AIIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

DOE/ER/45157--TS

Annual Progress Report
to
the Department of Energy
for
a program of research entitled:

RECEIVED
MAY 27 1994
OSTI

A STUDY OF MECHANICAL PROCESSING DAMAGE IN BRITTLE MATERIALS

for the period of:

1 April 1988 through 31 March, 1989

G. L. Report No. 4497

April 1989

Contract No. DOE DE-FGO3-84ER45157
Expiration: September 14, 1991

Principal Investigator:
B. T. Khuri-Yakub

Edward L. Ginzton Laboratory
W. W. Hansen Laboratories of Physics
Stanford University
Stanford, California 94305-1502

RECEIVED
MAY 27 1994
OSTI

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

REPRODUCTION OF THIS DOCUMENT IS UNLIMITED

A STUDY OF MECHANICAL PROCESSING DAMAGE IN BRITTLE MATERIALS

by

B. T. KHURI-YAKUB

We have made good progress on solving the problems we dealt with in our research on the evaluation of machining damage in brittle materials. Our first project deals with examining ceramics when they are in the green state, and evaluating the effect of density and mechanical properties variations on the final hot-pressed parts. The other aspect of the project deals with the direct characterization of surface and near-surface defects that are induced by machining operations. Our collaboration with Norton Co. and Cerbec Co. allows us to correlate our measurements to fracture tests on bend bar specimens and bearing balls.

For the ultrasonic inspection of green ceramics, it is necessary to introduce ultrasound in the sample without immersing it in water. For this purpose, several workers resort to vacuum packing of the sample in Scotch or other plastic tape, or immersing the transducers inside water balloons and bringing the external surface of the balloon in contact with the sample. Our approach is to develop air transducers based on using new types of matching layers. Such a technology will have a wide range of applications, and would be easier to implement without concern about sample contamination.

To carry out materials characterization in air, it is necessary to have a good pulser, transducer, and receiver. High voltage pulsers are available, thanks to the medical application of lithotripsy, where high-power ultrasound pulsers are used to shatter kidney stones. Low noise receivers are also available, due to various applications in electronics. The problem of coupling ultrasound into a sample is unavoidable, and is somewhat easier because green ceramics have a low density and the binder is typically a low-density plastic. Consequently, we concentrate our efforts on developing efficient and broadband air transducers operating at frequencies of up to 5 MHz.

The problem of using high-frequency ultrasound in air is a problem of excitation and not of propagation loss. Human tissue is more attenuating than air, and the medical ultrasound business flourishes with a variety of instruments. The problem of exciting ultrasound in air, however, is complicated by the necessity of having very low-density materials that act as matching layers for the transmission and reception of ultrasound with piezoelectric ceramics. Last year, we proposed to use silica aerogels as matching layers. The process needed to make such devices required us to first deposit a sealing layer of silicon oxide on the surface of the aerogel. This step would have to

be done in a reactor in an integrated circuit laboratory or foundry. Next, the aerogel would have to be attached to the ceramic and then diamond turned to the required thickness for a certain frequency of operation, which at 1 MHz is about 100 μm . These last two steps are prohibitively expensive. We solved the problem when we realized that ligneous materials such as cork and balsa wood can do the job and are inexpensive to acquire and shape.

We acquired several samples of both balsa wood and cork, and measured their ultrasonic velocities and impedances. We found their impedance to be in the range of 0.1 MRayl and their ultrasound velocity to be in the range of 300-800 m/sec. These properties are almost optimal for matching layers between piezoelectric ceramics, such as the lead zirconium titanate (PZT) family and air, which has an ultrasonic impedance of 0.0004 MRayl. We made several transducers using PZT-5H ceramic because of its high dielectric constant, and with matching layers of silicon rubber (RTV615), cork, and balsa wood. We are presently making detailed measurements of these devices to determine accurate values for the impedance, velocity, and attenuation of these ligneous materials in the frequency range of interest. Our initial measurements show that the transducers have a two-way insertion loss of 35 dBs, a fractional bandwidth of 7% at the center frequency of 1 MHz, and that both cork and balsa wood produce transducers with similar properties. This bandwidth is to be compared to 4% for the devices with a single matching layer of RTV615. The improvement in bandwidth is due to the better impedance match of the ligneous materials and their higher attenuation. This result is extremely encouraging, as we expect to be able to achieve bandwidths in the 20% range by using two matching layer designs, as will be outlined in the following paragraph. The use of ligneous materials forms the basis for a patent that we expect to have issue next year.

The main problem with the transducers we made to date are the lateral resonances of the ceramic plate, due to its finite width-to-thickness ratio. The solution is to dice the ceramic into many pieces with lateral dimensions that are smaller than the thickness, but to maintain them electrically in parallel. This development, and the making of a focused transducer for green ceramic evaluation, are the subjects of our proposal for the coming year.

