Mode identifications in Resonant Ultrasound Spectroscopy for Viscoelastic Properties Measurements with Abaqus

Hung-Ju Chou, Chun-Yi Wu and Yun-Che Wang*
National Cheng Kung University, Tainan, Taiwan
Department of Civil Engineering

* yunche@mail.ncku.edu.tw

ABSTRACT

Resonant ultrasound spectroscopy (RUS) has been developed for measuring the elastic constants of materials. The sprit of RUS is resonant frequency of elastic vibration, measuring the spectrum of mechanical resonances for a specimen of known shape. It is important for us to detect resonant frequency of materials. By RUS technique, we get shear modulus and linear viscoelastic damping in a quite short time. The finite element method also provides us a reliable simulation, the ABAQUS is required for us to verify and expect experimental results, and making a comparison between experiment and simulation.

Keywords: resonant ultrasound spectroscopy, linear viscoelastic damping

1. INTRODUCTION

Over the years, resonant ultrasound spectroscopy (RUS) has become a useful laboratory technique and method for measuring second-order elastic constants and ultrasonic attenuation in solids. The RUS technique requires only slightly corner contact force to mount specimens between two transducers. One transducer gives an amplitude and frequency excitation to a specimen, and the other as a resonant receiver. A number of normal modes of a sample are demonstrated in a few minutes.

2. THEORETICAL

In this paper, we demonstrated the first several modes of an isotropic aluminum cube, following Demarest the lowest mode for an isotropic cube.

$$v = \frac{\sqrt{2}}{\pi L}\sqrt{\frac{G}{\rho}} \tag{1}$$

where L is side of cube, ρ is density, G is shear modulus of material, and v is the lowest natural frequency. The fundamental mode is a torsion mode for a cube or a cylinder. Damping calculation is determined by

$$\tan\delta = \frac{\Delta\omega}{\omega_1\sqrt{3}} \tag{2}$$

where ω_1 is the resonant frequency of material, and $\Delta\omega$ is the full width of a resonant curve at half maximum amplitude.

3. EXPERIMENTAL

We set up experimental apparatus to measure and detect resonant frequency we interested. The piezoelectric shear transducers Panametrics V153-RB 1/0.5broadband shear with center frequency 1 MHz, and function generator SRS model DS345, and preamplifier SRS low-noise preamplifier model SR560, and oscilloscope Agilent Technologies DSO7032A digital storage oscilloscope, and Lock-In amplifier SRS model SR844 RF Lock-In Amplifier are required in RUS experiment. The specimen we prepared is a 16.46 mm aluminum cube of 11.71 g. Spectra for the aluminum cube is shown in Figure-1. Because of lack of cubic symmetry, we observed that modes do not degenerated theoretically, split into two or three frequencies peak in the experiment. This phenomenon might be caused by imperfection of materials.

4. SIMULATION

In order to simulate peak split phenomenon, we set up an isotropic cube of 20 mm long, density is 2630 kg/m3, 68 GPa Young's modulus, 0.36 Poisson's ratio, frequency range is from 10 kHz to 500 kHz, 80 the number of eigenvalues requested in ABAQUS for linear perturbation free vibration where shown in Figure-2 and Figure-3. By the eigenvalues from ABAQUS, we obtain resonant frequencies and deformation illustrations which shown in Figure-4. Furthermore, we assigned the cube to change its length for one side to be a parallelepiped. The imperfections of the cube increased in one side which are 1 %, 5 %, 10 %, and 15 %, respectively. We list every eigenvalues of each simulation in Table-1. Detailed results for the peak splitting are shown in Figure-5.

5. RESULTS AND DISCUSSION

We drive the experiment for scanning resonant frequency to detect more separated mode, measuring the resonant peak from 85004 Hz to 148966 Hz, including six modes, they are Td1, Fa1, Ss1, Da1, Dd1, Fs1 mode. By the fundamental peak of frequency 85004 Hz, we calculated the shear modulus of aluminum specimen; it is about 23.14 GPa which is a reasonable modulus. As to the linear viscoelastic damping tan δ, we observed that damping decayed from 5.50×10^{-4} to 2.17×10^{-4}, the results are shown in Figure-6.

We observed that damping proportioned to frequency to the power of minus n, that is $\tan\delta \propto v^{-n}$, where v is resonant frequency. In our experiment, the n was about 2.1.

6. CONCLUSIONS

The RUS techniques provide a large frequency range of scientific, and determined shear modulus and loss tangent damping of solids, we obtained the reasonable elastic modulus. A perfect cube lead degenerate, resonant peaks of the same mode occurred at the same frequency. Imperfection of cube causes peak split phenomenon. The linear viscoelastic damping is found decreasing as frequency increase for the first six mode of aluminum cube.

