An Experimental Investigation and Prediction of Laser Welding Process

MR. DHAVALKUMAR K. SONI
M. Tech. (CAD/CAM) PG student, U V Patel College of Engineering,
Ganpat University, Mehsana, Gujarat, India
dksony@gmail.com

PROF. D. M. PATEL
Associate professor,
Department of mechanical engineering, U V Patel College of Engineering,
Ganpat University, Mehsana, Gujarat, India
dhaval05@gmail.com

Abstract:
Fiber laser welding process has successfully used for joining similar as well as dissimilar metals. Welding with fiber laser is still a very young technology. Fiber laser for materials processing have undergone a rapid development in the past several years. In this study, the laser welding process on mild steel (IS 2062 Grade A) sheets of 1 mm using fiber laser have been experimentally investigated and the experimental results have been used to prepare the prediction model. A statistical design of experiment (DOE) method full factorial design with help of Design expert 8.0.7 software have been used for designing the experimental work. The selected laser welding input parameters (laser power, travelling speed and focal position) have been used for the three output parameters (ultimate tensile strength, depth of penetration and weld bead width) and the relation between these parameters have been analyzed. The effect of each parameter has been studied. Analysis of Variance (ANOVA) has been used for finding the contribution of each factor on the output parameters. The main effects plots and the interaction effect plots have been plotted in order to understand the actual effect of input on the output. The responses have been predicted by Artificial Neural Network (ANN) using MATLAB.

Keywords: *ANN, ANOVA, Fiber laser welding, Full factorial design (FFD), MATLAB*

1. Introduction

The word "laser" is an acronym for light amplification by stimulated emission of radiation. It was first proposed by Schawlow and Townes. Laser Beam Welding (LBW) is a modern welding process used to join multiple pieces of similar and dissimilar metal through the use of a laser beam. Due to its wide variety of application an experimental investigation and prediction of the process is of utmost important. In this paper influence of various input parameters on the varieties of output parameters related to laser welding process has been investigated. The variation between experimental and ANN results has been presented. The validation results show an error of 2 % to 4 % which are acceptable results for the industrial solutions.

2. Literature Review

Alexandra P. Costaa, Luı´sa Quintinoa, and Martin Greitmannb (2003) have worked on laser beam welding hard metals to steel. They have examined Laser beam weldability of hard metals to steel with high power (cw) CO_2 laser, (cw) Nd: YAG laser and (pw) Nd: YAG laser.

They have deduced that the laser beam welding process has the overall advantage of producing small beads and HAZ and minimizing residual stresses. Continuous Nd: YAG laser was found to present the best results.

A Ribolla, G.L. Damoulis and G.F. Batalh (2005) have investigated the use of Nd: YAG laser weld for large scale volume assembly of automotive body in white. They have suggested some advantages in laser welding as a variety of benefits over other types of welding. Deep penetration of precise narrow welds, small heat affected zone, low heat input, fast weld times, minimum part distortion, no secondary processing and high repeatability can be mentioned as great advantages.

K. R. Balasubramanian, G. Buvanashekaran and K. Sankaranarayanasamy (2006) have worked on Mathematical and ANN Modeling of Nd: YAG laser welding of thin SS Sheets. The effect of laser power (0.6-1.4 kW), welding speed (0.8-2 m/min) and shielding gas flow rate (5 - 15 l/min) on the weld-bead geometry i.e. depth of penetration (DOP), weld bead width (BW) was investigated. The experiment was designed on three levels Box-Behnken design with replication. Modeling was done using artificial neural network and multiple regression analysis. Comparison of neural network model and multiple linear regression model was made.

Jose´ Roberto Berrettaa and Wagner de Rossib (2007) have investigated the pulsed Nd: YAG laser welding of AISI 304 to AISI 420 stainless steels. They have studied the influence of the laser beam position, with respect to the joint, on weld characteristics. The joints were examined in an optical microscope for cracks, pores and to determine the weld geometry. The microstructure of the weld and the heat affected zones were observed in a scanning electron microscope. Vickers microhardness testing and tensile testing were carried out to determine the mechanical properties of the weld.

