Experimental and Metallurgical investigation on laser welding of dissimilar materials

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Abstract - *Laser welding is technique to join multiple pieces of metal through the use of a laser. The laser beam provides a concentrated heat source allowing for narrow, deep welds and high welding rates.*

Laser welding is used in high volume applications using automation in the automotive industry. It is based on keyhole or penetration mode welding. It is useful for welding of carbon steels, HSLA steels, Stainless steel, Aluminum and titanium. It is very useful for high quality welds.

Here, in my dissertation work fiber laser is used for practical experiments. 1kW fiber laser is used to weld 2 mm thick SS 304 and Mild steel sheet plates. The full factorial method is used to find out total number of experiments.

SS 304 and MS sheets are widely used in Dairy, Automotive, Chemical tanks and pipe manufacturing, Boiler and vessel manufacturing, Heat exchanger equipment , Power plant equipments because of it's high tensile strength, steel is quite strong in quality , thus these sheets can withstand high temperature and load also.

Laser Power, Travelling Speed and Focal Position are the Input parameters. Material characterization technique is utilized for microstructure and macrostructure observation. Hardness is measured by Vickers hardness testing machine. Microstructure, Macrostructure analysis and Hardness measurements are my Output parameters.

Key Words: *Laser power , Travelling speed , Focal position , Micro and macro structure analysis, Full factorial method.*

1. INTRODUCTION

The term "laser" derived as a short form for "**light amplification by stimulated emission of radiation**". It is the instrument that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation.

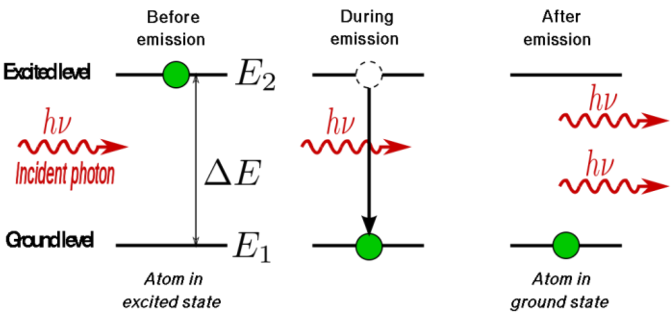
Laser is quite vary from variant sources of light in that it discharges light coherently, spatially and temporally. The spatial adjustment allows a laser to be centered to a tight spot, allowing applications such as laser cutting and printing. The spatial consistency also approve a laser beam to stay narrow over long distances, allowing applications such as laser pointers.

The types of lasers are created by gain medium. Gas, Chemical, Dye, Metal-vapour, solid, semiconductors are major gain mediums. Helium neon laser, Argon laser, Krypton laser, Carbon dioxide laser(CO_2), Carbon monoxide laser(CO), Ruby laser, Neodymium Yttrium aluminium garnet (Nd:Yag) laser,etc are main types of lasers.

1.1 LASER GENERATION PRINCIPLE

An electron comprises energy either from light (photons) or from heat (phonons), it gains that incident quantum of energy. But transitions are only excepted in between different energy levels such as the two shown above. This movements lead to emission lines and absorption lines.

When an electron is travelled from a lower to a higher energy level, it will not remain steady that way forever. An electron in an energized state may decompose to a lower energy state which is not occupied, according to an exacting time stable characterizing that evolution. When an electron decays without external impression, emitting a photon, that is known as "spontaneous emission".



$$E_2 - E_1 = \Delta E = h\nu$$

Fig .1 – LASER GENERATION PRINCIPLE

1.2 CLASSIFICATION OF LASER BEAMS CONTINUOUS MODE

The applications of lasers rely on a beam whose output power is stable with time. This laser is known as continuous wave (CW). Various types of lasers can be produced to work in continuous wave mode to assure such an application.

Lots of of these lasers actually give a number of longitudinal modes at the equal time, and beats among the a little different visual frequencies of those oscillations will in fact make amplitude variations on time balance shorter than the round-trip time (the reciprocal of the frequency spacing among modes).

