"Scanning acoustic microscopy: theory and applications to material characterization"

dr inż. Sylwia Pawlak

The Scanning Acoustic Microscopy (SAM) makes use of acoustic waves to create images of microscopic objects. The SAM can propagate the ultrasonic waves deep within materials. This interactions determine the size of the receiving signal and create the contrast in the image. The Scanning Acoustic Microscopy is a non-destructive technique. Those advantages include the detection of void delaminations, bubbles, cracks, fractures. They works is based on the interaction between sound waves and matter.

BASIC PRINCIPLES OF ACOUSTIC PROPAGATION

Ultrasound is a sound waves that has a frequency greater than 20kHz. They are composed of elastic vibrations between adjacent particles in a material. On a macroscopic scale sound travelling pressure wave. Waves are propagated through a medium by the vibration of molecules. Sound waves are expressed as sine waves with the specific wavelength, frequency, amplitude, propagation velocity, intensity (2). Wavelength is the distance between two point with the same phase. Frequency is the number of wavelengths that pass per unit time. Propagation velocity is the speed that sound waves propagate through a medium, and amplitude is the maximum displacement or distance moved by a point on a vibrating body or wave measured from its equilibrium position (Figure 1).

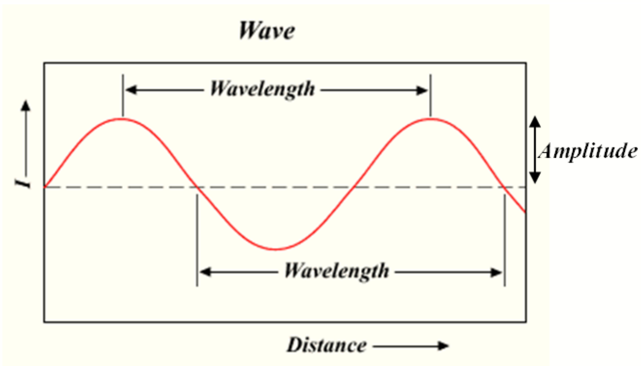

Figure 1. Wavelength and amplitude of a longitudinal wave

In the Scanning Acoustic Microscopy is measured the acoustic impedance (6),(7). The acoustic impedance is expressed as the product of the density and the speed of sound wave:

$$Z = \rho * c \qquad (1)$$

wher ρ is material density and c is sound velocity of the sample.

The SAM can image the acoustic impedance by exploiting the impedance dependence of the reflection coefficient R of the ultrasound longitudinal wave. For the reflection R can be used formula:

$$R = \frac{Z_{surface} - Z_{medium}}{Z_{surface} + Z_{medium}} \qquad (2)$$

where $Z_{surface}$ is impedance in surface and Z_{medium} is impedance in medium.

BASIC INFORMATION ABOUT THE SCANNING ACOUSTIC MICROSCOPY

The acoustic microscope works in the pulse reflection method. The most important component in the scanning acoustic microscopy is a high frequency piezoelectric sound transducer. This object transmits and receives sound pulses of high penetration rate. It is a sapphire cylinder with a ZnO film (1). A transducer generates a ultrasound pulse (piezoceramic layer converts electromagnetic vibrations into sound wave) which propagates along the delay rod. The transducer is immersed within a coupling medium (water). The immersion system cavity is therefore the acoustic spherical lens. A lens focuses beam within the sample. The acoustic objective receives the sound reflections from the sample. The information follows to the return to transducer. There transforms them into electromagnetic pulses detected by an oscilloscope and on the monitor display them as a pixel. The acoustic objective scans the sample line by line. Figure 2 shows a schematic of an acoustic microscope system.

