An Investigation of Dissimilar Welding Joint of AISI 304L Stainless Steel with Pure Copper by Nd:YAG Pulse Laser: Optimization of Tensile Strength

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

in

Mechanical Engineering

(Specialization: Production Engineering)

By

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Roll No: 209ME2200

DEPARTMENT OF MECHANICAL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY

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CERTIFICATE

This is to certify that the thesis entitled, ***"An Investigation of Dissimilar Welding Joint of AISI 304L Stainless Steel with Pure Copper by Nd:YAG Pulse Laser: Optimization of Tensile Strength,"*** submitted by ***Kamal Kumar Kanaujia (Roll Number: 209ME2200)*** in partial fulfillment of the requirements for the award of ***Master of Technology*** in the department of Mechanical Engineering, National Institute of Technology, Rourkela is an authentic work carried out under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to elsewhere for the award of any degree.

Place: Rourkela
Date:

Prof. S. K. Sahoo
Mechanical Engineering Department
National Institute of Technology
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DEPARTMENT OF MECHANICAL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY

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I feel pleased and privileged to fulfill my parent's ambition and I am greatly indebted to them for bearing the inconvenience during my M-Tech course. I express my appreciation to my friends for their understanding, patience and active co-operation throughout my M-Tech course finally.

Place: Rourkela

Date**:**

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ABSTRACT

Nd:YAG laser welding process has successfully used for joining a dissimilar metal AISI 304L stainless steel and pure copper plates. In this study, a statistical design of experiment (DOE) was used to optimize selected LBW parameters (laser power, welding speed and pulse duration). Taguchi approach was used to design the experimental layout, each factors having four levels. Joint strength was determined using the universal testing machine (UTM). The results were analysed using analyses of variance (ANOVA) and the signal-to-noise (S/N) ratio for the optimal parameters, and then compared with the base material. And the Response can be predicted by fuzzy logic experimental results point to that the laser-welded joints are improved successfully by optimizing the input parameters using the Taguchi fuzzy approach. Also find out the effect of the focusing position on the response.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1

INTRODUCTION

CHAPTER 1
Introduction

1.1. Background and Motivation

Laser welding is one of the nonconventional and non-traditional methods to join materials. Laser beam welding has high power density, high heating and cooling rates which result in small heat affected zones (HAZ) [15]. Industrial lasers are used for welding, cutting, drilling and surface treatment of a wide range of engineering materials. A wide range of materials may be joined by laser- similar metals, dissimilar metals, alloys, and non-metals. In the present scenario demand of the joining of dissimilar materials continuously increases due to their advantages, which can produce very narrow heat affected zone (HAZ), low residual stress, and small welding defects. There is no requirement of the filler metals and high cooling rate favours the formation of a fine microstructure so that can enhanced material strength without undergoing any finishing operations [2]. In this study Nd: YAG laser used which is a solid state laser. AISI 304L stainless steel with pure cupper can be joined by using Nd:YAG laser machine without using filler materials. The effect of the laser process parameters viz. power, velocity, pulse duration and focusing position on the weld joint tensile strength has been investigated. Joining of AISI 304L stainless steel with copper is considered to be a major problem due to the difference in thermal conductivities and thermal expansion and copper are hard to melt with lasers due to their high reflectivity [1, 6]. In Power generation industries the copper and steel joint have been widely been used due to their high electrical conductivity and stiffness. Laser is widely used as a thermal source for industrial applications; this is because of the local treatment, precise operation, and short processing time. One of the important industrial applications of laser processing is the laser welding, which offers considerable advantages over the conventional welding methods. High intensity laser beam melts and partially evaporates the welded material during the process. The laser also has the ability of pulse shaping at pulse repetition rates of up to several kilohertz and with a duration varying from 0.5 to 20 ms .This flexibility gives control of the thermal input with a precision not previously available. The demand for producing joints of dissimilar materials is continuously increasing due to their advantages, which can provide appropriate mechanical properties and good cost reduction [7, 8]. Laser welding is characterized by parallel-sided fusion zone, narrow bead and high penetration. That advantage comes from its high power density, which make the laser welding one of the keyhole welding processes.

Design of experiment (DOE) and statistical techniques are widely used for optimization of process parameters [6]. In the present study the welding process parameters of laser beam can be optimized to maximize the tension strength of the work piece also reducing the number of experiments without affecting the results [5]. The optimization of process parameters can improve quality of the product and minimize the cost of performing lots of experiments and also reduces the wastage of the resources. The optimal combination of the process parameters can be predicted. This work is concerned with the effects of welding process parameters on the tensile strength of AISI 304L stainless steel and pure copper joints. The objective of this study is to find out the optimal combination of the parameter, power, speed, and pulse duration and maximized the tensile strength of the weld. Experiments were designed by the Taguchi method using an L- 16 orthogonal array that was composed of three columns and 16 rows. This design was selected based on three welding parameters with four levels each. The selected welding parameters for this study were: power, speed, and pulse duration. The S/N ratio for each level of process parameters is computed based on the S/N analysis. There are three categories of quality characteristic in the analysis of the signal-to-noise (S/N) ratio, i.e. the smaller-the-better, the larger-the-better and the nominal-the-best. In this experiment the target is to maximize the tensile strength, therefore, the optimal level of the process parameters is the level with the highest S/N ratio [5, 6, 9]. Statistical analysis of variance (ANOVA) was also performed to indicate which process parameters are statistically significant; the optimal combination of the process parameters can then be predicted [5].

The fuzzy rule based method was used to predict the response (Tensile Strength). S/N ratio is taken as an output (in place of tensile strength).

1.2. Welding

Welding is the Process for joining separate pieces of metal in a continuous metallic bond. In this process the joining metals or non-metals can melt by the help of thermal source like a gas flame or electric arc or laser and then using filler metal. In other word 'welding' is define the joining of two or more surface under the influence of heat, so the product shall be nearly homogeneous union as possible.

1.2.1. Types of welding

There are so many types of welding process to weld metal or non-metals are given bellow.

Welding is generally two types: (i) Conventional (ii) Nonconventional

1.2.1.1. Conventional welding

Arc welding

(i) Shielded metal arc welding (SMAW), (ii) Gas metal arc welding (GMAW), (iii) Flux-cored arc welding (FCAW), (iv)Gas tungsten arc welding (GTAW) or tungsten inert gas (TIG) welding (v) Submerged arc welding (SAW), (vi) Plasma Arc Welding, (vii) Carbon arc welding, (viii) Atomic hydrogen welding, (ix)Arc spot welding, (x)Flux cored arc welding, (xi)Stud arc welding

Gas welding

(i)Oxy-acetylene welding, (ii)Air acetylene welding, (iii)Oxy-hydrogen welding, (iv)Pressure gas welding

Resistance welding

(i) Spot welding, (ii) Seam welding, (iii)Induction welding, (iv)Butt welding , (v)Flash welding,

(vi)Percussion welding, (vii) High frequency welding

Solid state welding

(i) Friction welding, (ii) Cold welding, (iii) Hot pressure welding, (iv)Ultrasonic welding,

(v) Diffusion welding, (vi) Forge welding, (vii) Explosive welding

Thermo chemical welding

(i)Thermit welding, (ii) Atomic welding

1.2.1.2. Nonconventional welding

Radiant energy welding

(i) Laser beam welding, (ii) Electron beam welding, (iii) X-ray welding

Other welding

(i) Electro slag welding, (ii) Induction welding, (iii) Electro gas welding, (iv) Under water welding, (v) Brazing, (vi) Soldering.

1.2.2. Advantages of welding

(i) The welded joint has higher efficiency compare to other joint.

(ii) No surface finish is required.

(iii) Less expensive.

(iv) Very less amount of filler material is required depend upon the process.

These advantages have made welding joining components in various machines and structures.

LASER stands for “Light Amplification by Stimulated Emission of Radiation

1.3. Basic principles of the laser and the welding process

The light amplifier in laser is a rod-shape crystal of neodymium-doped yttrium aluminium garnet (Nd:YAG), which is stimulated by a light pulse from an external rod-shaped flash lamp. A high-performance reflector ensures that the light from the lamp is used and coupled into the laser crystal efficiently. To enable the laser light to be emitted in amplified directional from, two mirrors (forming the resonator) are arranged outside the crystal so that the light from it is reflected back into itself and the crystal. One of the mirrors is partly translucent, thus enabling highly directional laser radiation to drawn from resonator. The radiation has narrow wavelength range of about 1064 nm. The high directionality and narrow wavelength range are the very factors that enable the extreme concentration of laser energy onto the work piece (with focusing by means of a suitable lens). The concentration is many times greater than that possible with normal light sources.

During the laser pulse, a work piece within the focus range is heated to above the melting point of the materials to be joined, and the materials liquefy and diffuse into diffuse in to each other. The laser takes effect within a relatively short time (0.5 ms to 20 ms). The fused materials then harden again to form a compact compound.

The high, short-term concentration of laser energy onto a limited volume means that heat is only produced where it is required. This property makes the laser an excellent tool for the laboratory and industrial applications.

1.3.1. Characteristics of Laser

(i) Monochromatic

(ii) Directional

(iii) Coherent

1.3.2. Classification of laser

Gas laser

Helium-neon laser, Argon laser , Krypton laser, Xenon ion laser, Nitrogen laser, Carbon dioxide laser, Excimer laser, Helium-neon laser.

Chemical laser

Hydrogen fluoride laser, Deuterium fluoride laser, COIL(Chemical oxygen-iodine laser), Agil (All gas-phase iodine laser)

Metal- vapor laser

Helium-cadmium (HeCd), Helium-mercury (HeHg), Helium-selenium (HeSe), Helium-silver (HeAg), Strontium Vapor Laser, Neon-copper (NeCu), Copper vapor laser, Gold vapor laser.

Solid -state laser

Ruby laser, Nd:YAG laser, Er:YAG laser, Neodymium YLF(Nd:YLF), Neodymium doped Yttriumorthovanadate(Nd:YVO_4)laser,Neodymium doped yttrium calcium oxo borateNd:$YCa_4O(BO_3)_3$or simply Nd:YCOB, Neodymium glass(Nd:Glass) laser, Titanium sapphire(Ti:sapphire) laser, Thulium YAG(Tm:YAG) aser,

Semi-conductor

GaN, AlGaInP, AlGaAs, InGaAsP, lead salt, Vertical cavity surface emitting laser(VCSEL), Quantum cascade laser.

Other type of laser

Free electron laser, Gas dynamic laser, "Nickel-like" Samarium laser, Raman laser, uses inelastic stimulated Raman scattering in a nonlinear media, mostly fiber, for amplification, Nuclear pumped laser.

1.3.3. Advantage of laser welding

i. Weld lines can be as narrow as 0.4mm
ii. Tensile strength of the weld bead is more than base metal
iii. Three-dimensional geometries can be welded
iv. Laser welding can produces a very narrow heat affected zone (HAZ) with low residual stress and small welding defects in the base metal.
v. The high cooling rate favours the formation of a fine microstructure so that can improve the mechanical properties.
vi. There is no requirement of the filler material because of ability to create welds that are full penetrating and improved material strength without undergoing any finishing operations.
vii. Laser welding is extremely advantageous in automotive application due to high density, high degree of automation and high production rate and repeatability of the process.

1.2.4. Disadvantages:

i. Initial cast is very high.
ii. Required skill operator and high maintenance cost.
iii. Slow welding speed.

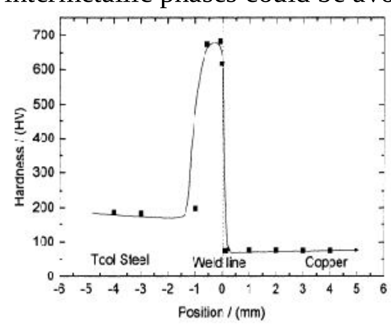
Chapter 2

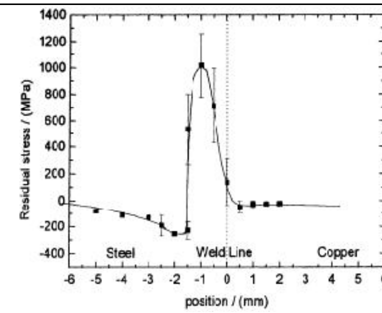
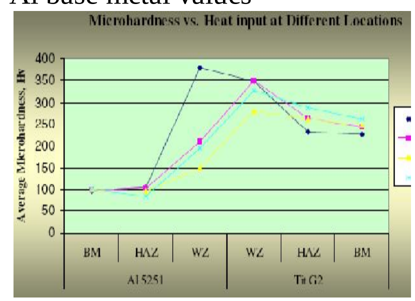
LITERATURE SURVEY

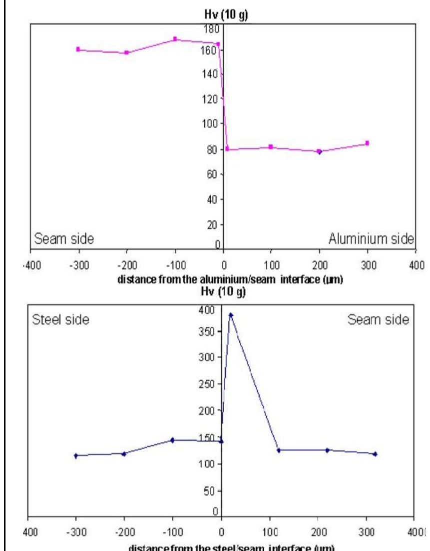
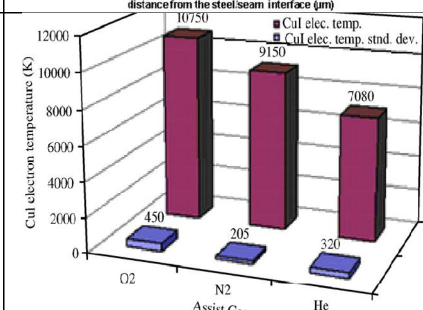
Literature survey

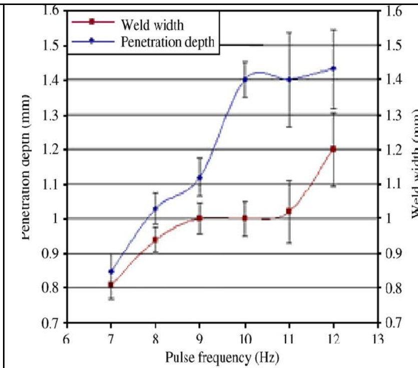
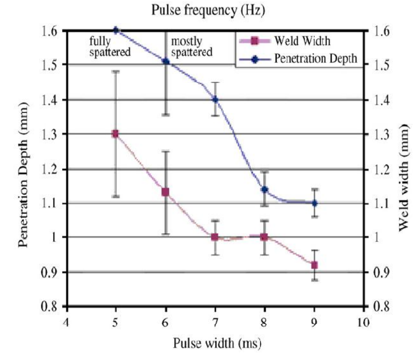
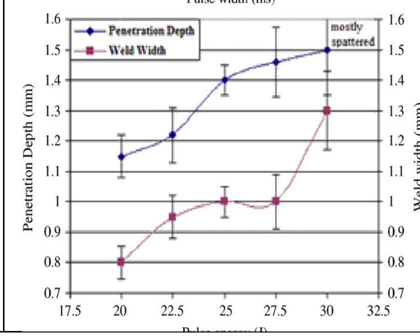
Topic	Author	Year	Laser type	Material	Expt. Range	Observation Parameter	Result
Dissimilar welding of carbon steel to 5754 aluminium alloy	M.J.Tarkamang et al.[1]	2009	Nd:YAG	Al alloy and steel	Peak power 1-2.7 KW, Pulse duration 3.7-10 ms, Velocity 5mm/sec, Pulse energy 10 J, Frequency 20/sec, Overlapping factor 40-90%, w/d ratio 1.5 mm, Power 200W,	OM, SEM, EDX, UTM	High peak power cause mode dilution, Hardness is also increasing with increasing the peak power. Longer pulse duration cause large weld width and also penetration depth. Welding efficiency increases with overlapping factor. Ideal parameter of welding peak power is1.43KW, Pulse duration is 5 ms, Overlapping factor 80% Hardness value increases with increasing the penetration depth.

