Tandem Wedge for In-service Inspection of Cladding to detect vertical flaws in Pressure Vessel Components

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Abstract

Cladding is a process of weld overlay to protect the base metal from corrosive fluids and fumes ensuring its longevity. Cladding aid to obtain a suitable material at a reasonable cost, consisting of low-cost base material with excellent mechanical properties (such as carbon steel), and another material resistant to corrosion, abrasion or oxidation (such as stainless steel, Inconel)

To ensure bonding between the clad and parent material, Non-Destructive Examination (NDE) Techniques are used. Among the various NDE techniques, conventional ultrasonic testing (UT) serves as a reliable method during the manufacturing stage.However, during operation there is a risk of defects propagating in the clad-parent material interface, thereby reducing the service life of the product.

The conventional UT methods are not effective in detecting vertical flaws in the interface region of cladding and base metal. To effectively detect vertical flaws, a Tandem Wedge was designed for generating Longitudinal acoustic wave (L-wave) with 45° refracted angle in steel. This paper details about the design and development of the Tandem wedge to detect vertical flaws in cladding.

Keywords: *Cladding, NDE, Ultrasonic Testing, Tandem technique, Wedge.*

1 INTRODUCTION

The surface in contact with corrosive fluids and gases during service are coated with high alloy deposit to safeguard the parent metal. This process of cladding is widely used for coating pressure vessel equipment in corrosive environment. Alloys in cladding are generally nickel chromium based alloys which are good in creep and corrosion resistance properties. The different methods of clad deposition over the parent metal are by roll bonding, explosive cladding and weld overlaying. Weld overlaying is the most popular and versatile form of cladding employed in a wide range of industries. Process deviations and unsound weld practices would result in planar and vertical flaws in the weld volume. Ensuring the soundness of the cladded joint is important in ensuring the service life and safety of the component. Lack of fusion and under clad cracks are the flaws which weaken the bonding between parent metal and clad. Propagation of these flaws during service of the component can pose a serious threat to the safe operation of the equipment. These flaws are periodically monitored during In-service inspection and shutdown maintenance carried out to assess the integrity of the cladding.

Non Destructive Examination techniques such as PT (Penetrant Testing) and UT (Ultrasonic testing) are being performed to test the integrity of the cladding. PT can only detect flaws which are open to the surface. As the cladding surfaces are inside diameters of pipes, shells and tube sheets, PT is not feasible as the cladded surface is inaccessible during in-service inspection.

When testing is carried out from the cladding surface, UT has been the most reliable NDE technique to detect flaws in the volume of the clad metal and clad- parent metal interface. Standard reference reflectors such as side drilled holes, flat bottom holes, notches are drilled into a specimen. Ultrasound reflection from the reflectors are captured on the cathode ray oscilloscope screen as a blip or an echo.Generally, in conventional UT, T-R (Transmitter - Receiver) probes are used to inspect the clad volume and also the clad – parent metal interface. As shown in Figure (1), A-scan presentation displays the amount of reflected ultrasound as a function of beam travel distance. The received energy is plotted along vertical axis as a percentage of full screen height. Flaws which are perpendicular to the direction of ultrasound can be easily detected. As the access to cladding surface is limited, a new approach is required to carry out testing of cladding during in-service inspection to monitor the propagation of flaws.

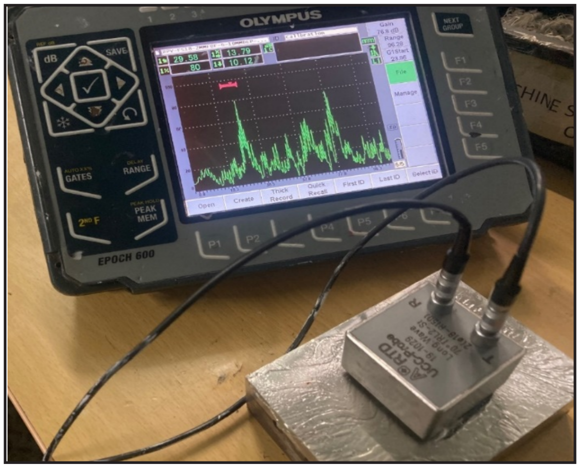


Figure 1: Focused T-R probe for inspection of clad-parent metal interface from cladding surface

2. PROPOSED METHODOLOGY

Tandem technique of ultrasonic testing is a reliable technique in detecting vertical flaws using angle beam. In this technique, two transducers or probes are used. One probe acts as a transmitter and another one as a receiver. The schematic representation of the technique is shown in Fig. 2.

