Optimization of Metal Inert Gas Pulse Brazing Process on Galvanized Steel Sheets Based on Taguchi Method

Khasempong Songsorn[1*], Keartisak Sriprateep[2] and Sampan Rittidech[1]

Abstract

The purpose of this research was to identify the optimal conditions of the galvanized steel sheets based on the Metal inert gas pulse brazing process (MIGPBP). The study used the Taguchi method to experimentally design the L_{25} orthogonal array, including five main parameters: 1) wire feed speed, 2) arc voltage, 3) travel speed, 4) peak current, and 5) pulse frequency. Each of these parameters consisted of 5 levels, and thus the experiment runs 25 times with 3 replications (75 experiments in total) to find the characteristics of the MIGPBP that were considered important parameters and were exhibited significantly, including: 1) zinc coated balance of joint (ZB), 2) area for penetration of filler metal into the fit-up (ARP), and 3) tensile shear strength (TSS). The results demonstrated that the optimum conditions of the MIGPBP of galvanized steel sheets for the ARP and TSS were 4 meter/minute wire feed speed, 18 V arc voltages; 0.6 meter/minute travel speed, 450 ampere peak current, and 35 Hz pulse frequency. For the ZB, the finding indicated the wire feed speed at 3.25 m/min, the arc voltages at 18 V, the travel speed at 0.9 m/min, the peak current at 425 A, and the pulse frequency at 35 Hz to be such optimal conditions which effected the quality of zinc coated balance of joint.

Keywords : Metal inert gas pulse brazing process, Taguchi method, Galvanized sheet steels, Optimal conditions

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1. Introduction

Currently, Thailand’s industries, such as the automotive industry, the shipbuilding industry, the construction industry, and even the medical industry, use the galvanized steel sheets as assembly materials for their products. In their manufacturing or production process [1], the joint process through welding or brazing is significantly employed because it is considered useful for an assembly production and the maintenance works. Thus, the brazing technology must efficiently respond to the industrial need.

The MIGPW [2] is a welding process in which the welding current has been designed as a pulse system. This MIGPW process contributes a low joining heat input, resulted in the removal of zinc coated around the joining area of work piece being welded and at the same time the process allows the melting filler materials flow through the joint area, leading to the none-melting base metal. With this welding process, very low de-coating surface can be achieved. The MIGP-brazing process (MIGPBP) [3] is an efficient technology of joining when utilized with the MIGP-welding (MIGPW) process. The MIGPBP can be used for many types of joint because of its efficient joint penetration control, with low spatter level, and up to 3-4 times more welding speed than conventional welding processes. Thus, the MIGPBP has been employed for joining of the galvanized sheet steels in Thailand and South East Asian industries.

The general procedures that could be used in searching for the optimal welding parameter settings are design of experiment techniques, such as fractional factorial design, soft computing techniques (e.g. genetic algorithm), multi-objective optimization method and Taguchi method [4]. In recent years, the Taguchi method is being increasingly used for the process optimization. In addition, it is a systematic application of design and analysis of experiments, aimed for optimal parameters setting selection in order to achieve a desired quality and productivity improvement, with minimum number of experiments [4-6].

Taguchi method has been successfully applied in manufacturing field for nearly three decades to robustly design products or processes having a single quality parameter. Some researchers [7-20] use the Taguchi’s orthogonal array (OA) experiment for selection of optimum levels of process parameter in welding. Haragopal et al. [7] use Taguchi method design parameter of Al-65032 alloy in GMAW process. Sathiya et al. [8] use Taguchi method for micro structural characteristics bead on plate welding of AISI 904 L super austenitic stainless steel in GMAW process. Sathiya et al. [9] use grey-based Taguchi method for micro structural characteristics bead on plate welding of AISI 904 L super austenitic stainless steel in Laser welding process. Hsuan-Liang Lin [10] use Taguchi method with grey relational analysis and a neural network to optimize a novel

GMA welding process. Aghakhani et al. [11] use Taguchi method design parametric Optimization on weld dilution of GMAW process. Her-Yueh Huang [12] use Taguchi method with grey relational for analysis the optimal effects of activating flux on the welded joint characteristics in GMAW process. Sukhomay Pal et al. [13] use grey-based Taguchi method for optimization of quality characteristics parameters in a pulsed metal inert gas welding process. Anawa and Olabi [14] use Taguchi method for minimization of weld pool fusion area and weld pool of dissimilar in Laser welding process. Saurav Datta et al. [15-17] use Taguchi's orthogonal array with grey relational analysis to determine the optimal process condition in Submerged arc welding processes so as to yield desired weld bead geometry. Therein, the significances of the process parameters were evaluated by analysis of variance. Juang and Tarng [18] use of Taguchi method to solve the optimal weld bead geometry in tungsten inert gas welding process. Tarng et al. [19] determined the optimal process parameters by using grey-based Taguchi methods in Submerged arc welding process by considering multiple weld qualities. In another work, P. Srinivasa Rao, et al. [20] determined the optimal GMAW-P process for effect of process parameters and mathematical model for the prediction of bead geometry.

