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2015 IOP Conf. Ser.: Mater. Sci. Eng. 100 012042

(http://iopscience.iop.org/1757-899X/100/1/012042)

Parametric studies on tensile strength in joining AA6061-T6 and AA7075-T6 by gas metal arc welding process

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Abstract. Proper selection of the welding parameters can result in better joining. In this study, the effects of various welding parameters on tensile strength in joining dissimilar aluminum alloys AA6061-T6 and AA7075-T6 were investigated. 2 mm thick samples of both base metals were welded by semi-automatic gas metal arc welding (GMAW) using filler wire ER5356. The welding current, arc voltage and welding speed were chosen as variables parameters. The strength of each specimen after the welding operations were tested and the effects of these parameters on tensile strength were identified by using Taguchi method. The range of parameter for welding current were chosen from 100 to 115 A, arc voltage from 17 to 20 V and welding speed from 2 to 5 mm/s. L16 orthogonal array was used to obtained 16 runs of experiments. It was found that the highest tensile strength (194.34 MPa) was obtained with the combination of a welding current of 115 A, welding voltage of 18 V and welding speed of 4 mm/s. Through analysis of variance (ANOVA), the welding voltage was the most effected parameter on tensile strength with percentage of contribution at 41.30 %.

1. Introduction

Gas metal arc welding (GMAW) process is a welding process which yields coalescence of metals by heating with a welding arc between a continuous filler metal electrode and the work piece. This method of welding is widely used in various industrial applications such as construction, piping and automotive sector [1-3]. The GMAW process is one of the most widely used in many industrial operations due to its comparatively easier handling, most cost effective and a variety of metals can be joined [4, 5]. Moreover, GMAW also offers the advantage of high deposition rate and high welding speed as well as deeper penetration because of high heat input [6, 7].

Arc welding of aluminum alloys with different grades will give problems due to the difference in thermal conductivity. The heat produced by the arc will flow more easily in the material with the larger thermal conductivity. This can result in lack of fusion of this material, at the same time an excessive melting at the material with lower thermal conductivity [6]. Luijendijk, have successfully studied about GMAW method on dissimilar aluminum alloys 5xxx series and 6xxx series [6]. Recently, Guo et al. been studied about joining dissimilar AA6061 and AA7075 by friction stir (FSW) [7]. However, the information about joining AA6061 and AA7075 by GMAW process is scarce.

Heat treatable AA6061-T6 (170 W/mK) and AA7075-T6 (130 W/mK) with its different thermal conductivity pose a challenge in obtaining good weld bead quality [8]. This is particularly evident when joining these dissimilar aluminum alloys together. The problems such as cracks, burn through and distortion is predicted to occur [9]. The input parameters such as welding current, welding voltage and welding speed play a very important factor in order to produce high quality of the joining [10]. Thus, this parameter should be estimated and their effect on the output joint quality should be investigated in order to achieve the optimum output and to mitigate the defects.

IOP Conf. Series: Materials Science and Engineering **100** (2015) 012042 doi:10.1088/1757-899X/100/1/012042

The aims of this study is to investigate the effect of process parameters such as welding current, welding voltage and welding speed on tensile strength on AA6061-T6 and AA7075-T6 by using the GMAW process. The highest tensile strength values of the processes parameter is obtained by analyzing the raw data for each of the specimen by using Taguchi method.

2. Experimental set up

For the experimental study, both materials AA6061 - T6 and AA7075 - T6 were prepared by cutting in to dimensions of 150 mm × 100 mm × 2 mm. The chemical compositions of both aluminum alloys and the filler are presented in table 1. Then, they were welded using a butt joint configuration with filler ER5356 by using a semi-automated GMAW machine model Dr Well DM-500 as shown in figure 1. The welding table is controlled with a touch screen welding program interface. All welded specimens were cut in to the standard dog bone shape using the American society for Testing of Materials (ASTM-E809) standards [11]. For each of experimental level, three tensile specimens were prepared.
In this experimental study, the Taguchi method is used for optimization of process parameters of GMAW of dissimilar aluminum alloys. Taguchi approach is a robust design method that uses experimental design called orthogonal arrays (OAs). Taguchi method is to study a large number of decision variables with a small number of experiments [12, 13]. By using and understanding the Taguchi method, welding quality and experimentation process were developed and improved. The range of parameter of welding current, welding voltage and welding speed were obtained by several preliminary experiments. The parameters (factors) and its levels are shown in table 2. Table 3 shows the L16 orthogonal array (OA) which were selected for the analysis.

