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PREDICTION WELDING QUALITY IN MULTI-PASS WELDING PROCESS USING MAHALANOBIS DISTANCE METHOD

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Abstract: The welding quality in multi-pass welding is mainly dependent on the pre-heating from pervious pass or root-pass welding. In this study, a Mahalanobis Distance and normal distribution method is illustrated and employed to determine whether welding faults have occurred after each pass welding and also to quantify welding quality percentage. To successfully accomplish this objective, sets of multi-pass welding experiment were performed with different welding parameters in each pass; the welded samples of SS400 steel flats adopting the bead-on-plate technique were employed in the experiment. The result of current and voltage for each pass is obtained through the real time mentoring systems. In order to verify the effect of the performance and weld quality of the different weld-pass, Mahalanobis distances for voltage and current values were calculated and used for qualitative and quantitative analysis with comparison to values obtained from the root-pass as reference welds. The results of the experiment and statistical analysis have demonstrated that the weld faults after each weld pass is feasible.

Introduction

The welding quality monitoring and quantifying welding quality is extremely important to avoid welding defect and faults on the manufactured product. The ability to monitor the welding quality is automatically is important in order to reduce production cost and to assure and improve weld [1-6]. Due to recent increase in emphasis on assurance welding quality, a real time quality monitoring and controlling welding parameter is critically important to avoid welding faults on the workpiece [5]. If weldments used without determining welding fault and quality could pose a critical risk on the welding product.

There has been myriad statistical method used to determine the welding online faults; however there is very limited literature describing the welding quality on multi pass welding is with respect to the welding parameter and welding conditions. In previous researches, many studies have investigated the welding online faults based on the welding voltage and current. For instants, Shengqiang et. al [1] used the concept of Mahalanobis distance method to perform the qualitative and quantities analysis GMAW welding fault and compared with the reference weld. The welding voltage and current values were calculated and used for qualitative and quantitative analysis with comparison to values obtained from the reference welds. Furthermore, Adolfsson et. al. [3] used statistical method based on the variance of the arc voltage to predict weld quality. The method involved in the automatic monitoring of the weld quality produced by robotized short-arc welding.

In this study, a five pass GMA welding experiment is performed on SS400 steel plate. The welding current and arc voltage obtained from the mentoring system are analyzed using the Mahalanobis distance (MD) and normal distribution method to determine welding fault and quantified welding quality. During welding process the data obtained consist of transformed current and voltage with rate of 12500 data per seconds. The fault and good welding is determined using the concentration current and voltage during welding process. MD values are being calculated through the obtained data and compared between the fault and good weld.

Development of Mahalanobis Distance Algorithms

The proposed statistical method is to determine the welding quality based on Mahalanobis distance and normal distribution methods. Mahalanobis distance (MD) is mainly used effectively to calculate the similarity of two unknown samples that may have similar spatial orientation but may be located far part [7-8]. This method is different from Euclidian distance by means: first by maintaining the correlation between data, and second by in dependency from the measurement scale. The calculation of MD is described in the field of statistics, and is commonly used for multivariate outlier detection [9]. MD is superior to other multidimensional distance, because it involves a covariance matrix which takes into account the distribution and size of each point. The MD is defined as;

$$MD_i = \left((x_i - \mu)^T C^{-1} (x_i - \mu)^{1/2} \right) \quad (1)$$

Where μ is the mean multivariate location and *C* is mean covariance matrix. For normally distribution data, the value of MD_i^2 is approximately chi-square distribution with *p* degree of freedom.

According to the concept of MD, multivariate outlier can simply be defined as observation having a large MD. In other word, a longer MD space illustrates the existence of an outlier. In quality control, a longer MD elucidates worse quality. Meanwhile, the magnitude of the compared values of MD is an indicator of a welding faults when large distance between points.

The welding quality whether it fault or good could be determined by the observations MD space of the multivariate outliers. In order to provide reliable measures for recognition of outliers current and voltage for welding quality, equation 1 is being transformed by means of robust procedure complied in matlab software, the transformed equation is define below;

$$M_d = \frac{V_i^{'2} - 2rV_i^{'} + C_i^{'2}}{1 - r^2} \quad (2)$$

Where $V_i^{'}$ and $C_i^{'}$ indicate the normalized *ith* value of welding current and voltage. Firstly the mean and standard deviations for voltage *V* and current *C* are calculate by following equations.

The value of voltage and current are normalized using equation below,

$$V_n^{'} = \frac{V_n - \bar{V}}{\sigma_V} \quad (3)$$

$$C_n^{'} = \frac{C_n - \bar{C}}{\sigma_C} \quad (4)$$

$$r = \sum_{i=1}^{n} \frac{V_i^{'} * C_i^{'}}{n} \quad (5)$$

It is important to normalize the value of *r* because it relies on the distribution of the data and indicates the relationships of the two parameters.

