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FEASIBILITY OF ULTRASONIC DETECTION OF NONBOND IN ATR FUEL PLATES

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METALS AND CERAMICS DIVISION

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AUGUST 1964

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ABSTRACT

This report discusses a feasibility study conducted at ORNL to detect conditions of nonbond between type 6061 aluminum cladding and 34 wt % U_3O_8-Al dispersion cores in the ATR roll-clad fuel plates. Discussion is presented on the ultrasonic through-transmission technique which was selected to monitor the bonding quality. The capabilities and limitations of this method as well as the significant results and conclusions that have evolved in this study are described. General conclusions are based mainly on results obtained in the evaluation of the 0.050-in.-thick (0.015-in. clad—0.020-in. core—0.015-in. clad) fuel plates which are representative of the latest fabrication practices.

INTRODUCTION

As part of a program to develop composite alclad plates for the ATR, studies have been conducted to determine the applicability of ultrasonic techniques for evaluating the bonding between the 34 wt % U_3O_8 type X8001 aluminum core and the type 6061 aluminum cladding. Lack of sufficient bonding could cause "hot spots" or uneven heat distribution leading to potential premature fuel element failure. A number of plates were evaluated ultrasonically to determine the capabilities and limitations of this technique as applied to ATR fuel plates. These studies were not intended to culminate in the complete development of techniques and systems; however, they were to demonstrate the feasibility and attainable sensitivity on the dispersion core and to serve as a guide in the preparation of purchase specifications.

THEORY

Through-transmission ultrasonics[1] were selected as the best, readily available method for nonbond detection in the thin-clad plates. Although this method has been applied to the inspection of uranium alloy[2] and UO_2-stainless steel dispersion[3] fuel plates, sufficient information was not available as to its suitability or attainable sensitivity when applied to a ceramic (U_3O_8) dispersion in aluminum. The different acoustical properties of the dissimilar materials in the core and the possible localized inhomogeneities in the U_3O_8 concentration were expected to cause difficulty in performing a sensitive inspection. In particular, there was no information relative to the minimum size nonbond which could be detected in the presence of acceptable variations in fuel concentration.

Figure 1 shows the test principles in a schematic form. A high-frequency ultrasonic beam is generated by a piezoelectric (or electrostrictive) transducer. This beam is transmitted through a coupling medium such as water. As the beam encounters an interface, a portion of the beam will be reflected and a portion will be transmitted through the interface. The amount of reflection is dependent, in part, on the acoustical mismatch at the interface. Thus, a beam being transmitted from one transducer to a similar receiving transducer will be attenuated by the presence of intermediate interfaces and such other factors as scattering, absorption, divergence, etc. As long as the intermediate material is uniform, a constant signal amplitude will be detected by the receiving transducer. However, a localized condition of nonbond with its drastically different acoustical impedance will cause a reduction in transmission. The amount of reduction will be primarily a function of the nonbond area as compared to the cross-sectional area of the ultrasonic beam.

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[1]R. C. McMaster (ed.), Nondestructive Testing Handbook, vol. II, sect. 43, The Ronald Press Company, New York, 1959.

[2]W. N. Beck and W. J. McGonnagle, Development of Ultrasonic Techniques for Inspecting Experimental Boiling Water Reactor Cast Uranium Alloy Cores and Fuel Plates, ANL-5653 (Dec. 1957).

[3]R. W. McClung, Feasibility Studies — Nondestructive Testing of the Enrico Fermi Reactor Core B Fuel Element, ORNL-3221 (Dec. 21, 1961).

