AIJREAS VOLUME 1, ISSUE 9 (2016, SEPT) (ISSN-2455-6300) ONLINE
ANVESHANA'S INTERNATIONAL JOURNAL OF RESEARCH IN ENGINEERING AND APPLIED SCIENCES

ANALYSIS AND OPTIMIZATION OF PROCESS PARAMETERS IN LASER WELDING OF DISSIMILAR MATERIALS IN LAP JOINT

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ABSTRACT

The need of joining of dissimilar materials goes on increasing day by day in industry due to its high demand. Dissimilar joints are based on both technical and economical aspects, because they can provide satisfactory service performance and reasonable cost savings. The demand for such joints in industry is huge. For example, in power plant industry more than thousand dissimilar joints are used. Joints between dissimilar metals are particularly common in components used in the automotive, power generation, chemical, petrochemical, nuclear and electronics industries. Dissimilar spot welded joints of medium carbon and stainless steel are currently used for car body assembling. But dissimilar spot welding can be more complicated than similar welding because of different thermo-physical properties of metal and inevitably, various thermal cycle experienced by each metal. So, the study of dissimilar material welding is of a great interest for many of the researchers.

In this project two dissimilar materials namely AISI 316L and AISI 1552 were taken for laser welding in lap joint configuration. Three process parameters i.e. scan speed, pulse frequency and pulse diameter at four levels were taken for optimization. Two response parameters namely weld hardness and length of heat affected zone were considered for different combinations of process parameters. Grey Taguchi methodology with L_{16} orthogonal array and ansys software are was used to optimize specified parameters. It is found that laser welding with scan speed of 45 mm/min, pulse diameter of 0.3 mm and pulse frequency of 7 Hz yields the optimal quality characteristics. In these levels hardness of weld zone was found to be 304.77 HV and length of HAZ to be 0.0852 mm.

INTRODUCTION:

Laser beam welding is a welding process used to join two metals by the use of a laser source. The laser source provides a concentrated and high density heat source, allowing for narrow, deep weld bead with high welding scan speed. The process is mostly used in high volume production industries, such as in the automotive industry. But now-a-days it has profound application in various metal working fields due to its advantageous effects over other machining operations. Laser beam welding has high power density which results in small heat affected zone due to high heating and cooling rates. Laser beam welding is a versatile process, which can weld almost all materials including aluminum, titanium, carbon steels, HSLA steels and stainless steel.

Laser source is characterized by coherent, collimated source of light. So the supply of energy can be regulated, well monitored and maintained properly in laser welding. Continuous or pulsed laser beam may be used depending upon the various applications in industry. Thin materials are welded by millisecond-long pulses while continuous laser systems are used for deep welds. The laser welding process operates at very high scan speeds with low distortion as intense energy beam of light is used as heat source. Since it requires no filler material, laser welding reduces costs. Laser welding can be automated for a stable, repeatable weld process.

With well-defined beams of high power density, lasers are excellent source for welding thin materials, operating in close proximity to heat-induced components. If a line-of-sight exists even complicated contour portions can be welded by laser. For laser welding the material can be any material which is welded conventionally but the material should be thin. However, lasers can also join materials which are very difficult to weld such as titanium, high carbon stainless steel and aluminium as well as welding dissimilar materials which are mostly incompatible. A schematic picture of laser machine in working condition is shown in Fig.

Objectives

The objectives of the thesis are listed below.