Table 1 Comparison of related research.

Ref.	Processes	Material	Method	Quality characteristics
[7]	GMAW	Al-65032 Aluminium	Taguchi	Mechanical properties
[8]	GMAW	904 L stainless steel	Taguchi	Weld bead geometry
[10]	GMAW	SAE 1020 & SUS 304SS	Grey, Taguchi	Weld bead geometry
[11]	GMAW	Mild steel	Taguchi	Weld dilution
[12]	GMAW	Mild steel	Taguchi	Weld bead geometry
[13]	PMIGW	Carbon steel	Grey, Taguchi	Weld bead geometry
[14]	LW	AISI 316 & AISI 1009	Taguchi	Welding fusion zone
[15]	SAW	Mild steel	Taguchi	Weld bead geometry
[18]	GTAW	Stainless steel	Taguchi	Weld pool geometry
[19]	SAW	Mild steel	Grey, Taguchi	Deposit rate, dilution
[20]	GMAWP	Mild steel	Grey, Taguchi	Weld bead geometry

Remark GMAW = Gas metal arc welding, SAW = Submerge arc welding, PMIGW = Pulse metal inert gas welding,
GTAW = Gas tungsten arc welding, LW = Laser arc welding, **MIGPBP** = Metal inert gas pulse brazing process

In this work, the Taguchi method was used to look for the optimal parameter setting of the MIGPB process. Wire feed speed, arc voltages, travel speed, peak currents and pulse frequency were considered the controllable factors. The zinc coated balance (ZB), area for penetration of filler metal into the fit-up (ARP), and tensile shear strength (TSS) efficiency were deemed the MIGPBP quality parameters show in Fig. 1. The impacts of individual process parameters on the quality characteristics were analyzed by using ANOVA.

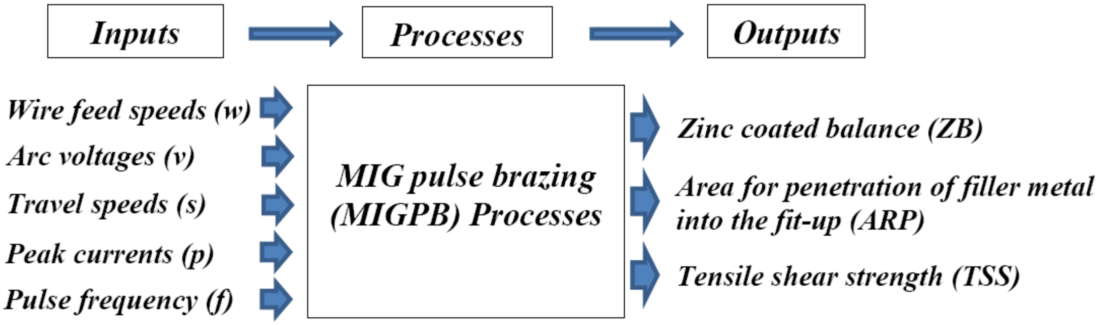

Fig. 1 Input and output parameters of the MIGPBP.

2. Methodology

This section describers the experimental setup used in the present work and explains the method for measurement of ZB, ARP and TSS.

2.1 Experiments set-up

2.1.1 MIGPB process (MIGPBP)

In this study, a galvanized sheet steels MIGPB layer was deposited by the MIGPBP using Fronius-Tranpulse 450 Inverter power source, as shown in Fig. 2 the schematic diagram of the semi-mechanized MIGPB station used during the experimentation.

2.1.2 Base material

In this study, specimens of materials was 0.8 mm galvanized sheet steels plate thick, with 7.02 µm galvanized coated thick. The chemical compositions of the galvanized sheet steels are shown in Table 2

Table 2 Chemical compositions (wt.%) of the base metal [20]

	C	Mn	Si	P	S	Fe
Galvanized sheet steel (%)	0.070	0.27	<0.020	0.012	0.010	Bal.

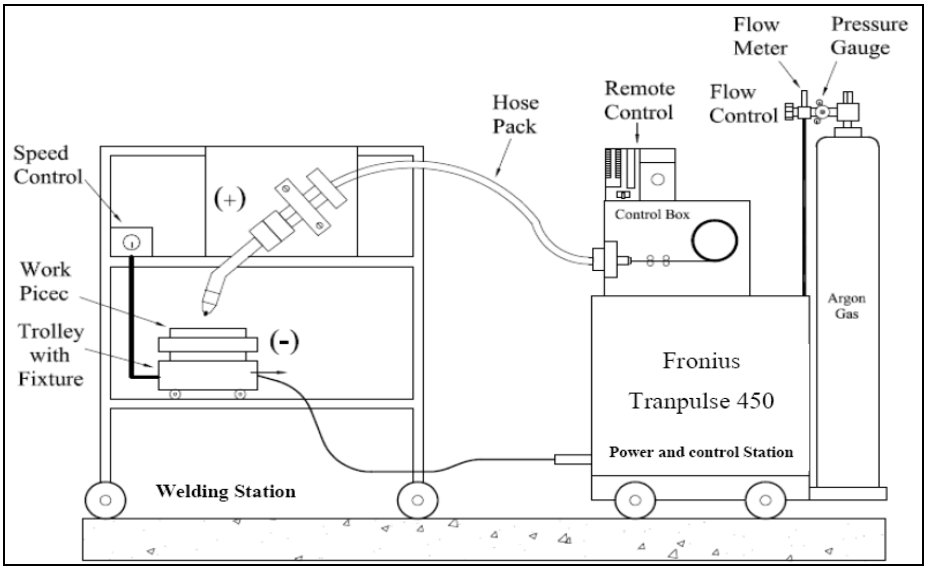

Fig. 2 The schematic diagram of MIGPBP set-up [21]

