A Study on Prediction of Welding Quality for Vertical-position Welding Using Mahalanobis Distance Method

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ABSTRACT

A vertical-position welding is generally defined as a weld that is applied to a vertical surface or one that is inclined 45 degrees or less. Arc welding on a vertical surface is much more difficult than welding in the flat or horizontal position due to the force of gravity which caused to welding faults. Furthermore, welding faults will effect decreasing the quality of the weld. Until now, arc welding process has been employed to an off-line method to detect welding fault. Also, it is quite difficult to increase the productivity as well as to reduce the production cost. To solve those problems, optimal algorithm for on-line monitoring system which based on Mahalanobis Distance (MD) method was proposed in this study. First, three different setting of Contact Tip to Working Distance (CTWD) were chosen 15, 20 and 25mm and found the optimal CTWD for automatic welding process. It was confirmed that MD verification based on optimized CTWD could be achieved the good welding quality and bead geometries which satisfied American Welding Association (AWS) standard.

Keywords:

On-line monitoring system, Mahalanobis distance, Vertical welding, Welding quality, Fault weld.

1. INTRODUCTION

Welding process has widely been used in many engineering application such as industrial constructions, shipbuilding, piping to transport the fluid oil or water, renewable energy constructions. This welding process plays an important role in the engineering application. However, there are many welding positions in the welding process such as horizontal and vertical position so that each welding position has different problems.
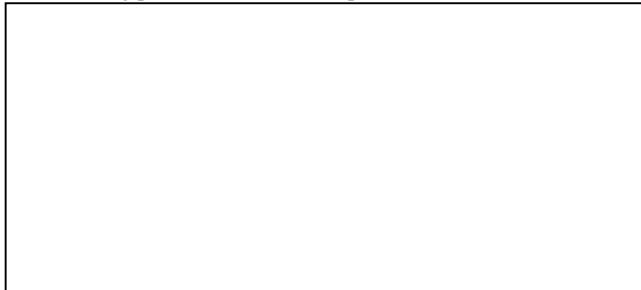
However, vertical welding process is much more difficult than welding in the horizontal position. Also, vertical welding position has been applied for large building structures.

The process of the vertical welding position has generally been done in either downward or upward position. The term of used, the vertical downward or vertical upward welding direction had different applications. The vertical downward has shallow penetration and the possibility burning through the metal is diminished. So that, it is suited for welding of the light metal. Furthermore, vertical downward welding is very important in production works due to its faster welding speed. The current setting in vertical arc welding should be less than those used for the same electrode in the flat position. The current setting for the vertical upward welding is slightly higher than this for the vertical downward welding on the same plate. In addition, the proper angle between the electrode and the base metal must be maintained to produce good weld. The electrode should hold at 90 degrees respect to base plate in vertical welding upward direction. The oscillated electrode can be applied when weaving is necessary. Furthermore, the welding fault in vertical welding process is likely more to occur than in the horizontal position due to the gravity force.

In arc welding process, the welding fault is normally detected using an off-line detection method so that the welding fault can be observed only after the welding process was finished, and hence it leaded to decrease productivity, and uncontrolled the welding quality during the welding process. Therefore, it is required the on-line techniques to detect the welding fault. Moreover the on-line welding fault detection method can be used as a feedback system to control the welding quality by optimizing the input parameters.

Process optimizing has also many advantages such as reducing cost of production, time saving and labors needed in a project. The final stage to optimizing the welding process is to apply for a welding automation system. The welding automation system with high in automatic degree, fast in welding speed, low in labor intensity, good in welded joint appearance and high in first-time welding pass rate, has been widely applied in recent years [1-7]. However, the accurate seam tracking, precise pipeline alignment and welding parameters optimizing have majorly been challenging for welding automation system. Optimizations of welding parameters have been focused to produce good and uniform bead geometry. In addition, the same welding parameters in different welding position will affect the different bead formation due to the influence of the gravity force [8]. Bead geometry as welding quality is influenced by the distribution and the amount of input energy on the workpiece surface area and the input energy dissipation in the workpiece[9]. In order to improve the welding quality and reduce production cost, it is important to

monitor the on-line welding quality automatically [10]. And hence, it is very important to implement an automatic on-line monitoring system to keep track of the welding process. Recently, a real-time welding controlling and quality monitoring systems is very important to avoid the welding fault on the workpiece as well as ensuring high welding quality [11]. To quantify the welding quality, it needed a method that can determine the welding fault by calculating the transformed welding current and arc voltage gained from on-line monitoring system. Afterward, the welding quality can be determined.