To optimise process parameters such as laser scan speed, pulse diameter and pulse frequency by Taguchi analysis

To maximize response i.e. hardness and length of heat affected zone by taking optimized values of input laser parameters

To identify the significant factors using ANOVA

To determine percentage contribution of factors for response

Experimental procedure:

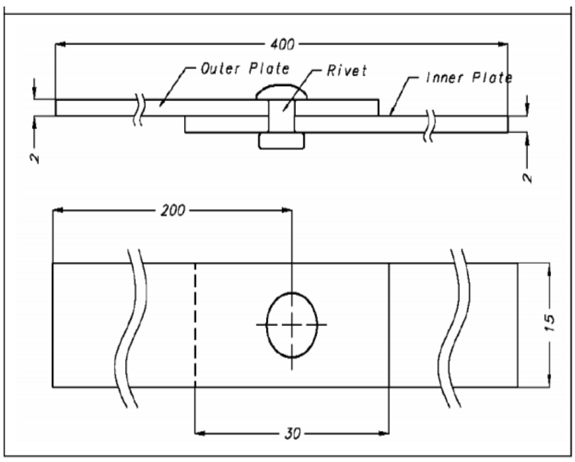
Material selection: AISI 316L stainless steel and AISI 1552 stainless steel were selected for laser welding. AISI 316L stainless steel was cut to dimension of 50 mm x 30 mm x 2.5 mm and AISI 1552 stainless steel was cut to dimension of 50 mm x 30 mm x 2.0 mm. 16 samples for each material were cut to the aforesaid dimension. Both the materials were undergone XRF test to know the chemical composition. The chemical compositions of both the materials are given in Table 1

Composition	C	Si	Mn	Ni	Cr	S	P	Cu	Fe
AISI 316L	0	0.529	1.551	11.37	17.026	0.007	0.054	0.22	66.772
AISI 1552	0.5	0.169	0.583	0.08	0.064	0.012	0.02	0.17	95.892

Taguchi analysis: Taguchi Method of experimental design is a simple, efficient and systematic approach to optimize designs for performance and cost. It can optimize process parameters reducing fluctuation of system performance to source of variation. Unlike other methods, Taguchi method uses the target point concept and tries to put the result at target point

Determination of Specifications:

The specifications of the present job has taken from the design considerations from the plate



Finite Element Model with Meshing, Boundary Conditions and Material Property

Figures shows the CAD model prepared in CATIA also the property of material given in same software. This model meshed in ANSYS for analysis with element size 0.5 mm brick and triangular meshing with fine type

Figure : CATIA Model

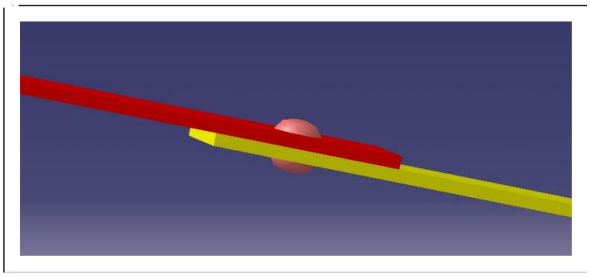
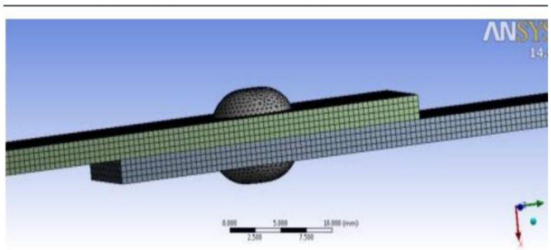
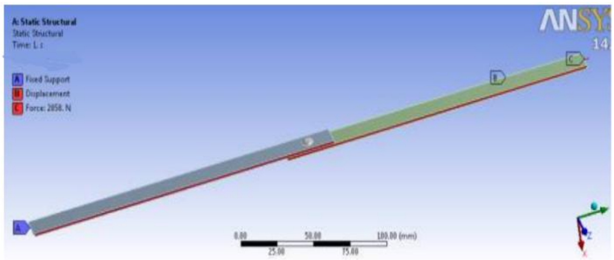
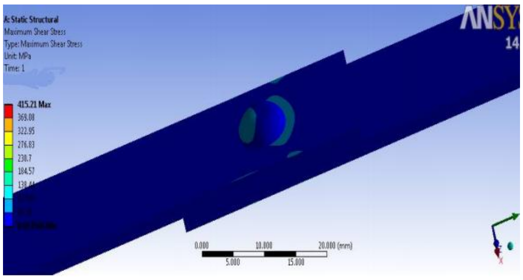


