July-August 2020
ISSN: 0193-4120 Page No. 1326- 1334

Weld Pool Centroid in the Application of Weld Seam Formation Control

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Abstract

The weld seam formation is one of the key aspects for welding quality. In this paper, a new method for seam formation control has been proposed, which is based on the weld pool image gray centroid. The tungsten inert gas arc welding is chosen to be the researched welding technology. Firstly, the experimental system, which is four degree of freedom, was set up. The composite filtering system was used to filter the weld arc producing during the welding procession, which is composed by the neutral light reduction filter and narrow band light filter. Nextly, several welding experiments under different penetration conditions were performed. The CCD camera captured the welding images and saved them to the computer. Then the images were processed by median filter and gray enhance operations. So the clearer weld pool images can be obtained. The front region of weld pool is chosen to be the procession district. Some analysis has been performed to the light radiation and heat conduction during the welding procession. On this basis, the weld pool image gray centroid value is chosen to be the parameter reflecting the heat distributed situation during the welding procession. The least square method is used to set up the relationship model between the pool centroid and the welding penetration conditions, which are unfused, fused and overfused. In the end, several experiments were performed to test the veracity of the model. The results showed that the welding penetrations predicted by the set up model are fit to the measured values. The accuracy of the model is 90%. The setup model can predict the weld seam formation effectively.

Keywords:*Welding, Weld pool image, Centroid, Penetration prediction,*

1. INTRODUCTION

Welding is one kinds of important technology for metal connection, which is widely used in the field of automobile production, spaceflight industry, shipbuilding industry, machine manufacture, and so on. However, the welding is still operated by mankind nowadays. The radiation, the splash, the gas producing during the welding procession have made a great damage to the health of human.Meanwhile, the quality and efficiency of welding have greatly determined by the welders'mood, the welders'health,or other factors. The quality of welding can hardly be controlled.Therefore, the realization of welding automation has great social and economic benefit.

Seam formation is one of the important technology to realize the welding automation, which reflects the welding penetration situation. The goal of seam formation control is to obtain a wonderful metallographic structure of the seam,which can ensure the quality of metal connection district.

For quality inspection of the weld seam, the X-ray testing and damage testing are the two common methods applied in industry nowadays. The X-ray method analyzed the metallographic structure by the X-ray images to inspection the welding quality. The damage testing method splits the weld seam and

July-August 2020
ISSN: 0193-4120 Page No. 1326- 1334

inspects the inner welding quality directly. The X-ray imaging device is needed for the first method, which is time wasting and money costing.The second method damage the seam to test the welding quality, whose practicability need to improve.

However, the experienced welders can infer the welding penetration condition by observing the weld pool, and obtain a wonderful seam. From the welding procession of mankind, it can be found that the pool may contain abundant information of welding. By the weld pool information, the heat distribution, the welding stability, the welding penetration, or other welding condition can be learned. Therefore, the welding penetration situation may be inferred indirectly by inspecting the change of weld pool, which supplied a new way for welding quality control.

It is the key to obtain a desired pool information for the penetration inspection method based on the weld pool. The sensor testing method applied in weld pool detection includes the vision sensor method, the weld arc sensor method, the pool oscillation method, the infrared sensor method, the optics sensor method, and so on[1-3]. The visual sensor method has been greatly applied in welding procession control, because it’s untouched and large information acquirement. In paper [4], the morphology algorithm based on multi-scale and multi-structuring elements was adopted to process the molten pool image.The complete edge of molten pool image can be exacted by the algorithm, which can be used to realize the automation of welding. In paper [5], a synchronous vision system with three CCD cameras is developed for observing the weld pool and the keyhole. Based on the experimental images, the relationship among the welding parameters and the geometrical parameters of the weld pool and the keyhole is studied, which lays a solid foundation for welding quality control system. Fang[6] has proposed an infrared visual sensing method to capture GasMetal Arc Additive Manufacturing (GMA-AM) weld pool image, which can be used to evaluate the quality of the molten pool objectively. Liu[7] proposed a weld pool identification model for penetration testing based on the vision sensor. In paper [8], images of the molten pools are obtained by high speed visual sensing system.Feature extraction and dimensionality reduction are carried out by principal component analysis. ELM algorithm is used to train the penetration identification model for identification. Ding[9] introduced a MLD model method for the modeling of the hybrid system and studied the GTAW welding penetration control strategy by the setup model. In paper [10], the images of front-side free surface and back-side width of the weld pool are captured with two CCD cameras in tungsten inert gas (TIG) arc welding process based on laser vision. The three dimensional weld pool surface is reconstructed using designed algorithm. Then, the correlation between the weld pool surface under different weld joint penetration and its back-side width is analyzed. Yang[11] proposed a penetration recognition model for aluminum alloy. In the single-sidewelding and double-side molding experiment clear weld pool imagesof three kinds of penetration status-incomplete ， complete and overpenetration have been obtained by near-infrared visual sensingmethod.The characters of weld pool image such as weld width, weld half-length,molten pool areaperimeter and parabolic coefficient which is associated to weld penetration can be extracted by aspecial image processing algorithm. The BP neuralnetwork is used to setup the model.In paper [12], visual sensing was applied from the topside to capture the whole weld pool, plasma arc and keyhole entrance. Dynamic information of the weld pool and keyhole entrance was extracted. Based on the deep learning algorithm and obtained topside weld pool images, the keyhole status and penetration was predicted.Gao[13] proposed a model to recognize the arc welding penetration status. the weld pool area, weld pool width and the distance between the weld pool centroid and the bottom were chosen to be the input model variables.The welding penetration status was chosen to be the model output.