The simple and robust method to quantify the welding fault might be employed by MD which was developed by Mahalanobis an Indian famous statistician in 1936. Since this time, there are few studies that have investigated the on-line welding faults which based on the welding current and voltage distributions which based on MD [9-12]. Kim et al. [9] used MD method to perform the welding quality of pipeline in overlay welding process by analyzed the welding current and voltage waveform to find the welding fault. Feng et al. [10] performed the qualitative quantities analysis to find welding fault in GMA welding process using MD. The parametric approach were used to detect fault position in short arc by Li and Simpson [13]. The prediction of weld quality based on arc voltage variance was used by Adolfsson et al. [14].

As seen from the reviewed literatures [9-14], most of investigations were limited to control welding fault and welding quality on horizontal position. Therefore, this study takes into consideration to develop the optimal algorithm of CTWD on a vertical welding processes by analyzed the transformed welding current and arc voltage obtained from the on-line monitoring system using the MD method. The experimental data during the vertical welding process is 2500 data per second which is consist of transformed welding current and arc voltage. Variations of waveforms obtained from the experimental results were applied to find optimal CTWD in order to achieve best quality of the weld. Transformed welding current and arc voltage were analyzed to quantify the welding quality. Finally the algorithms developed through additional experiments were verified by using optimized CTWD setting.

2. EXPERIMENTAL PROCEDURES

All the experiments in this study were conducted using GMA welding process on bead-on-plat welding. The experiments were carried on SS400 steel plates of size 50x30x10 mm^3. The chemical compositions for base metal and filler wire are presented in Table 1. CO_2 was used as a shielding gas and also constant current power source is used. Just prior to welding, sheets were cleaned with fresh steel wire brush followed by acetone swabbing. The bead-on-plate welding was performed with a GMA welding process [15].

Table 1: Chemical composition for Base metal & filler wire.

Material	C	Si	Mn	Ti	P	S
Base metal (%)	0.17	0.54	1.40	0.07	0.045	0.045
Filler wire (%)	0.07	0.54	1.18	0.07	Al	Zr
					0.08	0.05

The experimental design for the welding process parameters using the three different CTWD is presented in Table 2.

Table 2: Experimental design.

Contact Tip to Work Distance	15, 20, 25 mm
Welding Position	Vertical
Welding direction	Downward
Electrode angle	75°
Welding voltage	25 V
Arc current	260, 270A
Gas Flow rate	18 l/min
Welding Speed	53 cm/min

To carry out the experiment, it begins with setting up of the equipment (as shown in figure 1), followed by the rectangular steel plate is positioned vertically which is held in fix jig to minimize the welding distortion during the welding process, and then positioning the welding torch to the plate as can be seen in figure 2.
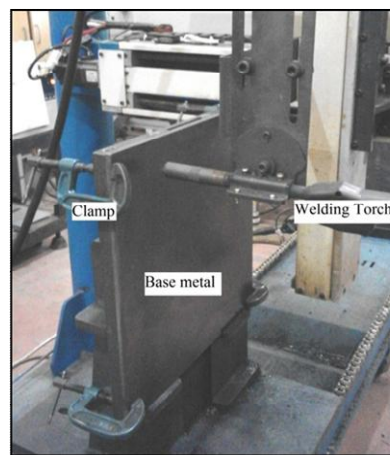

Figure 1: Overview of experimental setup.

Figure 2: Welding fixture of base metal and welding torch.

The arc voltage and welding current were set manually at the welding inverter and measured using the digital data acquisition system during welding process. The data acquisition system used a specifically designed power supply. Setting up experiment and establishing adequate operating condition should be required at initial trials. The GMA welding process might be applied for vertical position, in which the electrode moves from the top to downward direction which has programmed the welding speed.

