Review on Laser Welding of Titanium Alloy

Akshay Gaikwad[1], Prof. Hemant Deore[2], Vivek Kotwal[3], Akshay Pawar[4], Ankita Valli[5]

[1]*Student,Mechanical Engineering, Smt. Kashibai Navale College of Engineering,*
akshaygaikwad951@gmail.com
[2]*Professor, Mechanical Engineering, Smt. Kashibai Navale College of Engineering,*
deorehemant@gmail.com
[3] *Student, Mechanical Engineering, Smt. Kashibai Navale College of Engineering,*
vivekkotwal.vk@gmail.com
[4] *Student, Mechanical Engineering, Smt. Kashibai Navale College of Engineering,*
ap992218@gmail.com
[5] *Student, Mechanical Engineering, Smt. Kashibai Navale College of Engineering,*
ankitavalli@gmail.com

ABSTRACT

The high temperature properties, high strength-to-weight ratio, good fracture toughness, excellent corrosion resistance and good fatigue behaviour of titanium alloys allow countless application in various fields including the medical, automotive and aerospace industry. Various techniques have been considered to get reliable welds with less distortion for the fabrication of components in these industries. Laser welding provides a large benefit for the welding of titanium alloys because of its high precision and rapid processing capability. Effect of process parameters such as laser power, welding speed and beam diameter on laser beam welding of titanium alloy is studied in the present study. It has been clarified that the ratio of the pulse energy and pulse duration is the very important parameter for defining the depth of penetration during laser welding operation. Also it has been observed by many researchers that the variation of pulse duration at constant peak power has no effect on the depth of penetration. In order to increase the depth of penetration during welding, the role of the laser parameters such as pulse energy, duration and peak power are very important to join the titanium alloy by laser welding. TEM (Transverse electromagnetic mode) of laser is also having influence on mechanical properties of welded joint. For laser welding in Gaussian mode required high laser power and high welding speed, while in Donut mode it required high laser power and low welding speed for efficient laser beam welding.

Keywords: ***Laser welding, Titanium Alloy, Gaussian Mode, Donut Mode etc.***

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1. INTRODUCTION

Laser beam welding process is a unique welding process used to join multiple pieces of metal through the heating effect of a highly concentrated beam of coherent monochromatic light which is impinged on pieces of workpiece to be joined is called as LASER [8].

Laser used for welding

1) Co_2 Laser
2) Nd: Yag Laser
3) Disk Laser
4) Diode Laser
5) Fiber Laser

Laser beam welding is a high energy-density welding technique and well known for its high depth of penetration, high speed, minimum heat-affected zone, fine quality of welding seam, low heat input per unit volume and fiber optic beam delivery. The principle of operation as shown in Fig. 1. In this the laser beam is pointed on to a joint and the beam is moved along the joint. Metals will melt by this process in to a liquid, fuse them together and then make them solid again thereby joining the two pieces. Laser processing is free of electromagnetic fields and is, thus, suitable for welding different couples. With flexibility in the intensity of power, power distribution and scanning velocity the laser welding is emerging as a major joining process [4, 6]. A high potential for application of laser beam welding is shown, for example, for the material combinations steel-aluminium and aluminium-titanium. With proper process control and the common laser deep welding effect, it is possible to form only a least possible intermetallic phase hem and thus achieve better mechanical properties of the welded joint.

The procedures and equipment used for welding austenitic stainless steel and aluminium alloys can be used for welding of commercially pure titanium and many titanium alloys; at high temperatures their increase reactivity with atmospheric elements needs additional precautions to shield the molten weld pool. For welding titanium alloys either with the use of filler wire or powder or autogenously, laser welding has considerable flexibility. As laser welding permits the keyhole generation that effectively concentrates the energy input into a small area, there is good potential for welding titanium alloys since the microstructural variations are confined to the weld region and a narrow heat affected zone, which has been reported to preserve the corrosion resistance and mechanical strength of the weldment.[1]