M.s.w glowski, K. kwieciski, K. krasnowski and R. jachym (2009) have studied the characteristics of Nd: YAG laser welded joints of dual phase steel. They have presented the examination results of microstructure, mechanical properties, fatigue strength and residual stresses of Nd: YAG laser welded joints in dual phase HDT580X steel. They have concluded that the laser welding parameters were appropriate to obtain sound welds. They have indicated that it was possible to achieve good quality welds by the application of proper welding parameters.

G. Padmanaban and V.Balasubramanian (2010) has worked on an optimization of laser beam welding process parameters to attain maximum tensile strength in AZ31B magnesium alloy. An empirical relationship was developed to predict tensile strength of the laser beam welded AZ31B magnesium alloy by incorporating process parameters such as laser power, welding speed and focal position. The experiments were conducted based on a three factor, three level, central composite face centered design matrix with full replications technique. The empirical relationship can be used to predict the tensile strength of laser beam welded AZ31B magnesium alloy joints at 95% confidence level. The results indicate that the welding speed has the greatest influence on tensile strength, followed by laser power and focal position.

A. Ruggiero, L.Tricarico, A.G.Olabi and K.Y.Benyounis (2011) have investigated weld-bead profile and costs optimization of the CO_2 dissimilar laser welding process of low carbon steel and austenitic steel AISI316. The effect of laser power(1.1–1.43kW), welding speed(25– 75 cm/min) and focal point position(- 0.8 to - 0.2 mm) on the weld-bead geometry (i.e. weld-bead area, A; upper width, Wu; lower width, Wl and middle width, Wm) and on the operating cost C was investigated using response surface methodology (RSM). The results indicate that the proposed models predict the responses adequately within the limits of welding parameters being used. They have used regression equations to find optimum welding conditions for the desired geometric criteria. They have concluded that the welding speed is the parameter that most significantly influences the main weld bead dimensions.

P. Sathiya, K.Panneerselvam and R.Soundararajan (2012) have worked on optimal design for laser beam butt welding process parameter using artificial neural networks and genetic algorithm for super austenitic stainless steel. In that study, the weld bead geometry such as depth of penetration (DP), bead width (BW) and tensile strength (TS) of the laser welded butt joints made of AISI 904L super austenitic stainless steel were investigated. They have developed Artificial Neural networks (ANN) program in Matlab software to establish the relationships between the laser welding input parameters like beam power, travel speed and focal position and the three responses DP, BW and TS in three different shielding gases(Argon, Helium and Nitrogen).

Yang dongxia and Lixiaoyan (2012) has worked on Optimization of weld bead geometry in laser welding with filler wire process using Taguchi's approach. In their work, laser welding with filler wire was successfully applied to joining a new-type Al–Mg alloy. Welding parameters of laser power, welding speed and wire feed rate were carefully selected with the objective of producing a weld joint with the minimum weld bead width and the fusion zone area.

3. Design of Experiment, experiment work and measurement

Design of Experiments refers to the process of planning, designing and analyzing the experiment so that valid and objective conclusions can be drawn effectively and efficiently. In order to draw statistically sound conclusions from the experiment, it is necessary to integrate simple and powerful statistical methods into the experimental design methodology. In this work input parameters considered for laser welding are as laser power, travelling speed and focal position. Output parameters are ultimate tensile strength measured by universal testing machine, depth of penetration and bead width with use of optical microscope. Other parameters are considered as constant parameters. The material selected for the experiment work is mild steel IS 2062 grade A which is widely used in industrial practice. The joint type selected for the experiment work is square butt joint.

For this experiment 3 input factors are selected with their three levels. Design of experiment is carried out using full factorial design. In this design of experiment, all three factors and their unique factor level combinations *(3 P * 3 FP * 3 TS)* results in a total 27 observations.

For Design of experiment Design expert 8.0.3 is used. The experiment work is carried out on laser welding machine at Sahjanand laser technology limited as per the DOE table. The workpiece welded before & after the welding is shown in figure 1 and figure 2 respectively. After the experiment work the output response UTS was measured using universal tensile testing machine and weld bead geometry was measured using optical microscope. The result obtained after the experiment work are shown in the result table 1.