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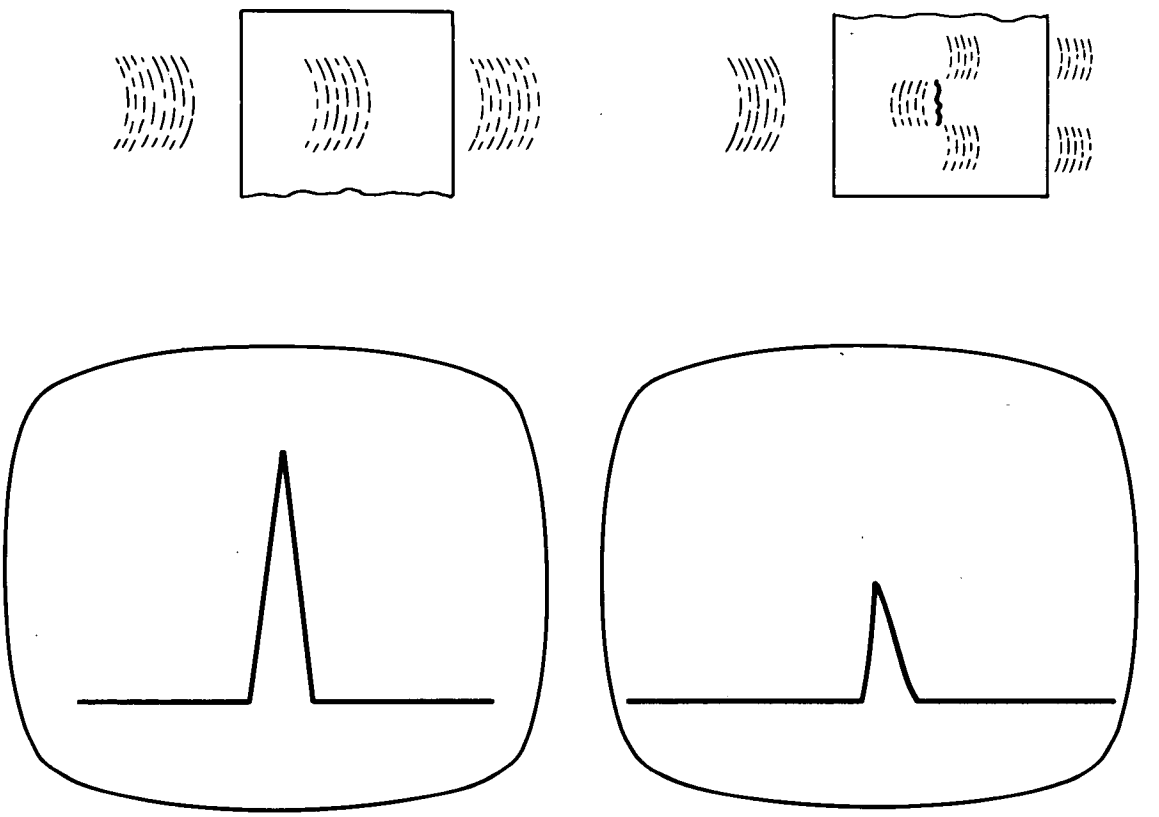

Fig. 1. Principles of the Ultrasonic-Through-Transmission Technique.

EQUIPMENT

Instrumentation

Commercially available pulsed-ultrasonic instrumentation was used for this study. The principal component was the instrument that produced the electrical signal to feed the piezoelectric transducer. This signal was a continuous series of 1-μsec pulses at a repetition rate of approximately 600 pulses per second. For rapid scanning over the plate surface, it is necessary to have the fast repetition rate to assure that every section of the plate which has been scanned has also been investigated by the ultrasound. Other features of the basic unit are detection, amplification, and display circuitry to process the data relative to the amount of sound transmitted through the fuel plates.

The basic instrument used was the Immerscope (manufactured by the Budd Company, Phoenixville, Pennsylvania). Possibly, other similar commercial instruments would have served. An item of auxiliary instrumentation provided an electronic gate to select and process the transmitted pulse. This pulse subsequently operated visual and/or audible alarms and generated an output signal suitable for actuating the stylus of a plan-view recorder. Thus, a map of the plate and its nonbond area was provided as a permanent record. Figure 2 shows one of these recordings with positive[3] writing for nonbond. This recording is of a plate which contains nonbonds made for display purposes.

Mechanical Scanning

Mechanical scanning equipment was required to provide precise control of the scanning parameters. The fuel plate was held such that the transverse direction (width) was vertical; it was moved through the ultrasonic beam in the longitudinal direction by means of a continuous roller-chain drive system which was originally designed as part of a tank system for the inspection of tubing.[4] The transducer system was adjusted in a

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[4]R. B. Oliver, R. W. McClung, and J. K. White, Am. Soc. Testing Mater., Spec. Tech. Publ. 223, 62 (1958).