In order to protect the mechanical properties of titanium alloys during laser welding, gas shielding is of more importance to prevent embitterment of the weld region and also the ensuing losses in ductility. Weld pool protection against atmospheric contaminations is achieved by using shielding gas, which also has been reported in order to improve the coupling of the material to the laser. In order to improve the coupling between the incident beam and the workpiece as well as avoid formation of oxide on the weld surface, many laser welding nozzles have been developed. Conical nozzle has been designed to stabilize the plasma plume that is used for obtaining good quality weld; ring nozzle has been designed to avoid contamination by the ambient air. Examination of the effect of lateral assist gas or coaxial shielding gas on the laser welding process has indicated that the height of the side nozzle and current rate of gas flow can strongly affect weld seam characteristics. The largest weld bead width on the bottom surface is obtained when the joint angle of side gas flow and coaxial gas flow are at about 40◦.For each welding speed at constant power, a greater penetration depth has been achieved with the use of helium gas than argon due to the lower ionization energy of argon that reduces energy transfer to the material. In laser welding the shielding gas applied to protect the molten material from oxidation; it causes defects in welding such as, cracks and porosity. Molten material has gas bubbles which cannot escape before solidification is the main reason for porosity in welding operation. Doing the welding process in vacuum environment is an easy way to decrease the porosity problem [1].

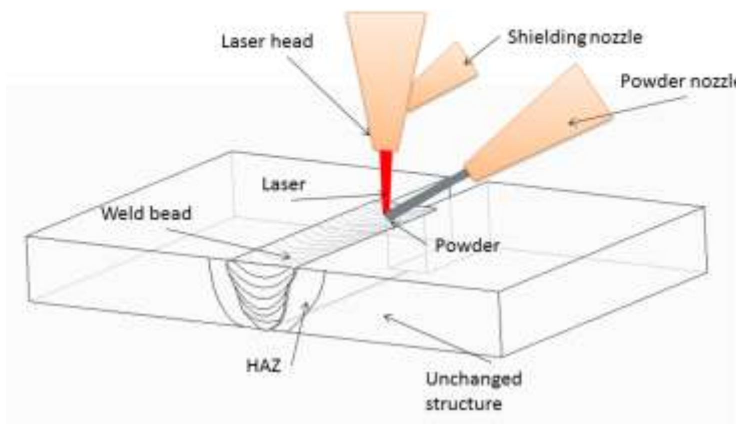


Fig-1: Principle of Laser welding

1.1 Material Type

Basically there are four types of alloys well-known by their microstructure:

Titanium - Commercially pure having (98% - 99.5%) of Titanium or strengthened by small additions of oxygen, carbon, nitrogen and iron. This commercially pure Ti is readily fusion welded.

Alpha alloys – Alpha alloys contain up to 7% aluminium and a small amount (< 0.3%) of oxygen, carbon and nitrogen. Alpha alloys are largely single-phase alloys In the annealed condition these alloys are fusion welded;

Alpha-beta alloys- Alpha-beta alloys have a characteristic two phase microstructure made by the adding of up to 6% aluminium and changing amounts of beta forming ingredients– chromium, vanadium and molybdenum. These alloys are readily welded in the annealed condition.

Ni-Ti alloys- **Ni-Ti**Alloys contain a large amount of the beta phase and it is stabilised by elements such as chromium and are not easily welded. Mostly used Ti alloys are listed in Table 1.In industry, the most widely welded titanium alloys are the commercially pure grades and variants of the 6%Al and 4%V alloy. [2]

ASTM Grade	Composition	UTS (min) MPa	Filler	Comments
1	Ti-0.15O_2	240	ERTi-1	Commercially pure
2	Ti-0.20O_2	340	ERTi-2	-
9	Ti-3Al-2.5V	615	ERTi-9	Tube components
4	Ti-0.35O_2	550	ERTi-4	-
7	Ti-0.20O_2-0.2Pd	340	ERTi-7	-
5	Ti-6Al-4V	900	ERTi-5	Workhorse alloy
25	Ti-6Al-4V-0.06Pd	900	ERTi-25	Corrosion resistant grade

Table-1: Mostly used titanium alloys and the suggested filler material [2]