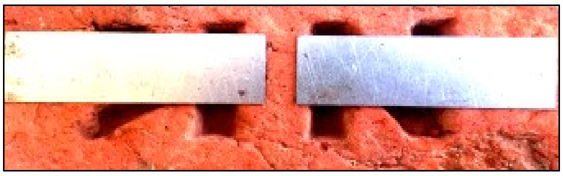

Figure 1 Work piece before welding

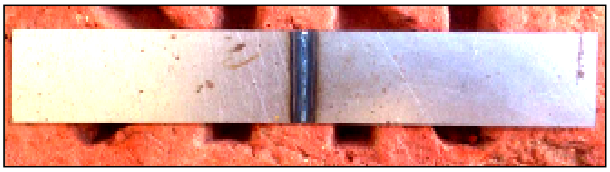

Figure 2 Work piece after welding

Table 1 Result table

	Input Parameters				Output Parameters		
Exp No.	Laser power (KW)	Travelling speed (mm/min)	Focal position (mm)		Ultimate tensile strength (Mpa)	Depth of penetration (mm)	Weld bead width (mm)
1	1.5	1000	0		389	0.979	1.015
2	1.5	1500	0		394	0.982	1.013
3	1.5	2000	0		402	0.985	1.011
4	1.5	1000	-0.35		396	0.981	1.013
5	1.5	1500	-0.35		400	0.983	1.011
6	1.5	2000	-0.35		405	0.987	1.005
7	1.5	1000	-0.7		412	0.991	1.019
8	1.5	1500	-0.7		416	0.994	1.015
9	1.5	2000	-0.7		419	0.997	1.009
10	1.75	1000	0		408	0.988	1.021
11	1.75	1500	0		412	0.992	1.016
12	1.75	2000	0		418	0.994	1.014
13	1.75	1000	-0.35		410	0.995	1.021
14	1.75	1500	-0.35		413	0.998	1.018
15	1.75	2000	-0.35		419	1	1.015
16	1.75	1000	-0.7		421	1.01	1.019
17	1.75	1500	-0.7		424	1.013	1.014
18	1.75	2000	-0.7		427	1.015	1.011
19	2	1000	0		417	0.99	1.021
20	2	1500	0		421	1.001	1.018
21	2	2000	0		425	1.008	1.016
22	2	1000	-0.35		419	1.01	1.021
23	2	1500	-0.35		421	1.013	1.018
24	2	2000	-0.35		423	1.016	1.014
25	2	1000	-0.7		425	1.019	1.021
26	2	1500	-0.7		426	1.021	1.018
27	2	2000	-0.7		427	1.023	1.016

From the table 1, it is identified that the minimum ultimate tensile strength value 389 Mpa is obtained at the value of 1.5 KW power, 1000 mm/min travelling speed and 0 mm focal position. The maximum ultimate tensile strength value 427 Mpa is obtained at two positions. One at the value of 1.75 KW power, 2000 mm/min travelling speed and -0.7 mm focal position and other is at the value of 2 KW power, 2000 mm/min travelling speed and -0.7 mm focal position. It is also identified that the minimum depth of penetration value 0.979 mm is obtained at the value 1.5 KW power, 1000 mm/min travelling speed and 0 mm focal position. The maximum depth of penetration value 1.023 mm is obtained at the value 2 KW power, 2000 mm/min travelling speed and -0.7 mm focal position. From the table 1, it is also identified that the minimum weld bead width value 1.005 mm is obtained at the value 1.5 KW power, 2000 mm/min travelling speed and -0.35 mm focal position. The maximum weld bead width value 1.021 mm is obtained at four positions. One at the value 1.75 KW power, 1000 mm/min travelling speed and 0 mm focal position, the second is at the value 1.75 KW power, 1000 mm/min travelling speed and -0.35 mm focal position, the third is at the value 2 KW power, 1000 mm/min travelling speed and 0 mm focal position and the last is at the value 2 KW power, 1000 mm/min travelling speed and -0.35 mm focal position.

4. Results and Discussion

Minitab 15 and Design expert 8.0.7 is used for graphical representation of the analysis results obtained by experimental work. Main effects plot for ultimate tensile strength, depth of penetration and bead width are presented in figure 3, figure 4 and figure 5 respectively.