Table 1. Chemical composition of aluminum alloys and filler wire.

Alloy	Al	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ni	Ti
AA6061-T6	97.30	0.79	0.43	0.30	0.03	0.86	0.01	0.18	<0.01	0.03
AA7075-T6	89.8	0.07	0.27	1.60	0.02	2.28	5.58	0.21	0.01	0.03
ER5356	Bal	0.03	0.15	0.01	0.14	4.83	0.01	0.11	---	0.09

Table 2. Process parameters and their levels.

Process Parameters	Levels of factors			
	1	2	3	4
Welding Current (A)	100	105	110	115
Welding Voltage (V)	17	18	19	20
Welding Speed (mm/s)	2	3	4	5

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Figure 1. The welding machine and its apparatus used in experiments (a) welding gas, (b) wire feeder and (c) welding table.

Table 3. L16 Orthogonal Array.

Experimental run	Welding current (A)	Welding voltage (V)	Welding speed (mm/s)
1	100	17	2
2	100	18	3
3	100	19	4
4	100	20	5
5	105	17	3
6	105	18	2
7	105	19	5
8	105	20	4
9	110	17	4
10	110	18	5
11	110	19	2
12	110	20	3
13	115	17	5
14	115	18	4
15	115	19	3
16	115	20	2

3. Results and Discussion

Figure 2 shows some of the weld appearance for the different combinations of parameter. All samples show good quality joints with minimal weld defects.

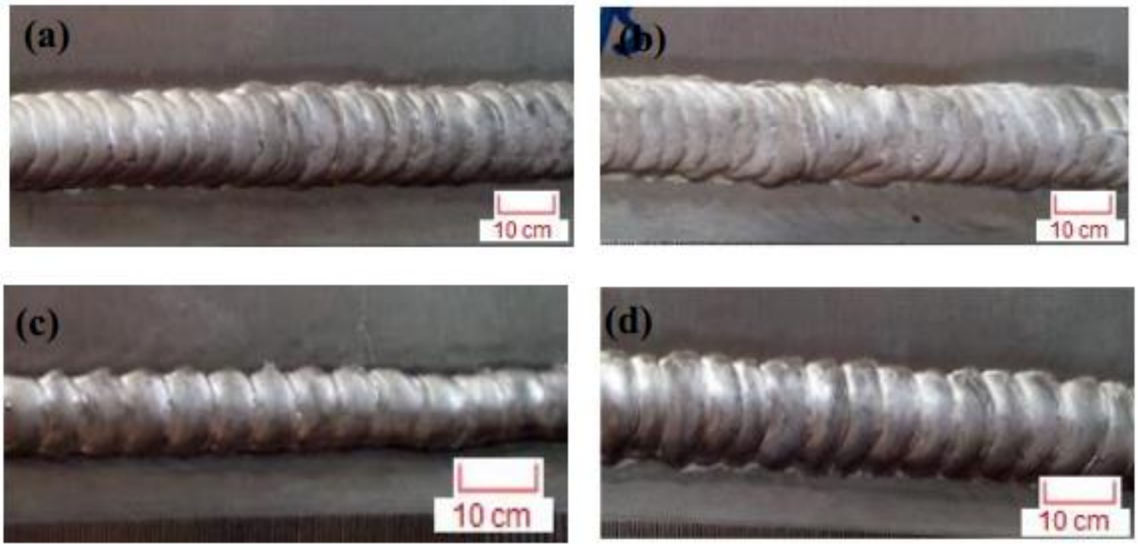

Figure 2. Weld appearance of specimens (a) specimen 1, (b) specimen 6, (c) specimen 9 and (d) specimen 14.

