# EXPERIMENTAL INVESTIGATION OF WELDING PARAMETER FOR AL 6061 – MG AZ31B MATERIAL ON FIBER LASER WELDING

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**ABSTRACT**

*Industries demand always for efficient process selection for welding advance materials and as well as for welding of dissimilar material. Dissimilar materials are different in nature hence difficult to weld. Conventional welding do not serve the purpose. To meet these challenges laser welding is one of the best option. Laser welding make feasible to weld dissimilar material with high weld accuracy and desirable weld properties. LBW was initially applied for thermoplastics in the 1970s. Laser welding has been used by the automotive industry for several years. Namely, Fiat installed a CO2 laser in 1975 to weld power train components. It can be used for lightest structure. In present study Experimental work carried out for welding on AL-MG Materials. Analyze effect of process parameters for dissimilar material; (Al alloys 6061 & Mg- AZ31B for Hardness and tensile strength. Taguchi base Design of experiment used for experimentation work. Experiments carried out using L9 orthogonal array. ANOVA analysis carried out to analyze parametric effect for hardness and tensile strength. Percentage contribution calculated for each parameter. Single objective optimization done for individual response. Also establish the mathematical models for hardness, Tensile strength & Bead width. From analysis it is observed that Laser power and cutting speed are the most critical parameters. They are the major contributor for response requirement. Focal length has less effect compared to power and speed.*

**Keyword: -** *Fiber Laser Welding, FSW, Taguchi, Optimization, AHP, MOORA etc….*

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## 1. INTRODUCTION

In the 1980's, car builders began replacing resistance spot welding by laser welding for the production of tailored welded blanks. In global competitive environment the industrial demand need generated for weld dissimilar metal by laser welding. A fiber laser is a laser in which the active gain medium is an optical fiber doped with rare-earth elements such as erbium, ytterbium, neodymium, dysprosium, and thulium. They are related to doped fiber amplifiers, which provide light amplification without lasing. Fibers have high surface area to volume ratio which allows efficient cooling. In addition, the fiber's wave guiding properties tend to reduce thermal distortion of the beam. Al-Mg Alloys are strain hardnable and have moderately high strength, excellent corrosion resistance even in salt water, and very high toughness even at cryogenic temperatures to near absolute zero. They are ease for fiber laser welding at less thickness. As a result find wide application in building and construction, automotive, cryogenic, marine applications.

### 1.1 Laser Welding

Laser welding has been used by the automotive industry for several years. Namely, Fiat installed a CO2 laser in 1975 to weld power train components. In the 1980's, car builders began replacing resistance spot welding by laser welding for the production of tailored welded blanks.

LBW is used to join metal pieces by the use of a laser. The beam of LBW provides high power density (104 $MW/m^2$), which facilitates for narrow, deep welding, high cooling rate and high welding rates. So the quality of welding is very high. The range of spot size of the laser is in between 0.1 mm to 10 mm. The depth of penetration in a LBW is directly related to the amount of laser power output; however it also depends upon the focus point (defocusing distance). The welding speed is depending on power supply, properties and thickness of the work pieces. As per necessity of application either continuous wave or pulsed laser beam can be used. Pulse laser is used for thin materials such as thin film, while continuous wave laser beam is used for thick materials. Materials like carbon steel, HSLA, stainless steel, aluminium and titanium can be welded by using LBW. However, high-carbon steels produce crack due to high cooling rate in LBW .

