ULTRASONIC DETECTION OF VOIDS IN CERAMIC COMPOSITES

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INTRODUCTION

Ceramic composites are intended to take advantage of the high temperature capabilities of ceramics while minimizing the disadvantages caused by their very brittle nature. The particular material under study consists of a Nicalon[a] fiber weave reinforcing fabric in a silicon carbide matrix formed by a chemical infiltration process [1]. The process can result in high porosity (10-50%) and voids because of incomplete infiltration by the SiC-containing vapor. The basic objective of this NDE study is detection and characterization of the porosity and voids.

Previous work [2,3] established correlations between ultrasonic attenuation and velocity and material porosity. The material was found to be highly attenuating, particularly at high frequencies, which limits useful measurements to those made by through-transmission techniques at frequencies of ~5 MHz or less, depending on sample thickness and porosity. Thermoelastic generation of ultrasound by a pulsed laser beam was found to have advantages over insonification by conventional piezoelectric transducers because of more direct coupling of ultrasound into the material and because of the higher energy available with the laser. The ability of ultrasonics to image variations in the distribution of porosity in samples was also demonstrated.

PULSED LASER GENERATION OF ULTRASOUND

Generation of ultrasound by a laser pulse was investigated in detail in order to optimize the laser parameters and understand the physical mechanisms involved. An incident pulsed laser beam can generate ultrasonic energy in a material by two different main mechanisms that depend on the energy density at the material surface. For low energy densities, the laser pulse is converted by the thermoelastic effect and a combination of shear and longitudinal waves is produced. At sufficiently high energy densities, ablation occurs in addition to thermoelastic conversion. This vaporization of a portion of the surface material or a surface coating, such as oil, imparts a normal impulsive force to the

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[a] Nicalon is a trade name of the Nippon Carbon Co., Tokyo, Japan.

surface. In addition to the thermoelastic waveform, the short laser pulse (typically 10 ns) produces a longitudinal pulse which is relatively sharp, and thus has a relatively high frequency content.

Figure 1 shows signals from laser generated, through-transmission, ultrasonic pulses in the SiC composite material. They were obtained with a capacitive detector and a metal coated sample (0.1 μm Pt) that provide a wideband measure of the absolute displacement of the sample surface. This avoids the resonant vibration modes of a piezoelectric transducer so that the details of the laser generation can easily be seen. The top trace was produced by a low energy laser pulse for which only thermoelastic conversion occurred, while the bottom trace was produced by a higher energy laser pulse that was well into the ablative regime. The pulses are similar to each other and to pulses produced by thermoelastic conversion in monolithic steel samples of comparable thickness. By comparison with theoretical modeling of the laser generation process, the features of the pulses can be identified. The laser pulse is incident at time LP. The arrival of the longitudinal component at the back surface of the sample is labeled L, and the point labeled S is the arrival of the shear wave component. The oscillations following these are produced by different vibration modes of the plate samples and from scattering from the porosity and reinforcing fibers.

The high frequency ablative pulse, which is normally a positive-going spike at the arrival point, L, is absent. We conclude that it has been filtered out by the material, and that the ultrasonic pulse which penetrates through the sample is primarily due to the thermoelastic process. Consequently, there is no advantage to operating in the ablative regime. If higher ultrasonic energy is desired, the laser energy can be increased while increasing the spot size to keep the