3.1. Parameter optimization

In order to investigate the effect of process parameters of the GMAW process, the tensile strength of the welded specimens were observed. In the Taguchi method, a loss function is defined to calculate the deviation between the experimental value and the desired value. Usually, there are three categories of the quality characteristic in the analysis of the signal-to-noise ratio, that is, the-lower-the-better, the-higher-the-better, and nominal-the-better [14-17]. Analysis of mean and signal-to-noise (S/N) ratio for each experiment collectively can generate and suggest the optimum level of process parameters to obtain the highest tensile strength of the weld. Therefore, this investigation focused on the-higher-the-better optimization analysis. All response was calculated as a follows:

$$S/N = -10\log 10\ [1/n \sum (1/y2)] \qquad (1)$$

Where n is number of experiment, in this case is 16 and y is the experimental value of the quality characteristic.

Mean responses of raw data and S/N ratios of tensile strength for each parameter are calculated and tabulated in table 4. The effect of process parameters on tensile strength were identified by obtaining the main effects plot for mean S/N ratios which expressed are in figure 3. The graphs show the level effects of each welding parameter on tensile strength.

In figure 3 (a), the mean S/N ratio shows an upward trend from 100 A to 115 A with only a negligible decrease at 105 A, indicating an overall increase in weld strength with the increase of welding current. Meanwhile, not recognizable pattern can be seen in figure 3 (b), where the S/N value increase from 17 V to 18 V, and began to decrease at higher voltage value. The decrease in S/N ratio value at higher voltage is due to excessive heat given to the work piece causing the joint to receive an excessive penetration, consequently creating defects due to high penetration. On the other hand, insufficient penetration is occurred at low value of welding voltage, also causing a decrease in tensile strength. The welding speed effect on tensile strength is clearly plotted in figure 3 (c). It showed that, the tensile strength value is low at the slowest (2 mm/s) and fastest (5 mm/s) welding speed. The highest tensile strength is obtained at welding speed of 4 mm/s and slightly lower at welding speed of 3 mm/s.

The response for S/N ratios and mean results were tabulated in table 5. It can be seen that, welding voltage is the most important parameter in order to obtain the optimum joint quality. This is followed by the welding speed and the welding current, in that order.

Table 4. Data summary for tensile strength.

Experimental run	WC	WV	WS	Tensile strength	S/N ratio for TS
1	100	17	2	182.37	45.2191
2	100	18	3	186.92	45.4331
3	100	19	4	182.70	45.2348
4	100	20	5	179.45	45.0789
5	105	17	3	185.02	45.3444
6	105	18	2	184.45	45.3176
7	105	19	5	180.21	45.1156
8	105	20	4	180.51	45.1300
9	110	17	4	186.82	45.4285
10	110	18	5	184.67	45.3279
11	110	19	2	180.84	45.1459
12	110	20	3	184.80	45.3340
13	115	17	5	184.24	45.3077
14	115	18	4	194.34	45.7712
15	115	19	3	187.21	45.4466
16	115	20	2	181.34	45.1699