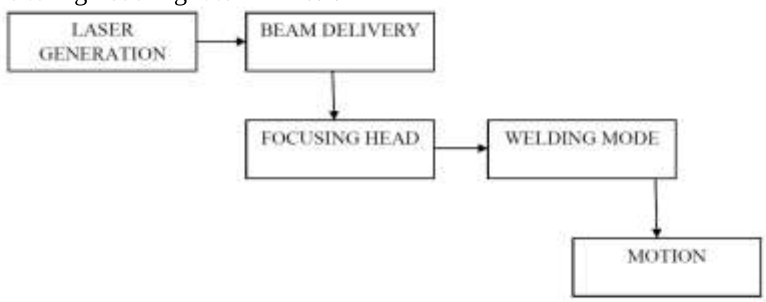


Fig-1 Flow chart of processing steps involved in laser beam welding

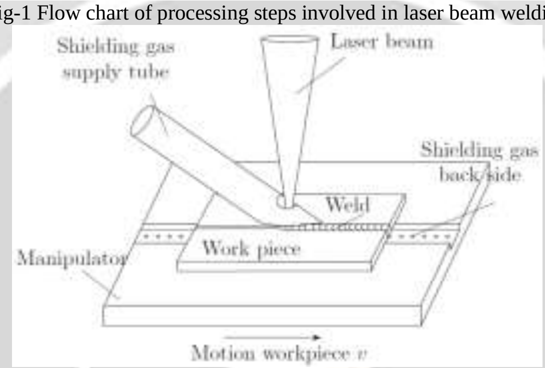


Fig-2 Diagrams of laser welding process

For AL/Mg Dissimilar LBW Sana BANNOUR et al (1) Maximum Micro Hardness Produce in fusion zone compare to Base Metal. Intermettalic compound are responsible in molten zone. Possibility to reduce hardness gradient with suitable heat treatment. Input process parameter power-2.5 to 5 watt, welding speed- 5 to 9 m/min, Defocus distance 0.4mm.Batahgy et al (2) investigated of Hardness measurements and tensile test of AA6061 alloy welds indicated a remarkable softening of the fusion zone due to dissolution of the strengthening precipitates, and this was recovered by aging treatment after welding. For alloys AA5052 and AA5083, softening of the fusion zone due to the loss of its work-hardened condition was much less in comparison with AA6061 alloy.

Jong et al (3)Appropriate butt-welding conditions for the AZ31 magnesium alloy were found to be a laser power of 1.2kW with a welding speed of 55~65mm/sec and a laser power of 1.5kW with a welding speed of 80~90mm/sec. Stable strength and elongation of butt-welded joints were obtained at a laser power of 1.2kW. In this study, the optimal result of 103% of the tensile strength and 47.1% of the elongation of the base metal was obtained at a laser power of 1.5kW with a welding speed of 80mm/sec. hardness of the welded joint was similar or slightly higher than that of the base metal.

## 2. EXPERIMENTAL PROCEDURE

In this experimental work, the sample is welded at three different levels of welding parameter i.e. voltage, current and speed as shown in table 1.

Table-1: Welding parameter and their levels

| Parameter | Range | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| Laser Power | 1800-2000 W | 1800 | 1900 | 2000 |
| Travelling Speed | 3200-3500 mm/min | 3200 | 3300 | 3400 |
| Focal Position | -1.5 to +1.5 mm | -1.5 | 0 | +1.5 |

The dimension of work sample is length 110 mm, width 70 mm, thickness 2 mm. Now the setup has been ready and was prepared for doing Fiber Laser welding on given sample. The Chemical Composition of Aluminium alloy 6061

& Magnesium AZ31B is shown in table 2, in which it shows the percentage of elements like carbon, iron, manganese, sulphur and phosphorous present.

Table-2: Chemical Composition of Aluminium alloy 6061 & Magnesium AZ31B

| Element | % Present | % Required |
|---|---|---|
| Cu | 0.211 | 0.15 to 0.4 |
| Si | 0.512 | 0.4 to 0.8 |
| Mn | 0.012 | 0.15 max |
| Mg | 1.1010 | 0.8 to 1.2 |
| Ti | 0.07 | 0.15 max |
| Cr | 0.092 | 0.04 to 0.35 |
| Al | 97.79 | 95.8 to 98.6 |
| Fe | 0.07 | 0.07 max |
| Zn | 0.13 | 0.25 max |

