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Nonlinear Propagation of Amplitude-Modulated Wave in C/C Composite

Kazuyoshi Nagae[1‡], Shiro Biwa[2] and Eiji Matsumoto[1] ([1] Graduate School of Energy Sci., Kyoto Univ., Kyoto; [2]Graduate School of Engineering, Kyoto Univ., Kyoto)

1. Introduction

Various types of composite materials are now in use in different fields. Ultrasonic waves can be employed to measure the elastic/viscoelastic properties and to monitor the damage of such composites. Due to the complex heterogeneity, however, some composite materials exhibit significant degrees of ultrasonic attenuation. This makes it difficult to obtain ultrasonic echoes in thick composites by conventional pulse-echo techniques. In this respect, it is desirable to use high-amplitude ultrasound for the characterization of such highly attenuative materials. In this regard, it is important to clarify the propagation behavior of high-amplitude waves in these materials.

It is known that some complex media such as sands and rocks exhibit strong nonlinear acoustic phenomena, due to the weak bonding between micro-grains. Recently, Inserra et al.[1)] studied nonlinear ultrasonic properties of thermally damaged granite samples using tone-burst waves and showed the possibility to characterize the material damage by the low-frequency component generation. If similar phenomena occur not only in natural materials such as rocks but also in engineering materials such as composite materials, it can be useful as an ultrasonic measure to characterize the material properties as well as their damage. It is the purpose of the present study to explore this possibility in unidirectionally reinforced carbon/carbon (C/C) composite material. To this purpose, the ultrasonic wave propagation through thick C/C composite samples were measured using an amplitude-modulated wave packet, and the amplitude spectra of the transmitted wave were obtained to examine the generation of low-frequency components.

2. Experimental Procedure

The experimental setup is schematically shown in **Fig. 1**. A Gaussian amplitude-modulated wave packet signal was programmed in a signal generator, amplified in a RITEC high-amplitude ultrasonic pulser, and applied to a Panametrics longitudinal-wave transducer (with nominal center frequency 1 MHz), which emitted a longitudinal Gaussian wave packet at center frequency 1 MHz, shown in **Fig. 2**, into the C/C composite sample (length 42.3 mm). The transmitted wave was detected by a similar transducer (with nominal center frequency 1 MHz), and stored into a personal computer via a digital oscilloscope. The amplitude spectra of the acquired waveforms were obtained by the fast Fourier transform technique.

E-mail: [2] biwa@kuaero.kyoto-u.ac.jp

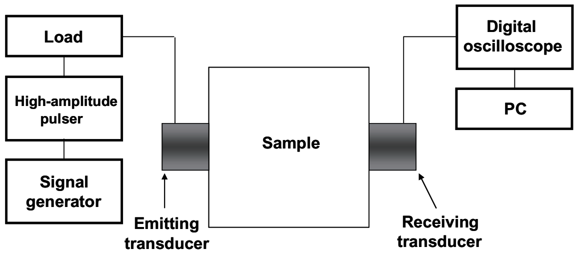

Fig. 1 Experimental setup.

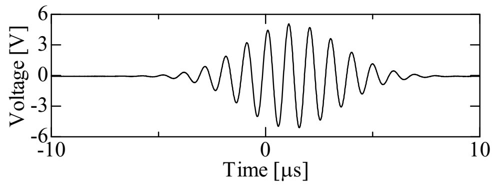

Fig. 2 Signal voltage applied to the transducer.

The sample was made of unidirectional C/C composite (provided by Toyo Tanso Co., Ltd.) which possessed significant anisotropy. Therefeore, the measurements were made for the propagation directions in the three symmetry axes. The fiber-reinforcing direction was named as X-direction, where the other two axes were named Y- and Z-directions, respectively. For comparison, the same measurements and the signal processing were also made for an aluminum block.

3. Results and Discussion

First, the transmitted waveforms in the aluminum block are shown in **Fig. 3** (a) for different driving voltage levels applied to the emitting tranducer, which retain a Gaussian shape even when multiply reflected in the sample. On the other hand, the transmitted waveforms in the Y-direction of the C/C composite sample are shown in Fig. 3 (b). It is noted here that the signal around 20 microseconds of the elapsed time is not relevant to the wave packet propagation, which is

