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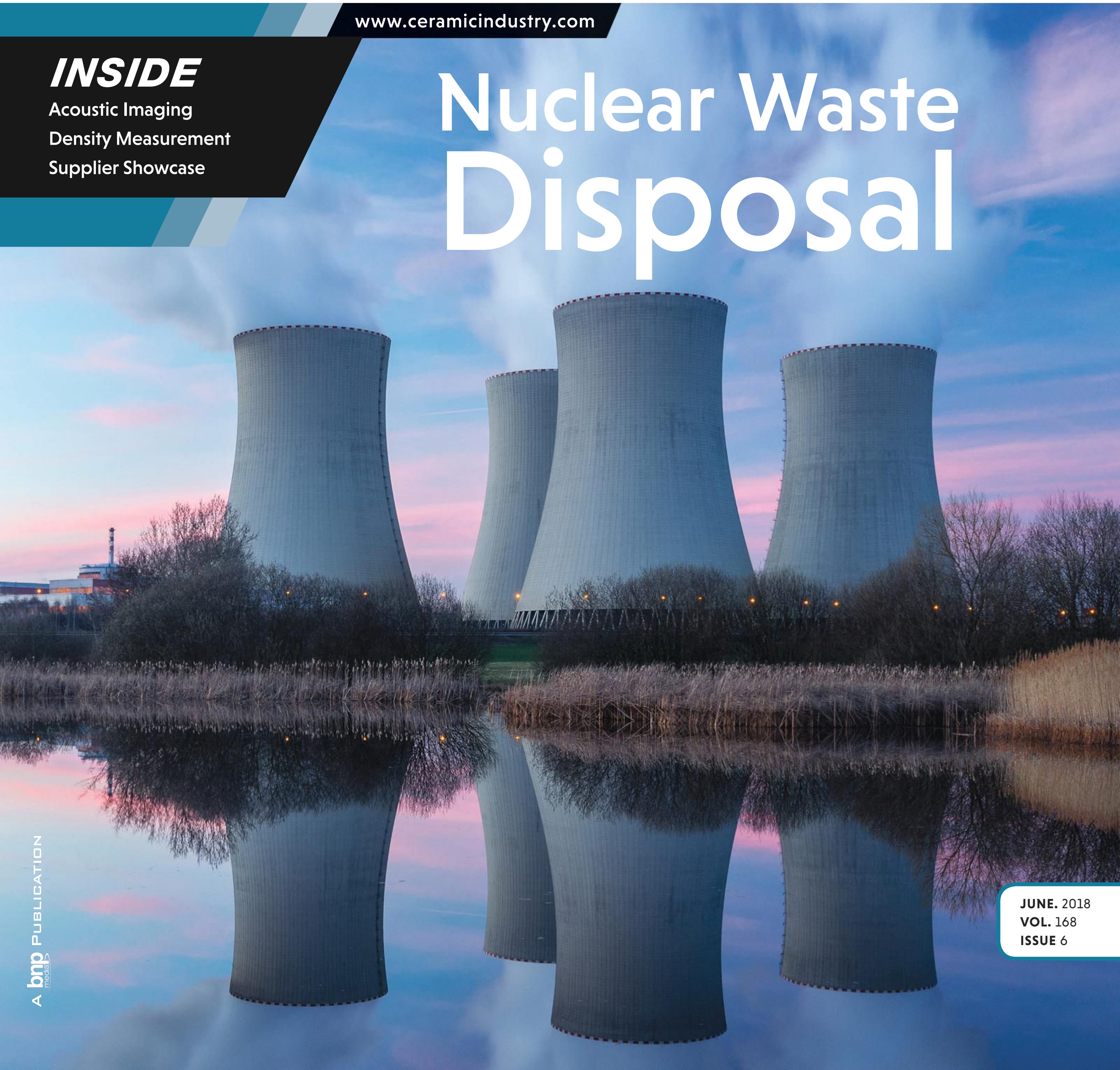

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Acoustically Imaging Diamond Drill Bit Inserts

Some defects in diamond drill bit inserts can be seen optically, but those that do not reach the surface require a different approach to make them visible.

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Internal defects (usually described as cracks or voids) in the diamond inserts that make up the drill head used in drilling oil wells typically consist of some type of gap in the diamond material. The mechanical forces applied to a diamond insert are so great that these defects may cause the insert to fracture, even though it cannot be scratched by the rock layers it is drilling through.

It is thus worthwhile to identify the inserts having internal gap-type defects and remove those inserts from the assembly process. Some defects in the diamond can be seen optically, but those that do not reach the surface require a different approach to make them visible.

