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An Analysis of the Mechanical and Metallurgical Behavior of AISI 4130 Steel After Co_2 Laser Beam Welding Process

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Abstract: ***Alloy metal has received special attention in the aerospace and defense areas. The AISI 4130 alloy steel had been also considered, since it is applied in landing gears, small aircrafts engine cradles, and besides general industries. The Laser Beam Welding of high strength metals obtained small Weld Zone and better quality with good appearance. In this research work, a Laser Beam Welding (LBW) is used to weld AISI 4130. The experiments are conducted accordingly combination of Taguchi L25 based 5 levels of Laser Power, Speed, Angle, Focal Length and Focal Point Position. The AISI 4130 weld joint Bead Width and tensile strength are measured and analysed by ANOVA. Microstructure and SEM with EDAX are using to analysis the AISI 4130 weld joint.***

Keywords: Laser Beam Welding, AISI 4130, ANOVA, WOA, SEM, EDAX.

I. INTRODUCTION

Aerospace projects should take into account the difficulties of transporting a load against the gravity force during take-off and flight in an efficient way, with minimum cost and maximum safety, because failures in any of these stages might implicate in catastrophic accidents, involving human lives. Many components under extreme loads had been welded, so civilian and military aerospace companies are looking for better welding procedures [1].

The key applications to guide this study were landing gears and engine cradles. These are complex structures usually made of AISI 4130 tubes of several dimensions and welded by different methods. In aeronautics, however, where the search for innovation is a paramount target, it is important to compare Laser Beam Welding (LBW) as an alternative better welding process.

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The LBW is fusion welding process and lasers score better than conventional CO_2 type lasers in terms of high energy density, deeper, narrower and possible high welding speeds especially in thin walled cross sections. These high aspect ratio welds are produced with a relatively low heat.

As a consequence laser welding can be used to a particular advantage where it is desirable to minimize HAZ, distortion and shrinkage stresses. So that, CO_2 lasers are invented and introduced into manufacturing sector [2].

II. LITERATURE REVIEW

The industrial concentration of advanced manufacturing of joining by LBW related past research is discussed in the following. Investigations on the microstructure and mechanical properties of AISI 4130 stainless steel and AISI 304 low alloy steel joints obtained by Gas Tungsten Arc Welding, Electron Beam Welding and Friction Welding are conducted, Arivazhagan, et al., [3]. Therefore, for better quality and bead formation, Electron Beam Welding is to be studied. Lateron, A review on Laser Beam Welding research shows that Ti-Al alloys combination gives better metallurgical and mechanical properties than other combination consisting of stainless steel-Al, Cu-Al and Ti-Al and thus focusing on Al to other materials presented, Kalaiselvan, et al., [4]. Further, The microstructures and the formation mechanism of a stainless steel/copper dissimilar joints by laser welding are examined, Shuhai Chen, et al., [5]. Therefore, the quantity of fused copper has to be restricted during the laser welding of stainless steel and copper. The metallurgical and mechanical properties of dissimilar laser welding of 304 and MS materials are studied, Saumil Bhatt and Dhaval Soni, [6]. GTAW method is used for investigating the properties of dissimilar joints of AISI 4130 and AISI 316 steels, Mostaan, et al., [7] and analysed the interface structure by Scanning Electron Microscope (SEM) and Energy Dispersive Spectroscopy (EDS). But the literature shows that a lacuna is found in consideration on the deviation of the Laser Beam angle, focal position and focal length on alloy Steel materials during LBW. Further, Metallurgical and SEM with EDAX are gaining importance in butt joint analysis.

A. Objective of Present Paper

The literature shows that little investigations on LBW, considering the Laser Power, Welding Speed, Beam Angle, Focal Point Position and Focal length.

Hence, a solemn attempt is made in the present work to conduct experimentation with an objective of joining AISI 4130 alloy steel and study the effect of input parameters on Bead Width and UTS. The optimal combination of input process parameters are estimated using Whale Optimization Algorithm. Optical Microstructure and SEM with EDAX are observed.

III. EXPERIMENTATION

Samples of 130x80x2 mm dimensions are prepared using EDM. Taguchi DOE Array L_{25} is considered to reduce the number of experiments based on five input parameters Laser Power (LP), Welding Speed (WS), Beam Angle (BA), Focal Point Position (FPP) and Focal Length (FL) of CO_2 Laser Beam Welding. The combination of process parameters are shown in Table - 1. Butt joint configuration is considered to join similar metal AISI 4130 weld samples by using Laser machine, Trump -1005.