Typically a little nanoseconds or fewer. In the mainstream cases these lasers are termed "continuous wave" as their output power is constant when an averaged over any other longer time durations, with the very soaring frequency power differences having small or no impact in the proposed application.

1.2.1 PULSED MODE

The Pulsed operation of lasers refers to whichever laser not classified as continuous wave, so that the optical power produces in pulses of a little duration at a few recurrence rate. This enclosed a broad variety of technologies conveying a number of diverse factors. Few lasers are pulsed basically because they cannot be operated in continuous mode.

This mode is ideal for cutting thin materials, as it allows stiff corners and complex details to be cut without unnecessary burning.

In some cases the function needs the assembly of pulses having as great an energy as possible. Since the pulse energy is similar to the normal power separated by the repetition rate, this goal can occasionally be fulfilled by decreasing the rate of pulses so that extra energy can be made up in between pulses.

1.3 TYPES OF LASERS

1.3.1 SOLID STATE LASER

Solid-state lasers utilize a crystalline or glass rod which is included with ions that supplied the essential energy states. The first working laser was a ruby laser, constructed from ruby (chromium- corundum).

The population inversion is really preserved in the dopant. These materials are forced optically using a shorter wavelength than the lasing wavelength, many times from a flashtube or from different laser.

The usage of the term "solid-state" in laser physics is limited than in typical use. Semiconductor lasers (laser diodes) are typically not regarded to as solid-state lasers.

1.3.2 GAS LASER

Gas lasers using various varied gases have been created and utilized for many purposes. The helium–neon laser (HeNe) is capable to control at a number of dissimilar wavelengths, however the enormous majority are engineered at 633 nm, these comparatively lesser cost but highly coherent lasers are really similar in optical research and educational laboratories.

Carbon dioxide (CO_2) lasers can release various hundreds of watts in a solitary spatial mode which can be determined into a small spot. This emission into the thermal infrared at 10.6 µm, these lasers are frequently used in industry for cutting and welding. The efficiency of a CO_2 laser is abnormally high over 30%.

1.3.3 SEMI-CONDUCTOR LASER

Semiconductor lasers (known by diode lasers or injection lasers) occupy structure that are much diverse from the gas and solid state lasers described earlier. They stand for an entirely unique approach to laser fabrication.

They supply lasers with properties diverse from those of the lasers that we have discussed. A semiconductor laser uses a small chip of semiconducting material as an active medium. Looking from size and appearance, the semiconductor laser is analogous to a transistor or to a semiconductor light emitting diode.

1.3.4 LIQUID LASER

Liquid laser utilize huge organic dye molecules as the vigorous lasing medium. These lasers can drop in a wide frequency range, they are frequency tunable. The spectral range of dyes includes infrared, visible and ultraviolet light. Pumping is by other pulsed/continuous laser, or by pulsed lamp. These lasers are utilized in spectroscopic investigation and photochemical experiments.

1.3.5 FIBER LASER

Solid-state lasers, where the light is travelled due to the total internal reflection in a single mode optical fiber are known as fiber lasers. Guiding of light premising a long gain regions providing excellent cooling conditions, fibers have high surface area to volume ratio which provides excellent cooling. In addition, the fiber's wave guiding properties tend to decrease thermal distortion of the beam. Erbium and ytterbium ions are normal active species in such lasers.[8]

In the fiber laser the active gain medium is an optical fiber doped with rare earth elements such as erbium, ytterbium, neodymium, dysprosium, and thulium. They are associated to doped fiber amplifier, which supplied light amplification without lasing.

1.4 ADVANTAGES OF FIBER LASER

- High efficiency
- Power
- High brightness
- Excellent beam quality
- Low operating cost
- Long life
- Reliability
- Easy coupling into fiber
- Low maintenance

1.4.1 DISADNATAGES OF FIBER LASER

- Pulse pedestals from non-ideal optical spectrum for higher energy pulses.
- Unwanted nonlinear optical effects at high pulse energy, such as self-phase modulation and Raman scattering.
- Attractive high core intensity- damage, nonlinear restrictions for pulsed applications.
- Small active volume- low pulse energy (~10mJ). Very high gain- can be difficult to control spurious lasing.
- Photo darkening (if not watchful).