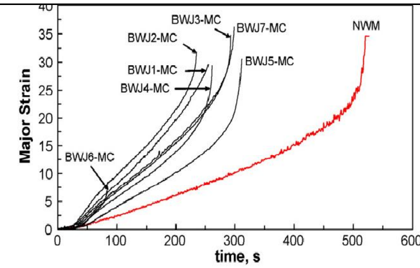
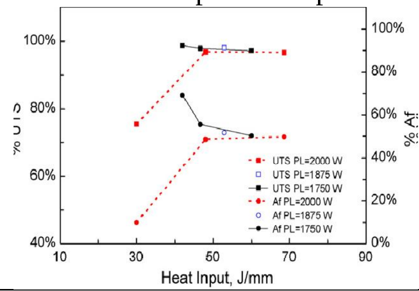
Pulse Nd-YAG laser welding of AISI 304 to AISI 420 stainless steel	Jose Rabrto Berretta et al.[2]	2007	Nd:YAG	AISI 304 to AISI 420 stainless steel	Energy 6 J, Average power 84 W, Pulse duration 7 ms, Pulse frequency 14 Hz, Speed 300 mm/min Pulse overlapping 30% Argon gas 10 lit/min	OP, SEM, EDX, UTM, Vickers Hardness Test	It can be observed that element distribution in the weld zone is homogeneous for all LASER beam position. Maximum hardness value in the HAZ of AISI 420. Tensile strength of AISI 420 is lower than AISI 304. Maximum welding efficiency get when position on the of the both specimen
Characteristics of deep penetration laser welding of dissimilar metal Ni-based cast superalloy K418 and alloy steel 42CrMo	Xiu-Bo Liu et al.[3]	2007	Nd:YAG	K418 and alloy steel 42CrMo	Power 2.5-3 KW, Velocity 15-20 mm/s, Gas flow rate 15 lit/min, Defocusing distance -3 to +1	OP, SEM, EDX	Weld depth increases with increasing laser power but not much in the weld depth. If velocity increases both depth and width decreases. Maximum hardness on the HAZ of 42 CrMo side then HAZ K418
Dissimilar autogenous full penetration welding of superalloy K418 and 42CrMo steel by a high power CW Nd:YAG laser	Xiu-Bo Liu.[4]	2007	Nd:YAG	K418 and alloy steel 42CrMo	Velocity 15-35 mm/s, Gas flow rate 5-20 lit/min, Defocusing distance -3 to +2, Power density 10^6-5×10^7	OM, SEM, EDX, EDS	With increasing velocity the weld width decreases because of heat input decreases. With increasing power the weld width slight increase With increasing power density the inside weld width also increases.

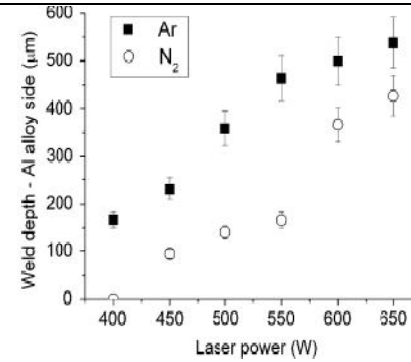
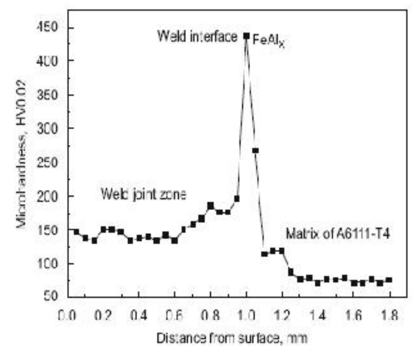
Using Taguchi method to optimize welding pool of dissimilar laser-welded components	E.M. Anawa et al.[5]	2007	CO_2 laser	AISI 316stainless-steel and AISI 1009 low carbon steel plates	Power 1.00-1.50KW, Welding speed 500-1000mm/min, Defocusing distance -1 to 0 mm.	MINITAB 13, ANOVA, Design-expert 7.	Increasing velocity the weld vaporization of metal decreases. With increasing power the weld width (W1) slight increase. With increasing power density the inside weld width (W2) also increases. Change the Defocusing distance (F) effects W1, W2 and did not affect the area. This may be interpreted that as F decreased, W1 increased, W2 decreased and vice versa, so the total area (A) will not be affected by changing F.
Optimization of tensile strength of ferritic/austenitic laser-welded components	E.M. Anawa et al.[6]	2008	Nd:YAG	AISI304 L/AISI12 L13.	Power 1.00-1.50KW, Welding speed 500-1000mm/min, Defocusing distance -1 to 0 mm.	Taguchi approach and (ANOVA)	Tensile strength increasing with increasing the power density and decreasing the speed When increasing the speed with or without changing the focus position tensile strength decreases. Changing the focus point position, the response will not be affected.
Characterisation of dissimilar joints in laser welding of steel–kovar, copper–steel and copper–aluminium	T.A. Mai et al.[7]	2004	Nd:YAG	Aluminium and copper copper–steel	Power - 350W, Frequency -500 Hz, Pulse duration -0.5 to2 0 ms, Velocity 150mm/s.	EDX,X-ray imaging	Melting ratio can play important role in defect free welding of dissimilar metal weld joint. So that heat distribution per unit area should be control and the formation of brittle intermetallic phases could be avoided. 

							
Modeling and optimization of tensile shear strength of Titanium/ Aluminum dissimilar welded component	E. M. Anawa et al.[9]	2009	Co_2 laser	Titanium / Aluminum	Laser power 0.9 to 1.35 KW, Speed 1600 to 2100, Focus -1 to 0.0 mm	Statistical techniques and Design of Experiment Design Expert software Taguchi optimization technique	The dissimilar joint between Aluminum and titanium alloys were effectively welded by CO2 laser welding with a single pass and without filler material using the overlap joint design. Tensile shear strength was almost same as the Al base metal values  Hardness variation shown in that graph.
Interface microstructure and mechanical properties of laser welding copper–steel dissimilar joint	Chengwu Yao et al. [10]	2009	CO_2	copper–steel	Thickness 7 to 10 mm, Power -8KW, Defocusing amount 3to4 mm angle-84 to 85 deg	OM, SEM, EDS, TEM	A copper and steel dissimilar joint free for the defects can be obtained when the amount of copper dissolved in the molten steel is very limited. The tensile properties of copper and steel dissimilar joint are outstanding.

Dissimilar material joining using laser (aluminium to steel using zinc-based filler wire)	Alexandre Mathieu .[11]	2005	Nd:YAG laser	Aluminium to steel using zinc-based filler wire	Laser power 1.4 to 2 KW, Defocusing length (1 to 3), Tilt angle of the assembly with respect to the laser beam axis 35- 45 deg, Braze welding speed 2 to 3.2 mm/min, Filler wire speed 2 to 3.2 mm/min Diameter of the fiber and the laser beam shaping (one-spot or two-spots),	Taguchi Design method, Optic shaping devices, back-scattered electron micrograph, UTM, Design of experiment, , FEM thermal simulation	Heterogeneous steel and aluminium assemblies have been done by laser braze welding. Zn base alloy have low melting temperature. There is no requirement of flux. The rupture occurs in HAZ of aluminium and steel itself. 
Spectroscopic characterization of low-nickel copper welding with pulsed Nd:YAG laser	S. Dadras et al.[12]	2008	Nd:YAG laser	nickel-alloyed copper	He, N_2 and O_2 are used, Pulse energy 25J, Frequency 10 Hz, pulse duration of 7 ms, Laser power 250 and 3571W.	Microscope, Table Curve software,	

							Weld width Penetration depth Penetration depth (mm) Weld width (mm) Pulse frequency (Hz) fully spattered mostly spattered Weld Width Penetration Depth Penetration Depth (mm) Weld width (mm) Pulse width (ms) Penetration Depth Weld Width mostly spattered Penetration Depth (mm) Weld width (mm)

Nd:YAG laser weldability and mechanical properties of AZ31 magnesium alloy butt joints	L.D. Scintilla et al.[13]	2010	Nd:YAG laser TRUMPF HL2006D	Magnesium alloy AZ31 sheets	Maximum power of 2000 W, Sheets thickness of 3.3 mm butt joint, He, argon gas are used, Speed 1.75 to 2.00 mm/min, Power 1750 to 2000, Focusing point position,	statistical method based on design of experiment, UTM	 it can be said that UTS improves considerably as laser beam scanning speed increases at the particular power. 
Transmission electron microscopy characterization of laser welding cast Ni-based superalloy K418 turbo disk and alloy steel 42CrMo shaft	Xiu-Bo Liu.[14]	2008	Nd:YAG laser	Ni-based superalloy K418 turbo disk and alloy steel 42CrMo shaft	Outer diameter of 38.5mm and Inner diameter of 27.5 mm, thickness of 5.5 mm of the shaft, Thin foils were prepared by cutting slices (0.15mm thick)	OM and SEM, TEM and SAED, XRD,	Based on the over TEM analyses, it can be accomplished that there are mainly FeCrNiC austenite solid solution dendrites as the matrix, (Nb, Ti) C type MC carbides, fine and dispersed Ni3Al phase as well as particle-like Laves phase in the welded seam. The continuation of these phases is governed by both the kinetic and thermodynamic principles of the non-equilibrium laser welding process.

Gap-free fibre laser welding of Zn-coated steel on Al alloy for light-weight automotive applications	Hui-Chi Chen.[15]	2010	Nd:YAG laser	Lap welding of Zn-coated steels, Al alloy, Mg alloy	Ar, N_2, Laser power 400 to 650 W, Speed 75 to 100 mm/min,	SEM, EDS,	 The sound welds with the narrower affected zone could be passed out using a single mode fibre laser. In twice over pass welding, the weld look and its corrosion resistance could be improved compared with single pass welding. Shielding gas played a vital role in determining the weld quality in the fibre laser welding of Zn-coated steel on Al alloy process. N_2 producing less hardness compare to Ar.
CW/PW dual-beam YAG laser welding of steel/aluminum alloy sheets	Shi Yan et al.[16]	2010	Dual-beam YAG laser	Lap welding of JSC270CC steel and A6111-T4 aluminum alloys	Dimension 100mm*20mm, Laser power 390 W, Peak power is 2.61 kW, Pulse frequency is 5 Hz, Pulse width 2.0ms and the welding speed is 0.06 m/min	Optical microscope, EPMA analysis,	The blowholes was generated in the welded joints, and the root-shape structures dose not form at the interface.  The deep penetration welding can be achieved with the low-power CW laser. At the same

							time, dual-beam laser welding can decrease or void the production of blowhole effectively.
Development of software using fuzzy Logic to predict erosive wear in slurry Pipeline system.	Rajat Gupta et al.[17]	2008	-	Brass and mild steel	-	Fuzzy logic	Two Fuzzy Inference Systems have been developed for the prediction of uneven wear for two materials, namely brass and mild steel respectively. We can use this FIS to predict the local wear rate in a slurry pipe as long as the concentration and size distribution of the solids across the pipe cross section are known.
A Neuro-Fuzzy Approach to Select Welding Conditions for Welding Quality Improvement in Horizontal Fillet Welding.	Hyeong-Soon Moon et al.[18]	1996	Gas tungsten arc Welding.			Fuzzy logic, neural network.	Unacceptable weld bead profiles have a significant effect on the performance of welds under load. Selection of the welding condition is very difficult because of the nonlinear characteristics and complexity of the welding processes. Fuzzy rule based method for examining welding conditions for weld defects were investigated in this paper.
Characterization of low pump Nd:YAG laser.	Abd Rahman Tamuri et al.[19]	2007	Nd:YAG laser	-	-	-	Nd:YAG laser had been effectively developed. The fundamental wavelength of the laser was 1064 nm. The threshold pump voltage was 200 V and the maximum output energy that could be achieved is up to 250 mJ. The intensity of the laser output was dependent on pump voltage with a threshold value of 190 V. The minimum pump voltage was 400 V which equivalent to 50 mJ of energy and was detected on burn paper.

Chapter 3

EXPERIMENTAL PREREQUISITES

CHAPTER 3

Experimental Prerequisites

3.1.Nd:YAG Laser:

The Nd:YAG 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. Nd:YAG is chosen for most materials processing applications because of the high pulse repetition rates available [19]. The power supply of pulsed Nd:YAG laser is designed to produce a maximum average power. The beam quality and output power are depending on length of resonator [19]. 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 [19]. Nd:YAG laser can be used for direct energy conduction welding of metals and alloys; the absorptive of metals increases as wavelength decreases. Since conduction welding is normally used with relatively small components, the beam is delivered to the work piece via a small number of optics. Simply beam defocusing to a projected diameter that corresponding to the size of weld to be made [19].

3.2.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.

3.2.1. Process gas:

Gases are used in welding because of three main functions:

(1) Shielding

(2) Plasma suppression

(3) Protection of optics

Shielding of the molten weld pool prevent oxidation and contamination, which could lead to porosity and embrittlement. Both the weld bead face and root face required shielding. Plasma is caused by ionization of ejected metal vapour and of the shielded gas. Plasma formation is particularly noticeable when welding with high power and speed below 1m/min. the effect is to defocus the beam, reduced the energy absorbed by the weld, and produce a distinctive nail head appearance in the weld bead section. Plasma is removed from the interaction zone by gas flow rate of about 10L/min.

List of shielding gas

(1) Helium
(2) Argon
(3) Nitrogen
(4) Carbon dioxide (CO_2)

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.

3.2.2. Joint:

The square butt (fig 1) or 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 cancavity and sagging. The beam must be aligned with the joint line over its entire length.

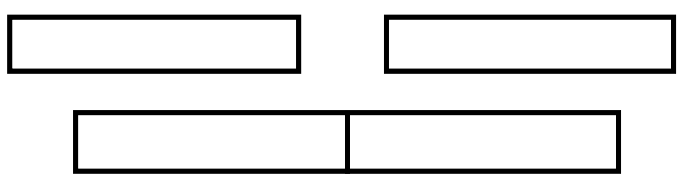


Figure 1 Square butt joint

3.2.3. 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 “Alfa Laser AL-T 200” and the specifications are given below:

Figure 2 Alfa laser AL-T200

Specifications of “Alfa Laser AL-T 200” 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

3.3.Applications:

(i)Power generation industries the copper-steel combinations have often been widely used due to their high electrical conductivity and stiffness.

(ii)Dissimilar joint can be used in automobile industries to replace the heavy metal by the light metal for the purpose of reducing the weight and reduce the fuel consumption.

(iii)Dissimilar joint commonly used in the following chemical, petrochemical, nuclear and electronics industries for the purpose of tailoring component properties or weight reduction.

3.4.Laser parameters:

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)

3.5.Jigsaw machine and grinding wheel machine:

Figure 3 Jigsaw and grinding wheel

Jigsaw can be used for cutting speciman from big metal sheet shown in fig 3

grinding wheel machine can be used for shaping the speciman for edge to edge contect shown in fig 3.

3.6.Material properties:

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.

3.7.Optical microscope :

Figure 4 Optical microscope

Optical microscope can be used for analysis of the weld bead are shown in fig 4.

