Experimental study on the influence of LBW process parameters on mechanical properties of dissimilar metal joints

B Narayana Reddy[a], P Hema[b*] and G Padmanabhan[c]

Department of Mechanical Engineering, Sri Venkateswara University, Tirupati

Keywords:
Laser Beam Welding,
Ultimate Tensile Strength,
Impact Strength,
Analysis of Variance,
TOPSIS

ABSTRACT

Laser Beam Welding technique is applied to conduct experiments on joining of dissimilar metals, AISI 4130 and AISI 310 steels so as to study the influence of process parameters on mechanical properties of joints. Taguchi L_{25} Orthogonal Array is selected to join 2mm thick dissimilar steels by varying Laser Power, Welding Speed, Beam Incident Angle, Focal Point Position and Focal Length. Output results of Ultimate Tensile Strength (UTS) and Impact Strength (IS) are measured. ANOVA is carried out to obtain the levels of influence of process parameters and statistical evolution of the results. TOPSIS optimization is applied to transmogrify a multi-criteria optimization problem into a single-criterion problem, so as to obtain optimal combination of process parameters of Laser Beam Welding. Then UTS and IS are maximised. Results have revealed that the proposed method is appropriate for solving multi-criteria optimization of process parameters.

1. Introduction

AISI 4130 and AISI 310, which come under the family of low alloys steel and medium carbon austenitic stainless steel, exhibit high tensile strength and carburization at elevated temperatures. The mechanical properties combined with resistance to high-temperature make these type of metals useful for many applications involving long-term exposure to elevated temperatures. Applications of steels are common in areas like power generation, Industrial heating equipments, Heat exchangers, Hydrocarbon processing Industry, etc. The unwarranted failure of structural materials is a major problem facing the manufacturing sector. Research shows that as the world advances in technology, manufactured products and other structures, particularly those comprising of welded joints are subjected to heavier loads, often beyond the designed load capacity of certain currently used materials. This situation has compelled researchers, field engineers and scientists to continually find new ways of weld methods including optimisation of Laser Beam Welding process parameters and properties geared towards improving the integrity of such welded joints. The strength of the welded joints is of importance which should take priority in all engineering endeavors because actual challenges relating to strength property feature prominently in material failure reports. Failures in most cases tend to commence at welded joints since such welded joints are not as strong as the parent metal in terms of strength and other related properties. Bearing in mind, the total weldment forming process during a welding operation, selected process parameters could either facilitate or hinder the desired end results of the welding process, Narayana Reddy, et al., [1].

*Corresponding author,
E-mail: hemasvumech@gmail.com(P Hema)

Therefore, deriving acceptable and optimal process parameters and their corresponding weld properties, demand the application of a suitable optimization tool or process. Optimization processes enable the researcher to find a reasonable cost effective and suitable method to arrive at a least economic process parameters and then the properties to reach weld integrity with higher UTS and IS, Narayana Reddy, et al.,[2].

TOPSIS is a technique being used to optimize the input process parameters which eventually give good and acceptable mechanical properties. The relationship between the input parameters and the output parameters are examined. Multi-criterion decision making (MCDM) is used to select a better alternative from several alternatives according to various criterion. TOPSIS, kenned as one of the available popular Multi Criterion Decision-Making methods, is predicted on the conception, that the culled alternative may have the shortest distance from the Positive Ideal Solution (PIS) and largest distance from Negative Ideal Solution (NIS). There is a possibility for an alternative, what has shortest distance from PIS but its distance from NIS is not longest. Ideal solution is the one which has the better level for all attributes considered whereas negative alternative is the one which has the worst attribute value. In classical MCDM method, parameters such as rating and weightage of the required criterion are known precisely. In short, the ideal solution is composed of all best values attainable of criteria, whereas the negative ideal solution is made-up of all worst values attainable of criteria. In TOPSIS, the input required by the user is very less and its output is facile to understand. The only judgment required the selection of weightage relative distance which depends on weightage and range of alternatives. TOPSIS considers the non-linear relationship between single dimension score and distance ratio leading to smoother trade off. TOPSIS is faster and easier considering both negative and positive criterion, Arun Kumar et al., [3].