1.5 AREA OF APPLICATION OF LASER

- Welding
- Cutting
- Micromachining
- Marking and Engraving
- Wafer Processing
- Telecommunication
- Spectroscopy
- Fractional resurfacing
- Microsurgical Applications
- Ranging
- Security

1.6 LASER BEAM WELDING

Laser beam welding (LBW) is a welding technique used to join multiple pieces of metal through the use of a laser. The beam provides a concentrated heat source, allowing for narrow, deep welds and high welding rates. The process is frequently used in high volume applications using automation, such as in the automotive industry. It is based on keyhole or penetration mode welding.

1.6.1 LASER BEAM WELDING OPERATION

Like electron beam welding (EBW), laser beam welding has high power density (on the order of 1 MW/cm^2) resulting in small heat-affected zones and high heating and cooling rates. The spot size of the laser can vary between 0.2 mm and 13 mm, though only smaller sizes are used for welding. The depth of penetration is proportional to the amount of power supplied, but is also dependent on the location of the focal point penetration is maximized when the focal point is slightly below the surface of the work piece.[7]

LBW is a versatile process, capable of welding carbon steels, HSLA steel, stainless steel, aluminum, and titanium. Due to high cooling rates, cracking is a concern when welding high-carbon steels. The weld quality is high, similar to that of electron beam welding. The speed of welding is proportional to the amount of power supplied but also depends on the type and thickness of the work pieces.

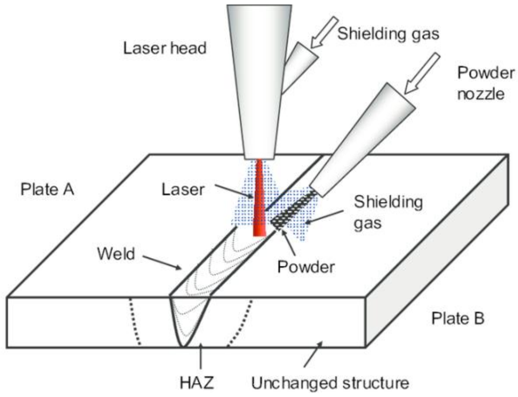


FIG 2 LASER BEAM WELDING

1.7 MATERIAL CHARACTERIZATION

Characterization, when used in materials science, refers to the broad and general process by which a material's structure and properties are probed and measured. It is a fundamental process in the field of materials science, without which no scientific understanding of engineering materials could be ascertained.

The scope of the term often differs; some definitions limit the term's use to techniques which study the microscopic structure and properties of materials, while others use the term to refer to any materials analysis process including macroscopic techniques such as mechanical testing, thermal analysis and density calculation. The scale of the structures observed in materials characterization ranges from angstroms, such as in the imaging of individual atoms and chemical bonds, up to centimeters, such as in the imaging of coarse grain structures in metals.

While many characterization techniques have been practiced for centuries, such as basic optical microscopy, new techniques and methodologies are constantly emerging. In particular the advent of the electron microscope and Secondary ion mass spectrometry in the 20th century has revolutionized the field, allowing the imaging and analysis of structures and compositions on much smaller scales than was previously possible, leading to a huge increase in the level of understanding as to why different materials show different properties and behaviors. More recently, atomic force microscopy has further increased the maximum possible resolution for analysis of certain samples in the last 30 years.

2 LITERATURE REVIEW

The Literature review contains special study on laser welding procedure with diverse lasers and effect of laser beam power, effect of focal point position, effect of travelling speed on different types of material and thickness. Microstructures, macrostructures and hardness are the major focusing properties of my research work.

