

Study on Laser Speckle Detection Characteristics of Aircraft Aluminum Honeycomb Structure

Qingfeng Yang*, Haibing Zhang^a, Xinbo Chen^b

School of Qingdao Campus, Navy Aviation University, Qingdao, China

*Corresponding author e-mail: 545238758@qq.com, ^a1061472949@qq.com,

^b2607088540@qq.com

Abstract. In order to detect the aircraft aluminum honeycomb structure defects quickly and accurately, improve the detection reliability, this paper uses the orthogonal optimization theory, using laser shearography detection method detects the specialized design and manufacture of specimens through experimental data, combined with the theoretical analysis and calculation, find the main influencing factors of detection ability is the heating time, followed by the minimum phase shift modulation, and finally gain setting. In this paper, the optimization scheme of laser misplacement speckle interference detection is provided, which provides a theoretical basis for test parts detection.

1. Introduction

Aircraft aluminum honeycomb structure consist of skin and honeycomb core, the skin is usually used Aluminum Alloy plate, it is the main part of the force of the honeycomb structure; honeycomb core with aluminum honeycomb; by adhesive tensile or pressure type corrugated bonding manufacturing method, multi cellular adhesive with epoxy resin, polyvinyl acetate, polyvinyl butyral. As a kind of composite structure, bearing capacity, impact resistance, good cushioning performance, aging resistance, mildew resistance, rain erosion, with good adhesive properties, formability and mechanical properties [1, 2], however, honeycomb composite material may appear various defects and damage due to changes in the atmospheric environment, load factors, fatigue stress and cracks in process. Debonding as a frequent internal defects, will change the mechanical state of the whole structure, reduce its strength and service the life [3]. This paper uses the orthogonal method to detect the defect with the aid of the laser misplaced speckle interference detection method, and improves the reliability of the detection. The device used is a LTI-6200 portable thermal loaded laser dislocation speckle detection system, and the laser dislocation speckle interference detection device, as shown in Figure 1.



Figure 1. Laser dislocation speckle interference detection device



2. The design and manufacture of aluminum honeycomb structure

In this paper, an aluminum honeycomb structure specimen and its internal debonding defect are designed to simulate the real aircraft aluminum honeycomb structure and internal debonding defects. The sample size is 150mm * 250mm, the following specific parameters: thickness of the honeycomb panel's skin were 0.3mm, honeycomb lattice length 4mm and the thickness of honeycomb sandwich foil were 0.04mm. Manufacturing defects in specimen, a layer thin film which the size in accord with the defect size sandwiched between the honeycomb with the skin, then bonding on the part which after the film, making one parts, defect that size is 20mm (0.80inch). The specimen drawings is shown in Figure 2.



Figure 2. Specimen drawings

3. Laser misplacement speckle interference detection principle

Digital Shear Speckle Pattern Interferometry (DSSPI) combines digital interferometry with digital speckle interferometry to form digital photoelectrical measurement technology, which can measure displacement displacement derivatives of deformed objects. The first derivative of off plane displacement is called slope, the two derivative of off plane displacement is called curvature, and the two order mixed derivative of off plane displacement is called twist [4].

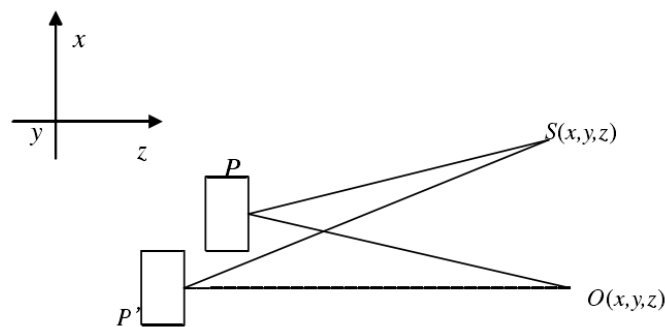


Figure 3. Deformation and phase relationship shearography

As shown in Figure 3, consider any point $P_1(x, y, z)$ on the surface, it moves to $P'_1(x + u, y + v, z + w)$ after the deformation. Send light source $S(x_s, y_s, z_s)$, after point P_1 , spread to the observer $O(x_o, y_o, z_o)$. The amount of optical path change is as follows:

$$\Delta_1 = (SP'_1 + P'_1O) - (SP_1 + P_1O) \quad (1)$$

In the type

$$\begin{aligned}
SP_1 &= \left[(x - x_s)^2 + (y - y_s)^2 + (z - z_s)^2 \right]^{1/2} \\
P_1O &= \left[(x - x_o)^2 + (y - y_o)^2 + (z - z_o)^2 \right]^{1/2} \\
SP_1' &= \left[(x + u - x_s)^2 + (y + v - y_s)^2 + (z + w - z_s)^2 \right]^{1/2} \\
P_1'O &= \left[(x + u - x_o)^2 + (y + v - y_o)^2 + (z + w - z_o)^2 \right]^{1/2}
\end{aligned} \tag{2}$$

The formula (2) is expanded by Taylor series, and the first order of the expansion formula is retained, and the substitution (1) can be obtained.

$$\Delta_1 = \left(\frac{x - x_o}{R_o} + \frac{x - x_s}{R_s} \right) u + \left(\frac{y - y_o}{R_o} + \frac{y - y_s}{R_s} \right) v + \left(\frac{z - z_o}{R_o} + \frac{z - z_s}{R_s} \right) w \tag{3}$$

In the type

$$\begin{aligned}
R_o &= \left[x_o^2 + y_o^2 + z_o^2 \right]^{1/2} \\
R_s &= \left[x_s^2 + y_s^2 + z_s^2 \right]^{1/2}
\end{aligned} \tag{4}$$

In the same way, for the point $P_1'(x, y, z)$ that the nearest neighbor to point $P_2'(x + \delta x, y, z)$, it moves to $P_2'(x + \delta x + u + \delta u, y + v + \delta v, z + w + \delta w)$ the change of the optical path caused by the displacement:

$$\begin{aligned}
\Delta_2 &= \left(\frac{x - x_o}{R_o} + \frac{x - x_s}{R_s} \right) (u + \delta u) + \\
&\left(\frac{y - y_o}{R_o} + \frac{y - y_s}{R_s} \right) (v + \delta v) + \left(\frac{z - z_o}{R_o} + \frac{z - z_s}{R_s} \right) (w + \delta w)
\end{aligned} \tag{5}$$

In the type, the displacement vector of the point $P_2(x + \delta x, y, z)$ is $(u + \delta u, v + \delta v, w + \delta w)$. Due to misplacement, the optical path difference caused by the deformation between two points is caused by the interference of a point $P_1'(x, y, z)$ like a plane point and a near neighbor $P_2'(x + \delta x, y, z)$.

$$\begin{aligned}
\Delta &= \Delta_2 - \Delta_1 \\
&= \left(\frac{x - x_o}{R_o} + \frac{x - x_s}{R_s} \right) \delta u + \left(\frac{y - y_o}{R_o} + \frac{y - y_s}{R_s} \right) \delta v + \\
&\left(\frac{z - z_o}{R_o} + \frac{z - z_s}{R_s} \right) \delta w + \left(\frac{1}{R_o} + \frac{1}{R_s} \right) (u + \delta u) \delta x \\
&= A\delta u + B\delta v + C\delta w + D(u + \delta u)\delta x
\end{aligned} \tag{6}$$

In the type

$$\begin{aligned} A &= \left(\frac{x - x_o}{R_o} + \frac{x - x_s}{R_s} \right) \\ B &= \left(\frac{y - y_o}{R_o} + \frac{y - y_s}{R_s} \right) \\ C &= \left(\frac{z - z_o}{R_o} + \frac{z - z_s}{R_s} \right) \\ D &= \left(\frac{1}{R_o} + \frac{1}{R_s} \right) \end{aligned} \quad (7)$$

Usually it (δx) is very small, it can be omitted. Therefore, the relation between the phase difference (φ_x) and the amount of dislocation (δx) caused by the deformation between two points is:

$$\varphi_x = \frac{2\pi}{\lambda} \left(A \frac{\partial u}{\partial x} + B \frac{\partial v}{\partial x} + C \frac{\partial w}{\partial x} \right) \delta x \quad (8)$$