Table 1. AISI 4130 Weld joint Beam Width and UTS

Trail	Control Process Parameters					Outputs	
	LP (KW)	WS (m/min)	BA (Degg.)	FPP (mm)	FL (mm)	BW (mm)	UTM (MPa)
1	1.4	1.2	88	-0.2	16	1.25	358
2	1.4	1.4	89	-0.1	17	1.20	581
3	1.4	1.6	90	0.0	18	1.27	588
4	1.4	1.8	91	0.1	19	1.38	472
5	1.4	2.0	92	0.2	20	1.11	488
6	1.6	1.2	89	0.0	19	1.48	590
7	1.6	1.4	90	0.1	20	1.25	617
8	1.6	1.6	91	0.2	16	1.28	550
9	1.6	1.8	92	-0.2	17	1.10	557
10	1.6	2.0	88	-0.1	18	1.10	521
11	1.8	1.2	90	0.2	17	1.52	598
12	1.8	1.4	91	-0.2	18	1.35	550
13	1.8	1.6	92	-0.1	19	1.28	630
14	1.8	1.8	88	0.0	20	1.12	526
15	1.8	2.0	89	0.1	16	1.36	550
16	2.0	1.2	91	-0.1	20	1.62	537
17	2.0	1.4	92	0.0	16	1.42	656
18	2.0	1.6	88	0.1	17	1.45	620
19	2.0	1.8	89	0.2	18	1.40	669
20	2.0	2.0	90	-0.2	19	1.45	538
21	2.2	1.2	92	0.1	18	1.77	578
22	2.2	1.4	88	0.2	19	1.57	611
23	2.2	1.6	89	-0.2	20	1.30	581
24	2.2	1.8	90	-0.1	16	1.45	518
25	2.2	2.0	91	0.0	17	1.52	590

The AISI 4130 welded samples are shown in the Figure 1. The weld geometry of the weld joints is measured. Then, the Bead Width of weld joint is captured by macrographs at 20X magnification using Struers Welding Expert System. Lateron, weld sample is prepared for tensile specimen as per ASTM and tested the UTS on Universal Testing Machine. Weld joints output results of Bead Width (BW) and Ultimate Tensile Strength (UTS) are shown in Table – 1. The results are analysed by ANOVA as presented in the following.

Fig. 1. Welded joint samples of AISI 4130 steel

IV. ANALYSIS OF VARIANCE (ANOVA)

ANOVA of BW and UTS results of AISI 4130 welded joints are shown in Table – 2 and Table - 3, respectively.

Table 2. ANOVA for BW of 4130 weld joints

S	DF	SS	Adj SS	MS Adj	F - value	P - value	% C
LP	4	0.33	0.33	0.0	49.8	0.001	47.55
WS	4	0.18	0.18	0.04	28.1	0.003	26.90
BA	4	0.04	0.04	0.01	07.4	0.039	7.06
FPP	4	0.06	0.06	0.01	09.2	0.027	8.77
FL	4	0.06	0.06	0.01	09.1	0.027	8.74
Error	4	0.01	0.01	0.001			
Total	24	0.69					
S = 0.04075 R-Sq = 99.0% R-Sq(adj) = 94.3%							

From Table - 2 show the Laser power has a contribution of 47.55% on Bead Width, followed by welding speed 26.90%, beam angle 7.06%, focal point position 8.77% and focal length 8.74%. The R^2 (99.0%) value confirms the reliability of the model. Hence, it is observed that the Laser power has greater influence on Bead Width on weld joint of similar metal AISI 4130 steel and has to be selected to obtain better Bead Width.

Table 3. ANOVA for UTS of AISI 4130 weld joints

S	DF	SS	Adj SS	MS Adj	F - value	P - value	% C
LP	4	31083	31083	7770.7	20.93	0.006	31.13
WS	4	21788	21788	5447.0	14.67	0.012	21.82
BA	4	16126	16126	4031.5	10.86	0.020	16.15
FPP	4	16583	16583	4145.7	11.16	0.019	16.61
FL	4	12779	12779	3194.7	8.60	0.030	12.80
Error	4	1485	1485	371.4			
Total	24	99844					
S = 19.27 R-Sq = 98.5% R-Sq(adj) = 91.1%							

From Table - 3 show that the Laser power has a contribution of 31.13% on UTS, followed by welding speed 21.82%, beam angle 16.15%, focal point position 16.61% and focal length 12.80%. The R^2 (91.1%) value confirms the reliability of the model. Hence, it is observed that the Laser power has greater influence on UTS on weld joint of similar metal AISI 4130 steel and has to be selected to obtain better UTS.

