Optimization of Angular Distortion on Weld Joints Using Taguchi Approach

by Amir Arifin

Optimization of Angular Distortion on Weld Joints Using Taguchi Approach

(Pendekatan Kaedah Taguchi untuk Mengurangkan Penyimpangan Angular pada Penyambung Kimpalan)

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ABSTRACT

Welding process is joining method which is extensively utilized in shipbuilding and automotive industry. Distortion is a classic problem encountered during the welding process which always occurs in welding processes. Distortion on weld joint involves many parameters that influence such as properties of materials and welding parameters. The objective of this work is to investigate effect of various processes of Shielded Metal Arc Welding (SMAW) on angular distortion in low carbon steel weld joints. To obtain optimum parameters of angular distortion, the effect various welding parameter is analysed using Taguchi Method. In this work, the effect of groove type, welding current and root opening are investigated for determining angular distortion. Taguchi method with L9 orthogonal array is utilized to analysed contribution for each parameter. ANOVA results revealed that the welding current the significant contribution parameter, on the other hand root opening shows minimum contribution to determine angular distortion value. Optimum parameter is obtained with groove type, welding current and root opening is X, 75A and 3 mm, respectively. Welding current parameter is considered the most significant contribution to determine for angular distortion effect due to has the highest contribution (50.04 %) than the other parameters groove type and root opening, with contribution value 21.76 %, 2.38%, respectively. Moreover, hardness test result on weld joint shows that X type groove has maximum hardness number than the other groove type.

Keywords: Taguchi Method; Angular Distortion; Carbon Steel

INTRODUCTION

Welding has played an important role in the construction of machinery and buildings. Welding is one of the methods of metal joining by liquefying some of the parent metal and filler metal with or without pressure and with or without filler metal. Shield Metal Arc Welding (SMAW) also known as manual metal arc welding is extensively utilized for fabricating the structural components due to flexibility of equipment and welding position (Alipooramirabad et al. 2017; Vasantharaja et al. 2017). Qualified and experienced welders contribute significantly to the quality of welded joints due to weld joint in SMAW defend on skill of the welder. Moreover, the selection of material and welding parameter are to be critical point for the quality of weld joint.

Distortion is defined as any change of desired shape or contour when the weld metal is allowed to move freely during the cooling process. Distortion on weld joint is one of classic issue which must be faced by welding fabricator (Papazoglou & Masubuchi 1978; Kim et al. 2015; Naik & Reddy 2016). The distortion causes the final shape of the weld joint does not correspond to the desired because of the distortion effects. Moreover stress distribution at weld joint is not uniform due to misalignment weld joint. Welding distortion provides unfavorable effects for the desired dimensional and shape accuracy. It would require additional work on fabrication which is increasing fabrication cost (Deng et al. 2013; Wang et al. 2016).

Distortion can be categorized to be three types comprising to transverse distortion, longitudinal distortion and angular distortion as shown on Figure 1. Angular distortion of weld joint is determined by some factors such as fusion zone dimension, type of joint, pass sequence of weld and material properties of material (Vinokurov 1977).
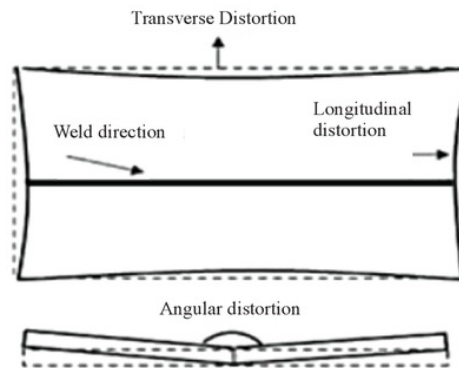

