DIFFERENTIATION OF VARIOUS FLAW TYPES IN CERAMICS USING THE SCANNING LASER ACOUSTIC MICROSCOPE

D. E. Yuhas, T. E. McGraw and L. W. Kessler
Sonoscan, Inc.
Bensenville, Illinois 60106

ABSTRACT

High frequency acoustic imaging represents a powerful technique for the nondestructive evaluation of optically opaque materials. In this report the Scanning Laser Acoustic Microscope (SLAM) is used to detect and characterize flaws in ceramics. SLAM micrographs showing typical examples of cracks, laminar flaws, porosity and solid inclusions are presented. The various flaw types are easily differentiated on the basis of their characteristic acoustic signatures. The importance of an imaging approach to the nondestructive evaluation of ceramics is demonstrated.

INTRODUCTION

This report is the first in a series of two papers describing high frequency (100 MHz) acoustic imaging of ceramics. The current investigation deals primarily with the recognition and interpretation of a variety of different flaw types. In this and other studies the Scanning Laser Acoustic Microscope has been used to investigate cracks, delaminations, porosity, machine damaged surfaces and solid inclusions. Examples of these are presented to provide a general overview of acoustic micrographs obtained with the SLAM and to gain an appreciation for the unique features of the various flaws. In a companion paper, attention is focused on implanted solid inclusions in silicon nitride discs. The differentiation of solid inclusions from cracks, delaminations and porosity is based on comparison of the characteristics of flaws found in these discs with those observed in other samples where the exact nature of the flaw type has been confirmed by destructive analysis. A SLAM catalogue of flaws is presented in this paper in order to provide the necessary background for the results presented on solid inclusions (companion paper).

EXPERIMENTAL APPARATUS AND TECHNIQUE

Figure 1 is a photograph of the SONOMICROSCOPE 100. The principles of operation have been described in the literature. Briefly, the instrument produces full grey scale acoustic images at frequencies from 30-500 MHz. The results appearing in this paper are all at 100 MHz where the field of view is 2x3 mm, resolution is about 1/2 wavelength, or 30 microns in silicon nitride (shearwaves), and images are produced in real time. The transmitting transducer is a piezoelectric element. A focused laser scans the sonified zone and acts as the receiving transducer. By synchronizing the laser scan with a television monitor, real-time acoustic images are obtained.

As a by-product of the technique, an optical image of the scanned surface is produced on a separate TV monitor. This image is quite useful in documenting the location of flaws.

Figure 1 - Scanning Laser Acoustic Microscope (SLAM) used in this investigation.

SLAM DATA

Two types of acoustic micrographs, amplitude images and interferograms are commonly used. They are easy to distinguish and both are useful for defect characterization. Figure 2 shows an amplitude image (top) and interferogram (bottom) obtained in the same silicon nitride test sample. The amplitude image shows the relative transmission level over the field of view. In the amplitude mode, bright areas correspond to zones in the sample with good acoustic transmission, whereas the darker areas are attenuating. The interferogram has a characteristic set of vertical fringes which are produced by electrical
mixing of the detected acoustic signal with a phase reference. In principle the interferogram is an acoustic hologram containing all three dimensions of information throughout the sample volume. In our employment of this mode, the hologram is not "reconstructed", rather graphical analysis of the fringes yield quantitative elastic property information. In particular, lateral shifts of the fringes indicate sonic velocity variations within the sample or thickness changes. In the interferogram (Fig. 2b) a lateral shift of one fringe corresponds to a 1.0 percent velocity variation. The field of view in this sample is 3 mm across; the spacing between the fringes in the interferogram is 85 microns. It can be determined from this figure that the silicon nitride sample shown is fairly clean and uniform in its elastic properties. The horizontal streaks in the acoustic images are due to surface texture caused by a grinding operation. Though visible, the grinding marks do not interfere with the visualization of buried flaws. By way of contrast, other ultrasonic inspection techniques require a high degree of surface flatness and polish. Therefore, poorly prepared samples such as this are ordinarily difficult to inspect.

ACOUSTIC CHARACTERISTICS OF FLAWS

The differentiation of various flaw types is made by comparing their characteristic signatures. In order to acquaint the reader with the various flaw characteristics, a series of micrographs illustrating a variety of flaw types is presented.

Influence of Porosity - Figure 3 shows an acoustic amplitude micrograph obtained on a reaction sintered silicon nitride turbine airfoil. This is a much more porous material than shown in Figure 2 as evidenced by the high attenuation regions. Destructive analysis of these samples indicates the presence of pores ranging in size from less than 1-50 µm. The larger pores are directly resolvable acoustically while the smaller pores give rise to the texture seen in this micrograph. A qualitative correlation was found between the porosity distribution determined acoustically and that obtained destructively by sectioning.

Recent investigations of a variety of silicon carbide samples reveal substantial changes in the characteristics of acoustic micrographs as a function of grain size and percentage of unreacted material.