| Element | % Present | % Required |
|---|---|---|
| Si | 0.04 | 0.2210 to 0.2 |
| Mn | 0.2210 | 0.2 min |
| Fe | 0.003 | 0.005 Max |
| Ca | 0.02 | 0.04 max |
| Cu | 0.03 | 0.05 max |
| Ni | 0.002 | 0.005 max |
| Ti | 0.01 | 0.05 max |
| Al | 2.61 | 2.5 to 3.5 |
| Zn | 0.71 | 0.6 to 1.4 |
| Mg | 96.29 | Rem |

Fig 2 shows the welded sample of both materials by using fiber laser welding.

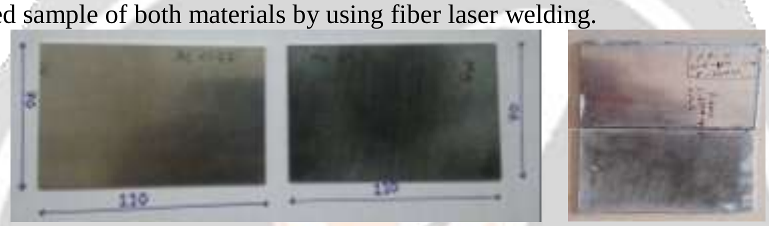

Fig -3 Welded Sample

Table-3 L9 Orthogonal Array Design matrix

| Sr.No. | Laser Power (Watt) | Travelling Speed (mm/min) | Focal Position (mm) | Tensile strength (MPa) | Haz Hardness (BHN) | Weld Hardness (BHN) |
|---|---|---|---|---|---|---|
| 1 | 1800 | 3300 | -1.5 | 25.632 | 15 | 21.33 |
| 2 | 1800 | 3400 | 0 | 65.243 | 60.67 | 66 |
| 3 | 1800 | 3500 | 1.5 | 80.121 | 65.33 | 70.67 |
| 4 | 1900 | 3300 | 0 | 15.146 | 20.33 | 24.33 |
| 5 | 1900 | 3400 | 1.5 | 57.353 | 50 | 58.33 |
| 6 | 1900 | 3500 | -1.5 | 56.786 | 56 | 60.67 |
| 7 | 2000 | 3300 | 1.5 | 10.234 | 15.67 | 20 |
| 8 | 2000 | 3400 | -1.5 | 10.458 | 10 | 16.33 |
| 9 | 2000 | 3500 | 0 | 15.379 | 20.33 | 24 |

Total nine experiments were performed based on L9 orthogonal array shown in Table 3. The effect of different parameters such as welding Laser Power (Watt), Travelling Speed (mm/min) and Focal Position (mm) of above material was analyzed and observed the tensile strength and hardness of all nine welded sample are also shown in Table 3. Then we Calculate ANOVA using Minitab 16.

## 3. RESULT AND DISCUSSION

### 3.1 Regression Analysis: Ultimate Tensile Strength versus A, B, C

R-Sq = 96.44% R-Sq(adj) = 85.77%

Analysis of Variance for Ultimate Tensile Strength

Table-4 ANOVA Table for Ultimate Tensile Strength

| Source | DF | Seq SS | Adj SS | Adj MS | F | P | Percentage Contribution |
|---|---|---|---|---|---|---|---|
| A | 2 | 3181.5 | 3181.5 | 1590.7 | 15.01 | 0.062 | 53.41 |
| B | 2 | 1928.6 | 1928.6 | 964.3 | 9.1 | 0.099 | 32.38 |
| C | 2 | 634.7 | 634.7 | 317.4 | 2.99 | 0.25 | 10.66 |
| Error | 2 | 212 | 212 | 106 | | | 3.56 |
| Total | 8 | 5956.8 | | | | | 100.00 |

- The above analysis helps to understand the impact of process parameters as an individual effect.
- F-test and P-test help to identify the key parameter in welding for stress analysis. The significant parameters based on F-test whose F-test values > 4 are current.

