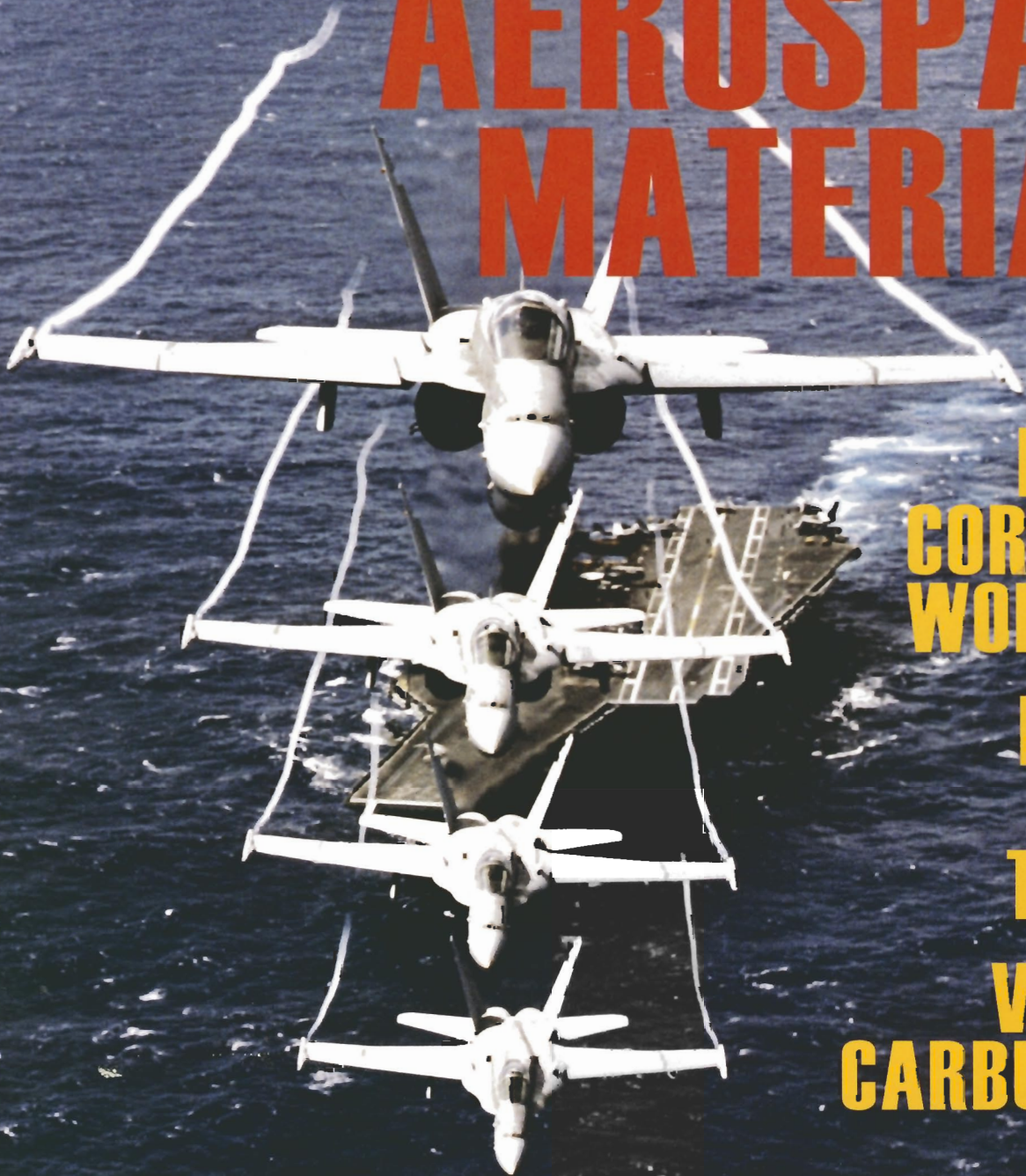


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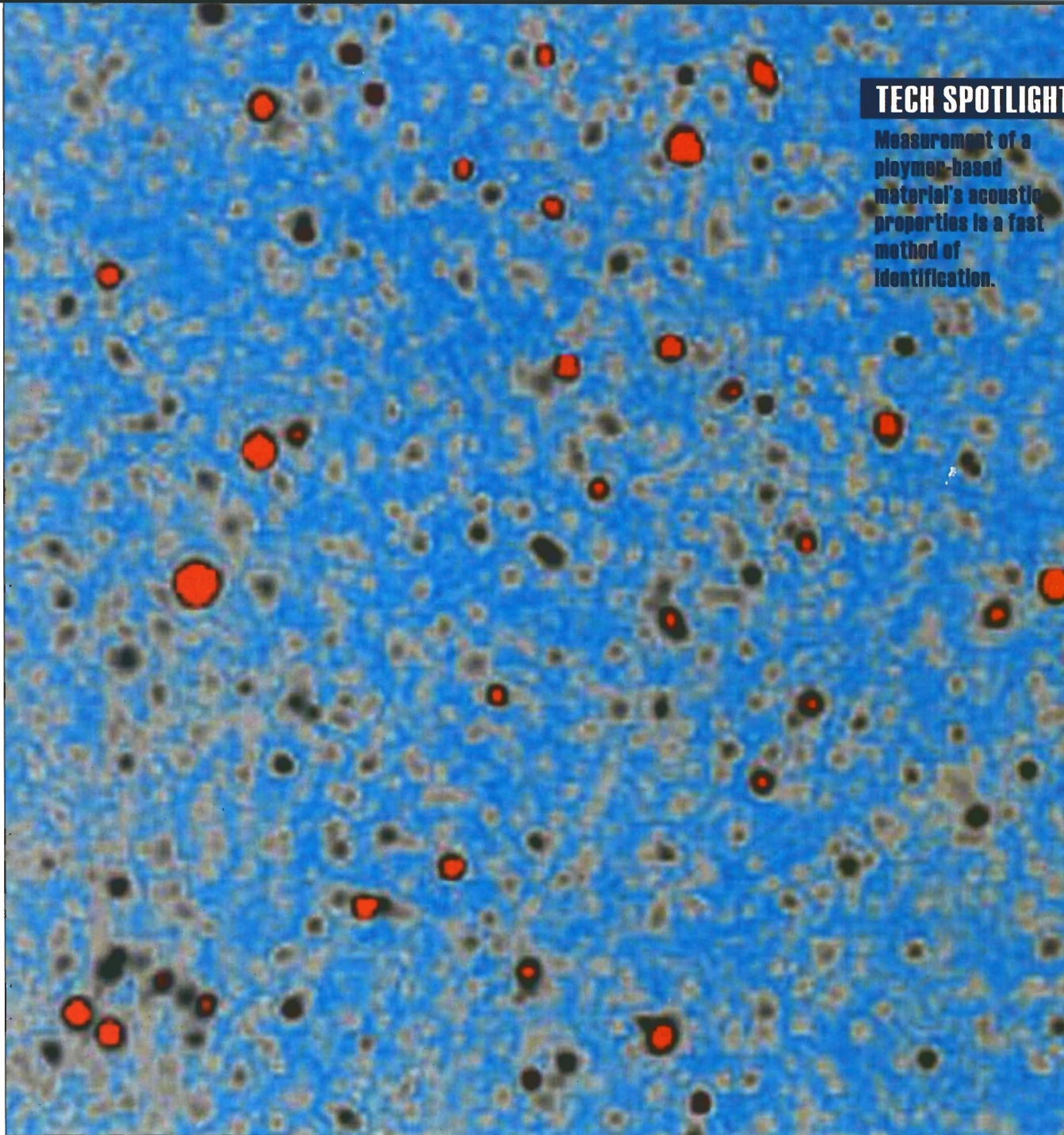
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Measurement of a polymer-based material's acoustic properties is a fast method of identification.



Acoustic microscopy can clearly define the relevant property distribution of materials at the microscopic level.

Acoustic Verification of Composites

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Measurement of a polymer-based material's acoustic properties is a fast method of identification. It is quick because it requires sending only a single pulse of ultrasound into the material, a process that takes a small fraction of a second. Often the initial step in the verification of a material's identity (and

sometimes the only step needed) is to find out the material's acoustic impedance. The acoustic microscope automatically determines the acoustic impedance of the material, and displays this value in units called MegaRayls. For polymer-based composites, acoustic impedance values range from about 3.0 MegaRayls to about 8.0 MegaRayls.

