

## PARAMETER OPTIMIZATION OF PREHEATING METHOD ON ALUMINIUM-STAINLESS STEEL METAL INERT GAS (MIG) DISSIMILAR WELDING

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**Abstract.** This paper investigates the parameter optimization of a preheating method on stainless steel SUS304 prior to aluminium-stainless steel dissimilar welding. The welding method used was metal inert gas (MIG) with butt joint type weld. The Taguchi L9 orthogonal array was used to investigate the optimum parameter, while the mechanical strength was investigated using tensile test. Optimum levels of the process parameters were analyzed using the Taguchi parametric design approach. Parameter analysis of the tensile test results indicate that the preheated specimen with 90 °C have the maximum ultimate tensile strength of 111.27 MPa. This value is in close proximity to the calculated value of 109.02 MPa with 2% error. Through analysis of variance (ANOVA), the welding current was the dominant contributing factor with 40%. It can be concluded that the highest tensile value (111.27 MPa) for AA6061-SS304 dissimilar welding was obtained using 90 °C preheating, voltage of 17.5 V and current of 110 A of current.

### Introduction

Metal inert gas (MIG) welding is a prominent fusion welding method and is widely used in various industrial applications such as in shipbuilding, construction and automotive sector. To meet new industrial demands, a new welding technique known as dissimilar welding was introduced in the market. Such technique opens the possibilities to join metals of dissimilar alloy or material together to form a unique part. Dissimilar welding research have seen many successful joining of different materials to aluminium, such as aluminium to steel [1], aluminium to copper [2], aluminium to magnesium [3] and aluminium to titanium [4]. Out of the many combinations, dissimilar welding between aluminium and various steel alloys has been one of the most widely studied upon. This is primarily due to the high strength and toughness characteristics of steel alloys that compliments well with the low cost, light weight and corrosion resistant characteristic of aluminium alloys [5], [6].

However, such combination is difficult due to the near zero solubility and the stark contrast of the melting temperature between aluminium and steel. Consequently, this facilitates the formation of a notorious  $Fe_xAl_y$  brittle intermetallic (IMC) compound between the two metals during welding [7], [8].

To mitigate the formation of such brittle structure, several researches have proposed the use of preheating prior to the welding process. Shah et al. [9] and Razak [10] have conducted the preheating method on tungsten inert gas (TIG) dissimilar welding AA1100-SUS304 and AA6061-SUS304, respectively, and both results have shown an increase in the tensile strength of the joint when steel is preheated up to 150 °C. Other researches by Kreimeyer and Vollertsen [11] as well as Bang et al. [12] also suggested a secondary heat source in order to preheat the steel counterpart prior to welding to enhance the joint strength output.

However, most of the papers mentioned above did not report on how the crucial welding parameters were systematically chosen to perform the task. It is therefore important that parameter optimization using parametric design and statistical means needs to be utilized in order to produce a

replicable outcome [13][14]. In this research, the Taguchi parametric design was utilized to perform AA6061-SUS304 MIG dissimilar butt joint welding with the preheating method in order to investigate the optimum welding parameter for the best joint quality.

### Experimental method

The base materials used in this experiment are AA6061 aluminium alloy and SUS304 stainless steel alloy. Both materials were cut into  $150 \times 55 \times 2$  mm dimensions. The filler metal used was aluminium-based ER4043. The chemical compositions of both base metals and filler metal are shown in Table 1.

Table 1. Chemical composition of base metal AA6061 and SUS304 (wt.%)

Composition	Mg	Si	Mn	Fe	Cu	Cr	C	Al
AA6061	0.775	0.643	0.073	0.303	0.236	0.191	-	Balance
SUS304	-	0.397	1.01	71.4	0.21	17.9	0.06	0.004
ER4043	0.05	5.0	0.05	0.3	0.12	-	-	Balance

The joining process was carried out by using an automated welding apparatus utilizing the Dr Well DM-500EF MIG welding machine. Once the base metals are clamped accordingly, a mobile torch was employed to preheat the stainless steel sheet to the desired temperature. An electronic thermometer was used to monitor the elevated temperature. After it has reached the desired temperature, butt joint type MIG welding was immediately commenced. All fabricated specimen were cut into the standard dog bone shape using the American Society for Testing of Materials (ASTM E8-09) guidelines and underwent tensile testing to evaluate the specimen's strength.

In order to investigate the optimum welding parameters, a Taguchi L9 orthogonal array (OA) was utilized. The preheating temperature as well as the welding's voltage and current are set as the main parameters to observe. Table 2 shows the three levels for the three factors.

Table 2. Three levels of preheating temperature, voltage and current.

Factors	Level 1	Level 2	Level 3
Preheating temperature ( $^{\circ}\text{C}$ )	90	180	270
Voltage (V)	17	17.5	18
Current (A)	105	110	115

### Results and discussion

Fig. 1 shows the weld appearance for the different temperature groups. All samples show good quality joints with minimal weld defects, with Figure 1(a) (preheating of  $90^{\circ}\text{C}$ ) showing the best overall appearance.

