THE OPTIMIZATION OF PROCESS PARAMETERS FOR LASER WELDED GALVANIZED AUTOMOBILE STEEL SHEETS USING A TAGUCHI METHOD

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Abstract- The aim of the study is to optimize the welding parameters for laser welded thin galvanized steel sheets using a Taguchi orthogonal array. The welding parameters such as laser power, welding speed and focal point position were determined and the optimum parameter combination for the maximum tensile load of the joints were predicted. Additionally, examination of the weld cross-sections, microhardness tests and fracture zone of the selected welded joints were conducted to understand the better performance of the joints. The optimum levels of the laser power, welding speed and focal position were found to be 3000 W, 100 mm/s and 0 mm, respectively.

Keywords- Laser Overlap Welding, Galvanized Steel, Parameter Optimization, Tensile Test

I. INTRODUCTION

Today, for the automotive industry weight reduction, crashworthiness and improvement of durability have become more important. Thin sheet metals have been adopted to reduce weight of the vehicle and galvanized steel sheets used as a corrosion resistance material. For the automotive industry the welding of zinc coated steel sheets is of great economic importance. Conventionally resistance spot welding used welding thin metal sheets. However excessively short electrode life and necessity of two side access are the most draw backs of this process [1].

Due to excellent advantages such as high speed, narrow heat affected zone (HAZ), Laser welding become a key method for welding thin galvanized steels in automotive industry [2]. Normally it is very challenging to achieve acceptable weld quality of galvanized steel sheets in zero gap lap joint formation. The reason for this is highly pressurized zinc vapor on the weld zone. The zinc coatings at the faying surface are vaporized because of the lower boiling of the zinc as compared to melting temperature of steel [3]. In the past decades, several researcher have investigated the effect of process parameters on the weld quality of zero-gap laser welded zinc coated steels. Ma et al. (2012) reviewed the laser welding of galvanized steel sheets and they reported different zinc vapor mitigation techniques in the literature [4]. Yang et al. (2011) investigated the effect of different shielding gases conditions on the laser zero-gap welded zinc coated steels. They stated that, full penetration sound welds can be achieved at low welding speed [5]. Chen et al. (2009) used vent holes for mitigating the zinc vapor. They stated that vent holes allowed formation of much stronger welds through riveting mechanism [6].

Due to welding process parameters are directly affecting the quality of the weld joints, it is necessary to work in the range of suitable process parameters. Several optimization methods are utilized in order to defining the optimum process parameters for getting sound welds. Taguchi method is one of the most familiar technique which let the analysis of experiments with the minimum number [7]. In Taguchi method with a specific design of orthogonal arrays allows studying the whole parameter range with a minimum experiment number.

In the literature, several researchers have used Taguchi method to optimize laser weld quality. Benyounis and Olabi (2008) have presented a review of the application of optimization techniques in several welding processes [8]. Zhao et al. (2012) investigated the effects of prescribed gap and laser welding parameters on the weld bead profile of galvanized steel sheets in a lap joint format and used Response Surface Method (RSM). They stated that a prescribed gap was needed to vent the pressurized zinc vapor and then obtain acceptable joint [9]. Anawa and Olabi (2008) used Taguchi method for the purpose of increasing the productivity and decreasing the operation cost of laser welding steel sheets [10]. Sathiya et al. (2011) carried out Taguchi method and desirability analysis to relate the parameters to the weld bead dimension, and tensile strength of the joints with under the various shielding gasses atmosphere [11].

In this study, optimum laser process parameters (power, speed and focal position) was determined and the contribution of the individual process parameters to the tensile load of the laser welded zero-gap zinc coated steel sheets was estimated using Taguchi method. In addition, the microhardness values in the different weld zones, icrostructural changes, of the selected samples were discussed to offer explanations for the better performance of the joints.

II. MATERIAL AND METHOD

The present study was performed on 0.75 mm thick galvanized steel. The steel sheets were sheared into 185 mm x 80 mm coupons. The configuration can be seen in Fig. 1. The IPG ytterbium fiber laser was used for welding experiments. During the welding process, 10 l/min Ar shielding gas was used.