2.1.3 Filler metal (Electrode solid wire)

The filler metal was solid wire AWS. ER CuSi-3 (Ø 0.8 mm). The chemical compositions of the filler metal are shown in Table 3.

Table 3 Chemical composition (wt.%) of the filler metal [20]

	Cu	Mn	Si	others
ERCuSi-3 (%)	>94	0.5-1.5	2.8-4.5	0.50

2.1.4 Shielding gas

Commercial Argon (99.98 %) is used as the shielding gas in all experiments. The flow rate of shielding gas is used to 10 l/min.

2.1.5 Specimens

The specimen consisted of two workpices dimension is shown in Fig 3. The surface was cleaned by Acetone before the MIGPBP. In preparing specimens for the MIGPBP, both specimens were put in forms of lap joint for 10 mm length, and joint fit-up of 0.50 mm as shown in Fig. 3

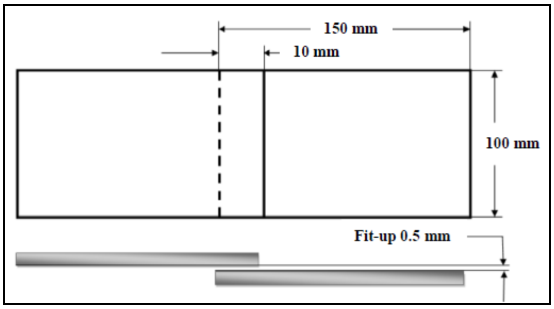

Fig. 3 Schematic preparing joint of specimens for MIGPBP. [21]

2.2 Measurement of MIGPB quality parameters

2.2.1 Measure the ARP of joint

Prepare the **MIGPB** joint specimens and cut them by a cutting machine and a hacksaw to have size of 15 x 20 mm. Cast specimens by coating resin to ease the next step preparation of specimens. Polish surface of specimens by using abrasive paper to make it easy for measuring area penetration of filler metal into fit-up. Monitor the ARP by utilizing the microscope and the OPTIKA program in order to measure area of the ARP (75 specimens in total) as shown in Fig. 4

2.2.2 Measure the ZB of joint

Prepare specimens and cut them to be sized for 15 x 25 mm. Clean specimens by using Acetone. Measure ZB of joint as shown in Fig. 5

After the MIGPBP, take specimens to measure the ZB to see the effect of Heat-Affected Zone (HAZ) on the upper, the lower, and the back sides of a joint edge. In doing so, the Scanning Electron Microscope (SEM), equipment for checking quantity of ZB, is used through the Energy Dispersive Spectroscopy (EDS) mode to test the ZB of ZB1, ZB2 and ZB3, as shown in Fig. 5

Fig. 5a presents checking points of the ZB at the upper and lower front sides of joint fit-up. All checking points of ZB1 and ZB2 were placed 1.00 mm apart from each other (see ZB1 [F-A], and ZB2 [A-F]. Hence, there were 6 checking points per each

Zone ranging from 1- 6 mm to be measured the average percentage of the ZB in ZB1 and ZB2. The same is true for measuring the ZB’s HAZ of joint at ZB3, directly resulted from the brazing (Fig. 5b). All checking points of the backside of joint were placed apart from each other 1.00 mm, including 6 checking points, to be checked the average percentage of the ZB in Zone ZB3.

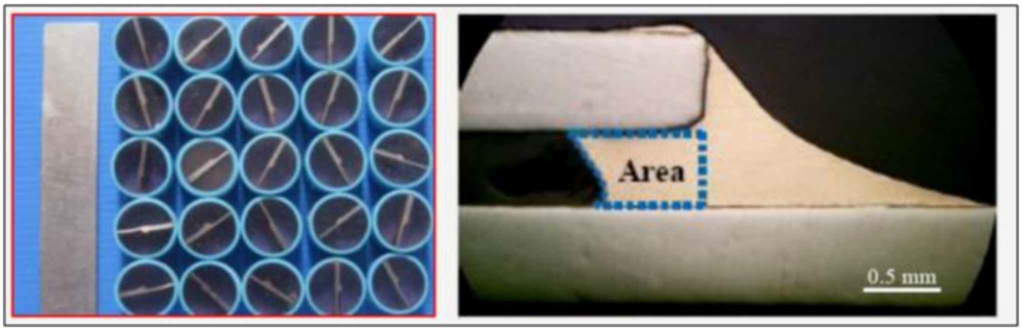

Fig. 4 Schematic measure areas for ARP of joint.