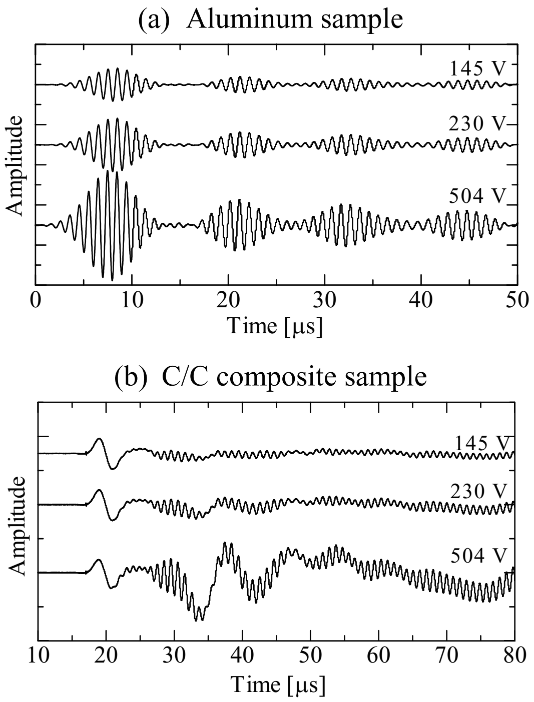

Fig. 3 Transmitted waveforms.

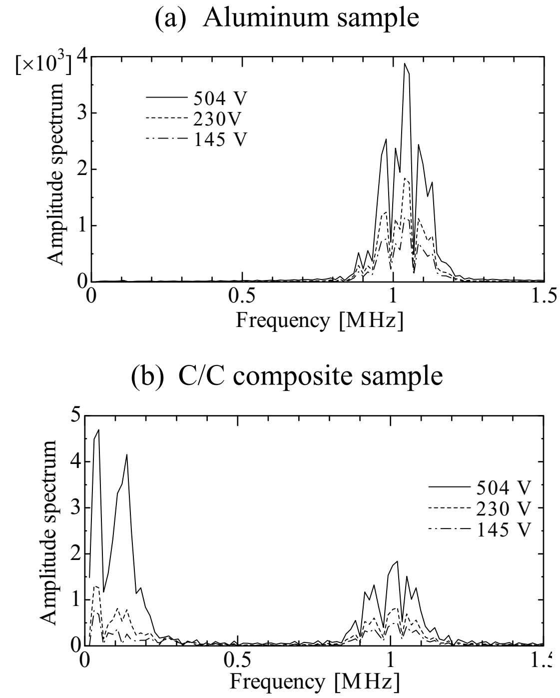

Fig. 4 Amplitude spectra of transmitted wave.

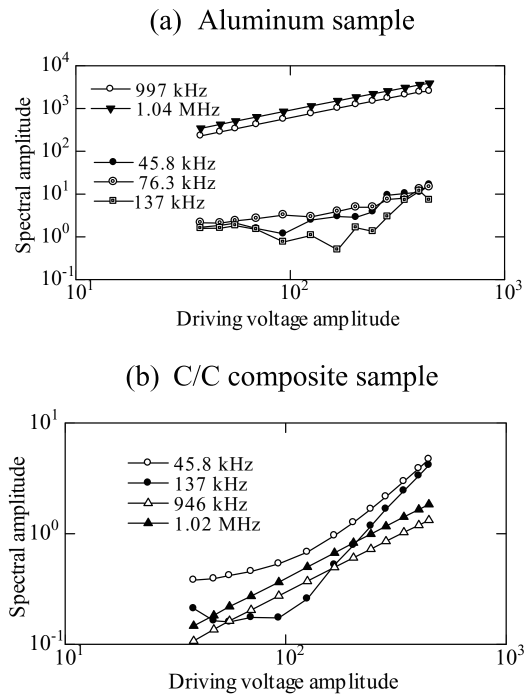

Fig. 5 Dependence of the spectral amplitudes on the driving voltage amplitude.

considered to be due to the electronic mismatching within the pulser at the start of the programmed signal. Therefore, the waveforms after around 25 microseconds should be considered as the transmitted wave packet. In Fig. 3 (b), the waveforms are quite different from the incident Gaussian shape, and there are no clear multiply-reflected signals. The waveforms look like those which are typically seen as a result of the so-called self-demodulation[2)], a typical nonlinear acoustic phenomenon so far observed in some fluids as well as sands and rocks.

The amplitude spectra of the transmitted wave are shown in **Fig. 4** (a) and (b) for the aluminum and C/C composite blocks, respectively. While the spectra are concentrated around 1 MHz for the aluminum block, there are remarkable low-frequency components below 0.2 MHz in the spectra of C/C composite. As can be seen in **Fig. 5**, these low-frequency components in the C/C composite grow in a non-proportional (nonlinear) manner with the driving voltage, so these are considered as an outcome of nonlinear ultrasonic property of the composite.

4. Conclusion

The nonlinear generation behavior of low-frequency components in the C/C composite subjected to an amplitude–modulated wave packet has been demonstrated in the present experiment. This feature can be used as a measure of the material property of inhomogeneous composites.

References

1. C. Inserra et al., Jpn J. Appl. Phys. 48 (2009) 07GD03.
2. V. Y. Zaitsev et al., Acoust. Phys. 45 (1999) 202.