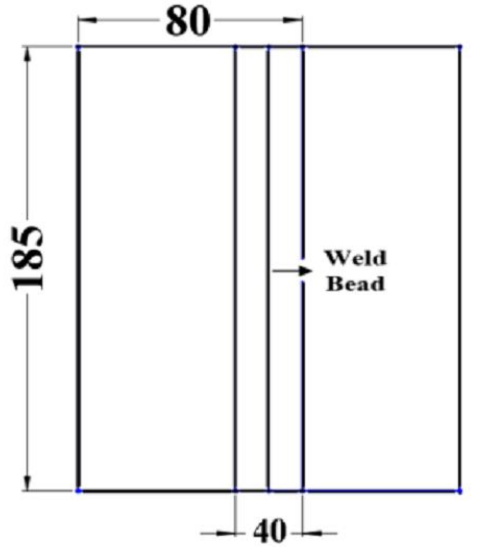


Fig. 1. Schematic illustration of the fiber laser welded steel sheets.

In this study, for optimizing the process parameters, the Taguchi method was used. Experiments were designed using an L9 orthogonal array, which means nine rows and three columns. Three levels were considered for each of the three parameters, which were laser power (LP), welding speed (WS) and focal point position (FPP). A negative defocus is obtained when the focal point position is below the specimen surface.

At the metallographic examination stage of the study, the samples were cut from the weld cross- section then mounted in Bakelite, ground and polished. 3% Nital solution was conducted to reveal the grain boundaries and weld zone microstructure. Then, samples were analyzed for microstructural changes using an optic microscope. Tensile samples were machined from the perpendicular to the welding direction in accordance with ASTM, E8/E8M.

III. RESULTS AND DISCUSSION

In this study, the parameter optimization procedure was done in order to get a welded joint that has the maximum tensile load (TL).

The tensile load of the joints was experimentally determined using tensile tests. At least three different specimens' tensile test results' average were taken. The experimental layout for the process parameters and average tensile load are shown in Table 1.

Table 1. Design matrix with experimental results.

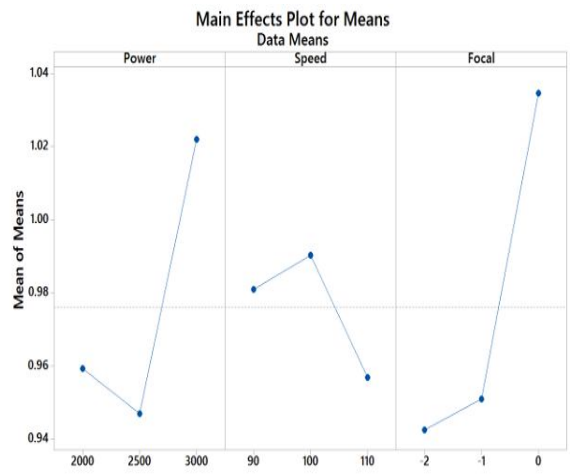
No	LP (W)	WS (mm/s)	FPP (mm)	TL (kN)	SN Ratio
111	2000	90	0	1.038	0.32395
122	2000	100	-1	0.895	-0.96354
133	2000	110	-2	0.945	-0.49136
212	2500	90	-1	0.965	-0.30945
223	2500	100	-2	0.943	-0.50977
231	2500	110	0	0.933	-0.60237
313	3000	90	-2	0.940	-0.53744
321	3000	100	0	1.133	1.08460
332	3000	110	-1	0.993	-0.06102

As can be seen in Table 2, focal point position was the most important parameter for the response. Laser power and welding speed followed this parameter, respectively.