3.8.Experimental set up for tensile Strength measurement

The whole experimental investigation were done using 'FIE' Electronic Universal Testing machine (UTM), model UTS-100 which can be used for conduction test in tension, compression and transverse test of metals and other material. Maximum capacity of the machine is of 1000 kN with measuring range between 0 to 1000 kN. The accuracy of measurement of the machine is ±1.0% kN Because load required for extrusion is of compressive type so, experiments were conducted using compression test

The UTM consists of three major parts

(i)Machine frame or Loading unit

(ii)Hydraulic system

(iii)Electronic control panel

3.8.1. Machine frame or Loading unit:

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 5

Figure 5 Machine frame

3.8.2. Hydraulic System unit:

Hydraulic system unit consists of motor pump unit with cylinder and piston. Safety valve is provided for additional safety are shown fig 6.

Figure 6 Hydraulic system

3.9.Taguchi methods:

Taguchi's philosophy is an efficient tool for the design of high quality manufacturing system. Dr. Genichi Taguchi, a Japanese quality management consultant, has developed a method based on orthogonal array experiments, which provides much-reduced variance for the experiment with optimum setting of process control parameters [5-9]. Thus the integration of design of experiments (DOE) with parametric optimization of process to obtain desired results is achieved in the Taguchi method. Orthogonal array (OA) provides a set of well-balanced (minimum experimental runs) experiments and Taguchi's signal-to-noise ratios (S/N), which is logarithmic functions of desired output serve as objective functions for optimization. This technique helps in data analysis and prediction of optimum results. In order to evaluate optimal parameter settings, Taguchi method uses a statistical measure of performance called signal-to-noise ratio. The S/N ratio takes both the mean and the variability into account. The S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). The standard S/N ratios generally used are as follows: Nominal is best (NB), lower the better (LB) and higher the better (HB). The optimal setting is the parameter combination, which has the highest S/N ratio [5, 9].

3.10. Fuzzy logic analysis:

Fuzzy logic developed by Zadeh in 1965 allows degrees of truthfulness that measure to what extent a given object is included in a fuzzy set. Fuzzy sets correspond to linguistic variables used in a human language[18]. Fuzzy truth values are determined by membership functions that determine the degree of membership of an object in a fuzzy set . A fuzzy system is a static nonlinear mapping between its inputs and outputs[17]. It consists of a fuzzifier, an inference engine, a data base, a rule base, and defuzzifier. The fuzzifier converts the crisp inputs to fuzzy sets, and the inference engine uses the fuzzy rules in the rule base to produce fuzzy conclusions, then the defuzzifier converts these conclusions into the crisp outputs. The process for the fuzzy logic controller is shown as Fig. 7. Based on the fuzzy rules, we adopt the Mamdani implication method for the fuzzy inference reasoning in this study.

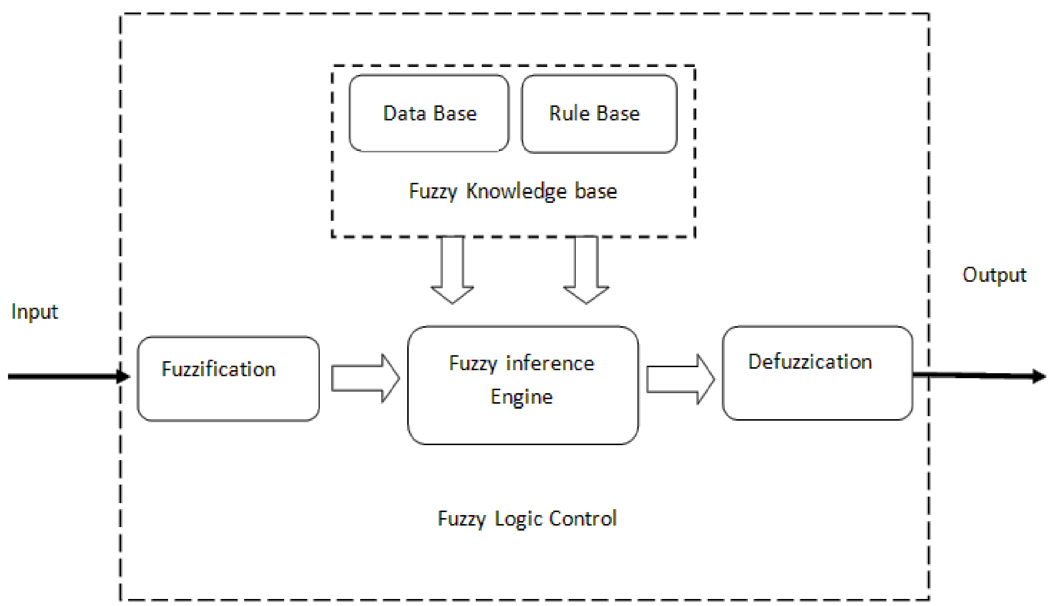


Figure 7 Mamdani modal

Chapter 4

EXPERIMENTAL WORK

CHAPTER 4

Experimental Work

4.1. Experimental Design

Experiments were designed by the Taguchi method using an L_{16} orthogonal array that was composed of three columns and 16 rows. This design was selected based on three welding parameters with four levels each. The selected welding parameters for this study were: power, speed, and pulse duration.

The S/N ratio for each level of process parameters is computed based on the S/N analysis. There are three categories of quality characteristic in the analysis of the signal-to-noise (S/N) ratio, i.e. the smaller-the-better, the bigger-the-better and the nominal-the-better. In this experiment maximizing the tensile strength so Therefore, the optimal level of the process parameters is the level with the highest S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) was also performed to indicate which process parameters are statistically significant; the optimal combination of the process parameters can be predicted.

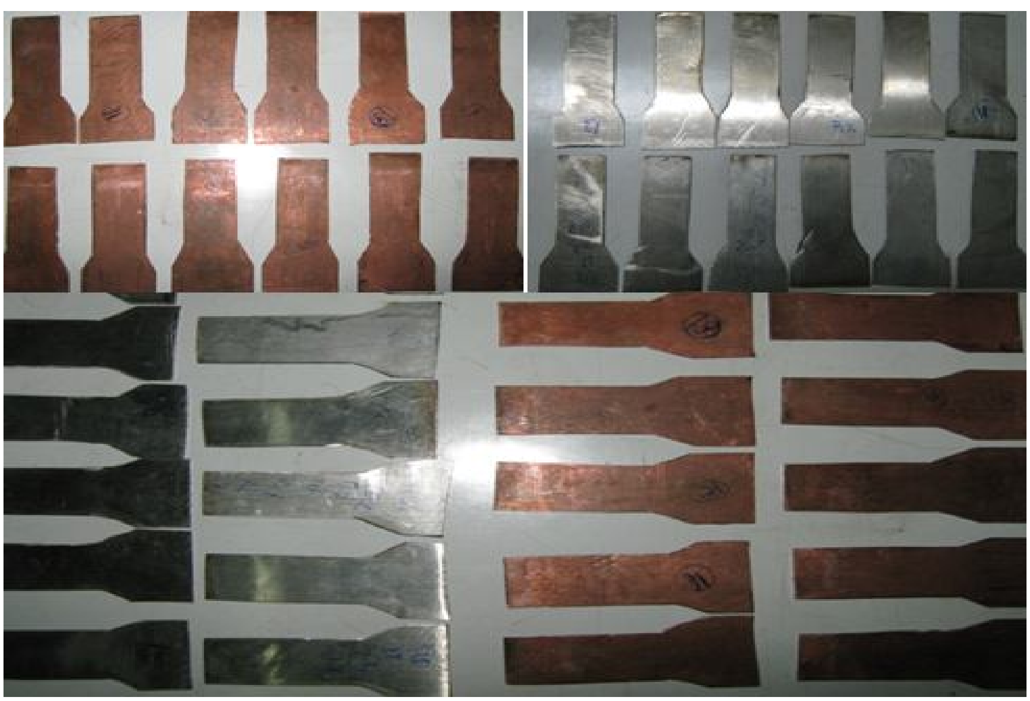


Figure 8 Half dog bone shape copper and AISI 304 work piece

Table 1 Process parameters and design level

S. N.	Variable	Code	unit	Level 1	Level 2	Level 3	Level 4
1	Laser power	P	kW	5.6	5.8	6	6.2
2	Welding speed	S	mm/min	.6	.8	1	1.2
3	Pulse duration	T_p	ms	13	14	15	16

The materials used in this investigation were plates of AISI 304L stainless steel and pure copper in dimensions of 80mm gauge length 20mm width and 1mm of thickness(half dog bone shape), each have used as a workpieces materials. Good surface finish is required for the workpiece for laser welding. The typical chemical compositions of the materials are given in Table2 and Table 3

Table 2 Chemical composition of copper

Material	C	Si	Cu
Copper	3.88	0.82	95.29

Table 3 Chemical composition of AISI 304 stainless steel

Material	C	Si	Cr	Mn	Fe	Ni	Tb
AISI 304 stainless steel	3.28	3.34	14.89	1.07	53.54	5.2	18.61

The joints were produced using Nd:YAG laser beam welding (LBW) at a maximum average laser power 200W, wavelength 1.06µm, peak pulse power 10KW, pulse energy 90J, focusing diameter 0.3-2mm and pulse duration .5-20ms. This flexibility gives control of the thermal input with a precision.

In the fuzzy system, welding power, welding speed, pulse duration were used as input variables. The combination of these variables was used to predict weld tensile strength in a form of S/N ratio (larger is batter), here S/N ratio used as a output.

In this work, two plates of AISI 304L stainless steel and pure copper have taken. The chemical compositions of these materials are presented in Table 2 and Table 3. A butt joint was applied for joining the two plates together. The plate’s edges were cleaned and grinded along the weld line to ensure full contact.

The experiments were carried out according to the design matrix given in Table 4 and the process parameters are used according to the given in Table 1. Argon gas was used as a shielding gas with a constant flow rate of 5 l/min, in this experiment the focus position of laser at welding line. The final workpice are shown in fig 9 and the weld bead area is shown in fig 10.

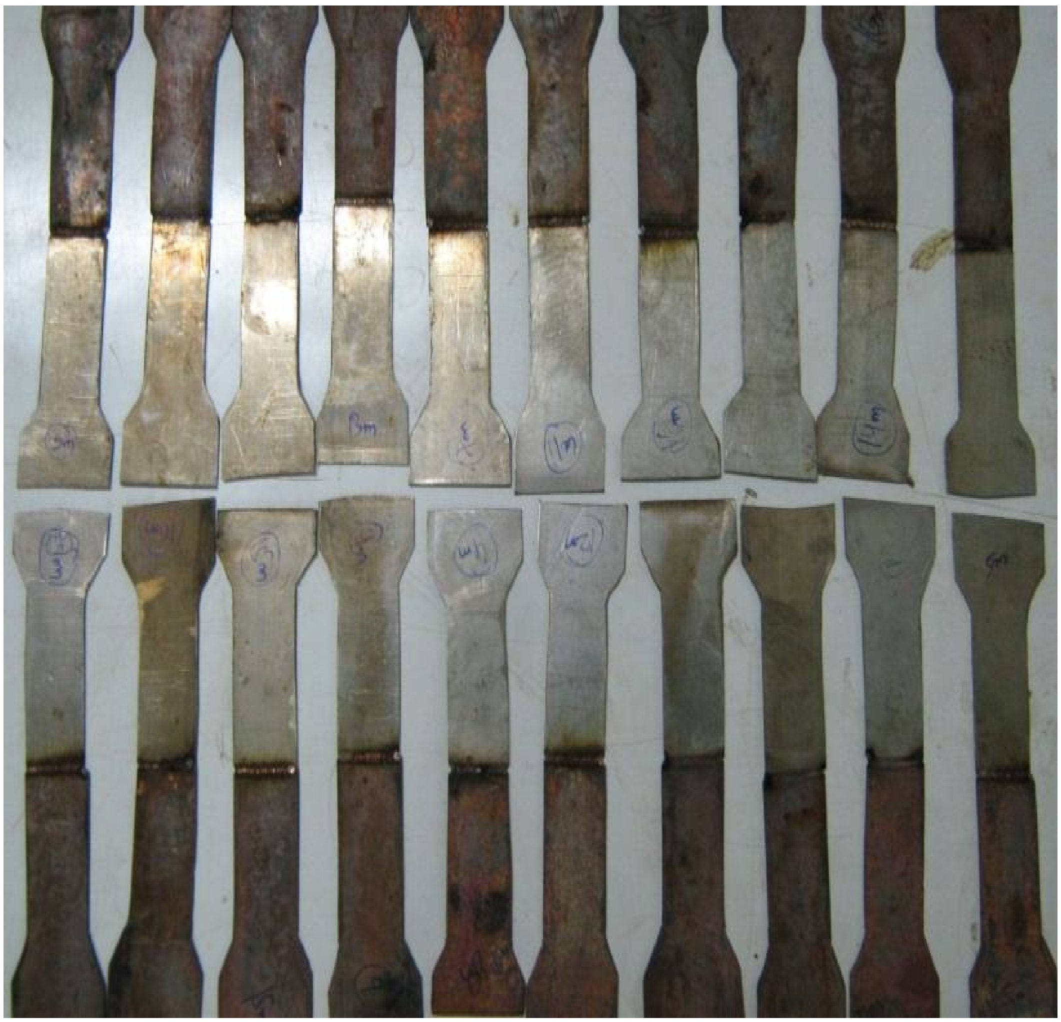


Figure 9 workpiece after welding

Experiment No. 1.

Table 4 Experimental details and response. When focus position of laser at the center of welding line (A).

Exp no.	P(kw)	S(mm/s)	T_p(ms)	Tensile strength
1	1	1	1	17.20
2	2	1	2	17.65
3	3	1	3	18.21
4	4	1	4	19.06
5	2	2	1	17.62
6	3	2	2	17.90
7	4	2	3	18.63
8	1	2	4	17.38
9	3	3	1	17.74
10	4	3	2	18.14
11	1	3	3	17.23
12	2	3	4	17.46
13	4	4	1	18.08
14	1	4	2	16.85
15	2	4	3	17.25
16	3	4	4	17.80

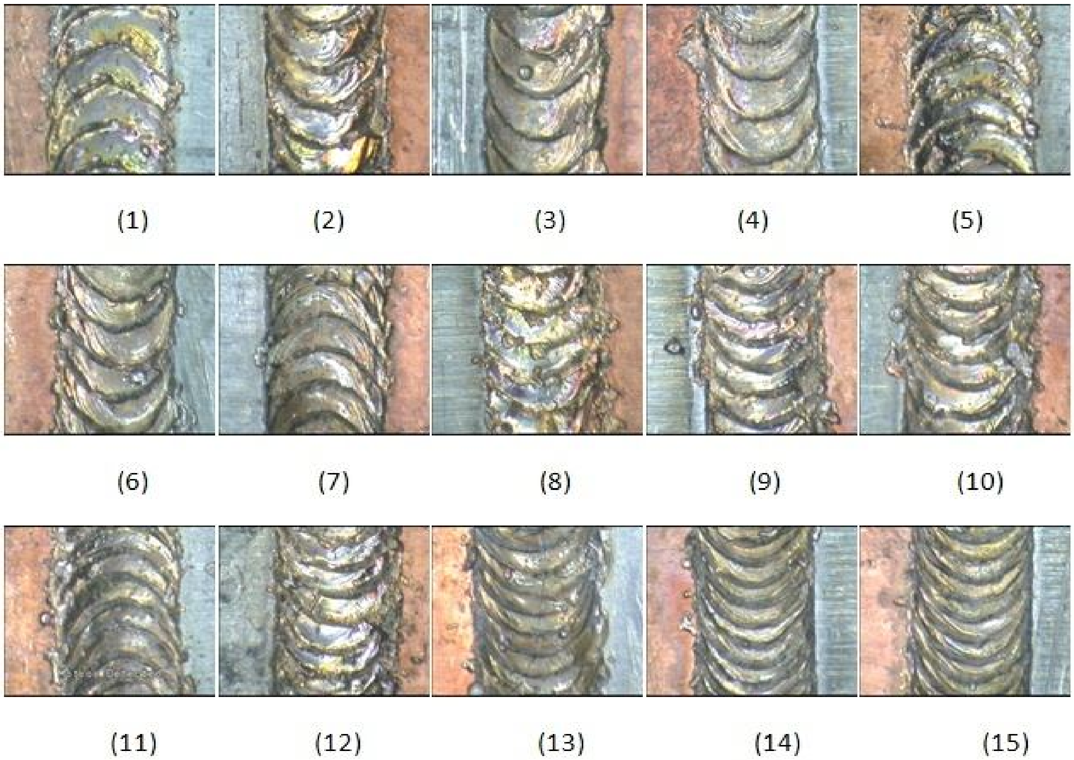


Figure 10 Surface of the weld zone

Nd: YAG laser machine used for welding. The tensile strength was applied to ensure that the fracture of the sample occurs in the base metal area, because the tensile strength of the produced joints is higher than the tensile strength of the base metal copper are shown in fig 11. Tensile test samples were tested at room temperature. Universal testing machine was used with a gauge length 160mm of the workpiec and the tensile strength result was given in the table 4.