After the welding process, the specimens were sectioned and polished with suitable abrasive and diamond paste.Then, the specimens were etched with nital and electrolytic to clearly reveal the bead geometry. The bead profiles were measured on the etched sample by optical microscopy. Bead geometry is characterized by the welding parameters[16]. The welding quality is quantified using MD method by calculating the experimental data related to welding current and arc voltage waveform obtained during the experiment.

To determining the welding fault, there are three steps; first step is setting up the threshold value (σ) of MD data. Second step, determining the welding fault referred to the threshold value 3σ[9]. Third step, is calculating the welding fault in every 0.25 second. Finally, quality of the vertical welding can be determined using the data of the welding fault percentage.

3. RESULT AND DISCUSSION

3.1 Development of optimal algorithm for CTWD setting

Figure 3 shows specimen which indicated the measured position to quantify the welding quality in order to determine the optimal CTWD. The specimen is divided into 2 different positions (start section and middle section) which indicated the marked 1 and 2.

Since welding quality at base metal are generally unstable for the initial and the end section area [11, 12], so that experimental data were selected 2 seconds after the start for the start section and the middle section at 20 seconds after the start.

The welding quality was calculated every 0.25 second which used 4 seconds for the selected data in every calculation. To quantify the welding quality, the reference was selected the experimental data for 2 to 6 seconds to CTWD at 15mm of start position.
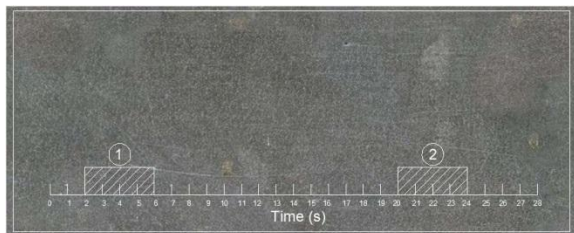

Figure 3: Measured position on weld base metal during welding process.

Figure 4(a) shows waveform of welding current and arc voltage of the start position at 15 mm. It can be found that the arc voltage and welding current waveforms from 0 to 1 second were great fluctuation in wave length, which continued stable with a small fluctuation up to 4 seconds. The middle position shown in figure 4(b) is indicated more stable waveform of arc voltage where fluctuations in wave length not much. However, there are more fluctuations in wave length of welding current from 2.5 to 4 seconds.

Figure 5(a) shows the fluctuation in wave length of arc voltage and welding current which had very high wave length about 0.75 to 1 second at 20 mm. While wave length of arc voltage continues with many fluctuations to 4 seconds. The welding current after 1 second, has been continued to oscillate more uniformly with few high fluctuations in wave length. The waveform of the arc voltage at figure 5(b) is better than those of arc voltage at the start position shown in figure 5(a). As shown in figure 5(b), the waveform of the welding current has few

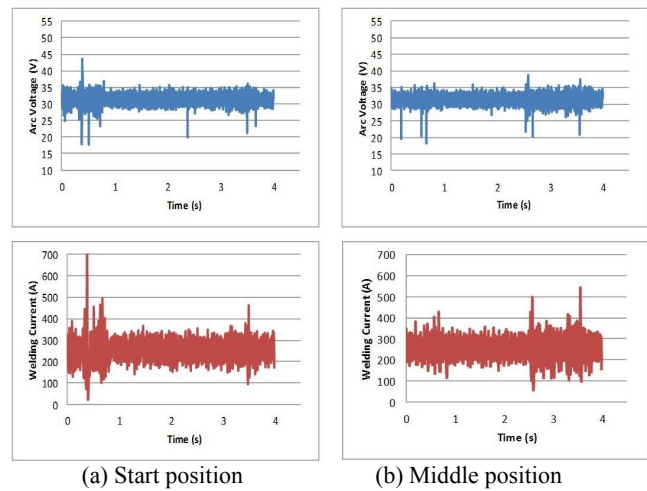fluctuations in wave length than those of arc current at the start position.

(a) Start position   (b) Middle position

Figure 4: Arc voltage and welding current waveform CTWD at 15mm.