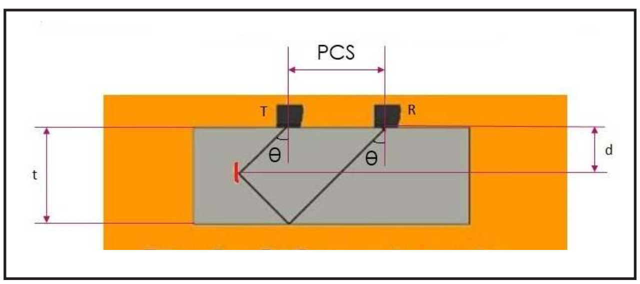


Figure 2: Tandem technique in UT

PCS : Probe Centre Spacing
T : Transmitter probe
R : Receiver probe
θ : Angle of ultrasound beam
t : Thickness of the specimen
d : Depth of the flaw

The PCS in tandem technique is calculated by the formula $PCS = 2 * (t - d) * tan\theta$

The specimen has a parent metal thickness of 40mm and the cladding thickness is 10mm. So the thickness of the specimen "t" is 50mm. The under clad cracks are present at the clad – parent metal interface. Hence, the depth of the defect 'd' is 40mm. Longitudinal wave angle beam of 45° is used for inspection. Therefore, the PCS is calculated from the data.

$$PCS = 2 * (50 - 40) * tan45$$

$$\therefore \; PCS = 20mm$$

Figure (3) shows the specimen dimensions and the tandem UT set-up. To maintain the PCS of 20mm with conventional angle beam UT probes is difficult because of the physical dimensions of the probes. To overcome this difficulty, a wedge is designed for the inspection of cladding from parent metal surface.

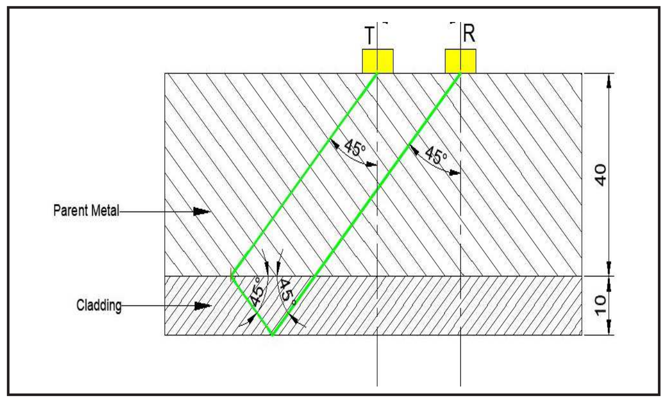


Figure 3: Set-up for Tandem UT

3. DESIGN OF TANDEM WEDGE

For the proposed technique, 2 straight beam (0°) pulse echo UT probes are used having the crystal diameter of 6mm. Straight beam or normal beam probes transmit longitudinal waves into the test specimen. In the proposed technique, longitudinal wave angle beam of 45° is used. Therefore, the 2 straight beam probes have to be placed on the wedge at an angle such that refracted beam angle is 45°.

The wedge is fabricated with PMMA (polymethyl methacrylate) material popularly known as "Perspex" or "Plexiglass". The acoustic velocity of the PMMA block is determined using a normal beam P/E (pulse echo) probe and the velocity of PMMA block is found to be **2730 m/s**

3.1 Incident angle calculation:

The incident angle or the wedge angle is calculated using Snell's law.

From the Snell's Law we have,

$$\frac{Sin\theta_I}{Sin\theta_R} = \frac{V_I}{V_I}$$

Acoustic Velocity (L wave) of PMMA V_P = 2730 m/s

Acoustic Velocity (L wave) of steel V_S= 5920 m/s

Refracted angle in steel θ_R = 45°

Incident angle θ_I =?

$$\frac{Sin\theta_1}{Sin45} = \frac{2730}{5920}$$

$$Sin\theta_1 = \frac{2730}{5920} \times Sin45$$

$$Sin\theta_1 = 0.326$$

θ_I = 19.03° (Incident angle / Wedge Angle)

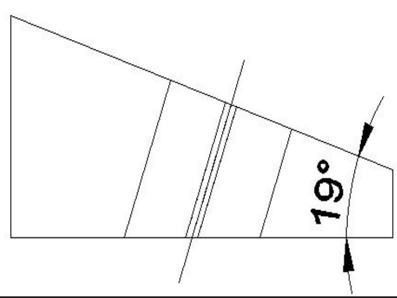


Figure 4: Incident angle

The wedge is designed with an incident angle of 19° as shown in the Fig. 4.

