Application of various forward and inverse scattering techniques to non-destructive testing

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1. Introduction

The ultrasonic non-destructive testing (UT) has attracted attention over the past few decades. The final goal of UT is to identify the position, shape, size of a defect. The ultrasonic waves satisfy the elastic wave equations in elastic materials. Numerical simulation tools are useful to understand the elastic wave propagation behavior. Therefore, in this presentation, some forward and inverse scattering techniques for UT application are introduced with the numerical results.

2. Forward analysis techniques

The main forward numerical techniques are the finite difference method (FDM), finite element method (FEM), and boundary element method (BEM). FDM and FEM are used to analyze wave propagation in a finite and heterogeneous domain. On the other hand, BEM can deal with infinite region without any modifications. However, BEM has a lot of trouble simulating the wave propagation in a heterogeneous domain. Therefore, the author uses he these forward numerical techniques differently in the problem settings. Especially, some numerical results obtained by the elastodynamic finite integration technique (EFIT), which is an improved FDM, the voxel based FEM, and the convolution quadrature time-domain BEM (CQBEM) [1] are demonstrated in this presentation.

3. Inverse scattering techniques

Several inverse scattering techniques have been applied to UT to reconstruct a defect in materials. The synthetic aperture focusing technique (SAFT) is the most widely used technique for the defect reconstruction in UT. The principle of SAFT is very simple, and is based on the superposition of received waveforms obtained by ultrasonic transducers. The phase information included in the received waveforms cannot be used in the general

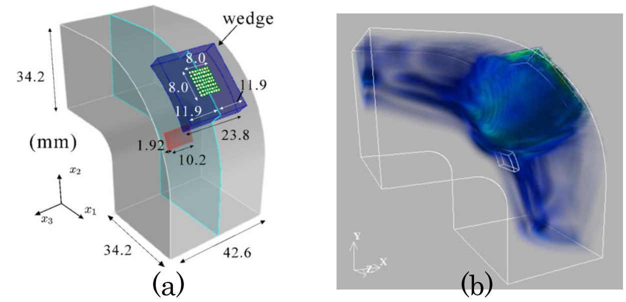

Fig.1: Elastic wave propagation in L-shaped CFRP (a) L-shaped CFRP model (b) a snapshot of elastic wave propagation in L-shaped CFRP.

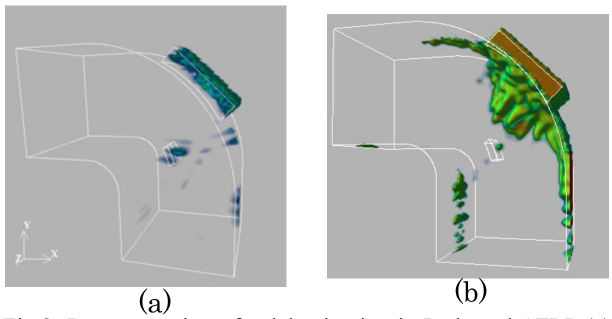

Fig.2: Reconstruction of a delamination in L-shaped CFRP (a) time-reversal result (b) reconstruction result obtained by cross-spectrum.

SAFT algorithm. Therefore, there is still room for improvement to achieve high accuracy for the defect shape reconstruction. From this perspective, the application of the other innovative inverse scattering techniques, such as the inverse scattering based on the Born and Kirchhoff approximations, and the time-reversal method, has been done to improve the accuracy of the defect shape reconstruction in UT. Some defect shape reconstruction results obtained by the time-reversal method are demonstrated in this presentation.

4. Numerical examples

Some numerical examples are shown in this section. Figure 1(a) shows a forward analysis model of L-shaped CFRP whose elastic constants vary in the carbon fiber direction [2]. A matrix array transducer is considered and the incident spherical wave is given from one element of

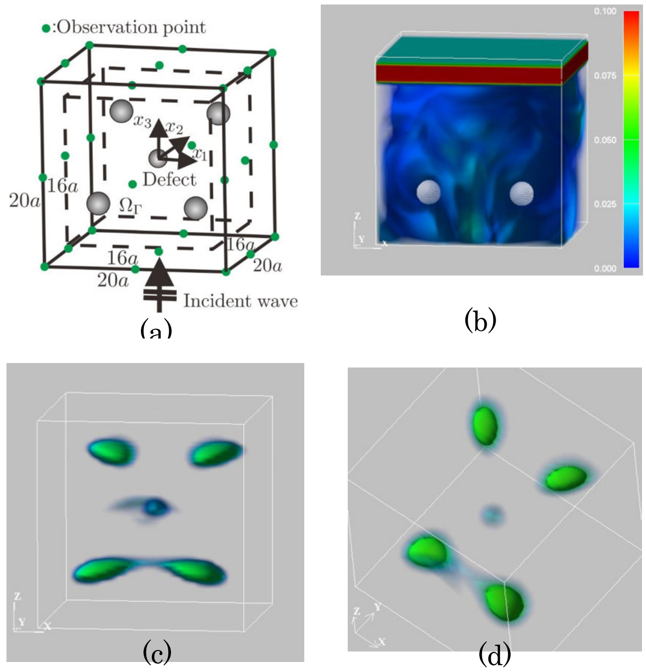

Fig.3: Shape reconstruction of cavities in an elastic solid (a) analysis model (b) a snapshot of elastic wave scattering (c) front view (d) obliquely upward view of the defect shape reconstruction result.

the transducer through the intermediary of a wedge. Figure 1(b) shows a snapshot of elastic wave propagation in L-shaped CFRP, which is obtained by the voxel based FEM. It can be confirmed that the qp-wave (quasi P-wave) propagates according to the carbon fiber direction. The carbon fiber direction of the L-shaped CFRP causes the anisotropic property and effects the wave propagation behavior. Scattered waves generated by the delamination in L-shaped CFRP are received by the array transducer, time-reversed, and sent back to the L-shaped CFRP. Figure 2(a) shows a snapshot of the time-reversal wave propagation in L-shaped CFRP. The superposition of time-reversed waves from the array transducer shows large values at the delamination of the L-shaped CFRP. In addition, Fig. 2(b) indicates the cross-spectrum between the time-reversed waves and the incident waves. The cross-spectrum shows large value at the vicinity of the delamination. Next, the time-reversal technique is applied to the reconstruction of 5 cavities in an infinite elastic solid, as shown in Fig.3(a). In this case, the topological sensitivity is utilized to determine the cavity position. Figure 3(b) shows a total elastic wave field around the 5 cavities at a certain time step. The CQBEM for 3-D elastodynamics, which is the suitable for wave analysis with an infinite space, is used for this computation. The CQBEM can produce stable time-domain solutions better than the classical BEM. It can be confirmed that the scattered waves are generated by the interaction between the cavity surface and the incident plane wave coming from the bottom. The scattered waves are received at the observation points shown in Fig.3(a). The received scattered waves are used for solving the corresponding adjoint problem. The numerical solutions obtained from the forward analysis results such as shown in Fig.3(b), and adjoint analysis results are used for the calculation of the topological sensitivity [3]. Figure 3(c) and (d) show the topological sensitivity in the front and obliquely upward view, respectively, of analysis domain. The topological sensitivity shows large values at the vicinity of 5 cavities. Therefore, the time-reversal technique with the topological sensitivity is effective for the defect position detection in UT.

5. Conclusions

Application of some numerical forward and inverse scattering techniques to NDT was introduced. Numerical results show the potential of the present methods for practical engineering UT applications. The author hopes our group research becomes a bridge between mathematics and engineering applications of UT.

References

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