ABSTRACT

Reliable ultrasonic inspections require a good understanding of the beam’s behaviour within the inspected material. Among the physical parameters characterising the interaction of the beam with its supporting medium, ultrasonic attenuation is important because it limits the volume of the system that should be inspected, and is an input parameter for mathematical models, which play an increasingly important role in non-destructive testing by allowing computer simulations. In this study the predominantly scattering-induced longitudinal wave attenuation in RPV cladding is measured as a function of the propagation direction. The experimental data is obtained by an enhanced measurement technique, which requires mapping of the ultrasonic field transmitted through plane-parallel test pieces of different thicknesses. The high accuracy of the measurement technique has been previously demonstrated, and its superiority over conventional approaches is shown here once again.

INTRODUCTION

The modelling of ultrasonic wave propagation and beam-defect interactions in RPV cladding is demanding due to its anisotropic structure, and it requires good knowledge of the intrinsic ultrasonic wave attenuation in order to obtain acceptable simulation results. The aim of this paper is to provide experimental input data for mathematical models to simulate ultrasonic inspections of reactor pressure vessels with strip cladding. The measurement of the absolute ultrasonic wave attenuation is a particularly difficult task, and there is a lack of reliable data in the literature. Both a conventional and a more advanced experimental technique are applied to measure the attenuation of longitudinal waves.

TEST SPECIMENS

Figure 1 illustrates the clad block utilised in this study. It is made of 32 layers of 120 mm wide strips of 308L cladding deposited by means of an automated submerged arc welding process. The clad block is sliced in the xy-plane from 0 to 90 degrees at 10 degrees increments to prepare 100x100x20 mm3 parallel-sided plates. The direction of the columnar grains in the cladding almost coincides with the direction labelled z in Figure 1, but macro-structural examinations revealed that the grains are tilted by about 10 degrees towards the welding direction labelled y.
MEASUREMENT SYSTEM

A flat 0.5 inch diameter transducer operating at a nominal frequency of 2.25 MHz is used to generate an ultrasonic beam in water. As a receiver a needle-type hydrophone is used, which is connected to a three-axial motorised positioning stage for movements parallel to the transmitter face and in the direction normal to it. The emitted ultrasonic field of the transducer is mapped twice by means of the hydrophone. Firstly, without the sample in place, and then with the austenitic clad plate placed between transmitter and receiver. Each map of the beam consists of a matrix of 111x111 observation points. First neighbouring observation points are separated by a distance equal to the linear dimension of the hydrophone, which is 0.635 mm.

RESULTS

Two distinct data procedures are applied to process the raw data. The first procedure simulates a conventional technique commonly used to evaluate the ultrasonic attenuation. To this end, all the A-scans recorded by the hydrophone within the surface of the simulated receiver are integrated over the transducer’s surface in the time domain. It is assumed that the fictitious transducer has the same area and the same axis as the transmitter. Subsequently, the integrated A-scan is Fourier-transformed into the angular frequency domain to obtain the spectrum of the signal.

The longitudinal wave attenuation coefficient at 2.05 MHz obtained by means of the simulated through-transmission technique is illustrated in Figure 2. Normal incidence transmission coefficients that account for the energy loss due to the beam transmission through the solid-water and water-solid interfaces are incorporated in the data processing as well as a well-known procedure based on the work of Rogers and Van Buren(2) to correct losses due to diffraction.

![Figure 1: Longitudinal wave attenuation coefficient in strip cladding at 2.05 MHz obtained by means of the simulated conventional approach.](image-url)

The second data processing procedure applied to the raw data is the so-called energy approach. Each A-scan acquired by the hydrophone is Fourier-transformed into the angular frequency domain to obtain the spectrum of the incident and transmitted signals at each observation point. The transformation yields a frequency-dependent, complex field, which can be further represented in terms of plane waves to obtain the corresponding two-dimensional spectra in the Fourier space domain. A simple analysis of the propagation of a plane wave through an attenuating plate of thickness $d$ leads to the following relationship between the attenuation coefficient and the energies carried by the incident and the transmitted beam

$$
\alpha_{\text{energy}}(\omega) = \frac{10}{d} \log \left( \frac{E_i(\omega)}{E_r(\omega)} \right).
$$

(1)
where \( \omega \) is the angular frequency and \( d \) is the thickness of the plate. The subscripts “in” and “tr” indicate the incident and transmitted signals, respectively. A comprehensive review of the energy approach is given in reference 3. The longitudinal wave attenuation coefficient obtained by using Equations 1 is illustrated in Figure 2.

The longitudinal wave attenuation coefficient obtained by using Equations 1 is illustrated in Figure 2.

![Figure 2 - Longitudinal wave attenuation coefficient in strip cladding at 2.05 MHz obtained by means of the energy approach.](image)

### CONCLUSIONS

The attenuation coefficient of a beam of longitudinal plane waves has been measured as a function of the grain orientation. Contrary to the behaviour of data obtained by means of the conventional approach that of the data obtained by means of the so-called energy approach agrees qualitatively with theoretical predictions. The energy approach requires more effort to evaluate the intrinsic attenuation of the investigated material from the raw data, but in return it eliminates the need for data corrections based on oversimplifying assumptions. More accurate experimental data is now available to simulate ultrasonic inspections of reactor pressure vessels with strip cladding.

### REFERENCES