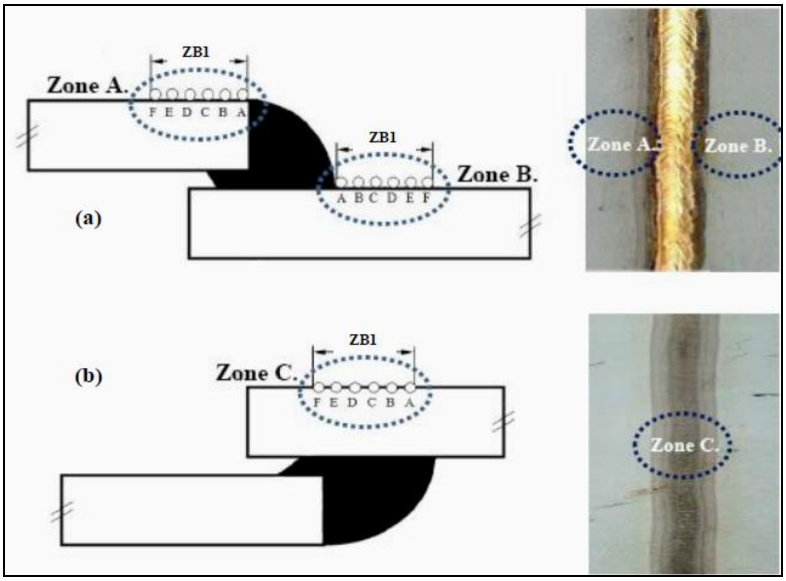

Fig. 5 The schematic determination of zinc coated balance of joints (a) ZB_1 (F-A) is an upper border (Zone ZB1) and ZB2 (A-F) is a lower border (Zone ZB2) of joint. (b) ZB_3 (F-A) is a backside of the HAZ (Zone ZB3) of joint.

2.2.3 TSS testing of joint

Prepare the width and length of specimens at size of 24 × 250 mm [Fig. 6a] to be measured their TSS of joint in accordance with Standard No. JIS-Z-3194 [22]. By using a universal testing machine (shown Fig. 6b) on a 50 ton scale, TSS tests were done at room temperature and then, recording of the failure load was conducted.

2.3 Plan of experiments

This paper used the Taguchi method to optimize MIGPB parameters for galvanized steel sheets. Five parameters were used; each contains five levels [23-25] shown in Table 4. The MIGPB parameters were determined by varying ranges of the wire feed speed (*w*) at 3-4 m/min, of arc voltages (*v*) at 15-19 V, of travel speed (*s*) at 0.6-1 m/min, of peak currents (*p*) at 350-450 amp, and of pulse frequency (*f*) at 25-45 Hz.

By taking into consideration the parameters' degree of freedom of, plan of experiments in this study adopts Taguchi's orthogonal array to test 5 parameters. Each parameter incorporates 5 levels. Thus, L_{25} orthogonal array (OA) is designed to be 5 columns in accordance with parameters and 25 rows in agreement with 5 levels of each parameter for the MIGPBP of the galvanized steel sheets, as shown in Table 5.

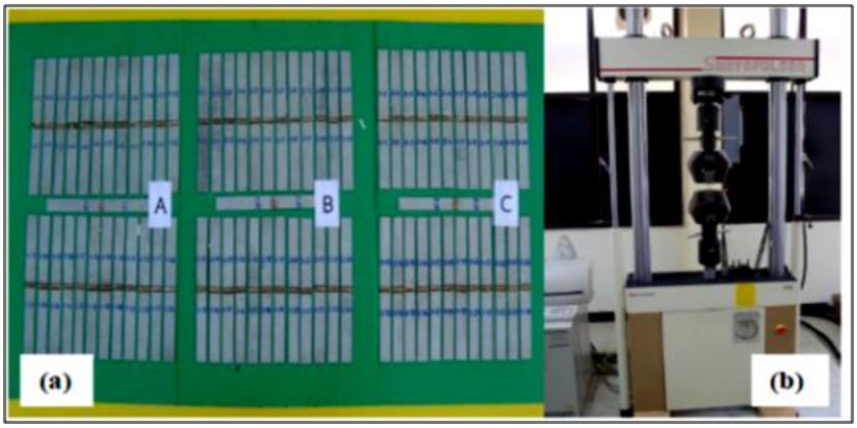

Fig. 6 TSS test specimens (a) and Universal testing machine.(b)

2.3.1 Analysis of the S/N ratio

In the Taguchi method, the term signal represents the desirable value for the characteristic and term noise represents the undesirable value (S.D.) for the out characteristic. This method is useful for studying the interactions between the parameters, and also it is a simple, efficient and systematic approach to determine optimal MIGPBP parameters. The difference between the functional value and objective value is emphasized and identified as the loss function which is derived as follows [26] :

$$L(y) = \frac{L''(m)\,(y-m)^2}{2!} = k(y-m)^2 = k(MSD) \qquad (1)$$

Where $L(y)$ is loss function, y is value of the quality characteristic, m is target value of y, k is proportional y constant, which depends on financial criticality of y, and MSD is mean square deviation for the output characteristic. Eq. (1) can be expressed by signal-to-noise S/N ratio η and can be rewritten as follows :

$$\eta = -10Log_{10}(MSD) \qquad (2)$$

As mentioned earlier, there are three categories of experimental results, i.e. The lower-the-better, nominal-the-better and higher-the-better.