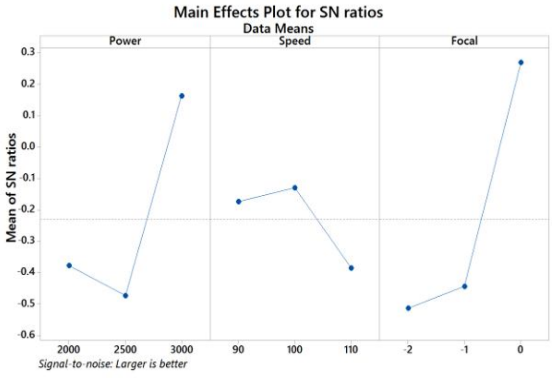
Table 2. Response table for the S/N ratios for the tensile load.

Level	LP (W)	WS (mm/s)	FPP (mm)
1	-0.3770	-0.1743	-0.5129
2	-0.4739	-0.1296	-0.4447
3	0.1620	-0.3849	0.2687
Delta	0.6359	0.2553	0.7816
Rank	2	3	1

The S/N ratios' main effect plot showed how each process parameter affects the response characteristic. The means of the S/N ratios exhibit a good correlation with the main effects of the mean of means (Fig. 2).



(a)



(b)

Fig. 2. Effects plots of (a) mean of means and (b) S/N ratios for the response.

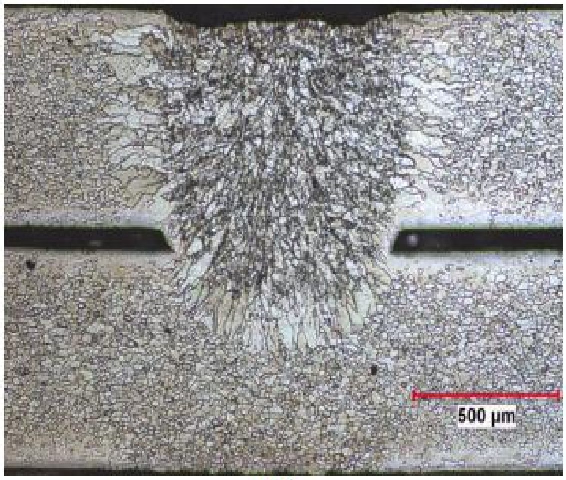
In this study, the optimal parameter combination was found to be 3000 W for laser power, 100 mm/s for welding speed and 0 mm for the focal point position. This parameter combination was Sample 321 in the orthogonal array in Table 1; thus, no additional confirmation experiments were required.

ANOVA is the statistical treatment most commonly applied to the results of experiments to determine the percentage contribution of each parameter. To determine the relative effect of the process parameters, the standard ANOVA procedure was performed using the mean values. The ANOVA table indicates the order of importance of the welding parameters for the peak tensile load of the welded sample. The ANOVA results shows that for the response focal point position has the greatest effect with a contribution of 38.02 %. Laser power and welding speed effects were 23.8 % and 4.36 % respectively (Table 3). This result is in a compatible with Table 2 which is the response table for S/N ratios. Due to the interactions between the processes parameters were not defined, the residual error was large in ANOVA.

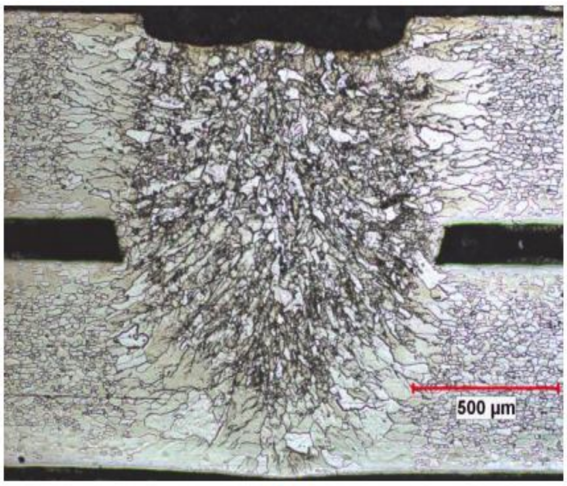
Table 3. ANOVA table for means.