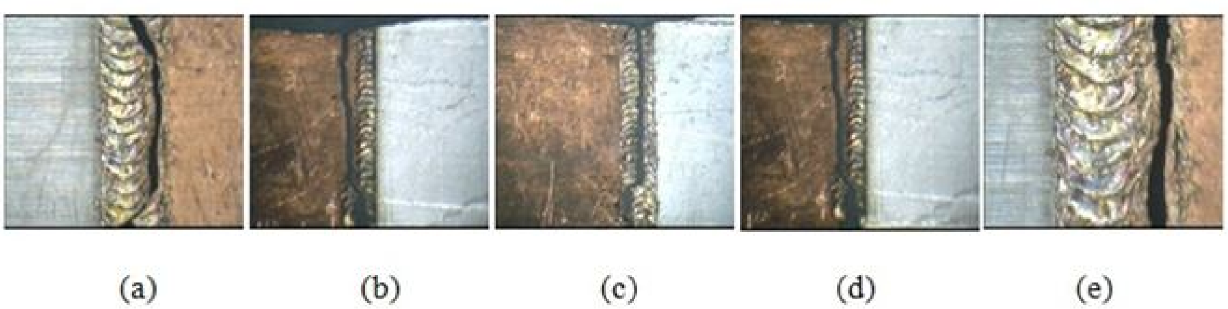


Figure 11 Fracture in occur after testing

Chapter 5

RESULTS AND DISCUSSION

CHAPTER 5

Results and Discussion

5.1.Orthogonal array experiment and the S/N ratio

In this study, an L_{16} (4^3) orthogonal array with three columns and 16 rows was used. This array can handle four-level process parameters. Sixteen experiments were required to study the welding parameters using the L_{16} 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 S/N ratio for ‘‘bigger is better’’ target for all the responses were calculated as follows:

$$S/N=-10\,log_{10}(\sum\frac{1/y2}{n}) \tag{1}$$

Where y is the average measured tensile strength and “n” the number of experiment runs, in this study n=16.The experimental lay-out for the welding process parameters using the L_{16} orthogonal array is shown in Table 4 and the responses for S/N ratio are presented in Table 5. Show how each factor affects the response characteristic. The main effect plots for S/N ratio exhibited in Fig. 12 created by MINITAB. The rank in Table 6 indicates that power has stronger effect on the response followed by speed, than pulse duration have minimum effect on response.

Table 5 Responses

Exp no.	P(kw)	S(mm/s)	T_p(ms)	Tensile strength	S/N	Fuzzy Value	Error
1	1	1	1	17.20	24.7106	25.1	-1.57584
2	2	1	2	17.65	24.9349	24.8	0.541009
3	3	1	3	18.21	25.2062	25	0.818053
4	4	1	4	19.06	25.6025	25.6	0.009765
5	2	2	1	17.62	24.9201	25.1	-0.72191
6	3	2	2	17.90	25.0571	25.1	-0.17121
7	4	2	3	18.63	25.4043	25.3	0.41056
8	1	2	4	17.38	24.8010	24.8	0.004032
9	3	3	1	17.74	24.9791	25.1	-0.484
10	4	3	2	18.14	25.1727	25.1	0.288805
11	1	3	3	17.23	24.7257	24.8	-0.3005
12	2	3	4	17.46	24.8409	24.8	0.164648
13	4	4	1	18.08	25.1440	25.1	0.174992
14	1	4	2	16.85	24.5320	24.8	-1.09245
15	2	4	3	17.25	24.7358	24.8	-0.25954
16	3	4	4	17.80	25.0084	25.1	-0.36628
							$\sum$=-2.55987

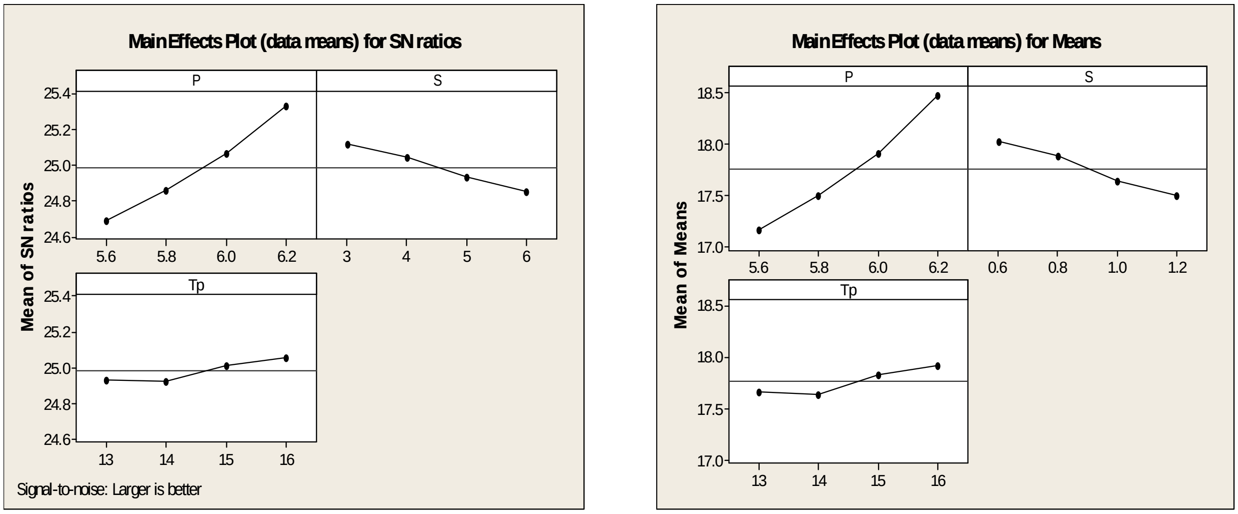


Figure 12Main effect plots for tensile strength

Table 6 Response Table for Signal to Noise Ratios Larger is better

Level	1	2	3	4	Delta	Rank
p	24.69	24.86	25.06	25.33	0.64	1
S	25.05	25.05	24.93	24.86	0.26	2
T_p	24.94	24.93	25.02	25.06	0.14	3

5.2.ANOVA

The purpose of ANOVA is to investigate which welding process parameters significantly effects on the response.

Table 7 ANOVA table

Source	DF	Squares SS	Adj MS	F	P
P	3	3.84915	1.28305	77.92	0.001
S	3	0.68765	0.22922	13.92	0.001
T_p	3	0.2309	0.16442	4.67	0.010
Error	6	0.0988	0.01647		
Total	15	4.8665			
S = 0.128323	R^2= 97.97%	R^2(adj)=94.92%			

In the ANOVA table (Table 7), the F value is used to test the significance of a factor. A high F value for a parameter means that the effect of the parameter on the characteristics is large. The result in Table 7 shows that the highest F value in the process was obtained for laser power P equal to 77.92. The F value for the speed was equal to 13.92, which indicates that the speed has a relatively lesser effect on the process and similarly the F value of T_p is very low so it indicates it has very less effect on the response and the main effect plot give the optimized value are shown in fig 12. The best result gain when input process parameters are P -6.2, S-.6, and T_p-16.

The regression equation in terms of actual input factor

Tensile strength at A = 4.31 + 2.18 P - 0.923 S + 0.0990 Tp (2)

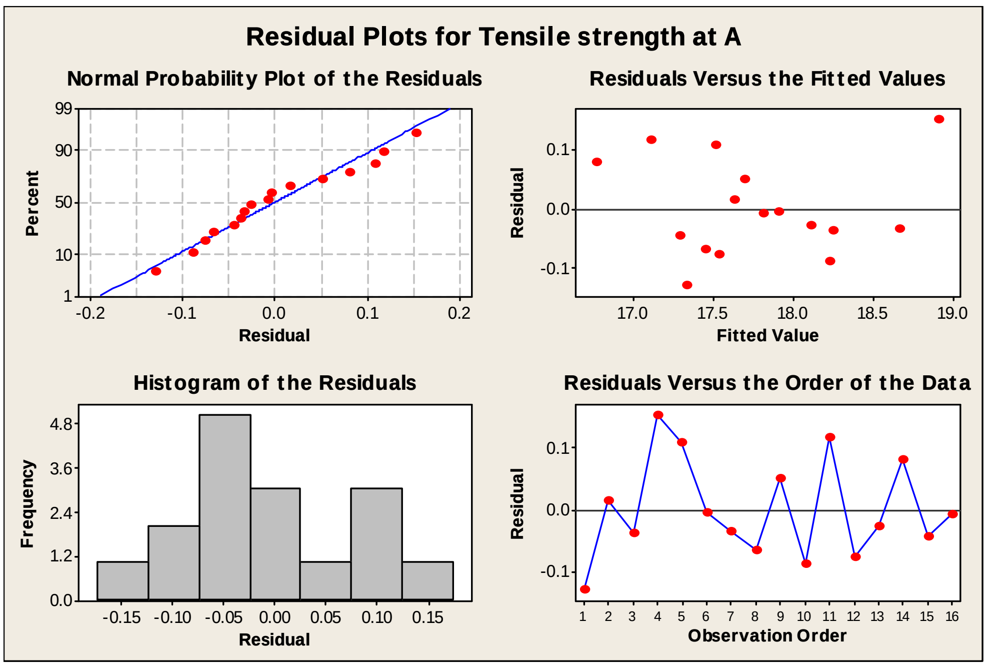


Figure 13 Residual plots for tensile strength

The residual plot of tensile strength is shown in Fig 13. This layout is useful to determine whether the model meets the assumptions of the analysis. The residual plots in the graph and the interpretation of each residual plot indicate below:

a. Normal probability plot indicates the data are normally distributed and the variables are influencing the response. Outliers don’t exist in the data, because standardized residues are between -0.2 and 0.2.

b. Residuals versus fitted values indicate the variance is constant and a nonlinear relationship exists as well as no outliers exist in the data.

c. Histogram proves the data are not skewed and not outliers exist.

d. Residuals versus order of the data indicate that there are systematic effects in the data due to time or data collection order.

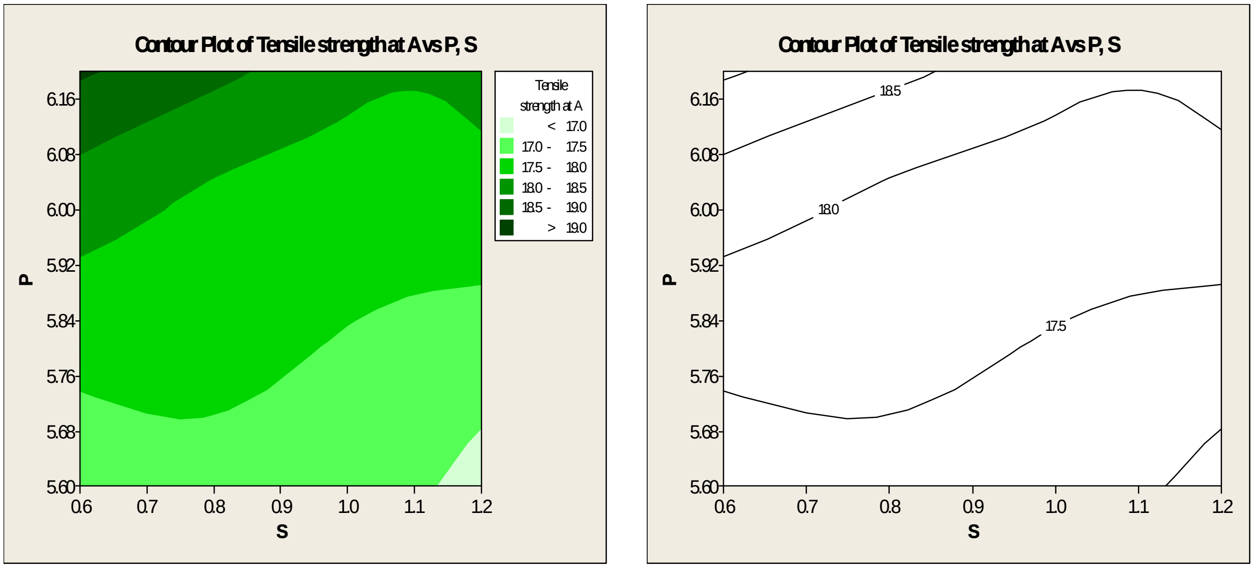


Figure 14 Contour graph shows the effect of P and S parameter on the response

Response will be change by change the power “P” and speed “S” value is shown in given contour plot fig 14.the colour variation indicated the variation of the tensile strength from light green to dark green colour. That value of the response shown on the line of the contour.

5.3.Fuzzy logic analysis

A fuzzy system is a static nonlinear mapping between its inputs and outputs. It consists of a fuzzifier, an inference engine, a data base, a rule base, and defuzzifier. The fuzzifier converts the crisp inputs to fuzzy sets, and the inference engine uses the fuzzy rules in the rule base to produce fuzzy conclusions, then the defuzzifier converts these conclusions into the crisp outputs. The process for the fuzzy logic controller is shown as Fig. 15. Based on the fuzzy rules, we adopt the Mamdani implication method for the fuzzy inference reasoning in this study Fig. 15.

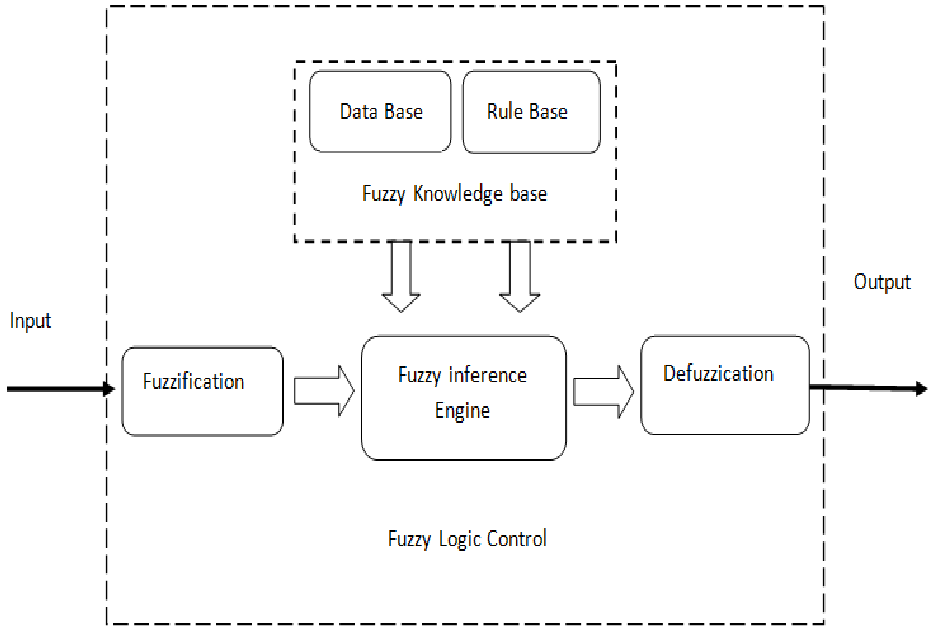


Figure 15 Fuzzy logic control system

Fuzzy logic control system the input variable is defined as; small, medium, and large and the output variable; very small, small, medium, large, and very large. The membership functions of all input variables and output variables used in the fuzzy system are triangular type are Shown in fig 16.