P. Sathiya, K. Panneerselvam and M. Abdul Jaleel (2012) conceded trials on the laserbeam welding(LBW) of a 3 mm thick sheet of AISI904 L super austenitic stainless steel. Input parameter taken were beam power, travel speed and focal position for three different shielding gases (argon, helium, nitrogen) to measure their response on the weld bead geometry(depth of penetration (DP), bead width (BW)) and tensile strength (TS). Full factorial design was used to carryout the experimental design. Artificial neural networks (ANNs) program was developed in MatLab software to establish the relationship between the laser welding input and output parameter. Genetic algorithm (GA) was used to optimize the process parameter. [1]

Shanmugarajan B. , Rishabh SHRIVASTAVA , Sathiya P. , Buvanashekaran G. (2016) Taguchi based optimization of laser welding parameters for autogenous laser welding of P92 material has shown that for the given conditions, 3 kW of laser power, 1 m/ min welding speed and positioning the focal plane of the laser at 4 mm from the surface of the base material have evolved as the optimal parameters.

From ANOVA, amongst the parameters experimented, welding speed has the most significant contribution with 74.39% followed by laser power with 14.63% and focal length with 10.97%

Microhardness survey across welds with optimised parameter did not indicate any softening in the HAZ/BM boundary and microstructural analysis did not reveal any deleterious phases, which confirms that the parameters obtained through optimisation are valid.[2]

K. R. Balasubramanian, G. Buvanashekaran, K. Sankaranarayanasamy Laser welding trials on AISI Stainless sheet 304 were carried out based on three level Box-Behnken design with replication, resulting in 15 trials. Mathematical and ANN modeling was done to predict the output parameters for the given input. The effects of input parameters on weld bead geometry are investigated.

Beam power and welding speed are the major parameters influencing the depth of penetration and bead width. Even though Gas flow rate is not having significant influence, it is essential for shielding the weld pool to avoid the atmospheric contamination during welding. The input and out put parameters are analysed using Neural Networks model (NN) with different network configurations. A suitable neural Network model (4 neurons with 1 hidden layer) with best R^2 value is arrived at. Expressions for depth of penetration and bead width are extracted from the neural network model.[3]

S. Kano, A. Oba, H.L.Yang Y. Matsukawa Y. Satoh H. Serizawa H. Sakasegawa H. Tanigawa H. Abe (2016) To investigate the effects of fiber laser welding parameters on microstructure and mechanical property, SEM/OM observation, Nano-indentation hardness test were performed on specimens prepared at different welding speeds and beam positions. It is observed that HAZ width was influenced by welding speeds and beam positions .[4]

G. PADMANABAN, V. BALASUBRAMANIAN(2010) The joint fabricated with the laser power of 2 500 W, welding speed of 5.5 m/min and focal position of −1.5 mm shows higher tensile properties compared with their counterpart

3 DESIGN OF EXPERIMENT

In this dissertation work input parameters considered for laser welding are parameters which are easily controllable by operator like as laser beam power, welding speed and focal position. An important asset of laser welding is the high level of control which is available over the variables affecting the process. The weld geometry can be tailored to meet requirements of the job and the results can be readily duplicated. Microstructure , macrostructure are the output parameters , which are measured by OLYMPUS-GX41 Optical microscope, and hardness is measured by Vickers hardness testing machine. Other parameters are considered as constant parameters.

3.1 INPUT PARAMETERS

Laser Beam Power(W)

Lasers are rated by their power output in terms of Watts. Since laser welding is a thermal process, the amount of heat produced is related to its capabilities. Given all other consideration being equal (e.g., power distribution, spot size, etc.), increased power allows for faster processing speeds and the ability to weld deeper. Power density combined with a material ability to couple with the wavelength of the laser, are the key parameters in determining weld penetration and weld speed.

Welding Speed (mm/min)

Laser welding speeds have been found to fit empirical formulas based on the available laser power, focused spot size, properties of the material to be welded, weld joint geometry, and shield gas type and optimization (especially for high power density keyhole welding). Above a threshold amount, the speeds are directly proportional to available power density. This takes into account the lasers performance features (e.g. power and mode) in addition to the focusing system's characteristics (e.g. spot size).

Focal Position (mm)

Generally the focal plane of the beam is positioned at the plate surface for thin sheets or about one third of the plate thickness below the surface for thick plates. However, the optimum position is closer to the lower surface of the plate when using inert gas.

