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60	*Abstract :* Plate type fuel elements have been fabricated for the neutron source reactor "KAMINI" in the Radiometallurgy Division. These plate fuel elements have been fabricated using the picture frame technique. An important step in the evaluation of the quality of the plate fuel elements is the non-destructive inspection of bonding between the clad plates and the meat and the picture frame. From the available techniques for lack of bond inspection, a choice was made to use the ultrasonic immersion testing technique. This report records the experience gained in the development of the ultrasonic immersion testing technique for the evaluation of bonding in these fuel plates, with a back-up support of metallography.	
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1.0 INTRODUCTION

Plate type fuel elements have been widely used in research reactors because of their ease of fabrication and good heat transfer characteristics. The plate type fuel elements for the Neutron Source Reactor(NSR), KAMINI, being set up in the Indira Gandhi Centre for Atomic Research, Kalpakkam, India, use aluminium-uranium alloy as the fuel, commonly known as the meat, and are fabricated using the picture frame technique. In this, the alloy meat is placed in a rectangular aluminium frame and is sandwiched between two aluminium cladding plates. The assembly is then subjected to hot rolling for bonding, followed by cold rolling and trimming.

A sketch of the basic plate type fuel element is shown in Fig. 1. Characteristics of the fuel plate like dimensional conformance and surface defects, bonding of the clad plates to the meat and picture frame and fuel homogeneity are inspected to evaluate the quality of these plate fuel elements.

1.1 Bond Testing

A good metallurgical bond between the meat and the clad is very essential to ensure quick and uniform heat transfer to the coolant. A localised lack of bond region in a fuel plate may give rise to hot spots which may lead to rupture. A lack of bond may be caused by improper cleaning of the mating surfaces before bonding or because of surface oxidation and film formation.

A variety of techniques like blister testing, ultrasonic testing [1,2,3], infrared imaging [4,5] and electrode-potential testing [6,7] have been used for detection of lack of bond in fuel elements. Blister tests usually enables detection of gross non-bond areas as its effectiveness depends on the quantity of gases entrapped in the affected zone. Infrared imaging although a sensitive technique, has some limitations in the present case due to the high thermal conductivity of aluminium. Design and construction of suitable probes makes the electrode potential test somewhat difficult to implement. A choice was therefore made to use immersion ultrasonic testing for evaluation of bonding in these fuel elements. This report records the experience gained in the development of an immersion ultrasonic testing programme for evaluation of non-bond areas in these fuel plates with a back up metallography support.

2.0 ULTRASONIC IMMERSION TEST

A high sensitivity can be achieved using the immersion test as focused probes can be used. For the present experiments a Krautkramer USIP-11 system was used with a 10 MHz point focused probe with a focal length of 35 mm in water with a focal spot size of 1.5 mm. The focal length of the probe as calculated for water gets shortened when it enters a metal due to the large difference between the velocities of ultra-sound in water and metal and this was taken into account while adjusting the equipment in order to ensure that the focal point of the beam was in the centre of the fuel plate being inspected.

An immersion scanning set up was designed and fabricated for carrying out these tests in a controlled and repeatable manner. A sketch of the scanning system is presented in Fig. 2(a) and a photograph in Fig. 2(b). The scanning assembly consists of the transducer held in a scanner tube which in turn is held by the manipulator assembly for positioning the transducer at any angle or height (max. 15 cms/fine movement 0.25 cm) from the object under test. The manipulator is fixed to the X-Y carriage bridge assembly.

The movement of the X or Y carriage (maximum traverse 40 cms) is possible by rotating a single knob and locking either the Y or the X carriage movement. The accuracy of movement is ±1 mm. The tank, in which the fuel plates rest on two wedges immersed in water is independent of the scanner-manipulator system. The leveling of the tank is done by adjusting three leveling screws.