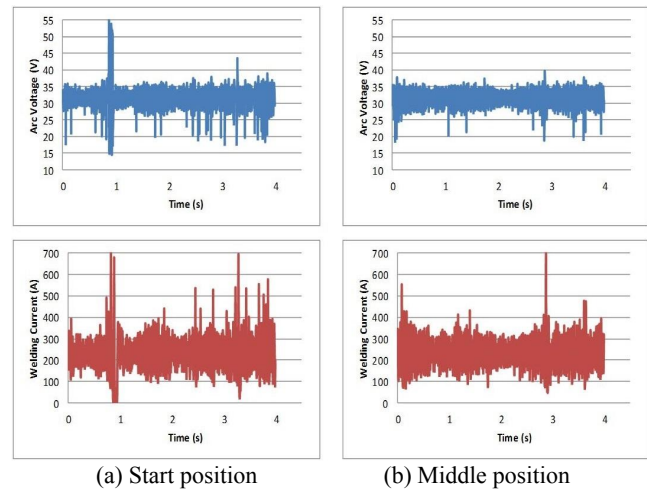(a) Start position   (b) Middle position

Figure 5: Arc voltage and welding current waveform CTWD at 20 mm.

It can be confirmed in figure 6 that waveform both welding current and arc voltage at the start and the middle positions for CTWD at 25 mm are more fluctuation in wave length. As the welding quality is affected by waveform both welding current and arc voltage, the fluctuated wave length indicated the welding fault has occurred [9].

All the waveform of welding current and arc voltage CTWD at 15 mm and 20 mm have similar pattern as well as waveforms at the middle position have more stable those at the start position as shown in figures 4 and 5.

Furthermore, increasingly fluctuating wave length of the welding current and arc voltage will cause higher welding fault and welding quality will be reduced. Therefore it can be concluded that the waveform both welding current and arc voltage CTWD at 15 mm are more stable than those two others.

To determine the quality of the weld, the transformed arc voltage and welding current obtained from the on-line monitoring system are employed to analyze using MD.
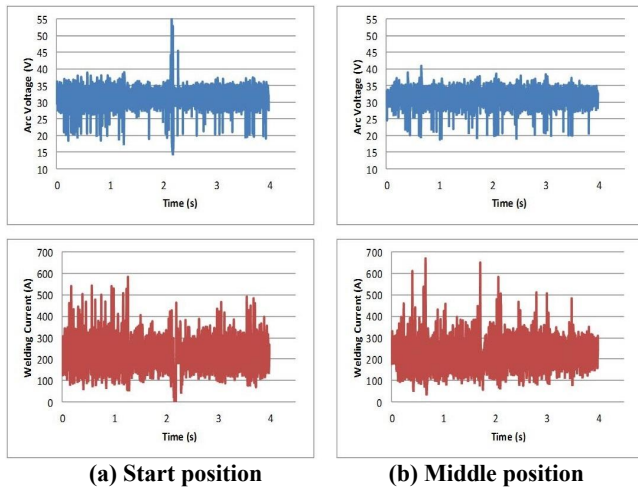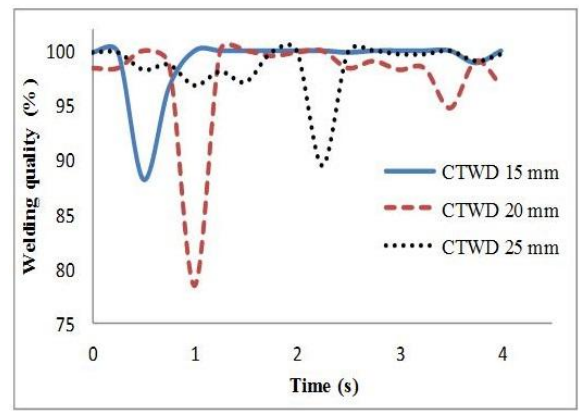
(a) Start position   (b) Middle position

Figure 6: Arc voltage and welding current waveform CTWD at 25 mm.