The formula (8) shows that it (φ_x) is a function of the corresponding change of displacement (δu , δv , δw) between two points ($P_1(x, y, z)$, $P_2(x + \delta x, y, z)$). In the same way, the relation between the phase difference (φ_y) and the misplacement (δy) is that when the position is misplaced along the direction (y), the relation between the phase difference and the misplacement is:

$$\varphi_y = \frac{2\pi}{\lambda} \left(A \frac{\partial u}{\partial y} + B \frac{\partial v}{\partial y} + C \frac{\partial w}{\partial y} \right) \delta y \quad (9)$$

In the actual optical path, the light (S) and camera observation points (O) are often arranged in the plane ($x - z$) and the point (O) on the z axis. Usually, the size of the object is much smaller than that (R_o , R_s), so that $x_o = y_o = 0$, $y_s = 0$, $R_o = z_o$. Supposing the angle between the illumination direction and the observation direction is θ , then A , B , C can be simplified as

$$\begin{cases} A = -\sin \theta \\ B \approx 0 \\ C = -(1 + \cos \theta) \end{cases} \quad (10)$$

After the coefficient is simplified, formula (8) and (9) can be reduced to

$$\begin{aligned}\varphi_x &= -\frac{2\pi}{\lambda} \left[(1 + \cos \theta) \frac{\partial w}{\partial x} + \sin \theta \frac{\partial u}{\partial x} \right] \delta x \\ \varphi_y &= -\frac{2\pi}{\lambda} \left[(1 + \cos \theta) \frac{\partial w}{\partial y} + \sin \theta \frac{\partial u}{\partial y} \right] \delta y\end{aligned}\quad (11)$$

In many cases, the in-plane displacement is negligible compared with the displacement. It ($\frac{\partial u}{\partial x}$) can be ignored when the dislocation is aligned along the direction and the direction of illumination is consistent with the direction (x) of observation. When $\theta \approx 0$, expression (11) can be rewritten.

$$\varphi_x = -\frac{4\pi}{\lambda} \frac{\partial w}{\partial x} \delta x \quad (12)$$

At this time, the contour line stripe of the direction (x) derivative of the surface displacement can be obtained directly.

4. Orthogonal table design

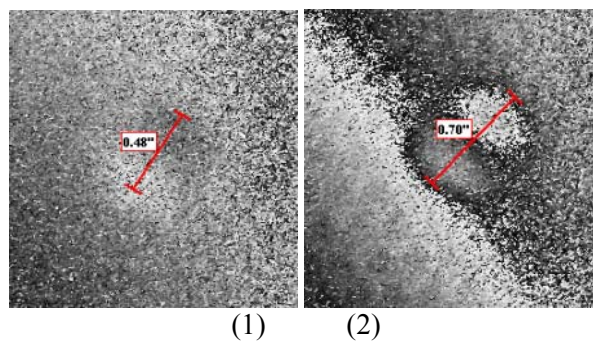
The parameters that affect the detection capability of laser speckle interference include the minimum phase shift modulation, the gain setting and the heating time. In this paper, the minimum phase shift modulation, gain setting and heating time are taken as the factors of the orthogonal table. The different values of each factor are taken as the horizontal values of the orthogonal table, and the factors and horizontal tables are shown in Table 1.

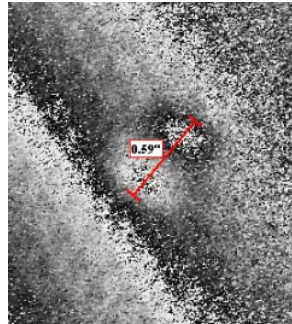
Table 1. Factors and level tables

Factor Level	A Minimum phase shift modulation	B Gain setting	C Heating time (S)
1	0.04	2.5	2.0
2	0.06	5.0	5.0
3	0.08	7.5	7.0
4	0.10	10.0	10.0

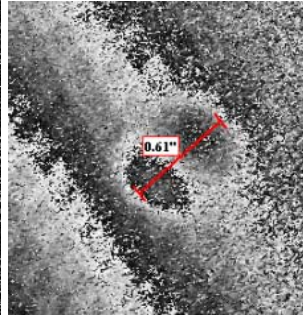
5. Test results and analysis

The defect and defect size as shown in Figure 4, the brackets represent Arabia digital test no.

