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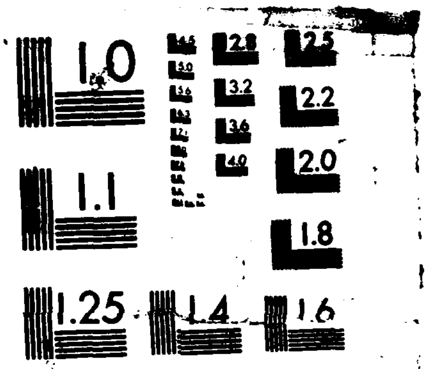

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TECHNICAL REPORT ARCCB-TR-86027

ULTRASONIC SCANNING FOR FINDING INTERFACE VOIDS OF COMPOUND CYLINDERS

Y. F. CHENG

C. E. COBB

AUGUST 1986

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER
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1. REPORT NUMBER ARCCB-TR-86027	2. GOVT ACCESSION NO. ADA180178	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ULTRASONIC SCANNING FOR FINDING INTERFACE VOIDS OF COMPOUND CYLINDERS		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Y. F. Cheng and C. E. Cobb		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Armament Research, Develop, & Engr Center Benet Weapons Laboratory, SMCAR-CCB-TL Watervliet, NY 12189-4050		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS AMCMS No. 6940.00.3410.012 PRON No. 1A525FCP1A1A
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Armament Research, Develop, & Engr Center Close Combat Armaments Center Dover, NJ 07801-5001		12. REPORT DATE August 1986
		13. NUMBER OF PAGES 22
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Presented at the 32nd International Instrumentation Symposium (Instrument Society of America), Seattle, WA, 5-8 May 1986.
Published in Proceedings of the Symposium.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Nondestructive Evaluation
Ultrasonics
Metal-Composite Compound Cylinders

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In this report, a review is made of the pulse-echo method of ultrasonic imaging as a technique in nondestructive evaluation. A discussion on the image formation of A-, B-, C-scans and three-dimensional display is included. Scanning patterns obtained from a testing block are shown. Finally, the method is evaluated for finding interface voids of metal-composite compound cylinders. Preliminary experiments were made and the results are given. A special probe with multiple transducers is suggested.

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ACKNOWLEDGEMENTS

Telephone conversations with Dr. V. Neeley and assistance received from G. Capsimalis and R. Peterson at the beginning of this project are hereby acknowledged.

INTRODUCTION

Figure 1 shows a cross-section of a metal-composite compound cylinder. The inner cylinder was made of steel with equally-spaced shallow grooves running in the axial direction in its inner diameter (ID). The outer cylinder was made of graphite-epoxy prepreg tape with fibers running in both axial and circumferential directions. The purpose of this study was to evaluate the applicability of the ultrasonic pulse-echo method as a nondestructive evaluation (NDE) technique for finding voids at the metal-composite interface.

The ultrasonic pulse-echo technique and the image formation of A-, B-, C-scans and three-dimensional display are briefly reviewed. Images obtained from an aluminum testing block are shown. Preliminary experiments were made to find interface voids on metal-composite blocks, with and without grooves on the surface, and results are shown. A special probe with multiple transducers for finding interface voids in the metal-composite cylinder is suggested.

EXPERIMENTAL METHOD

The use of ultrasonic waves for the purpose of nondestructive evaluation is well established with a variety of techniques available (refs 1-4). Through-transmission, pulse-echo, and wavefront reconstruction methods are among those used for void detection. The pulse-echo method was used for the present study. For completeness, a brief review of this method follows.

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[1] R. C. McMaster, NDT Handbook, The Reynolds Press, NY, 1963.
[2] J. Krautkramer and H. Krautkramer, Ultrasonic Testing of Materials, Springer-Verlag, Berlin, 1969.
[3] J. R. Frederic, Ultrasonic Engineering, John Wiley and Sons, NY, 1965.
[4] W. J. McGonnagle, Nondestructive Testing, Gordon and Breach, NY, 1966.