Figure 7(a) shows the results of compared the welding quality of three different setting of CTWD at the start position. It shows the lowest value of welding quality of CTWD at 15 mm is around 88% at 0.5 second and continues stable around 99% which the quality average is 98.96%. For CTWD at 20 mm, lowest value of welding quality is around 78% at 1 second and the average of the quality is 97.54%. The lowest welding quality for CTWD at 25 mm is 89% at 2.25 seconds and the average quality is 98.45%. It can be observed from three different setting that CTWD at 15 mm has highest welding quality at the start position.

The welding quality with three different setting of CTWD at middle selection is shown in figure 7(b). From the figure, the welding quality of CTWD at 15 mm has the lowest quality 94% at 2.75 seconds and the average quality 99.39%. While the welding quality of CTWD at 20 mm has average quality 99.37% with the lowest quality 95% at 3 seconds.

CTWD at 25 mm has lowest quality compared the others, also its average welding quality is 98.36%, and the lowest quality values is 95% at 0.75 second. As comparison CTWD at 20mm and CTWD 15mm, it looks like higher quality, but in fact it has lower quality as shown in figure 7(b). Furthermore, CTWD at 25 has lowest welding quality compared those of two others. The welding quality of the start position of CTWD at 15, 20, 25 mm are 98.96%, 97.54%, and 98.45% serially. The welding quality of middle position of CTWD at 15, 20, and 25 mm are 99.39%, 99.37% and 98.36% successively. According to Kim et al. [9] the threshold value of the welding quality are defined by 92.6%, so that all the welding quality in figure 7 (a) and (b) above the threshold value, therefore it confirmed as good quality. Based on observation of figure 7(a) and (b), it is still difficult to define the best of 3 different CTWD setting, and thus, the CTWD setting can clearly be represented in figure 8.

From the figure 8, it can be observed that the average qualities of the start and middle positions CTWD at 15 mm were 98.96% and 99.39% respectively. Also, the average qualities of the start and middle position CTWD at 20 mm indicated 97.54% and 99.37% respectively. Finally the average qualities for the start and middle position CTWD at 25 mm presented 98.45% and 98.36% respectively. From the observation, it is clearly indicated that the welding quality CTWD at 15 mm has highest welding quality both the start and middle position compares with those two others. Therefore, the optimal CTWD was chosen 15 mm.

(a) Start position
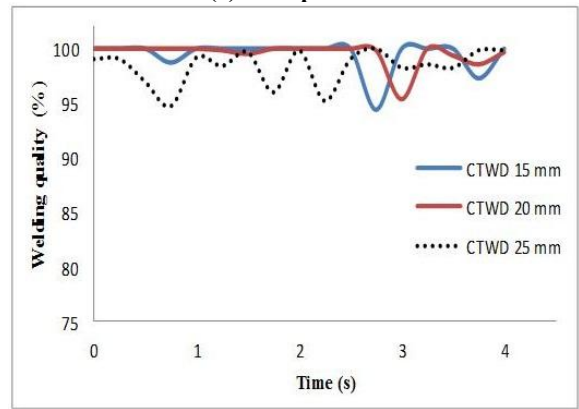
b) Middle position

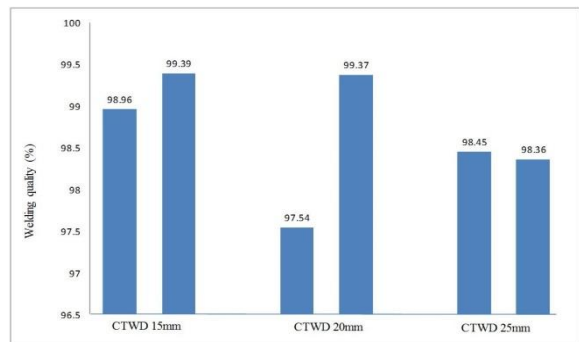Figure 7: Welding quality comparison among CTWD at 15, 20, 25 mm.

Figure 8: Welding quality comparison of CTWD at 15, 20, 25 mm.

3.2 Verification of the developed algorithm for optimal CTWD

The verification of the developed MD algorithm on vertical position welding to quantify the welding quality is using the fixed setting parameters and optimal CTWD at 15mm.

