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EXPERIMENTAL INVESTIGATION ON WELDING OF DISSIMILAR MATERIAL AISI 304 WITH AISI 4140 BY LASER BEAM WELDING

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Abstract-The purpose of this study is to investigate the microstructure and mechanical properties of AISI 304 stainless steel and AISI 4140 low alloy steel joints by laser welding. The detailed analysis was conducted on weld bead hardness and impact strength for each of the weldments.The optimization of the process parameters is carried out by using Taguchi's signal-to-noise ratios (S/N) and the results are compared by ANOVA.The results of the analysis shows that the laser power is more significant process parameter for responses (weld bead hardness and impact strength). The optimum combination parameters for welding of dissimilar materials of AISI 304 with AISI 4140 using laser welding for higher weld bead hardness are 9 KW laser power, 50 mm/min scan speed, and 4 Hz frequency of laser welding.The optimum combination parameters for welding of dissimilar materials of AISI 304 withAISI 4140 using laser welding for higher impact strength are 9 KW laser power, 50 mm/min scan speed, and 2 Hz frequency of laser welding.
Keywords: Laser Welding, Dissimilar Weldment, AISI 304, AISI 4140, ANOVA.

1. INTRODUCTION

Welding is a process of joining the surfaces of two work-pieces (usually metals) through localized coalescence. It is a precise, reliable, cost-effective, and high-tech method for joining materials. No other technique is as widely used by manufacturers to join metals and alloys efficiently and to add value to their products. Welding joints different metals with the help of a number of processes in which heat is supplied either electrically or by mean of a gas torch.Laser welding is a non-contact fusion welding process which involves melting and joining of two similar/dissimilar materials by the applications of heat generated by a fine focused spot of laser beam. One of the earliest and most widely practiced applications of laser material processing was joining of metallic sheets using a continuous wave laser. Now-a-days the automobile (Audi A2), aerospace and marine industry relies on lasers for a clean non-contact source of heating and fusion for joining of sheets [1]. More than any other conventional process, laser joining is applicable to inorganic/organic and similar/dissimilar materials with an extremely high precision, versatility and productivity of that can only be matched with electron beam welding. Unlike electron beam welding, laser beams are not affected by magnetic fields and joints are not required to be there in vacuum chamber [2&3]. Laser welding can be performed with or without filler material, in various environments (vacuum, air, pressurized chambers, or controlled atmospheres) and in some locations which are normally inaccessible or accessible only from one side. In addition to simple linear welds the latest laser welding facilities are capable of performing complex angular and curvilinear (non-linear) welds. Moreover, multi beam techniques are easily realized in laser welding. In comparison to conventional / arc welding, laser welding scores several advantages like high depth to width ratio, narrow weld widths with controlled bead size, faster welding with a higher productivity, less distortion due to small spot size, narrow heat affected zone, amenability to welding dissimilar materials and minimum contamination.

Olabiet al. (2013), investigation was carried out on optimizing the CO_2laser welding process for dissimilar materials (low carbon steel and austenitic steel AISI 316**)** using CW 1.5 kW CO_2laser. By fixing welding speed on 57.93 cm/min, focal point position on 0.35 mm and laser power on 1.30 kW, can be more efficient and smart, as it ensures a pretty higher value of ultimate tensile strength (360 MPa) and impact strength 70.44 J.**Rakesh et al. (2014)**studied the effect of process parameters on thermal history of laser welding of AISI-304 stainless steel. From the studies on effect of process parameters it has been observed that the cooling rate is significantly affect by the varying welding power and welding speed. It has been observed that the heat affected zone and fusion zone also increases with increase of welding power and decrease of welding speed respectively.**Rathod and Haribhakta (2014)** used fiber laser welding process for butt welding of thin austenitic stainless steel (AISI 304L) plates. The experiments are designed with full factorial approach. Butt welding trials are conducted as per DOE using 100W SPI fiber laser source in the continuous wave mode on 0.2 mm and thick sheet.**Moharana et al. (2015)** investigate mechanical and metallurgical characteristics of continuous wave CO_2 laser welded dissimilar couple of AISI 304 stainless steel and commercially pure copper sheets in autogenous mode. Macroscopic examination has been carried out to observe the macro-segregation pattern of Cu, Fe and Cr rich phases in different zones, and the thickness of HAZ was found to be around 10 μm.**Shaibu et al. (2015)**this research work analyses the thermal, metallurgical and physical stages of AISI

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304 Stainless Steel-Copper dissimilar couple during laser welding in keyhole mode numerically and then validated experimentally. 10.6 μmwavelength CO_2laser welding machine is used for conducting this experimental analysis and the process is simulated by finite volume method. It is observed that the computational model have good concurrence with the experimental results, after the calibration between simulation and experimental results for the same parameter set.**Shuhai Chen et al. (2015)**investigated the effect of processing parameters (welding speed, laser power as well as the offset and incline angle of the laser beam in the direction of the stainless steel) on the microstructures and mechanical property of stainless steel/copper laser welding. It is observed that offsetting and inclining the laser beam in the direction of the stainless steel can effectively suppress the melting of the copper and ensure the joining occurs via welding–brazing.