Based on the existing welding penetration control method, a new method for the weld seam penetration inspection has been proposed in this paper. The tungsten inert gas arc welding(TIG) is chosen to be the researched technique. The weldingexperimental system has been setup. Then welding experiments were performed. Several groups of weld pool images under different penetration conditions have been captured in real time, which are the unfused, fused and overfused penetration condition. Then some analysis have been performed to the captured images. The weld pool grey centroid is determined to be the parameter for the weld seam penetration inspection. On this basis, the least square method is used to setup the relationship model between the weld pool centroid and the penetration situation. The setup model can be used to predict the seam penetration, which supplied a new way for seam penetration control.

2.EXPERIMENTAL SYSTEM

The tungsten inert gas arc welding(TIG) is chosen to be the researched technique. The whole experimental system mainly includes the four axis mechanic body, the CCD visual sensor, the control industry, the image capture system, the motion control system, and so on, which is shown in Fig.1.

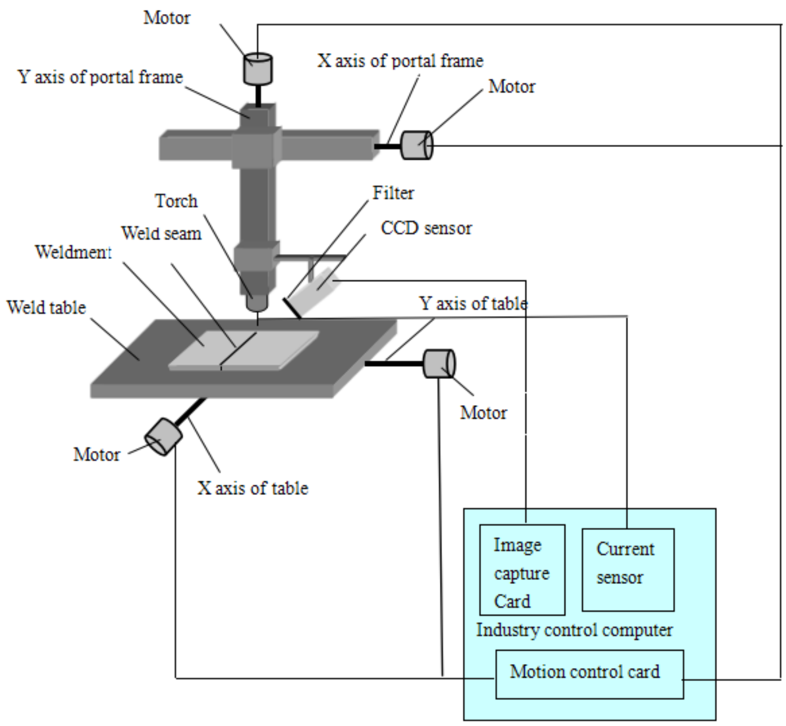


Fig.1. Welding Experimental System

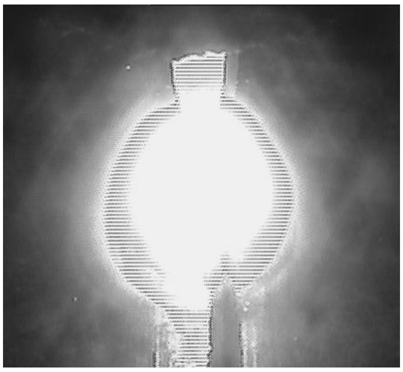
The mechanic body of the system contains the portal frame and the welding table, which are driven by step motors. The fixture are installed on the welding table and used to clamp workpiece.There are travel switch installed along the axis on the portal frame and the welding table. The travel switches are used to prevent over travelling. When welding, the Y direction is set to be the feed direction. The CCD sensor captures welding images in real time. After decoded by images captured card and A/D transferred, the digital images have been sent to the industry computer and saved in the the hard disk. In order to filter the arc disturbance produced during the welding procession, filter system has been installed on the front of the CCD camera. So clearer welding images can be captured in real time.

