NDT of Lattice Sandwich Metal Plate by Using DC Potential Drop Method

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Abstract: To evaluate the feasibility of the Direct Current Potential Drop (DCPD) for NDT of lattice sandwich plate, a code for numerical simulation of DCPD is developed based on the resistance network approach to validate the DCPD for lattice material NDT application. The surface plates and the truss bars are modeled as resistance networks. A lot of numerical simulations are performed by using the developed code for different flaw sizes, electrodes arrangement etc. The results show that the DCPD is suitable for detecting welding flaws in the lattice sandwich plate.

Key Words : Lattice sandwich metal plate, Welding flaw, DCPD, Impedance network method, Numerical simulation

1. Introduction

Ultralight lattice material is a newly developed multifunctional material, which plays an important role in aerospace engineering, transportation and many other industries for its features of both high strength and low density[1]. As shown in Fig.1, lattice sandwich metal plate of stainless steel is a typical type of ultralight lattice material, which consists of two surface plates and an inner layer of truss or other geometry that are often bonded together by welding techniques. Flaws in welding joints occurred during manufacture and/or service may significantly reduce the strength of lattice material. Hence, Pre-Service Inspection (PSI) and In-Service Inspection (ISI) are required to guarantee the safety of this kind of new material and structures by employing proper NDT tools.

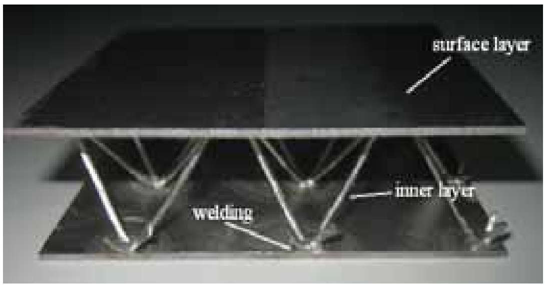


Figure 1. An example of sandwich plate

Until now there is still no satisfactory NDT method being established for these new and relatively complex material and structures. The conventional UT and RT method are not applicable as the surface layers are very thin and the flaws are not volumetric. Through a lot of observations, it is found that the Direct Current Potential Drop (DCPD) is a good option for the inspection of welding flaws in the sandwich plate. The DCPD method may shows its advantage in the NDT of the lattice sandwich metal plate because of its features of simplicity, fast and without skin depth effect.

DCPD is widely used to measure the depth of a crack because the initiation and propagation of crack can change the distribution of surface potential [2-3]. For the sandwich plate, impedance property of the welding joints may be disturbed by the welding flaws significantly. Therefore, there is a good possibility to detect flaws in the welding joints of the sandwich plate by using the measured potential signals[4].

In order to evaluate the feasibility of the DCPD for NDT of lattice sandwich metal plate, the resistance network method is updated to simulate DCPD signals on the sandwich plate surface. A numerical code is developed based on the updated method for calculating the potential distribution. A lot of numerical simulations are performed by using the newly developed code for flaws of different sizes, positions and different electrode arrangements.

2. Numerical method for simulation of DCPD of the lattice sandwich plate

The numerical simulation method is performed based on the resistance network approach and Kirchhoff's current law. In practice, the sandwich plate is discretized into small pieces that are approximated by a 3D resistance networks. Figure 2 shows part of a sandwich plate of truss inner layer and the corresponding resistance network model. The surface layers are discretized into resistances of total number M in x direction and N in y direction respectively, while each truss bar of the inner layer is approximated by one resistance. The welding joints at ends of the truss bar are taken as two resistances, with their values depending on the welding joint area.

Based on the Ohm's law, these resistances can be calculated by using the formulas as follows:

$$R_x = L \times N / (\sigma \times T \times W \times M) , \tag{1}$$

$$R_y = W \times M / (\sigma \times T \times L \times N) , \tag{2}$$

$$R_{bar} = L_{bar} / (\sigma_{bar} \times S_{weld}) , \tag{3}$$

where, L, W, T represent the length, width and thickness of surface layer, R_x and R_y are resistances of surface layer in x direction and y direction, σ is the conductivity of surface layer; R_{bar} is the resistance of truss bar, L_{bar} , S_{bar} are the length and cross section area of truss bar, and σ_{weld} is the conductivity of the weld metal.