AISI 4140 is a chromium-molybdenum alloy steel. The chromium content provides good hardness penetration, and the molybdenum content ensures uniform hardness and high strength. AISI 4140 chrome-molybdenum steel can be oil hardened to a relatively high level of hardness. The desirable properties of the AISI 4140 include superior toughness, good ductility and good wear resistance in the quenched and tempered condition. AISI 4140 is capable of resisting creep in temperatures up to 538°C (1000°F) and maintaining its properties even after long exposure at comparatively high working temperatures.AISI 304 is the most versatile and the most widely used of all stainless steels. Its chemical composition, mechanical properties, weldability and corrosion/oxidation resistance provide the best all-round performance stainless steel at relatively low cost. AISI 304 steel has excellent corrosion resistance in a wide variety of environments and when in contact with different corrosive media. It also has excellent low temperature properties and responds well to hardening by cold working.

From the literature survey, it is observed that the austenitic stainless steel (AISI 304) and low alloy steel (AISI 4140) possess a good combination of mechanical properties, formability, weldability, and resistance to stress corrosion cracking and other forms of corrosion. Owing to these attributes at moderately high temperatures, such combinations of metals are extensively used in the power generation industry e.g.in a nuclear water reactor, dissimilar metal welds are employed to connect the low alloy steel reactor pressure vessel and stainless steel pipe systems. But this dissimilar metal weldment with conventional welding processes faces number of problems such as: Carbide formation due to higher carbon content of AISI 4140 than that of AISI 304, Unexpected phase propagation in dissimilar joints cause the grain boundary corrosion at weld interface. These all problems cause deterioration of the mechanical properties and corrosion resistance of the joints.

2. EXPERIMENTAL WORK

Experiments were designed by the Taguchi method using an L_9 orthogonal array. This design was selected based on three welding parameters with three levels each. The selected welding parameters for this study were: Laser Power, scan speed and pulse frequency. The S/N ratio for each level of process parameters is computed based on the S/N analysis. The butt joints were produced using Nd:YAG laser beam welding (LBW) at a maximum average laser power 200W, wavelength 1.06μm, peak pulse power 10KW, pulse energy 90J, focusing diameter 0.3-2mm and pulse duration 0.5-20ms.Before welding the samples were grinded properly by manual grinder in order to eliminate burr, oxides present over it, and making the single 'V' grove for filling of metal by using electrode

The experiments have been conducted using the CNC Laser beam welding Machine available at M/s Vishkarma Engineering, Chandigarh in the Machine Tool Room. The Laser welding apparatus is shown in Figure 1 with working of Laser on workpiece.

Figure 1: Laser welding Machine of Dissimilar metal

3. RESULTS AND DISCUSSIONS

The effect of Laser Welding parameters i.e. Laser Power (KW), Scan Speed (mm/min), Frequency (Hz) is evaluated using Taguchi. The experiments were performed on Laser Welding Machine and measure the Weld bead Hardness. Now, for analyzing the experimental data from the test, the data is feed into the Minitab software for finding the optimum value from the parameters being taken in this experimentation.

Figure 2 (a) shows the effect of Laser Power (KW) on Mean of S/N Ratios of Weld bead Hardness. Graph plotted by utilizing the Weld bead Hardness results obtained by variation of Laser Welding machine parameters i.e. variation of Laser Power 5KW to 9KW, Scan Speed 30mm/min to 50mm/min, Frequency 2Hz to 6Hz. It is clear that there is increase in Weld bead Hardness with the change of Laser Power from 5KW to 7KW and then increases further from 7KW to 9KW.Figure 2 (b) shows the effect of Scan Speed (mm/min) on Mean of S/N Ratios of Weld bead Hardness. It is clear that there is increase in Weld bead Hardness with the change of Scan Speed from 30mm/min to 40mm/min and then increases continues further from 40mm/min to 50mm/min.Figure 2 (c) shows the effect of Frequency (Hz) on Mean of S/N Ratios of Weld bead Hardness. It is clear that there is slightly decrease in Weld bead Hardness with the change of Frequency from 2Hz to 4Hz and then increases further from 4Hz to 6Hz.