Laminar Flaws - Figure 4 is an acoustic micrograph showing a laminar flaw found in a reaction sintered silicon nitride turbine blade. The central dark zone (D) indicates an extended area of increased acoustic attenuation. This same region shows perturbed, discontinuous interference fringes indicating increased scattering (not shown). The region away from the flaw (the background structure) is similar to that presented in Figure 3 and is attributed to porosity in the blade.
Crack Detection (Acoustic Shadow) - The fracture characteristics revealed by acoustic microscopy depend on the crack orientation relative to the direction of sonic propagation, the size of the crack opening, the roughness of the fracture interface, and the extension of the fracture beneath the surface. The acoustic transmission level across the fracture interface may vary from almost total attenuation (evidenced by a shadow, as shown schematically in Fig. 6) to only slight variations in acoustic contrast. Similarly, the perturbation of the interferogram fringe spacing may range from complete disruption to an almost imperceptible fringe shift.

Fig. 4 - Acoustic amplitude micrograph of laminar flaw found in a ceramic turbine airfoil.

Figure 5 is an optical reflection micrograph confirming the acoustic results presented in Figure 4. The most apparent feature is a 100 micron diameter pore located near the center of the section (see arrow). Contiguous with the pore is a laminar crack-like flaw running horizontal in the micrograph. Both the crack and pore lead to high sound attenuation thus producing a dark region in the acoustic micrograph (see Fig. 4). The length of pore and crack is approximately 600 microns which is comparable dimensionally with the dark zone imaged acoustically. Remember that the acoustic micrograph provides a two-dimensional projection image of the defect. Several serial sections would be required to map the entire flaw optically.

Fig. 5 - Optical reflection micrograph on turbine airfoil section confirming the flaw found in Figure 4.

Fig. 6 - Schematic illustrating the effect of crack shadowing observed in the SLAM.

Fig. 7 shows acoustic micrographs of a fracture opening to the surface of an alumina sample. The micrographs are oriented such that the sound field propagates out of the plane of the paper at an angle of 45° from left to right across the field of view. Sound propagating through the sample is attenuated at the fracture interface resulting in a shadow to the right of the fracture. The primary feature that distinguishes a surface opening crack is the abrupt and sharply defined onset of the shadow region. This is seen as a sharp boundary separating the light and dark portions of the micrographs in Figure 7. The interferogram fringes are almost obliterated in this area, indicating almost total sound attenuation. By measuring the length of the shadow and using the known propagation angle, measurement of crack extension beneath the surface is made. In Figure 7 the propagation angle was 45°, the shadow is approximately 1 mm in length, thus the crack extends 1 millimeter below the surface.
Micro Cracks - Mode Conversion - For large cracks which extend several wavelengths below the surface (greater than 200 microns) the primary micrograph feature is the shadow zone. Smaller cracks are rendered visible due to easily detected mode conversion at the flaw site.

Figure 8 shows a micrograph obtained in the vicinity of a Vickers indent in a hot-pressed silicon nitride test bar. The presence of the mode-converted surface-skimming bulk wave leads to the characteristic cone-shaped ripple pattern observed in the vicinity of the flaw. Explanation of the detection phenomenon and the image characteristics have been reported elsewhere.

A nice feature of the intrinsic mode conversion at the site of small cracks is that it is easy to detect flaws at low magnification. Waves generated at the flaw site propagate several millimeters beyond the flaw site, thus leading to enhanced detection sensitivity and remote sensing capability.

Characteristics of Inclusions - Figure 9 shows a typical silicon nitride sample with an implanted solid inclusion. The primary features which distinguish this flaw type from other defects are the - 1) bright center with acoustic transmission greater than or equal to the background structure. 2) ring pattern due to diffraction of sound by the inclusion, 3) and the well-defined boundary of the flaw. These image characteristics seem to be prevalent for solid inclusions observed so far and they are quite different type from porosity variations in laminar flaws. The micrograph was obtained on a sample containing an implanted 400 micron diameter silicon inclusions. The image size, the diameter of the first ring, is 160 microns and the flaw is 900 microns below the surface. To obtain the relationship between SLAM image size and the actual flaw size, it may be necessary to account for the effects of diffraction and beam spreading. This point is investigated in greater detail in the companion paper.

The flaw is presented to illustrate the unique morphology of solid inclusions.
SUMMARY

Examination of a variety of different flaws in ceramics has led to the development of a series of unique image characteristics. These acoustic signatures can be used to differentiate various flaw types. Many of the interpretations rely on defect morphology. Thus, underscoring the utility of the imaging approach. This is particularly important, for example, in detecting solid inclusions in porous ceramics. Acoustic images also provide a handle on the determination of flaw sizes. The extension of cracks below the surface are directly obtainable from micrographs. Estimates of the size of solid inclusions are also obtainable. However, in this case, it may be necessary to correct recorded image size for beam spreading and diffraction effects.

REFERENCES


