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Mechanical parameters identification for laminated composites based on the impulse excitation technique

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ABSTRACT

This study suggests a simple, quick and non-destructive method for investigation of mechanical parameters (dynamic Young's modulus, dynamic shear modulus and Poisson's ratio) detection for rectangular plate structures in laminated composites which only utilizes the fundamental resonant frequency in flexural and torsional modes, mass and dimensions of structures. The method is based on the impulse excitation technique (IET) to pick up the fundamental resonant frequency and then the corresponding formulas are applied to evaluate the mechanical parameters. Numerical simulations using finite element method (FEM) and experimental investigations of several cases based on IET are introduced to verify the accuracy of the IET formulas. The results show that the IET is applicable for mechanical parameters identification for laminated composites plates. The method is expected to detect mechanical parameters of other more complicated structures.

1. Introduction

The IET method is a convenient and non-destructive testing method covers determination of the dynamic Young's modulus and dynamic shear modulus of elastic materials, which is based on the structures of these materials possess specific mechanical resonant frequencies that are determined by the elastic properties. The methods use the measurement of resonant frequency of structures for the purposes of dynamic mechanical parameters detection [1]. There are different strategies suggested for mechanical parameters detection purposes depending on the type of the mode parameters used: natural frequency, displacement signal, loading force, deflection [2–4]. All of these have their advantages and disadvantages. The natural frequencies are commonly used to detect the dynamic modulus of structures by comparison. The IET method is easy to perform and requires a very short time and non-destructive. In this technique, dynamic Young's modulus and dynamic torsional modulus can be calculated directly using the data of resonant frequency, dimensions and mass.

Ferreira et al. proposed some methods about analysis of structures in composites using the finite element method and Yang et al. developed approaches of damage detection for composites [5–16], it is essential to know the mechanical parameters of materials before establishing the FEM model [17–19]. However, the mechanical parameters cannot be obtained accurately using theoretical method. Therefore, the IET methods for the measurement of dynamic Young's modulus and the dynamic shear modulus that are based on the resonant frequencies of a structure present a very attractive possibility since these are quite easy and convenient to obtain from experiments. The dynamic Young's modulus and dynamic shear modulus detection methods associated with resonant frequency measurement have drawn special attention in the literatures [20–24]. Generally, there are two procedures to accomplish the dynamic Young's modulus and dynamic shear modulus detection in structures. The first procedure is picking up the vibration signals of structures. The second procedure is analyzing the vibration signals and getting the resonant frequency in flexural and torsional modes. When the resonant frequency is known and the dynamic Young's modulus and dynamic shear modulus can be calculated using their relationship with resonant frequencies respectively. However, so far only the dynamic Young's modulus and dynamic shear modulus detection methods for simple structures (beams of rectangular cross section and rods of circular cross section) are well established and the calculation formulas of dynamic Young's modulus and dynamic shear modulus are also reported [25,26]. The reason is that the correction factors depend the shape of structures are difficult to obtain accurately. Thus some researches have been done about mechanical parameters detection in different materials [27–35,3,36], environmental variability [37–41,28,42,43], different dimension sizes [44], etc., based on beams of rectangular cross section and rods of circular cross section only.

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Moreover, we try to do some exploration about mechanical parameters detection for laminated composites based on plates of rectangular cross section.

Because there is little research for indentifying the dynamic Young's modulus and dynamic shear modulus of laminated composites, the purpose of the present work is to do some numerical simulations and experimental investigations to prove the existing formulas based on IET are applicable to calculate the dynamic Young's modulus and dynamic shear modulus for laminated composites. With this method, Numerical models using FEM software ANSYS are built and some experimental investigations are performed. The simulation results are compared with literatures and the precision of the present method is examined. The performance of this method has also been examined using experimental data of a laminated plate. The detection result shows that the proposed method can be applied to real structures. The rest of the paper is organized as follows. The next section introduces the formula based on IET to calculate the dynamic Young's modulus, dynamic shear modulus and Poisson's ratio of structures. Numerical simulations and Experimental investigations are presented in Sections 3 and 4, respectively.