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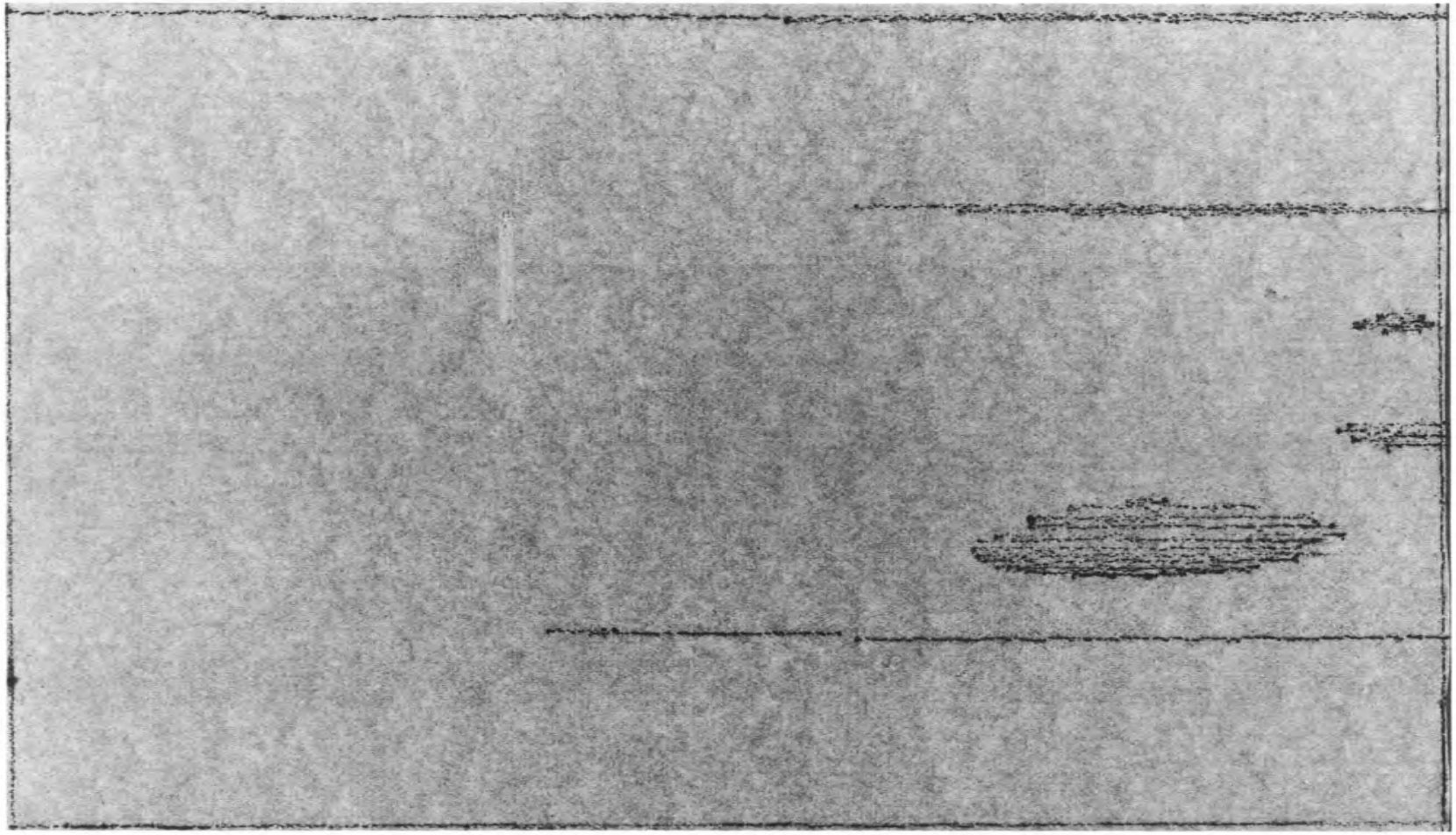

Fig. 2. A "C" Scan Recording of Nonbond. The dark areas of writing indicate nonbond.

vertical direction to obtain the lateral indexing following each longitudinal pass of the fuel plate. The transverse (vertical) movement of the opposing transmitting and receiving transducers was accomplished with the cross-feed mechanism of a small lathe. Figure 3 is a photograph of the temporary scanning system which was used. As used during the feasibility study, manual operation of the cross feed was necessary, but this can be readily mechanized. Data potentiometers were used to translate mechanical motion into an electrical driving signal for the plan-view recorder.