2. BACKGROUND- LASER WELDING PROCESS

Titanium alloys can be welded by using a continuous and pulsed wave mode laser. In pulsed laser applications, a small molten pool is formed by each laser pulse and within a few milliseconds it resolidifies. When the peak power is low or the spot size is increased, welding occurs in conduction mode and a shallow and smooth weld pool is produced. On the other hand, when the peak power is increased or the spot size is reduced, a much deeper weld pool is obtained that is characterized as penetration or keyhole mode welding as reported. In keyhole mode laser welding, two plasmas, one inside the keyhole and other above the workpiece surface, occur. The plasma produced by laser radiation affects the welding process and an excess in the plasma has some disadvantages such as blocking, reflecting or refocusing the laser beam that can result in insufficient penetration, burn- through, irregular weld shape, or damage of beam delivery optics. Inside the keyhole, two absorption mechanisms usually exist in laser deep penetration welding: the beam energy is absorbed by the material through either Fresnel absorption of the keyhole wall during multiple reflections of the beam on the wall or the inverse Bremsstrahlung absorption of the electrons of the plasma. Although in continuous type lasers it is easier to control the laser welding processes, it has disadvantages or thin material processing. Seam welding is the most important pulsed laser application describes the seam welding as a series of overlapping spot welds to form a fusion zone or seam. The formation and the quality of seam welds are the results of a combination of various pulsed laser processing parameters, such as the travel speed, the average laser power, the pulse energy, the pulse duration, the average peak power density and the spot area. As mentioned by this abundance gives control of the thermal input with a precision not previously available and also permits a wide range of experimental conditions to be applied. On the other hand controlling so many parameters increases the complexity of laser.

Lima shown that pulse shaping technique can be used to prevent cracking in welded TiN coated titanium alloy through development in the transfer of nitrogen to the volume of the weld. The gap in-between the joint interfaces has been varied to evaluate porosity formation and/or reduction in the titanium alloy. They have shown that, acceptable results can be achieved when the gap distance is 0.1mm. In this study, the effect of pulsed laser seam welding parameters for joining 3mm thick Ti6Al4V has been investigated using the Lumonics JK760TR pulsed Nd:YAG laser.[1,2]