- % contribution helps to identify the contribution of each parameter over response. Analysis states that Laser Power contributed more for stress.

### 3.2 Regression Analysis: HAZ Hardness versus A, B, C

R-Sq = 90.01%   R-Sq(adj) = 60.05%
Analysis of Variance for HAZ Hardness

Table -5 ANOVA Table for Hardness on HAZ

| Source | DF | Seq SS | Adj SS | Adj MS | F | P | Percentage Contribution |
|---|---|---|---|---|---|---|---|
| A | 2 | 1743.7 | 1743.7 | 871.8 | 4.29 | 0.189 | 42.80 |
| B | 2 | 1501.5 | 1501.5 | 750.8 | 3.69 | 0.213 | 36.86 |
| C | 2 | 421.5 | 421.5 | 210.8 | 1.04 | 0.491 | 10.35 |
| Error | 2 | 406.9 | 406.9 | 203.4 | | | 9.99 |
| Total | 8 | 4073.6 | | | | | 100.00 |

The above analysis helps to understand the impact of process parameters as an individual effect.

- F-test and P-test help to identify the key parameter in welding for stress analysis. The significant parameters based on F-test whose F-test values > 4 are current.
- % contribution helps to identify the contribution of each parameter over response. Analysis states that Laser Power contributed more for stress.

### 3.3 Regression Analysis: Weld Zone Hardness versus A, B, C

R-Sq = 91.63%   R-Sq(adj) = 66.51%
Analysis of Variance for Weld Zone Hardness

Table-6 ANOVA Table for Hardness on Weld Zone

| Source | DF | Seq SS | Adj SS | Adj MS | F | P | Percentage Contribution |
|---|---|---|---|---|---|---|---|
| A | 2 | 1849.3 | 1849.3 | 924.6 | 5.27 | 0.159 | 44.14 |
| B | 2 | 1542.6 | 1542.6 | 771.3 | 4.4 | 0.185 | 36.82 |
| C | 2 | 447.3 | 447.3 | 223.6 | 1.27 | 0.44 | 10.68 |
| Error | 2 | 350.8 | 350.8 | 175.4 | | | 8.37 |
| Total | 8 | 4190 | | | | | 100.00 |

- The above analysis helps to understand the impact of process parameters as an individual effect.
- F-test and P-test help to identify the key parameter in welding for stress analysis. The significant parameters based on F-test whose F-test values > 4 are current.
- % contribution helps to identify the contribution of each parameter over response. Analysis states that Laser Power contributed more for stress.

### 3.4 Mathematical Model

Final Equation in Terms of Coded Factors:
Ultimate Tensile Strength = 30.3 - 22.5 A + 16.9 B + 9.14 C      HAZ Zone Hardness = 19.6-15.8A+15.1B+8.33 C
Weld Zone Hardness = 26.0 - 16.3 A + 14.9 B + 8.44 C
This mathematical model generated by Minitab 16.0 versions.