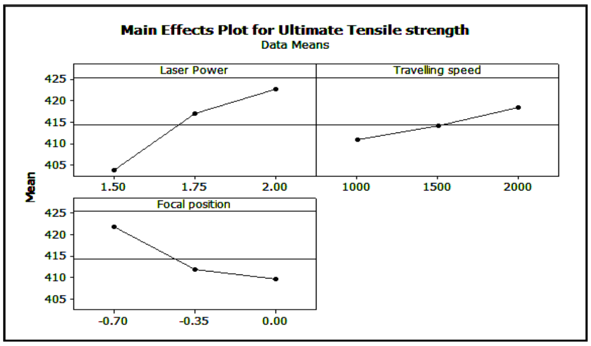

Figure 3 Main effects plot for UTS

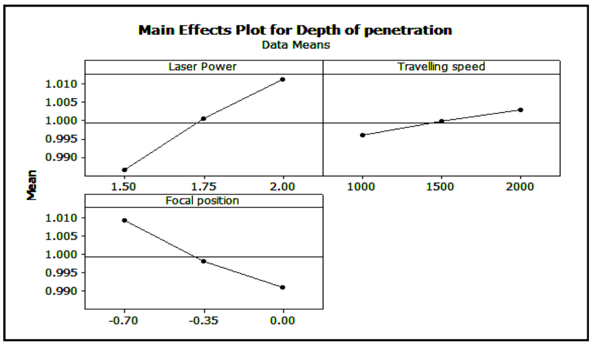

Figure 4 Main effects plot for DOP

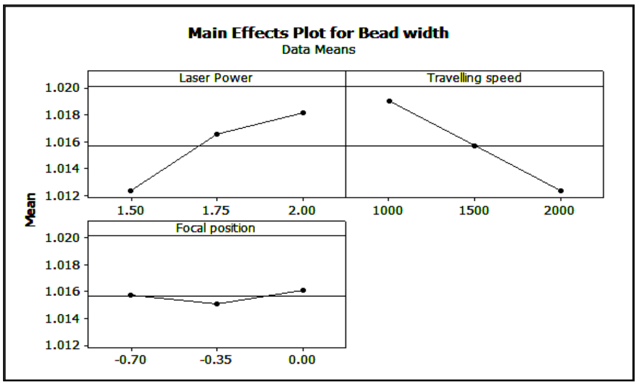

Figure 5 Main effects plot for bead width

Table 2 shows the percentage contribution of each input factor on the output parameter after ANOVA.

Table 2 Percentage contribution of each input parameter on the output parameter

INPUT	OUTPUT		
	Ultimate tensile strength (Mpa)	Depth of penetration (mm)	Weld bead width (mm)
Laser power (KW)	57.25	58.43	37.07
Travelling speed (mm/min)	8.65	4.54	46.08
Focal position (mm)	26.08	32.26	1.7
Error	8.01	4.83	15.77

For preparing the prediction model Matlab 2011a was used. The neural network toolbox gives a better way for using ANN to prepare the prediction model. The Comparisons of ANN model with experimental values of ultimate tensile strength, depth of penetration and weld bead width is shown in table 3.

Table 3 Comparisons of ANN model with experimental values of ultimate tensile strength, depth of penetration and weld bead width