Quantification of welding Quality

The normal distribution is important concept beside MD to quantify the welding quality. The normal distribution is described by the density function;

$$f(x) = \frac{1}{\sqrt{2\pi^2}} e^{-\frac{(x-\mu)}{2\sigma^2}} \quad (6)$$

According to general quality control (QC) and the theory of the normal distribution, the threshold for considering a point to belong to the distribution is commonly set to ±3σ. That is, if results are within the range of ±3σ this shows predicted results good and outliers.

MD values distribution is assumed to obey normal distribution rule. However, MD values are always positive, therefore, the range of MD is acceptable from 0 to ±3σ. This indicates that if the calculated MD from welding voltage and current lie in the range from 0 to ±3σ, welding quality is considered to be good weld. Conversely, if the values of MD lie outside this range welding quality regards as fault. Therefor the welding quality can be quantified as formula below;

$$Q(\%) = \frac{n}{N} x100\% \tag{7}$$

where n is the number of the quantified data , and N is the total number of the data obtained in one second.

Experimental Procedures

To perform GMA robotic welding on SS400 steel which is mainly used in structural requires specification on the manual welding condition. The welding details based on standard Welding Specification Procedure (WPS) and manual welding conditions based on preliminary experiments to drive a stable bead area.

The experiment parameters selected as shown in table 1. In each pass the welding parameter such as arc voltage and welding current are different, but welding speed and the gap between two plates is the same in both cases. Fig. 1 shows the experiment setup.

Table 1; GMA welding process parameters for five different weld.

Pass	Current (A)	Voltage (V)	Welding Speed (cm/min)
1	200	23	11
2	280	26	11
3	240	25	11
4	260	25	11
5	230	20	11

For quantifying welding quality, the result data of arc voltage and welding current from the online monitoring system were obtained and changed from analog to digital. Through the defined formulas above, mean and standard deviations, MD the sample data was analyzed and quantified to determine the welding quality per seconds of welding for each pass.

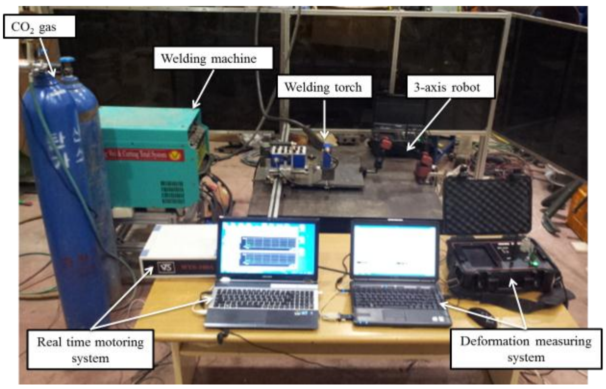
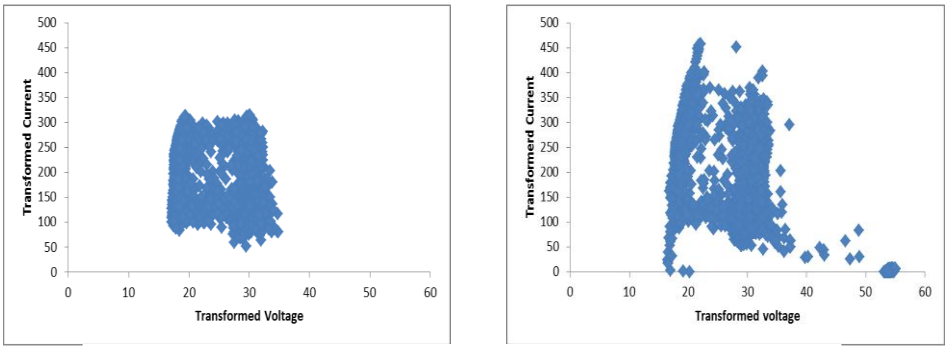


Fig. 1. Multi-pass GMA welding experiment setup.

Using the calculated MD, normal distributions methods to quantify welding quality is obtained. There are three steps in determining the welding faults, first the weld fault is determined by concentration of transformed current and voltage which is set as reference for quality weld. Second determine the behavior of MD with respect to time during welding process and lastly determine welding quality percentage using normal distribution.

Results and Discussion

The input variables that have the greatest impact factor on weldability are welding current, arc voltage, and welding conditions, whereas the output variables that occur on the plate are bead width and bead width. During initial welding state the welding regarded as welding reference because at the beginning and end part of the welding, the process is unstable and welding quality is regarded as fault compared with other part of welding.



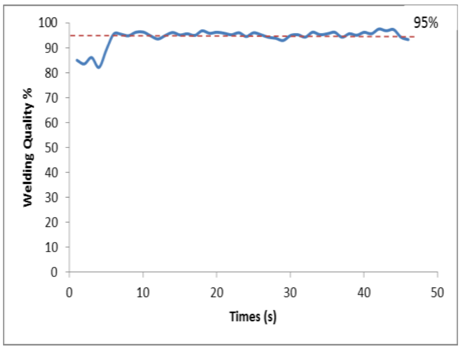
(a) Good weld (b) Fault weld

Fig. 2 Sample typical transformed welding current and arc voltage.