July-August 2020
ISSN: 0193-4120 Page No. 1326- 1334

3.ACQUIREMENT AND PRETREAMENT OF WELD POOL IMAGE

3.1 Acquirement of weld pool image

It’s the key to acquire clear weld pool image for the weld seam penetration control. However, during the actual welding procession, the light produced by the weld arc is very strong. The weld pool is usually covered by the strong arc light. For the new method proposed in the paper, the arc light should be firstly filtered. If only use the narrow band filter method, the arc light can’t be filtered completely. The light is still very strong and the detail of pool can’t be distinguished. However, if only used the traditional neutral filter method, the arc light can be greatly reduced, while the contrast of the weld pool will be reduced at the same time. The detail information of weld pool can’t be distinguished. The images filtered by the narrow band filter method and the neutral filter method are shown in Fig.2(a) and Fig.2(b).



(a)Image filtering by narrow band filter

(b) Image filtering by neutral filter

Fig.2. Welding Images Filtering by Narrow Band and Neutral Filter

In this paper, a composite filter system is set up, which is composed of a narrow band filter and a neutral filter. The center wavelength of the narrow band filter is 650nm. And the 7# neutral filter is used to make up the composite filter system. So clearer weld pool image can be obtained, which is shown in Fig.3.

Fig.3. Image Filtered by Composite Filter System

3.2 Pretreament of weld pool image

In order to reduce the noise disturbance, the 3×3 template median filter operation and image gray transformation operation are performed. So the contrast between the weld pool and the weld seam can be enhanced. The images after the median filter operation and gray enhance operation are shown in Fig.4.

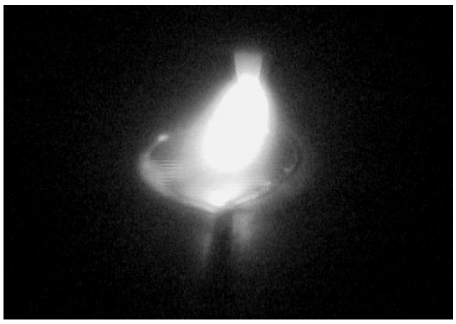


Fig.4. Image after Median Filter Operation and Grey Enhance Operation

4. DEFINITION OF WELD POOL CENTROID

Heat exists during the whole welding procession. The heat source, such as the laser, the plasma, the arc, and so on, melt the welding medium to realize the connection of the metal by heat radiation. As is known to us, there is closed connection between heat and light. Different heat distributed situation will lead to different light radiation condition. And the gray distribution of the whole weld pool image will be different, too. Therefore, the heat transmission of the weldment can be inferred from the weld pool gray distribution.

When the weldment is under different penetration condition, which are the unfused condition, the fused condition and the overfused condition, the heat radiation situation is different. The grey distribution of weld pool will be different,too. In this paper, the weld pool centroid is chosen to be the parameter determined the whole gray distribution of the weld pool image. The definition of weld pool centroid is shown in formula 1.

$$C=\frac{\sum_{j=1}^{N}\sum_{i=1}^{M} g(i,j)\times i}{\sum_{j=1}^{N}\sum_{i=1}^{M} g(i,j)} \qquad (1)$$

In formula 1, i, $j$are the two direction of the pool image. $M$and$N$are the pixel number along the $i$and$j$direction. g(i, j) is the gray value at the point (i, j).

5. DEFINITION OF WELDING PENETRATION

The welding penetration can't be directly inspected when the weldment isn't destroyed. Or the expensive X-ray camera should be firstly installed to inspect the inner metallographic structure. However, the penetration can be inferred indirectly by another parameter. For the penetration inspection, the pool width at the back of weldment is usually used to be the determined parameter[14-15]. According to the weld pool width at the back of weldment, the welding penetration can be divided into three statue in this paper,which are the unfused condition, the fused condition and the overfused condition. The welding penetration conditions are shown in Table1.