Figure : Meshing of CAD Model

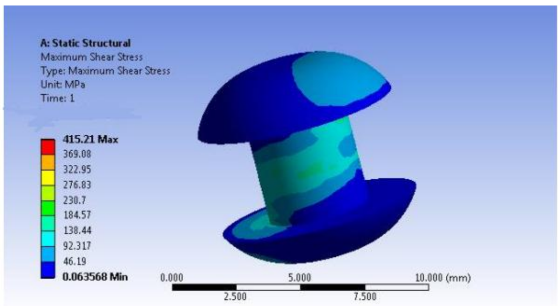




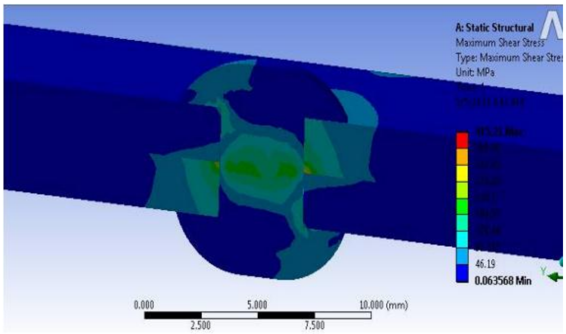
Boundary Condition



Stress Distribution on Riveted Lap Joint



Stress Distribution on Rivet



Cut Section Model

The results obtained from ANSYS (Workbench) software for the Single riveted lap joints are compared with analytical data it is shown that maximum shear stress with the help of FEM in the range of 138.44 Mpa To 184.57 Mpa and Manual Data of maximum shear stress is 170.31 Mpa both are the nearer it conclude that the result of both are match with each other.

- Finite Element Method is found to be most effective tool for designing mechanical components like riveted lap joints.

• ANSYS can be used for analysis of complex and simple models of different type without any effect on practical and economical issues

Hardness measurement: In this work, hardness of weld zone was taken as one response parameter. Vickers hardness measuring machine was used to measure hardness. The Vickers test is more frequently used than other hardness tests since the required calculations are independent of the size of the indenter and the indenter can be used for all materials irrespective of hardness. It measures macro-hardness of the work piece.

Weld hardness values

Run No.	HV 1	HV 2	HV 3	Avg. HV
1	265.0	262.8	263.9	263.9
2	288.9	284.0	285.4	286.1
3	281.8	283.2	283.4	282.8
4	289.0	289.1	285.9	288.0
5	281.2	284.7	284.3	283.4
6	265.6	265.8	266	265.8
7	296.4	296.8	294.5	295.9
8	280.8	286.1	286	284.3
9	288.2	287.2	288.9	288.1
10	290	293.0	287.6	290.2
11	258.1	250.1	253.8	254.0
12	258.2	254.9	260.3	257.8
13	286.1	288.2	283.7	286.0
14	278.4	275.8	274.7	276.3
15	263.0	264.4	264.3	263.9
16	248.0	248.9	247.4	248.1

Haz measurement: Heat affected zone (HAZ) was taken as another response parameter for optimization of process parameters. HAZ of welded portion was determined by the FESEM. But as FESEM machine incorporates very small samples and for microstructure determination smooth surface is required, so sample preparation plays an important role in determining HAZ.

In first stage the welded samples were cut by the wire EDM. It was cut in such a way that the small piece of sample would contain the weld zone. In wire EDM brass electrode was used to prepare samples of size 1 mm x 0.5 mm. All the 16 samples were cut into desired size and taken further for polishing.