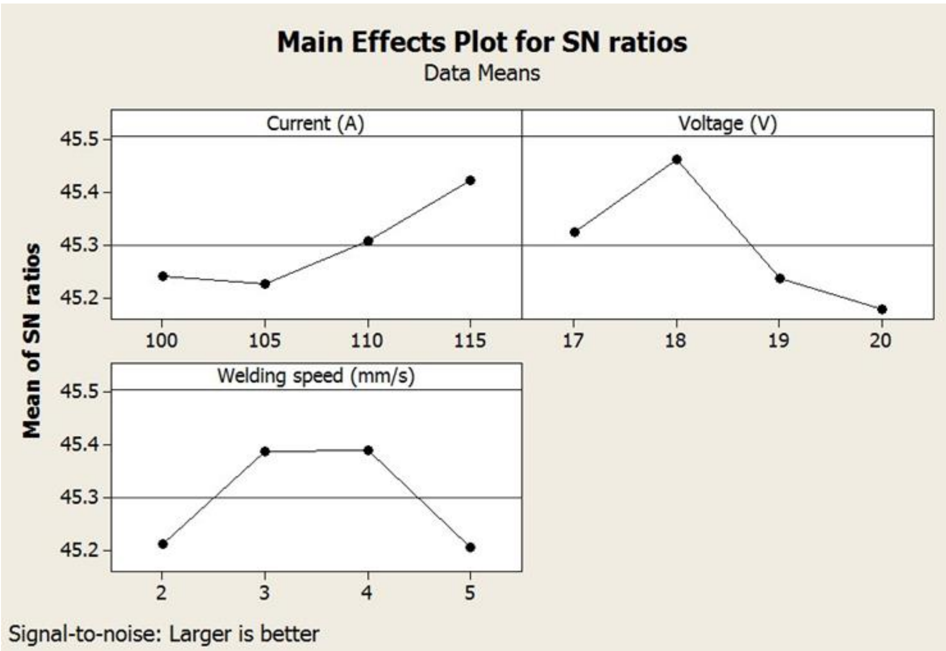

Figure 3. Main affects plots for means (tensile strength).

Table 5. Response for S/N ratios and mean.

Level	Response data S/N rations for Tensile Strength		
	WC	WV	WS
1	45.21	45.32	45.24
2	45.39	45.46	45.23
3	45.39	45.24	45.31
4	45.21	45.18	45.42
Delta	0.81	0.28	0.20
Rank	3	1	2

3.2. Analysis of Variance (ANOVA)

The effects of different welding parameters on tensile strength were obtained by ANOVA. The most influences parameter on output process can be identify by ANOVA [18]. In the analysis, the sum of squares and variance are calculated. The ANOVA result is tabulated in Table 6 showed the sum of square (S), variance, F-ratio (F), P-value (P) and percentage of contribution (%C) were calculated. The percentage of contribution can be calculated by using equation below:

$$\% \mathrm{C} = \frac{\mathrm{SSd}}{\mathrm{SSt}} \tag{2}$$

First, statistically, F-ratio named after Fisher [19], is used in order to find out the significant factors that affecting the welding process. In analysis, the larger the F value specifies that the variation of the process parameter makes a big effect on the quality in terms of tensile strength in welding process [18, 20, 21]. Welding voltage has the highest F value with 10.53 verified welding voltage is the most influenced factor as ranked as shown in table 5. Meanwhile, for P-value, it is to verify the significance of factors. In this case, at 90% confident level, P-value should be <0.1. In descending order, the percentage of factors contribution was identified with; welding voltage (41.30%), welding speed (29.12%) and welding current (21.73%) at residual error of 7.85%, welding voltage was proven to be dominant factor.

Table 6. Analysis of variance (ANOVA) for S/N ratios

Source	DF	Sum of square (S)	Variance	F-ratio (F)	P-value (P)	%C
Current (A)	3	0.09677	0.09677	5.54	0.037	21.73
Voltage (V)	3	0.18393	0.18393	10.53	0.008	41.30
Welding Speed (mm/s)	3	0.12970	0.12970	7.42	0.019	29.12
Residual error	6	0.03495	0.03495			7.85
Total	15	0.44534				100

S/N : Signal-to-noise; ANOVA: Analysis of variance

S= 0.07632, R-Sq=92.2% and R-Sq(Adj)=80.4%

4. Conclusion

In this paper, the effect of process parameter in GMAW dissimilar aluminum alloys sheets on tensile strength was successfully conducted. The conclusion that can be made based on the results obtained in the investigation, welding voltage is the most highly effective parameters that control the weld strength, whereas, welding current and welding speed are slightly less effective factors. The percentage of contribution of parameter is determined by using ANOVA. Through ANOVA, welding voltage was found to be dominant contribution with 41.30 %. The highest tensile strength obtained by Taguchi method in combining these three factors are experimental number 14 at welding current of 115 A, welding voltage of 18 V and welding speed of 4 mm/s with calculated highest tensile strength value of 194.34 MPa

Acknowledgement

The author would like to thank Mr. Rafiqul, Mr. Ihsan and Mr. Naqiudin for technical supports. Also,financial support through Fundamental Research Grant Scheme, project no. FRGS/1/2013/TKOI/UMP/02/2 is gratefully acknowledged

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