2.1 Reference Standard

The objective of these experiments was to intercept non-bond areas equivalent to that of a 1.5 mm diameter circle. A reference standard (sketch shown in Fig. 3 a&b) was fabricated to simulate lack of bond regions with varying magnitude. For this, an aluminium plate of equivalent thickness was taken and flat bottom holes of varying diameter were drilled to a depth of 0.5 mm so that the metal travel distance from the other surface is equal to the depth at which the lack of bond regions occur (0.5 mm or 1.5 mm). Another aluminium plate was then placed against the side containing the holes and the two plates were sealed together along the ends with an adhesive (M-seal). This was done to ensure that no water would enter the drilled holes and the air entrapped in these would simulate non-bond regions.

2.2 Observations

With the appropriate setting of the ultrasonic flaw detector the signals received from the simulated non-bond regions in the reference standard are presented in Fig. 4a,b & c. The actual fuel plates were then tested and lack of bond signals intercepted were compared to those recorded from the simulated non-bonds for classification. Typical non-bond signals from a fuel plate are presented in Fig. 5 a&b.

To verify the sensitivity achieved, the test was applied on a fuel plate which was earlier subjected to a blister test and showed a visible blister of about 1 sq.cm. in size. After complete mapping using the ultrasonic scanner (Fig.6) the fuel plate was thoroughly examined metallographically.

3. METALLOGRAPHY

Metallographic verification of the lack of bond present in the fuel plate was carried out by sectioning the portion marked ABCD in Fig. 6, containing the flaw indicated by ultrasonic examination. The piece was mounted in cold setting resin to expose the edge AB, showing the thickness of the plate. Standard metallographic procedure was followed for mechanical polishing,and successive parallel sections of the specimen were observed by grinding in steps till the edge CD was reached. Electrolytic polishing technique was standardised to avoid flow of material so that fine planer indications of non-bond was not lost during preparation.

In a few sections, a discontinuous line of lack of bond (Fig.9)was revealed beyond the length indicated by the ultrasonic test . Representative photomicrographs of lack of bond regions intercepted in fuel plates are presented in Fig. 7 to 9.

4. DISCUSSION

A fair agreement between the metallography results with the ultrasonic indications of non-bond regions demonstrated the reliability of the ultrasonic testing procedure. Non-bond area of magnitude 3 sq.mm could be clearly intercepted using this set up. In case of plates with visible blisters following a blister test, the actual lack of bond area as revealed by metallographic examination was observed to be larger than the size of the blister as seen on the surface. In more than one section, metallography revealed a fine discontinuous line of lack of bond beyond the area indicated by ultrasonic testing (Fig. 9). This fine lack of bond was difficult to detect ultrasonically because the ultrasound beam could travel through the region as though it was continuous. Concurrent metallographic examination of fuel plates with ultrasonic non-bond indication played a very important role in understanding the significance of the ultrasonic signals and finally taking accept/reject decisions while inspecting the production lots.

