Ultrasonic testing of thin-walled titanium weld joint with adhesion detector

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Abstract. The paper has summarized ultrasonic testing methodology for 0.6-mm thin-walled titanium weld joints. Aspects of adhesion detection (weld joint areas with incomplete fusion, which are good at conducting ultrasonic waves but bad at providing mechanical resistance) are considered. It is proposed that an angular cavity can be used as an indicator of incomplete fusion in the weld joint. Various modes of Lamb waves and their propagation in the material were analyzed and the optimum testing parameters were selected. Wavelet-analysis and precision digital filters with a small increment allowed great informative value of the wave signal to be achieved. The results of ultrasonic scanning were compared to the data obtained in metallographic study.

1. Introduction

Critical thin-walled shells are used in nuclear engineering. Strict requirements, as to strength and absence of defects, are imposed on weld joints. Selective methods and ultrasonic testing systems (UTSs) are being developed to test quality of the shell weld joint. The basis for selection of ultrasonic testing method rests on a high-sensitivity requirement imposed on testing, which is performed in the conditions of curved weld joints with complicated grooving and one-sided access to the weld joint. In this case, the most complicated weld joints, from the standpoint of ultrasonic testing, are the weld joints with bottom spacing rings made of materials which tend to adhesion – formation of weld joint areas that are good at conducting ultrasonic waves but bad at providing mechanical resistance. This paper summarizes methodical solutions for ultrasonic testing of a curved VT-20 alloy shell, which is more difficult to test due to the above-mentioned factors.

2. Unit under Test

The shell is made of two 0.6-mm thick hemispheres. Welding is performed using electron beam method. VT-20 alloy bottom spacing ring with 2×0.6-mm annular cross-section is mounted under the weld joint to prevent electron beams from emerging to the internal surface. Based on the required strength properties of the shell, the weld joint is to be welded to the full depth with allowable penetration into the bottom spacing ring.

For example, [1] reports that many alloys tend to adhesion while in welding. The specified alloys contain titanium. To factor out the adhesion effect on ultrasonic testing validity, the weld joint is designed to incorporate a cavity $0.13^{+0.025}_{-0.025} \times 0.13^{+0.025}_{-0.025}$ mm in size. Figure 1 shows the weld joint grooving design. The cavity is a physical tracer of the weld-joint root penetration. In case the weld joint root has not been penetrated, the cavity acts as a good ultrasonic wave reflector.
Figure 1. Weld joint grooving design:
1 – hemisphere 1; 2 – hemisphere 2; 3 – bottom spacing ring.

Figures 2 and 3 show the immersion test setup for the shell. The shell weld joint runs horizontally, the shell is installed on the motor-driven support that rotates about a vertical axis, the ultrasonic beam of piezoelectric transducer (PET) is transverse (figure 2) or along (figure 3) to the weld joint with the angle of incidence $\phi$ ($\Delta X$ and $\Delta Y$ are lengths of PET movement to obtain the required ultrasonic wave entry angle). The mechanical manipulator is used to align the transducer with the inspected article. The manipulator makes the transducer to move in three coordinates and change the angle of inclination.

Figure 2. Test system configuration (sonic test in the transverse direction):
1 – bracket; 2 – personal computer; 3 – flaw detector; 4 – immersion solution; 5 – bath; 6 – piezoelectric transducer; 7 – motor unit; 8 – support; 9 – shell; 10 – weld joint.
3. **Control Waves**

In ultrasonic testing of sheets, pipes and shells less than 5 mm in thickness, Lamb waves can be used in the most effective manner [1-3]. Parameters of their propagation in the material are calculated using dispersion equations [2]. For VT-20 alloy 0.6 mm in thickness, dependences of basic parameters are of the form represented in figure 4. The plots show that the modes above the zero ones are propagating at the frequencies 3 MHz or more. At the same time, dependencies of the excitation angles at the zero and higher-mode frequencies are approaching each other starting with the frequency near 7 MHz. In this context, 5 MHz has been selected as the frequency for the piezoelectric transducer to insure good sensitivity and at the same time to leave the results of tested nonzero modes (signal merging) unaffected. The piezoelectric transducer uses spherical focusing as the most sensitive one. The informative testing mode and its excitation angle for the shell material are determined by the phased-array scanning based on the method in Ref. [4]. The analysis was used to select the mode \( a_0 \) and the excitation angle 28°.

![Diagram](image)

**Figure 3.** Test system configuration (sonic test in the longitudinal direction).

![Graph](image)

**Figure 4.** Dependencies of Lamb wave parameters on the frequency in 0.6-mm thick VT-20 alloy.
4. Instrumentation
The testing instrument R163-L8 used to test the shell weld joint has advanced functionalities to operate with Lamb waves. More particularly, the instrument software enables time-and-frequency analysis of wave signals (wavelet analysis). Thus, the frequency-rate mode dependencies can be specified to select appropriate filters. Thus, the frequency-rate mode dependencies can be specified to select appropriate filters.

5. Testing Sensitivity Evaluation
Ultrasonic testing capabilities were estimated by scanning of the shell weld joints made under various welding conditions, and thus characterized by different depth of penetration. The obtained ultrasonic scanning data were further compared to metallographic study of the weld joint. The areas with incomplete fusion were broken lengthwise; the areas with complete fusion were sectioned. Figure 5 shows photographs of the sections typical for defects.

![Photographs of the sections with the weld joint defects.](image)

(a) section, pore 0.1 mm in diameter; (b) longitudinal fault, incomplete fusion 0.3 mm; (c) section, quality weld joint

Figure 5. Photographs of the sections with the weld joint defects.

Metrological evaluation of the testing method sensitivity proved its capability in longitudinal and transverse scanning to detect the areas 0.3 mm long, where the cavity was fused incompletely, and the pores 0.3 mm in diameter, with confidence as good as 0.95.

6. Conclusion
The results of the study demonstrated that a cavity can be used effectively in terms of detecting incomplete fusion in ultrasonic testing of adhering alloys. With a spherically focused sensor at 5MHz, the cavity $0.13 \pm 0.025 \times 0.13 \pm 0.025$ mm in size is identified with confidence, when Lamb waves $a_0$ are excited in the shell. Wavelet-analysis and precision digital filters with a small increment of 1 MHz for frequency and of 10 ns for time allowed great informative value of the wave signal to be achieved.

References
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