Table 1

Width of Weld Pool at the Back under Different Penetration Condition

Penetration condition	Unfused	Fused	Overfused
Width of weld pool at the back	<1.82mm	>1.82mmand <2.64mm	>2.64mm

6. OBTAINMENT OF EXPERIMENTAL DATA

Based on the setup experimental system, several welding experiments are performed. The welding condition of experiments are shown in Table2. So several groups of welding images can be obtained and used to be training sample data.

Table 2

Welding Experiment Conditions

Weldment Q535 (mm×mm×mm)	Argon Flow (L/min)	WeldingCurrent (A)	WeldingSpeed (mm/s)	SampleTime (ms)
200×150×2	9	80	2.50	40

The detail procession of welding experiments can be shown as following. At the started position, the torch are set to point to the weld seam. The y axis is set to be the feeding direction, which is driven by step motors. During the welding procession, the CCD captured images in real time and saved them into the harddisk of industry computer. The captured welding image number is 400 and the welding condition is shown in Table 2. The front side of the

July-August 2020
ISSN: 0193-4120 Page No. 1326- 1334

weldment after the welding experiment is shown in Fig.5, and the back side of the weldment after the welding experiment is shown in Fig.6. The pool width values at the back of the weldment are shown in Fig.7.

Fig.5. Front Side Image of Weld Seam after Welding Experiment

Fig.6. Back Side Image of Weld Seam after Welding Experiment

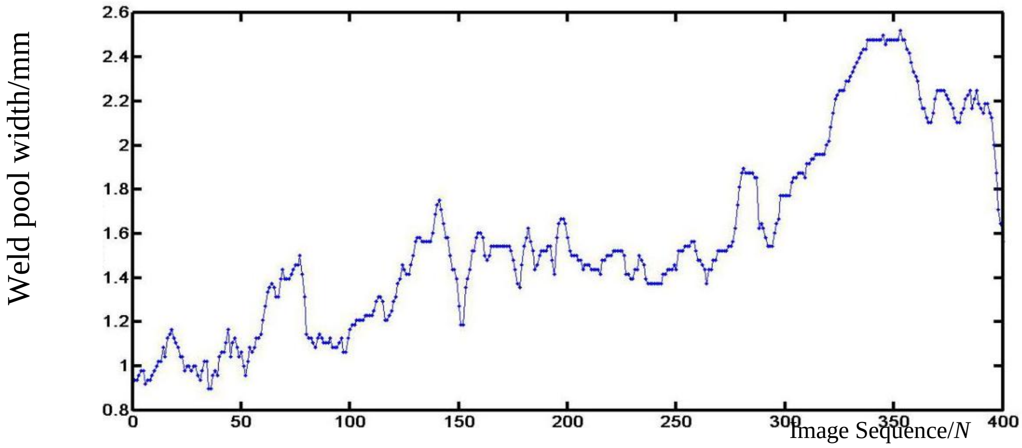


Fig.7. Weld Pool Width at the Back of Weld Seam

7. SET UP OF THE WELDING PENETRATION PREDICTION MODEL

Heat exists during the whole welding procession. The heat source, which may be the laser,the plasma, the arc, and so on, melt the welding median to realize the connection of weldment by heat radiation. However,heat and light are the two closed physical parameter. Different heated condition will lead to different light radiation situation. The penetration condition of weldments can be divided into three stages,which are the unfused condition, the fused condition and the overfused condition. When the weldments are under different penetration condition, the heat distributed situation will be different, and the brightness of the pool will be different at the same time, which will lead to the different distributed of the pool images.

In this paper,the weld pool centroid is chosen to be the physical parameter which determines the heat distribution during the welding procession. The definition of the centroid is shown in formula 1. The penetration condition can be divided according to the pool width at the back of the weldment, which is shown in Table.1. The least square method is used to set up relationship model between the weld pool centroid and the penetration status. The set up model can be used to predict the welding penetration in real time, which supply a new way for welding penetration inspection.

The least square method is that to find a function to get the least value of $\sum_{i=1}^{N}\omega(C_i)[Y_i-\rho(C_i)]^2$. The $\omega(C_i)$ are the weight coefficients. Yi are the measuring penetration status.The expression of the function ρ(x) is shown in formula 2, which is constituted by a group of linearly independent functions[16-17].

$$\rho(x)=a_0+a_1x+\cdots+a_mx^m \quad (2)$$

In Eq.2, the$a_n$are the weight coefficients, which can be determined by the training procession. *x*are the weld pool centroid.