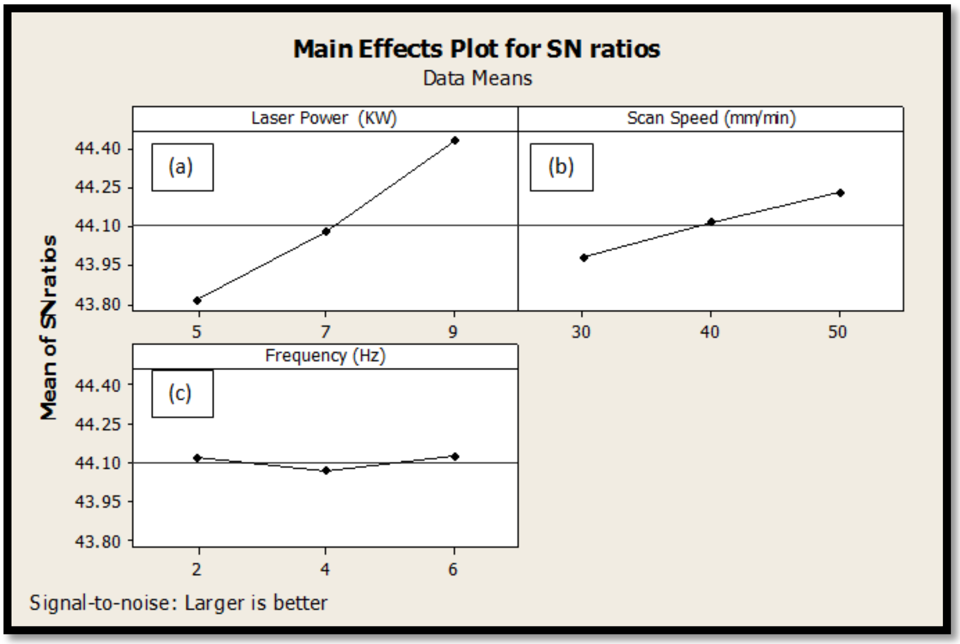

Fig 2: Mean of S/N ratio of graph for Weld Hardness

Analysis of Variance for MEAN1, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Laser Power (KW)	2	128.963	128.963	64.481	62.18	0.016
Scan Speed (mm/min)	2	25.407	25.407	12.704	12.25	0.075
Frequency (Hz)	2	0.889	0.889	0.444	0.43	0.700
Error	2	2.074	2.074	1.037		
Total	8	157.333				

S = 1.01835 R-Sq = 98.68% R-Sq(adj) = 94.73%

Fig 3: ANOVA for Weld bead Hardness

The figure 3 shows the ANOVA for weld bead hardness of laser welding of dissimilar metal i.e. AISI 304 with AISI 4140. From the ANOVA, it is observed that laser power is most significant parameter, which effects on hardness of weld bead. More laser power means more energy is provided to melts the electrode and solidify on the gap to make weld joint.

