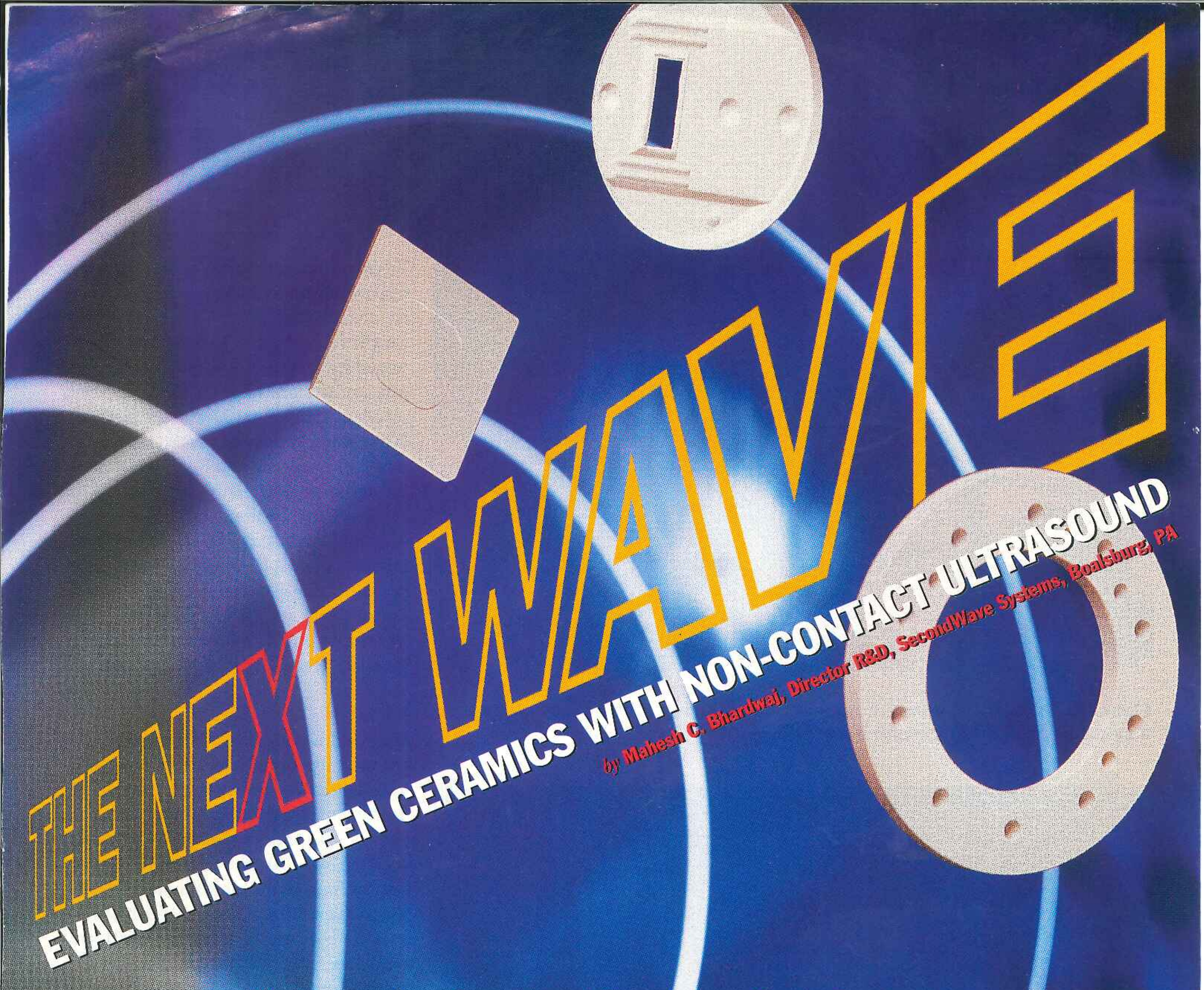

THE NEXT WAVE

EVALUATING GREEN CERAMICS WITH NON-CONTACT ULTRASOUND

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Until recently, the significance of analyzing ceramics—particularly whitewares and construction materials—during the green stage has generally been ignored. However, it is becoming increasingly apparent that many post-sintering failures are related to compaction pressure, the powder-binder ratio, the inhomogeneous segregation of powders, the rate of slip formation, particle size and other similar parameters—all of which can be measured in the green stage.

Figure 1. Ultrasonic non-contact analysis system, shown here with non contact transducers and a green ceramic tile sample (left).

