or 3.2 mm with TIG used for applying the voltage potential to increase the bead root width. They found that the welding root bead width enhanced at optimal welding condition and applied suitable current is about 30 amps.

A.G. Olabi et al.[13] have used neural network and the Taguchi approach for the optimization of the welding speed, the laser power and the focal position for CO2 laser keyhole welding of medium carbon steel butt joining. Analysis of data from this approach is reasonably correct. They did not find any drawbacks to the use of this approach.

A.G. Olabi et al.[14] optimized welding parameters such as welding speed, laser power and focal length for the CO2 laser welding process, when dissimilar materials are involved. It has been observed that welding speed being the most significant parameter and focal length being the least. Mathematical model involving important parameters was determined by design expert software. A laser power of 1.1 KW and welding speed of 72.66cm/min was found optimum under given conditions.

Katayama et al.[15], a reduction of the porosity is observed in the formation of AA5052 aluminium alloy weld beads when welding with high-power CW CO2 and Nd:YAG laser under vacuum. More recently, the same authors

(Katayama et al., 2011) have developed a new vacuum chamber providing 0.1–10 kPa, with which a high power disk laser is successfully employed to obtain high penetration AA5052 welds. Weld penetration depth is seen to increase with decreasing ambient pressure (higher vacuum) and low welding speed. The morphology of the obtained welds is also seen to be modified by vacuum conditions (Katayama et al., 2011). Other works have focused on the effect of the nozzle shape and design (Ancona et al., 2005), or on the influence of shielding gas contamination, the inclination angle of the nozzle, the flow and the density of the protection gas (Tani et al., 2007a, 2007b). Theoretical considerations analysed in Tani et al. (2007a) indicate that coaxial nozzles lead to a better protection against atmospheric contamination in the welding zone.

III. CONCLUSION

Over the past few decades, several technologies have been employed to solve existing issues in dentistry. Laser technology has thus far been the latest addition among these technologies that clearly has made a remarkable impact and hence replaced some of the conventional techniques due to its high precision level, biocompatibility and minimal side effects. Laser welding is one of the very recent yet versatile techniques used in dentistry, which is capable of manufacturing good quality weld joints with remarkable consistency.

It has offered greater advantages such as reasonable hardness, reduced heat affected zone and toughness over other compatible technologies available so far. Most importantly, this technology offers dental patients an intraoral surgery with limited anesthesia or without anesthesia, better comfort level, speedy recovery and aesthetic satisfaction. In light of a huge demand in laser welding technology, this paper has demonstrated the fundamentals of laser technology along with laser welding principles, a brief overview of laser welding for dental materials and a laser welding phenomenon in a systematic manner. Laser welding technologies that currently available are already high-end technology. Further areas of improvement may combine the diagnostic and therapeutic laser welding technologies in one single device.

Laser welding input parameters play a very significant role in determining the quality of a weld joint.

- The joint quality can be defined in terms of properties such as weld bead geometry, mechanical properties and distortion.
- The content of Mn and Cr element in welding joints is favourable for enhancing the tensile strength and the corrosion fatigue resistance of welding joints.
- The welding speed is the most effective parameter affecting the main weld bead dimensions as the area and the middle width.
- The depth of penetration and width of the welds were found to increase with heat input.
- The focal position is a key parameter in high-power fiber laser welding of thick plates.
- Weld morphology is strictly influenced by the welding regime wherein they are produced

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