Run order	scan speed	pulse diameter	pulse frequency	Hardness	HAZ
1	30	0.3	1	263.9	0.05
2	30	0.6	3	286.1	0.09
3	30	0.9	5	282.8	0.14
4	30	1.2	7	288.0	0.20
5	45	0.3	3	283.4	0.06
6	45	0.6	1	265.8	0.04
7	45	0.9	7	295.9	0.13
8	45	1.2	5	284.3	0.11
9	60	0.3	5	288.1	0.06
10	60	0.6	7	290.2	0.08
11	60	0.9	1	254.0	0.04
12	60	1.2	3	257.8	0.07
13	75	0.3	7	286.0	0.06
14	75	0.6	5	276.3	0.07
15	75	0.9	3	263.9	0.09
16	75	1.2	1	248.1	0.08

STATISTICA software package was used for the convenience of calculation of SN ratio and other parameters which are necessary for the determination of optimized parameters. Table shows values of signal to noise ratio for each run.

Run no.	Scan speed	Pulse diameter	Pulse frequency	Hardness	HAZ	SN Ratio hardness	SN Ratio HAZ
1	30	0.3	1	263.9	0.05	48.4288	26.0206
2	30	0.6	3	286.1	0.09	49.1304	20.9151
3	30	0.9	5	282.8	0.14	49.0296	17.0774
4	30	1.2	7	288.0	0.20	49.1878	13.9794
5	45	0.3	3	283.4	0.06	49.0480	24.4370
6	45	0.6	1	265.8	0.04	48.4911	27.9588
7	45	0.9	7	295.9	0.13	49.4229	17.7211
8	45	1.2	5	284.3	0.11	49.0755	19.1721
9	60	0.3	5	288.1	0.06	49.1909	24.4370
10	60	0.6	7	290.2	0.08	49.2539	21.9382
11	60	0.9	1	254.0	0.04	48.0967	27.9588
12	60	1.2	3	257.8	0.07	48.2257	23.0980
13	75	0.3	7	286.0	0.06	49.1273	24.4370
14	75	0.6	5	276.3	0.07	48.8276	23.0980
15	75	0.9	3	263.9	0.09	48.4288	20.9151
16	75	1.2	1	248.1	0.08	47.8925	21.9382

Taguchi methodology for Hardness

Shows the variation of SN ratios of hardness values with controllable parameters.

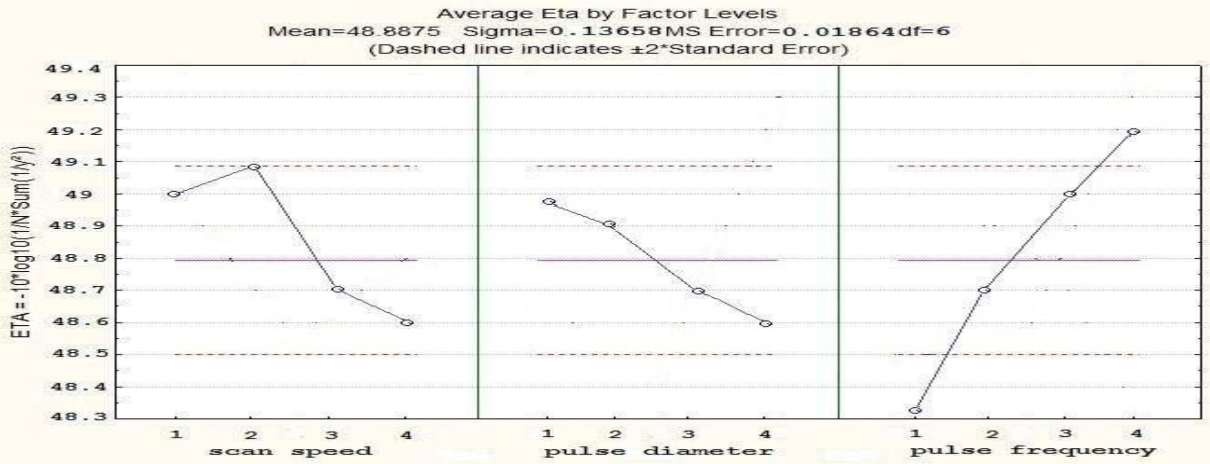


Fig.: Main effect plot for SN ratios of hardness

Main effect plot in Fig. 19 indicates that scan speed at 2nd level, pulse diameter at 1st level and pulse frequency at 4th level are optimized levels for maximizing weld hardness. So optimized process parameters for hardness are:

