Distribution Features of Small Defects in Precision Weldments of Titanium Alloy

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Abstract. The detection method of real time radioscopy was adopted to test titanium alloys precision weldments with complex structure non-destructively. The location of small defects in the line grey distribution curve was determined based on the analysis of X-ray detection images and the geometry relationship of precision weldments components, and a formula which can calculate the depth of defects was deduced. In order to improve the accuracy of defect locating a formula which can calculate the deviation of defects was deduced also by adopting the method of rotation weldments in this paper. Automated extraction algorithm of projection distance was developed according to the characteristic of the typical defects — peak anomaly and slant concave anomaly in the line grey distribution curve. The experimental results show that the defect depth, deviation and distribution along the longitudinal direction of weld can be figured out, and the spatial distribution features of defects can be determined, the above features will provide better basis for further structural integrity evaluation of the precision weldments.

1. Introduction
Titanium alloy is widely used in aerospace industry and military products because of its excellent over-all properties. Laser welding is greatly fitted to weld titanium alloy sheets because of its marked features such as energy concentration, small heat input, good formation of weld, purification effects and so on. However, porosities and other defects will occur in the weld because of quick cooling velocity and bad protection [1]. Because the fatigue life will reduce when there are porosities and other defects in the weld, catastrophic accident will take place in some severe states, so nondestructive testing must be done to ensure the security of important structures. A three-dimensional nondestructive testing software environment based on CAD which can rapidly and reliably evaluate the structure integrity of aircraft parts with complex structure were established by W. Deng et al [2]. Eddy current and thermography testing were adopted to detect carbon fiber intensified composite nondestructively by X. E. Gros et al [3]. Defect simulation and automated defect detection based on the multiple view geometry using the X-ray testing method in aluminum castings were researched by D. Mery [4-5]. But the above researches were mostly proceeded on the larger defects, and not too much researches were carried out on the spatial distribution features of small defects in the precision weldments with complex structure. For that there are no special demands for weld surface roughness and internal structure when using the X-ray detection, and quick and visual detection results can be obtained, it will benefit to the detection of weldments with complex structure. So the spatial distribution features of
small defects in complex structure were studied by using real time radioscopy system. Firstly a formula which can calculate the defect depth was deduced, and a formula which can calculate the deviation of defects was deduced also. Then the automated extraction algorithm of projection distance was provided by combining the line grey distribution features of typical defect-peak anomaly and slant concave anomaly. Finally the spatial distribution features of small defects were determined in this paper.

2. Experiments
When testing the I-section structure laser weldments of titanium alloy using X-ray inspection system, detection images of high quality are not obtained easily if the perpendicular irradiation is adopted. So rotation weldments is needed in order to obtain better detection results (see Figure 1). The optimum technological parameters of X-ray testing were determined through theoretical calculation and a lot of experiments, and the X-ray detection images were obtained (see Figure 2). According to the variation rules of X-ray penetration weldments, the defects position in the line grey distribution curve can be deduced [6].

\[
d = \left( \frac{2}{\tan \alpha} + \delta \right) \cdot \frac{d_r}{\sin \alpha} \quad \text{(see Figure 3)}
\]

\[
x = \frac{d_r - d_l}{\sqrt{2}} \quad \text{(see Figure 4)}
\]

3. Defect locating
According to the geometric relationship of Figure 3 and Figure 4, regarding the focus of weld center line and horizontal line as the grid origin, the following formula can be obtained:

\[
x = \frac{W - x}{\tan \alpha} + \delta - \frac{d_r}{\sin \alpha}
\]
When $x$ is more than zero, the defect is located in the left side of weld center; and when $x$ is equal to zero, the defect is located in the weld center; whereas when $x$ is less than zero, the defect is located in the right side of weld center.

Where $d$ is the distance from defect center to wing plate surface (mm); 
Where $d_1$ is the projection distance from defect center to the thickest place of X-ray penetration weldments when weldments right turning (mm);
Where $d_2$ is the projection distance from defect center to the thickest place X-ray penetration weldments when weldments left turning (mm);
Where $W$ is the width of sternum (mm);
Where $\delta$ is the thickness of wing plate (mm);
Where $x$ is the deviation of defect (mm);

4. The automated extraction algorithm design of projection distance
The analysis results of line grey distribution curve show that there are two typical anomaly—peak anomaly and slant concave anomaly in the line grey distribution curve [7]. So the automated extraction algorithm of defect projection distance can be divided into two parts, one is the automated extraction algorithm design of projection distance for peak anomaly, the other is the automated extraction algorithm design of projection distance for slant concave anomaly.