Ex.	Inputs			Outputs								
	LP	TS	FP	UTS	ANN UTS	% Error	DOP	ANN DOP	% Error	BW	ANN BW	% Error
1	1.5	1000	0	389	389	0.01661	0.979	0.977	0.21438	1.015	1.021	-0.61068
2	1.5	1500	0	394	391	0.85335	0.982	0.983	-0.07088	1.013	1.015	-0.19416
3	1.5	2000	0	402	398	0.99438	0.985	0.994	-0.91371	1.011	1.013	-0.23438
4	1.5	1000	-0.35	396	392	1.02545	0.981	0.979	0.15812	1.013	1.013	-0.03317
5	1.5	1500	-0.35	400	397	0.64295	0.983	1.002	-1.89339	1.011	1.020	-0.84352
6	1.5	2000	-0.35	405	399	1.38094	0.987	0.979	0.81054	1.005	1.002	0.283224
7	1.5	1000	-0.7	412	405	1.73718	0.991	0.981	0.98357	1.019	1.005	1.421786
8	1.5	1500	-0.7	416	410	1.44231	0.994	1.013	-1.92076	1.015	1.020	-0.48252
9	1.5	2000	-0.7	419	416	0.78134	0.997	1.019	-2.21011	1.009	1.008	0.090228
10	1.75	1000	0	408	407	0.12480	0.988	0.979	0.88421	1.021	1.020	0.128501
11	1.75	1500	0	412	409	0.65175	0.992	1.001	-0.86645	1.016	1.021	-0.4526
12	1.75	2000	0	418	415	0.75392	0.994	1.010	-1.57465	1.014	1.025	-1.04363
13	1.75	1000	-0.35	410	409	0.34737	0.995	0.979	1.57797	1.021	1.015	0.544878
14	1.75	1500	-0.35	413	409	0.85167	0.998	0.993	0.53503	1.018	1.018	-0.02138
15	1.75	2000	-0.35	419	413	1.35594	1	1.007	-0.72544	1.015	1.022	-0.68682
16	1.75	1000	-0.7	421	418	0.81306	1.01	0.999	1.04174	1.019	1.004	1.504377
17	1.75	1500	-0.7	424	418	1.36873	1.013	1.003	1.02709	1.014	1.008	0.612229
18	1.75	2000	-0.7	427	431	-1.05012	1.015	1.022	-0.69695	1.011	1.011	-0.03292
19	2	1000	0	417	421	-0.86887	0.99	0.989	0.12044	1.021	1.016	0.486895
20	2	1500	0	421	427	-1.48114	1.001	1.001	-0.0022	1.018	1.013	0.474028
21	2	2000	0	425	426	-0.31769	1.008	1.010	-0.21972	1.016	1.020	-0.42236
22	2	1000	-0.35	419	420	-0.28186	1.01	0.980	2.96388	1.021	1.021	-0.04357
23	2	1500	-0.35	421	424	-0.82223	1.013	1.003	1.00193	1.018	1.013	0.533281
24	2	2000	-0.35	423	427	-0.98156	1.016	1.025	-0.88083	1.014	1.013	0.122919
25	2	1000	-0.7	425	419	1.31200	1.019	0.978	3.97927	1.021	1.010	1.037258
26	2	1500	-0.7	426	422	0.91150	1.021	1.011	0.97943	1.018	1.005	1.23222
27	2	2000	-0.7	427	434	-1.63012	1.023	1.042	-1.82237	1.016	1.014	0.22126
				Total error in %		9.931	Total error in %		2.480	Total error in %		3.59

Here, for the purpose of validation of ANN model, all these 27 input parameters are given to the prediction model and the comparison is carried out as presented in table 3. The comparison shows that the **9.931 %** variation in results of Ultimate tensile strength, **2.48 %** in depth of penetration and **3.59 %** in weld bead width.

5. Conclusion

In the presented work, experiments are carried out for ultimate tensile strength, depth of penetration and weld bead width with variables as laser power, focal position and travelling speed. There are 27 experimental readings taken for all variables to conduct the parametric study as per the full factorial design.

The ANOVA analysis also conducted to know the percentage contribution of the input parameters on output parameters. The parametric study indicate that the percentage contribution of laser power is of **57.25 %**, travelling speed of **8.65 %** and focal position of **26.08 %** for ultimate tensile strength, which shows that the influence of travelling speed on ultimate tensile strength is less compare to other parameters. The percentage contribution of laser power is of **58.43 %**, travelling speed of **4.54 %** and focal position of **32.26 %** for depth of penetration, which shows that travelling speed, has very less influence compare to other parameters. The focal position is identified to be significant factor with laser power for the depth of penetration. The percentage contribution of laser power is of **37.07 %**, travelling speed of **46.08 %** and focal position of **1.7 %** for bead width, which shows that travelling speed, has highest influence on bead width compare to other parameters.

Based on the experimental results, the ANN model is trained for prediction of laser welding process parameters. For the validation purpose all the 27 experimental readings are validated through the application of developed ANN model. The comparison shows that the 9.91 % variation in results of ultimate tensile strength, 2.48 % in depth of penetration and 3.59 % in weld bead width. So the developed ANN model gives accurate results and can be used to predict the output parameters such as ultimate tensile strength, depth of penetration and weld bead width for given input parameters such as laser power, travelling speed, and focal position. Based on industry practice, the variation in results is very less and acceptable.