2. Literature Review

In any welding process of dissimilar metals, it is important to use optimal parameters whichcan be obtained by scientific optimisation techniques. Quite a good number of published papers show the usability of optimisation techniques for both non-fusion and fusion weldings including LBW of different materials. A brief literature is presented in the following:

Mechanical property (Micro-hardness) is analysed in an optical microscopy investigation on dissimilar welded joints of AISI 304L and AISI 310 steels by using Gas Metal Arc Welding (GMAW), Sandeep et al., [4]. Therefore, GTAW method is used for investigating the characterization of dissimilar joints of AISI 310 steel to Inconel 657 by Naffakhet et al., [5]. Geometrical, Chemical and Mechanical characterisation of AISI 304 and AISI 1010 welded joints obtained by Nd:YAG Laser Welding are investigated using Electron Microscope and Energy Dispersive Spectroscopy (EDS), so as to correlate the tensile test with digital images. It is shown that the compositional mixture present in dissimilarwelded joints affects the mechanicalbehaviour of the joint, Pascua, et al. [7]. The microstructure of dissimilar butt joints obtained from metals of AISI 321 and AISI 1010 are influenced by welding speed, Elena et al., [7].

MCDM methods have received much attention from researchers and practitioners in evaluating, assessing and ranking alternatives across diverse industries. Among numerous MCDA/MCDM methods developed to solve real-world decision problems, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is satisfactorily being used for different applications. Gas Tungsten Arc Welding of Incoloy 800HT and TOPSIS method is used for optimal combination of process parameters, Arun Kumar et al., [3]. Friction Stir Welded Aluminium composite joints are studied for quality and the study reveals that the optimal process variables combination is analysed using TOPSIS approach, Subramanya, et al., [8], but not for joining of dissimilar metals.

Hence the present experimental work is taken up on joining of dissimilar metals of AISI 4130 and AISI 310 by LBW to optimize the process parameters.

2.1. Objective of the paper

Various studies reveal the different optimization techniques for obtaining the suitable process parameters. However, the research on TOPSIS based optimization of LBW of dissimilar metals is limited. Therefore, an initial attempt is made in the present paper to implement TOPSIS approach for multiple response optimization. Design of experiments and combination of process parameters are derived from Taguchi's L_{25} orthogonal array.

3. Experimental Process

The influential parameters and their levels are selected from the literature review **and** are shown in Table. 1. Experiments are carriedout based onTaguchi L_{25} Orthogonal Array design of experiments for Laser Beam Welding. DOE is shown in the Table 2. The experiments are conducted with a CO_2 LBW system of 4kW (Trump Model), keeping the average power of the CO_2 LBW constant at 4 KW throughout. The experimental welding process and welded samples of LBW are shown Fig. 1. Test Specimens are prepared as per standard UTS of ASTM E 8M-01 and IS of ASTM E23. Tested specimen of

Table 1
Influential parameters and their levels.

Levels	A-Laser Power (Watts)	B-Welding speed (m/min)	C-Beam Angle (degrees)	D-Focal Point Position (mm)	E-Focal Length (mm)
Level-1	1400	1.2	88	-0.2	16
Level-2	1600	1.4	89	-0.1	17
Level-3	1800	1.6	90	0	18
Level-4	2000	1.8	91	0.1	19
Level-5	2200	2	92	0.2	20

Table 2
DOE for the experimental work with mechanical properties.

S. No.	Input Process Parameters					UTS (Mpa)	IS (J)
	A	B	C	D	E		
1	1	1	1	1	1	498.46	10
2	1	2	2	2	2	554.61	11
3	1	3	3	3	3	555.38	16
4	1	4	4	4	4	611.54	10
5	1	5	5	5	5	295.38	10
6	2	1	2	3	4	608.46	14
7	2	2	3	4	5	170.77	03
8	2	3	4	5	1	470.77	06
9	2	4	5	1	2	574.61	12
10	2	5	1	2	3	400.00	03
11	3	1	3	5	2	610.00	15
12	3	2	4	1	3	604.61	12
13	3	3	5	2	4	620.00	16
14	3	4	1	3	5	597.69	19
15	3	5	2	4	1	363.08	09
16	4	1	4	2	5	609.23	17
17	4	2	5	3	1	610.00	13
18	4	3	1	4	2	577.69	14
19	4	4	2	5	3	607.69	15
20	4	5	3	1	4	582.31	10
21	5	1	5	4	3	568.46	18
22	5	2	1	5	4	582.31	16
23	5	3	2	1	5	620.00	18
24	5	4	3	2	1	616.15	17
25	5	5	4	3	2	610.77	18