To obtain optimal MIGPBP performance, the higher-the-better characteristic for the ZB, ARP and TSS must be taken. The equation for calculating S/N ratio for the higher-the-better characteristic is defined as :

$$\text{S/N} = -10Log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \qquad (3)$$

Where n is the number of observations and y is the observed data or each type of the characteristic.

3. Results and discussion

3.1 Analysis of variance

An ANOVA [27] of the data with the ZB, ARP and TSS in the specimens, with the objective of analyzing the influence of the wire feed speed (*w*), arc voltages (*v*), travel speed (*s*), peak currents (*p*) and pulse frequency (*f*) on the total variance of the results.

An objective of this research is to study the relations of MIGPBP parameters including wire feed speed (*w*), arc voltages (*v*), travel speed (*s*), peak currents (*p*), and pulse frequency (*f*) that influence the response of ZB, ARP and TSS. ANOVA or F-Ratio which represents variance ratio is used to test significance of each parameter in the experiment. Results of experiments are presented in Table 6.

Table 7-9 show the results of the ANOVA with the influence of the wire feed speed (*w*), arc voltages (*v*), travel speed (*s*), peak currents (*p*), and pulse frequency (*f*) to perform the MIGPBP operation in the specimens, respectively. This analysis was carried out for a level of significance of 5%, i.e. for a level of confidence of 95% The last column of the tables previously shown the percentage of contribution *P* of each factor on the total variation indicating then, the degree of influence on the result.

Table 7 provides variance analysis of an average of S/N ratio that influences the ZB of joint. The finding confirms that wire feed speeds and travel speeds are most important parameters influencing the ZB at the P-value < 0.05, while arc voltages, peak currents, and pulse frequency are less important. In terms of F-Value analysis, the main parameters affecting the ZB of joint are orderly presented by ranking from the highest to lowest percentage contribution: travel speeds (P^b= 66.49%), wire feed speeds (P^b = 14.79%) peak currents (P^b = 6.56%), pulse frequency (P^b = 5.72%) and arc voltages (P^b = 5.09%).

Table 4 MIGPB parameter and their levels.

Symbol	MIGPB parameters	Unit	Level 1	Level 2	Level 3	Level 4	Level 5
w	Wire feed speed	m/min	3.00	3.25	3.50	3.75	4.00
v	Arc voltages	V	15	16	17	18	19
s	Travel speed	m/min	0.60	0.70	0.80	0.90	1.00
p	Peak currents	amp	350	375	400	425	450
f	Pulse frequency	Hz	25	30	35	40	45

Table 5 Experimental design using an L_{25} OA.

Exp.	**MIGPBP parameters level**				
number	**w**	**v**	**s**	**p**	**f**
1	1	1	1	1	1
2	1	2	2	2	2
3	1	3	3	3	3
4	1	4	4	4	4
5	1	5	5	5	5
6	2	1	2	3	4
7	2	2	3	4	5
8	2	3	4	5	1
9	2	4	5	1	2
10	2	5	1	2	3
11	3	1	3	5	2
12	3	2	4	1	3
13	3	3	5	2	4
14	3	4	1	3	5
15	3	5	2	4	1
16	4	1	4	2	5
17	4	2	5	3	1
18	4	3	1	4	2
19	4	4	2	5	3
20	4	5	3	1	4
21	5	1	5	4	3
22	5	2	1	5	4
23	5	3	2	1	5
24	5	4	3	2	1
25	5	5	4	3	2

Fig. 7 presents mean of S/N ratio for the optimum conditions of ZB. When looking upon the relations between S/N ratio and each controlled parameter, the analytical results indicate that wire feed speeds at 3.25 m/min, arc voltages at 18 V, travel speeds at 0.9 m/min, peak currents at 425 amp, and pulse frequency at 35 Hz are the optimal conditions of ZB.

Table 8 gives the results of the variance analysis of S/N ratio that have impacts on ARP. It indicates that, by taking the P value < .05 into account, of 5 parameters studied, there is no parameter that affects ARP. When considering F-Value, the findings appear that Pulse frequency *(Pb = 24.67%)* is the most important parameter influencing ARP. As for other parameters such as wire feed speeds *(Pb = 16.80%)*, arc voltages *(Pb = 12.80%)*, travel speeds *(Pb = 11.12%)* and peak currents *(Pb = 10.86%)* are ranked sequentially important to ARP.