### 3.5 Effect of Ultimate Tensile Strength

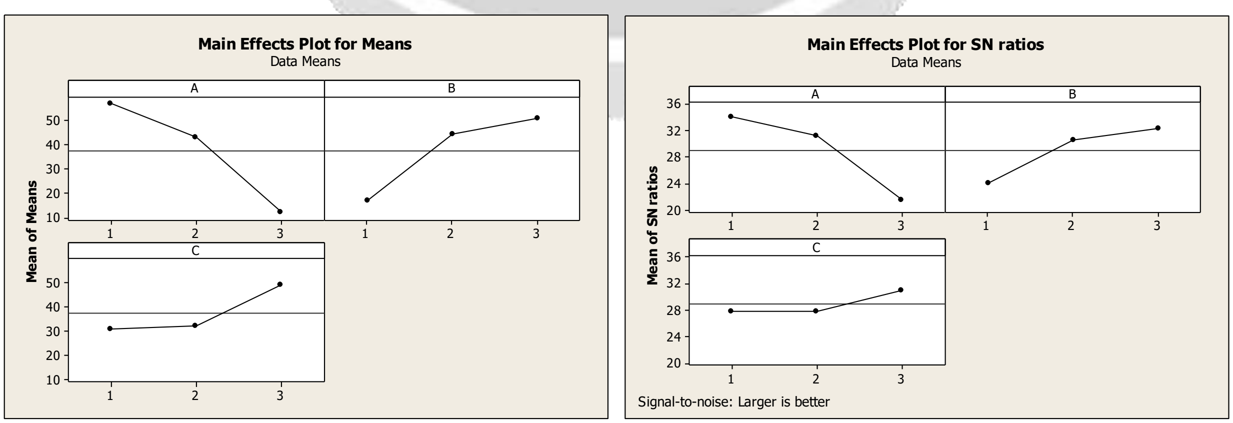


Fig-4 Main Effects Plot for Ultimate Tensile Stress

Graph state that as power increases the ultimate tensile strength decreases. Effect of speed is oposite to power, as travelling speed increases the ultimate tensile strength also increases. The focul length has not initially much effect on ultimate strength but large variation took play a vital effect and increase the ultimate tensile strength. ANOVA Analysis states that the power and travelling speed are the key effective parameter for the hardness. The percentage contribution of power is 42.80 %. Travelling speed has 36.86 % contribution, while focus length has contribution about 10.35%.

### 3.6 Effect of HAZ Hardness

Graph state that as power increases the hardness decreases. Hence increase in power up to certain limit is desirable. Effect of speed is opposite to power, as travelling speed increases the hardness in weld zone increases which leads to brittle the area. So always lower speed is desirable. Increase in focal length also reduces the hardness. ANOVA Analysis states that the power and travelling speed are the key effective parameter for the ultimate tensile strength response. The percentage contribution of power is 53.41 %. Travelling speed has 32.38 % contribution, while focus length has contribution about 10.66%.