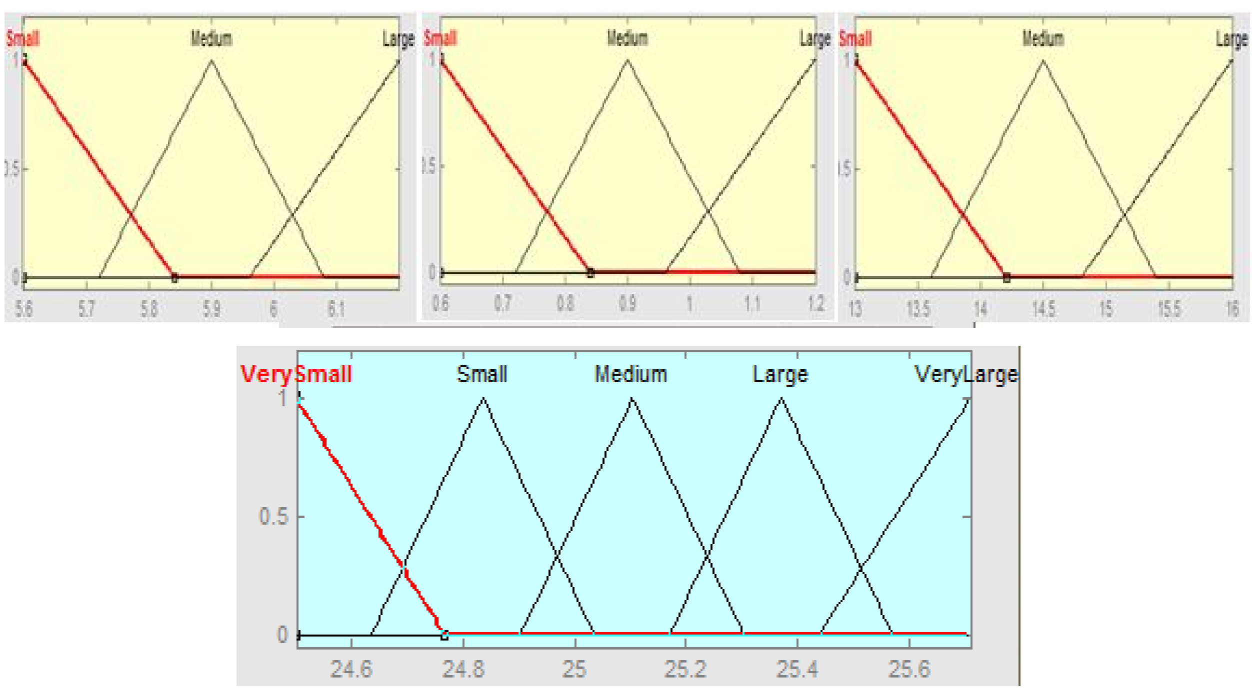


Figure 16 Membership function of input/output

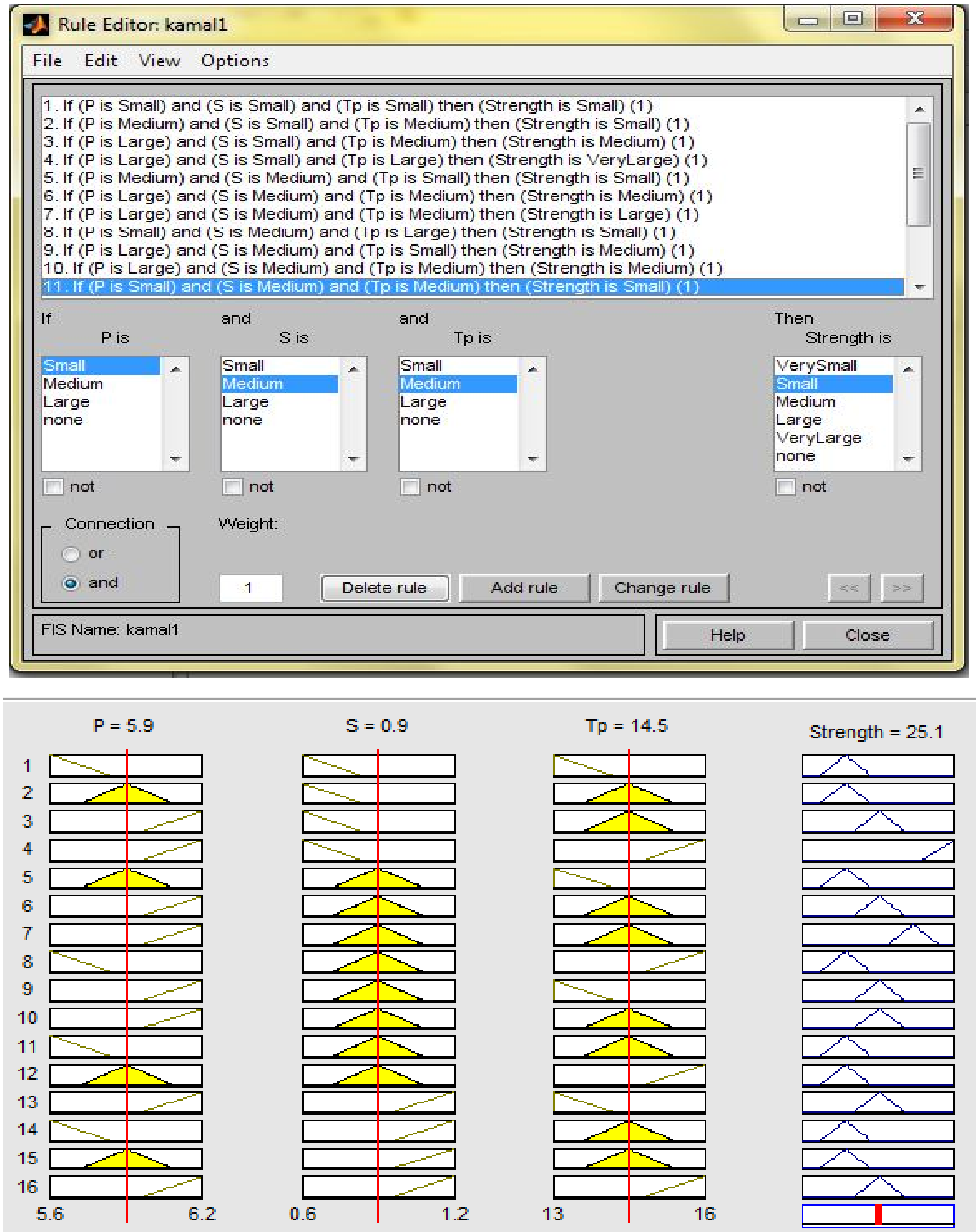


Figure 17 Fuzzy rule

The fuzzy rules were constituted of linguistic representations for the relationships between input (welding power, welding speed, Pulse duration) and output variables(S/N ratio) are shown in fig 17. There are 16 rules taken as per the Taguchi design of experiment. Prediction of the responses using Fuzzy decision making logic is compared with the results obtained from the experiments. Average percentage error is 2.55987 Calculated as the difference between the observed and predicted value.

Similarly two more experiment has been done. Taking same process parameter only changed focusing position of the laser beam. Experiment no. 2 focusing position of laser beam 0.5mm toward the copper plat (A') and experiment no. 3 focusing position of laser beam 0.5 toward the AISI 304 stainless steel plate (A"). The experimental result is given below.

Experiment No. 2

Table 8 Experimental details, response, S/N ratio, fuzzy value and error. When focus position of laser at 0.5 mm toward the copper side (A').

Exp no.	P(kw)	S(mm/s)	T_p(ms)	Tensile strength	S/N	Fuzzy Value	Error
1	1	1	1	16.85	24.5320	24.5	0.130441872
2	2	1	2	17.31	24.7659	24.7	0.266091683
3	3	1	3	17.8	25.0084	24.9	0.433454359
4	4	1	4	18.62	25.3996	24.8	2.360667097
5	2	2	1	17.12	24.6701	24.7	-0.121199347
6	3	2	2	17.61	24.9152	25.1	-0.7417159
7	4	2	3	17.56	24.8905	24.9	-0.038167172
8	1	2	4	16.63	24.4178	24.5	-0.336639665
9	3	3	1	17.36	24.7910	24.8	-0.036303497
10	4	3	2	17.42	24.8210	24.8	0.084605777
11	1	3	3	16.41	24.3022	24.3	0.009052678
12	2	3	4	16.89	24.5526	24.5	0.21423393
13	4	4	1	17.31	24.7659	24.8	-0.137689323
14	1	4	2	16.26	24.2224	24.2	0.092476385
15	2	4	3	16.62	24.4126	24.4	0.051612692
16	3	4	4	17.24	24.7307	24.8	-0.280218514
							$\sum$=1.9507

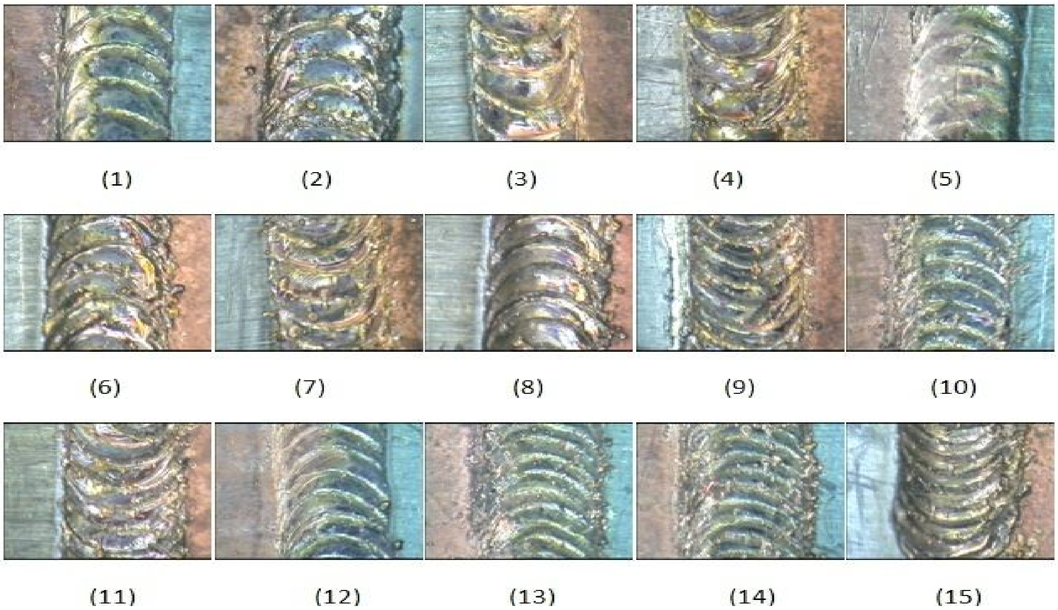


Figure 18 Surface of the weld zone

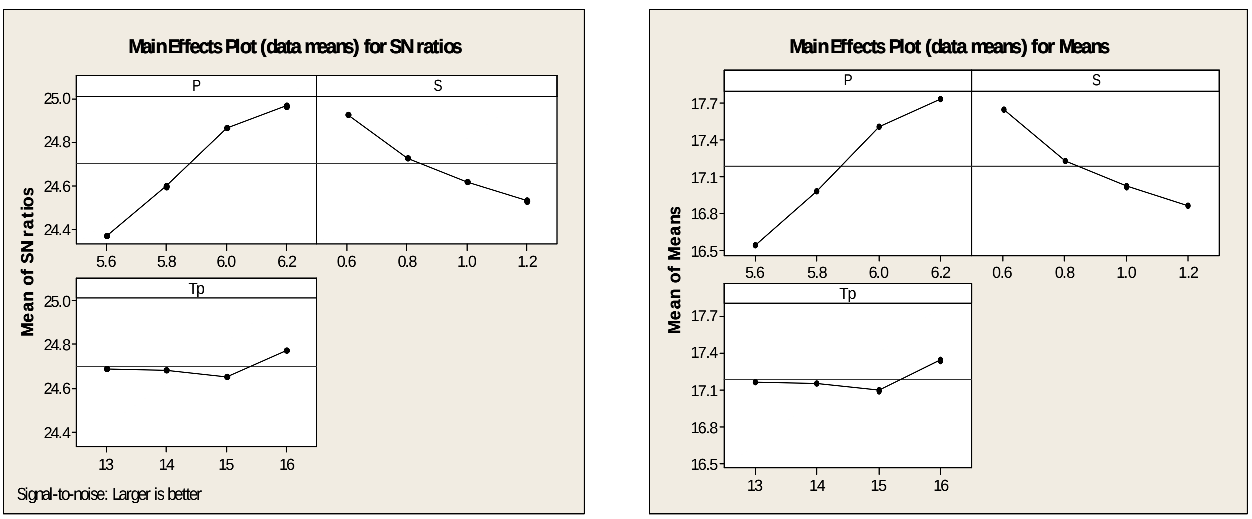


Figure 19 Main effect plots for strength

Table 9 Response Table for Signal to Noise Ratios Larger is better

Level	1	2	3	4	Delta	Rank
p	16.54	16.99	17.50	17.73	1.19	1
S	17.65	17.23	17.02	16.86	0.79	2
T_p	17.16	17.15	17.10	17.35	0.25	3

Table 10 ANOVA table

Source	DF	Squares SS	Adj MS	F	P
P	3	3.41732	1.13911	31.67	0.001
S	3	1.39227	0.46409	12.9	0.005
T_p	3	0.14027	0.04676	1.3	0.385
Error	6	0.21579	0.03569		
Total	15	5.16564			
S = 0.189643	R^2 = 95.82%	R^2(adj)= 89.56%			

In the ANOVA table (Table 9), the F value for Power is 31.67, Speed is 12.9 and the pulse duration is 1.3. The R^2 is 95.82%. The main effect plot give optimum combinations for input process parameter that give maximum output are shown in fig 19.