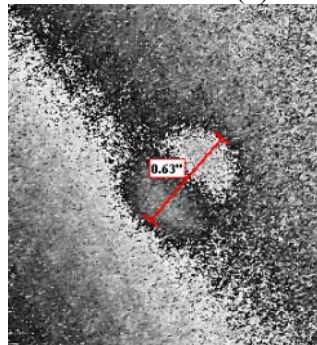




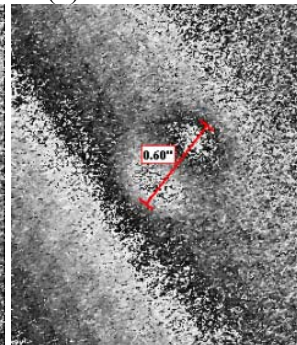
(3)



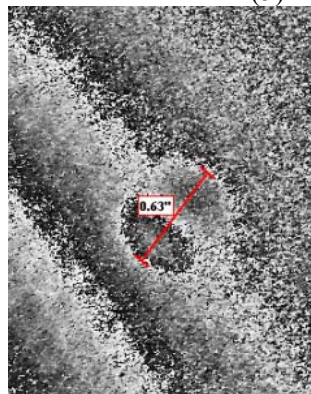
(4)



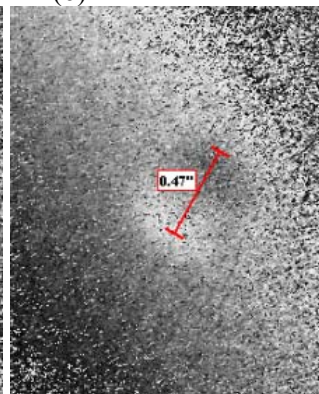
(5)



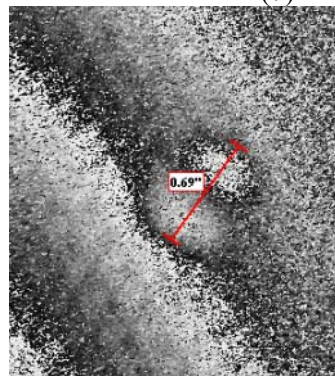
(6)



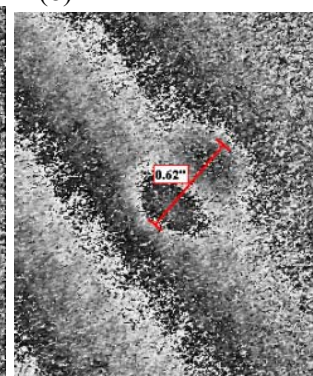
(7)



(8)



(9)



(10)