Validation: Validation is carried-out to establish the trueness of the experimentation. $F_{Experimental}$ - Value is greater than F_{table} = 6.39 and P-Values are less than 5%.

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Thus the process parameters have significant effect on the weld joints at 95% confidence level.

V. OPTIMIZATION OF AISI 4130 WELD JOINT

The optimization technique is used to identify the optimal values by Whale Optimization Algorithm (WOA). WOA is adaptive metaheuristic search algorithm based on the evolutionary idea of natural selection. As such they represent an intelligent exploitation of global search in the presence of large numbers of local search used to solve optimization problems.

The objective functions are generated for Laser Power (LP), Welding Speed (WS), Beam Angle (BA),

Focal Point Position (FPP) and Focal length (FL) using regression equations, which are obtained from the MINITAB with the help of weld joint Bead Width.

$$\text{Bead Width } Z_1 = -271 + (0.01054\ LP) - (4.10\ WS) + (6.06\ BA) - (0.77\ FPP) - (0.83\ FL) + (0.899\ WS^2) - (0.0335\ BA^2) - (4.05\ FPP2) - (0.018\ FL^2) - (0.000105 \times LP \times WS) - (0.000132 \times LP \times BA) + (0.00045 \times LP \times FPP) + (0.000081 \times LP \times FL) + (0.1 \times WS \times FPP) + (0.0643 \times WS \times FL) + (0.0134 \times BA \times FL) \quad (1)$$

$$\text{UTS } Z2 = -48860 - (6.8 \times LP) - (6174 \times WS) + (1176 \times BA) + (427 \times FPP) + (819 \times FL) - (0.000525 \times LP^2) - (586 \times WS^2) - (8.1\ BA^2) - (694\ FPP^2) - (13.8\ FL^2) - (0.306 \times LP \times WS) + (0.099 \times LP \times BA) - (0.101\ LP \times FPP) + (0.0193\ LP \times FL) + (101\ WS \times BA) - (22\ WS \times FPP) - (23.1\ WS \times FL) - (3.51\ BA \times FL) \quad (2)$$

Multi objective function $Z = w_1 Z_1 + w_2 Z_2$

$$Z = 0.5 \times Z_1 + 0.5 \times Z_2 \quad (3)$$

The Multi objective regression equations are solving by WOA tool, the optimized process parameters are obtained as shown in Table - 4. The WOA Using, the best and mean fitness of Bead Width and UTS are obtained is shown in Figure 2.

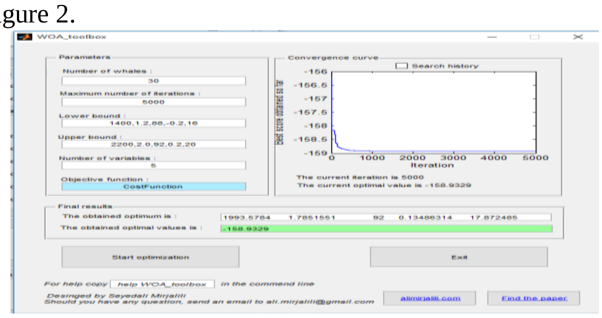

Fig. 2.Optimization of WOA

Table 4. Optimum values of SA, GA and WOA

LP (W)	WS (m/min)	BA	FPP (mm)	FL (mm)	BW (mm)	UTS (Mpa)
1993.57	1.7	92º	0.13	17.87	1.30	529.17

6. Metallurgical Analysis of 4130 Weld joint

The metallurgical analyses of the weld joints are studied based on the structures obtained from optical microscope and Scanning Electron Microstructure with Energy Dispersive X-Ray Analysis (EDAX) on various areas of Base Metal, HAZ and Fusion Zone are discused in the following.

A. Microstructure Analysis of 4130 Weld joint

The microstructure of weld joint of similar metal AISI 4130 is presented in the following. The microstructure of AISI 4130 weld joint is shown in Figure 3.