To avoid cross talk between the Transmitter and receiver, acoustic barrier is placed between them. Cork sheet of 1mm is used an acoustic barrier. The image of the fabricated wedge is shown in the Fig. 5.

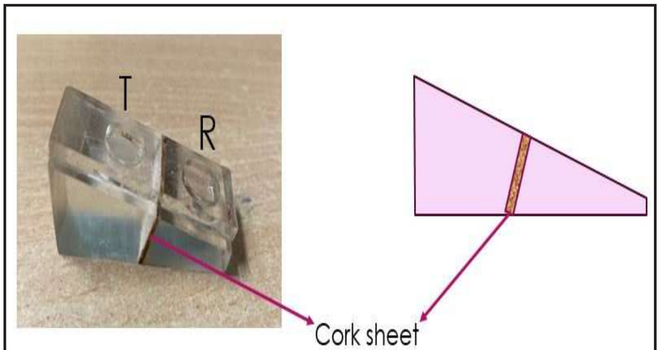


Figure 5: Tandem wedge

3.2 Sensitivity calculation:

The probe specifications are:

Nominal Frequency: 2.25 MHz

Crystal size: Ø6mm

$$Sensitivity \ \frac{\lambda}{2} \quad \text{where } \lambda \text{ is wavelength}$$

$$\lambda = \frac{Velocity}{Frequency}$$

$$\lambda = \frac{5900 \text{ x } 1000}{2.25 \text{ x } 1000000}$$

$$\therefore \lambda = 2.62mm$$

$$Sensitivity = \frac{2.62}{2}$$

$$\therefore \boldsymbol{Sensitivity = 1.31mm}$$

3.3 Determination of wedge delay:

The probe delay of the Transmitter and Receiver is determined individually using a V2 calibration block.

Delay in Transmitter = 11.630 µ sec

Delay in Receiver = 7.315 µ sec

$$Delay\ in\ tandem\ wedge = \frac{11.630 + 7.315}{2}$$

Delay in tandem wedge = 9.472 µ sec

The wedge is fabricated with an incident angle of 19° and PCS of 20mm to fasten 2 straight beam probes which act as a transmitter and a receiver. Figure (6) shows the image of the wedge and probes used for inspection.

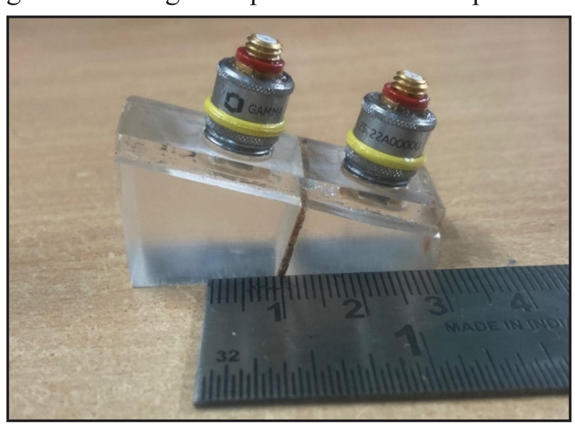


Figure 6: Tandem wedge with 2 straight beam probes

4. REFERENCE BLOCK

Standard reflectors like side drilled holes or flat bottom holes are used in UT. Reflection from the standard reflectors are set reference reflection. To detect vertical flaws at the interface between clad and parent metal, flat bottom hole of Ø2mm is drilled at the interface for a depth of 25 mm as per the requirements of American Society of Mechanical Engineers (ASME) standard section V as shown in Fig. 7. The parent metal thickness of the reference block should be comparable to that of actual pressure vessel parent metal thickness.

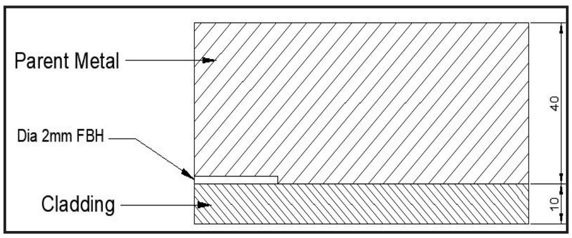


Figure 7: Reference block

4.1 Calibration

The calibration is done by taking the reference from the Ø2mm FBH and setting the echo height at 80% Full Scree Height (FSH) as shown in the Fig. 8. Also the velocity of the steel is 5920 m/s and probe delay determined is 9.727 µ sec.

Figure 8: Reference echo calibration

5. EXAMINATION WITH TANDEM WEDGE

The examination of cladding using the tandem wedge is carried out from the parent metal surface. The surface finish is improved by cleaning or by buffing to achieve good surface contact between the wedge and the job surface. Oil + grease is used as a Couplant. UT with the tandem wedge is performed in 4 directions (2 axial directions and 2 circumferential directions) to detect vertical flaws in the clad-parent metal interface.