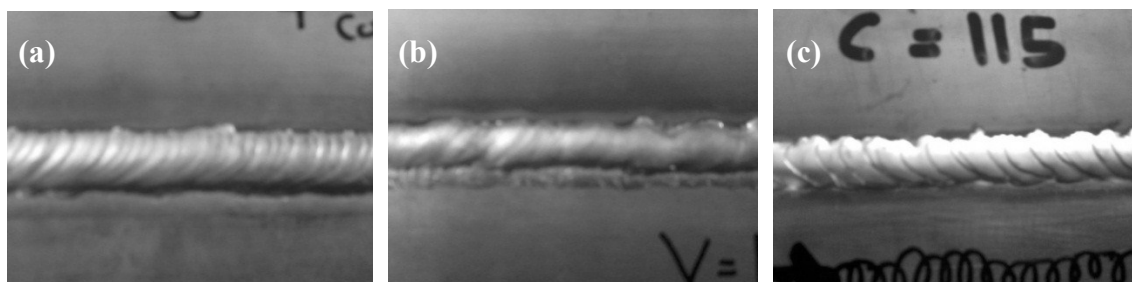


Fig. 1. Weld appearance of specimen with preheating temperature of (a)  $90^{\circ}\text{C}$  (b)  $180^{\circ}\text{C}$  (c)  $270^{\circ}\text{C}$ .

From the tensile test values, the larger-the-better S/N ratio can be calculated using Eq.1;

$$S/N = \eta_{dB} = 10 \log \left[ \frac{1}{\frac{1}{n} \sum_{i=1}^n \frac{1}{y_i^2}} \right] = -10 \log \left( \frac{1}{n} \sum_{i=1}^n \frac{1}{y_i^2} \right). \quad (1)$$

where the  $n$  represents the number of test and  $y_i$  is the experimental value [15]. Table 3 below shows the tensile strength mean value and S/N ratio for the L9 orthogonal array. It can be seen that the highest mean value is from specimen 2 with 111.27 MPa with 90 °C preheating temperature (level 1), 17.5 V welding voltage (level 2) and 110 A welding current (level 2).

Table 3. Tensile strength mean value and S/N ratio for L9 orthogonal array

Experiment	Joining Parameters			Mean value (MPa)	S/N ratio
	Preheating temperature (°C)	Voltage (V)	Current (C)		
1	<b>90</b>	17	105	104.53	40.385
2	<b>90</b>	<b>17.5</b>	<b>110</b>	111.27	40.928
3	<b>90</b>	18	115	66.46	36.451
4	180	17	115	95.04	39.558
5	180	<b>17.5</b>	105	88.34	38.923
6	180	18	<b>110</b>	89.28	39.015
7	270	17	<b>110</b>	60.53	35.639
8	270	<b>17.5</b>	115	80.97	38.166
9	270	18	105	82.67	38.347

The analysis above has shown the best parameter levels to achieve maximum tensile strength (highlighted in bold). Through this method, the optimum value of the tensile strength can be calculated using Eq. 2 below;

$$\begin{aligned} \text{Tensile strength (MPa)} &= PT_1 + WV_2 + WC_2 - 2T. \\ &= 104.52 + 111.266 + 111.266 - (2 \times 109.02) = 109.02 \text{ MPa}. \end{aligned} \quad (2)$$

where  $PT_1$  is the average tensile strength at 90 °C preheating temperature;  $WV_2$  is the average tensile strength at 17.5 V voltage;  $WC_2$  is the average tensile strength at 110 A current; and  $T$  is the overall mean of the tensile strength. Substituting the values calculated from Table 3, the highest tensile value was calculated to be 109.02 MPa.

Since the combination of  $PT_1$ ,  $WV_2$  and  $WC_2$  has already been conducted (sample 2), this value was found to be in excellent proximity to the experimental value of 111.27 MPa with only 2% error. The analysis of variance (ANOVA) was also conducted and show that the percentage of factors contribution was found to be, in descending order; current (47%), preheating temperature (30%), voltage (14%) and error (9%). Current and preheating temperature was proven to be the dominant factor.

## Conclusion

Dissimilar metals joints between AA6061 aluminum alloy and SUS304 stainless steel alloy were fabricated using MIG welding to investigate the parameter optimization analysis using the Taguchi method. All specimen show good weld appearance with minimal weld defects. The best weld appearance was from sample 2, with preheating 90 °C, voltage 17.5 V and current 110 A. Consequently, sample 2 also obtained the highest tensile strength of 111.27 MPa. Using the same factor levels, the calculated highest tensile value was shown to be 109.02 MPa, which is in excellent proximity to the experimental value with 2% error. Through ANOVA, welding current was found to be the dominant contributing factor with 40%.

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