Figure 9 shows the position and bead geometry for analysis. The experimental data were taken 2 seconds before and after the points 1 and 2 so that each selected data has 4 seconds duration. At point 1(start position) and 2(middle position), the welded specimen is cut in the transverse direction for bead geometry analyzing.

Figure 10 represented the welding qualities obtained from the transformed welding current and arc voltage using MD analysis which the quality was calculated in every 0.25 second. The

quantified average welding quality in the start and middle positions are 98.12% and 98.18% respectively which is represented by dash line as seen in figure 10 (a) and (b), with the minimum quality in every 0.25 second is above 93%.
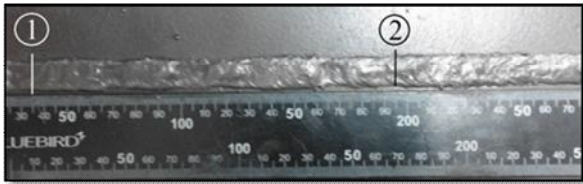

Figure 9: The positioned of data and weld beads selection for analysis.

As shown in figure 10, the welding quality is mainly affected by both arc voltage and welding current. The welding quality decreased when the wave length of arc voltage or welding current increased. And thus, by controlling the welding current and voltage on on-line monitoring system, the desired welding quality can be achieved.

The higher distance of wave length indicated the welding fault has occurred, but it is difficult to detect the fault which based on only one input parameter because there are two parameters that could effect on the welding quality, and hence it needs a tool to analyze at the same time both welding current and arc voltage data.
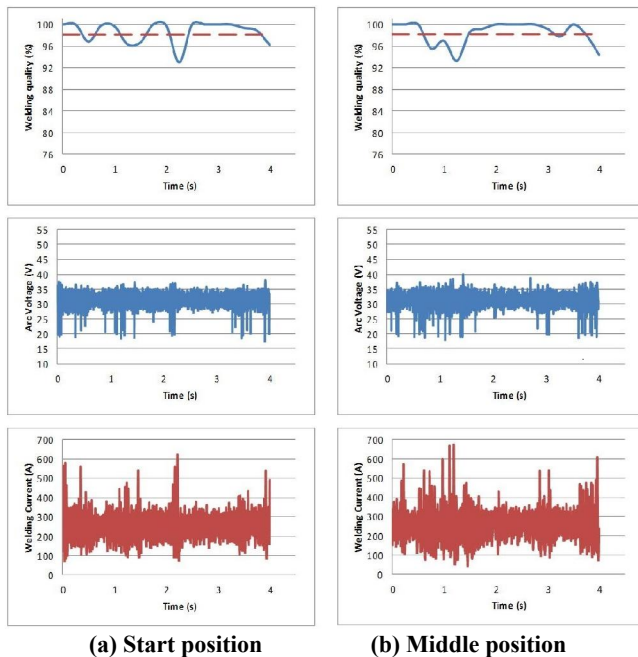

(a) Start position   (b) Middle position

Figure 10: Welding quality, arc voltage and welding current waveform of CTWD at 15mm.

Since MD offers the solution from existing problem by analyzing both welding current and arc voltage waveforms in simple way, the analyzed data can be used as a feedback to control the input parameters during the welding process. Also it can be confirmed to define the welding quality in relation to the welding fault on vertical position during GMA welding process. Therefore, it is can concluded that developed algorithm has advantage to detect the welding fault during on-line monitoring.

Table 3 shows the bead geometry of the start position has very good shape but the penetration is shallower than in the middle
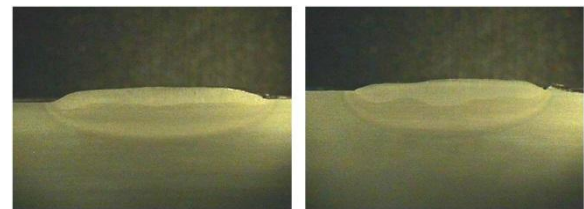
position. While at the middle position, the bead geometry is better than in the start position which has deeper penetration and lower of bead height. It was happened because of the typical initial of the welding process less stable compare to middle position of GMA welding process. Hence it can be cleared that the middle position is better than the starting position of the GMA welding process.