Pulse-Echo Scanning

In pulse-echo scanning, a narrow beam transducer is employed to project a short pulse of ultrasonic waves at normal incidence into the medium as well as to detect the reflection of the pulse from the boundaries and internal discontinuities of the medium. The position where reflection occurs can be located from information on the time taken for the return journey and the velocity of sound in the medium. Figure 2 depicts a simplified diagram of the apparatus. The trigger simultaneously activates the time base control and the pulse generator. At the same time, a signal is passed via the amplifier to the Y-plate of the cathode-ray oscilloscope; a peak, A, thus appears at the left-hand side of the screen. The transmitting transducer is excited by means of the radio-frequency oscillator, the output of which is controlled by the pulse generator. In this way, intermittent trains of ultrasonic waves are propagated into the medium. Upon reflection, these waves are detected by the receiving transducer. The induced electrical signals are amplified, rectified, and fed to the Y-plate of the oscilloscope to give the peak, B. Because of the time delay due to the ultrasonic waves travelling through the medium, the peak, B, is displayed farther along the time base. The use of the single probe pulse-echo method for flaw detection is straightforward where the specimen has two parallel surfaces and the defect is linear and roughly parallel with them but not too close to a surface or to another defect.

A-Scan Presentation

In the absence of a defect, only two peaks, A and B, appear on the screen of the oscilloscope in the A-scan presentation, Figure 3. In Figure 3(a), A represents the instant of transmission of the pulse into the specimen and B represents that of its return from the other surface. When a defect is present, a discontinuity of characteristic impedance occurs and some energy is reflected back to the transducer. This results in the appearance of another peak, C, between A and B, as shown in Figure 3(b). The distance, AC, is a measure of the depth of the flaw. Using pulses of sufficiently short length, a depth resolution of a few wavelengths can be realized.

B-Scan Presentation

In B-scan, the transducer is made to scan along one direction as depicted in Figure 4. One of the orthogonal deflection voltages of the cathode-ray tube display is proportional to the transducer position and the other to the time elapsed since the last pulse was transmitted, the signal depth. The reverberated pulses intensity-modulate the display. The resulting image is a section of the specimen lying in the plane of the propagating beam.

C-Scan Presentation

In C-scan, the image lies in a plane normal to the propagating beam. It is produced by scanning the transducer over a rectangular area. Both deflection voltages of the cathode-ray tube display are made proportional to the transducer coordinates. By time-gating the received signal, one can obtain an image of a plane at any selected depth in the specimen.

Three-Dimensional Display

The three-dimensional display presents the image of an axonometric projection, i.e., the presentation on a single plane of a three-dimensional object placed at an angle to the plane of projection.

Equipment

A Holosonic Model 200 Imaging System consisting of a mechanical scanner and an electronic processor was used in this study. The mechanical scanner provides a means of traversing the transducer in a precise X-Y scanning pattern over a selected area. The electronic processor includes pulse generator, oscillator, trigger, amplifier, rectifier, gate, and others.

The transducer was a broadband longitudinal wave immersion focused type. It has a diameter of 25.4 mm (1 in.), nominal focal length of 101.6 mm (4 in.) in water, and a frequency of 5 MHz.

An experiment was made to ascertain the accuracy of measurements. The specimen was a 12.7 mm (0.5 in.) thick aluminum block with three sets of flat bottom holes drilled into the bottom of the block. The first set of holes had a diameter of 3.175 mm (0.125 in.), a depth of 6.35 mm (0.25 in.), and formed two words - "3 D". The second set consisted of four holes in a line. They were 3.175 mm (0.125 in.) in diameter and 2.54 mm (0.1 in.) to 10.16 mm (0.4 in.) in depth with an incremental step of 2.54 mm (0.1 in.). The third set was similar to the second except that the holes had a diameter of 6.35 mm (0.25 in.).