Means of S/N ratio shown in Fig 8 give an idea “the larger the better” of parameters that have great influence on the ARP. It is found that wire feed speeds at 4 m/min, arc voltages at 18 V, travel speeds at 0.6 m/min, peak currents at 450 amp, and pulse frequency at 35 Hz are the optimum conditions for the ARP.

Table 6 L_{25} OA of Taguchi for ZB[a], ARP[a], TSS[a] and S/N ratio values for the Experiments.

Exp.	w	v	s	p	f	ZB	ARP	TSS	S/N ratio (dB)		
number	(m/min)	(V)	(m/min)	(amp)	(Hz)	(%)	(mm^2)	(MPa)	ZB	ARP	TSS
1	3.00	15	0.60	350	25	67.687	0.291	298.05	36.610	49.486	-10.722
2	3.00	16	0.70	375	30	76.430	0.398	315.93	37.665	49.992	-8.002
3	3.00	17	0.80	400	35	80.720	0.474	319.85	38.140	50.099	-6.484
4	3.00	18	0.90	425	40	82.130	0.316	313.20	38.290	49.916	-10.006
5	3.00	19	1.00	450	45	73.710	0.332	317.63	37.351	50.038	-9.577
6	3.25	15	0.70	400	40	81.263	0.260	277.27	38.198	48.858	-11.701
7	3.25	16	0.80	425	45	82.277	0.218	252.79	38.306	48.055	-13.231
8	3.25	17	0.90	450	25	82.923	0.257	285.91	38.374	49.125	-11.801
9	3.25	18	1.00	350	30	82.533	0.428	294.85	38.333	49.392	-7.371
10	3.25	19	0.60	375	35	68.803	0.416	316.25	36.752	50.001	-7.618
11	3.50	15	0.80	450	30	80.187	0.465	318.70	38.082	50.068	-6.651
12	3.50	16	0.90	350	35	81.707	0.378	313.06	38.245	49.913	-8.450
13	3.50	17	1.00	375	40	73.713	0.198	282.19	37.351	49.011	-14.067
14	3.50	18	0.60	400	45	69.263	0.547	326.68	36.810	50.282	-5.240
15	3.50	19	0.70	425	25	73.837	0.317	306.35	37.365	49.724	-9.979
16	3.75	15	0.90	375	45	73.387	0.290	301.56	37.312	49.587	-10.752
17	3.75	16	1.00	400	25	76.050	0.295	304.97	37.622	49.685	-10.604
18	3.75	17	0.60	425	30	69.283	0.283	303.26	36.813	49.636	-10.964
19	3.75	18	0.70	450	35	75.283	0.438	319.76	37.534	50.096	-7.171
20	3.75	19	0.80	350	40	76.080	0.293	304.33	37.625	49.667	-10.663
21	4.00	15	1.00	425	35	79.443	0.422	320.19	38.001	50.108	-7.494
22	4.00	16	0.60	450	40	68.050	0.492	322.21	36.657	50.163	-6.161
23	4.00	17	0.70	350	45	71.747	0.473	316.67	37.116	50.012	-6.503
24	4.00	18	0.80	375	25	75.853	0.383	304.54	37.599	49.673	-8.336
25	4.00	19	0.90	400	30	77.060	0.311	304.86	37.737	49.682	-10.145
Means						75.980	0.359	305.64	37.595	49.691	-9.188

Remark [a]Average of thrice replications.

The analytical results of the analysis of variance for TSS presented in Table 9 demonstrate that at the significant level 0.05 (P-value < .05) there is no parameter influencing the TSS of joint. However, when consider at the most influential parameter that affects TSS, the findings point out that Wire feed speeds *(Pb = 39.96%)* is ranked first, and orderly followed by Pulse frequency *(Pb= 15.65%)*, Travel speeds *(Pb = 7.27%)*, Peak currents *(Pb = 7.16%)* and Arc voltages *(Pb = 7.03%)*.

As shown in Fig 9. the result showed that the optimum conditions for the TSS of joint in the MIGPBP are Wire feed speeds at 4 m/min, Arc voltages at 18 V, Travel speeds at 0.6 m/min, Peak currents at 450 amp and Pulse frequency at 35 Hz. These optimum conditions resulted from the study retested to confirm their optimal conditions will be further.

Table 7 Results of ANOVA for S/N ratio of the ZB.

Analysis of Variance for SN ratios							
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P-value**	**P^b (%)**
Wire feed speed, *w*	4	1.172	1.172	0.293	10.92	0.02	14.79
Arc voltage, *v*	4	0.403	0.403	0.101	3.76	0.114	5.09
Travel speed, *s*	4	5.269	5.269	1.317	49.11	0.001	66.49
Peak current, *p*	4	0.520	0.520	0.130	4.85	0.078	6.56
Pulse frequency, *f*	4	0.453	0.453	0.113	4.22	0.096	5.72
Residual Error	4	0.107	0.107	0.027			1.355
Total	24	7.924					100

Remark [b]Percentage of contribution.