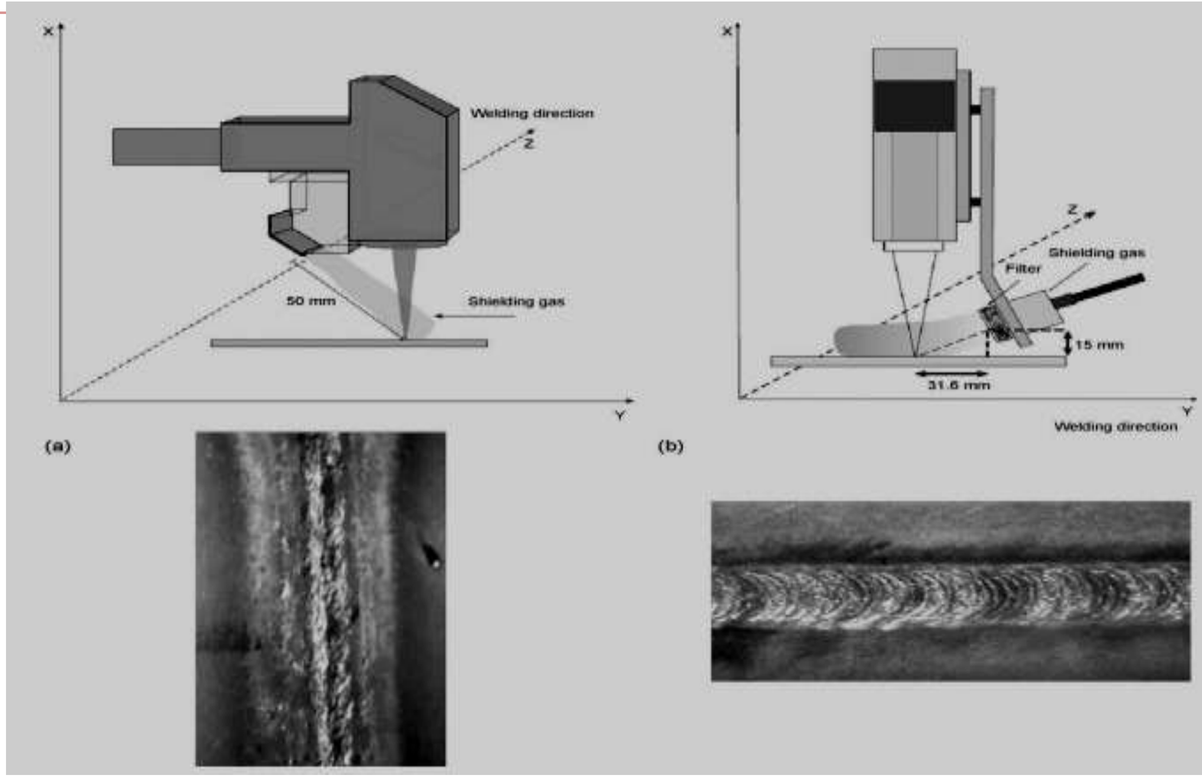


Fig-2: Shielding gas nozzle setups and oxidation effects [1]

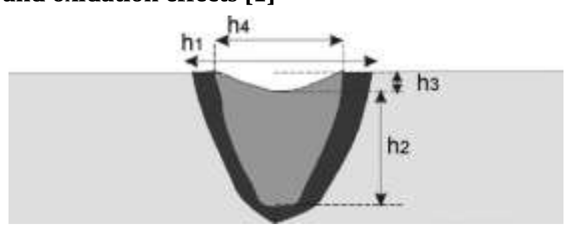


Fig-3: Characterization of welding cross-section.[1, 2]

2.1 The geometry of the welded cross-section

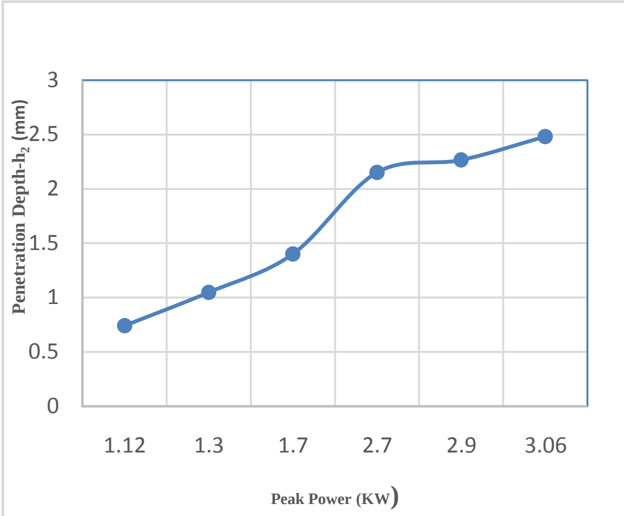
h_1- It represents the width of heat affected zone.
h_2- It represents the penetration depth of the welding.
h_3 -It represents the dimensions of underfill defects
h_4- It represents the width of weld pool.

3. LITERATURE REVIEW

E. Akmanet al, has experimented laser beam butt welding of a small square shape(30mm×30mm×3mm) ti6al4v titanium alloy plates have been done using gsi lumonicsjk760tr series laser (class 4) system in a cnc cabin. The jk760tr series of laser is an Nd:yag laser which has 500 hz maximum repetition rate and0.3–50ms pulse length. The average power that can be achieved is 600watt and it also jk760 tr series laser has a pulse shaping ability. Output power of laser is givenvia a 600 jm radius fiber optic cable to the focus head at the workstation for process. In the experiment, square shape pulse has been used to all workpieces. The laser beam is pointed on titanium plates using 160mm plano convex lens. The least spot size on the plates has been 0.4mm. During welding operation, the laser beam has been focused on 2mm under the surface of the plates to get sufficient power density for the cross-section. In this case the spot size on the plates is 0.65mm.the laser output parameters are changed in the experimentation. There is always a cracking risk due to the fast cooling of welded joint. To minimise this defect in welding, samples have been fixed on the ground by clamps.

Titanium is very reactive material at high temperature with ambient gases. Therefore during the welding application a shielding gas has been used to guard the HAZ and melt pool from oxidation till necessary cooling has occurred. At this point shielding gas usage and nozzle set up are very essential; development of turbulence on the sample surfaces must be prevented. In experiments two dissimilar nozzle designs have been used. One of the nozzles has been set as array and made by small sized gas exits and 5 bars helium applied in the experiment and 50mm far from the welding area (see Fig. 2a).