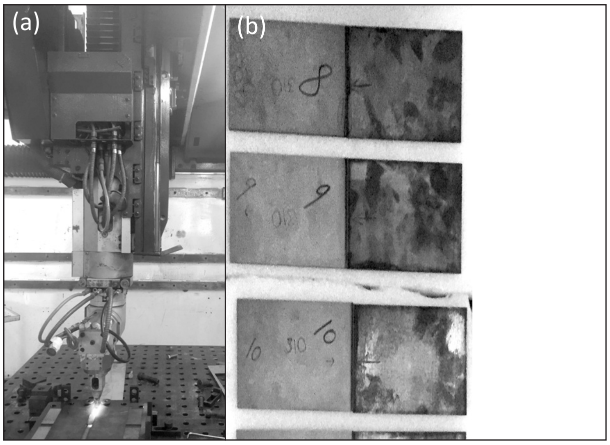

Fig. 1. (a). LBW expermental process and (b). welded work piecess.

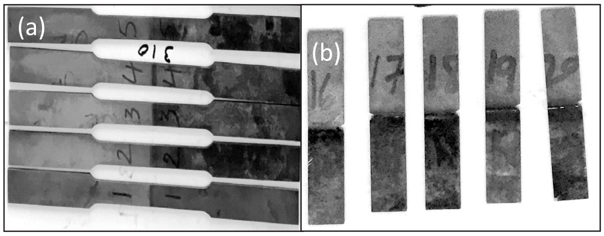

Fig. 2. LBW specimens as per ASTM: (a) Tensile test, (b) Imapct test.

Table 3
ANOVA for UTS.

Source	DF	SS^2	Adj SS	Adj MS	F	% C
A	4	88009	88009	22002	6.71	27.4
B	4	77169	77169	19292	5.89	24.1
C	4	15181	15181	3795	1.16	4.7
D	4	61353	61353	15338	4.68	19.1
E	4	66297	66297	16574	5.06	20.7
Error	4	13112	13112	3278	-	4.1
Total	24	321121	-	-	-	100

S = 57.25 R^2 = 96% R^2 (adj) = 75.5%

dissimilar metal joints are shown in Fig. 2. Then the test results of each joint sample are presented in Table 2 (Columns UTS and IS).

4. Analysis of Variance (ANOVA)

Statistical analysis ANOVA conducted on the results of UTS obtained from experiments are shown in Table 3. Input parameters are shown in column, followed by Degrees of Freedom, Seq SS, adj SS, adj MS and percentage of contribution (%C). Similarly, the columns in

Table 4
ANOVA for IS.

Source	DF	SS^2	Adj SS	Adj MS	F	% C
A	4	265.44	265.44	66.36	18.13	54.55
B	4	98.64	98.64	24.66	6.74	20.27
C	4	9.44	9.44	2.36	0.64	1.94
D	4	72.64	72.64	18.16	4.96	14.93
E	4	25.84	25.84	6.46	1.77	5.31
Error	4	14.64	14.64	3.66	-	3.01
Total	24	486.64	-	-	-	54.55
S = 1.913 R^2 = 97% R^2 (adj) = 81.9%						

Table 4 show the results of ANOVA for IS with same parameters and symbols.

4.1. Validation

F - Test for Laser Power-Null hypotheses (Ho): Significant difference between the experimental and theoretical results. $F_{calculated}$ = 6.71, $F_{(0.05,\ 4,4)}$ = 6.39 (table value). Since the calculated value is greater than the table value, the null hypothesis is rejected at 5% of risk or 95% of confidence level. That is, there no significant difference between the experimental and theoretical results. Hence the experiments conducted are correct.