The regression equation in terms of actual input factor

Tensile strength at A' = 5.56 + 2.04 P - 1.29 S + 0.0502 Tp (3)

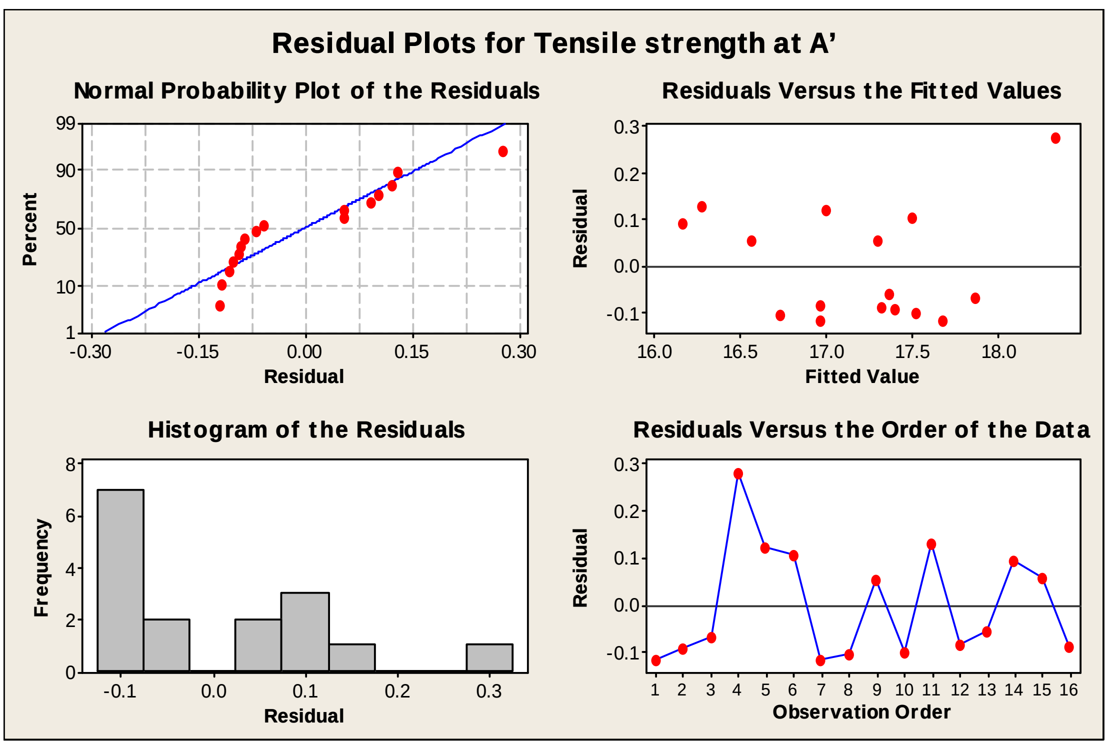


Figure 20 Residual plots for tensile strength

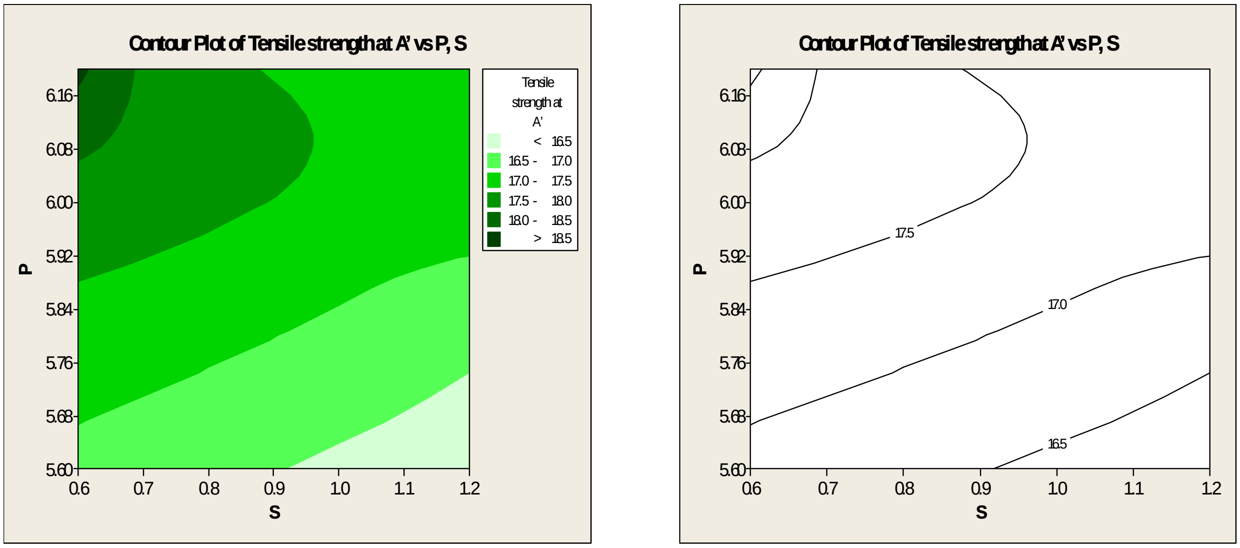


Figure 21 Contour graph shows the effect of P and S parameter on the response

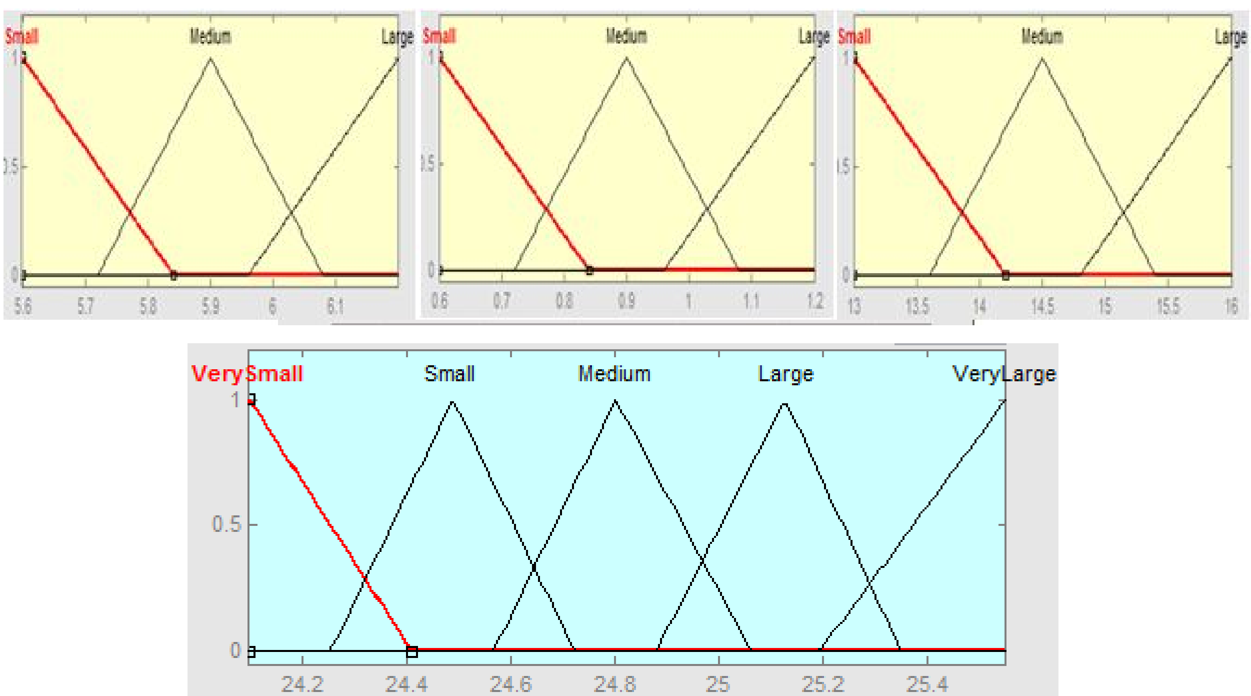
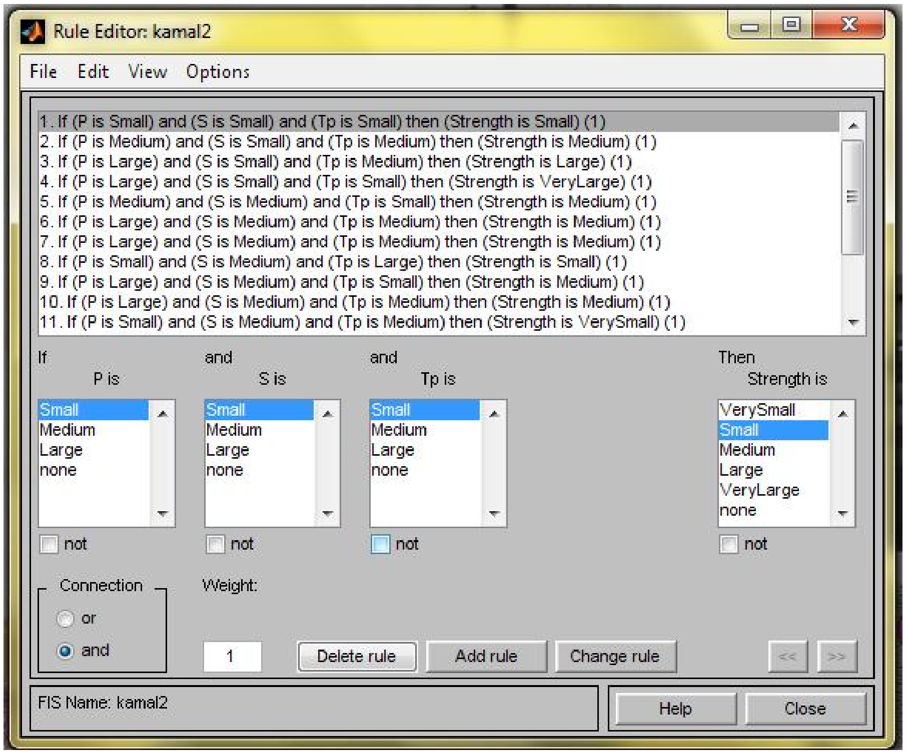


Figure 22 Membership function of input/output



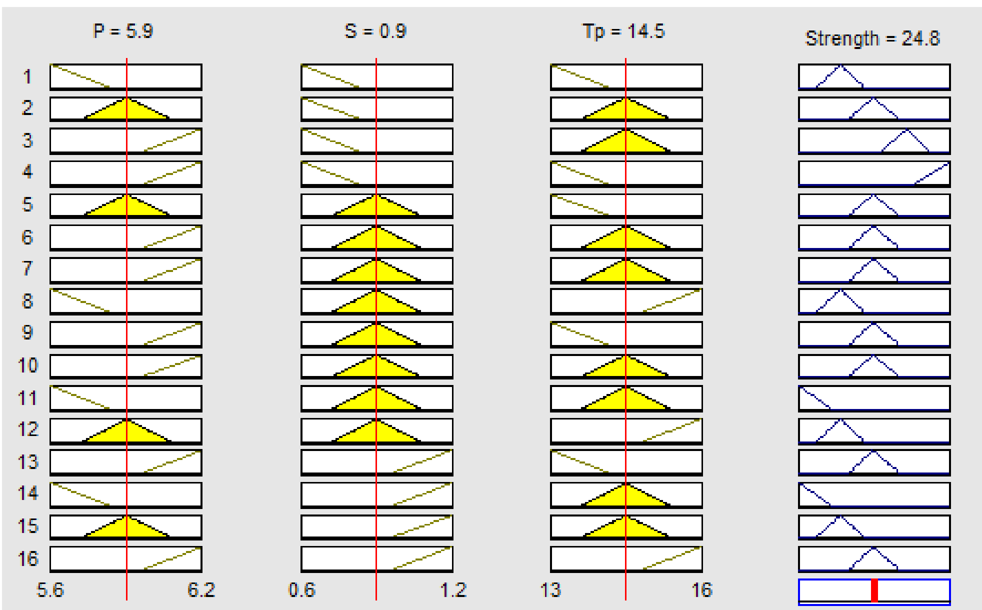


Figure 23 Fuzzy rule

The average error getting by fuzzy logic is 0.45314

Experiment No. 3

Table 11 Experimental details, response, S/N ratio, fuzzy value and error. When focus position of laser beam 0.5 mm toward the stainless steel plate side.

Exp no.	P(kw)	S(mm/s)	T_p(ms)	Tensile strength	S/N	Fuzzy Value	Error
1	1	1	1	16.12	24.1473	24.2	0.217769
2	2	1	2	16.2	24.1903	24.2	0.040083
3	3	1	3	16.56	24.3812	24.3	-0.33416
4	4	1	4	17.2	24.7106	24.4	-1.27295
5	2	2	1	16.15	24.1635	24.2	0.150826
6	3	2	2	16.32	24.2544	24.5	1.002449
7	4	2	3	16.84	24.5268	24.4	-0.51967
8	1	2	4	16.09	24.1311	24.1	-0.12905
9	3	3	1	16.21	24.1957	24.2	0.017769
10	4	3	2	16.78	24.4958	24.4	-0.39262
11	1	3	3	15.95	24.0552	24.1	0.185892
12	2	3	4	16.05	24.1095	24.1	-0.03942
13	4	4	1	16.35	24.2704	24.2	-0.29091
14	1	4	2	15.75	23.9456	24.1	0.640664
15	2	4	3	15.95	24.0552	24.1	0.185892
16	3	4	4	16.18	24.1796	24.2	0.084298
							$\sum$=-0.45314

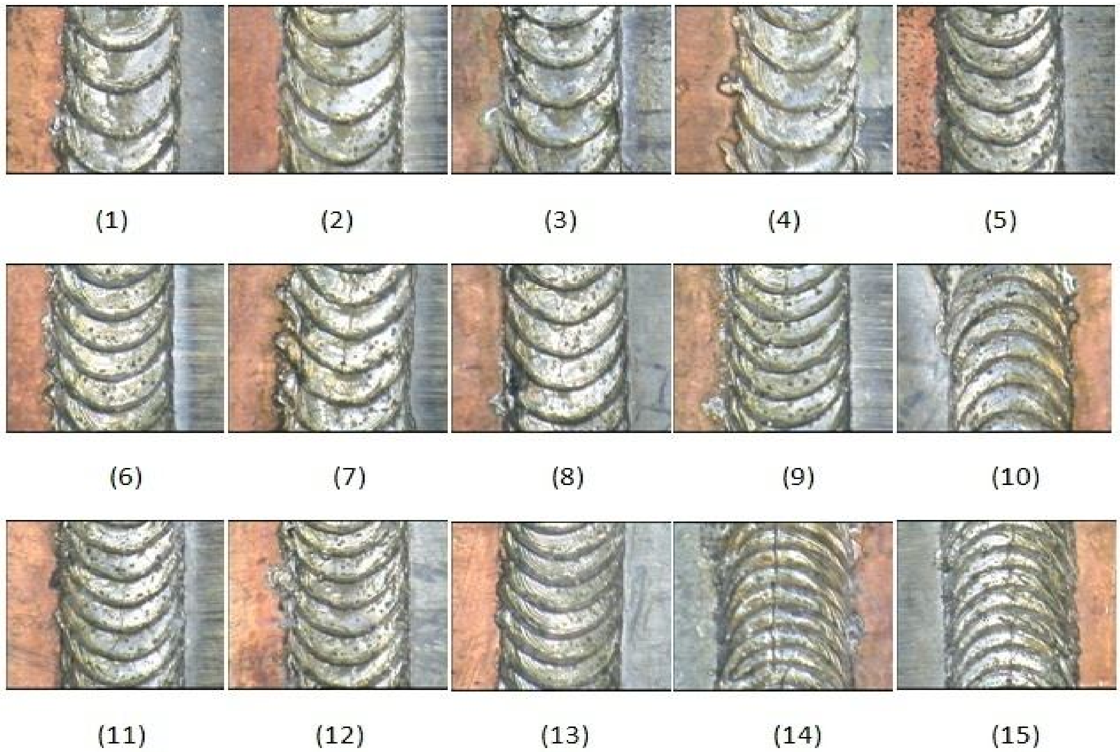


Figure 24 Surface of the weld zone

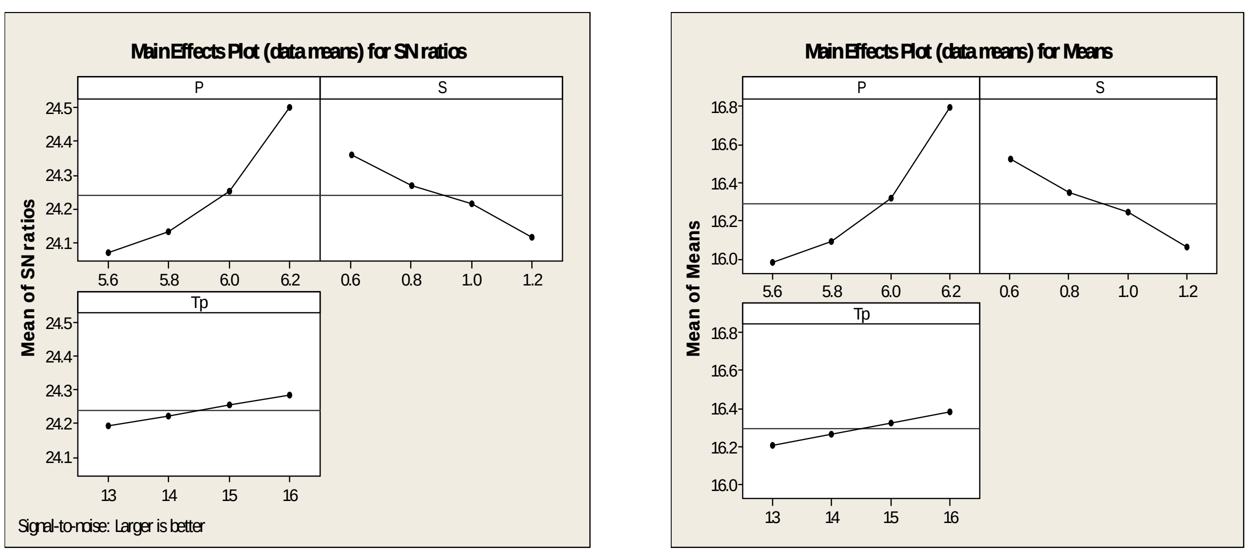


Figure 25 Main effect plots for strength

Table 12 Response Table for Signal to Noise Ratios Larger is better

Level	1	2	3	4	Delta	Rank
p	24.07	24.13	24.25	24.50	.43	1
S	24.36	24.27	24.11	24.11	.24	2
T_p	24.19	24.22	24.25	24.28	.09	3

Table 13 ANOVA table

Source	DF	Squares SS	Adj MS	F	P
P	3	1.56748	0.52249	52.82	0.001
S	3	0.44922	0.14974	15.14	0.003
T_p	3	0.06732	0.0224	2.27	0.181
Error	6	0.05935	0.00989		
Total	15	2.14338			
S = 0.0994569	R^2 = 97.23%	R^2(adj)= 93.08%			

In the ANOVA table (Table 11), the F value for Power is 52.82, Speed is 15.14 and the pulse duration is 2.27.The R^2 is 97.23%. The main effect plot give optimum combinations for input process parameter that give maximum output are shown in fig 25.