When a new lot of parts has been received, one of the parts is positioned under the transducer and evaluated. If the acoustic impedance of the last several lots of this part

from the same supplier was 3.20, and the acoustic impedance of the current part is 3.20, chances are that the materials are the same.

The acoustic impedance values of several polymers and a polymer-based composite are shown in Table 1. Note the small but measurable difference between Acrylic #1 and Acrylic #2.

The measurement of acoustic impedance does not prove conclusively that the materials are the same, because it is possible for two different polymer-based composites to have

the same, or very similar, acoustic impedance values. However, the risk of confusion can largely be eliminated by separating the acoustic impedance into its components.

Measuring density and velocity

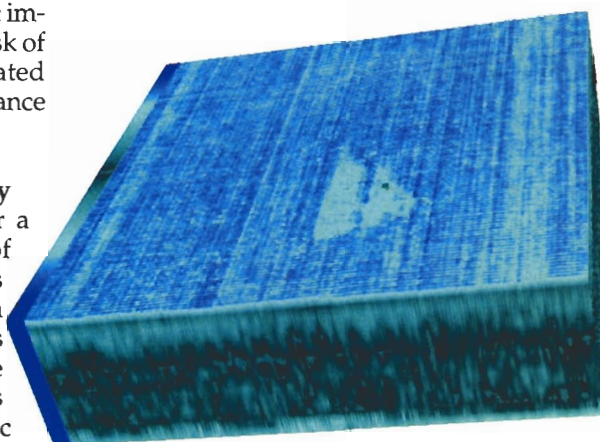
The acoustic impedance for a given material is the product of that material's density and its acoustic velocity, the speed with which ultrasound travels through the material. Since the acoustic microscope measures the travel time of the ultrasonic pulse over a known distance, and since the acoustic impedance is already known, both the density and the acoustic velocity are easily determined.

For example, one part made from polyvinyl chloride (PVC) had a known previous acoustic impedance value of 3.20 MegaRayls. An incoming lot of these parts also demonstrated an acoustic impedance of 3.20, but to make verification more rigorous, this value was separated into its components. The speed of ultrasound through the new part was measured at 3.228 millimeters per microsecond, which in turn gave a density of 1.37 grams per cubic centimeter. Since the acoustic velocity and density both corresponded very closely to the same values for previously received lots of parts, it was quickly determined that the possibility for any significant change of material in these parts was very small.

Analysis of two samples

The graph shows both the anticipated and measured values for two samples of fiberglass/epoxy composite samples. There are unexpected discrepancies in both samples.

In Composite A, the velocity was measured at 2.30 mm/μs, close to the expected velocity of 2.26 mm/μs for this material. However, the measured acoustic impedance is substantially different from the expected value: 2.05 MegaRayls vs. 2.44 MegaRayls. This material will re-



The reinforcements in this polymer composite can be determined via acoustic microscopy because the matrix and the reinforcement have different acoustic impedances.

**Table 1 —
Acoustic impedance**

Polymer	Acoustic impedance
Polyvinyl chloride	3.20
LPDE	1.90
Polystyrene	2.40
Acrylic #1	3.20
Acrylic #2	3.30
Filled thermoset resin	4.30

quire further investigation to determine the reason for the discrepancy. A history of measured values of materials in several earlier shipments would be a good starting point.

Composite B displays a different pattern. The two acoustic impedance values, at 1.99 and 1.96, are acceptably similar. But the acoustic velocity, expected to be 1.88 mm/μs, measures significantly higher at 2.13 mm/μs. In this case also, more information is needed to explain the difference.

Profiling acoustic attenuation

If even more detailed verification of a material is needed, the acoustic attenuation of the polymer-based composite can be measured. Attenuation means the extent to which the ultrasonic pulse is absorbed by a given material as it travels through

that material; attenuation is therefore measured in decibels of ultrasound lost per millimeter.

Attenuation can be measured straightforwardly by inserting a single pulse into the material and receiving the echo from the back surface of the sample. The amplitude of the received echo is measured. If the thickness of the current sample is the same as the thickness recorded for earlier samples, then the measure-

ments are comparable and the attenuation should be the same. If there are questions about the acoustic impedance of a sample, or about the sample's acoustic velocity or density, measuring the attenuation coefficient is an informative step because attenuation is independent of density and velocity.