Figure 5(a) shows a C-scan image of the block with gate extending from slightly below the top surface to slightly above the bottom surface as sketched in Figure 5(b). It can be seen that the bottoms of all holes are displayed in the figure. If the gate width is reduced, only those holes terminated within the gate will be seen.

Figures 6(a) through 6(d) show B-scan images at four different planes as indicated in Figure 6(e). Each picture clearly shows all holes in its plane.

Finally, Figure 7 represents a three-dimensional display of the specimen. Both top and bottom surfaces of the aluminum block and all holes are clearly shown.

PRELIMINARY EXPERIMENTS AND RESULTS

If ultrasonic pulses were sent from the outside diameter (OD) side of the compound cylinder, Figure 1, energy loss in the composite material would have an influence on the echo reflected from the interface. Therefore, experiments were made such that ultrasonic pulses were sent through the metal.

Experiment for Finding Interface Voids at Metal Side of a Metal-Composite Block

Figure 8(a) shows a sketch of the model. Sloped voids of maximum depth of 0.69 mm (0.027 in.) and 101.6 mm (4 in.) long were machined into the surface of a 24.38 mm (0.96 in.) thick aluminum block, which was in close contact with a 2.54 mm (0.1 in.) thick graphite-epoxy panel. The assembly was immersed in a water tank. Figure 8(b) shows the image of a C-scan of 139.7 mm (5.5 in.) long at the interface. The image has a length of 31.75 mm (1.25 in.) and shows voids of 20.64 mm (13/16 in.) long which corresponds to (20.64)(139.7)/(31.75) = 90.8 mm (3.57 in.) in the model. It also shows that the detectible gap has a thickness of (0.69)(101.6-90.8)/(101.6) = 0.073 mm (0.003 in.).

Experiment for Finding Effects of Grooves on Top Surface

Since the metal part of the compound cylinder, Figure 1, has shallow grooves on its ID, an experiment was made to find the effects of top surface grooves on the detectibility of interface voids. Figure 9(a) shows a sketch of the model. Shallow grooves of 1.14 mm (0.045 in.) deep were machined into the top surface of the aluminum block. Due to the difference in velocities of sound in water and aluminum (1500 m/sec and 6400 m/sec, respectively), a difference of $(1.14/1500)\times 10^{-3} - (1.14/6400)\times 10^{-3} = 0.58$ μsec of time of arrival of an ultrasonic pulse through the land, L, and groove, G, sections of the model occurs at the interface. The sloped voids of maximum depth of

0.69 mm advance the time of arrival of pulse by $(0.69/6400)\times10^{-3} = 0.1$ μsec. With proper gate settings, C-scan images were obtained at the interface for land and groove sections as shown in Figures 9(b) and 9(c), respectively. Finally, Figure 9(d) shows a three-dimensional display of the interface containing both the land and groove sections. (It should be noted that the interface is ultrasonically divided into land and groove sections and physically remains one surface.) Voids can clearly be seen in all three figures. The three-dimensional display further shows the difference of time of arrival of ultrasonic pulses at the interface through the land and groove sections.

Experiment for Finding Interface Voids at Composite Side of a Metal-Composite Block

This experiment was made to answer the question: "Is it possible to detect interface voids at the composite side of the block?" Two flat bottom holes of 10 mm (0.39 in.) in diameter were machined into the surface of the graphite-epoxy panel. One hole had a depth of 0.127 mm (0.005 in.) and the other hole a depth of 0.254 mm (0.01 in.). The voided surface was in close contact with a 12.7 mm (0.5 in.) aluminum block. Figure 10(a) shows a C-scan image of the interface. Both voids can clearly be seen. Dark spots at the center of both voids are due to the center mark of the machining tool. Another C-scan image, Figure 10(b), showing the exact location of both voids was made without the aluminum block. A comparison between Figures 10(a) and 10(b) clearly demonstrates the ability of the pulse-echo method for detecting interface voids at the composite side of the block.