P - Value for Laser Power - Null hypothesis (Ho): No difference on the experimental and theoretical results. P calculated value: 0.008, Risk level is taken as α: 0.05 or 95% confidence level. P-value calculated is less than α = 0.05. Hence, the null hypothesis is accepted for all the results at 95% confidence level.

The percentage of contribution of each parameter for Ultimate Tensile Strength is shown in Table 3. It is clear from the experimental results, that the percentage of contribution values by Laser power 27.41%, followed by welding speed 24.03%, beam angle 4.73%, Focal point position 19.11% and Focal length 20.65%, respectively. It can be seen that the focal point position has greater influence on Ultimate Tensile Strength. R^2 = 96% confirms the reliability of experiment. From the above results, it is clear that the Laser Power is the major factor with 27.41%, which is to be selected effectively to get better Ultimate Tensile Strength.

Similarly, Percentage of contribution of each parameter for IS is shown Table 4. It is clear from the experimental results, that the percentage of contribution by Laser power is 54.55%, followed by welding speed 20.27%, beam angle 1.97%, focal point position 14.93% and focal length 5.31%, respectively. It is observed that the laser power has greater influence on IS. Value of R^2=97% confirms the reliability of experiments. It is also clear from the results that the Laser Power is the major factor with 54.55%, is to be selected to get better Impact Strength. The analysis is carriedout on LBW compatible PC-AT using MINITAB.

5. Optimization of Process Parameters

TOPSIS technic is used for analysing the results and determining the optimal process parameters. The procedural steps involved in solving optimization problem by TOPSIS are presented step by step in table from - 5 to 10, respectively.

Step - 1: Read alternate and objectives matrix (O_{ij}) with weightages (W_j) and types of objectives i = 1, 2,... m - No. of alternatives and j = 1, 2,… n - No. of objectives. The objectives of the matrix is shown in Table 5.

Table 5
Objectives matrix.

Expt. No.	UTS (Mpa)	IS (J)
1	498.46	10
2	554.61	11
3	555.38	16
.	.	.
.	.	.
.	.	.
23	620.00	18
24	616.15	17
25	610.77	18
Max	620	19
Min	170.77	3
W_j	0.5	0.5
OT	2	2

Step - 2: The responses are removed (O_{ij}) and the responses are converted to normalized value (N_{ij}) by the formula (1). The normalized values of the responses are shown in Table 6.

Table 6
Normalized response values.

Expt. No.	UTS (Mpa)	IS (J)
1	0.1804	0.1469
2	0.2007	0.1615
3	0.2010	0.2350
4	0.2213	0.1469
5	0.1069	0.1469
.	.	.
.	.	.
.	.	.
14	0.2163	0.2791
.	.	.
.	.	.
.	.	.
23	0.2244	0.2644
24	0.2230	0.2497
25	0.2210	0.2644

Normalized value of $N_{ij} = \dfrac{O_{ij}}{\sqrt{\sum_{i=1}^{m} O_{ij}^2}}$ (1)

$$N_{11} = \frac{O_{11}}{\sqrt{\sum_{i=1}^{m} O_{i1}^2}} = \frac{498.46}{\sqrt{498.46^2 + 554.61^2 + 555.38^2 + ... + 610.77^2}} = 0.1804$$

Step - 3: Specific weightages are assigned to each of the responses in order to rank the responses. The assumed weightages are multiplied with normalized value to get weighted normalized value using eq. 2. In the present study, equal weightages of $w_j = 0.5$ is assigned to the two responses. Weighted normalized results are shown in Table 7.

Performance matrix $A_{ij} = N_{ij} x W_j$ (2)

Step - 4: The positive (P_j) and negative ideal solution (M_j) are calculated using equations (3) and (4). The UTS and IS are maximization objectives. Hence, the positive and negative ideal results are calculated by equations 3a & 3b and are shown in the table 8.

Table 7
Weighted normalized value.