Based on the numerical model and the Kirchhoff's law, the current conservation equation of each node can be derived as follows[5]:

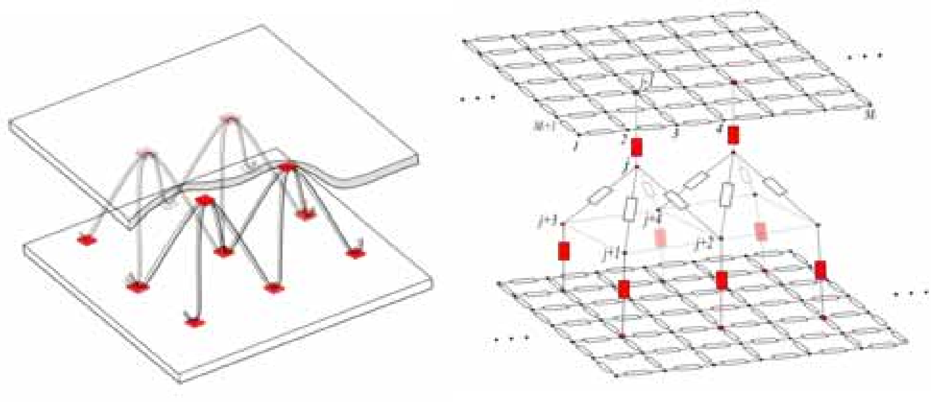
For inner node,

$$I_{j-1,j} + I_{j,j+1} + I_{j,j+2} + I_{j,j+3} + I_{j,j+4} = 0, \qquad j = 1,2,\cdots,N \tag{4}$$

where, N is the total number of inner nodes, $I_{j-1,j}$ is the current between $j-1$ and $j-th$ node, which is equal to $(V_j - V_{j-1}) / R_{j,j-1}$, V_j the potential at node j, and $R_{j,j-1}$ the resistance between the node $j-1$ and j. Similarly, $I_{j,j+1} = (V_{j+1} - V_j) / R_{j,j+1}$, $I_{j,j+2} = (V_{j+2} - V_j) / R_{j,j+2}$, $I_{j,j+3} = (V_{j+3} - V_j) / R_{j,j+3}$, $I_{j,j+4} = (V_{j+4} - V_j) / R_{j,j+4}$.

For boundary nodes, corresponding current equation also could be derived similarly. For example, the equation for node 1 of Fig.2 (b) is:

$$I_{1,2} + I_{1,M1+1} = 0 . \tag{5}$$



(a) Sandwich plate with a truss inner layer (b) 3D numerical model for sandwich plate

Figure 2. Modelizing of DCPD problem for sandwich plate

Then, from current equations given above, the governing equations in matrix form can be obtained as follows:

$$[A]\{X\} = \{0\}, \tag{6}$$

where, matrix $[A]$ is a coefficient matrix correlating with resistances, and $\{X\}$ is a potential vector.

Denoting the potential vector at excitation electrodes as vector $\{X_1\}$, and other unknown potential values as $\{X_2\}$, the Eq. (6) can be expressed as:

$$\begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{Bmatrix} X_1 \\ X_2 \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \end{Bmatrix}, \tag{7}$$

From Eq. (7), the equation to calculate unknown potential expression of $\{X_2\}$ can be induced:

$$[A_{22}]\{X_2\} = -[A_{21}]\{X_1\} \tag{8}$$

Based on the matrix equation, a code for numerical simulation of DCPD of sandwich plate is developed.

Numerical simulation of Equation (8) needs great storage space and is time consuming because the proper solution requires huge number of nodes. As matrix $[A_{22}]$ is symmetric, large and sparse, one dimension compressing data storage method of the matrix $[A_{22}]$ is introduced to reduce the amount of data storage. The conjugate gradient solution is adopted to solve the equation. In this way, the potential value of each node can be obtained.

To determine the proper number of nodes for simulation, potential distribution of network models with different nodes are calculated. Fig.3 illustrates the dependence of potential value on the number of nodes. The potential results converge to a steady value with increasing the number of nodes, which proves the validity of the simulation.