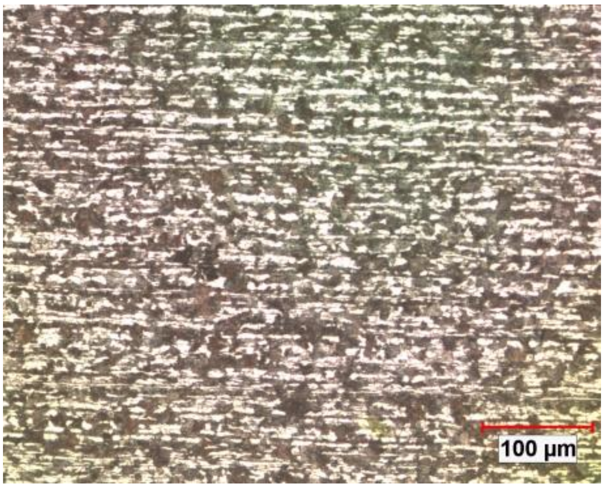

Fig. 3.Fig. 3 (a). Microstructure of base metal AISI 4130

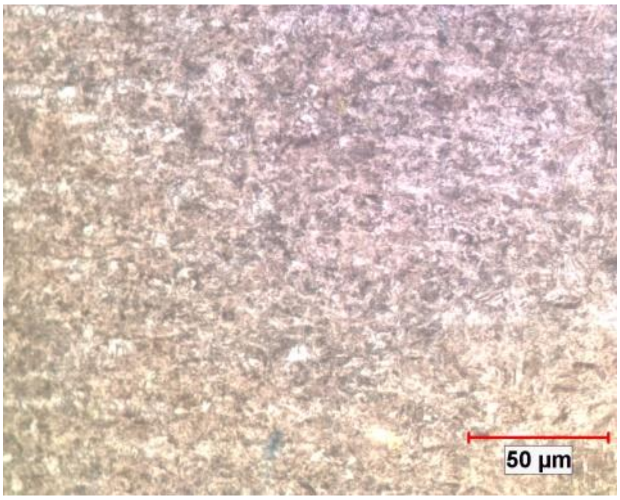

Fig. 4.Fig. 3(b). HAZ of AISI 4130 weld joint

The Figure 3 (a) shows the base metal AISI 4130 microstructure consists of fine grains of Ferrite and Pearlite. The interlayer of weld zone and base metal completely disappeared in the HAZ. The microstructure consists of Pearlite, Ferrite and Martensite as shown in Figure 3 (b). The AISI 4130 Weld joint (after butt welding) microstructure consists of Ferrite, Bainite and Martensite in the shape of grains and needles of various sizes and but with uniform distribution shape is shown in Figure 3 (c). Weld integrity is so well that weld line is completely disappeared. No weld defects or inclusions are observed at weld interface.

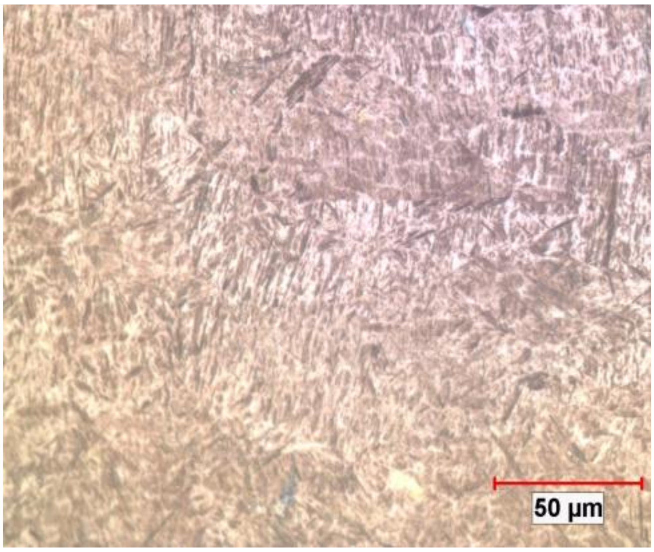

Fig. 3(c). Fusion Zone of AISI 4130

B. SEM analysis of 4130 Weld joint

The SEM of weld joint of similar metal AISI 4130 is presented in the following. The Weld joint SEM with EDAX energy level is shown in Figure 4.

