

STUDY OF LASER WELDING TECHNIQUE FOR TITANIUM ALLOY SHEET

*S.S. Shirguppikar¹, V.S. Ganachari², P.S. Dhaingade³, A.D. Apte⁴

Address for Correspondence

¹Assistant Professor, Mechanical Engineering Department, PVPIT, Budhgoan, Sangli.

^{2,3,4}Assistant Professor, Mechanical Engineering Department, ADCET, Ashta, Sangli.

ABSTRACT

In order to achieve reliable welds with minimum distortion for the fabrication of components for the aerospace industry. Several techniques were explored using the CO₂ and the Nd:YAG pulsed laser. In the tests it was established that a satisfactory weld can be obtained using the CW laser. Of these techniques, laser welding can provide a significant benefit for the welding of titanium alloys because of its precision and rapid processing capability. For pulse mode Nd:YAG laser welding, pulse shape, energy, duration, repetition rate and peak power are the most important parameters that influence directly the quality of pulsed seam welds. In this study, experimental work involved examination of the welding parameters for joining a 3-mm thick titanium alloy using the Lumonics JK760TR Nd:YAG pulsed laser. It has been determined that the ratio between the pulse energy and pulse duration is the most important parameter in defining the penetration depth.

KEYWORDS- Laser, Titanium Alloy, pulse and continuous wave.

INTRODUCTION

The high strength, low weight and outstanding corrosion resistance possessed by titanium and titanium alloys have led to a wide and diversified range of successful applications in aerospace, chemical plant, power generation, oil and gas extraction, medical, sports, and other industries. Welding of titanium by various arc welding processes is widely practiced, and good service performance of welds is proven. Newer joining methods, such as laser welding, have been successfully adapted for titanium. Application of appropriate welding technology to the design, manufacture and application of titanium products is as important in design as the specification of the alloy. Titanium is a unique material as strong as steel but half its weight, with excellent corrosion resistance. Traditional applications are in the aerospace and chemical industries. More recently, specific alloys are finding use in the manufacture of implantable medical devices and sensors.

Titanium is one of the most important non-ferrous metals and finds extensive application in the aerospace industry, because of its light weight (density 4.5 g/cm³), excellent corrosion resistance, high strength level, attractive fracture behaviour and high melting point (1678°C). Since pure titanium exists in two allotropic forms: alpha alloy and beta alloy. Laser welding technology was considering for the fabrication of these components because its heat input is much lower than that of arc welding, the distortion. Shrinkage and residual stress can be minimized and the mechanical properties are also excellent, resulting from the contribution of martensite due to the rapid solidification titanium alloys can be used as replacements for aluminium-based materials to achieve improved mechanical properties at elevated temperatures for applications such as the external shells of turbines, the power units for avionics and the landing gear structural components. Alternatively, as titanium exhibits very low corrosion rates in human body fluids as demonstrated other applications that are relevant to the medical industry include prosthetic devices such as artificial heart pumps, pacemaker cases, heart valve parts as well as load bearing bone such as for hip bone replacement.

MATERIAL TYPES

There are basically four types of alloys distinguished by their microstructure:

Titanium - Commercially pure (98 to 99.5% Ti) or strengthened by small additions of oxygen, nitrogen, carbon and iron. The alloys are readily fusion weldable;

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

Alpha-beta alloys - These have a characteristic two-phase microstructure formed by the addition of up to 6% aluminium and varying amounts of beta forming constituents - vanadium, chromium and molybdenum. The alloys are readily welded in the annealed condition;

Ni-Ti alloys- Alloys which contain a large amount of the beta phase, stabilised by elements such as chromium, are not easily welded. Commonly used alloys are listed in Table 1 with the appropriate ASTM grade, the internationally recognised designation. In industry, the most widely welded titanium alloys are the commercially pure grades and variants of the 6%Al and 4%V alloy.

