An Experimental Investigation of Laser welding Process Parameter for Titanium Material

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Abstract— **The method to weld Titanium Alloy with high power (CW) CO_2 laser has been analyzed. The principal purpose of this study was to find out the determinative effect of laser beam location with respect to the joint. Laser welding method was effectively used for joining titanium alloy. In the present study, laser welding method onTitanium Alloy sheet of 2 mm, 3mm, 5mm by investigation resulted to identify the anticipation model. A statistical DOE method full factorial design with help of design expert software has been used to designing experimental work. The chosen laser welding input factors (laser power, travelling speed & focal position) have been used & the co-relation between these various factors has been investigated.**

Keywords- Laser, Titanium alloy, Taguchi, Annova, Minitab17

Introduction

Titanium and titanium alloys are widely used in space, aerospace, ship and chemical, nuclear energy and medical industries, because of many advantages such as low specific weight, high strength, excellent corrosion resistance, attractive fracture behavior and high melting point . Weld ability of commercial pure titanium and most titanium alloys is good in general, although special cares must be taken during the welding process because pure titanium and titanium alloys are highly susceptible to contamination from atmospheric gases Pure titanium is extremely chemical reactive at high temperature and it is easy to absorb harmful gases from the ambient atmosphere (oxygen, hydrogen and nitrogen) therefore the titanium may be exposed to contamination during the welding process and also during the subsequent cooling phase, till the temperature of titanium surface decrease below 300 °C (or 600 °C in a case of some titanium alloys. When the shielding is insufficient the heated titanium surface absorbs gases from the air atmosphere and additionally titanium forms brittle carbides, nitrides and oxides causing hardness increasing and simultaneously reducing the fatigue strength and notch toughness of the welded joint and heat-affected zone (HAZ). The grove of the weld also must be perfectly protected by shielding gas. Additionally any surface impurities can diffuse into the titanium, causing porosity and brittleness, thus the joint area must be decreased and cleaned precisely. The content of carbon in the pure titanium should not exceed 0,1 %, but even very low content of carbon may results in titanium carbides formation which have very high hardness up to 900 HV, and additionally in a case of even low content of oxygen the carbon oxide and/or carbon dioxide may be formed causing weld porosity. The electrical and thermal conductivity (16,4 W/m·K) of titanium is relative low, and significantly affects the thermal cycle of welding, thus the cooling rate of weld metal and heat affected zone (HAZ) is relative low. The low cooling rates usually leads to grain growth of weld metal and HAZ as well. In a case of overheating of the joint, when the heat input of welding is too high, the brittle ω phases may be formed at the stage of low rate cooling resulting in hardness, brittleness increase. Additionally, as a result of high temperature gradients, significant stresses in the weld metal and HAZ may occur and sometime even cracks.

Principle of Laser Generation

The generation of a laser beam is essentially a three step process that occurs almost instantaneously. The pump source provides energy to the medium, exciting the laser medium atoms such that electrons held within the atoms are elevated temporarily to higher energy states. The electrons held in this excited state cannot remain there indefinitely and drop down to a lower energy level. In this process, the electron looses the excess energy gained from the pump energy by emitting a photon. This is called spontaneous emission and the photons produced by this method are the seed for laser generation. The photons emitted by spontaneous emission eventually strike other electrons in the higher energy states. “Eventually” is a very short time due to the speed of light and density of excited atoms! The incoming photon “knocks” the electron from the excited state to a lower energy level creating another photon. These two photons are coherent meaning they are in phase, of the same wavelength, and traveling in the same direction. This is called stimulated emission The photons are emitted in all directions, however some travel along the laser medium to strike the resonator mirrors to be reflected back through the medium. The resonator mirrors define the preferential amplification direction for stimulated emission. In order for the amplification to occur there must be a greater percentage of atoms in the excited state than the lower energy levels. This “population inversion” of more atoms in the excited state leads to the conditions required for laser generation.

Problem Statement

Joining of dissimilar materials is one of the challenging tasks facing modern manufacturers. Dissimilar joining technologies find applications in many sectors including microelectronics, medical, optoelectronics and Microsystems. The tiny geometry of the joints and the different optical and thermal properties of the materials makes laser welding one of the most suitable production methods. This work presents the results of an investigation into laser welding of titanium alloy without filler materials using a 350W pulsed CW laser. The mixing behavior of the materials in the fusion zone, the microstructure, the presence of defects, hardness and residual stress of the joints were all investigated.