2. Technique methods

The IET measures the fundamental resonant frequency of plates of rectangular cross section with suitable geometry by exciting them mechanically by an impact hammer. An accelerometer senses the resulting mechanical vibrations of plates and transforms them into electric signals. Support locations, impulse locations and signal pick-up points are selected to induce and measure specific modes of the transient vibrations. The signals are analyzed and the fundamental resonant frequency is isolated and measured by the signal analyzer, which provides a numerical reading that are the first-order flexural resonant frequency and the first-order torsional resonant frequency of plates vibration. The appropriate fundamental resonant frequencies, dimensions, and mass of the specimen are used to calculate dynamic Young's modulus, dynamic shear modulus, and Poisson's ratio.

For the calculation of Young's modulus and shear modulus based on the theory of Pickett [25] have been employed, which describe the calculation of the Young's modulus and shear modulus from resonant frequency, dimensions, mass and Poisson's ratio of a rectangular solid.

Support the structures at the fundamental nodal points. The locations of fundamental nodal points are $0.224L$ from each end for flexural modes and it should be the center point of structure for torsional mode, as shown in Fig. 1.

By experimental modal analysis (EMA), the fundamental flexural resonant frequency and fundamental torsional resonant frequency will be obtained accordingly, and the Young's modulus and shear modulus will finally be calculated from the formulas, as shown in the following two sub-sections.

2.1. The calculation of dynamic Young's modulus

The diagram of plate cross-section is shown in Fig. 2. For a fundamental flexural vibration, the Young's modulus of plate can be expressed as [24]:

$$E = 0.9465(mf_f^2/b)(L^3/t^3)T_1 \tag{1}$$

where E is the Young's modulus (Pa), m is mass (g), b is width (mm), L is length (mm), t is thickness (mm), f_f is the fundamental flexural resonant frequency (Hz), T_1 is correction factor for fundamental flexural mode to account for the thickness of the plates, which is calculated by

$$T_1 = 1 + 6.585(1 + 0.0752\mu + 0.8109\mu^2)(t/L)^2 - 0.868(t/L)^4 - \left[\frac{8.340(1 + 0.2023\mu + 2.173\mu^2)(L/t)^4}{1.000 + 6.338(1 + 1.1408\mu + 1.536\mu^2)(L/t)^2}\right] \tag{2}$$

where μ is Poisson's ratio. To simple the calculation, if $(L/t \geqslant 20$, T_1 can be simplified as

$$T_1 = 1.000 + 6.585(L/t)^2 \tag{3}$$

and E can be directly obtained using Eq. (1).

If $L/t \leqslant 20$ and μ is known, T_1 can be calculated using Eq. (2). Then E can also be directly obtained using Eq. (1).

If $L/t \leqslant 20$ and μ is not known, then we must assume an initial Poisson's ratio and use an iterative process to determine a value of Poisson's ratio. The iterative process is shown in Fig. 3.

2.2. The calculation of dynamic shear modulus

For the fundamental torsion frequency of a plate, the shear modulus G can be calculated as follow [24]:

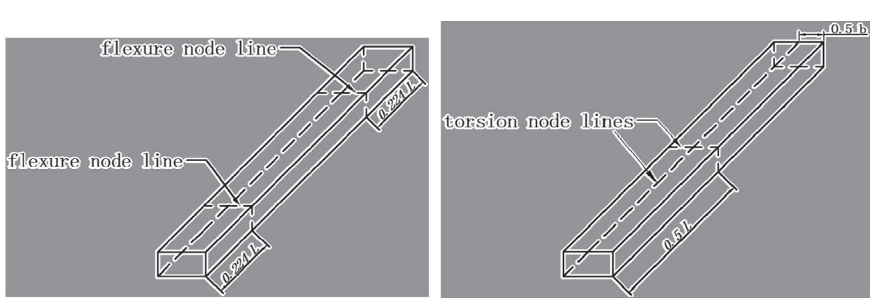
$$G = \frac{4Lmf_t^2}{bt}[B/(1 + A)] \tag{4}$$

where G is dynamic shear modulus (Pa), f_t is fundamental torsional resonant frequency of the plate (Hz). A and B are the empirical correction factor dependent on the width-to-thickness.

$$B = \left[\frac{b/t + t/b}{4(t/b) - 2.52(t/b)^2 + 0.21(t/b)^6}\right] \tag{5}$$

and

$$A = \left[\frac{[0.5062 - 0.8776(b/t) + 0.3504(b/t)^2 - 0.0078(b/t)^3]}{[12.03(b/t) + 9.892(b/t)^2]}\right] \tag{6}$$



(a) The flexural modes (b) The torsional modes

Fig. 1. The diagrammatic sketch of structures.