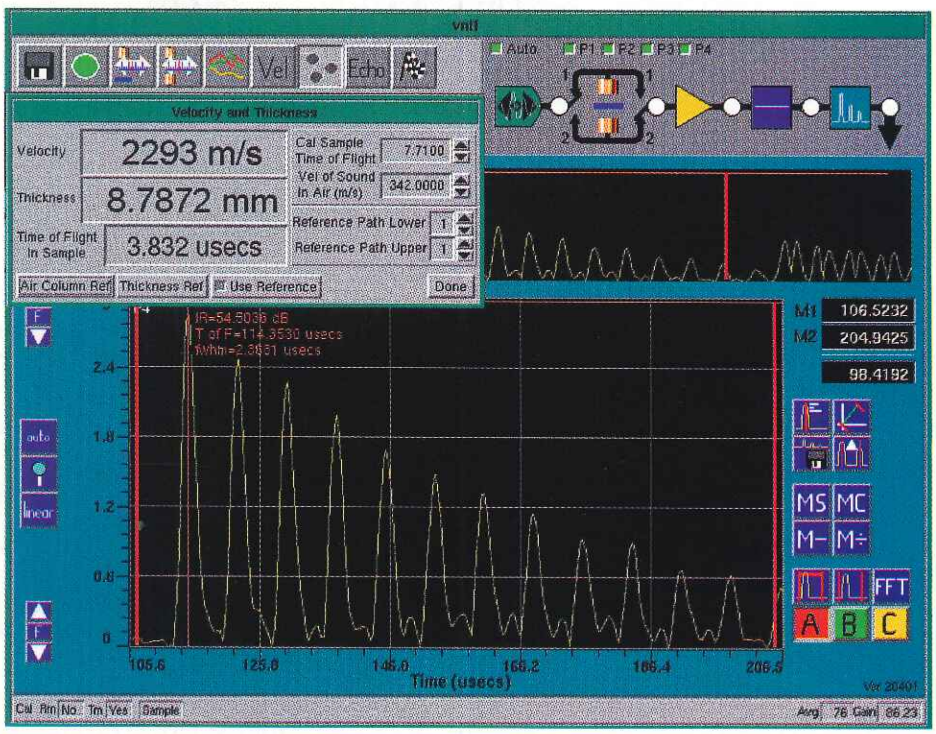

Figure 2. NCA 1000 screen displaying thickness and ultrasound velocity of a test material. Both measurements are automatically performed by this system.

To characterize the green bodies, ceramists heavily rely upon material density. Material density can be simply estimated by weight volume ratio. It can also be determined by mercury pycnometry, tapping, wax immersion, oil displacement, water repellant spray, x-ray and other methods. While some of these methods (weight-volume ratio, tapping and oil displacement) are desirable as a quality control tool for low-cost, high-volume ceramic component manufacturing, others are environmentally unsafe, hazardous to employees' health, expensive, bulky or destructive. Today's industry demands a simple, non-destructive and non-intrusive method for the characterization of material density.

Ultrasound and Ceramics

Because it is non-destructive and non-hazardous, ultrasound presents an ideal solution. Ultrasonic velocity and attenuation can be directly related to the test material's density and microstructure.[1] However, until the early '70s, the ultrasound method was confined to the metals industry. Ultrasound manufacturers assumed that ceramics were acoustically noisy materials, and were thus not suitable for this method. Further, until the mid-'80s, the ultrasound method was limited by the liquid coupling of the transducer to the test material, therefore rendering it useless for the analysis of green, porous and other liquid-sensitive materials.

Since then, significant advances in transducer designs have opened the way to reliably test green and sintered materials by dry contact coupling.[2,3] In recent years, dramatic advancements in transducer and instrumentation technology have elevated ultrasound characterization to new heights. It is now possible to ultrasonically analyze materials without putting them in contact with any type of machinery or gadget—thereby keeping them free from contamination and destructive environments.

Non-Contact Ultrasound

To realize non-contact ultrasound, the very high acoustic impedance mismatch

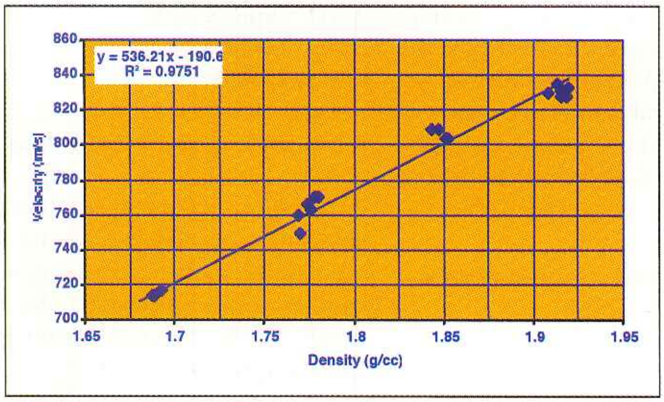

Figure 3. A reference relationship between green alumina density and ultrasonic velocity.