CONCLUSIONS AND DISCUSSIONS

Results from preliminary experiments show that:

1. It is possible to detect ultrasonically interface voids of 0.073 mm (0.003 in.) thick or more in a metal-composite block.

2. Grooves of 1.14 mm (0.045 in.) depth at the top face of an aluminum block ultrasonically divide the interface into two sections, land and groove, with a difference in time of arrival of an ultrasonic pulse of 0.58 μsec. (In steel-water combination, the time difference for a 1.14 mm groove is 0.57 μsec). With proper gate setting, interface voids can be readily found.

It is tentatively concluded that the ultrasonic pulse-echo method could be used as an NDE technique for finding voids at the interface of a metal-composite compound cylinder. A special probe for this purpose is suggested and conceptually sketched in Figure 11. Transducers are mounted on the circumference of a cylindrical rod. They can be electronically switched to cause beam rotation while the rod is guided down the ID of the cylinder. All transducers are connected in a parallel manner. The switching circuit is such that only one transducer can be excited and receive an echo at a time. With enough transducers, two passes down the ID of the cylinder with proper gate settings would reveal all voids at the interface.

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1. R. C. McMaster, NDT Handbook, The Reynolds Press, NY, 1963.

2. J. Krautkramer and H. Krautkramer, Ultrasonic Testing of Materials, Springer-Verlag, Berlin, 1969.

3. J. R. Frederic, Ultrasonic Engineering, John Wiley and Sons, NY, 1965.

4. W. J. McGonnagle, Nondestructive Testing, Gordon and Breach, NY, 1966.

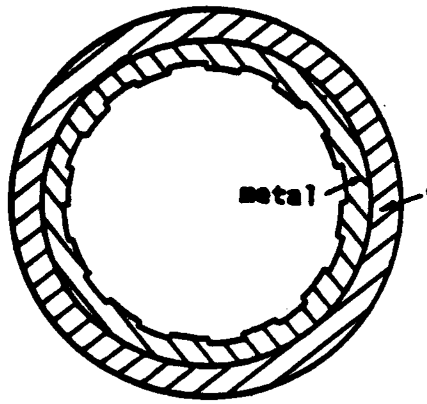


Figure 1. Cross-section of a compound cylinder.

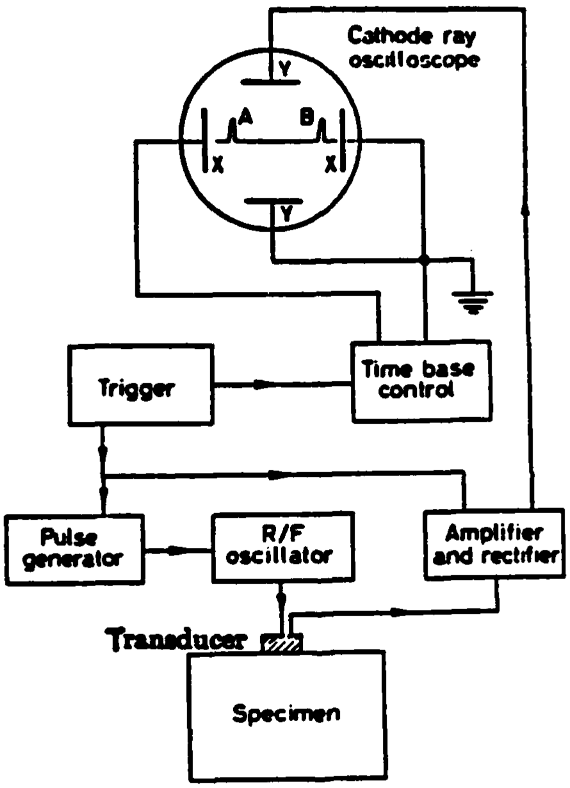


Figure 2. Block diagram of the apparatus used for the ultrasonic pulse-echo method.

