Indian Society for
Non-Destructive Testing
Hyderabad Chapter

Proc. National Seminar on
Non-Destructive Evaluation
Dec. 7 - 9, 2006, Hyderabad

Automatic Detection and Quantification of Incomplete Penetration in TIG Welding Through Segmentation and Morphological Image Processing of Thermographs

N.M. Nandhitha[1], N. Manoharan[1], B. Sheela Rani[1], B. Venkataraman[2],
P. Kalyana Sundaram[2] and Baldev Raj[2]
[1]Sathyabama Institute of Science and Technology, Deemed University, Jeppiaar Nagar, Old Mammalapuram Road,Chennai-600 119
[2]Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam-603 102

Abstract

Infrared Thermography is an advanced Non Destructive Evaluation technique based on the detection of infrared radiation. It is best suited for online weld monitoring to produce defect free welds. The most important step involved in online weld monitoring is to develop an automated algorithm for weld defect detection and quantification. Incomplete Penetration occurs when penetration of the weld metal into the joint is insufficient compared to that specified by the welding symbol. It is caused by too low welding current or too high welding speed or incorrect joint geometry. It can contribute to failure as stress raisers and least resistant path. It manifests itself as variation in the hottest region in a thermograph. The paper aims at developing an image-processing algorithm for automatic identification and quantification of Incomplete Penetration in Tungsten Inert Gas (TIG) welding from the acquired thermograph. The developed image processing algorithm acquires the input thermograph, performs color to gray level conversion, edge detection by Sobel filter mask and morphological processing such as dilation, erosion and region filling to detect and quantify the defect. The feature vectors used for quantifying the defect are area, major axis length and minor axis length.

Keywords: *Thermographs, Depth of penetration, TIG welding, Sobel, dilation and erosion*

1. Introduction

Gas Tungsten Arc Welding (GTAW) commonly referred as Tungsten Inert Gas (TIG) welding is best suited for precision welding in atomic energy, aircraft, chemical and instrument industries. It is an arc welding process wherein coalescence is produced by heating the job with an electric arc struck between a Tungsten electrode and the job. A shielding gas is used to avoid atmospheric contamination of the molten weld pool. TIG welding is one of the widely used methods for joining metals. In spite of the numerous advances in the science and technology of welding, failures do occur and weld is still considered to be the weakest portion. This is because the formation of the weld is affected by a number of process parameters, which make it difficult to ensure the quality of the weld. Conventionally, the quality of the weld is ascertained only after the welding has been completed through the use of Non Destructive Testing (NDT) such as ultrasonic or radiography. Since each of these techniques is applied only after the welding is completed, a lot of time, material and manpower is wasted before one comes to know about the soundness of the weld.

Inherent Limitations in conventional welding processes can be overcome if the weld is continuously monitored in real time for the assessment of defects and their automatic elimination by on-line control of the welding parameters. Moreover, the defective weld can be repaired immediately without continuing the process further. This strategy to monitor, control and maintain quality of welds is commonly known as adaptive welding or intelligent welding. Intelligent welding, as the name implies, combines welding equipment with intelligent sensing and control, knowledge of human experts, and Artificial Intelligence (AI) to improve joining efficiency and reduce the weld inhomogenities and defects.

Sensors are the key to success of intelligent welding. Non-Destructive Testing (NDT) sensors, which have been considered, for on-line monitoring include optical, radiography and Infrared (IR). Of the three, optical sensors provide information limited to the surface such as bead width; misalignment etc. Real time radiography using image intensifier based system has been used in process control of arc welding. However, the hazards involved in the use of radiation sources have limited the potential applications. Infrared, on the other hand, has the advantage that it can reveal surface and near surface perturbations.

After acquiring thermal images, features corresponding to weld defects are extracted. These feature vectors are related to the corresponding deviations in physical parameters responsible for the defect. With this mapping, the respective physical parameter is then controlled to produce defect free welds. This paper presents an algorithm for automatic identification and quantification of Incomplete Penetration, a commonly occurring defect during TIG welding. Thermographs of three depths of penetration are considered.

The paper is organized as follows. Section 2 gives a brief review of Infrared Thermography in Non Destructive Testing. Section 3 deals with thermographs of Incomplete Penetration. Section 4 discusses the feature extraction of defects and section 5 deals with Results. Section 6 is conclusion and future work. The functions are implemented in Mat lab

2. Review of Infrared Thermography in Non Destructive Testing

Active Infrared thermo graphic non-destructive Testing is a means of providing quantitative information about hidden defects or features in a material [1]. Since then, numerous groups worldwide have used Infrared investigation techniques in the inspection of subsurface defects and features, thermo physical properties, coating thickness and hidden structures. Thermographs are used to the control of welding process problems, such as arc misalignments [2]. Infrared sensors are best suited for weld quality detection as the perturbations that arise due to variations in arc positioning, heat input and the presence of contaminants distinctly manifests itself as differences in the spatial and temporal surface temperature distributions [3]. Hence image analysis techniques can be developed to quantify the changes in the temperature distribution there by enabling adaptive welding techniques for automated weld control.