Objectives

1) To decide the range of process parameters with the help of pilot experiments.
2) To study the effect of these process parameters on tensile strength of welded joints.
3) To characterize and optimize the process for obtaining maximum tensile strength
4) To develop an analytical approach by using Taguchi method for predicting the effect of process parameters on tensile strength of the welded joints .
5) To validate the experimentally optimized stress with ANSYS package.

Scope

This study can be extended for effect of the welding speed, the electrode feeding technology (filler material) and gap between the work pieces can be analyzed further. This study can be extended by considering effect of welding sequence on tensile strength of butt weld joint, lap joint. This study can be extended by considering effect of torch angle and number of welding passes on residual stresses. This study can be extended by considering effect of welding parameters on hardness of butt and lap welded joint.

Methodology

1. Observation and study of existing and required laser welding method and analysis of process parameters to build new process line.
2. Literature survey about experimental investigation and analysis of laser welding parameters.
3. Study of basic characteristics of laser welding method & selection of material on strength basis criteria.
4. Selection of parameters for the process.
5. Preparation of single butt joint by using Laser welding process.
6. Testing of joints on UTM for finding out the failure criteria.
7. Evaluation of test results.
8. Evaluation of test results by using Minitab 17 for finding out optimum reading..
9. Finally analysis of variance.
10. Evaluation of test results in terms of main effect plots and residual errors.

Literature Review

Bikash Ranjan Moharanaa Sushanta Kumar Sahua Susanta Kumar Sahooa Ravi Batheb (1) Macroscopic examination has been carried out to observe the macro-segregation pattern of Cu, Fe and Cr rich phases in different zones, and the thickness of HAZ was found to be around 10 µm. The micro-channels formed from the steel side to weld pool describe that the copper solidifies first and provides the nucleation surface for the residual melt to grow. These tubular micro-channels formed may be due to carbide precipitation. The EDS analysis conforms the well mixing of SS and Cu inside the weld pool. The mechanical properties in terms of tensile stress found up to 201 MPa and the fracture are obtained outside the weld zone.

Anurag Khajanchee , Prabhash Jain , Sharad K. Pradhan (2) The effect of laser power and weld speed on the output responses such as weld-depth, weld-width, weld pool area, are to be investigated. Several approaches have been proposed in the literature to optimize these parameters hence it is felt that a review of the various approaches developed would help to compare their main features and their relative advantages and limitations to allow choose the most suitable approach for a particular application.

Yuan Chen, Shaogang Wang, Ziyi Wang and Li Zhao (3)
Ti-22Al-25Nb (at%) alloy with the thickness of 3.5 mm is welded by using electron beam welding (EBW) based on electron beam oscillation. Numerical simulation analysis of EBW process, and microstructure and mechanical properties of welded joint are systematically investigated. Microstructure analysis shows that base metal consists of phases α 2, B2 and O. The fusion zone (FZ) of joint in as-welded condition consists of single phase B2. During EBW process, the transformation from phase B2 to phase α 2 or phase O is restrained in FZ due to the rapid cooling rate. Results of numerical simulation demonstrate the thermal change in EBW process and verify the micro structural evolution of weldment. Electron beam oscillation can stir the molten pool and stabilize the keyhole, thus the mechanical properties of welded joint are greatly improved.

Rajib Kumar Mandal , Asish Bandyopadhyay and Santanu Da (4) Laser beam welding (LBW) is nowadays increasingly used in the fabrication industry due to some of its distinct advantages. LBW offers high energy density around its focus thereby making it well suited for welding of certain category of materials that are considered difficult-to-weld. Since the laser follows the principles of optics, it is easy to regulate the laser beam by selecting appropriate lenses. In the present work, laser beam welding (LBW) is carried out to make lap joint of two acrylic flats- one opaque and the other transparent. Laser beam passes through the transparent piece of plastic flat and is focused on to the opaque flat around the interface region. Laser beam gets absorbed in the opaque flat in the interface region and generates heat energy causing local melting, and subsequent welding of both the flats. Clamping pressure is varied four times, and two levels of current flow and scanning speeds are set to find out a condition corresponding to sound, strong weld joint within the experimental domain.