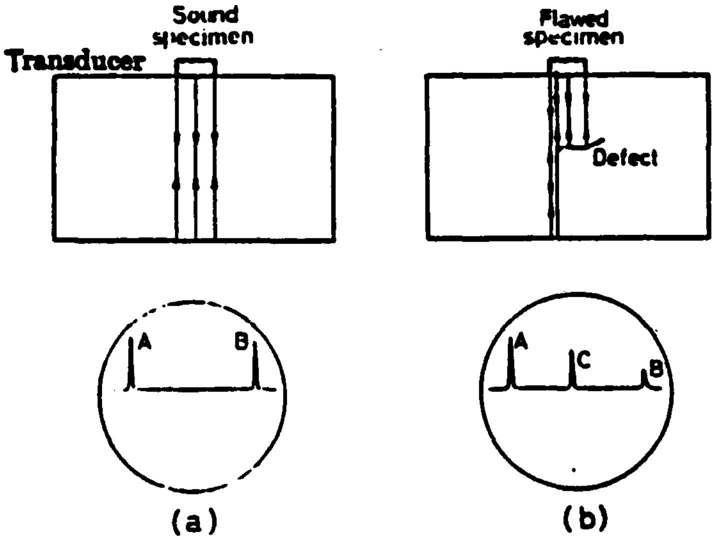


Figure 3. Typical A-scan representation of the ultrasonic pulse-echo method.

(a) sound specimen
(b) flawed specimen

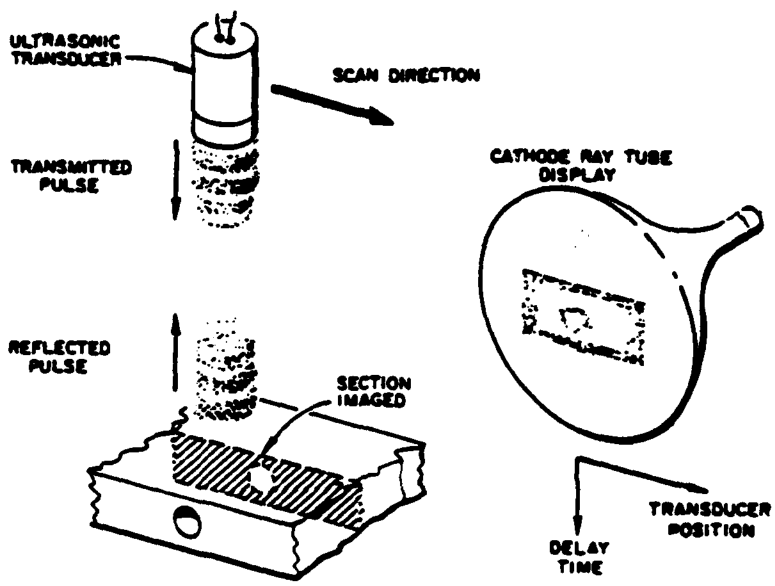


Figure 4. B-scan arrangement and image presentation of the ultrasonic pulse-echo method.