1. Scan speed: 45 mm/min
2. Pulse diameter: 0.3 mm
3. Pulse frequency: 7 Hz

Analysis of Variance for SN ratios of hardness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
scan speed	3	0.5184	0.5184	0.17281	9.27	0.011
pulse diameter	3	0.3313	0.3313	0.11044	5.92	0.032
pulse frequency	3	2.3617	2.3617	0.78722	42.22	0.000
Residual Error	6	0.1119	0.1119	0.01864		
Total	15	3.3233				

S = 0.1365 R-Sq = 96.6% R-Sq(adj) = 91.6%

ANOVA for SN ratios given in Table related to hardness was performed and found that all the process parameters have significant effect on hardness. Pulse frequency is the most significant factor for determining weld hardness. R^2 value of 91.6% confirms the reliability of the experiment. Later general regression analysis was performed and a relationship was established between input parameters and hardness given in Equation 5.

Hardness = 280 - 0.298 (*scan speed*) - 12.6 (*pulse diameter*) + 5.32 (*pulse frequency*) (5)

Taguchi methodology for HAZ

Fig. shows the variation of SN ratios of HAZ values with controllable parameters.

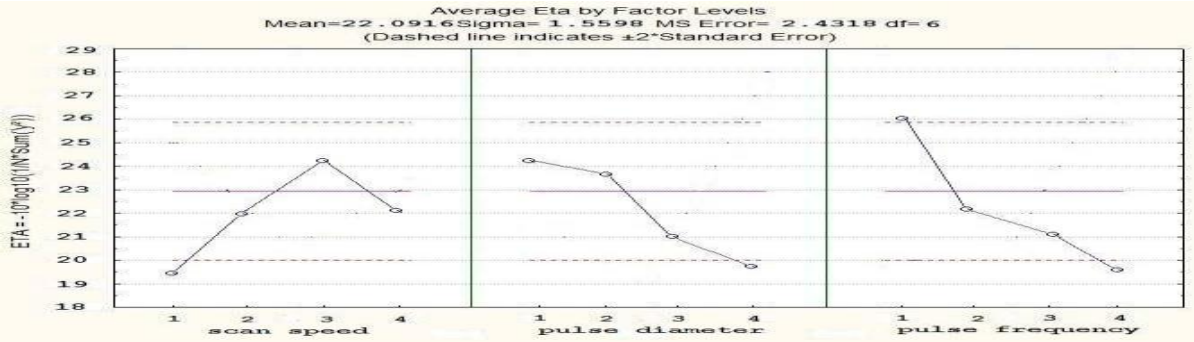


Fig. Main effect plot for SN ratios of HAZ

Main effect plot in table indicates that scan speed at 3rd level, pulse diameter at 1st level and pulse frequency at 1st level are optimized levels for maximizing weld hardness. So optimized process parameters for hardness are:

1. Scan speed: 60 mm/min
2. Pulse diameter: 0.3 mm
3. Pulse frequency: 1 Hz

Table : Analysis of Variance for SN ratios of HAZ

Source	DF	Seq SS	Adj SS	Adj MS	F	P
scan speed	3	48.52	48.52	16.173	6.65	0.025
pulse diameter	3	68.98	68.98	22.995	9.46	0.011
pulse frequency	3	91.94	91.94	30.648	12.61	0.005
Residual Error	6	14.59	14.59	2.431		
Total	15	224.03				
S = 1.559 R-Sq = 93.5% R-Sq(adj) = 83.7%						

ANOVA for SN ratios given in Table 7 related to HAZ was performed and found that all the process parameters have significant effect on hardness. Pulse frequency is the most significant factor for determining weld hardness. R^2 value of 83.7% confirms the reliability of the experiment. Later general regression analysis was performed and a relationship was established between input parameters and hardness given in Equation 6.