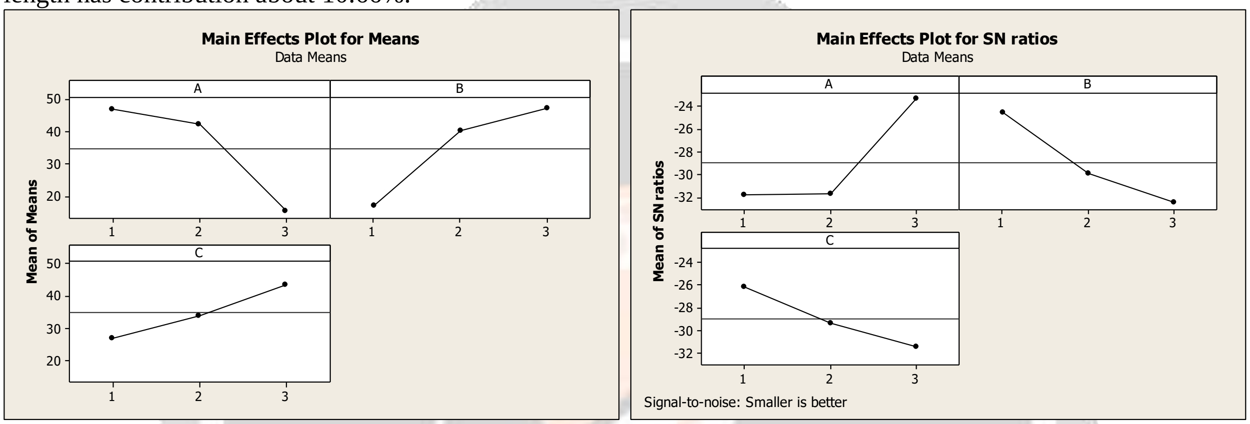


Fig-5 Main Effects Plot for Hardness on HAZ Zone

### 3.7 Effect of Ultimate Tensile Strength

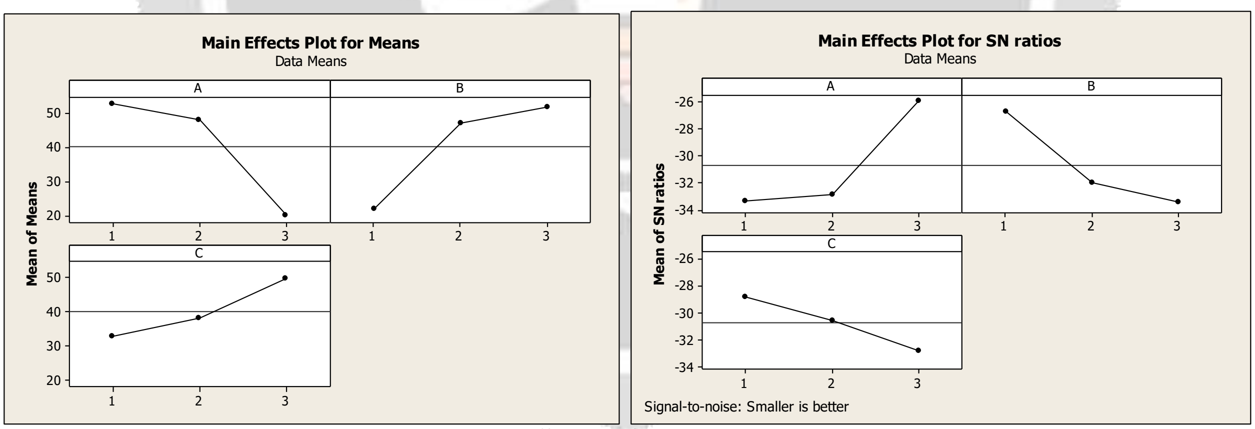


Figure.-6 Main Effects Plot for Hardness on Weld Zone

Graph state that as power increases the hardness increases. The variation in hardness is intially at lower rate but then after it increases in gradually Effect of speed is oposite to power, as travelling speed increases the hardness in weld zone decreases. So always lower speed is desirable. Increase in focal length also reduces the hardness. ANOVA Analysis states that the power and travelling speed are the key effective parameter for the ultimate tensile strength response. The percentage contribution of power is 44.14 %. Travelling speed has 36.82 % contribution, while focus length has about 10.68 %.

## 4. Optimization

The results obtained for evaluation and selection of fiber laser welding process parameter using combine application of AHP/MOORA method. In this research ranking of all 9 alternative is carried out based on the weighted assessment value. According to performed experimental design, it is clearly observed that experiment or alternative number 3 gives the best multi- performance features of the fiber laser welding process among the 9 experiments. And also find by Gray relational analysis (GRA) optimization.

## 5. Confirmation test

The confirmation test is the final step undertaken during this experiment on the optimize run no 3. The purpose of the confirmation runs is to validate the conclusion drawn during the analysis phases. In addition, the confirmation tests need to be carried out in order to ensure that the theoretical predicted model for optimum results using the software was accepted or in other word to verify the adequacy of the models that were developed. Three confirmation tests were carried out in order to compare the experimental results from the prediction made by the ANOVA. Fig-5 shows the three series of parameters settings for the confirmation test. The parameters values were selected between the high and low range of the process factor that have been studied from previous experiment.

Table-7 True value of confirmation test experiment

| Exp. No. | Laser Power (Watt) | Travelling Speed (mm/min) | Focal Position (mm) |
|---|---|---|---|
| 3 | 1800 | 3500 | 1.5 |

**Comparison of the test results**

Based on the above discussed in chapter the comparison of the test results between the theoretically prediction and confirmation test results was the final consideration that will evaluate whether the optimum parameters predicted were in the allowable range.