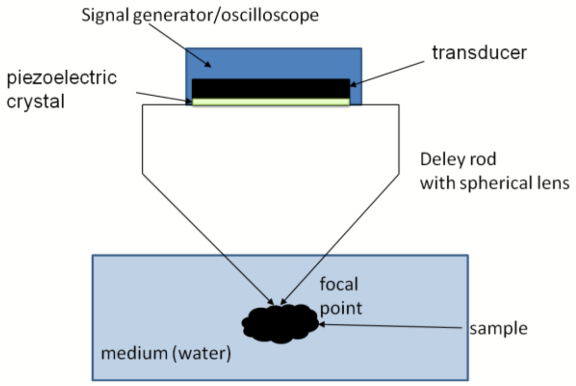

Figure 2. Schemat of the Scanning Acoustic Microscope

The result of the SAM is determined by aperture and acoustic wavelength, which is depends on the material but this microscope can detected damage to a minimum size of 0,3 µm. Depending on the critical defect size and defect depth the working frequency and transducer design have to be chosen (5). The important information is that the SAM works in real time mode.

The Scanning Acoustic Microscope works on several modes (Figure 2). A 2D scan gives information about x-y plane and 3D scan image provides information about x-y plane and the time of flight the acoustic beam (4). The most popular are scan A, scan B, scan C and scan X. Scan A mode is used to characterize a single point of interest in a specimen. The B-scan mode generates a top-down or X-Z axis image. The C-scan is a compilation of A-scan but not in one point but along X-Y axis, they a display of the image of reflected echoes at the focused plane of sample. Scan X is used to view image at a depth of the sample (8).

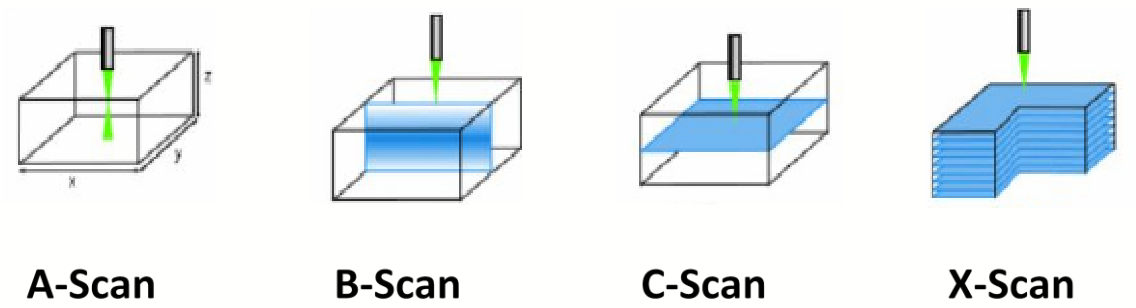

Figure 3. Scan mode in Scanning Acoustic Microscope

RESULTS

Having described the principles of the scanning acoustic microscope is now presented same results. The scanning acoustic microscopy is being used to analysis: bonded and soldered structures, castings, interface and semiconductor components, material stress and crack propagation, interface evaluations of thin coatings, biological, geological and ceramics structures, detection of delaminations in packages, 3-dimensional imaging of welding, determining volume defects (9).

One of the applications of the scanning acoustic microscopy was in the study of bio-ceramics mater. In Figure 4 is presented an acoustic image of hydroxyapatite sintered at various temperatures. This material is characterized by inhomogeneous and different pores sizes.

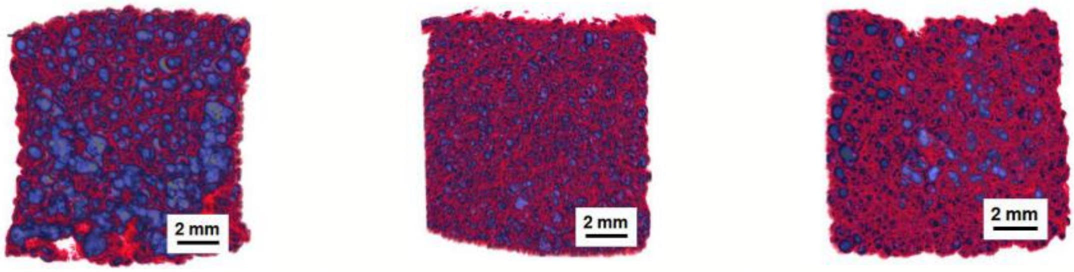

Figure 4. Visualization of micropores or inhomogeneous material (hydroxyapatite) using the SAM