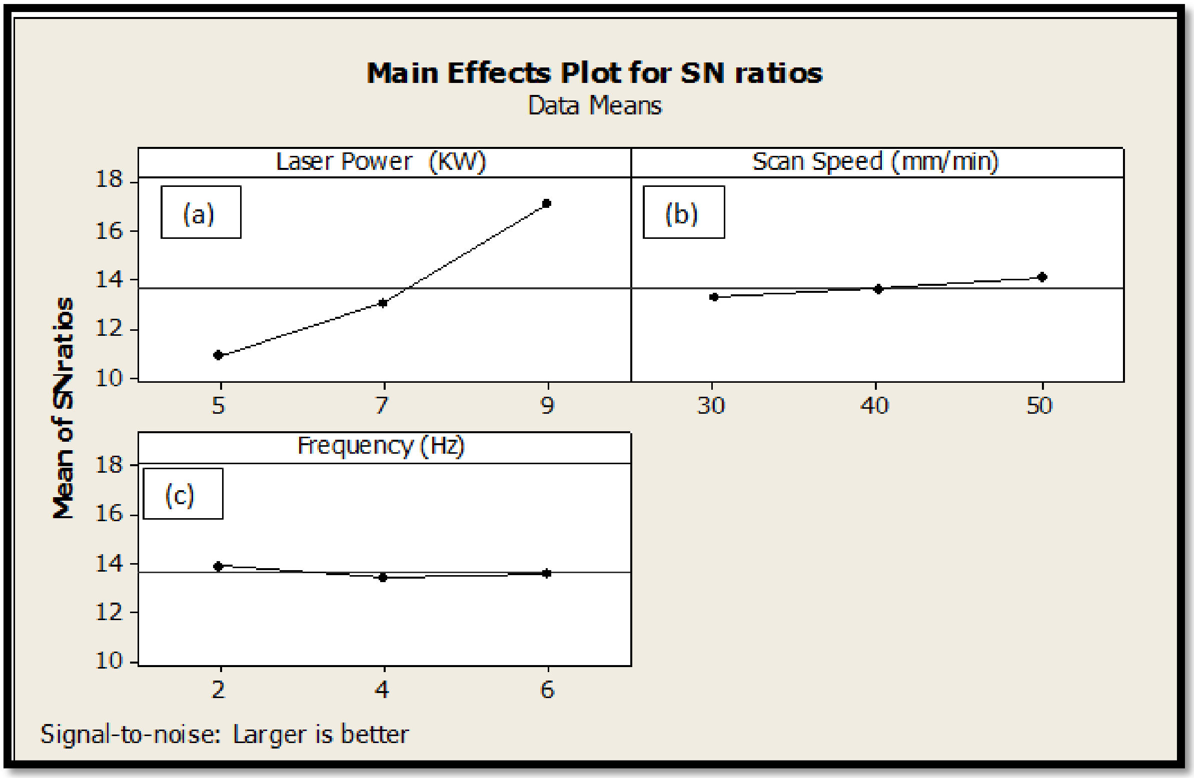

Fig 4: Mean of S/N ratio of graph for Impact Strength

Figure 4 (a) shows the effect of Laser Power (KW) on Mean of S/N Ratios of Impact Strength. It is clear that there is increase in Impact Strength with the change of Laser Power from 5KW to 7KW and then increases further from 7KW to 9KW.Figure 4 (b) shows the effect of Scan Speed (mm/min) on Mean of S/N Ratios of Impact Strength. Graph plotted by utilizing the Impact Strength results obtained by variation of Laser Welding machine parameters i.e. variation of Laser Power 5KW to 9KW, Scan Speed 30mm/min to 50mm/min, Frequency 2Hz to 6Hz. It is clear that there is increase in Impact Strength with the change of Scan Speed from 30mm/min to 40mm/min and then increases continues further from 40mm/min to 40mm/min.Figure 4 (c) shows the effect of Frequency (Hz) on Mean of S/N Ratios of Impact Strength. It is clear that there is slightly decrease in Impact Strength with the change of Frequency from 2Hz to 4Hz and then increases slightly from 4Hz to 6Hz.
The figure 5 shows the ANOVA for impact strength of laser welding of dissimilar metal i.e. AISI 304 with AISI 4140. From the ANOVA, it is observed that laser power is most significant parameter, which effects on impact strength of weld bead. More laser power means more energy is provided to melts the electrode and solidify on the gap to make weld joint.

Analysis of Variance for MEAN2, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Laser Power (KW)	2	21.5556	21.5556	10.7778	97.00	0.010
Scan Speed (mm/min)	2	0.3889	0.3889	0.1944	1.75	0.364
Frequency (Hz)	2	0.0556	0.0556	0.0278	0.25	0.800
Error	2	0.2222	0.2222	0.1111		
Total	8	22.2222				

S = 0.333333 R-Sq = 99.00% R-Sq(adj) = 96.00%

Fig 5: ANOVA for Impact Strength

4. CONCLUSIONS

Anoptimalsetofprocessvariablesforeachresponse which givesoptimumperformancehasbeeninvestigatedusingtechnique. The following conclusions have drawn by experimental work:

1. Theeffectofprocess parameters of laserwelding for dissimilar welding of AISI 304, and AISI 4140 i.e. laser power, scan speed and frequency onresponsevariablessuchasweld bead hardness and impact strength hasbeenthoroughlystudied.The

laser power is more significant process parameters for responses, weld bead hardness and impact strength.

2. It is noted that the maximum mean of weld bead hardness (HV) is 171 (HRC) which is at 9 KW laser power, 50 mm/min scan speed, and 4 Hz frequency of laser welding.
3. It is noted that the maximum impact strength is 7 (joule) which is at 9 KW laser power, 50 mm/min scan speed, and 4 Hz frequency of laser welding.
4. The optimum combination parameters for welding of dissimilar materials of AISI 304 with AISI 4140 using laser welding for higher weld bead hardness are 9 KW laser power, 50 mm/min scan speed, and 4 Hz frequency of laser welding.
5. The optimum combination parameters for welding of dissimilar materials of AISI 304 with AISI 4140 using laser welding for higher impact strength are 9 KW laser power, 50 mm/min scan speed, and 2 Hz frequency of laser welding.

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