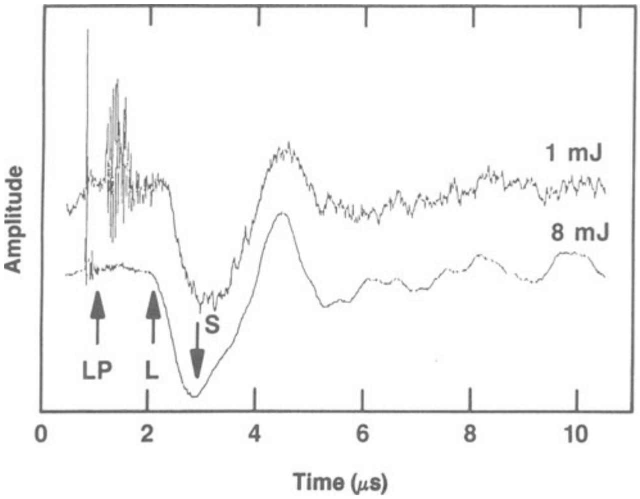

Fig. 1 Thermoelastic (1 mJ) and ablative (8 mJ) laser generated ultrasonic pulses result in similar displacements in the far surface of the sample.

energy density in the thermoelastic regime so that the surface is not damaged by ablation. (Note also that the surface does not need to be coated with a contaminating coupling material.)

DETECTION AND CHARACTERIZATION OF INDIVIDUAL VOIDS

The work on ultrasonic detection of porosity was concerned with the collective behavior of a large number of pores which permeate the sample and are either too small or too closely spaced to be individually resolved. The detection and characterization of individual voids or agglomerations of voids is also of importance. The ability of ultrasonics to resolve these against a background of distributed porosity was the topic of this phase of the study.

The work discussed here was conducted with a sample containing seeded voids. The sample, prepared at Oak Ridge National Laboratory, was 45 mm in diameter, 11.5 mm thick, contained 40% by volume of Nicalon plain weave cloth in a 30-60-90 layup, and was about 85% of theoretical density. The voids were nominally 2 and 5 mm in diameter, 2.5 mm thick, and located ~2 mm from opposite surfaces of the sample. Ultrasonic inspection was performed in through-transmission with focused, broadband, 2.25 MHz piezoelectric transducers. The transducers were focused on the respective surfaces of the sample to approximate a point source and detector pair. This simplified the geometry of the inspection. The ultrasonic response of this sample is shown in Fig. 2 for three cases, when the transmitted beam is unobstructed and when it encounters the 2 and 5 mm voids, respectively. Between the vertical dashed lines the wave forms are similar with only the signal amplitudes affected by the presence of the voids.

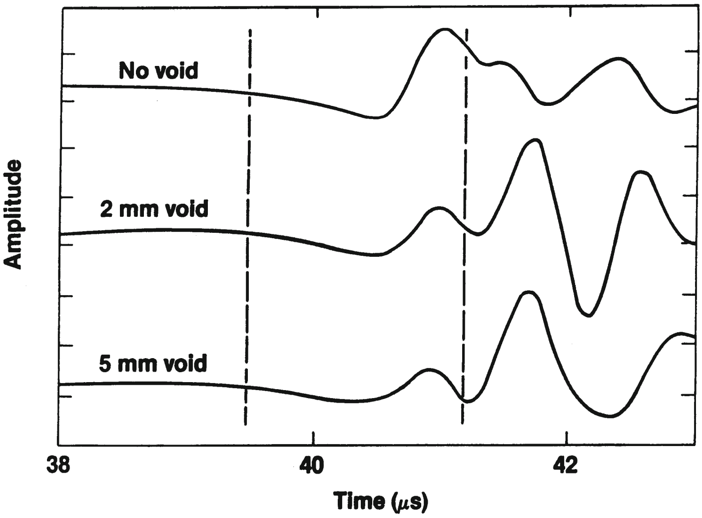

Fig. 2 Voids affect the amplitude of the signal between the dashed lines, but do not change the shape or the time-of-arrival.