3.1.1 CONSTANT PARAMETERS

1. Beam source: Fiber laser
2. Work piece material: AISI SS 304 & MS – IS 2062 Grade A
3. Work piece thickness: 2 mm

4. Spot diameter: 0.5 mm

5. Wavelength: 1064 nm

6. Shielding gas: Argon

7. Gas pressure: 0.5 bar

3.1.3 OUTPUT PARAMETERS

1. Microstructure Analysis
2. Macrostructure Analysis
3. Hardness Measurement

3.2 FULL FACTORIAL METHOD

A full factorial experiment is an experiment whose design consists of two or more factors, each with discrete possible values or levels, and whose experimental units take on all possible combinations of these levels across all such factors.

A full factorial design may also be called a fully crossed design. Such an experiment allows the investigator to study the effect of each factor on the response variable, as well as the effects of interactions between factors on the response variable.

For the vast majority of factorial experiments, each factor has only two levels. For example, with two factors each taking two levels, a factorial experiment would have four treatment combinations in total.

3.3 DESIGN OF EXPERIMENT TABLE

TABLE 1- DOE TABLE

Serial No	Laser Power (W)	Travelling Speed(mm/min)	Focal Position (mm)
1	900	500	-3
2	900	500	-2
3	900	500	-4
4	900	700	-2
5	900	700	-4
6	900	900	-2
7	900	900	-4
8	900	900	-3
9	800	500	-4
10	800	700	-3
11	800	700	-4
12	800	900	-2
13	800	500	-2
14	1000	500	-3
15	1000	500	-4
16	1000	700	-4
17	1000	900	-3
18	1000	900	-4
19	1000	700	-3
20	1000	700	-2

4. EXPERIMENTAL SETUP

For the experimental work I got opportunity to do work at Sahajanand Laser Technology Limited, Sector 26 GIDC, Gandhinagar. The overall experimental set-up contains the collection of Material, experimental planning and monitoring of process.

4.1 MATERIAL SELECTION

Material selection is the most important to this experiment because different materials have different working parameters based of their properties. The right selection of the welding material is the most important aspect to take into consideration in laser welding process. Work piece material that has been selected for this dissertation work is AISI Stainless Steel 304 and Mild Steel–IS 2062, because it is widely used in automotive, dairy, chemical tanks & pipes, hospital equipment and boiler & vessel manufacturing, reactor, heat exchange equipment, bridges and power plants applications owing to its high in tensile strength, steel is quite strong in quality, thus the sheets can withstand high temperature and load and much different industry for various applications. The required AISI SS 304 and MS-IS 2062 material for this experimental work is provided by the same company i.e. Sahajanand Laser Technology Limited.

4.2 SPECTRO TEST RESULTS

TABLE 2- AISI 304 SS MATERIAL SPECTRO TEST RESULT

Elements	Contents in (%)
Carbon	0.068
Silicon	0.260
Sulphur	0.003
Phosphorus	0.038
Manganese	0.840
Nickel	8.130
Chromium	18.900
Molybdenum	0.200

TABLE 3- IS 2062 MILD STEEL MATERIAL SPECTRO TEST RESULT

Elements	Contents in (%)
Carbon	0.038
Silicon	0.012
Sulphur	0.010
Phosphorus	0.012
Manganese	0.190
Nickel	0.010
Chromium	0.024
Molybdenum	0.003
Vanadium	NIL
Copper	0.005
Aluminium	0.043

4.3 EXPERIMENTAL SETUP WITH FIXTURE

Fixture set up is prepared at Sahjanand Laser Technology Private Limited.

All welding material SS 304 and mild steel is provided by same company.

FIG. 3 EXPERIMENTAL SET UP WITH FIXTURE.

4.4 WELDED SAMPLES

FIG.4 WELDED SAMPLES

5. ANOVA ANALYSIS

Analysis of variance (ANOVA) is analogous to the regression in that it is utilized to inspect and model the connection between a response variable and one or more autonomous variables. However, analysis of variance differs from regression in two ways: the independent variables are qualitative (categorical), and no hypothesis is made about the nature of the relationship (that is, the model does not include coefficients for variables).