Table-8 Comparison test results

| Exp. No. | Experimental (Confirmation test) | | | Prediction (by Mathematical Model) | | |
|---|---|---|---|---|---|---|
| | UTS N/mm2 | WELD BHN | HAZ BHN | UTS N/mm2 | WELD BHN | HAZ BHN |
| 1 | 82.121 | 65.66 | 73.67 | 85.92 | 74.09 | 79.72 |
| 2 | 80.365 | 70.66 | 69.56 | | | |
| 3 | 84.94 | 72.89 | 75.36 | | | |

Tables-7 show the comparison of test results between theoretical prediction and confirmation test is very nearest.

## 6. CONCLUSIONS

- Quality weld is depending upon selection of process parameter.
- Power is effective parameter for ultimate tensile strength and hardness in weld zone as well as in HAZ. Too much power generates more energy which reduces weld strength and too low power gives adverse effect on ultimate tensile strength. So optimum set of power required for effective combined response.
- Travelling speed is second important parameter for ultimate tensile strength and hardness in weld zone as well as in HAZ. Low speed gives better ultimate tensile strength but it increase hardness in weld zone whichn is not desirable. So multiobjective optimization needed to get combined response effect. Focal length is important factor for hardness in weld zone.
- AHP/MOORA base multi objective optimization help to select set of process parameter which combines response. It is observed that MOORA base multi objective optimization state different set of parameter against single objective optimization.

## 7. REFERENCES


1) Sana BANNOUR et al, “ Microstructure and properties of weld between 5754 AL alloy and AZ31 Mg alloys using Yb: Yag Laser” 20th International Symposium on High Power Laser Systems & Applications (2014)
2) El-Batahgy, M. Kutsuna, “Laser Beam Welding of AA5052, AA5083, and AA6061 Aluminum Alloys” Advances in Materials Science and Engineering Volume 2009, Article ID 974182, 9 pages
3) Rattana et all, “ Dissimilar Material Laser welding between magnesium alloy AZ31B and Aluminum Alloy A5052-O” Science And Technology of Advanced Material Volume-6(2005)199-204
4) Coelho et all, “ Microstructure and Mechanical Properties of Magnesium Alloy AZ31 B laser Beam Weld” Materials Science and Engineering A 485 (2008) 20–30
5) Jong et al, “Characteristics of Butt- Welded Joints on AZ31B Magnesium Alloy Using a Nd:Yag Laser” International Journal Of Precision And Manufacturing Engineering Volume-11,no-3,pp.369-373(2010).
6) CHOWDHURY et al, “Microstructure and Mechanical Properties of FLW and DLW AZ31 Magnesium Alloy” The Minerals, Metals & Materials Society and ASM International 2010.
7) Junhao Sun , Qi Yan, Wei Gao, Jian Huang, “Investigation of laser welding on butt joints of Al/steel dissimilar materials” Materials & Design 83 (2015) 120–128

8) J. Ahna,n, L. Chen b, C.M. Davies, J.P. Dear, "Parametric optimization and micro structural analysis on high power Yb-fiber laser welding of Ti–6Al–4V"Optics and Lasers in Engineering 86 (2016) 156–171
9) Chen et al, "Fiber Laser Welding of dissimilar alloys of Ti-6AL-4V and inconel 718 for aerospace applications" Int. J. Adv. Mfg. Technology (2010).
10) Zhang et al, " Modulated fiber laser welding of high reflective AZ31" Int. J. Adv. Mfg. Technology (2014)
11) Subbaiah et al, "Comparative evaluation of tungsten inert gas and laser beam welding of AA5083-H321" / Sadhana Vol. 37, Part 5, October 2012, pp. 587–593.
12) Dr.O.P.Khanna, "Welding Technology", 21st Reprint, Dhanpat rai Publications(P) Ltd. 2012