FIGURE 1. Various types of distortion on welded joints

Commonly distortion occurs in complex weld join where many suffered heat penetration of the electrodes. Heat input and cooling cycle play important role to determine deformation in welding joint (Kim et al. 2015; Guo et al. 2016). Furthermore, geometry of joint is significant parameters to determine evolution for microstructure and residual stress distribution of weld joint (Karadeniz et al. 2007; Kumar & Shahi 2011; Alipooramirabad et al. 2017). Figure 2 shows distribution profile of residual stress in butt weld. In the middle position of weld, maximum tensile stress (σ_m) occurred along the length of x axis with b as tension zone (Kou 2003). Moreover, residual stress contributes to the appearance of hydrogen-induced cracking and stress corrosion cracking.
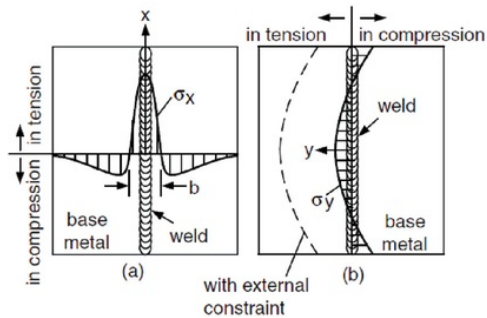

FIGURE 2. Distribution of residual stress in butt weld for longitudinal (a) and transverse direction (b) (American Welding & Phillips 1957)

Previous works have been conducted by some author to investigate welding parameter effect on the weld joint (Naik & Reddy 2016). Moreover, some efforts also have been done to predict weld joint deformation (Papazoglou & Masubuchi 1978; Akella et al. 2013; Kozak & Kowalski 2015). Not only in experiments but also in numerical analysis route has been massively investigated to predict weld joint distortion (Deng et al. 2013; Alipooramirabad et al. 2017; Nagaraju et al. 2017).

This paper focuses on the influence of SMAW weld process parameters for the angular distortion control. Taguchi optimization is utilized to obtain optimum condition for minimum distortion. Taguchi Method was developed by Genichi Taguchi has been applied widely in various manufacturing process to improve quality and reduce manufacturing cost (Unal & Dean 1991; Wang et al. 2016; Arifin et al. 2017; Mbuya et al. 2017). Moreover, Taguchi method is design of experiment (DOE) which is effective to reduce number of experiment (Cesarone 2001; Roy 2010).

Three parameters for welding parameter is involved to obtain optimum condition which consist of welding current, groove type and root opening. Using Taguchi method interaction and significant contribution of parameter welding can be determined (Hafeez et al. 2002).

METHODOLOGY

To achieve robust design for welding process, Taguchi method is utilized due to a more structured and efficient approach to obtaining a robust design compared to the full classic factorial design method (Hafeez et al. 2002; Fei et al. 2013; Vimal et al. 2015) . In this work Taguchi method is used to obtain optimum condition of minimum distortion for carbon steel plate. Welding parameters comprising to groove type, welding parameter and root opening can be shown on the Table 1.

TABLE 1. SMAW welding parameter

Factor	Level		
	1	2	3
Groove type	V	I	X
Welding current (I)	75	100	125
Root opening (mm)	2	3	4

L9 orthogonal array Taguchi method is suitable to apply for three factors with three levels as shown on the Table 2.

To get an accurate angular distortion results, dial indicator is utilized to measure weld joint distortion. Figure 2 shows a measurement scheme of angular distortion for low carbon steel plate.

TABLE 2. Taguchi L9 Orthogonal Array

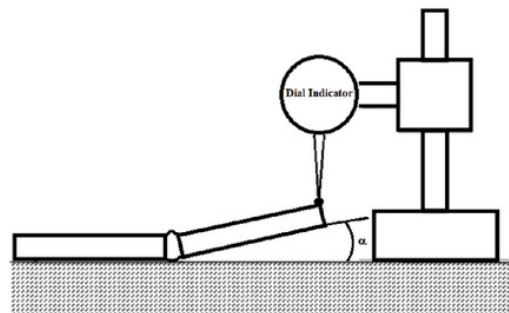| No	Factor			Experimental Value		
	A	B	C	Groove type (A)	Welding current (B)	Root opening (C)
1	1	1	1	V	75	2
2	1	2	2	V	100	3
3	1	3	3	V	125	4
4	2	1	2	I	75	3
5	2	2	3	I	100	4
6	2	3	1	I	125	2
7	3	1	3	X	75	4
8	3	2	1	X	100	2
9	3	3	2	X	125	3

FIGURE 3. Schematic of angular distortion measurement using a dial indicator

RESULTS AND DISCUSSION

SMAW method is utilized to weld low carbon steel plates in this work. SMAW is a welding method which relies on the welder skills. Accordingly all of welding is performed by certified welders. Dial indicator results were recorded with three time replication as shown on Table 3.