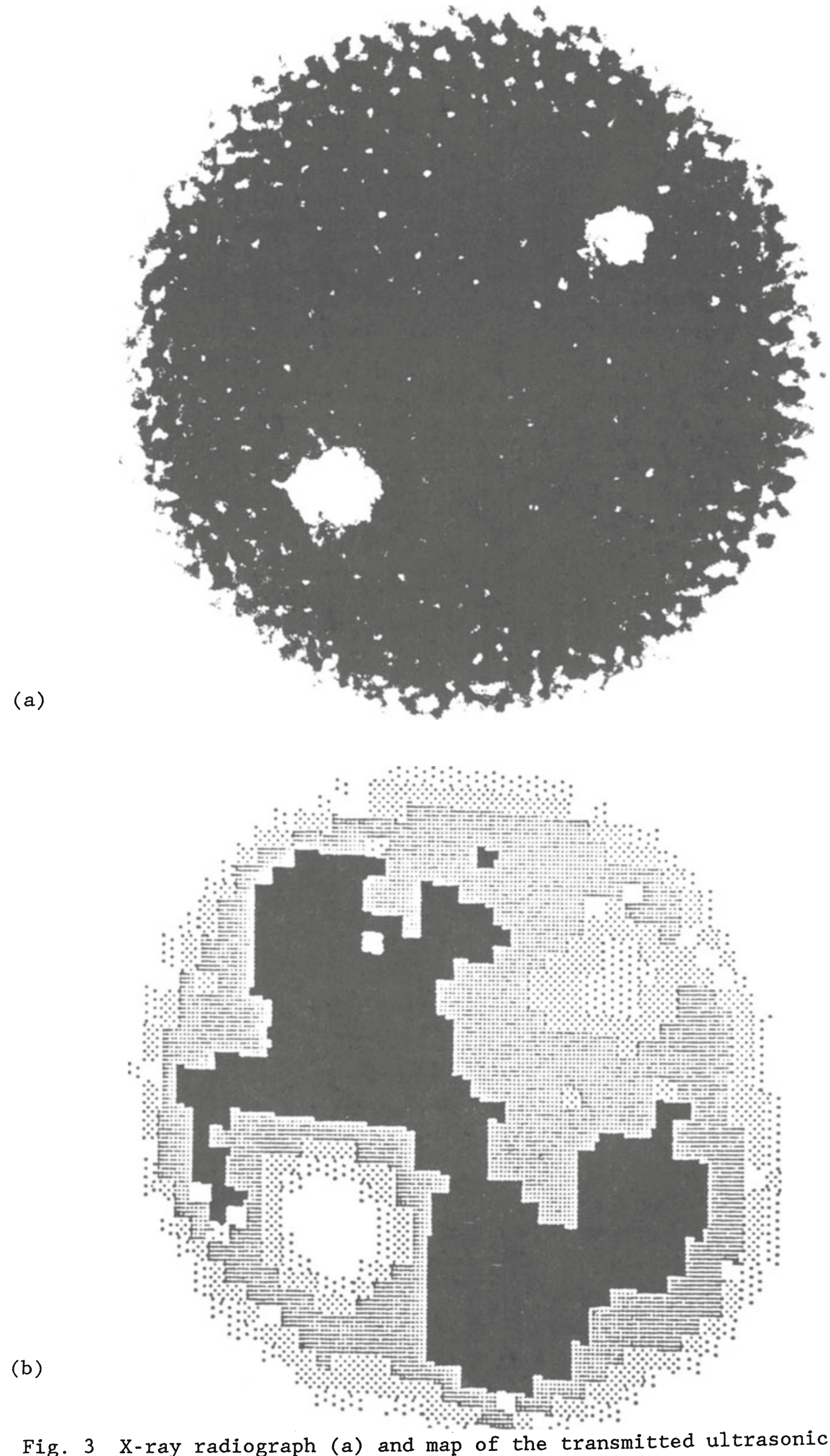

Fig. 3 X-ray radiograph (a) and map of the transmitted ultrasonic energy (b) revealing the presence of two seeded voids.