Even more distinctive information can be obtained by measuring the acoustic attenuation at three or more different ultrasonic frequencies. For example, attenuation can be measured with transducers of 50 MHz, 100 MHz, and 230 MHz. The resulting three values make it unlikely that two dissimilar materials could have the same three-frequency attenuation profile.

Fast Fourier Transforms

Fast Fourier Transforms are a better and faster way to build a far more comprehensive profile. The ultrasonic transducer that sends the pulse into the sample and that collects the return echoes is identified by its core frequency — 100 MHz, for example, or 230 MHz. However, the pulse that goes into the sample from a 230 MHz transducer is not entirely of ultrasound at 230 MHz frequency. Instead, the pulse is made up of a large number of frequencies on both sides of 230 MHz. The range might be from 180 MHz to 260 MHz, for example. The distribution along this range will be a little different in the return echo from the distribution in the original pulse.

Table 2 — Analysis of two composite samples

Material	Anticipated velocity, mm/μs	Measured velocity, mm/μs	Anticipated impedance, MegaRayls	Measured impedance, MegaRayls
Fiberglass/epoxy composite A	2.26	2.30	2.44	2.05
Fiberglass/epoxy composite B	1.88	2.13	1.99	1.96

Fig. 3 — Acoustic attenuation profiles for three polymers. Each polymer attenuates the various ultrasonic frequencies differently, but higher frequencies (at the right) are more highly attenuated.

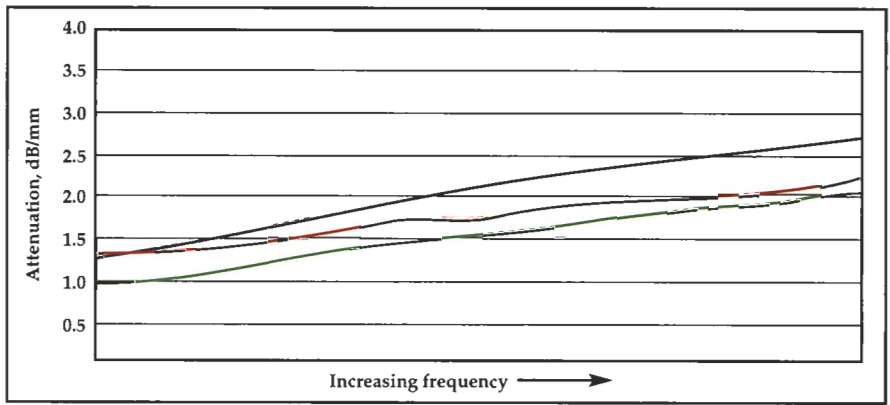
By taking advantage of Fast Fourier Transforms, the return echo signal for a single pulse can be decomposed into its separate frequencies. For example, a 230 MHz transducer will generate usable return echo signals by most of the frequencies from 180 MHz to 260 MHz, for about 40 to 50 frequencies. Each of these frequencies will have its own acoustic attenuation, which can be measured. Since higher ultrasonic frequencies are more easily attenuated (i.e., they are absorbed more readily moving through a material), the attenuation coefficients of the various frequencies in a single return echo signal will form a profile that is characteristic of the material.

Figure 3 shows the profiles made by FFT decomposition of the return echo signals for three different polymers. Note that the attenuation is higher for the higher frequencies at the right end of each profile. Although the three polymers are similar in their composition, their profiles have significant differences. When it is critically important to determine whether two or more polymers are identical, FFT decomposition of the acoustic attenuation values is both precise and very quick.

Samples that are imaged or simply profiled on an acoustic microscope are typically flat, although cylindrical samples can also be imaged. However, measuring the acoustic properties of a material involves only a single pulse with no lateral scanning of the transducer. Therefore, the geometry of the part is for the most part irrelevant: all that is needed is access to one surface of the part and an internal interface within a reasonable depth. Given these conditions, the measurements described here can generally be carried out in a few minutes.

For most parts in most circumstances, the results measured are the results expected, but some deviation from previous results can signal the possibility of significant changes in processing and assembly. ●

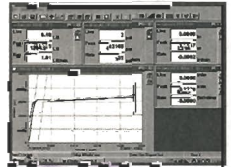
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