NONDESTRUCTIVE TESTING I:
CORRELATION OF DETECTABLE FLAW SIZE WITH GRAIN STRUCTURE
BY ULTRASONIC TECHNIQUES IN GRAPHITE

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Ultrasonics is a branch of acoustics dealing with periodic waves of frequencies above the audible range (greater than approximately 20,000 Hertz). The maximum usable ultrasonic frequency is about 10^{10} Hz, corresponding to a wavelength in air of about 3.4×10^{-6} cm and in water of 1.5×10^{-5} cm. Because of their short wavelength, ultrasonic waves travel through a medium in much sharper beams and can form sharper shadows than can audible or low frequency sound waves. Hence, they can be used to detect small flaws, voids, or inclusions in a given material.

The standard ultrasonic sources are piezoelectric and magnetostrictive ocsillators. Both of these are electroacoustic transducers, whose flexibility depends on the design and limitations of the oscillating electrical circuits. Since ultrasonic waves of sufficiently high frequency and intensity can be made to travel in a beam with little spreading, such a beam can explore a physical medium and detect nonhomogeneities in it by reflection. This is the principle of the Ultrasonic Reflectoscope, invented by F. A. Firestone, in which an ultrasonic beam or pulse penetrating a material produces an echo when it strikes a flaw or discontinuity that has different acoustical properties from the surrounding material. This echo can be detected by the same transducer that emits the original pulse.

An important factor in ultrasonic flaw detection is the particular material being inspected. Certain characteristics of the material determine the size of the smallest detectable defects. One of these is called back scattering. A certain amount of the energy from the incident ultrasonic beam will be scattered back to the transducer because of tiny individual reflections from the grains or characteristic voids in the material in which it is propagating. This residual acoustic "noise" will set a limit on the size of a defect than can be detected. Graphite is a material which is particularly susceptible to this problem. Another factor limiting the size of detectable flaws is overall attenuation of the ultrasonic beam. As the beam travels through the material, its strength continually decreases, due to beam spreading, back scattering, etc. Thus, the minimum detectable defect is a function of its depth in the material and of the scattering and other attenuative properties of the material being inspected.

Another factor affecting response is the nature of the defect (voids or inclusions). The strength of the reflection from a defect depends on the relative acoustic impedances between the medium and the defect; therefore, more energy would be reflected from a void of a given size than from an inclusion of the same size because only a portion of the energy is reflected from the inclusion (the remaining energy travels into and past the inclusion).

The ultimate criterion for defect resolution is its size relative to the wavelength of the ultrasonic pulse. As a rule-of-thumb, a flaw is considered to be potentially detectable if its relative dimensions are no smaller than one-half the wavelength of the ultrasonic wave passing through the graphite.

The wavelength of an ultrasonic pulse traveling through a material can be expressed as:

$$L = \frac{1}{f}\sqrt{\frac{E\ (1-\mu)}{\rho\,(1+\mu)\ (1-2\mu)}} \qquad (1)$$

where
L = wavelength
f = frequency
E = Young's modulus
ρ = density
μ = Poisson's ratio

The velocity of the ultrasonic wave can be expressed as:

$$c = Lf \qquad (2)$$

$$c = \sqrt{\frac{E\ (1-\mu)}{\rho\,(1+\mu)\ (1-2\mu)}} \qquad (3)$$

Obviously, the higher the frequency of the ultrasonic wave, the smaller the flaw that can be detected. However, as previously mentioned, graphite is a highly attenuative material for ultrasonic waves. The attenuation is strongly dependent on the frequency; the higher the frequency, the more attenuative graphite becomes. These attenuation properties of graphite limit the upper frequency which can be used for adequate penetration; thus, limiting the minimum detectable flaw size.

An experiment was devised in order to determine if any correlation exists between the grain structure (size) and the resolution of detectable flaws in graphite using ultrasonic techniques. Six grades of graphite were selected for this experiment. The grain structure ranged from moderately coarse to fine-grain. Each grade of graphite was machined into a 1" x 2" x 6" test block, and a series of seven calibration holes were drilled on one end and one side of each test block. The holes ranged from 0.0135 inches in diameter to 0.2010 inches, and were approximately one-half inch deep.

These calibrated test blocks were

subsequently tested using ultrasonic techniques. The materials with coarser grain structure exhibited more back scatter and "noise", limiting the resolution of the smallest detectable flaw size. The finer grain materials showed less back scatter, were less attenuative to ultrasonic waves, and smaller defects could be dectected.

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