Lakshmanan Vellaichamya , Pradeep Benedict Thomas Gerarda , Sathiya Paulraja (5) Micro structural characterization and mechanical properties of P91 and Incoloy 800HT dissimilar laser beam welded joint were analyzed. In addition to that, metallographic studies were conducted using Optical microscopy, Scanning electron microscopy (SEM) equipped with Energy-dispersive X-ray spectroscopy (EDX) and X-Ray diffraction analysis (XRD). Effect of specific point energy on weld microstructure was predicted and it was compared with fusion zone hardness. The δ-ferrite content of the welds was predicted and it was correlated with the results measured by ferritoscope. Increase in heat input led to a minimal increase in the weld bead width and also the depth of penetration as predicted by micro structural studies. The traces of δ-ferrite in the interface of P91 side led to higher strength and micro hardness of the weld. Failure of tensile specimens in the HAZ of Incoloy 800HT side was because of lower ferrite content (0 to 0.36) in that region and also due to the presence of the brittle intermetallic phases. The tensile strength of higher specific point energy welds was greater compared to other welds because of precipitation hardening and presence of δ-ferrite.

Experimental Prerequisites

CW Pulsed Laser:

The CW pulsed laser is commonly used type of solid-state laser in many fields at present because of its good thermal properties and easy repairing. The generation of short pulse duration in laser is one of the researcher areas. CW pulsed laser is chosen for most materials processing applications because of the high pulse repetition rates available. The power supply of pulsed CW pulsed laser is designed to produce a maximum average power. The beam quality and output power are depending on length of resonator . The beam quality is important to the laser designer because the quality of a given beam profile depends on the application for which the beam is intended. The beam quality can be improved by inserting an aperture inside the resonator in order to reduce the effective radius of the gain medium.

Processing parameters:

Processing is normally carried out at room temperature in a clean environment. Appropriate fixturing is needed to ensure that the parts do not move relatively to one another welding to prevent misalignment and the formation of gap. Molten weld metals are protected from environmental contamination by a quiescent blanket of inert shielding gas such as argon.

1. Average peak power (kW)
2. Pulse energy (J)
3. Pulse duration (ms)
4. Average peak power density (kW/m^2)
5. Laser spot area (m^2)
6. Mean laser power (kW)
7. Pulse repetition rate
8. pulse-to-pulse time (ms)
9. Duty cycle
10. Pulse frequency (in Hz)

Process gas:

Argon gas is used as process gas because its high density assists in removing plasma. It has lower ionization potential then helium, it shield the welding bead pool more effectively. It is relatively cheap. The addition of argon to helium, is amount up to 50%, may improve the economics of welding, without sacrificing plasma control

Joint:

The square butt I-joint is ideal for laser welding. Strength is generated from the complete weld bead penetration. However, it is the least forgiving. Air gap arise from poor fit up of part, or from the roughness of cut plate edged. Air gap must be less than about 5% of the plat thickness to avoid bead concavity and sagging. The beam must be aligned with the joint line over its entire length.

Fixturing:

Accurate fixturing is necessary in laser welding gap along the joint line cannot be tolerated by small focused beam. Fixturing is a time-consuming and expensive manufacturing phase, but is compensated for higher quality product and a reduced need for post-welding reworking. Joint parts may be fixtured in a frame to avoid angular and bending shrinkage.

Experimental work has been done on "Laser Line IRB 1410-B" and the specifications are given below

Specifications of "Laser Line IRB-1410 B" given bellow

Wavelength	1.06μm
Maximum average power	200W
Pulse energy	90J
Peak pulse power	100KW
Pulse duration	0.5-20ms
Pulse frequency	20Hz
Focus diameter	0.3-2.2mm

Design of Experiment

Design of Experiments (DOE) pertain to the process of planning, designing and analyzing the experiment so that valid and objective conclusions can be tired efficaciously and efficiently. In order to show statistically sound conclusions from the experiment, it is necessary to incorporate simple and powerful statistical methods into the experimental design methodological analysis. In the present work input parameters considered for laser welding are as laser power, travelling speed and focal position. Output parameters are ultimate tensile strength (UTS) measured by universal testing machine other parameters are considered as constant parameters. The material selected for the experiment work is Titanium alloywhich Output parameters are ultimate tensile strength (UTS) measured by universal testing machine other parameters are considered as constant parameters. The material selected for the experiment work is titanium alloy which is widely used in industrial applications. The joint type selected for the experiment work is square butt joint.

Selection of parameter

For the proposed work of laser welding of titanium alloy following parameters are to be selected.