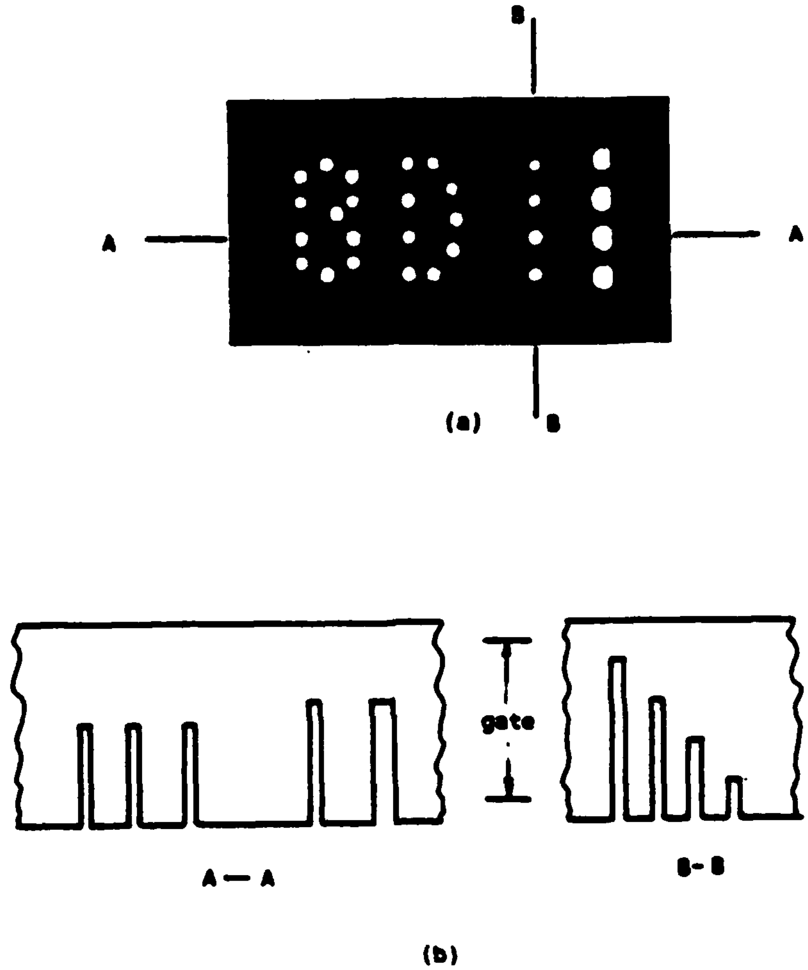


Figure 5. C-scan image of an aluminum testing block.