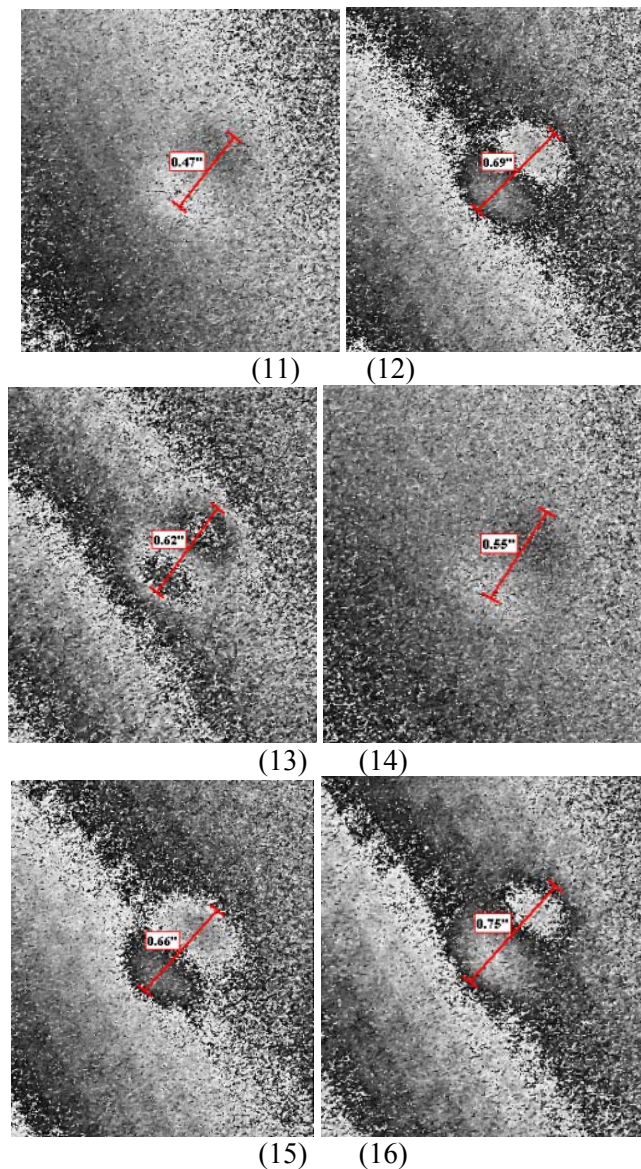


Figure 4. Defect and defect size diagram 4

The experimental scheme and test results, as shown in Table 2, are made up of the orthogonal array.

From table 2, we know that the most important factor is the heating time, the next is the minimum phase shift modulation, and the last is the gain setting. The best way is heating time 5.0S, minimum phase shift modulation 0.10 and gain setting 10. The engineering mean of the optimal scheme is equal to the horizontal effect of the total average plus the level of each factor of the experimental scheme, that is, inch, the relative error is 0.075inch, and the absolute error is 9.375%.

Table 2. Test results and factors analysis

<div>Factor Column number Test number</div>	A	B	C	Blank	Defect size d_i (inch)
	1	2	3	4	
1	1	1	1	1	0.48
2	1	2	2	2	0.70
3	1	3	3	3	0.59
4	1	4	4	4	0.61
5	2	1	2	3	0.63
6	2	2	1	4	0.60
7	2	3	4	1	0.63
8	2	4	3	2	0.47
9	3	1	3	4	0.69
10	3	2	4	3	0.62
11	3	3	1	2	0.47
12	3	4	2	1	0.69
13	4	1	4	2	0.63
14	4	2	3	1	0.55
15	4	3	2	4	0.66
16	4	4	1	3	0.75
K_{1j}	2.38	2.42	2.30	2.35	$T = \sum_{i=1}^{16} d_i = 9.76$ $\bar{d} = T/16 = 0.61$
K_{2j}	2.33	2.47	2.68	2.26	
K_{3j}	2.47	2.35	2.35	2.59	
K_{4j}	2.58	2.52	2.48	2.56	
$\overline{K_{1j}}$	0.595	0.605	0.575	0.5875	
$\overline{K_{2j}}$	0.5825	0.6175	0.67	0.565	
$\overline{K_{3j}}$	0.6175	0.5875	0.5875	0.6475	
$\overline{K_{4j}}$	0.645	0.63	0.62	0.64	
R_j	0.25	0.17	0.38	0.33	
Primary factor to secondary factor	C A B				
Optimal scheme	C ₂ A ₄ B ₄				

6. Conclusion

(1) The orthogonal optimization method can be used to optimize the parameters of laser misalignment speckle interferometry for aircraft aluminum honeycomb composite structure defects, and the experimental and analytical results are ideal.

(2) The most important factors affecting the defect detection ability are the heating time, the second is the minimum phase shift modulation, and the last is the gain setting.

(3) The optimal scheme obtained by analysis and calculation is not included in the 16 experimental schemes that have been done in the orthogonal table, which embodies the superiority of the orthogonal design.

(4) By orthogonal method, we can optimize the detection parameters of laser mismatch speckle interferometry, reduce the number of trials, save a lot of time, save costs, and lay a theoretical foundation for specimen detection.

References

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