7. REFERENCES

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8. TABLES

Al cube	mode	Al cube01	mode
68374	Td1	67996	Td1
68374	Td1	68856	Td1
91032	Fa1	90424	Fa1
91032	Fa1	90424	Fa1
91032	Fa1	91173	Fa1

Table-1 Eigenvalues from ABAQUS, showing frequency of 68374 Hz represents Td1 mode for aluminum cube, two separated frequencies of 67996 Hz and 68856 Hz still represent Td1 mode.

9. FIGURES

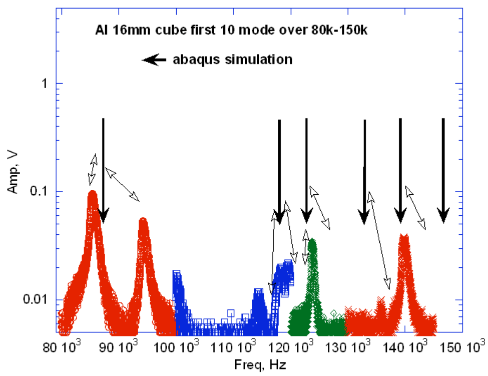

Figure-1 Spectra of aluminum cube, the fundamental peak occurred at the frequency of 85004 Hz, split into 93193 Hz, indicating the same torsion mode.

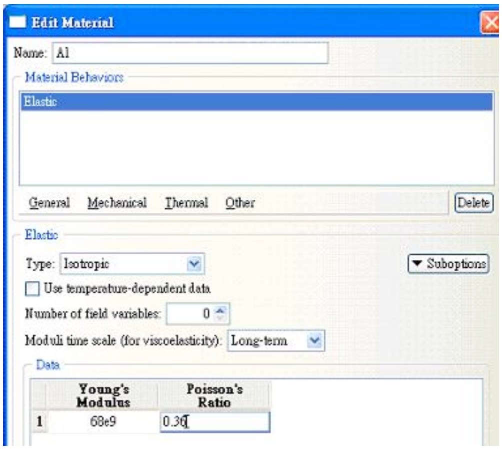

Figure-2 Set-up Young's modulus and Poission's ratio for isotropic aluminum cube in ABAQUS.

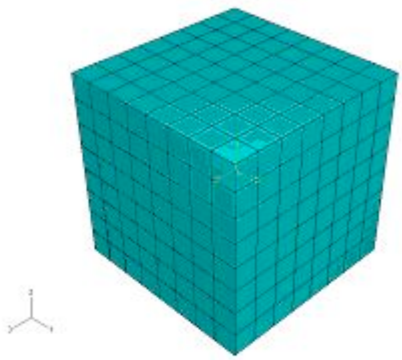

Figure-3 Mesh the model for 512 elements 729 nodes in ABAQUS.

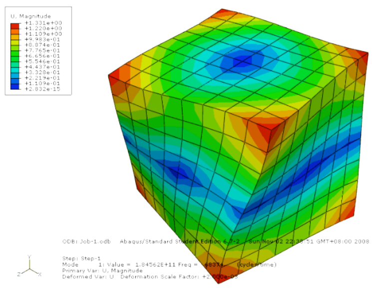

Figure-4 Deformation of aluminum cube, the fundamental torsion mode from ABAQUS.

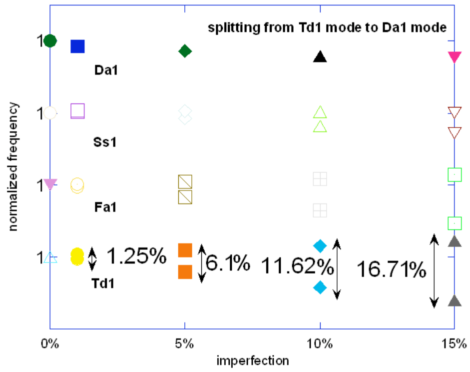

Figure-5 The peak split phenomenon of Td1 mode for aluminum cube, split phenomenon increased as imperfection of cube increased.

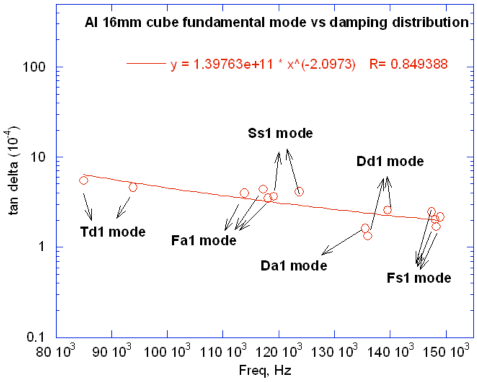

Figure-6 Damping of the first six fundamental modes for aluminum cube.