Table 3: Bead dimension and welding quality

Position	Bead Width (mm)	Bead height (mm)	Penetration (mm)	Welding Quality
1	18.69	1.46	0.62	98.12%
2	16.81	1.12	1.42	98.18%

According to American Welding Society(AWS) the maximum bead height (convexity) for the bead width between 8 to 25mm should be required less than 3mm [17]. According to table 3, the experimental results for bead width at start position and middle position are 18.69mm, 16.81mm in series, which the bead height are 1.46mm, 1.12mm in sequent, so that the all the bead height still below 3mm. Therefore the beads dimensions are in the AWS range.

As shows in figure 11, the shape of the weld surface is convex which desired shape than concave shape, because the concave weld surface, and internal shrinkage stresses will place the weld metal on the surface into tension. Furthermore it cause centerline cracking, conversely, and the internal shrinkage will pull the surface into compression on convex weld surface [18]. The illustrations are shown in figure 12. And thus, the concave weld surface should be avoided to diminish the crack possibility.

(a) Start position   (b) Middle position
Figure 11: Bead Geometry.

The bead dimension that has more penetration than bead width can be induced centerline cracking since when bead shape has more penetration than width to the weld cross section as illustrated in figure 13. The grains growth solidify perpendicularly to the surface of the steel intersect in the middle, but not gain fusion across the joint [18]. Hence, the each bead shape should be wider than it's deep to avoid bead shape induced cracking. The wider bead than its penetration will lead to a crack – free weld. As it can be observed in table 3 that the ratio between bead width and penetration are higher bead width values than penetration values. Since Omer et al [18] has recommended to avoid centerline cracking at least the ratio 1:1, the experimental result in table 3 is categorized as good weld bead.

Table 3 shows the welding qualities of the start and middle positions are 98.12% and 98.18% respectively in relation with the bead geometry. It shows welding quality predicted by MD method could be achieved good bead geometry that fulfilled AWS standard. Therefore, it can be concluded that increasing the welding quality are associated with an increased bead shape which is indicated by increasing the penetration and decreasing the bead width but the ratio still higher for the bead width.
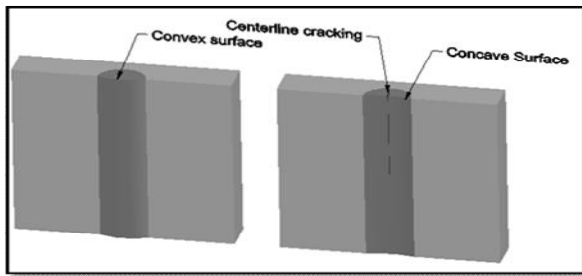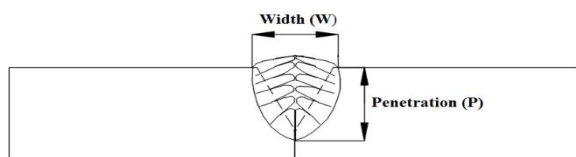
Figure 12: Surface profile induced cracking.

Figure 13: Bead shape induced cracking.

4. CONCLUSIONS

This study has been done the development of optimal algorithm employed MD to optimize the welding parameter on vertical welding process, and the following conclusion can be drawn.

(1) The optimal CTWD is at 15mm which achieved the highest quality of weld by using MD method whereas the welding quality 98.96% and 99.39%, because of the highest welding quality compared to CTWD 20 and 25mm which have the welding quality 97.54%, 99.37, 98.45% and 98.36% respectively.

(2) The verification of MD value which based on optimal CTWD was obtained the good quality of the weld which was indicated by good bead geometry that fulfilled to AWS standard. The quality of the weld that obtained from experiments using optimal CTWD setting is 98.12% and 98.18%. Furthermore, the increasing quality from start position to middle position also followed by the increasing the bead quality that represented by good bead geometry.

(3) The developed optimal algorithm is a novel method for vertical welding application, so that the welding quality can be manipulated by controlling the welding parameters for an on-line monitoring system, and thus, it is useful method as a core of welding control system.

For further study, it is recommended to use MD to define the correlation between the welding qualities and metal transfer especially on vertical welding process.

ACKNOWLEDGMENTS

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