ISSN: 2321-8169
789 –795



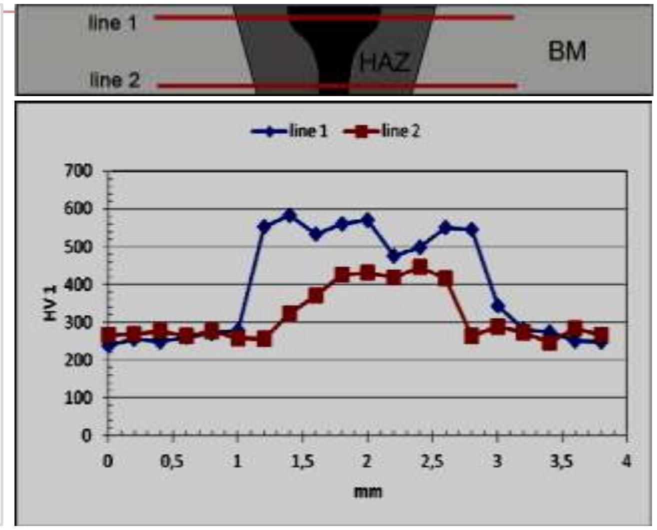


Fig-4: Peak power effect on penetration depth

Fig-5: Hardness distribution on the cross section ofTi-alloy (Ti-6Al-4V)butt joint 2.0 mm[11].

The second nozzle has 24mmexit size also it has been kept to the weld area as close as possible and 1.5 bars helium gas has been applied (see Fig.2b). In the second nozzle, to avoid the turbulences which might occur on the surface of material wire filter has been used. The nozzle shown in Fig. 1b is used during the whole experiment phase as it prevents oxidation (see Fig. 2b). In Fig. b the overlapping spots welds are seen more clearly and the welding surface is shiny. The geometry of the welded cross-section offers very important information about the quality of the laser welding process. The cross-sections of welded the materials are characterised by use of four geometric parameters. These parameters are shown in Fig. 3 . The gap between the edges of the two workpieces is very essential to avoid formation of porosity. Hence, before the welding process the work piece edges is made smooth. The workpieces are clamped to each other tightly to get the less gap formation in between the edges and to decrease the breaking off risk during solidification. After welding application, cross-section of workpieces has been prepared for optical microscopy using standard methods including grinding, polishing and etching. And also the mechanical properties of the welded materials have been inspected using tensile tests [1, 2].

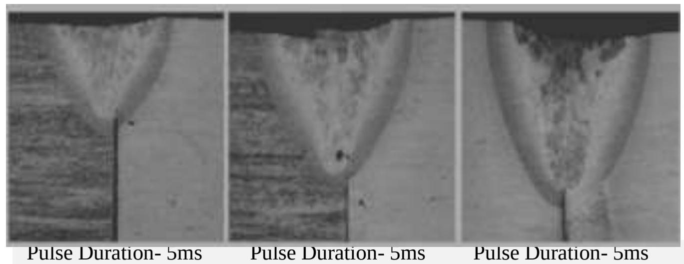
The average hardness distribution in base-metal (BM), heat affected zone (HAZ) and fusion zone (FZ) are shown in the figure.5. Surface hardness on the top surface are presented by line 1 and surface hardness on bottom surface are presented by line 2.A higher value of Vickers hardness in HAZ and FZ as compared to BM was observed. However, the hardness value was maximum in FZ of different conditions of welding. The value hardness was found to be decreased with increasing laser power and increased with increasing welding speed. Donut mode of welding had higher hardness value compared to the Gaussian mode of welding, irrespective of other process parameters. Laser welding application begins with the determination of peak power which is the most important parameter affected on welding depth. Unsuccessful results can be obtained if the melt pool is too large or too small or if significant vaporization occurs during welding. Therefore, the control of laser power level as well as the pulse length is very critical. Penetration depth is increased with increase of peak power at constant pulse duration and spot diameter. Fig. 4 shows the cross-section of the welded specimens welded under the peak powers from 1.12 to 2.68kW [1, 2].