References

1. Abdel, Monem EI and Batahgy (1997). Effect of laser welding parameters on fusion zone shape and solidification structure of austenitic stainless steels. Materials letters 32.
2. Alexandra, P. Costa, Luisa Quintino, Martin, Greitmann (2003). Laser beam welding hard metals to steel. Journal of Materials Processing Technology 141 163–173.
3. Asif Iqbal, Saeed., Khan, M., Mukhtar and Sahir, H. (2011). ANN Assisted Prediction of Weld Bead Geometry in Gas Tungsten Arc Welding of HSLA Steels. Proceedings of the World Congress on Engineering 2011 Vol I WCE. July 6 - 8, 2011, London, U.K.
4. Balasubramanian, K. R., Buvanashekaran G. and Sankaranarayanasamy K. (2006). Mathematical and ANN Modeling of Nd: YAG Laser Welding of Thin SS Sheets. International Journal for the Joining of Materials, Volume 18 No. 3/4 , December 2006, pp 99-104. ISSN 0905-6866.
5. Bansal, G. Rajkumar and Murugan, N.(2012). Prediction of Weld Bead Geometry using Artificial Neural Networks on 2205 Duplex Stainless Steel. European Journal of Scientific Research ISSN 1450-216X Vol.78 No.1 (2012), pp.85-92.

6. Design-Expert® V8 software for educational purpose by stat-ease.
7. http: // www. aws. org. Date:11/3/2013, time : 10:30 am.
8. http:// www.powerlase.com/applications/machinetools.html,
9. http://en.wikipedia.org/wiki/List_of_welding_processes#Arc_welding,
10. Jose, Roberto Berrettaa and Wagner, de Rossib (2007). The Pulsed Nd: YAG laser welding of AISI 304 to AISI 420 stainless steels / Optics and Lasers in Engineering 45. 960–966.
11. Khan, M.M.A. and Romoli, L. (2012). Experimental investigation on seam geometry, microstructure evolution and micro hardness profile of laser welded martensitic stainless steels. Optics & Laser Technology 44 (2012) 1611–1619.
12. Laser and its applications by Popular Science & Technology Series, Page 6-20.
13. Laser Institute of America handbook of Laser Materials Processing, Page 5-18.
14. Laser Material Processing by William M. Steen and Jyotirmoy Mazumder, 4th Edition, Springer publications, chapter 1, Page 11-50.
15. Masoumi, M., Marashi, S.P.H. Pouranvari, M. Sabbaghzadeh, J. and Torkamany, M. J. (2009). Assessment of the effect of laser spot welding parameters on the joint quality using Taguchi method. METAL 2009 19. – 21. 5. Hradec nad Moravicí.
16. Matlab R2011a software for technical computing by Mathworks.
17. Minitab 16 software for quality improvement by MINITAB.
18. Padmanaban, G. and Balasubramanian, V. (2010). An Optimization of laser beam welding process parameters to attain maximum tensile strength in AZ31B magnesium alloy Optics & Laser Technology 42 (2010) 1253–1260.
19. Recent advances in laser processing of materials by jacques perrière and eric millon, Elsevier publications, Page 12-40.
20. Ribolla, A., Damoulis, G.L., Batalha G.F. (2005). The use of Nd: YAG laser weld for large scale volume assembly of automotive body in white Journal of Materials Processing Technology 164–165 1120–1127.
21. Sathiya, P., Aravindan, S., Ajith, P. M. Arivazhagan, B. and Noorul, Haq A. (2010). Micro structural characteristics on bead on plate welding of AISI 904 L super austenitic stainless steel using Gas metal arc welding process/ International Journal of Engineering, Science and Technology, Vol. 2, No. 6, pp. 189-199.
22. Sathiya, P., Panneerselvam, K. and Soundararajan, R. (2010). Optimal design for laser beam butt welding process parameter using artificial neural networks and genetic algorithm for super austenitic stainless steel / Optics & Laser Technology 44.1905–1914.
23. Sivarao, Shukor., Anand, T.J.S. & Ammar. DOE Based Statistical Approaches in Modeling of Laser Processing. International Journal of Engineering & Technology IJET-IJENS Vol: 10 No: 04.
24. Stanislav, Tomas and Michal (2012). The Differences between laser and arc welding of HSS steels. Physics Procedia 39.
25. Wglowski, M.S., Kwieciski, K. Krasnowski, K., Jachym, R. (2009). Characteristics of Nd: YAG laser welded joints of dual phase steel. Archives of civil and mechanical engineering, Vol. IX No. 4.
26. Yilbas, B.S.N, Arif, A.M. Abdul Aleem, B.J. (2010). Laser welding of mild steel sheets under nitrogen assisting gas ambient. Optics & Laser Technology 42. 760–768.