Expt. No.	UTS (Mpa)	IS (J)
1	0.0902	0.0734
2	0.1003	0.0807
3	0.1005	0.1175
4	0.1106	0.0734
5	0.0534	0.0734
.	.	.
.	.	.
.	.	.
14	0.1081	0.1395
.	.	.
.	.	.
.	.	.
23	0.1122	0.1322
24	0.1115	0.1248
25	0.1105	0.1322

$$\text{Maximization}\begin{cases} P_j = \max_{i=1}^{m}(A_{ij}) & (3a) \\ M_j = \min_{i=1}^{m}(A_{ij}) & (3b) \end{cases}$$

$$\text{Minimization}\begin{cases} P_j = \min_{i=1}^{m}(A_{ij}) & (4a) \\ M_j = \max_{i=1}^{m}(A_{ij}) & (4b) \end{cases}$$

Table 8
Positive (P) and Negative (M) ideal solution.

	UTS	IS
P_j(max)	0.1122	0.1395
M_j(min)	0.0309	0.0220

Step -5: The separation between each alternative is computed using equations (3a) and (3b). The separation of each alternative from better / positive solution is given by eq. (5).

Table 9
Closeness coefficient value.

Expt. No.	SP_i	SM_i	R_i	Rank
1	0.0697	0.0785	0.5297	20
2	0.0599	0.1061	0.6390	17
3	0.0249	0.1361	0.8451	9
4	0.0661	0.1081	0.6204	18
5	0.0884	0.0763	0.4632	21
6	0.0368	0.1294	0.7786	12
7	0.1429	0.0215	0.1307	25
8	0.0992	0.0696	0.4122	23
9	0.0521	0.1141	0.6866	16
10	0.1241	0.0467	0.2735	24
11	0.0294	0.1354	0.8214	10
12	0.0515	0.1176	0.6955	15
13	0.0220	0.1425	0.8660	7
14	0.0040	0.1590	0.9752	1
15	0.0869	0.0742	0.4605	22
16	0.0148	0.1475	0.9086	6
17	0.0441	0.1238	0.7373	14
18	0.0375	0.1260	0.7706	13
19	0.0295	0.1352	0.8210	11
20	0.0665	0.1042	0.6106	19
21	0.0119	0.1501	0.9266	4
22	0.0231	0.1387	0.8573	8
23	0.0073	0.1547	0.9546	2
24	0.0147	0.1482	0.9097	5
25	0.0075	0.1539	0.9533	3

Table 10.
Average closeness coefficient value.

Levels	A	B	C	D	E
Level-1	0.6194	0.7929	0.6812	0.6954	0.6098
Level-2	0.4563	0.6119	0.7307	0.7193	0.7741
Level-3	0.7637	0.7697	0.6635	0.8579	0.7123
Level-4	0.7696	0.8025	0.7180	0.5817	0.7465
Level-5	0.9203	0.5522	0.7359	0.6750	0.6864

$$SP_i = \sqrt{\sum_{j=1}^{n}(A_{ij}-P_j)^2} = \sqrt{(0.0902-0.1122)^2+(0.0734-0.139555)^2} = 0.0697 \quad (5)$$

The separation of each alternative from worst / negative solution is given by eq. (6)

$$SM_i = \sqrt{\sum_{j=1}^{n}(A_{ij}-M_j)^2} = \sqrt{(0.0902-0.030906)^2+(0.0734-0.022035)^2} = 0.0785 \quad (6)$$

Step - 6: Relative closeness value of the particular alternative to the ideal solution is measured, which is expressed as:

Determine relative closeness

$$R_i = \frac{SM_i}{SP_i + SM_i} = \frac{0.07849}{0.0697+0.07849} = 0.5297 \quad (7)$$

The closeness coefficient values are ranked based on higher order to find the set of process variables having the most and least preferred solutions. Table 9 shows the positive and negative solutions closeness coefficient values and their rankings.

Step - 7: Average closeness coefficient value for each level of process variables are computed as shown in table 10. From the table, the optimal combination of process variables are: Laser Power 2.2KW, Speed 1.8m/min, Angle 92^o, focal point position 0 mm & Focal Length 17 mm.

The maximum coefficient value of Laser power at level - 5 as shown in table 10. Hence, from the experimental results maximum UTS is obtained at laser power is 2.2KW (level - 5). So that the Experimental Results are coinciding the best values of TOPSIS.

6. Conclusions

The Conclusions derived from the experimental investigation are given in the following.