3.1 Effect of Welding Speed

An increase in welding speed decreased the fusion zone width at fixed/varying laser power & mode of laser welding respectively. The grain size and hardness was increased with increasing the speed of welding in Gaussian mode of welding. While in Donut mode, the grain size was decreased with increasing welding speed and hardness was increased with increasing welding speed. An increased welding speed i.e. a decreased duration/time of welding leading to lower heat input which reduced the size of the fusion zone. A smaller grain structure is expected with increasing welding speed because of a decreased heat input with increased welding speed. However, in Gaussian mode of welding relatively coarse grain structure was obtained with increasing welding speed. Heat input is inversely proportional to the welding speed and an increase in welding speed decreases in heat input rate which may normalizes the stresses across the weld pool [8].

3.2 Effect of Laser Power

Fusion zone width as well as grain size of different LBW samples increased as a function of laser power irrespective of the speed of laser welding. However, with increase in laser power the mechanical properties decreased. It is expected that heat input increases with increase in laser power, results in a deeper and wider fusion zone. Also as heat input increases with increase in laser power, a slower cooling rate is expected which increased the grain size of LBW. This is in line with the findings of various researchers[1]. It is well understood that as grain size increases, the mechanical properties of a material are decreases [10].



Pulse Duration- 5ms	Pulse Duration- 5ms	Pulse Duration- 5ms
h_1 -1,654	h_1 -1,945	h_1 -2,353
h_2 -0,740	h_2 -1,047	h_2 -1,401
h_3 -0	h_3 -0	h_3 -0
h_4 -1,384	h_4 -1,489	h_4 -

Fig-6: Effect of peak power on penetration depth [2]

3.3 Effect of Laser Beam Diameter

A higher beam diameter is expected to spread the laser power to a wider area resulting an increased fusion zone. It is expected that the heat transfer and fluid flow process is different for different beam profiles and this will affect the grain size and mechanical properties of the welded samples. The residual stress developments were found to be more uniform and higher in wider beam diameter. A higher beam diameter should decrease the residual stress in the fusion zone [8].

4. CONCLUSION

For laser welding in Gaussian mode required high laser power and high welding speed, while in Donut mode it required high laser power and low welding speed for efficient laser beam welding. The magnitudes of residual stress developments were found to be higher in Donut mode compared to Gaussian mode of laser welding. From the study of effect of process parameters like laser power, welding speed and beam diameter on the laser welding following conclusions can be made:

[1] The width of the fusion zone at bottom surface was lower than that at top surface of the laser welding. The width of the fusion zone decreased with increasing welding speed and it increased with increasing laser power respectively. The Donut mode of welding had a larger fusion zone compared to Gaussian mode of welding.

[2] The grain size of both HAZ and FZ increased with increase in welding speed and power input of Gaussian mode of laser welding. Whereas the grain size decreases with increase in the welding speed for donut mode of welding.

[3] The Vickers hardness values increases with increase in welding speed and decreases with increase in laser power. The Vickers hardness value was higher for Donut mode of welding compared to Gaussian mode of welding.

[4] The development of residual stress at FZ and HAZ are higher in Donut mode of welding. The stresses were also more uniform in Donut mode compared to Gaussian mode of welding. It was also observed that the residual stresses at FZ and HAZ were more uniform at higher speed of welding.

The pulsed Nd:YAG laser welding technique has been employed to join Ti6Al4V titanium alloys. In general, the results show that it is possible to control the penetration depth and geometry of the laser weld bead by precisely controlling the laser output parameters. It has been seen that peak power is the most important parameter while determining the penetration depth which is equal to pulse energy per pulse duration. If the peak power is increased too much, the temperature of the workpieces exceeds to the evaporation point of the Ti6Al4V alloy, which promotes the crater formation on surface of the materials. And also the hardness values are higher at high peak powers. Whereas the increase in average power increases total heat input to the target reducing the cooling and hardness values. The autogenous butt joint with regular bead profiles can be made using the high-power Nd: YAG pulsed laser, the undercut and slump being controlled by the pulse energy, pulse duration, frequency, waveform and overlapping rate.

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