TABLE 3. Angular distortion measurement results

Factors			Replication		
A	B	C	Angular Distortion		
Groove type	Welding current	Root opening	θ	θ	θ
V	75 A	2 mm	0.242	0.308	0.264
V	100 A	3 mm	0.267	0.333	0.333
V	125 A	4 mm	0.354	0.516	0.393
I	75 A	3 mm	0.224	0.179	0.123
I	100 A	4 mm	0.263	0.222	0.278
I	125 A	2 mm	0.319	0.428	0.374
X	75 A	4 mm	0.213	0.168	0.146
X	100 A	2 mm	0.255	0.278	0.213
X	125 A	3 mm	0.275	0.264	0.297

Since the objective of this study is to reduce the angular distortion through optimum process parameters in SMAW, the smaller-the better quality characteristic is utilized in this work. The smaller-the better quality characteristic can be expressed as:

$$\frac{S}{N} = -10 \log \frac{1}{n} \sum_{i=1}^{n} y^2 i \qquad (1)$$

In order to obtain the optimum level of three parameters, Figure 3 is plotted S/N ratio response table for angular distortion. The maximum S/N ratio response value at each level has given at minimum angular distortion value.

ANALYSIS OF VARIANCE (ANOVA)

The objective of analysis of variance investigating significant parameters process on angular distortion. In this work groove type (A), welding current (B) and root opening (C) were evaluated in related factors to determine angular
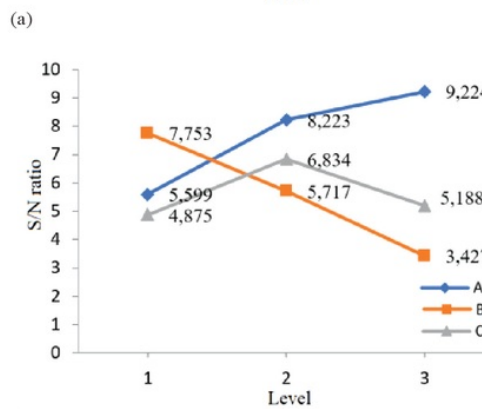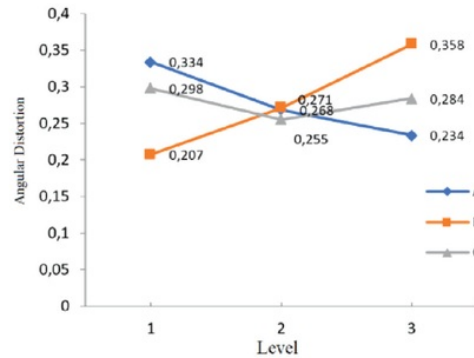

(a)

(b)

FIGURE 4 Response graphs of angular distortion (a) and S/N ratio (b)

distortion effect. The increasing of groove type (A) and root opening (C) level will decrease angular distortion value. On the other hand, the increasing level of welding current will increasing angular distortion.

Table 4 shows analysis of variance result after pooling is conducted. Welding current is the is the most significant factor for all angular distortion parameter studied. Welding current gives a contribution rate of 50 % for angular distortion, 21.7 % for groove type.