Parameter	Levels		
	1	2	3
Laser Power(W)	2000	2500	3000
Welding speed (mm/sec)	20	40	60
Focus Diameter (mm)	0.6	0.8	1.0

Orthogonal Array Experiment

In this study, an L_9 orthogonal array with three columns and 9 rows was used. This array can handle three-level process parameters. Nine experiments were required to study the welding parameters using the L_9 orthogonal array. In order to evaluate the influence of each selected factor on the responses. The S/N ratios for each control factor had to be calculated. Suitable S/N ratio must be chosen. It is possible to choose the S/N ratio depending on the aim of the design. In this study, the S/N ratio was selected according to the criterion the bigger-the-better, in order to maximize the responses.

The experimental lay-out for the welding process parameters using the L_9 orthogonal array is shown in Table

Parameter 1	Parameter 2	Parameter 3
1	1	1
1	2	2
1	3	3
2	1	2
2	2	3
2	3	1
3	1	3
3	2	1
3	3	2

Experimental layout using L_9 Orthogonal Array

Expt No.	Power	Speed	Focus Dia
1	2000	20	0.6
2	2000	40	0.8
3	2000	60	1.0
4	2500	20	0.8
5	2500	40	1.0
6	2500	60	0.6
7	3000	20	1.0
8	3000	40	0.6
9	3000	60	0.8

Specimen

Specimen 1 of (Ti-6Al-4V) laser welded

Specimen 2 of (Ti-6Al-4V) laser welded

Testing of Specimen by UTM

Prior to joining materials should be cleaned thoroughly. If the component contains residual from prior processing, they are often baked to remove moisture and contaminants. Surface are abutting edges should be as smooth as possible to avoid welding imperfections the mechanical properties of base materials should be measured to establish a baseline against which the properties of the welded joint can be compared Machine frame and loading unit consist of two cross heads and one lower table. Center cross head are adjustable by means of geared motor. Compression test is carried out between center and lower table while tension test is carried out between center table and upper cross head. Load is sensed by means of precision pressure transducer of strain gauge type. Loading unit is shown in Fig.

Figure UTM frame

Taghuchi design method

Taguchi Technique is employed to set up the experiments. The Taguchi methodology has become a important tool for improving output throughout analysis and development, so better quality product may be produced quickly and at minimum price. Dr.Taguchi of japan was developed the techniques of optimization of various factors and parameters which affects on the relative performance of the object. Basically taguchi design involves orthogonal array, S/N ratio and mean of the distribution S/N ratios (S/N), that are log functions of relative output, function objective functions in improvement, help in data analysis and estimation of optimum results. The signal-to-noise (S/N) ratio for each level was based on the S/N ratio analysis. Based on the tensile strength of the weld joint (larger-the-better), a higher S/N ratio produced a better quality. The standard S/N ratio formula for this type of response is:

S/ N = -10log(M.S.D.)

Where, M.S.D. is the mean square deviation for the output characteristic.

$$n_i = -10 \log \left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Y_{ij}^2}\right]$$

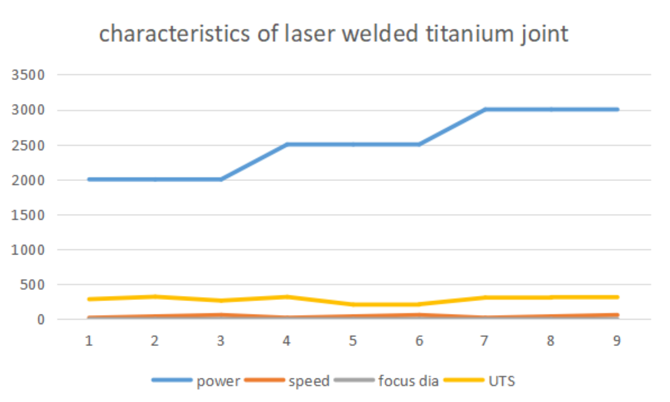
Where ‘i’ is the number of a trial; ‘Yij’ is the quality of the ith trial and jth experiment; ‘n’ is the total number of experiments.