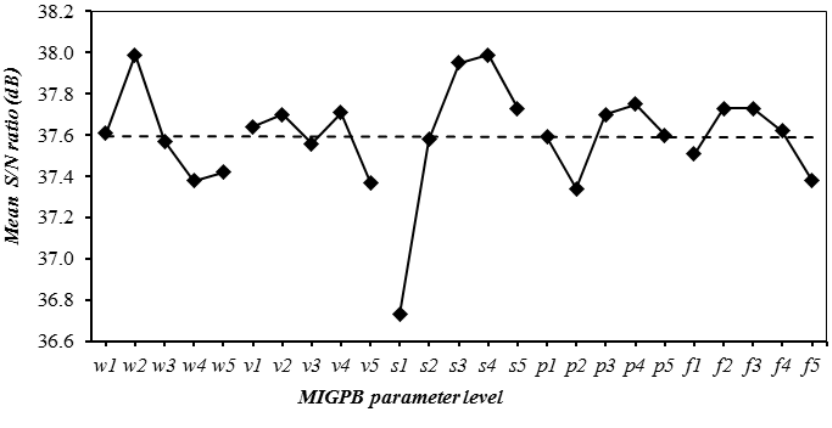

Fig. 7 Mean of S/N rations graph for ZB

Table 8 Results of ANOVA for S/N ratio of the ARP.

Analysis of Variance for SN ratios							
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P-value**	**P^b (%)**
Wire feed speed, *w*	4	4	21.65	21.65	5.41	0.71	16.80
Arc voltage, *v*	4	4	16.49	16.49	4.12	0.54	12.80
Travel speed, *s*	4	4	14.33	14.33	3.58	0.47	11.12
Peak current, *p*	4	4	14.00	14.00	3.50	0.46	10.86
Pulse frequency, *f*	4	4	31.79	31.79	7.95	1.04	24.67
Residual Error	4	4	30.61	30.61			23.75
Total	24	24	128.87				100

[b] Percentage of contribution.

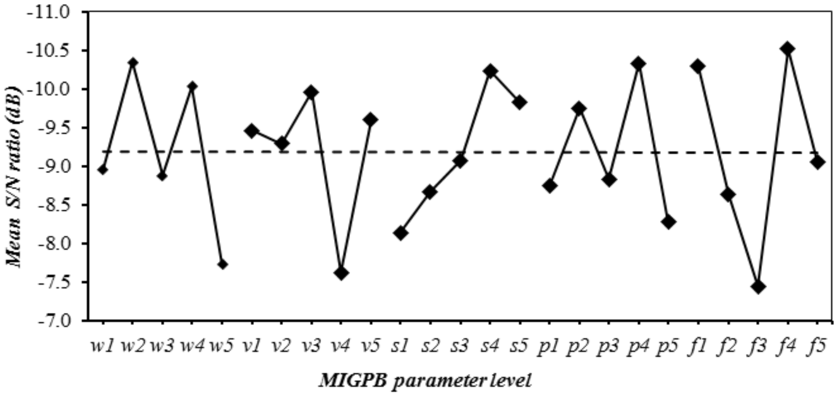

Fig. 8 Mean of S/N rations area for ARP

Correlations

The correlations between the factors of MIGPBP parameters are wire feed speed (*w*), arc voltages (*v*), travel speed (*s*), peak currents (*p*) and pulse frequency (*f*). The ZB, ARP and TSS were obtained by multiple linear regressions as follows:

$$ZB = 76.267 - 3.581(w) - 0.488(v) + 20.675(s) + 0.0157(p) - 0.065(f): R\text{-}Sq = 46.7 \quad (4)$$

$$ARP = 0.217 + 0.0448(w) + 0.0043(v) - 0.208(s) + 0.000090(p) + 0.00123(f): R\text{-}Sq = 15.1 \quad (5)$$

$$TSS = 236.491 + 9.154(w) + 2.347(v) - 22.126(s) + 0.041(p) - 0.030(f): R\text{-}Sq = 12.2 \quad (6)$$

Table 9 Results of ANOVA for S/N ratio of the TSS.

Analysis of Variance for SN ratios							
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P-value**	**P^b (%)**
Wire feed speed, *w*	4	2.4095	2.4095	0.6024	1.74	0.302	39.96
Arc voltage, *v*	4	0.4239	0.4239	0.1060	0.31	0.861	7.03
Travel speed, *s*	4	0.4382	0.4382	0.1096	0.32	0.854	7.27
Peak current, *p*	4	0.4320	0.4320	0.1080	0.31	0.857	7.16
Pulse frequency, *f*	4	0.9438	0.9438	0.2360	0.68	0.640	15.65
Residual Error	4	1.3821	1.3821	0.3455			22.92
Total	24	6.0296					100

Remark [b]Percentage of contribution.