Longitudinal scanning speeds in excess of 200 ipm were readily attainable with this system. Faster scans would be practical if mechanical stability and the necessary instrument responses were maintained.

REFERENCE STANDARDS

Nonbond areas of known size in standard fuel plates are needed for instrument calibration, inspection standardization, and more particularly in the early stage, for the determination of attainable sensitivities. The best and most reproducible fabrication technique for simulated nonbonds has been the use of end mills to produce shallow, flat-bottomed holes of known diameter in finished fuel plates. These holes are then plugged in such a fashion that the acoustical mismatch at the bottom of the hole corresponds as closely as possible to that expected from a naturally occurring nonbond. It was assumed that the nonbond would be an extremely thin void and have a reflection coefficient

$$\left(\frac{\text{amplitude of reflected signal}}{\text{amplitude of incident signal}}\right)$$

of 99% or greater. A rather quick method of obtaining this condition was to place a thin piece of paper at the bottom of the hole. This paper was then covered as the hole was plugged with a waterproof substance such as wax or Apiezon (manufactured by Metropolitan-Vickers Electrical Company, Ltd.). Regardless of the plugging technique, care must be exercised to prevent improvement of the ultrasonic coupling across the interface at the bottom of the hole. Any such coupling will permit the transfer of energy, which will reduce the response, causing the reference defect to appear as a smaller nonbond area. This could obviously result in inspection at a greater sensitivity than is desired, producing spurious rejections.