The regression equation in terms of actual input factor

Tensile strength at A" = 8.23 + 1.34 P - 0.745 S + 0.0580 Tp (4)

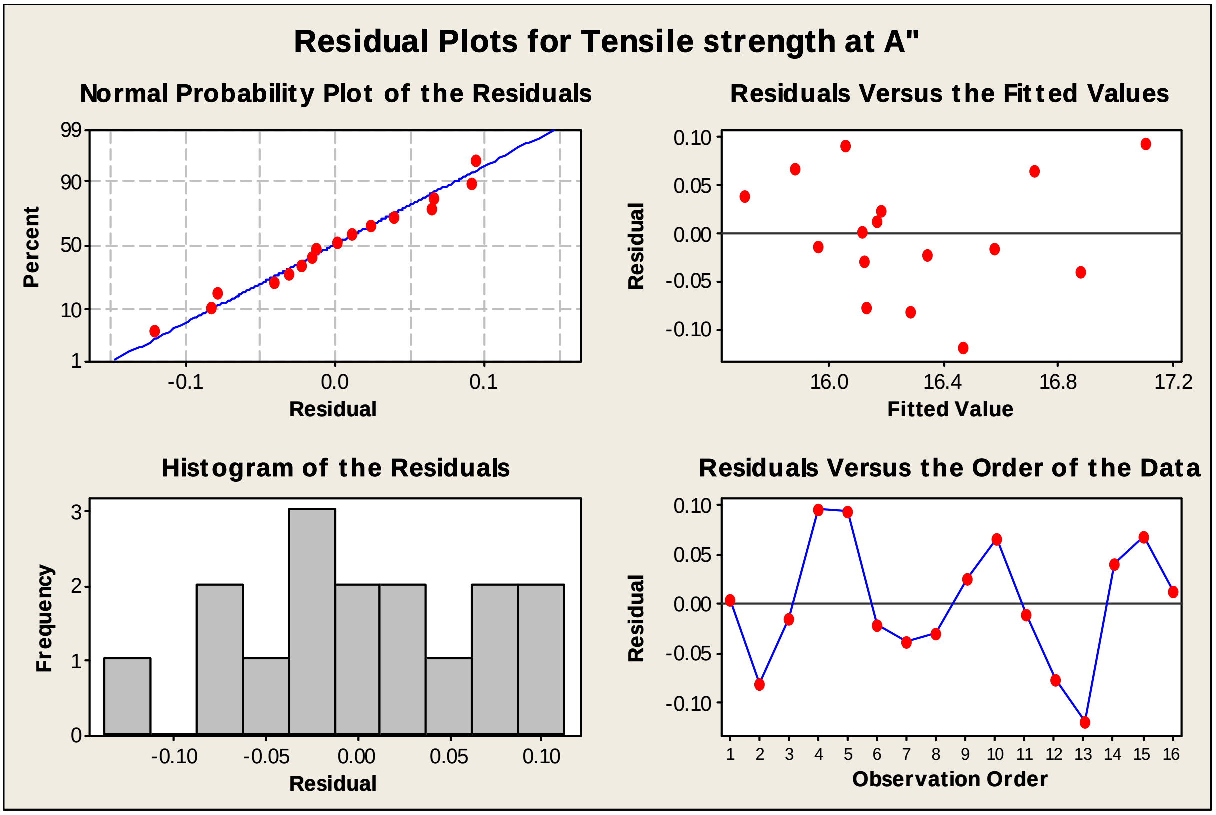


Figure 26 Residual plots for tensile strength

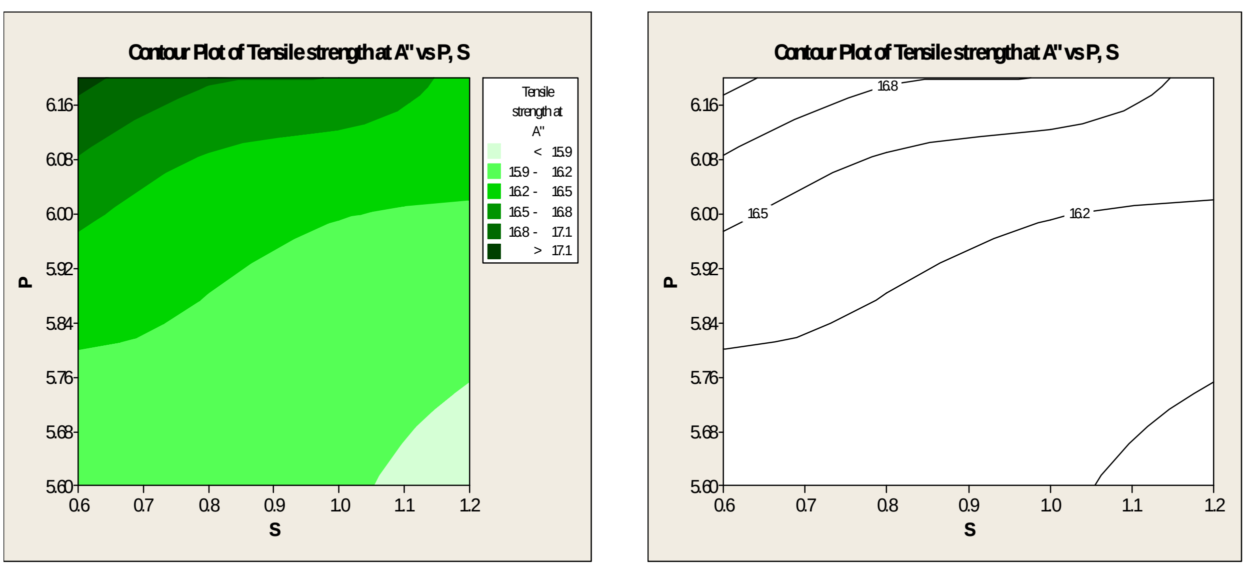


Figure 27 Contour graph shows the effect of P and S parameter on the response

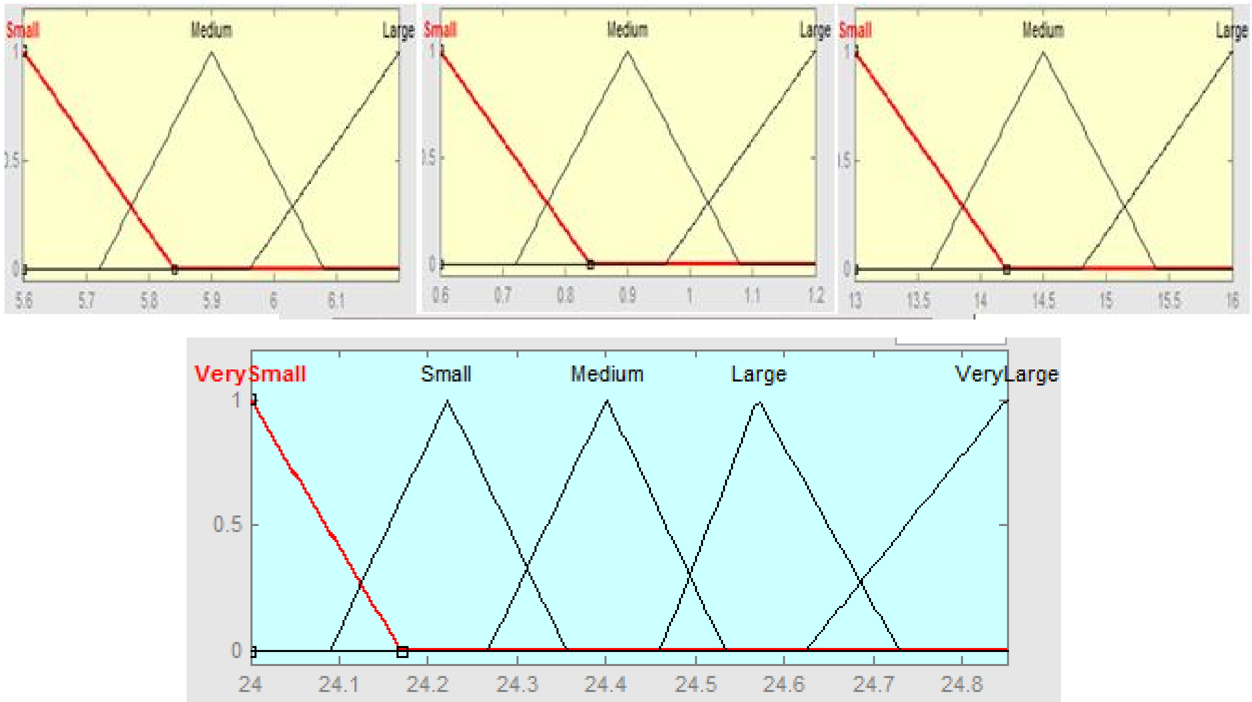
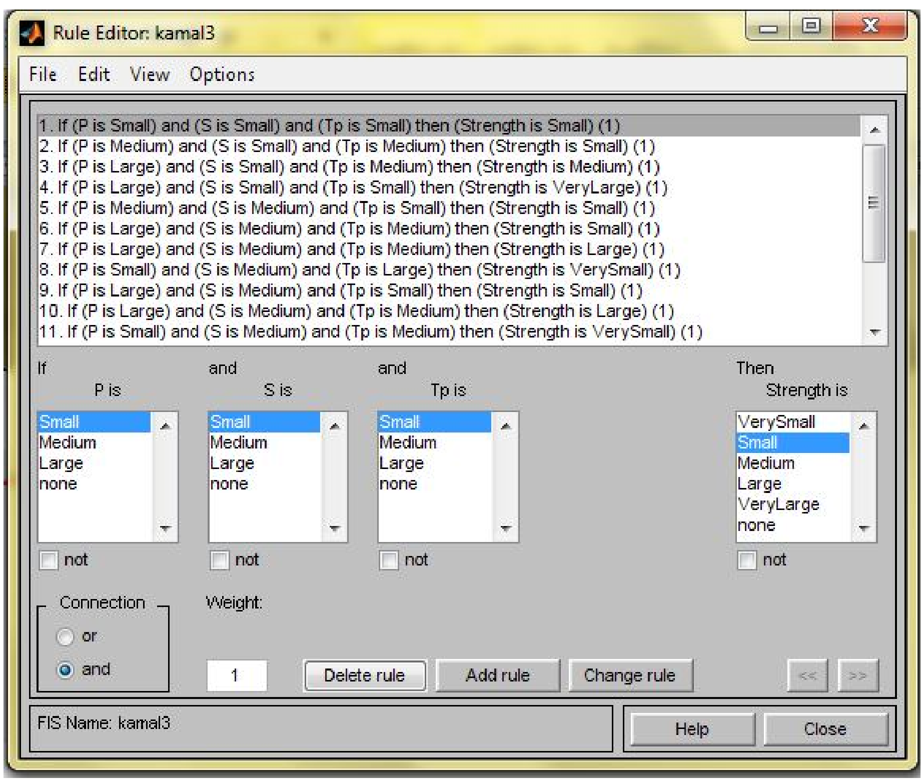


Figure 28 Membership function of input/output



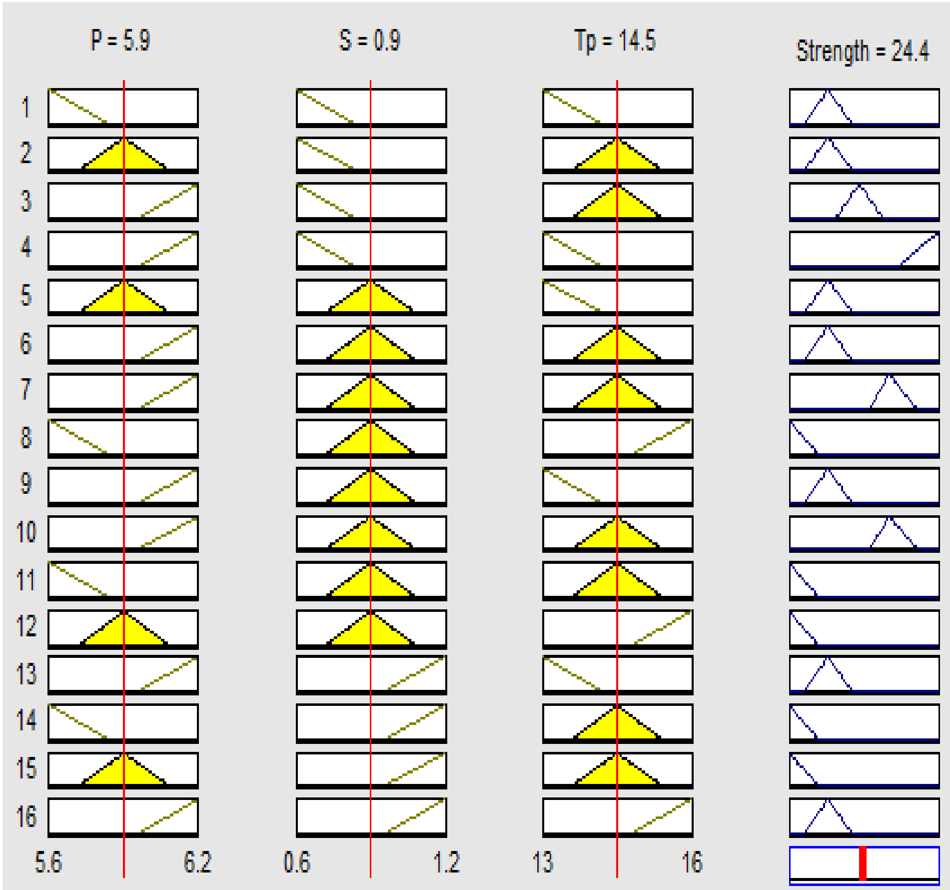


Figure 29 Fuzzy rule

The average error getting by fuzzy logic is 0.45314 are shown in table 11.