Table: 1 Commonly used titanium alloys and the recommended filler material

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	..
4	Ti-0.35O ₂	550	ERTI-4	..
7	Ti-0.20 O ₂ -0.2Pd	340	ERTI-7	..
9	Ti-3Al-2.5V	615	ERTI-9	Tube components
5	Ti-6Al-4V	900	ERTI-5	'Workhorse' alloy
23	Ti-6Al-4V ELI	900	ERTI-5ELI	Low interstitials
25	Ti-6Al-4V-0.06Pd	900	ERTI-25	Corrosion resistant grade

LASER WELDING PROCESS

Titanium alloys can be welded using a pulsed and continuous wave (cw) mode laser. In pulsed laser applications, a small molten pool is formed by each laser pulse and within a few milliseconds it re-solidifies. 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

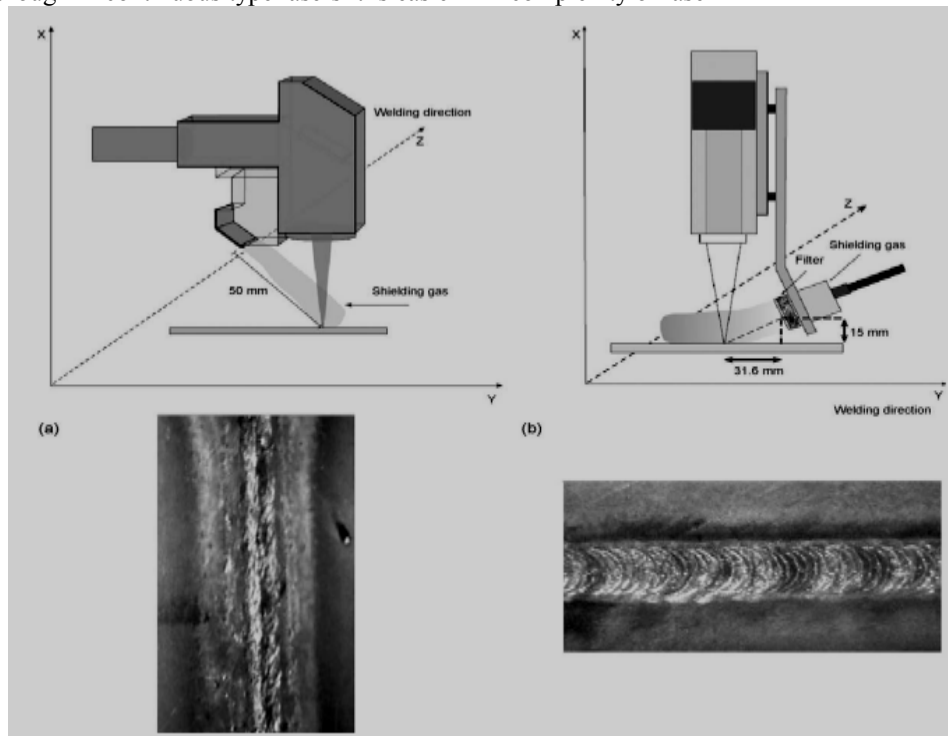


Fig: 1 Shielding gas nozzle setups and oxidation effects

Lima has recently shown that pulse shaping technique can be used to prevent cracking in welded TiN coated titanium alloy through an improvement in the transfer of nitrogen to the volume of the weld. The gap 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 obtained 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.

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.

MATERIALS AND METHODS

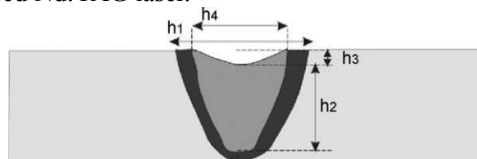


Fig: 2 Characterization of welding cross-section.

Lima has recently shown that pulse shaping technique can be used to prevent cracking in welded TiN coated titanium alloy through an improvement in the transfer of nitrogen to the volume of the weld. The gap 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 obtained when the gap distance is

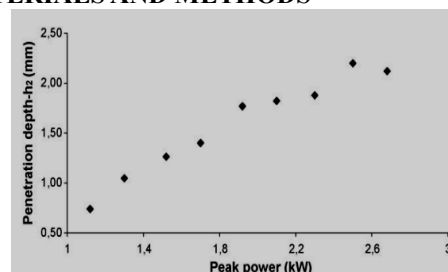


Fig: 3 Effect of peak power on penetration dept

In this study, butt welding of a small square shape (30mm×30mm×3mm) Ti6Al4V titanium alloy plaques have been done using GSI lumonics JK760TR Series Laser (Class 4) system in a CNC cabin. The chemical composition in weight percentage of the titanium substrate is shown in Table 1. The JK760TR Series of laser is an Nd:YAG laser that has 0.3–50ms Pulse length and 500 Hz maximum repetition rate. The average power that can be obtained is 600Watt. And also JK760 TR series laser has a pulse shaping ability. Laser output power is delivered via a 600 μm radius fiber optic cable to the