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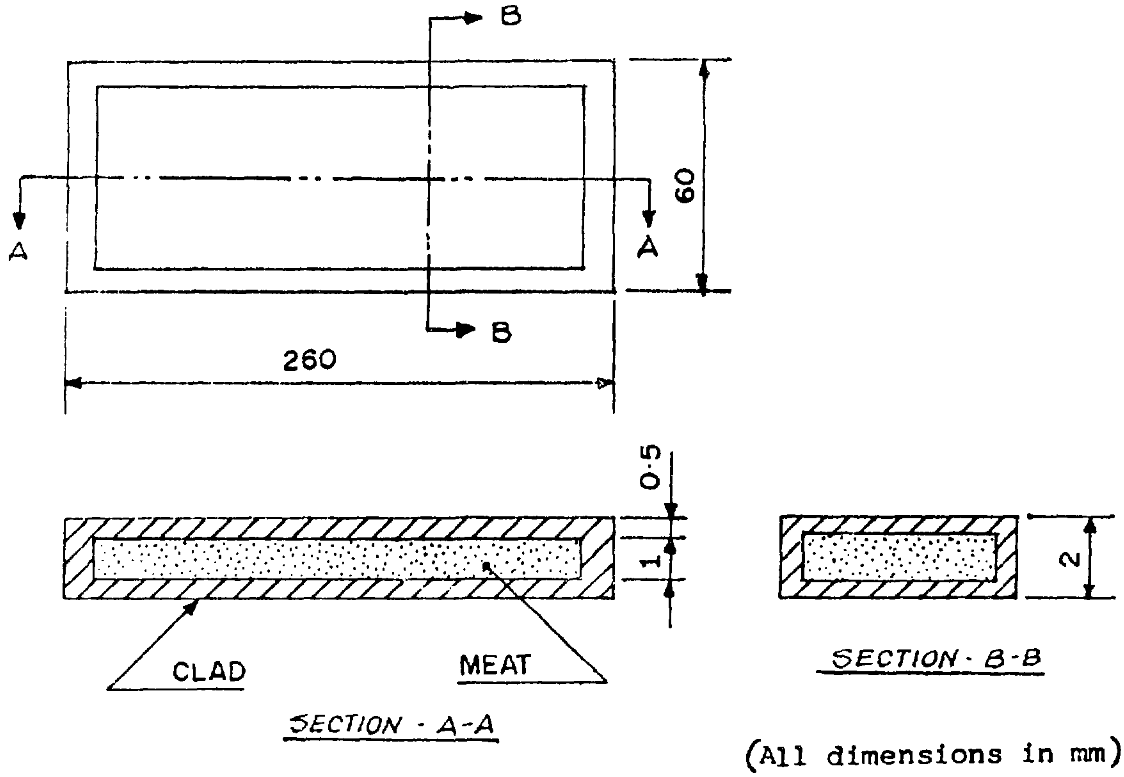


Fig.1. Sketch of the plate type fuel element.