Analysis of Variance

ANOVA is a statistically based, objective decision-making tool for determining any differences in the average execution of groups of items tested. ANOVA helps in formally testing the significance of all main factors and their interactions by comparing the mean square against an approximation of the experimental errors at specific confidence levels. The intent of ANOVA is to examine which welding process parameters significantly affect the superior characteristic. This is achieved by separating the total variability of the S/N rations which is measured by the sum of the ratio, into endeavor by each of welding process parameters in the total sum of the squared deviations can be used to evaluate the value of process parameter change on the choice of characteristics.

Table: Experimental Results for UTS

	Input Parameter			Output
Expt no.	**Power (W)**	**Speed**	**Focus Dia(mm)**	**Ultimate Tensile strength (Mpa)**
1	2000	20	0.6	285.74
2	2000	40	0.8	320.84
3	2000	60	1.0	265.55
4	2500	20	0.8	318.17
5	2500	40	1.0	208.42
6	2500	60	0.6	213.82
7	3000	20	1.0	308.45
8	3000	40	0.6	314.85
9	3000	60	0.8	304.52

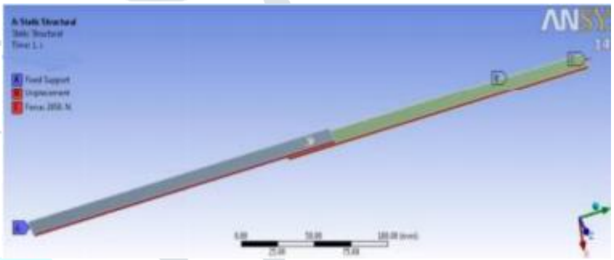


Characteristics of laser welded titanium joint.

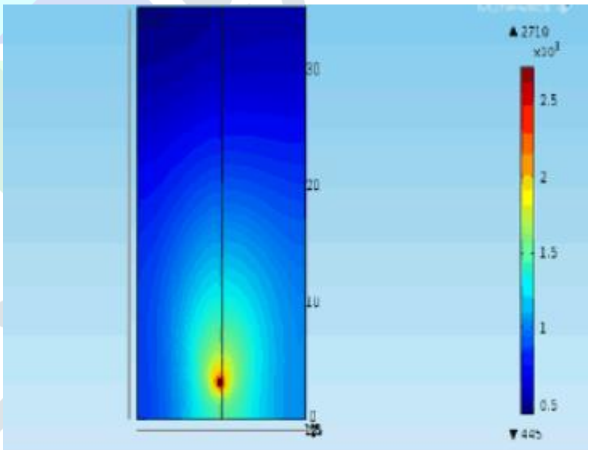
Analysis of joint

ANSYS Work bench 14.5 can be thought of as a software platform or framework where you perform your analysis (Finite Element Analysis) activities. In other words, workbench allows you to organize all your related analysis files and databases under same frame work. Among other things, this means that you can use the same material property set for all your analyses.

The ANSYS Workbench platform allows users to create new, faster processes and to efficiently interact with other tools like CAD systems. In this platform working on Metaphysics simulation is easy. Those performing a structural simulation use a graphical interface (called the ANSYS Workbench Mechanical application) that employs a tree-like navigation structure to define all parts of their simulation: geometry, connections, mesh, loads, boundary conditions and results. By using ANSYS workbench the user can save time in many of the tasks performed during simulation. The bidirectional links with all major CAD systems offer a very efficient way to update CAD geometries along with the design parameters.



Boundry Conditions of specimen in ansys



Analysis of specimen in ansys

Result & Discussion

In this work effect of main input welding parameters on the tensile strength of laser welded joint in welding process were investigated. As stated earlier for each output data points, readings are taken for an ultimate tensile strength, Final results are shown in table From the table, it is identified that the minimum ultimate tensile strength value 208.42 Mpa is observed at 2500 W power, 40 mm/sec welding speed and 1.0 mm focus diameter. The maximum ultimate tensile strength value 320.84 Mpa is obtained at the value of 2000 W power, 40 mm/sec welding speed and 0.8 mm focus diameter.

Conclusion

Using Laser welding can produce small welding pool area and narrow HAZ.

Laser power has strong effect on fusion area. By varying the power input significant change can be observed in responses, so the amount of power applied should be carefully selected.

It is necessary that the edges of the plate were cleaned and grinded along the weld line to ensure full contact. Welding speed is the factor which has the greater influence on tensile strength followed by laser power and focus diameter.

A maximum tensile strength of 320 MPa is obtained under the welding conditions in which laser power is 2000 watt, welding speed of 40 mm/ sec and focus dia. is 0.8.

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