	DF	Adj SS	Adj MS	F	P	%
LP	2	0.009704	0.004852	0.71	0.584	23.8
WS	2	0.001774	0.000887	0.13	0.885	4.36
FPP	2	0.015534	0.007767	1.14	0.468	38.2
Error	2	0.013647	0.006823			
Total	6	0.040659				

The significant parameters that affect the quality of laser welded joints are focal point position, laser power and welding speed, respectively. However the interaction between laser power and welding speed is quite important for the weld quality. Weld bead geometry is influenced by heat input [2]. At constant focal point position level, laser power is the most effective factor in terms of heat input. With the increasing laser power, heat input per unit length increased. And also the weld bead width increased with the increasing heat input (Fig. 3). The increase of laser power causes more heat input. Under the high laser power, if the welding speed was not chosen properly the weld bead was broadened and surface quality of the weld was decreased. And also the results showed that laser power have a positive effect on the penetration depth. At the constant welding speed and focal point position parameters the penetration depth increased the laser power increased.



(a)



(b)

Fig. 3. Cross sections of the joints (a) Heat Input: 22.22 j/mm – Sample 111, (b) Heat Input: 30 j/mm – Sample 321.

The microstructural examination, microhardness and failure characteristic evolution of the optimum sample which have the highest (Sample 321) tensile load was conducted. Three different zones including fusion zone (FZ), heat affected zone (HAZ) and base metal (BM) were revealed by examining the selected sample's cross-section. The microstructure of the base metal in Fig. 4 has a ferritic microstructure with relative homogeneous grain size.

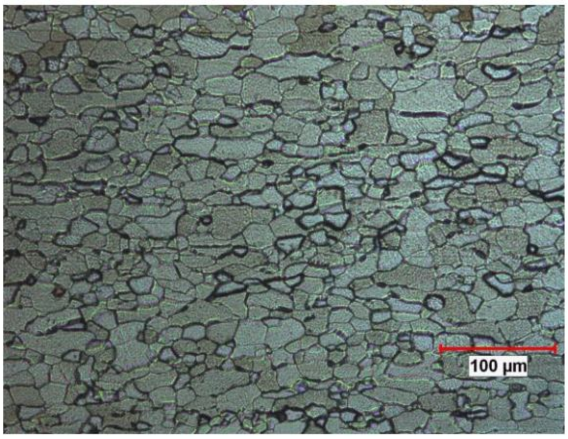


Fig. 4. Optical micrograph of the base metal

The HAZ of the welded joint for optimum sample was narrow. It consists mainly of coarse ferrite as can be seen in Fig. 5. The fusion zone microstructure viewed through an optical microscope is shown in Fig. 6. The FZ contained a large amount of acicular ferrite and small areas of bainite.