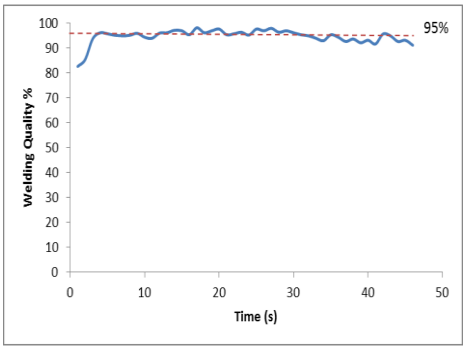
Fig. 2 shows typical transformed averaged arc voltage and welding current graphs for sample of two weld pass. The data shown in Fig. 2(a) is obtained from the sample weld which shows that the distribution of data is more concentrated during welding process compared to the Fig. 2 (b) where data is more distributed outward to each other.

This preliminary analysis determines fault weld and good weld and this analysis also set as a reference to determine the fault welding quality percentage. According to MD concept, a longer data space existence between each other indicates the fault weld. Therefore, Fig. 2(a) is found to be faultless weld, whereas Fig. 2(b) is found to a fault weld. The start and end welding current and arc voltage was also recorded on the online monitoring system, and present on transformed current verse transformed voltage. The result shows that current and voltage are very low and unstable during start and end welding process.

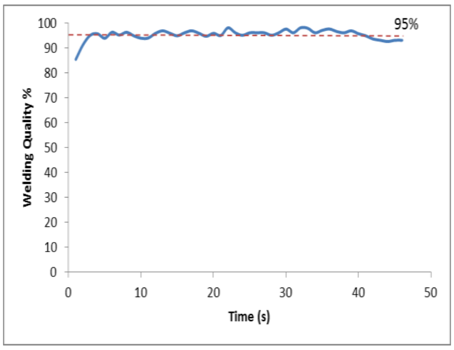
Fig. 3 shows the quanitified welding quality percentage obtained from MD analysis of five-pass welding experiments. For all pass experiment the thresold values of the welding quality is defined by 95 %, which is represented in dash lines in Fig. 3. According to MD normal distribution and six sigma theory the thresold value should be below value of 99.9%. This means that, if the quantified welding quality obtained from the experiment is above threshold value, the welding quality could be considered good weld quality, instead if the value of the quantified welding quantified welding quality are below threshold value, the welding quality is regraded as fault. Fig. 3(a) and (b) shows the quantified good welding quality for at first pass and second pass respectivily, since the welding quality percentage is above and around threshold value. The welding quality at third and forth pass is not good, since quality worsen with time. The worst welding was quanitified at last pass, where the quality percentage is below the threshold percentage. This clearly shows that welding process parameter and welding conditions has a great influence on welding quality such arc voltage, welding current. In multi-pass welding, previous heat input has also a large impact on the quality of the next weld pass.



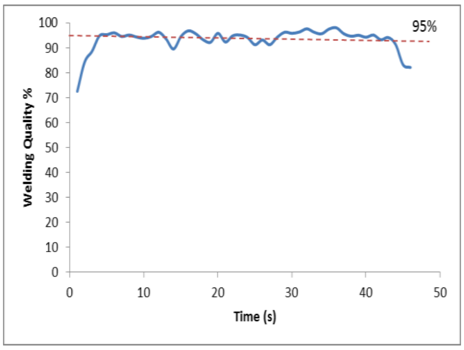
(a) First weld pass



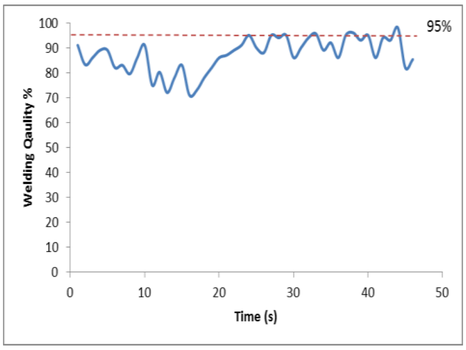
(b) Second weld pass



(c) Third weld pass



(d) Fourth weld pass



(e) Fifth weld pass

Fig.3. Quantified welding quality with respect of time.

Conclusion

This study investigates the application of statistical method for quantifying the welding quality and determines the relationship between welding process parameter, welding conditions and welding quality in a multi-pass GMA welding.

The proposed method employs the MD and normal distribution to evaluate the welding quality in a five pass welding. The transformed arc voltage and welding current data obtained from the experiment were analyzed using MD and normal distribution. Typical transformed arc voltage and welding current graphs describes as reference for determining welding quality percentage. The results obtained clearly predict that welding parameters has a large impact on welding quality. The bead geometry also indicated the effect of welding parameter on the weld joint quality. Controlling the welding parameters such as arc voltage, welding current and welding conditions such cooling time between each pass could help in controlling welding quality and maintaining good weld quality. These results also suggest that statistical such as Mahalanobios distance (MD) and normal distribution method could be used to determine the online welding quality to avoid joint failure.

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