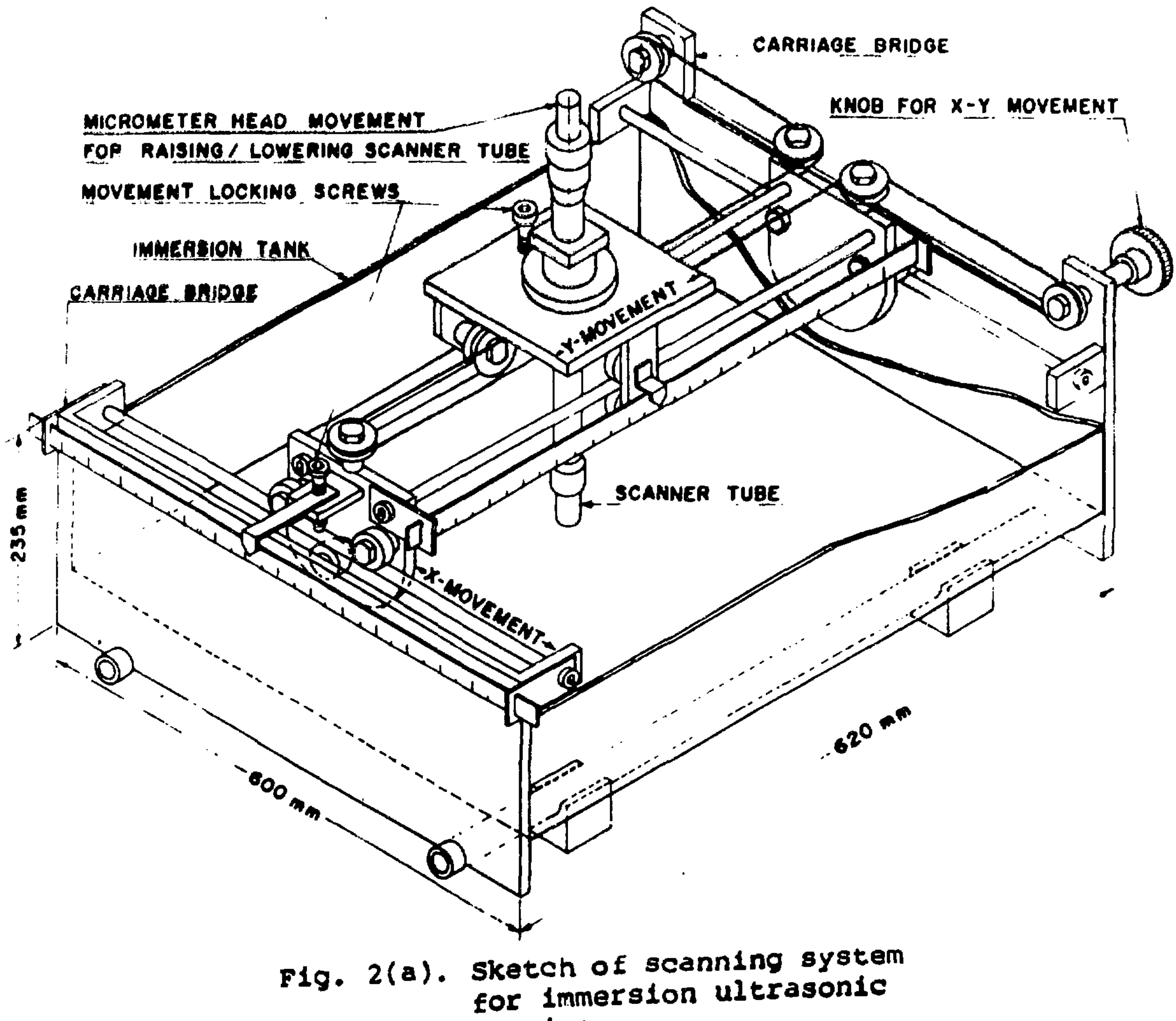


Fig. 2(a). Sketch of scanning system for immersion ultrasonic testing.