3. Numerical results

To validate the feasibility of DCPD for lattice material NDT application, electric potential distribution on surface layer of sandwich plate in case of flaws of different sizes, positions and different electrode arrangements is calculated, and change in the potential drop of a specimen with flaw in welding joint is analyzed by using difference operation because the change of the potential value of actual welding flaw is very small. The difference operation is adopted to extract the flaw signals from the potential distribution, in practice, potential drops in each welding sub-region are interpolated based on the values outside the sub-region. The flaw signals are obtained by subtract the original potential drop signal from the interpolated ones.

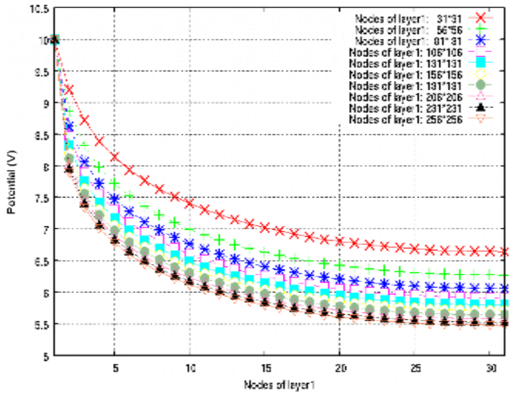
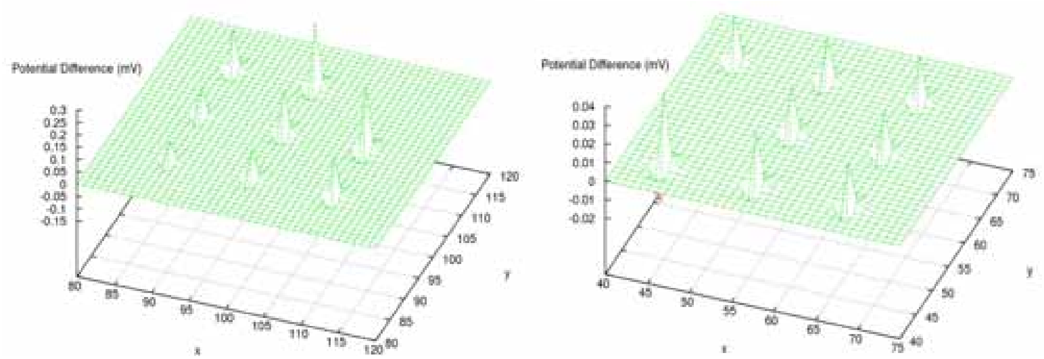


Figure 3. Potential results of simulation for sandwich plate

The numerical model selected is as follows: the material of both surface and inner layer are chosen as stainless steel of SUS304 type (conductivity 1.4 MS/m). The length, width and thickness of the surface layer are selected as 250 mm, 250 mm and 1mm, respectively. The length and cross-section area of the truss bars are 24 mm and 1 mm^2 respectively. A Nickel-based weld metal is selected (conductivity 0.92 MS/m). The length, width and thickness of welding layer are estimated as 1 mm, 2 mm and 1 mm, respectively. A DC current of 10 A is applied to the specimen through electrodes by a constant electric current source. There are 10×10 welding joints between the surface layer and the inner layer. The position of a welding joint is denoted by (i, j), the sequence number of the welding joint in x and y direction.

3.1 Results for different flaw positions

A lot of simulations for sandwich plate with a flaw of different positions are conducted to investigate the influence of flaw position. Figure 4 shows part results processed by difference and interpolation, of which (a) displays a potential difference distribution on surface layer with a flawed welding joint at position (10,10,1), while (b) gives that for a flaw at position (4,5,1). The positon (4,5,1) means that the welding joint is one of 4^{th} in x and 5^{th} in y direction among the 10×10 welding joints between the top surface layer and the inner layer, while (10,10,1) is similar.



(a) Welding flaw at position (10,10,1) (b) Welding flaw at position (4,5,1)

Figure 4. Potential difference distribution for different flaw positions

From the signals processed, the position of welding flaw can be recognized. When there is a flaw, potential difference peak will decrease. For a 100% welding flaw, the potential peak value will become 0 as shown in Fig. 4 (a) and (b). These results indicate that the position of welding flaw could be recognized from the distribution of potential drops.