Thermographs are used as a cross reference for the finite element simulations. Infra Red Thermograph has shown promise to detect the changes in several welding parameters by monitoring the surface temperature distributions of plates being welded [4]. During the welding process, the position of the camera was fixed relative to the welding gun to provide measurement of temperatures in the weld pool and its vicinity. Experimental conditions were carefully maintained to minimize errors. Thermal imaging provides whole-field information in a practical solution, and it therefore constitutes a unique tool for the evaluation of inputs to a thermo-mechanical determination of distortion or residual stress caused by a welding process. Thermal non-destructive evaluation techniques are used for investigating different defects and material systems using several thermal non-destructive testing and evaluation techniques [5]. In their work after the detection of defects, representative images obtained from the thermo graphic investigation underwent quantitative analysis with the intention of obtaining information about the defects in space and time.

3. Thermographs of Incomplete Penetration

Incomplete Penetration occurs when penetration of the weld metal into the joint is insufficient compared to what is specified for the joint according to the welding symbol. It is caused by too low welding current or too high welding speed or incorrect joint geometry. It is a serious defect as it can contribute to failure as stress raisers and least resistant path.

During the welding process, the high temperatures associated with the arc and appropriate thermophysical properties such as thermal diffusivity cause strong spatial temperature gradients to occur in the weld pool. Convection in the weld pool, shape of the weld pool and heat transfer in both the solid and liquid metal determines the temperature distributions in thermal maps. The thermal maps produced by infrared thermal imaging instruments are called thermographs. Thermograph is defined as a 2D radiance function g(x, y), where x and y denote spatial coordinates and the value of g at any point is proportional to the radiance or energy emitted from the scene at that location. Traditionally, low intensities are represented by dark shades and high intensities by bright shades. For an ideal weld with constant conditions, thermographs show repeatable and regular patterns. Perturbations in welding penetration clearly manifest itself in hot spots (brightest spot) of thermographs. With the decrease in degree of penetration or increase in Lack of Penetration, the area, major axis length and minor axis length of the hotspot also decreases. Thermographs for three different depths of penetration namely 100%, 80% and 60% are shown in Fig.1, Fig.2 and Fig.3.

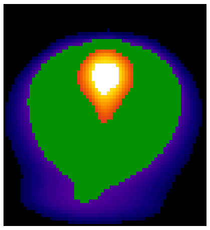

Fig. 1: Thermograph (100% Penetration

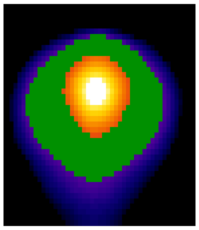

Fig. 2: Thermograph (80% Penetration)

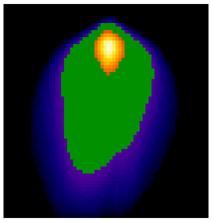

Fig. 3: Thermograph (60% Penetration)

4. Feature Extraction of Defects

An image is defined as a two-dimensional function, f(x,y) where x and y are spatial co-ordinates, and the amplitude of f at any pair of co-ordinates (x,y) is called the intensity or gray level of the image at that point. When x, y, and the amplitude values of f are all finite and discrete, the image is called a digital image. A digital image is composed of a finite number of elements, each of which has a particular location and value. These elements are referred to as pixels.

4.1 Image Acquisition and Preprocessing

It involves acquiring thermographs. The key function of pre-processing is to improve the image in ways that increase the chances for success of the other processes. In this case, pre-processing involves the conversion of colored image into binary image to remove computational complexity. Moreover gray level resolution of thermograms is improved by increasing the number of bits used for representing each pixel from 8 to 16.

4.2 Segmentation

Segmentation subdivides an image into its constituent regions or objects. The level to which the subdivision is carried out depends on the problem being solved. That is, segmentation should stop when the objects of interest in an application have been isolated. Image segmentation algorithms are usually based on one of two basic properties of intensity values namely discontinuity and similarity. In this work, the first approach is used to partition an image based on abrupt changes in intensity, such as edges in an image. The commonly used filters for edge detection are Prewitt, Sobel, Canny, Laplacian of Gaussian. Though Prewitt masks are simpler to implement than the Sobel masks, the later have superior noise suppression characteristics. Sobel masks used for edge detection are as shown below

-1	0	1
-2	0	2
-1	0	1

-1	-2	-1
0	0	0
1	2	1

4.3 Morphological Processing

Mathematical morphology is for extracting image components that are useful in the representation and description of region shape such as boundaries, skeletons etc. It involves dilation, region filling and erosion.

4.3.1 Dilation

Dilation is for bridging the gap between the pixels in an image. With A and B as sets in Z2, the dilation of A by B is

$$A+B=\{z\backslash(B\hat{})znA \neq \Phi\} \qquad (1)$$

Where B is the structuring element. The structuring element chosen is 'line'.

4.3.2 Region Filling

Region filling makes all the pixels in the bounded regions as white thereby differentiating it from the background. The procedure to fill the region with 1's is

$$Xk=(Xk-1+B)nA^{c} \qquad (2)$$

Where k=1,2,3…. And B is the symmetric structuring element and X_0=p, where p is the point inside the boundary. Structuring element chosen is 'holes'.