TABLE 4 ANOVA *result for* Angular distortion

Source	Pool	SS	DF	MS	F Ratio	SS`	Ratio (%)
A	Y	0,047	2	0.023	12,005	0.043	21,757
B	Y	0,102	2	0,051	26,308	0.099	50,035
C	Y	0,009	2	0,004	2,206	0.005	2,384
Error		0,039	20	0,002	1	120,039	25,824
Pooled		0.048	22	0.002			
SS_t		0.337	26	0.082		120,186	100
Mean		2,099	1				
SS_{total}		2,296	27				

ANOVA results show that the root opening does not give a significant contribution to determining angular distortion results. Table 2 also shows that the contribution error in this work is 25,824 % where such percentage means that all significant factors affect the average value; therefore, it is enough to be involved in the experiment. This is due to the requirement by Taguchi method that the contribution must be $\leq 50\%$. To obtain the optimum condition average of angular distortion based on "smaller the better" could be determined by Equation (1).

$$
\begin{aligned}
\text{Distortion}_{prediction} &= \overline{A3} + \overline{B1} + \overline{C2} - 2\bar{y} \qquad (1) \\
&= 0.234 + 0.207 + 0.255 - 2 \times 0.279 \\
&= 0.138°
\end{aligned}
$$

The 90% confidence interval (CI_{mean}) for the expected yield from the verification experiment can be determined by Equation (2) as,

$$
CI_{mean} = \pm \sqrt{F_{\alpha,v1,v2} . MS_e . \left(\frac{1}{neff} \right)} \qquad (2)
$$

$$
neff = \frac{number\ of\ experiment}{1 + DOF}
$$

$$
CI_{mean} = \pm 0.002
$$

The confidence interval for the optimum angular distortion value can be determined as $0.138° \pm 1.30°$. Based on analysis using Taguchi method welding current (B) is the critical factor to determine of distortion of weld joint which it is to be the main consideration to avoid distortion on the weld joint. The other hand, root opening (C) does not play an important role to determine for distortion of the weld joint. Welding current value represents the amount of heat input value causing thermal expansion.

HARDNESS DISTRIBUTION

Hardness distribution profile of groove type has been investigated using Vickers method. The carbon steel plates with three type of groove type (X, I and V) are welded using welding current 125°C. Figure 4 shows weld metal zone has maximum hardness number for each sample of groove type. Hardness numbers tend to decrease gradually to base metal zone which is a common trend for hardness distribution profile on weld joint (Kou 2003; Ragu Nathan et al. 2015; Nagaraju et al. 2017) .

Hardness result revealed that X groove type has maximum hardness value as shown on the Figure 4. Geometry groove of type X has large area for weld metal filler which is received more heat input than the other groove types. Peak temperature during welding is determined by heat input (Karadeniz et al. 2007). The increasing of peak temperature will increase cooling rate of weld joint. At a high cooling rate will form martensite phase having a fine grain structure which has a high hardness value (Callister & Rethwisch 2013; Alipooramirabad et al. 2017; Habibpour et
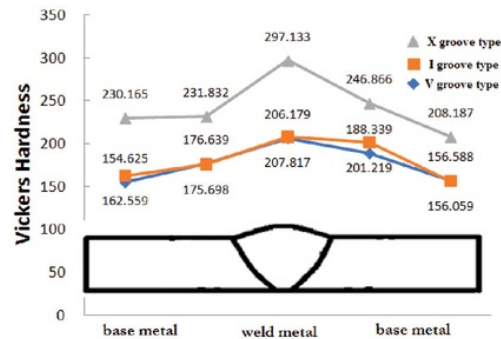

FIGURE 5. Hardness distribution of groove type with welding current 125°C

al. 2017). Moreover, residual stress distribution control is key parameter for angular distortion (Murugan & Gunaraj 2005). Homogeneity of thermal distribution will reduce residual stress on the weld joint. X groove type geometry is believed to facilitate homogeneity thermal distribution to reduce angular distortion. The highest hardness number on weld metal of X groove type indicate that material properties of weld join tend to brittle due to more martensite phase content.

CONCLUSION

Effects of parameter welding of angular distortion have been analyzed using Taguchi Method. ANOVA reveals that welding current is the significant contribution parameter and the other hand root opening shows do not give a significant contribution to determine the angular distortion. The optimum parameter is obtained by groove type, welding current and root opening is X, 75A and 3 mm, respectively. To improve weld joint of plate carbon steel in term of angular distortion, welding current is important role to minimize of distortion. The welder should highly consider determining the value of welding current to avoid distortion. Maximum hardness number was obtained on X groove type.

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