3.2 Results for different flaw sizes

A sandwich plate with welding flaws of different sizes is calculated to investigate the effect of flaw size on the potential signals. Flaws ranging from 0% to 100% (with step of 20%) are considered. Figure 5 depicts potential signals of a welding flaw for different percentage at a fixed position, in which it can be seen that the potential difference peak of welding flaw decreases with the increase of flaw percentage. For a welding joint without flaw, the peak value is about 0.028mV, while for the welding joint with flaw of 60%, the peak value will drop to 0.021mV. If the welding joint is fully broken, the peak value of the signal will become 0.

According to the relationship of potential difference peak value with welding flaw proportion, we can size the flaw by calibration of peak value in a defect testing.

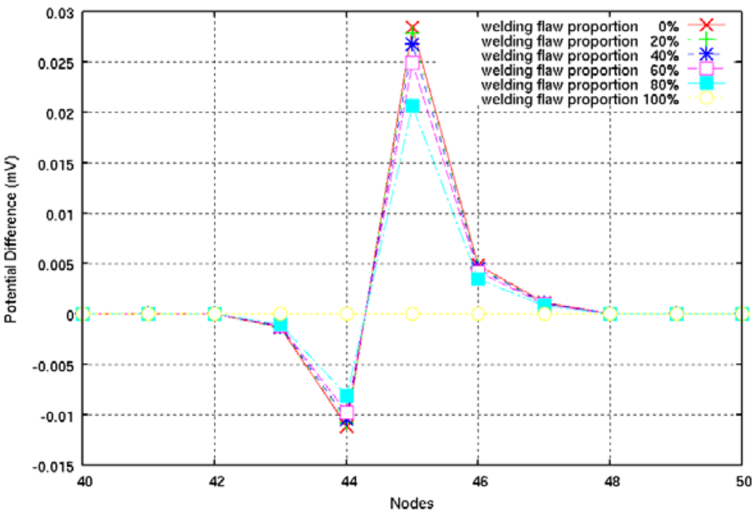


Figure 5. Potential difference for welding flaw with different sizes

3.3 Results for different electrode arrangements[6]

To investigate the influence of electrode arrangement on potential signals, the distribution of potential difference for a welding-flawed specimen with electrodes of different arrangements is calculated.

The two electrodes are set at center of ridge, vertical position or vertices on surface layer, respectively. Some typical arrangements are shown in Fig.6. For these different electrode arrangements, the potential difference of a 50% welding flaw at position (4,5,1) is calculated and compared. The results show that for each electrode arrangement, the potential difference of welding flaw is in proportion relative to those of corresponding unflawed welding joint .But their absolute value are different as shown in Figure 6. From the results it can be seen that the change of potential difference is affected by arrangement of electrodes. This means that the potential drop signals could be improved through adjusting the arrangement of electrodes.

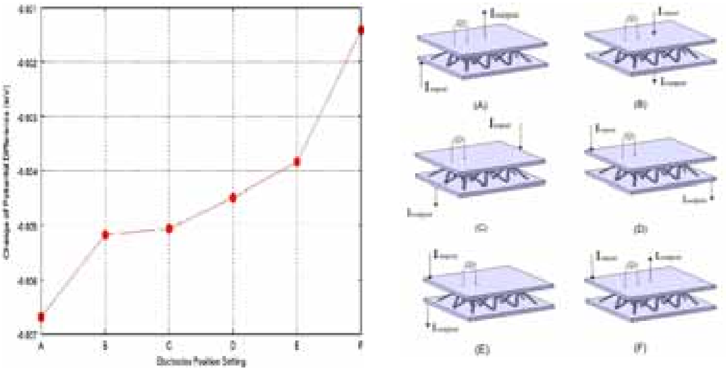


Figure 6. Comparison of results for different electrode arrangements

4. Conclusion

To investigate the validity of DCPD in inspection of the lattice sandwich metal plate, a code for numerical simulation of DCPD of sandwich lattice metal plate is developed based on the resistance network approach. A lot of numerical simulations are performed by using the developed code for specimen with flaws of different sizes, positions and electrode arrangements. From the simulation results, it is found that the DCPD is suitable for detecting welding flaws in the lattice sandwich metal plate. In addition, the potential drop signals can be improved by adjusting the arrangements of electrodes.

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