According to the deduced procession introduced above, the welding penetration prediction model based on the weld pool centroid can be expressed as following[16-17]:

$$f(x)=a_0+a_1x+a_2x^2+\cdots+a_5x^5+\zeta \quad (3)$$

In formula 3, the *x* is the weld pool centroid value. *f*(*x*) is the prediction value of the welding penetration. $\xi$is the compensation value of the model, which can be used to compensate the parameters' measuring error or other uncertain disturbance producing during the welding procession.

400 groups of experimental data are chosen and input to the formula 3. So the weight coefficient of the model is obtained, which is shown as following:

$$\begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix} = \begin{bmatrix} -1.36\times10^{-5} \\ 0.012 \\ -4.08 \\ 707.21 \\ -6.13\times10^{4} \\ 2.13\times10_{6} \end{bmatrix} \quad (4)$$

8. TESTING EXPERIMENTS

To test the accuracy of the setup model, another group of data are chosen and input to the setup model, which is shown in formula 3. The testing results are shown in Fig.8.

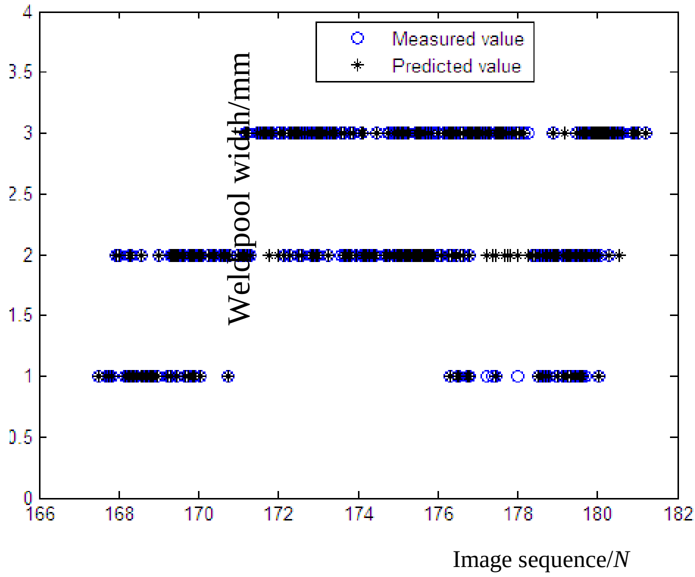


Fig.8. The testing results

The horizontal ordination in Fig.8 are the weld pool centroid values. The verticalordination in Fig.8 are the penetration status. The values of the verticalordination in Fig.8 can be 1, 2 or 3, which represents the unfused condition, the fused condition and the overfused condition of the welding penetration. The dots in the figure represent the real measuring values of the welding penetration,while the stars in the figure represent the predicted values of the welding penetration. From the figure, we can find that most of the measuring values are overlap with the predicted values, which show that the set up model can predict the welding penetration condition well. The accuracy rate of the model can be shown in formula 5.

$$\bar{e}=\frac{n}{N} \quad (5)$$

In formula 5, N are the number of the testing points, which is 400 in the paper.n are the number of points which are predicted correctly.

After calculating, the accuracy rate of the set up model is up to 90%, which showed that the values predicted by the set up model are fit to the measuring values. The set up predicted model has some kind of accuracy.

9. CONCLUSION

1. Tungsten inert gas arc welding(TIG) is chosen to be the researched welding technique. The welding experimental system, which is four degree of freedom, is set up. Welding experiments are performed. The composite filter system is set up, which is composed of neutral light reduction filter and narrow band filter. So several groups of weld pool images can be captured. Each group contains 400 images.
2. Severalpretreamentoperations are performed to the captured weld pool images, which contains the median filter operation and the gray enhance operation. So the disturbance produced by the welding arc can be filtered, and the contrast ratio of the image can be enhanced. Several clearer weld pool images can be obtained.
3. Some analysis has been performed to the weld pool images. In order to quantify the penetration condition, the width of the pool at the back of the weldment is chosen to be the parameter affecting the weld penetration condition. So the penetration situations can be determined. Several groups of training data can be obtained.
4. The weld pool centroid value has been set to the input parameter.And the penetration conditions have been determined to be the output, which are the unfused condition, the fused condition and the overfused condition. The least square method is used to set up the prediction model for weld seam formation inspection.
5. Testing experiments have been performed to the set up model. The results show that the penetration values calculated by the prediction model are fit to the measured values. The final accuracy rate of the model is 90%, which has supplied a new way for weld seam formation inspection.

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