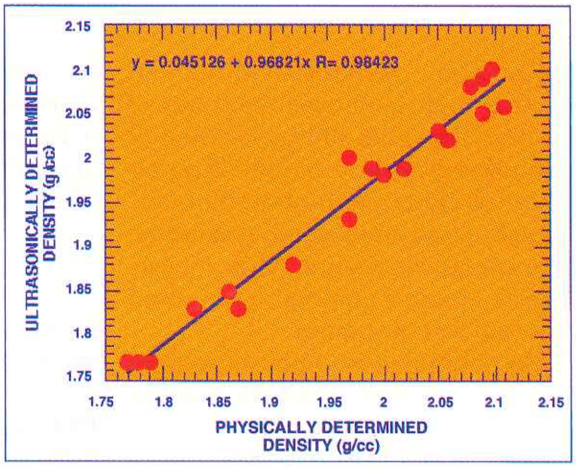

Figure. 4. Relationship between ultrasonically and physically determined densities of green alumina.

Table 1. Ultrasonic densities of ceramic tiles at various locations, shown in Figure 5.

Sample # And Measurement Location (Fig. 5)	Density (G/Cc)
1-1	1.915
1-2	1.936
1-3	1.912
1-4	1.912
1-5	1.919
2-1	1.954
2-2	1.986
2-3	1.968
2-4	1.954
2-5	1.954
3-1	1.940
3-2	1.926
3-3	1.947
3-4	1,922
3-5	1.943
4-1	1.929
4-2	1.936
4-3	1.936
4-4	1.936
4-5	1.931
5-1	1.972
5-2	1.957
5-3	1.950
5-4	1.943
5-5	1.979

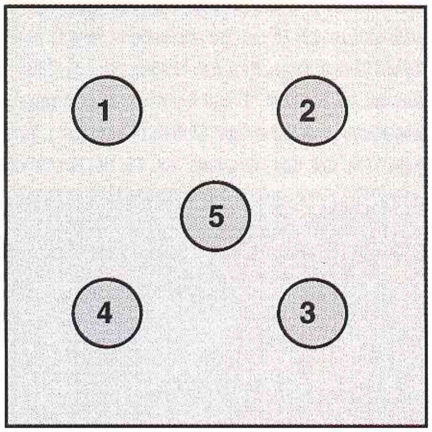

Figure 5. Locations on green ceramic tiles where velocities and densities were determined. See Table 1.

between air and test materials had to be overcome. After a nearly 20-year struggle, piezoelectric transducers with extremely high sensitivity became a reality in 1995.* In a frequency range of 100 kHz to 5 MHz, the new transducers are only 30 dB below conventional contact transducers. These characteristics are enough to overcome the air-material acoustic impedance barrier, thus opening the way for non-contact transmission of ultrasound through materials, including green ceramics.

In 1997, a non-contact analyzer** was developed (see Figure 1). The instrument is characterized by >150 dB dynamic range and 1 ns time-of-flight accuracy. After a simple setup procedure, this system automatically determines the test material thickness and velocity (directly related to density) and displays this information in an easy-to-understand format (see Figure 2).

The procedure for determining material density involves the establishment of a reference velocity-density relationship. This simple exercise can be executed by measuring ultrasound velocities of control samples in a process variable, such as compaction pressure (see Figure 3). From this relationship, samples of unknown density can be easily determined by simply monitoring their ultrasound velocities.

Figure 4 shows a correlation between ultrasonically and physically determined densities of a number of green alumina tile samples. In this investigation, the tile samples were furnished by the National Institute of Standards & Technology (NIST), Washington, D.C. Physical densities (mercury pycnometry) were independently determined by NIST using mercury pycnometry, and there were good correlations with the ultrasonically determined densities.[4]

Successful Integration

Since the development of non-contact ultrasound, it has been routinely applied to analyze a number of green ceramics and other materials.[5,6,7] Table 1 lists ultrasonically determined densities in several green tiles at various locations in each sample, corresponding with Figure 5. Each point of

*Worldwide patent pending and in process.

**NCA-1000™

measurement corresponds to 12 mm diameter with ultrasound frequency of 1 MHz. The point of measurement is approximately equal to the active diameter of the transducer. Non-contact transducers with <2 mm active area diameters have been successfully produced to interrogate velocity-density variations in very small regions of the test materials.

The accuracy (based upon the repeatability of observations at a given point) of density measured ultrasonically is much better than 1%. This is comparable to other well-known methods of density measurements, such as weight-volume ratio and mercury pycnometry, with the added benefit of non-contact measurement.

Non-contact ultrasonic instruments and associated transducers have been successfully integrated into ceramic and materials factories and laboratories worldwide, and can be used for both on-line and off-line materials testing applications. Besides characterizing thickness and velocity, the instrument also determines microstructure, properties and defects in a variety of materials, including sintered ceramics, metals, composites, polymers, laminates, particulate and fibrous materials. ⊕

For more information about non-contact ultrasonic analysis, Circle 201.

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