In longitudinal wave (L-wave) UT inspection, a phenomena of Mode Conversion occurs. While the L-wave is desired in the test specimen, a mode converted Shear wave (S-wave) is also generated into the test specimen. Also when L-wave encounters with the wall of the specimen or flaws at an angle which is not perpendicular to the ultrasonic beam, a mode converted S-wave is generated. Though the energy of the mode converted S-wave is low as compared to the energy of L-wave, it is very important to study the characteristics of the S-wave generated in the test specimen. The Fig. 9 shows the study of the mode converted S-wave. From the figure (9) we can see that the mode converted S-wave will not interact with the receiver probe.

From the Snell's Law we have,

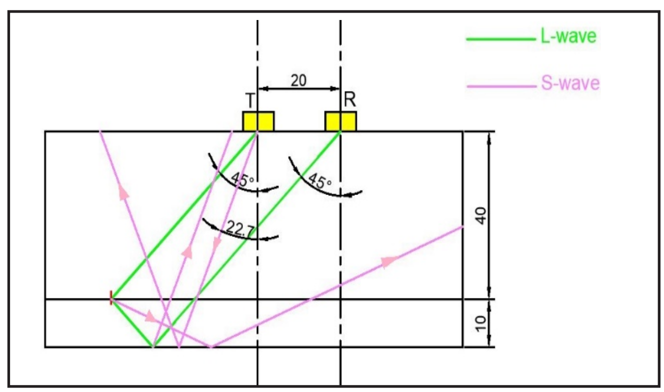
$$\frac{Sin\theta_S}{Sin\theta_T} = \frac{V_S}{V_T}$$

$$\frac{Sin\theta_S}{Sin45} = \frac{3240}{5920}$$

$$Sin\theta_S = \frac{3240}{5920} \text{ x } Sin45$$

$$Sin\theta_S = 0.387$$

$$\theta_S = \mathbf{22.7^o} \textbf{ (Mode Converted shear wave angle)}$$



6. COMPARISON OF TANDEM WEDGE UT WITH THE EXISTING METHOD OF UT

Study was carried out to compare the results of conventional UT examination and Tandem wedge UT examination. A shell with 40mm parent metal thickness and 10mm cladding on the inner surface of the shell was examined using conventional focused T-R probe. A flaw was picked from the clad-parent metal interface at a depth of 10.27mm from the cladding surface as shown in Fig. 10.

The same flaw was picked up by the Tandem wedge during inspection from the parent metal surface (from outer surface of the shell) shown in Fig. 11. The Tandem technique in UT will not give the depth of the flaw. As we have calculated the PCS for a particular depth of 40mm from parent metal surface, we can interpret that the echo is from 40mm depth from the outer surface i.e. form the clad-parent metal interface. Thus flaws in the clad-parent metal interface are detectable using the Tandem wedge.

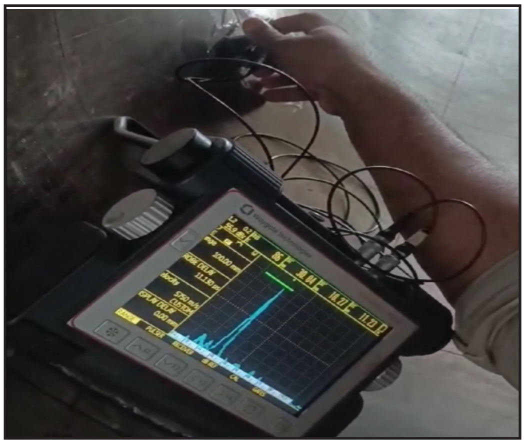


Figure 10: Flaw picked with conventional focused T-R probe during inspection from cladding surface

Figure 11: Defect picked while examination from OD surface using Tandem wedge

7. CONCLUSION

This paper has provided details of the design and development of Tandem wedge for testing of cladding in pressure vessels. The study shows that Tandem wedge technique is a reliable UT method for detecting vertical flaws during in-service inspection of cladding. As the cladded surface is inaccessible during in-service inspection, the Tandem Wedge UT technique offers the flexibility to carry out testing from parent metal side. The de-bonding between the clad and parent metal can be detected using straight beam UT probes and vertical flaws like under clad cracks can be detected using the Tandem Wedge technique.

Further study will be carried out with advanced ultrasonic testing methods like PAUT & TOFD for detection of vertical flaws in the interface of cladding and parent metal.

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