(a) image
(b) sketch showing gate

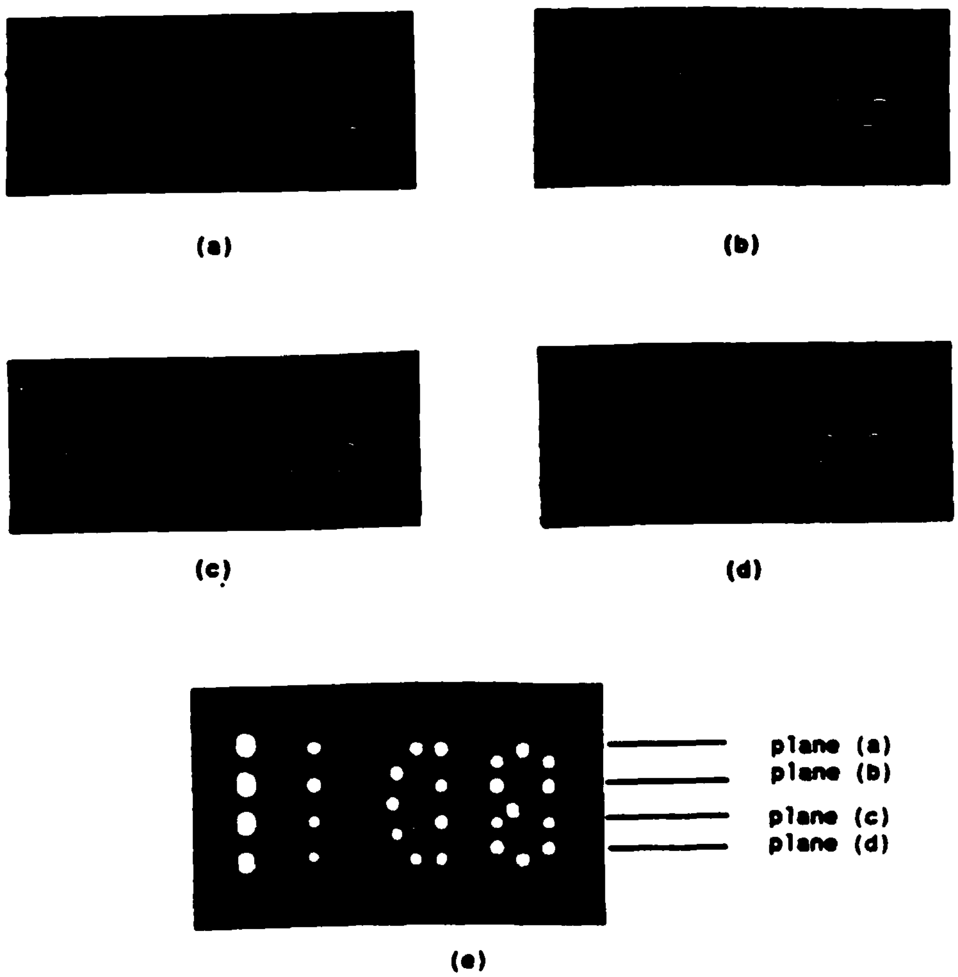


Figure 6. B-scan images of an aluminum testing block.

(a) image for plane (a)
(b) image for plane (b)
(c) image for plane (c)
(d) image for plane (d)
(e) sketch showing locations of planes

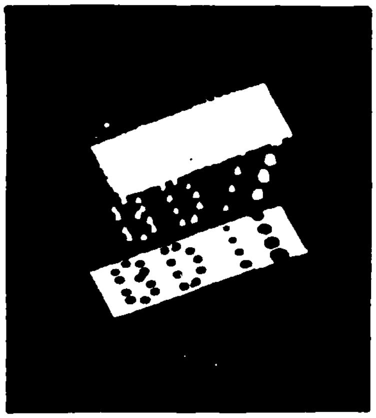
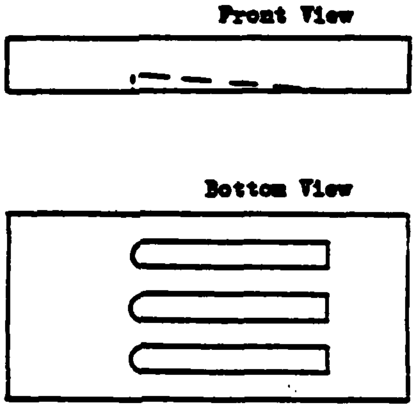
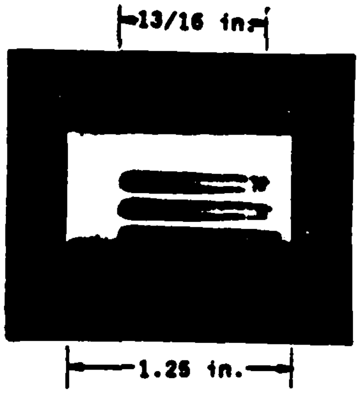


Figure 7. Three-dimensional display of an aluminum testing block.



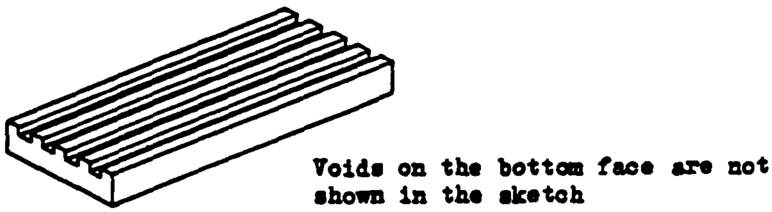
(a) (Not in scale)



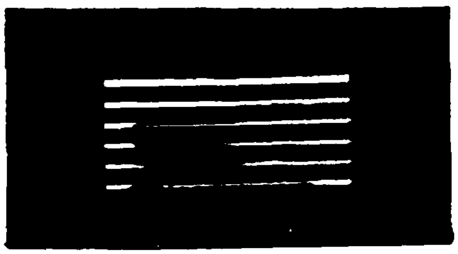
(b)

Figure 8. C-scan image of a metal-composite block with voids at metal side.