4.1. The automated extraction algorithm design of projection distance for peak anomaly
The automated extraction algorithm design of projection distance for peak anomaly can be described as follows (see Figure 5), the horizontal distance between the thickest place of X-ray penetration weldments and the peak anomaly is the projection distance.

Peak hunting and curve fitting are adopted when designing the algorithm, firstly hunt the position $x_1$ of peak anomaly. The position of the thickest place of X-ray penetration weldments can be determined by adopting the method of curve fitting, the position of the crossing point of the above two fitting lines is the position of the thickest place of X-ray penetration weldments. So the projection distance can be obtained by the following formula:
\[
    d = x_2 - x_1
\]
In addition, it is needed to setup two thresholds in the course of hunting peak anomaly, only the peak anomaly whose projection distance is between the two thresholds can be considered as a defect. The selection of threshold can be determined by adopting the method of experiments.

4.2. The automated extraction algorithm design of projection distance for slant concave anomaly
The identification of slant concave anomaly is more difficult than that of peak anomaly. So the automated extraction algorithm of projection distance for slant concave anomaly was designed as follows (see Figure 6).

Firstly hunt the maximum peak of line grey distribution curve, then calculate the slope variation which is located in the right side of the peak, it can be regarded as a slant concave anomaly when three times slope variations emerge, and the position $x_1$ and $x_2$ of inflection points whose slope have changed can be hunted, the center coordinate of the two inflection points is the center position of the slant concave anomaly, i.e.
\[
    x_m = x_1 + \frac{x_2 - x_1}{2}
\]
and the position of the thickest place of X-ray penetration weldments can be determined by adopting the method of curve fitting, the position of the crossing point of the above two fitting lines is the position of the thickest place of X-ray penetration weldments. So the projection distance can be obtained by the following formula:
\[
    d = x_3 - x_m
\]
Similarly two thresholds must be setup in the course of hunting the slant concave anomaly, only the slant concave anomaly whose projection distance is between the two thresholds can be considered as a defect. The selection of threshold can be determined by adopting the method of experiments.

The automated extraction of projection distance was proceeded on the defects of simulation samples by using the above two algorithms, and the deviation and depth of defect can be calculated by substituting projection distance which was already calibrated into the deduced formulas. Meantime the true depth of defects can be measured by destructive testing of simulation samples, the reliability of the algorithm can be verified by comparing the difference of calculated values and measured values for defect depth. 22 defects were verified in this paper, the average relative error of calculated values and measured values for defect depth is 8.39 percent, Figure 7 shows the linear relationship of calculated values and measured values for defect depth.

Figure 8 shows the three-dimensional distribution features of defects in the simulation samples. For that the cooling velocity is quickened when welding the simulation samples, a lot of porosities can not escape from the weld. So the positions of some defects move to the root of the weld. Though only some defects are located in the position of bonding surface between sternum and wing plate (the thickness of wing plate is 1.6mm), they may have great influences on the weld quality. And we can see that the deviations of defect are mostly in the scope of [-0.2 0.2], this indicates that the defects are mainly located in the neighborhood of the weld center. Also the distribution of defects along the weld orientation can be obtained from the Figure 8. According to the above analysis the three-dimensional distribution features of small defects can be determined, we believe that this approach is applicable to the locating and quantification of small defects in precision weldments with complex structure.
6. Conclusion

(1) Precision weldments of titanium alloy with complex structure were detected by using the method of real time radioscopy. Based on the distribution curve of line grey calculation formula of defect depth was deduced, and calculation formula of defect deviation was deduced by adopting the method of rotation weldments also.

(2) In order to achieve the automated extraction of projection distance which is the distance from the defect center to the thickest place of X-ray penetration weldments, automated extraction algorithm of projection distance for peak anomaly and slant concave anomaly was designed individually.

(3) The experimental results show that the calculated values is the same as the measured values basically, and their relationship curve is linear. The total samples of detected defects are 22, and the average relative error of calculated values and measured values for defect depth is 8.39%.

(4) Three-dimensional distribution features of small defects in precision weldments with I-section structure were determined preliminarily, we believe this approach is applicable to the locating and quantification of small defects.

References

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