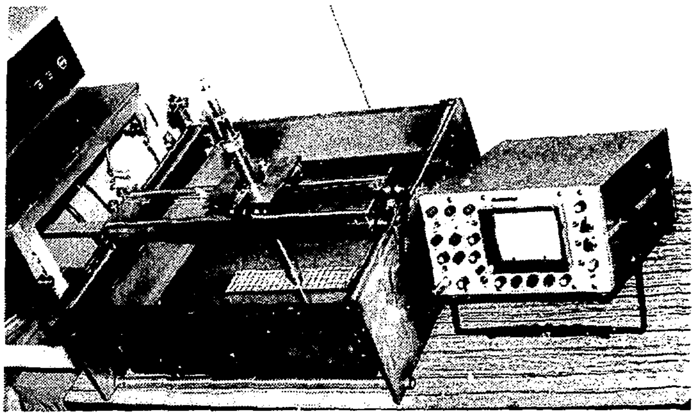


Fig. 2 (b). **Photograph of complete ultrasonic scanning system.**

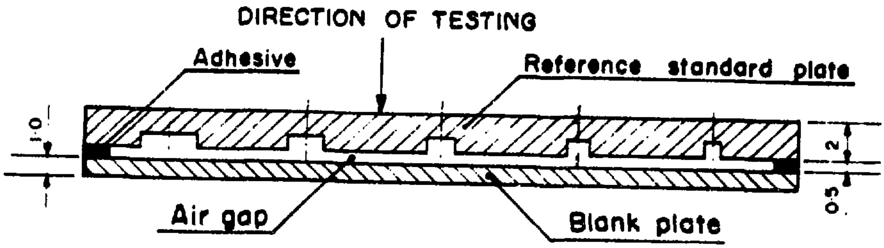
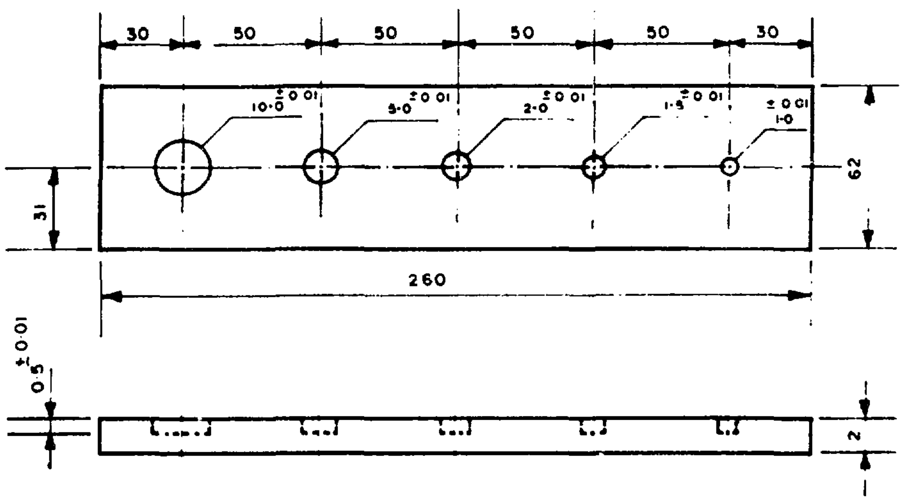


Fig.3 (a). Construction of reference standard plate(schematic)



(All dimensions are in mm.)

Fig.3 (b). Reference standard plate

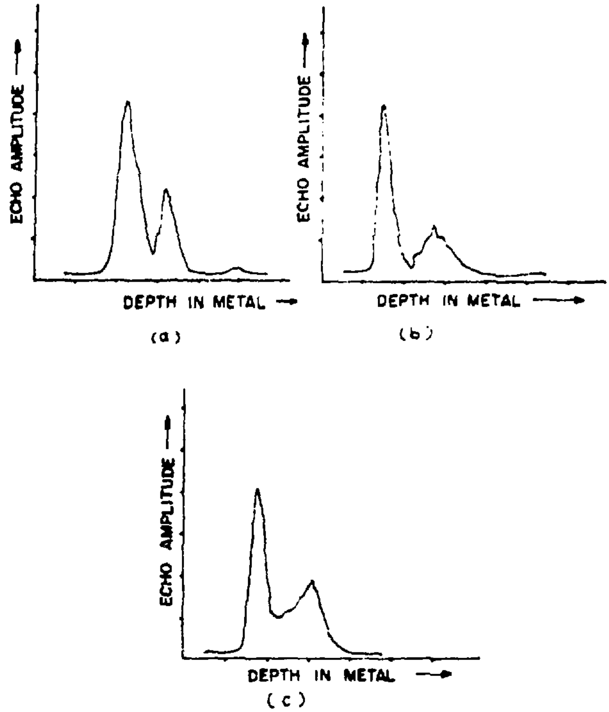


Fig.4. Lack of bond indication from reference standard (a) 10mm ϕ flaw (b) 5mm ϕ flaw (c) 2mm ϕ flaw.