Imaging Basics

Internal defects large and small are easily imaged with ultrasound rather than light. Ultrasound pulsed into a basically homogeneous material such as diamond will be reflected by any material interface it encounters. In diamond, ultrasound is reflected by the material interface between the diamond and the air (or other gas, or vacuum) in the gap. A solid material inclusion within the diamond is imaged because it also reflects ultrasound, but at a somewhat lower amplitude.

Figure 1 Optical photo of diamond drill head insert.

Imaging is done with an acoustic micro-imaging tool.* Inserts may be imaged singly or in small numbers by a laboratory tool, or in larger numbers by an automated tool when arranged in a suitable tray. In either case, the basics of imaging are the same. The transducer that pulses ultrasound into the insert and that receives the return echoes from internal interfaces scans back and forth a few millimeters above the top surface of the insert. Its purpose is to send a pulse of ultrasound into each of thousands or millions of x-y locations on the insert's surface. The transducer travels at a speed that may exceed 1 m per sec when it is scanning a tray of inserts.

Diamond has the highest acoustic velocity of any material, and it absorbs very little of the ultrasound. Sound, including ultrasound, travels through diamond at about 12,000 m per second. Suppose a crack lies 1 mm below the surface. To determine the color of a pixel to represent one of the thousands of x-y locations needed to image the diamond, the following events occur:

- Ultrasound is launched by the transducer and travels through a column of water (because ultrasound does not travel through air) maintained by a jet attached to the transducer's surface.

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*such as Sonoscan's C-SAM®

- The pulse of ultrasound encounters the interface between the water and the diamond surface, and is partly reflected back to the transducer. The rest of the ultrasound crosses the surface and travels deeper into the part.
- The ultrasound encounters the interface between diamond and the air in the crack. The percentage of ultrasound reflected at an interface depends on the physical characteristics of the two materials. Diamond has the highest acoustic velocity of any material, while air transmits ultrasound poorly or not at all. At this diamond-to-air interface, the differences in density and acoustic velocity are so enormous that virtually all of the ultrasound is reflected back to the transducer.

When the return echo reaches the transducer, the echo's amplitude, acoustic frequencies, polarity and time of flight from the defect to the top surface of the diamond are recorded. In reflection mode imaging, the amplitude of the strongest echo is used to determine the pixel color for that x-y location. Reflection mode is the most widely used imaging mode; about a dozen other modes are available.

Figure 2 Optical photo of the top surface of the insert.

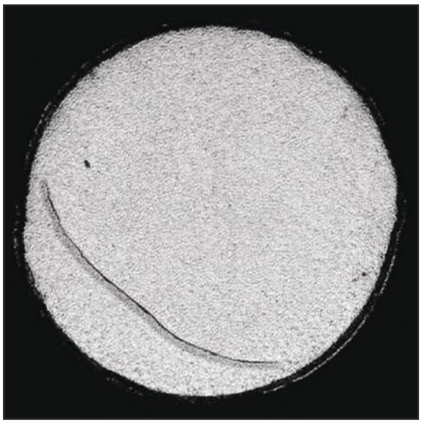

Figure 3 Acoustic image of surface of the insert. Note the long crack.

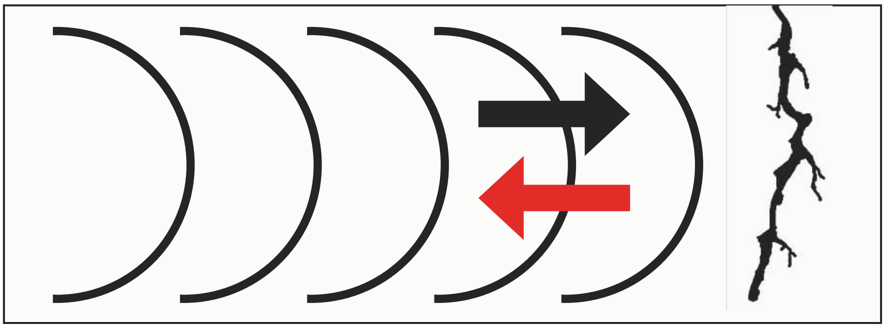

Figure 4 Illustration of acoustic surface wave imaging finding cracks (and other gaps). A pulse reflected by a crack will not reach the transducer.

Sample Studies

The insert shown optically in Figure 1 has a diameter of 20 mm; the height of the entire insert is 13.5 mm. The diamond layer on top has a thickness of 1 mm, while the tungsten carbide base has a thickness of 12.5 mm. The acoustic images illustrating this article were all made from this sample.