In effect, analysis of variance extends the two-sample t-test for testing the equality of two population means to a more general null hypothesis of comparing the equality of more than two means, versus them not all being equal.

5.1 ONE WAY ANOVA

One-way analysis of variance tests the equality of population means when classification is by one variable. The classification variable, or factor, usually has three or more levels (one-way ANOVA with two levels is equivalent to a t-test), where the level represents the treatment applied. For example, if you conduct an experiment where you measure durability of a product made by one of three methods, these methods constitute the levels. The one-way procedure also allows you to examine differences among means using multiple comparisons.

Method

Null hypothesis All means are equal Alternative hypothesis At least one mean is different Significance level α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor Levels Values
Travelling Speed (mm/min) 3 500, 700, 900

Analysis of Variance

Source DF Adj SS Adj MS F-Value P-Value
Travelling Speed (mm/min) 2 1095 547.6 0.08 0.924
Error 17 116905 6876.8
Total 19 118000

Model Summary

S R-sq R-sq(adj) R-sq(pred)
82.9262 0.93% 0.00% 0.00%

Means

Travelling
Speed
(mm/min) N Mean StDev 95% CI
500 7 900.0 81.6 (833.9, 966.1)
700 7 914.3 90.0 (848.2, 980.4)
900 6 916.7 75.3 (845.2, 988.1)

Pooled StDev = 82.9262

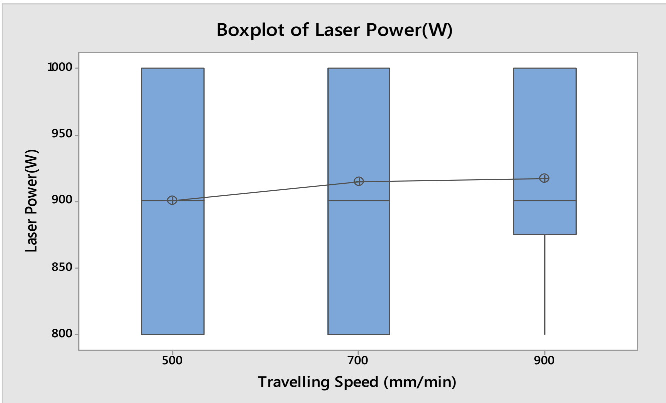


FIG.5 ONE WAY ANOVA ANALYSIS OF LASER POWER ANDTRAVELLING SPEED

5.2 NESTED ANOVA

We can use Fully Nested ANOVA to perform fully nested (hierarchical) analysis of variance and to estimate variance components for each response variable. All factors are implicitly assumed to be random. MINITAB uses sequential (Type I) sums of squares for all calculations. You can analyze up to 50 response variables with up to 9 factors at one time. If your design is not hierarchically nested or if you have fixed factors, use either Balanced ANOVA or GLM(General linear model). Use GLM(General linear model) if you want to use adjusted sums of squares for a fully nested model.

5.2.1 Nested ANOVA: Laser Power (W) versus Travelling Speed (mm/min)

Analysis of Variance for Laser Power(W)

Source DF SS MS
Travelling Speed (mm/min) 2 1095.2381 547.6190
Error 17 116904.7619 6876.7507
Total 19 118000.0000

Variance Components

Source Var Comp. % of Total StDev
Travelling Speed (mm/min) -951.749* 0.00 0.000
Error 6876.751 100.00 82.926
Total 6876.751 82.926

* Value is negative, and is estimated by zero.