Both the x-ray radiograph and the map of the transmitted ultrasonic energy presented in Fig. 3 show the voids clearly. The ultrasonic energy is determined from the portion of the ultrasonic signal between the vertical dashed lines in Fig. 2. The seeded internal voids are also seen in Fig. 4, which is a line scan taken along a sample diameter containing both voids. The transmitted ultrasonic energy dips by about 10 and 6 dB, respectively, for the two voids. A similar line scan for an identical sample containing no voids showed fluctuations of about 2 dB caused by variations in sample porosity and reinforcement. It appears that the 2 mm void is close to the limit of resolution. Smaller voids might be detected, but their size could not be accurately determined from such c-scans. Also, a void of this size would be indistinguishable from a collection of several closely spaced small voids. This is not surprising since the ultrasonic wavelength in the sample is approximately 3.5 mm and the periodicity of the reinforcing weave is about 1.5 mm. However, since the time-of-arrival of the transmitted ultrasonic pulse is insensitive to the presence of a void, as shown in Fig. 2, it should be possible to distinguish voids from variations in material porosity.

SUMMARY AND CONCLUSIONS

High porosity ceramic composite materials present a complex medium for the propagation of ultrasound; however, ultrasonic inspection can detect voids, agglomerates of pores, and variations in porosity content when through-transmission techniques are used. We found that for laser generation of ultrasound the portion of the ultrasonic pulse which actually penetrates the ceramic composite sample is a result of the thermoelastic process. Consequently, the material can be inspected without ablative surface damage; the energy in the laser pulse can be increased without entering the ablative regime by defocusing the laser spot.

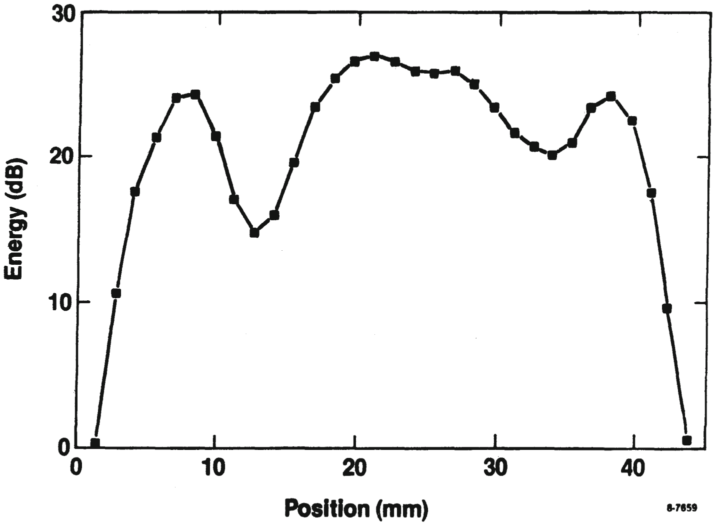

Fig. 4 Transmitted ultrasonic energy at points along a sample diameter containing both seeded voids.

The void detection study determined that voids smaller than the ultrasonic wavelength (typically 3.5 mm) can be detected. However, their sizes probably cannot be accurately determined nor can several closely spaced small voids be resolved. Voids can be distinguished from areas of high porosity since they do not affect the ultrasonic velocity while high porosity does. Details of the material structure, such as the size and spacing of the reinforcement and the porosity, are the major factors affecting the detection limits for voids.

ACKNOWLEDGMENT

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REFERENCES

1. A. J. Caputo, D. P. Stinton, R. A. Lowden, and T. M. Bessmann, "Fiber-Reinforced SiC Composites with Improved Mechanical Properties," Am. Ceram. Soc. Bull. 66, 368 (1987).
2. J. B. Walter, L. A. Lott and P. M. Gammell, "Ultrasonic Characterization of Porosity in Advanced SiC Ceramic Composites," Nondestructive Testing of High-Performance Ceramics, Conference Proceedings August 25-27, 1987, American Ceramic Society, pp.156-162 (1987)
3. J. B. Walter, L. A. Lott and K. L. Telschow, "Ultrasonic Characterization of Ceramic-Ceramic Composites," Review of Progress in Quantitative Nondestructive Evaluation, 7B, Plenum Press, pp.971-978 (1988)