We have also considered the problem of making air transducers with two matching layers to improve their insertion loss and bandwidth. The problem here is that it is not always possible to obtain the correct impedance for the first matching layer which faces the air. We developed a theoretical model to account for this difficulty, and came up with the optimum transducer design under these restrictive conditions. The solution to this problem, along with early experimental results, was presented at the IEEE Sonics and Ultrasonics Symposium, held in Chicago in October, 1989. The paper is attached as Appendix A. We concluded that it is indeed possible to make devices with

a fractional bandwidth of 30% and a two-way insertion loss of about 35 dBs . Our aim for the coming year is to build devices based on the criteria developed on the paper in Appendix A.

We continued our work on the characterization of machining damage in ceramics by considering the special problem of bearing balls. Bearing balls may be the first wide-range industrial application for hot-pressed ceramic materials. The major problem with the bearing balls is their sensitivity to small surface and near-surface defects. At present, the bearing balls are inspected by an operator with an optical microscope. Besides the fatigue factor, which limits the inspection, it is not possible to inspect for near-surface defects with this method. We developed an amplitude and phase acoustic microscope and constructed a special fixture to rotate the bearing balls under a focused transducer.

Near-surface defects are inclusions or voids that develop during the processing of the parts, while surface defects are the result of machining operations. The most difficult defects to detect are narrow and shallow surface cracks that have smooth edges. We determined theoretically the effect of such cracks on the return signal of an acoustic microscope, and find that most of the change is in the phase of the return signal. For this purpose, we developed the phase measurement capability in our instrument. Our calculations indicate that scratches that are $1.5\text{ }\mu\text{m}$ wide by $1.5\text{ }\mu\text{m}$ deep induce a phase change of 10 degrees in the return signal of the microscope, as compared to a return from a defect-free region while operating at a frequency of 100 MHz . Such a phase change is easily detected by our instrument, as indicated in Appendix B, which is another paper we presented at the IEEE Symposium. We also measured, in a standard XY imaging scan mode, several bearing balls with defects; the results can be found in Appendix B. Defects are indicated by variations in the amplitude and phase of the return signal from a baseline. We expect to implement a method where the bearing balls are rolled for a certain period of time that insures inspection of every location of the bearing. Locations where the signal varies from the baseline will be counted to indicate the total defect count in a bearing ball. The electronics of the microscope, along with the mechanical scanner, are the object of another patent application which was filed last year. We have already licensed the technology to Hitachi Construction Co. and have ongoing discussions regarding exclusive U.S. rights to the technology with Cerbec Co.

Our major instrument limitation at the moment is noise due to the mechanical scanner. Our aim next year is to improve this scanning scheme, and increase the speed of data acquisition in the system. Another object of our research next year is the development of theory to predict the sensitivity limits of the measurement technique to both near-surface and all types of surface defects.

In summary, we made excellent progress last year. Our work on air transducers will have major impact not only on the inspection of green ceramics, but also on other structural materials, such as composites, woods, and other plastics, and to a lesser extent on metals such as aluminum and steel, which could be inspected, with more difficulty, at elevated temperatures. The work on the amplitude and phase microscope and bearing ball scanner is certain to have an impact on the bearing ball inspection problem, and will help bring these into the market with higher confidence.

REFERENCES

B. T. Khuri-Yakub, J. H. Kim, C-H. Chou, P. Parent, and G. S. Kino, "A New Design for Air Transducers," Presented at the IEEE Ultrasonics Symp., Chicago, IL, 2-5 October 1988. Published in Proc. IEEE Ultrasonics Symp., Vol. 1, 503-506, Ed: B. R. McAvoy (Institute of Electrical & Electronics Engineers, Inc., New York, 1988).

P. Parent, C-H. Chou, and B. T. Khuri-Yakub, "Ball Bearing Inspection with an Acoustic Microscope," Presented at the IEEE Ultrasonics Symp., Chicago, IL, 2-5 October 1988. Published in Proc. IEEE Ultrasonics Symp., Vol. 2, 1111-1113, Ed: B. R. McAvoy (Institute of Electrical & Electronics Engineers, Inc., New York, 1988).

C-H. Chou and B. T. Khuri-Yakub, "Design and Implementation of Mixed-Mode Transducers," IEEE Trans. on UFFC (accepted for publication).

B. T. Khuri-Yakub, C-H. Chou, P. Parent, and C. Cinbis, "Amplitude and Phase Acoustic Microscopy and its Application to QNDE," Presented at Acoustical Imaging, Sendai, Japan (June 1988).

C-H. Chou, P. Parent, and B. T. Khuri-Yakub, "Acoustic Microscopy with Mixed-Mode Transducers," Presented at the Fifteenth Review of Progress in Quantitative NDE, San Diego, CA, July 31-August 5, 1988. Published in Review of Progress in Quantitative Nondestructive Evaluation, Eds: D. O. Thompson and D. E. Chimenti (Plenum Press, New York, 1988).

P. Reinholdtsen and B. T. Khuri-Yakub, "Three-Dimensional Image Processing for Acoustic Microscopy," Presented at the Fifteenth Review of Progress in Quantitative NDE, San Diego, CA, July 31-August 5, 1988. Published in Review of Progress in Quantitative Nondestructive Evaluation, 299-308, Eds: D. O. Thompson and D. E. Chimenti (Plenum Press, New York, 1988).

Figures removed

**DATE
FILMED**

6 / 29 / 94

END