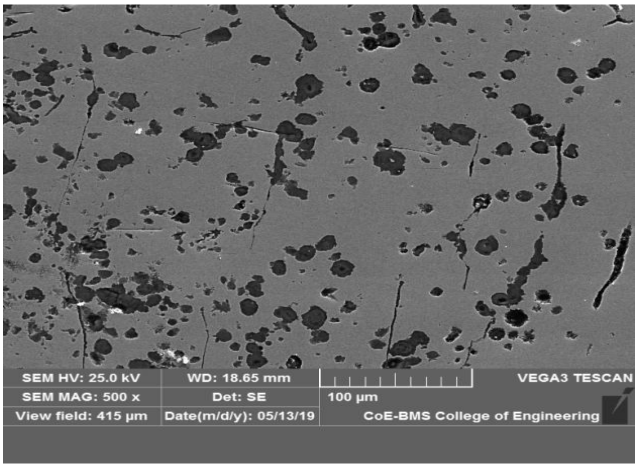

Figure 4(a): Weld Zone SEM of AISI 4130 weld joint

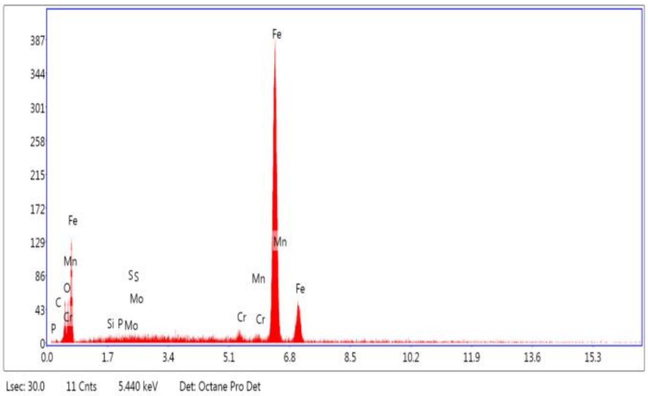

Figure 4(b): EDAX of AISI 4130 weld joint

Table 5: EDAX of AISI 4130 steel weld zone

Element	C	O	Si	P	Mo	S	Cr	Mn	Fe
Weld Zone	2.43	6.15	0.15	0.12	0.27	0.00	1.42	1.19	88.27
Atomic %	9.09	17.24	0.25	0.17	0.12	0.01	1.23	0.97	70.93

The SEM and EDAX analyses of the fusion zone of the weldments are shown in Figure 4 (a) & (b) respectively EDAX analysis of the weld zone illustrated that it possesses major element Fe followed by C, Cr, Mn, Mo, Si and P elements are also present with little amounts as shown in Table 5. Therefore, Cr, Mo, Si can diffuse from the weldmetal to the base metal, so to form a secondary precipitates. But carbon diffused from base metal to weld metal and in the weldmetal the presence of Mo and P precipitates are confirmed by EDAX analysis.

VI. CONCLUSIONS

Conclusions drawn from the experimental and WOA results are presented in the following.

- ANOVA shows that the Laser Energy (Laser Power) is the major influencing process parameter on Bead Width and UTS of AISI 4130 weld joint. Whereas welding speed influences Bead Width of AISI 4130 weld joint.
- Weld integrity is so well and weld line was completely disappeared in the both side of weld zone. The weld zone in LBW joint is very small and at the adjacent interface surface (HAZ).
- The multi-optimal combination of processes parameters obtained by WOA. The better Bead Width and Maximum UTS.

REFERENCES

1. Narayana Reddy, B., Hema, P., Eswara Reddy, C. and Padmanabhan, G., "Role of Laser Beam in Welding and Assembly: A Status Review" Proceeding of 10th COPEN, Dept. of Mechanical Engineering, IIT Madras, 1056-1060, Dec 20-23, 2017.
2. Narayana Reddy, B., Hema, P. and Padmanabhan, G., "Experimental study on the influence of LBW process parameters on Mechanical Properties of dissimilar metal joints", MTT Journal, CMTI 2019.
3. Arivazhagan, N., Surendra Singh, Satya Prakash and Reddy, G.M., "Investigation on AISI 304 austenitic stainless steel to AISI 4140 low alloy steel dissimilar joints by Gas tungsten arc, Electron beam and Friction welding", Materials and Design, Vol. 32, pp. 3036-3050, 2011.
4. Kalaiselvan, K., Elango, A. and Nagarajan, N. M., "Comparative Studies on Dissimilar Metals Thin Sheets using Laser Beam Welding-A review", International journal of Mechanical, Aerospace, Industrial, Mechatronics and Manufacturing Engineering, Vol. 8, No. 10, pp. 1753-1756, 2014.
5. Shuhai Chen, Jihua Huang, Jun Xia, Hua Zhang and Xingke Zhao, "Microstructural Characteristics of a Stainless Steel/Copper Dissimilar Joint Made by Laser Welding", Metallurgical and Materials Transactions A,Vol. 44, Issue 8, pp. 3690–3696, 2013.
6. Saumil Bhatt, R. and Dhaval Soni K., "Experimental and Metallurgical investigation on laser welding of dissimilar materials", International Research Journal of Engineering and Technology, Vol. 05(5), pp. 205-213, 2018.
7. Mostaan, H., Poorkabirian, M. and Rafiei, M., "The Interface Structure in Dissimilar Welding of AISI 4130 to AISI 316L Steels Using ERNiCr-3 Filler Metal", International Journal of ISSI, Vol. 15(1), pp. 1-8, 2018.

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