The usual practice is to image the depth most likely to harbor a defect. Trying to image the whole thickness of a sample can result in images of defects whose depth cannot be determined. The process of specifying the desired depth is called gating: echo signals whose arrival times indicate that they originated within the selected gate are used to make the image. Other echoes are ignored. In more analytical work, gates may be set to "slice" a sample into a few or a dozen or even hundreds of depths. All are scanned at the same time, and each produces its own acoustic image. In the sample illustrated here, the depths of greatest interest are all of the diamond layer (including the top surface), the bond between the diamond and the tungsten carbide below, and perhaps the bulk of the tungsten carbide.

Figure 2 is the optical image of the top surface of the insert. It is featureless except for a long but very faint crack in the lower left quadrant. Optically, the crack is so faint that it is barely visible, but its location can be judged from the acoustic images.

Figure 3 was made by scanning the surface of the diamond. The crack at the lower left is plainly visible because its acoustic visibility is related to the depth to which the crack extends below the surface of the diamond. Also visible in this surface scan are a few other small dark areas that may be significant.

The sample was next imaged by the acoustic surface wave method, which interrogates the immediate sub-surface in order to find gap-type defects, chiefly cracks. This method is also known as Rayleigh Wave imaging. A pulse is inserted into the sample and travels

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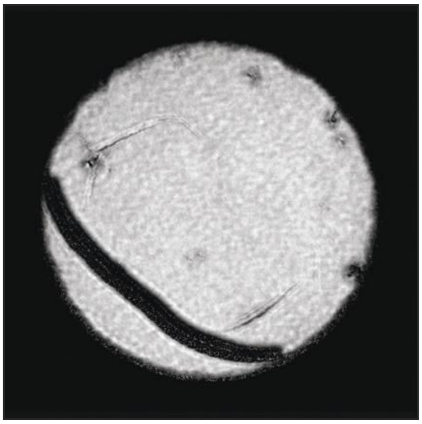

Figure 5 Acoustic surface wave image of the top 500µ (roughly) of the insert.

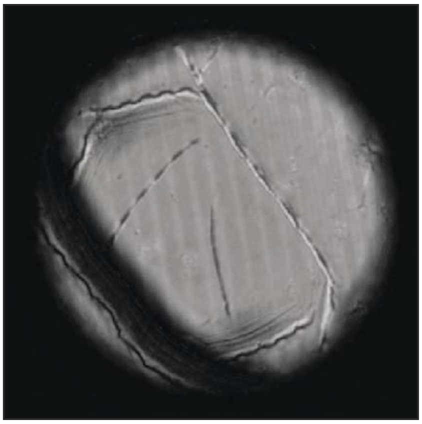

Figure 6 Acoustic reflection-mode image of the interface between diamond and tungsten carbide.

along just below the surface for a short distance. If there is no subsurface feature to block the pulse, it is detected by the transducer a few millionths of a second after launch. Its high amplitude will create a bright white pixel in the acoustic image.

However, if the pulse encounters a crack or other feature that will prevent its arrival (see Figure 4, p. 19), there will be no amplitude to measure and the pixel will be black. This method is also used to image spherical silicon nitride bearing balls to detect subsurface cracks that will escape optical inspection but that are close enough to the surface to cause failure in service.

The surface wave image of the sample is shown in Figure 5. The long crack already seen in Figure 3 here appears much wider. The crack is probably somewhat angled, so that during the surface wave scan it will block the pulse sent from the transducer at numerous x-y locations in a row.

Also visible in Figure 5 are two narrow cracks and several small, more or less rounded features that may be voids. The surface scan (Figure 3) showed them as very tiny features. Surface wave scanning here shows them as larger features. They probably lie more or less at mid-depth in the 1-mm-thick diamond. The pulse used in surface wave scanning is thought to be blocked by features that extend as deep as 500 microns—half the 1 mm thickness of the diamond. These voids have largely disappeared at the 1 mm depth that is the interface between the diamond and the tungsten carbide.

Figure 6 is a reflection mode (not surface wave) image gated on the interface between the diamond and the tungsten carbide. The nearly vertical straight gray and lighter gray lines represent channels that fit into each other for added strength. The large crack in the lower left, first noted in the optical image of the surface, is here broad and dark. Several cracks first appear at this depth; one group forms a rough rectangle. The rectangle itself encloses two additional cracks, one of which (running northeast) may lie entirely in the tungsten carbide below the diamond. The voids seen in Figures 3 and 5 are also faintly visible here.

Avoiding Expensive Repairs

Drill heads using diamond inserts that have been imaged acoustically and found to contain no internal defects are less likely to fracture during the drilling process. Their greater longevity means that the costly process of removing the drill head for repairs can be performed less often. **Ci**

For more information, call (847) 437-6400 or visit www.sonoscan.com.