HAZ = 0.047 - 0.001 (*scan speed*) + 0.067 (*pulse diameter*) + 0.01 (*pulse frequency*) (6)

Prediction of taguchi result:

The optimized Taguchi result was predicted by the software which is illustrated in Table. It was confirmed that scan speed at 45 mm/min, pulse diameter of 0.3 mm and pulse frequency of 7 Hz has maximum weld hardness and minimum HAZ.

Table : Factor levels for predictions

Scan speed (mm/min)	Pulse diameter (mm)	Pulse frequency (Hz)	S/N Ratio	Mean
45	0.3	7	-1.50767	0.820625

CONFIRMATORY TEST RESULT

The final step is to confirm the validity of the optimization technique and verify the improvement of the performance characteristics by welding same sample with predicted optimized level setting. That means again laser welding was done for the specified sample with 45 mm/min scan speed, 0.3 mm pulse diameter and 7 Hz frequency. The same procedure was followed to find weld hardness and length of heat affected zone. The weld hardness was found to be 304.77 HV and length of HAZ to be 0.0852 mm.

Again considering the predicted optimized parameters and using Equation 5 and Equation 6, weld hardness was calculated to be 300.05 HV and length of HAZ to be 0.0948.

Comparison of result

parameters	Predicted result	Actual result	Percentage error
Weld Hardness	300.05 HV	304.77 HV	1.54%
HAZ	0.0948 mm	0.0852 mm	11.26%

Analyzing actual result we found that actual hardness number is the highest among all hardness numbers. So hardness is actually maximized in the optimized levels. But in case of length of HAZ the actual value is not the smallest among all length of heat affected zones. It is somehow elevated above the minimum length of HAZ. So length of HAZ is minimized at the optimized levels. Hence it is confirmed that the optimization technique applied is adequate and validate. Table above compares the predicted result and actual result of both the responses. The percentage error in predicted result for weld hardness was calculated to be 1.54% and for length of HAZ to be 11.26%.

CONCLUSIONS:

Two dissimilar materials named AISI 316L stainless steel and AISI 1552 stainless steel were welded in lap joint configuration by laser welding. Taguchi methodology was used to optimize controllable variables. Some of the important salient features were observed in laser welding are discussed below.

- Laser welding with scan speed of 45 mm/min, pulse diameter of 0.3 mm and pulse frequency of 7 Hz yields the optimal quality characteristics.
- Hardness of weld zone was found to be 300.05 HV and length of HAZ to be 0.0948 mm at optimal setting from optimization model.
- Hardness of weld zone was found to be 304.77 HV and length of HAZ to be 0.0852 mm experimentally at optimal setting.
- Stress of weld zone was found to be 415Mpa and it is safely recommended.
- For laser welding of austenitic stainless steel and carbon steel it was found that hardness decreases with increase in scan speed and pulse diameter whereas hardness increases with increase in pulse frequency.
- For the same samples, HAZ decreases when scan speed increases whereas HAZ increases when pulse diameter and pulse frequency increases..
- In the welding process pulse frequency has highest influence on determining weld hardness and length of HAZ when responses are analyzed individually. But when both the responses were considered simultaneously, it is found that pulse frequency has lowest influence on weld hardness and length of HAZ.
- Pulse diameter is the most significant factor for determining quality characteristics when both weld hardness and length of HAZ are considered.
- The highest SN ratio in predicted result indicates that the optimization model is adequate.
- From predicted result of hardness and HAZ it is clear that hardness is actually maximized and HAZ is minimized approximately.

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