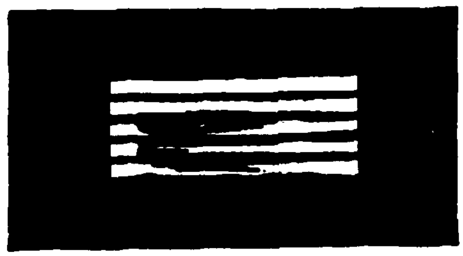
(a) sketch of the metal part of the block
(b) C-scan image of the interface



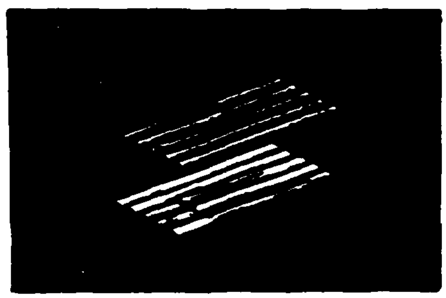
(a)



(b)



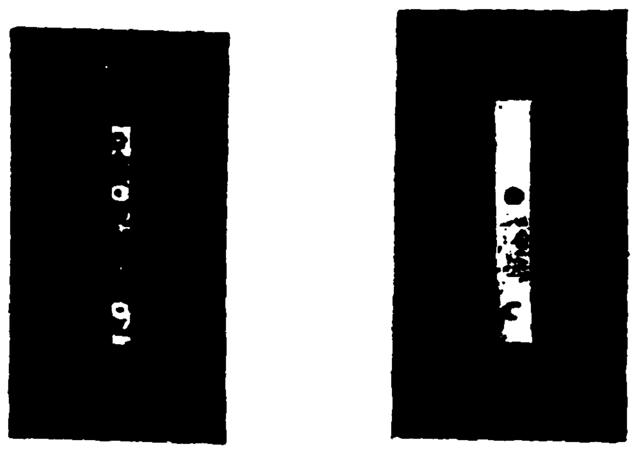
(c)



(d)

Figure 9. C-scan images of a metal-composite block with grooved top surface.

(a) sketch of the metal part of the block
(b) C-scan image of land section of the interface
(c) C-scan image of groove section of the interface
(d) three-dimensional display of the interface



(a) (b)

Figure 10. C-scan images of a metal-composite block with voids at composite side.

(a) C-scan image of the interface
(b) C-scan image of composite only

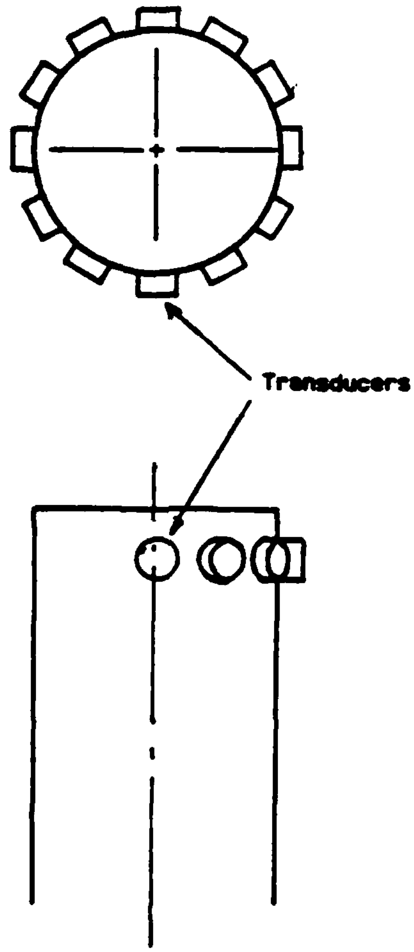


Figure 11. A conceptual sketch of a special probe.

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