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Damage detection in sandwich structure using tap test

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ABSTRACT

This paper presents an acoustic-based damage detection method. The tap test uses the radiated sound from a structure during a tap. This non-destructive evaluation (NDE) method has the ability indicating damage such as disband in sandwich structure. It has been shown that the characteristics of sound radiating from structure are changed by the presence of defect in the composite structure. In this study, a numerical method was developed to simulate a tap test. The tapping sound is directly coupled to the structural motion. Therefore, impact response analysis should be performed. In this study, the spring element method is applied to composite sandwich plates for impact analysis and the Rayleigh integral equation is used to compute the radiated sound from the structure. And it will be discussed that how the sound based tap test can be applied to composite sandwich structures.

Keywords: Damage, Detection, Sandwich, Tap test

1. INTRODUCTION

Composite sandwich plates are widely used in aerospace industry because of high specific strength and stiffness. However, composite sandwich exhibits a relatively low impact damage resistance by the low fracture toughness of matrix in the laminate face sheet. Impact damage of composite sandwich panel is difficult to detect because of sandwich nature, and it can cause significant reduction of load capacity of composite sandwich [1]. The tap test is one of the oldest non-destructive testing method and it is widely used to inspect composite structures. The tap test requires an operator to tap a structure to be inspected with hammer, and listen to the resulting sound radiated from the structure. When a composite structure is struck with a hammer, the characteristics of the impact response are dependent on the local impedance of the structure and on the hammer used. Damage such as an adhesive disbond results in a decrease in structural stiffness, and hence a change in the nature of impact [2]. Kim presented the version of the tap test which depends on the measurement of the force and sound input to the structure during the tap [3]. In this study, tap test was used to detect the disbond between face sheets and core of sandwich structure.

2. NUMERICAL SIMULATION OF TAP TEST

For structurally radiated sounds, the sound field is directly coupled to the structural motion. Therefore, impact response analysis should be performed. In this study, the radiated sound induced by tap was computed by solving the Rayleigh integral equation. And spring element method was applied to sandwich plates to simulate an impact response.

2.1 Modeling of sandwich plates using spring element method

Recently Choi proposed a spring mass method to investigate the impact response of sandwich structures [4]. Fig. 1 shows spring element model. In this model, the sandwich structure was constructed as assembly of face modeled with four-node plate elements and core modeled with eight-node solid elements.

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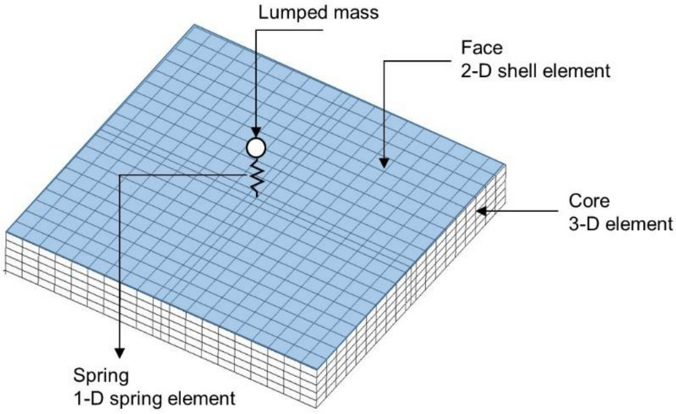


Fig. 1 Spring element model of sandwich plate for impact analysis

Fig. 2 shows the debonding model of sandwich plate. The nodes of the debonding area are detached and not to be connected to each other when the sandwich structure is impacted by lumped mass. The analysis model of the sandwich plate is 19 × 19 × 1.5 cm^3, and the boundary condition of the plate is four edges clamped. The face of sandwich plate has a lay-up of $[0/45/-45/0]_S$. and the size of debonding is 0.3 x 0.3 cm^2.

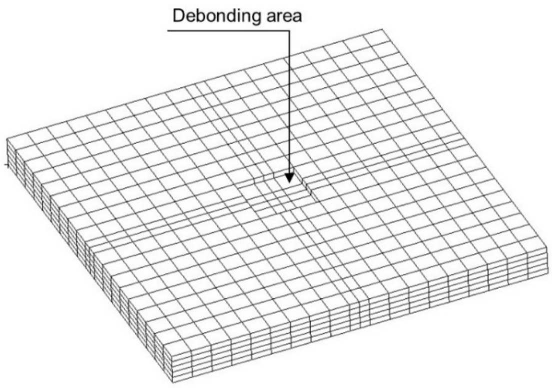


Fig. 2 Debonding model

2.2 Equivalent mass model

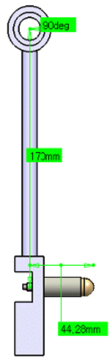
The hammer shaped impactor is simplified by a concentrated mass in order to use the spring element method. Kim has proposed the equivalent spring element model to model hammer shaped impactor. And showed that the equivalent mass model provided an appropriate solution [3]. The equivalent concentrated mass is determined as described in the following procedure:

$$\begin{aligned} & mgR_c \times (1-\cos\theta) = \frac{1}{2} I_0 \dot{\theta}^2 \\ & v_i = \dot{\theta} \times R_i \end{aligned} \tag{1}$$

where R_c is the mass center of the impactor, θ is the angle rotated from the neutral position, I_0 is the mass moment of the inertia of the impactor with respect to rotation center, v_i is the impact velocity of the impact position and $\dot{\theta}$ is the angular velocity of the impactor. The equivalent impactor mass is computed as follows:

$$\frac{1}{2} I_o \dot{\theta}^2 = \frac{1}{2} m_e v_i^2 \tag{2}$$

where m_e is the equivalent concentrated mass of the impactor. To verify the equivalent mass model, two type of impactors are considered. Model parameters are mass and mass moment of inertia of impactor. In this case, the impact velocity is 0.337 m/sec and the equivalent mass of type A is 0.092 kg. Fig. 3 shows the configuration of the impactors.



- Material : Aluminum
- Impactor mass : 0.1237 kg
- Center of mass (R_c) : 127 mm
- Mass moment of inertia (I_0) : 2670 kg mm^2
- Center of percussion (R_i) : 170.0 mm

Fig. 3 Configuration of impactor

The material properties are also shown in Table 1. Fig. 4 shows the comparison of the impact force histories of undamaged and debonded sandwich plates. It can be observed from the result that the maximum contact force decreased and the contact duration increased due to debonding.

Table 1 Material properties

Material properties of lamina	E_1 = 132.0 GPa, E_2= 8.0 GPa $G_{12} = G_{13} = G_{23}$ = 3.74 GPa ν_{12} = 0.3 ρ =1600.0 kg/m^3 Thickness = 0.14 mm
Material properties of impactor	E = 70.0 GPa ν = 0.3 ρ = 2700.0 kg/m^3

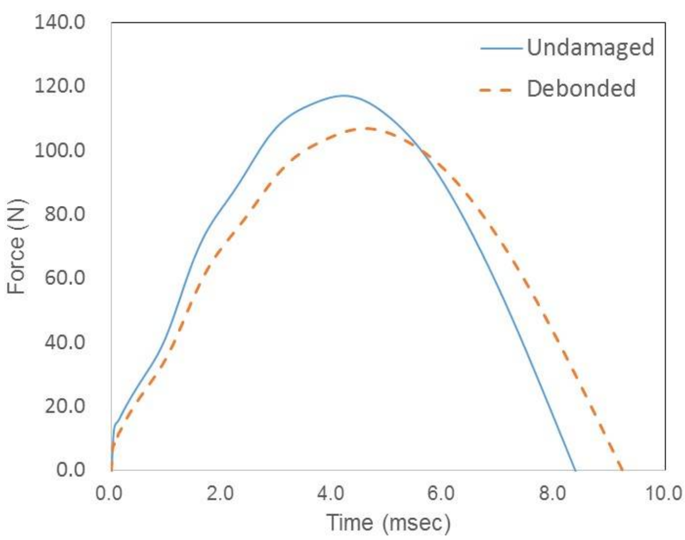


Fig. 4 Comparison of impact force history between undamaged and debonded sandwich plate

2.3 Calculation of acoustic sound radiation

The acoustic pressure radiated from a vibration plate can be obtained by evaluating the Rayleigh surface integral where each elemental area on the plate's surface is regarded as a simple point source of an outgoing wave and its contribution is added with an appropriate time delay. Referring to Fig. 5, the acoustic pressure $P(r,t)$ at observation point r_0 with a Cartesian coordinate (x_0, y_0, z_0) at time t caused by the vibration of the plate is calculated by using the Rayleigh surface integral, which is shown in Eq. (3):

$$p(r,t) = -\frac{\rho_a}{2\pi}\int_{(S)}\frac{1}{|r-r_0|}\frac{\partial^2}{\partial t^2}W(r_0, t-\frac{|r-r_0|}{c_a})dS \tag{3}$$