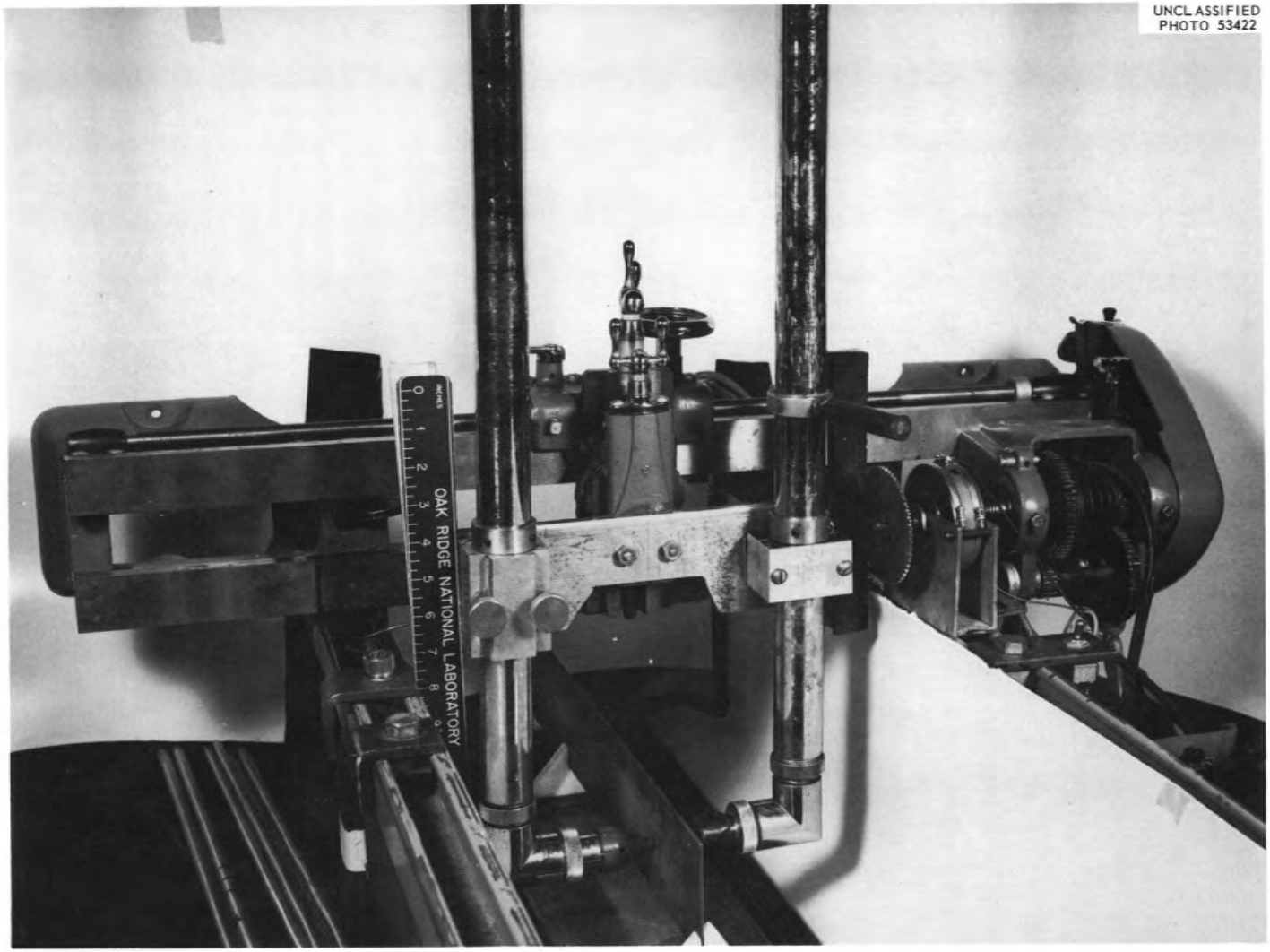

Fig. 3. Mechanical Device for Vertically Indexing Ultrasonic Search Tubes.

CALIBRATION

Simulated nonbonds of 1/16-, 3/32-, and 1/8-in. diam were placed in both the frame and core areas of a sample test plate using the end-mill and plug technique. This plate then became the ultrasonic standard. A frequency of 5 mc was determined to be the best for generating meaningful ultrasonic data. Higher frequencies would have been more susceptible to variations resulting from attenuation differences within the core and thickness changes in the fuel plate. As mentioned previously, the response to a nonbond is detected as a decrease in transmitted sound and the degree of response is a function of the nonbond area as compared to the cross-sectional area of the sound beam. Since the most readily available transducers were 3/4 in. in diameter, reinforced plastic collimators were used to restrict the sound beam and thus improve both sensitivity and resolution.

RESULTS AND CONCLUSIONS

A number of ATR developmental fuel plates have been examined by comparing them with the reference plates containing the drilled holes. Most all of the preliminary bond evaluation work was done using fuel specimens 0.050-in. thick (0.015-in. clad—0.020-in. core—0.015-in. clad).

Final conclusions are based on the results from twenty-two 0.050-in.-thick plates, although twenty-seven ATR fuel plates considered representative of final fabrication procedures were evaluated. Five of the twenty-seven were 0.100-in.-thick (0.040-in. clad—0.020-in. core—0.040-in. clad) plates. Only one of the five was rejected using a 1/16-in.-diam reference; however, this small sampling is not sufficient to give an indication of the expected rejection rate. Of the twenty-two 0.050-in.-thick plates, only one was rejected using a 1/16-in.-diam reference. A typical discontinuity detected by the 1/16-in. ultrasonic evaluation is shown in Fig. 4. This discontinuity is located at the core-to-clad interface in a 0.050-in.-thick plate.

As is evident, the rejection rate for the last twenty-two 0.050-in.-thick plates is approximately 4 1/2%. We feel that, if a larger number of plates were inspected, this rejection rate would probably be lower.