4.3.3 Erosion

Erosion aims at removing the irrelevant details in an image.

With A and B as sets in Z2, the erosion of A by B is

$$A-B=\{z\backslash (B)z\ C\_A \} \qquad (3)$$

B is the structuring element. The structuring element chosen is diamond.

4.3.4 Feature Extraction

The extracted defects are then quantified using feature vectors. The feature vectors used for description are major axis length, minor axis length and area.

5. Results

The outputs from the image processing algorithm for thermographs depicting three different levels of penetration namely, 100%, 80% and 60% are shown in Fig.4, Fig. 5 and Fig.6 respectively.

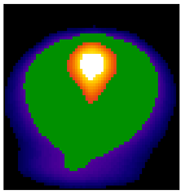

Fig. 4a: Input image (100%)

Fig. 4b: Gray scale image (100%)

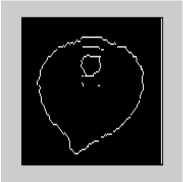

Fig. 4c: Edge Detected image(100%)

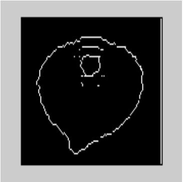

Fig. 4d: Dilated Image (100%)

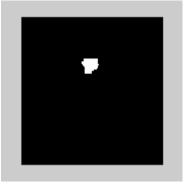

Fig. 4e: Region filled Image (100%)

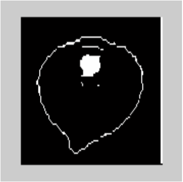

Fig. 4f: Eroded Image (100%)

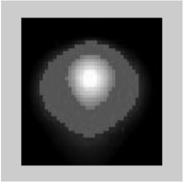

Fig. 5a: Input image (80%)

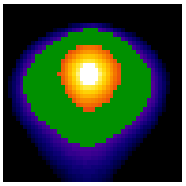

Fig. 5b: Gray scale image (80%)

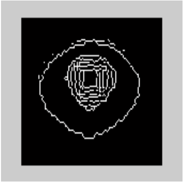

Fig. 5c: Edge detected image (80%)

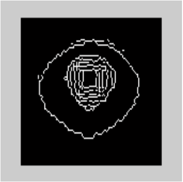

Fig. 5d: Dilated Image (80%)

Fig. 5e: Region filled Image (80%)

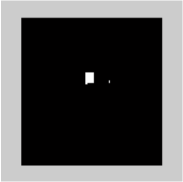

Fig. 5f: Eroded image (80%)

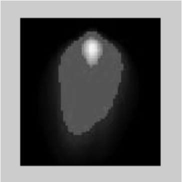

Fig. 6a: Input image (60%)

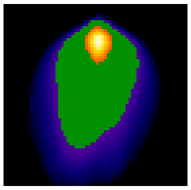

Fig. 6b: Gray scale image (60%)

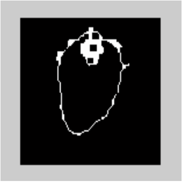

Fig. 6c: Edge detected image (60%)

Fig. 6d: Dilated Image (60%)

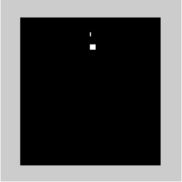

Fig. 6e: Region filled Image (60%)

Fig. 6f: Eroded image (60%)

Table 1: Quantification of weld defects

Feature Vector / Depth of penetration	100%	80%	60%
Major Axis Length (Pixels)	16.2663	9.8274	5.7735
Minor Axis Length (Pixels)	11.5435	9.1034	4.6188
Area (Pixels)	138	66	20
Major axis length (cm)	0.4879	0.2948	0.1732
Minor axis length (cm)	0.3463	0.2731	0.1385
Area (sq.cm)	0.1242	0.0594	0.018

6. Conclusion and Future Work

The developed image processing algorithm automatically detects and quantifies the hot spot. The feature vectors used for quantification are major axis length, minor axis and area. It is found that all these values decrease as the depth of penetration decreases. These three parameters can then be used to relate the deviations in the physical parameter responsible for the defect. Neuro fuzzy software can also be developed to obtain the deviations in physical parameters in order to control them.

7. References

1. Vavilov et al, “Theoritical and practical aspects of the thermal NDT of bonded structures”. Research Techniques in NDT, Academic Press, Vol 5, pp.239 -280. 1982
2. Khan et al, “Infra Red Thermography as a control for the welding process”, Proceedings of SPIE, - The International Society for optical Engineering 446, pp.154-163, 1984
3. Nagarajan et al, “Control of the welding process using Infra Red sensors” IEEE Transactions on Robotics and automation, Vol 8, No1, pp.86-93, 1992.
4. Maldague, *Theory and Practice of Infrared Technology for Nondestructive testing* John Wiley – Inter Science, 64p., 2001
5. Avdelidis , “Detection of water deposits and movement in porous materials by Infrared Imaging” Journal of Infrared Physics and Technology, Vol 44, No3, pp.183-119, 2003