The SAM is a good techniques to detect small defects in the surface and under the surface. Using this technique it is possible to find cracks smaller than 1 μm. Surface near cracks, delaminations, void or inclusions due to their different elastic properties from the surrounding materials. In figure 5 is presented an acoustic identification of the defects within the massive forging ingot. The SAM identification of defects at difference depth from the surface (3). In the figure 5 are visible defects (holes), contains a carbon stalagmite (yellow arrow indicates the carbide localized inside the void) and some porosity. In figure 6 is presented a deeper layer in this material (forging ingot).

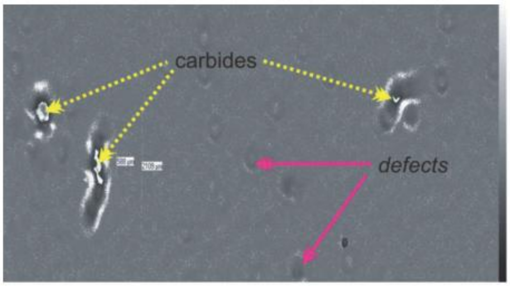

Figure 5. Visualization of carbides localized inside the void and common defects (porosity) in ingot

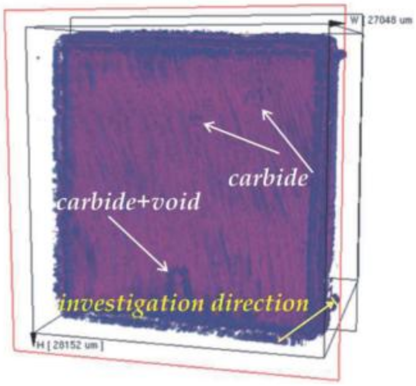

Figure 6. Image to the sample forging ingot applying the method "layer by layer" from the surface registered by the SAM

The potential of the acoustic microscope to map the subsurface mechanical properties of a material has found strong applications in non-destructive testing of materials.

CONCLUSIONS

The scanning acoustic microscope is a microscopy that used a high frequency ultrasound. The SAM is a non-destructive method, which works on the principle of propagation and reflection of acoustic waves at interfaces and is able to provide information about local density. It is a good technique to image the microstructure of materials. It is commonly used in failure analysis and non-destructive evaluation. This microscope penetrates most solid materials and has applications in all materials.

REFERENCES

1. Briggs, A., 1992, Acoustic Microscopy, Oxford University Press, UK
2. Hansen C., Fundamental of Acoustic, Australia
3. Kowalski J., Pstruś J., Pawlak S., at al., 2011, Influence of the reforming degree on the annihilation of the segregation defects in the massive forgins ingots, Archives of Metallurgy and Materials
4. Krautkrämer J., Krautkrämer H., 1990, Ultrasonic testing of materials, Berlin; New York: Springer-Verlag
5. Parker N, Povey J., 2009, Scanning acoustic microscopy for mapping the microstructure of soft Materials, What Where When Multi-dimensional Advances for Industrial Process Monitoring, Leeds, UK,
6. Povey, M. J. W., 1997, Ultrasonic Techniques for Fluids Characterization, Academic Press, USA
7. Rienstra S,Hirschberg A., 2013, An Introduction to Acoustics, Eindhoven
8. Win SAM Vario I to III, SAM 2000, KSI, Krämer Scientific Instruments, Lerchenweg, Germany
9. Yu Z., Boseck S., 1995, Scanning acoustic microscopy and its applications to material characterization, Reviews of Modern Physics 67, 863