Expected Mean Squares

1 Travelling Speed (mm/min) 1.00(2) + 6.65(1)
2 Error 1.00(2)

5.2.2 Nested ANOVA: Laser Power(W) versus Focal Position (mm)

Analysis of Variance for Laser Power(W)

Source DF SS MS
Focal Position (mm) 2 8678.5714 4339.2857
Error 17 109321.4286 6430.6723
Total 19 118000.0000

Variance Components

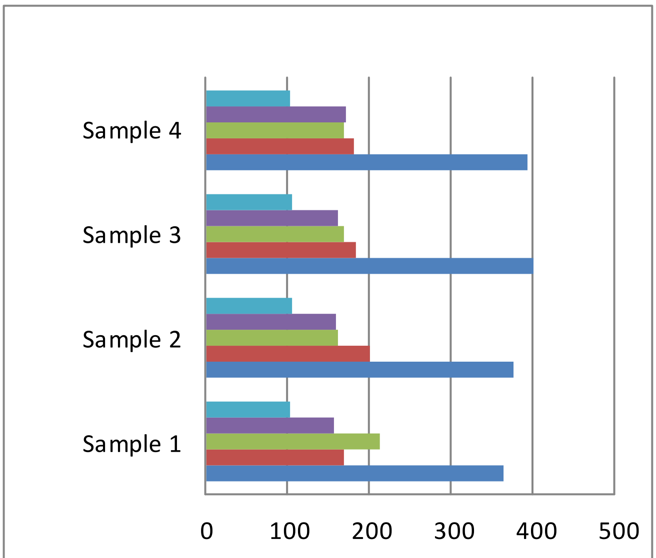
Source Var Comp. % of Total StDev
Focal Position (mm) -319.296* 0.00 0.000
Error 6430.672 100.00 80.191
Total 6430.672 80.191

* Value is negative, and is estimated by zero.

Expected Mean Squares

1 Focal Position (mm) 1.00(2) + 6.55(1)
2 Error 1.00(2)

6. RESULT AND DISCUSSION



	Sample 1	Sample 2	Sample 3	Sample 4
BASE-MS Side	102.5	105.5	104.5	103.5
BASE-SS Side	156.5	160	162.5	172.5
HAZ-MS Side	212.5	162.5	168.5	168.5
HAZ-SS Side	169.5	200	184	182
Weld	364.5	375	401	392

FIG. 6 HARDNESS RESULT FOR SAMPLES.

For Sample 1 to 4 Power remains constant 900W but focal position and travelling speed is varying. For these samples Hardness is high at weld area. 401 Hv is the highest hardness at weld for sample 3. Stainless steel side Heat affected zone has high hardness compare to mild steel side heat affected zone.

Stainless steel side base metal has high hardness compare to mild steel side base metal. For sample 2 HAZ SS side has highest hardness 200Hv. For Sample 1 HAZ MS side has 212.5 Hv hardness. For Sample 4 BASE SS side has 172.5 Hv hardness. BASE MS side has little fluctuations in hardness. While all other side has more fluctuations in hardness.

Welding specimens are free from unnecessary cracks, All welding samples have good weld penetration. Hardness is vary according to all three input parameters. I have measured all time high hardness at weld area compare to other areas like heat affected zone and base metal .

For Sample 1 to 4 power remains constant 900W. For these samples weld zone has high hardness compare to remaining zones. Mild steel Base side has lower hardness compare to other zones. For these samples heat affected zone mild steel side has high hardness compare to heat affected zone stainless steel.