where ρ_a and c_a are, respectively, the mass density and wave velocity of the acoustic medium, $\partial^2 W/\partial t^2$ is the acceleration of the plate element, which was calculated from impact response analysis, and applied with an appropriate time delay. The properties of air as the acoustic medium are density ρ_a = 1.21 kg/m^3 and speed of sound c_a = 340m/s. A comparison of sound pressure histories computed by analysis both with and without debonding is shown in Fig. 6. The sound pressure histories were analyzed when the impact velocity was 0.337 m/sec. The sound pressure was calculated at 15.0 cm above the center of the plate, and Fig. 7 shows the spectra of sound pressure history. This was achieved by carrying out a Fourier transform of the sound pressure histories. From the results, it is observed that the impact on the damaged area did not excite the higher structural modes as strongly as the impact on the undamaged area. Therefore, the sound produced does not contain higher frequencies and the structure sound is "duller".

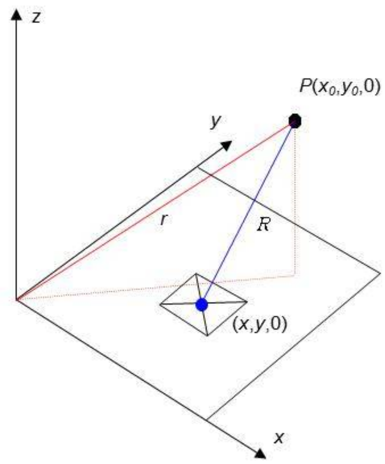


Fig. 5 Coordinate system used for evaluating acoustic pressure

3. CONCLUSIONS

The purpose of this study was to investigate the physical basis of tapping. The sound based tap test was applied to composite sandwich structures. The changes in the sound produced when a damaged area is tapped due to a change in force is transmitted to the structure by the tap. It has been shown that the tap test may be analyzed by using impact and an acoustic sound analysis process. The equivalent spring element model was proposed to model the hammer shaped impactor. The sandwich model was used to numerically investigate the impact and acoustic response during tap test. The numerical results show that there is a strong correlation between the debonding and reduction in impact force and the contents of high frequency of sound pressure. The results presented above show that it is possible to detect damage of sandwich structure using an impact force or sound pressure by comparing either the time history or the corresponding spectrum with signals from a structure.

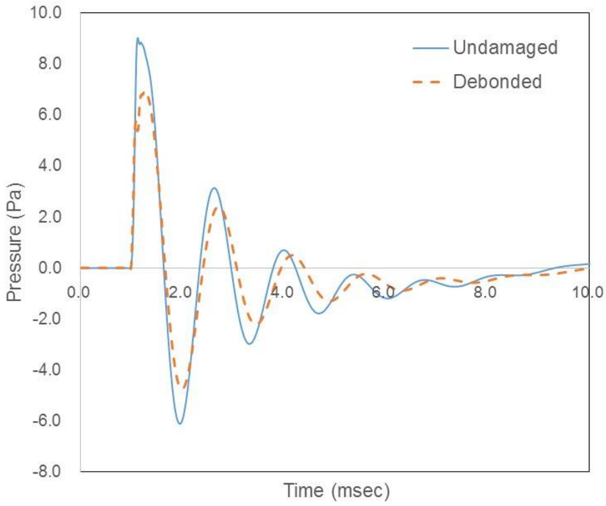


Fig. 6 Comparison of sound pressure history between undamaged and debonded sandwich plate

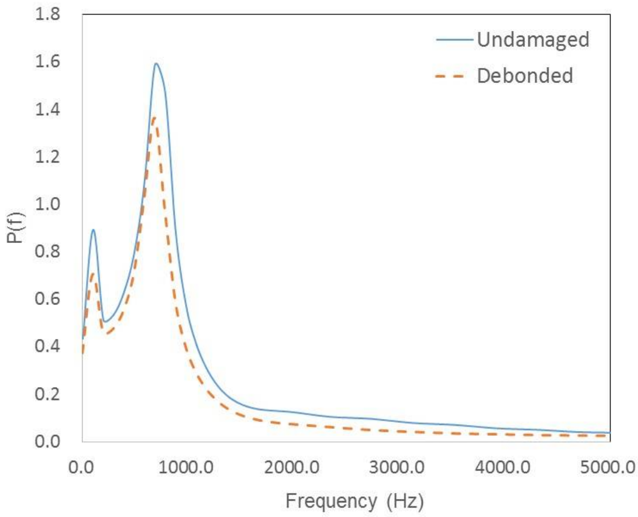


Fig. 7 Comparison of spectra of sound between undamaged and debonded sandwich plate

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