5.4. Effect of focusing position

Table 14

Tensile strength at A	S/N	Tensile strength at A’	S/N	Tensile strength at A”	S/N
17.20	24.7106	16.85	24.5320	16.12	24.1473
17.65	24.9349	17.31	24.7659	16.2	24.1903
18.21	25.2062	17.8	25.0084	16.56	24.3812
19.06	25.6025	18.62	25.3996	17.2	24.7106
17.62	24.9201	17.12	24.6701	16.15	24.1635
17.90	25.0571	17.61	24.9152	16.32	24.2544
18.63	25.4043	17.56	24.8905	16.84	24.5268
17.38	24.8010	16.63	24.4178	16.09	24.1311
17.74	24.9791	17.36	24.7910	16.21	24.1957
18.14	25.1727	17.42	24.8210	16.78	24.4958
17.23	24.7257	16.41	24.3022	15.95	24.0552
17.46	24.8409	16.89	24.5526	16.05	24.1095
18.08	25.1440	17.31	24.7659	16.35	24.2704
16.85	24.5320	16.26	24.2224	15.75	23.9456
17.25	24.7358	16.62	24.4126	15.95	24.0552
17.80	25.0084	17.24	24.7307	16.18	24.1796

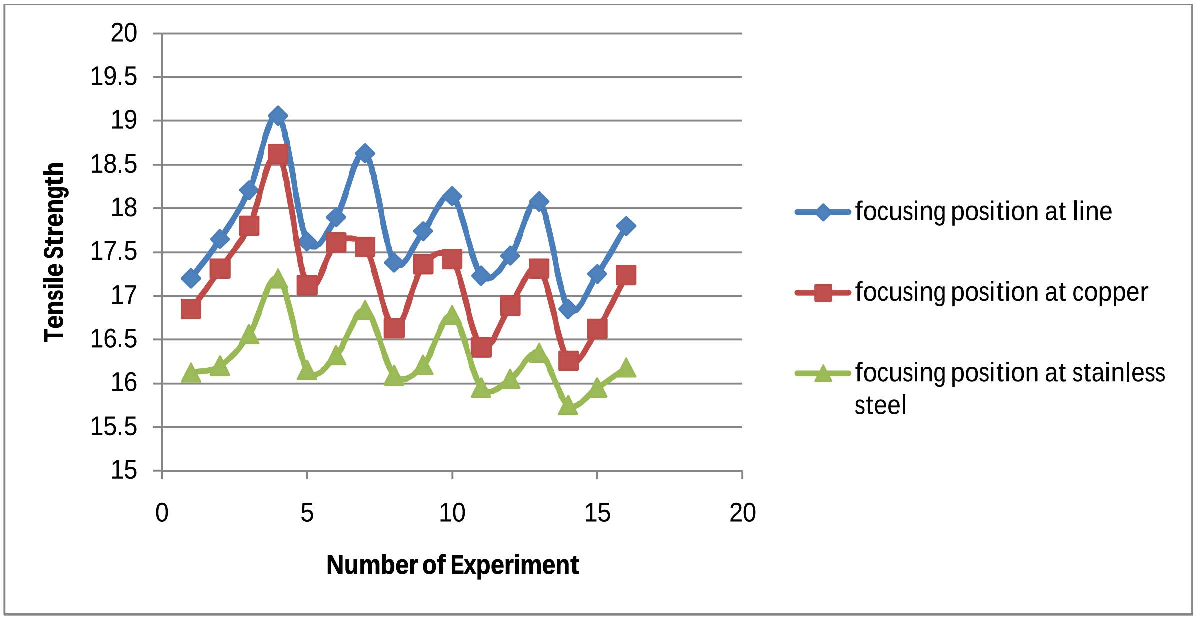


Figure 30 Effect of focusing position

After analysis of the all three output finds that the tensile strength can be varied by changing the focusing position of the laser beam all values are shown in table 14. When focusing position is taken at the welding line tensile strength is maximum and minimum when focusing position taken toward the stainless steel.

Chapter 6

ANALYSIS OF WELD BEAD

CHAPTER 6
Analysis of Weld Bead

6.1.Welding pool area:

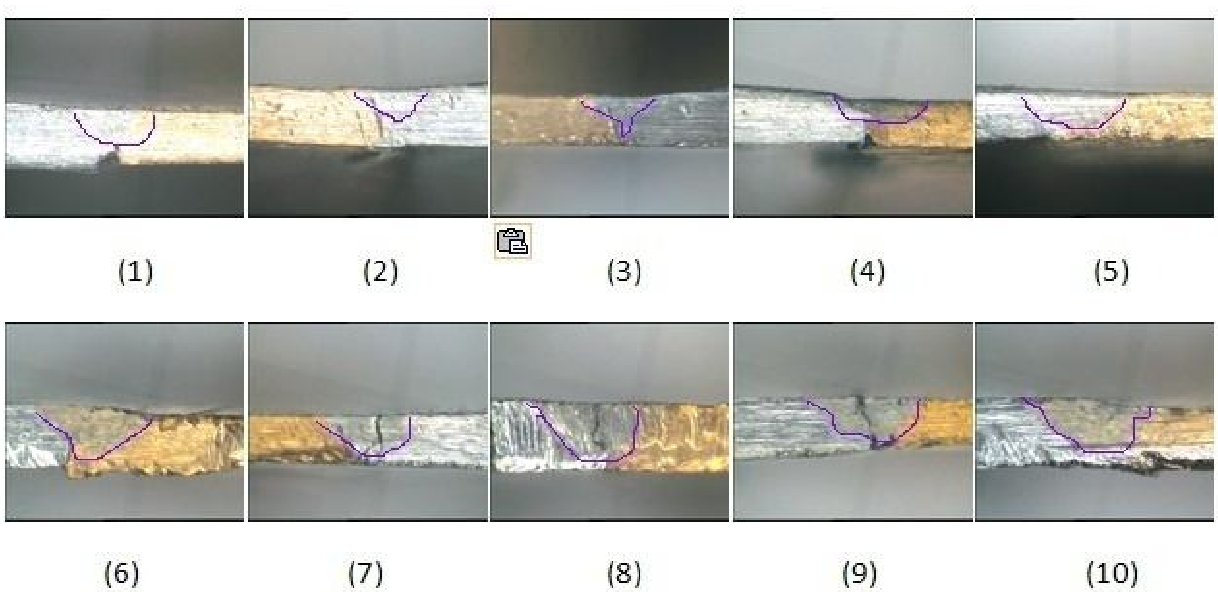


Figure 31 Welding pool

welding speed has significant effect on the welding pool area .the increasing in welding spees “S” rate,lead to the reduction of the fusion area of the welding pool. An increase in S leads to a decrease in welding pool area. This is due to the laser beam travelling at high speed over the welding line when S is increased. Therefore, the heat input decreases leading to less volume of the base metal being melted, consequently the width of the welded zone decreases. Power also have significant effect on the welding pool area. The change in the laser power “P” rate would lead to change in fusion area value. Increases laser power fusion area also increasing because of heat input per unit area will be increasing.

6.2.Effect of overlapping factor:

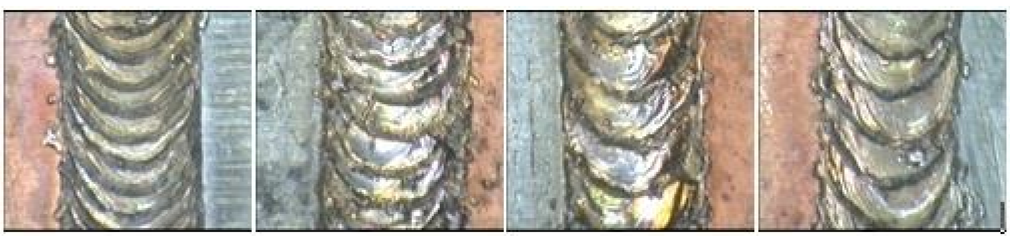
In pulsed laser welding, an increase in welding speed when laser frequency and average power are constant will decrease the overlapping factor. Since it can be envisaged that the energy pumped to an area comes not only from a single pulse but also from overlapping pulses.

The overlapping factor of successive pulses (O_f) was calculated using

$$O_f=1-((S/f)/\ (A+V\ T_p))*100 \quad (5)$$

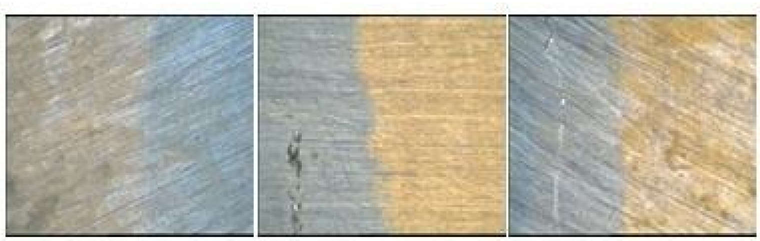
Where S is the welding speed, f is laser frequency, T_p is pulse duration and A is referring to the spot size on the work piece.

Low overlapping factor caused not only inadequate bounding between steel and copper but also produced cavities in the weld root. Decreasing overlapping factor will control interaction time between steel and copper and provide a fast cooling rate. This will restrict diffusion to a limited depth. By increasing the overlapping factor heat input per unit length will increase and solidification rate will decreases. It means that an optimized overlapping factor is required to obtain a good joint. Therefore interaction time between liquid copper and liquid steel will increase and inter metallic formation is predictable.



(1) (2) (3) (4)

Figure 32 overlapping factor decreasing with increasing the speed



(1) (2) (3)

Figure 33 Joint surface of AISI 304L stainless steel and copper

6.3.Welding defect

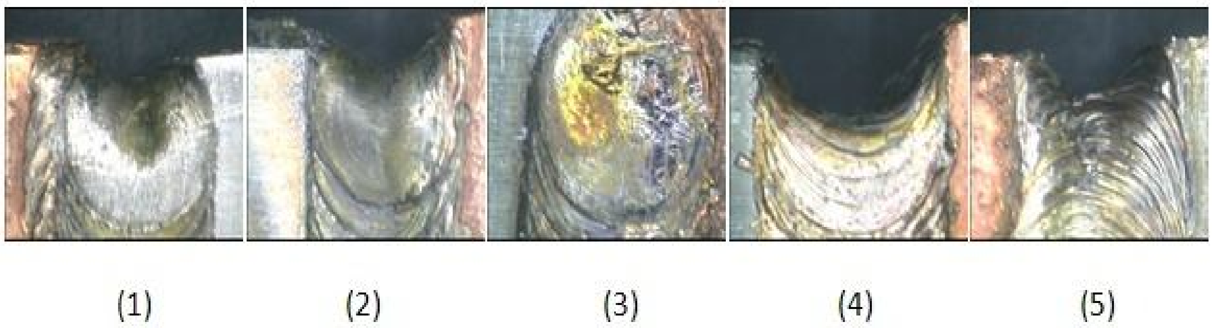


Figure 34 Mass loss

This defect cause by high penitaration rate , high pressur of laser beam and due not proper size of the work picce so that loss of material can be take place at the other end. So that size and shape of the work piece also play major role in the laser welding.

6.3.1. Misalignment:

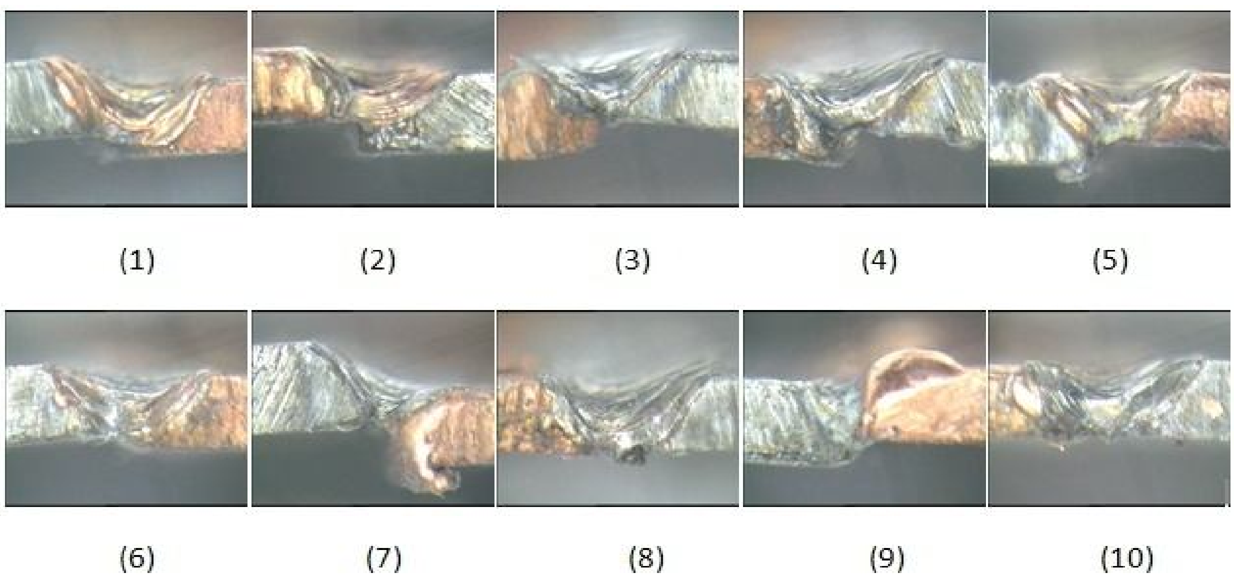


Figure 35 Misalignment

That defect cause by not proper alignment of the work piece to each other. So that it is necessary that the plate’s edges were cleaned and grinded along the weld line to ensure full contact. That defect can decrease the mechanical strength of the weld bead.

6.3.2. Welding Crack

Figure 36 Crack

Solidification cracking occurs during solidification phase of the weld bead in susceptible alloy. Solid forms in the weld metal as interlocking dendrites during cooling, accompanied by the rejection of alloying element and impurities at the solid-liquid interface. The presence of tensile stresses can lead to solidification crack in these regions. Crack will take place at the center of the weld bead due to the residual stress. This will be occurring more when the focusing position of the laser beams more toward the stainless steel side. Due to the decreasing in the solubility of alloying elements could lead the creak. They should decrease the mechanical and functional properties of the joint are shown in fig 36.

6.3.3. Spatter:

Spatter is the term used to describe liquid particle that are expelled during welding, which adhere to the surface of the base metal or weld bead, spatter can rise from the volatility of alloying elements or in stabilized in the key hole during welding. It is normally removed mechanically after welding and does not affect the mechanical property of weld are shown in fig 37.

Vaporization of volatile alloying element weakens the weld bead in alloy that rely on solid solution strengthening for example the loss of Mg reduced the weld bead strength of 5000 series of aluminum alloys.

Figure 37 Spatter

Chapter 7

CONCLUSIONS

CHAPTER 7
Conclusions

i. Laser welding is a very successful process to join AISI304L stainless steel and oxygen free copper.

ii. Using laser welding can produce small welding pool area and narrow HAZ.

iii. 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.

iv. Welding speed has the stronger effect on the fusion area, which is inversely proportional to response.

v. It is necessary that the edges of the plate were cleaned and grinded along the weld line to ensure full contact.

vi. Focusing position of the laser beam also effect the response in case of joining of copper and stainless steel.

vii. Main effect plot gives the optimum factor levels as P = 6.2, S = .6 and T_p = 16.

viii. Experimental results are prediction by fuzzy logic approach. The predicted an average percentage error is 2.55987, 1.9507 and 0.45314 for all three experiments.

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