FIG. 7 MICROSTRUCTURE FOR SAMPLE 1

FIG 8. MICROSTRUCTURE FOR SAMPLE 2

FIG 9. MICROSTRUCTURE FOR SAMPLE 3

FIG 10. MICROSTRUCTURE FOR SAMPLE 4

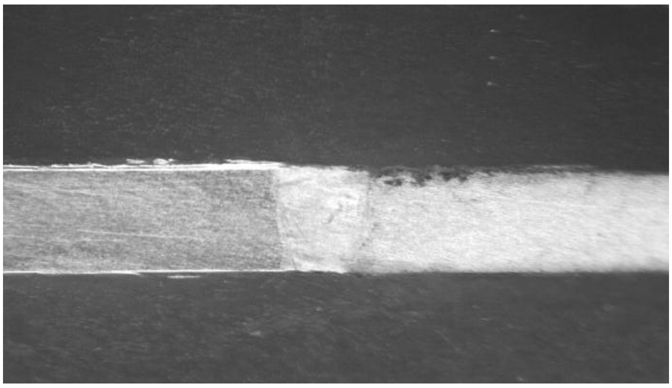


FIG. 11 MACROSTRUCTURE FOR SAMPLE 1

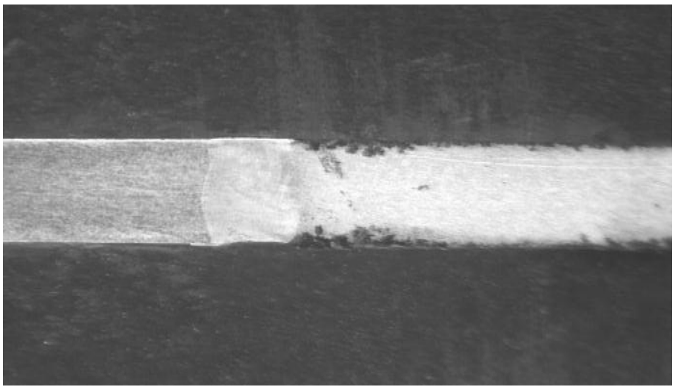


FIG. 12 MACROSTRUCTURE FOR SAMPLE 2

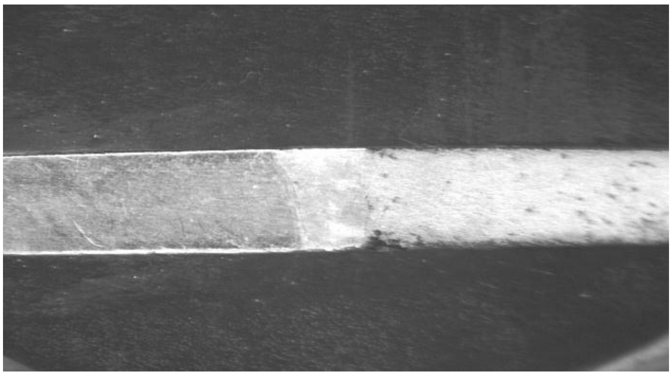


FIG. 13 MACROSTRUCTURE FOR SAMPLE 3

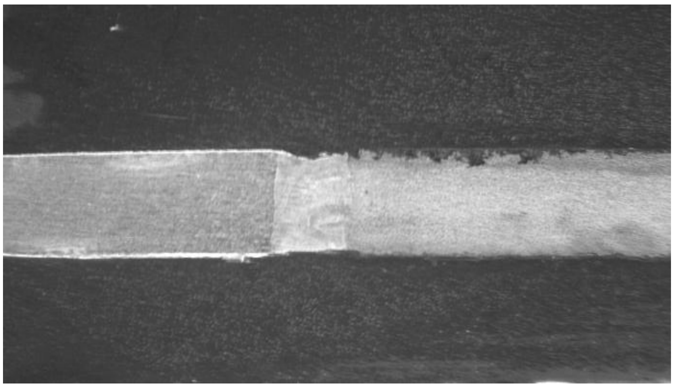


FIG.14 MACROSTRUCTURE FOR SAMPLE 4

In this experimental work , I have selected 1KW Fiber laser machine for laser welding. Travelling speed and focal position has 3 levels. Power has 3 levels 800, 900, 1000 (W) . Travelling speed has 3 levels 500, 700, 900 (mm/min) . Focal position has -2, -3, -4 (mm) three different levels.

Overall All welding samples has good microstructure with austenitic grains at base metal and heat affected zone interface. All microstructures are free from cracks and any other defects. Good weld fusion is represented in all welding samples. Welding sample 3 has ferrite and pearlite matrix.

For all macrostructures There is a good fusion of weld. Microstructures are observed with optical microscope (OLYMPUS –GX41) with 200X . Aquaregia reagent etchant is used for microstructure work. Macrostructures are observed with stereo zoom microscope with 10X. Same Aquaregia reagent is also used for macrostructure work.

Welding specimens are free from unnecessary cracks, All welding samples have good weld penetration. Hardness is vary according to all three input parameters. I have measured all time high hardness at weld area compare to other areas like heat affected zone and base metal .

Overall I have measured, All microstructures have fine austenitic grains at base metal and heat affected zone interface and All macrostructures have good fusion of weld.

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