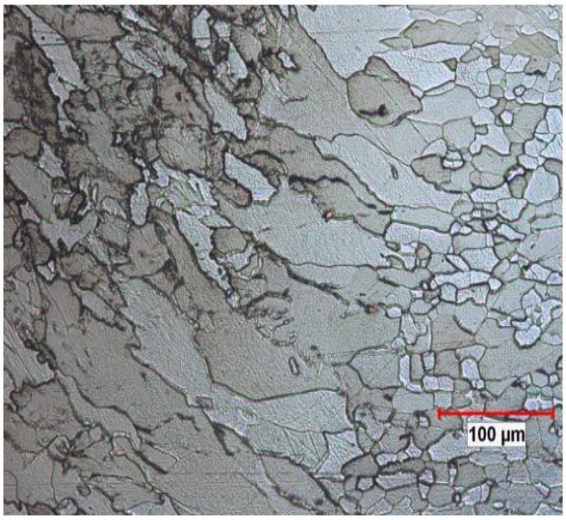


Fig. 5. Optical micrograph of the HAZ

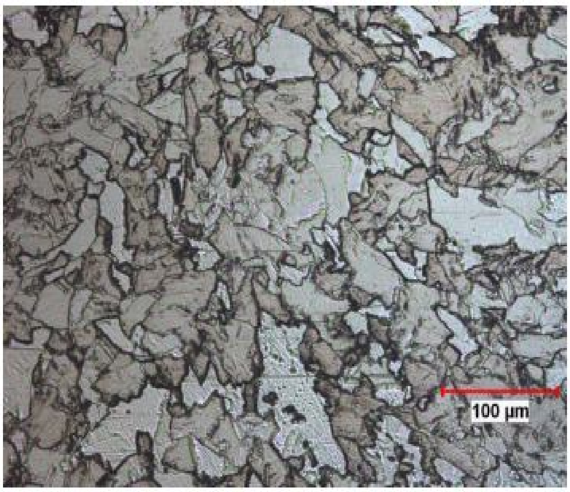


Fig. 6. Optical micrograph of the fusion zone

Microhardness measurements were performed in the different weld zones of the selected sample. The average microhardness values of the fusion zone, heat effected zone and base metal was 173.7, 109.8, 92.2 (HV0.1) respectively.

CONCLUSION

In this study, the laser process parameters such as power, welding speed and focal point position have been optimized to maximize the tensile load. The optimum combination of laser welding process parameters was found 3000 W, 100 mm/s and 0 mm. In these parameter combination maximum tensile load was achieved which was 1.13 kN. After optimization procedure, the microstructural examination and microhardness evolution of the optimum weld (sample 321) that have the highest tensile load were discussed. It was found that, in the fusion zone of the laser welded sample had highest hardness value.

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REFERENCES

[1] Zhao, Y., Zhang, Y., Hu, W., Lai, X. 2012, “Optimization of laser welding thin-gage galvanized steel via response surface methodology” Optics and Lasers in Engineering 50, 1267–1273.

[2] Yuce, C., Tutar, M., Karpat, M., Yavuz, N. 2016, “The Optimization of Process Parameters and Microstructural Characterization of Laser Welded Dissimilar HSLA and MART Steel Joints” Metals, 6(10), 245.

[3] Li, X., Lawson, S., Zhou, Y., Goodwin, F. 2007, “Novel technique for laser lap welding of zinc coated sheet steels”, Journal of Laser Applications, 19:4,259-264.

[4] Ma, J., Kong, F., Carlson, B., Kovacevic, R. 2012. “Mitigating Zinc Vapor Induced Weld Defects in Laser Welding of Galvanized High-Strength Steel by Using Different Supplementary Means”, Welding Processes, Dr. Radovan Kovacevic (Ed.), InTech, DOI: 10.5772/53562.

[5] Yang, B.Y., Carlson, B., Kovecevic, R. 2011, Laser Welding of High-Strength Galvanized Steels in a Gap-Free Lap Joint Configuration under Different Shielding Conditions”, Welding Research, Vol.90:8-18.

[6] Chen, W., Ackerson, P., Molian P. 2009. “CO2 laser welding of galvanized steel sheets using vent holes”, Materials and Design (30): 245-251.

[7] Tutar, M., Aydin, H., Yuce, C., Yavuz, N., Bayram, A. 2014, “The optimisation of process parameters for friction stir spot-welded AA3003-H12 aluminium alloy using a Taguchi orthogonal array”. Mater. Des. 63, 789–445 797.

[8] Benyounis, K. Y., Olabi, A. G. 2008, “Optimization of different welding processes using statistical and numerical approaches - A reference guide”. Adv. Eng. Softw. 39, 483–496.

[9] Zhao, Y., Zhang, Y., Hu, W., Lai, X. 2012, “Optimization of laser welding thin-gage galvanized steel via response surface methodology”, Opt. Lasers Eng. 50, 1267–1273.

[10] Anawa, E. M., Olabi, A. G. 2008, "Optimization of tensile strength of ferritic/austenitic laser-welded components", Opt. Lasers Eng, 46, 571–577.

[11] Sathiya, P., Abdul Jaleel, M.Y., Katherasan, D., Shanmugarajan, B. 2011, "Optimization of laser butt welding parameters with multiple performance characteristics", Opt. Laser Technol. 43, 660–673.

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