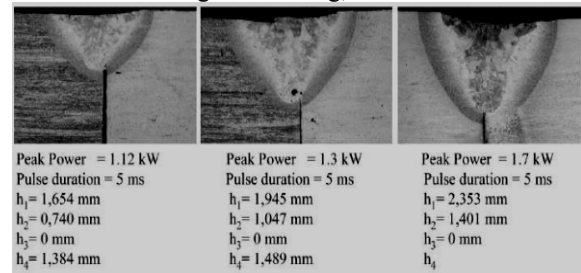
focus head at the workstation for process. In the experiment, square shape pulse has been applied to all workpieces. The laser beam is focused on titanium plates using 160mm Plano convex lens. The minimum spot size on the plates has been 0.4mm. During welding application, the laser beam has been focused on 2mm under the surface of the plates to obtain enough power density for the cross-section. In our case the spot size on the plates is 0.65mm. The laser output parameters are varied in the experiment. There is always a cracking risk due to the rapid cooling of welded joint. To overcome this defect during welding, samples have been fixed on the ground using clamps. Titanium is reactive material at high temperature with ambient gases. For this reason during the welding application a shielding gas has been used to protect the melt pool and HAZ from oxidation until sufficient cooling has occurred. At this point shielding gas usage and nozzle set up are very important; formation of turbulence on the sample surfaces must be avoided. In experiments two different nozzle designs have been used. One of the nozzles has been arranged as array and formed by small sized gas exits and 5 bars helium applied during the experiment and 50mm far from the welding area (see Fig. 1a). The second nozzle has 24mm exit size and it has been kept to the weld area as close as possible and 1.5 bars helium gas has been applied (see Fig. 1b). In the second nozzle, to prevent the turbulences which might occur on the material surface wire filter has been used. The nozzle shown in Fig. 1b is used during the whole experiment phase since it prevents oxidation (see Fig. 1b). In Fig. 1b the overlapping spots welds are seen more clearly and the welding surface is shiny. The geometry of the welded cross-section gives very important information about the quality of the laser welding. The welded cross-sections of the materials are characterized by using four geometric parameters. The first one is called "h1" and it represents the width of heat affected zone. The second depth is called "h2" and it represents the penetration depth of the welding. The third depth is called "h3" and it represents the dimensions of under fill defects. The fourth depth is called "h4" and that one represents the width of weld pool. These distances are shown in Fig. 2.

The gap between the edges of the two workpieces is very important to prevent porosity formation. Therefore, before the welding process the edges of the workpieces have been made smooth as much as possible using milling cutter. The workpieces are clamped each other tightly in order to get the minimum gap formation between the edges and to reduce the breaking off risk during solidification. After welding application, cross-sections of workpieces have been prepared for optical microscopy using standard procedures including grinding, polishing and etching. And also the mechanical properties of the welded materials have been examined using tensile tests.

RESULTS AND DISCUSSION

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. 3 shows the cross-section of the welded specimens welded under the peak powers from 1.12 to 2.68kW. During the welding, laser beam



CONCLUSIONS

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.

REFERENCES

1. J. Mazumder and W.M. Steen. *Met. Trans. A*, 32A(1982) 865-871.
2. G. Thomas, V. Ramachandra, M.J. Nair. K.V. Nagarajan and R. Vasudennm, *Welding J.*, 71 (1992) 15s-20s.
3. *Journal of material processing technology* 65 (1997) 203-208.
4. Steen WM, Dowden J, Davis M, et al. Apoint and line source model of laser keyhole welding. *J Phys D* 1988;21:1255-60.
5. *Engineering Science and Mechanics*, Pennsylvania State University, University Park, PA 16802
6. Akarapu, R., and Segall, A. E., 2008, "Active Stressing and the Micro- Manipulation of Stress-States for Delaying Fracture During Unsupported Laser Cutting," *ASME J.Manuf. Sci. Eng.*,130(6),p.061004.
7. R. R. Boyer, "An overview on the use of titanium in the aerospace industry.
8. Gerevey, D., Sallamand, P., Cicala, E., Ignat, S., 2005. Gas protection optimization during Nd:YAG laser welding. *Opt. Laser Technol.* 37, 647-651.
9. Dowden J, Kapadia P. A mathematical investigation of the penetration depth in keyhol welding with continuous CO2 lasers. *J Phys D* 1993;28:2252-61.
10. Yih-fong T. Gap-free lap welding of zinc-coated steel using pulsed CO2 laser. *Int J Adv Manuf Tech* 2006;29:287-95.