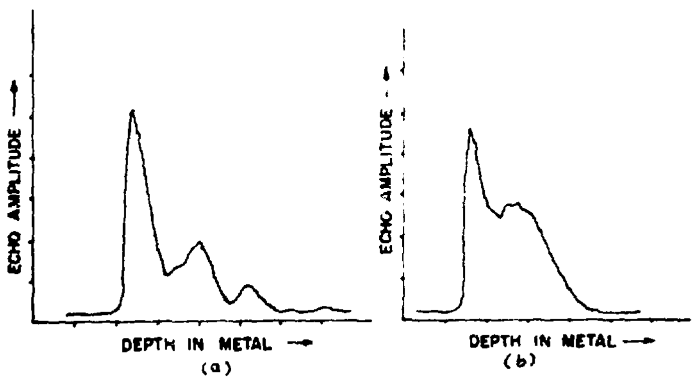
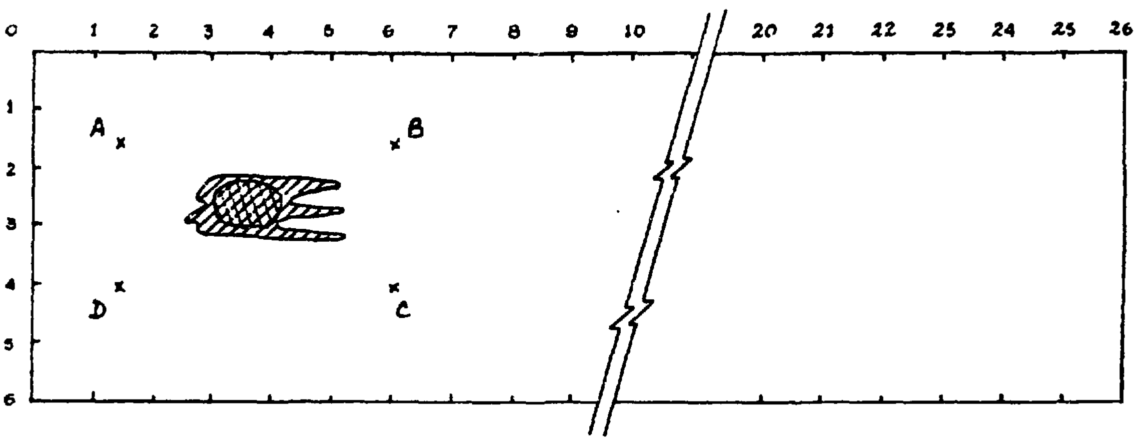


Fig.5. Lack of bond indication from defect regions in a typical plate fuel element.



▨ Area of lack of bond mapped by ultrasonic testing

▩ Area of visible blister

Fig.6. Ultrasonic test map of a blister on a plate type fuel element. The region ABCD was used for metallographic verification.

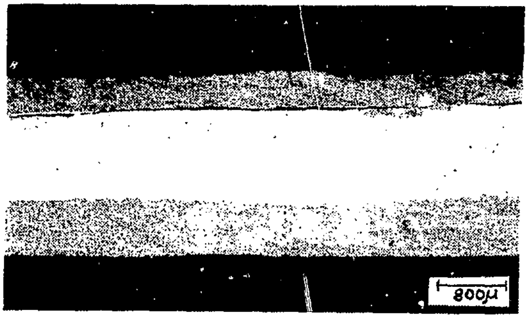


Fig. 7. Photomicrograph of a lack of bond section in a fuel plate.

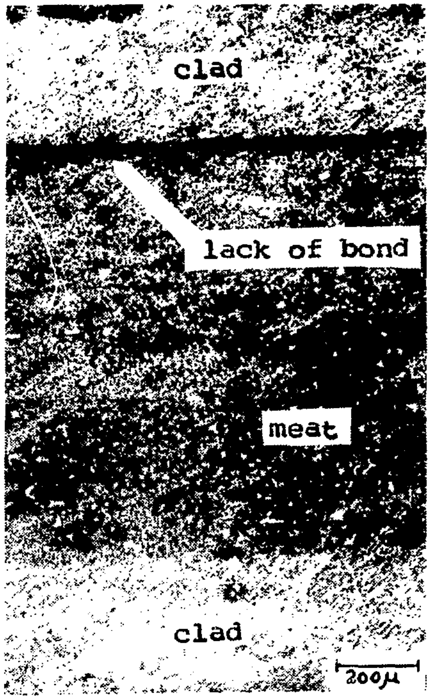


Fig. 8. Photomicrograph showing a good bond (lower region) and a lack of bond (upper region).

Fig. 9. Photomicrograph showing discontinuous line of lack of bond.

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