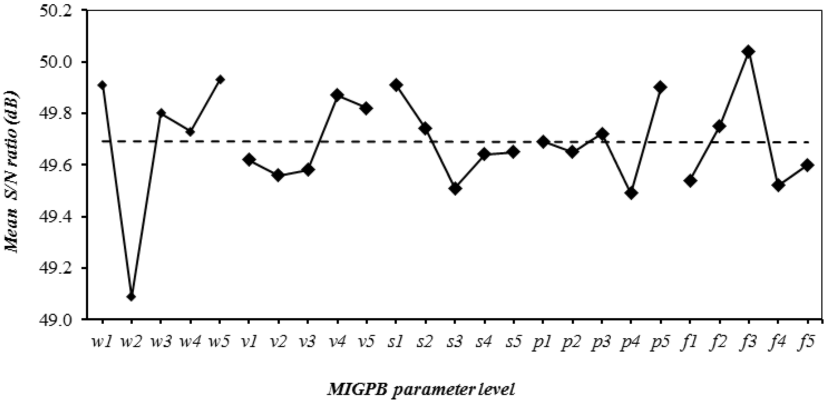

Fig. 9 Mean of S/N ratios graph for the TSS

4. Confirmation tests

Table 10, 11 and 12 provide a comparison of means of S/N ratio from multiple linear regressions (equation 4 - 6) and from experiment. In the MIGPBP, means of S/N ratios of the ZB, ARP and TSS of joint, derived from the multiple linear regression, are 38.789 dB, -2.458 dB, and 50.888 dB respectively and those derived from the experiment are 38.429 dB, -4.731 dB, and 50.510 dB. These results obviously point out that values from the equations are almost similar to those from the experiment.

Furthermore, comparisons between results from the experiment and from the L_{25} orthogonal array reveal that means of S/N ratio of the ZB, ARP and TSS of joint in the MIGPBP of the galvanized steel sheets rise up 0.055 dB, 0.509 dB, and 0.228 dB, or increase 0.14%, 9.71%, and 0.45%, respectively.

Table 10 Results of the confirmation experiment for ZB.

MIGPB performance	Initial MIGPB parameters	Optimal MIGPB parameters	
		Model, Eq. (4)	Experiment
Level	*w*2 *v*3 *s*4 *p*5 *f*1	*w*2 *v*4 *s*4 *p*4 *f*3	*w*2 *v*4 *s*4 *p*4 *f*3
ZB (%)	82.92	78.84	83.45
S/N ratio (dB)	38.374	38.789	38.429
Improvement of S/N ratio = 0.055 dB.			

Table 11 Results of the confirmation experiment for ARP.

MIGPB performance	Initial MIGPB parameters	Optimal MIGPB parameters	
		Model, Eq. (5)	Experiment
Level	*w*3 *v*4 *s*1 *p*3 *f*5	*w*5 *v*4 *s*1 *p*5 *f*3	*w*5 *v*4 *s*1 *p*5 *f*3
ARP (mm^2)	0.547	0.432	0.580
S/N ratio (dB)	-5.240	-2.458	-4.731
Improvement of S/N ratio = 0.509 dB.			

Table 12 Results of the confirmation experiment for TSS.

MIGPB performance	Initial MIGPB parameters	Optimal MIGPB parameters	
		Model, Eq. (6)	Experiment
Level	*w*3 *v*4 *s*1 *p*3 *f*5	*w*5 *v*4 *s*1 *p*5 *f*3	*w*5 *v*4 *s*1 *p*5 *f*3
TSS (MPa)	326.68	318.99	335.34
S/N ratio (dB)	50.282	50.888	50.510
Improvement of S/N ratio = 0.228 dB.			

However, There are also related researches, Haragopal, P. et al. [7] applied Taguchi's experimental design in mixed welding process. They studied the factors such as wire feed speed, travel speed, arc voltage. The results indicated that the factor affecting heat input which directly affecting the quality of joints.

According to the study conducted by Sukhomay Pal et al., [13] Taguchi's experimental design was used with GMAW-P process. The material used in this study was mide steel. The factors used in this study are wire feed speed, travel speed, pulse frequency, table feed rate and arc voltage. Results indicated that the level adjustment for each factors could affecting the completeness of each joint. Pulse frequency and arc voltages have effect on geometry of the joint and the mechanical properties.

In addition, P. Srinivasa Rao, et al., [20] studies the GMAW-P process and the best factor. Material used in their study is mide steel plate. The factors such as wire feed speed, travel speed, pule frequency, peak current and arc voltage were employed in this study. It was found that travel speed, peak current and pule frequency have the greatest influences upon the shape of joints.

5. Conclusions

The aim of this research is to search for the optimal conditions of parameters in the MIGPBP of the galvanized steel sheets by applying the Taguchi method to analyze and design the orthogonal array. Based on the Taguchi method, L_{25} orthogonal array is developed to be the plan of experiment and data collection. In this research, indicators of the MIGPBP are the ZB, ARP and TSS of joint, wherein five observed parameters which are expected to influence the MIGPBP include wire feed speed (w), arc voltages (v), travel speed (s), peak currents (p), and pulse frequency (f). All experimental results are compared with each other to verify the optimal of parameters for the MIGPBP. The experimental results suggest that means of S/N ratio of the ZB, ARP and TSS of joint in the MIGPBP are 0.055 dB, 0.509 dB, and 0.228 dB respectively, which are the increased values in relation to those of the initial experiment.

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