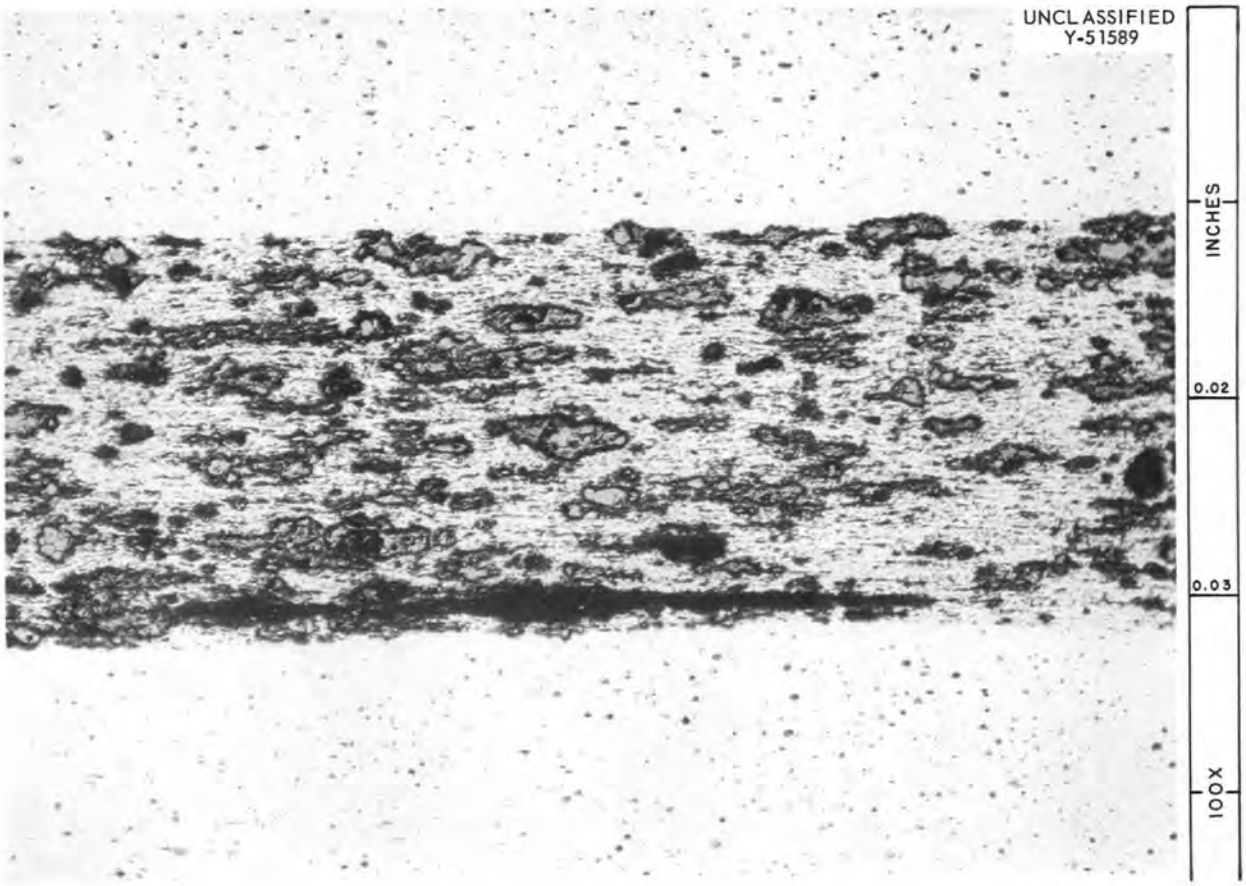

Fig. 4. Typical Discontinuity Located at the Core-to-Clad Interface in a 0.050-in.-Thick ATR Plate. Etched electrolytically with fluoboric acid.

For instance, recent work on approximately 650 0.050-in.-thick HFIR fuel plates, which are roll bonded in a manner very much like the 0.050-in.-thick ATR plates, has demonstrated a 1/16-in. nonbond rejection rate of approximately 2 to 3% (after visually detected blistered plates were removed).

As a result of these tests, it is evident that the ultrasonic-through-transmission technique is a fast, reliable inspection method capable of detecting 1/16-in.-diam nonbond areas in U_3O_8-Al fuel plates proposed for the ATR.

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