1. Sound welds are obtained by LBW of dissimilar metals of AISI 316 & AISI 4130 steels.
2. ANOVA results show that the Laser Power 27.41% is the major influencing process parameter on UTS, whereas Laser Power 54.55% on IS.
3. As per the ANOVA, Percentage of contribution by the Laser Power is the major factor, which is to be selected to get better Ultimate Tensile

Strength and Impact Strength.

4. The multi-optimal combination of processes parameters obtained by the application of TOPSIS are: Laser Power 2.2KW, Speed 1.8m/min, Angle 92°, focal point position 0 mm & Focal Length 17mm.

Acknowledgement

The authors are grateful acknowledge Welding of Magod Laser Machining Pvt. Ltd., Bengaluru - 560105, India, for permitting to conduct the experiments.

References

1. Narayana Reddy, B; Hema, P; Eswara Reddy, C; Padmanabhan, G: ‘Proceeding of 10th International Conference on Precision, Meso, Micro and Nano Engineering Manufacturing Engineering Section’, Department of Mechanical Engineering, IIT Madras, Dec 2017, 20-23.
2. Narayana Reddy, B; Hema, P; Padmanabhan, G: ‘Proceedings of the 1st International Congress on latest innovations in Materials Engineering & Technology’, Lendi Institute of Engineering & Technology, June 2018, 24.
3. Arun Kumar, S; Paulraj, S: ‘Optimisation of Process Parameters for Gas Tungsten Arc Welding of Incoloy 800HT Using TOPSIS, 'Materials Today: Proceedings', vol. 4, 2017, 2031–2039.
4. Sandeep Singh; Sanjeev Kumar; Harvant Singh; Lovedeep Singh: Experimental Investigation on AISI 304l & AISI 310 Alloys Welded by Gas Metal Arc Welding (GMAW) Process, 'ARME, vol. 3, no. 2, 2014, 9-13.
5. Naffakha, H; Shamaniana, M; Ashrafizadeha F: ‘Dissimilar welding of AISI 310 austenitic stainless steel to nickel-based alloy Inconel 657, 'Journal of Materials Processing Technology', vol. 209, 2009, 3628-3639.
6. Pascua, A; Stanciua, E M; Voiculescub, I; Ţiereana M H; Roatăa, L C; Ocaña, J L: Chemical and Mechanical Characterisation of AISI 304 and AISI 1010 Laser Welding, 'Materials and Manufacturing Processes', 2015.
7. Elena, MS; Alexandru, P; Mircea, HT; Ionut CR; Ionelia V; Iosif, H; Catalin, C: Dissimilar Laser Welding of AISI 321 and AISI 1010, 'Technical Gazette', vol. 25, no.2, 2018, 344-349.
8. Subramanya, RP; Arun, S; Mervin, H; Shrikantha Rao: Multi Response Optimization of Friction Stir Welding Process Variables using TOPSIS approach, 'IOP Conf. Series: Materials Science and Engineering', vol. 376 (012134), 2018, 1-7 ◘

B Narayana Reddy is presently doing in Research Scholar, Department of Mechanical Engineering, Sri Venkateswara University College of Engineering, Tirupati. He completed his M. Tech in Industrial Engineering from SVU College of Engineering, Tirupati. He has Published 3 papers in International Journals and 5 papers are presented in Conferences/ Seminars. His areas of interest are Materials Joining, Advanced machining Processes and Optimization Techniques. (E-mail: nari.biju@gmail.com)

Dr. P Hema is presently workingin Assistant Professor, Department of Mechanical Engineering, Sri Venkateswara University College of Engineering, Tirupati. She obtained her Ph.D from Sri Venkateswara University in 2014. She has Published 25 papers in International Journals and 14 papers are presented in Conferences/ Seminars. Her areas of interest are Materials Joining, Advanced machining Processes. (E-mail : hemasvumech@gmail.com)

Prof. G Padmanabhan is retired as Professor in Department of Mechanical Engineering, Sri Venkateswara University College of Engineering, Tirupati.He obtained his Ph.D from Indian Institute of Technology, New Delhi in 1990. He has Published 50 papers in International Journals, 15 papers in National Journals and 18 papers are presented in Conferences/ Seminars. His areas of interest are Industrial Engineering and Advanced machining Processes. (E-mail: gpnsvuce@yahoo.co.uk)