Analysis of Propagation and Radiation of A_0-mode Lamb Wave in a Layered Waveguide Plate by FEM Simulations

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1. Introduction

In-vessel structures of a sodium-cooled fast reactor (SFR) are submerged in opaque liquid sodium in the reactor vessel. The ultrasonic inspection techniques should be applied for observing the in-vessel structures under hot liquid sodium. Ultrasonic sensors such as immersion sensors and rod-type waveguide sensors have developed in order to apply under-sodium viewing of the in-vessel structures of SFR [1, 2]. Recently the novel plate-type ultrasonic waveguide sensor has been developed for the versatile application of under-sodium viewing in SFR [3].

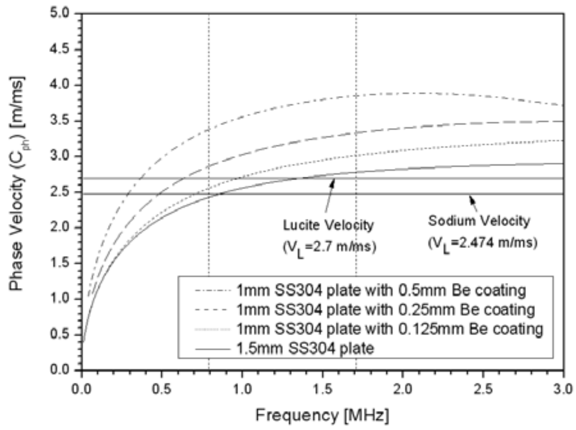
In previous studies, to improve the performance of the ultrasonic waveguide sensor module in the under-sodium application, the dispersion effect due to the 10 m long distance propagation of the A0-mode Lamb wave should be minimized and the longitudinal leaky wave in liquid sodium should be generated within the range of the effective radiation angle. A new concept of ultrasonic waveguide sensors with a layered-structured plate is suggested for the non-dispersive propagation of A0-mode Lamb wave in an ultrasonic waveguide sensor and the effective generation of a leaky wave in liquid sodium.[4]

In this work, the propagation and radiation of the leaky Lamb wave in the waveguide sensor coated with Beryllium has been performed by FEM simulations.

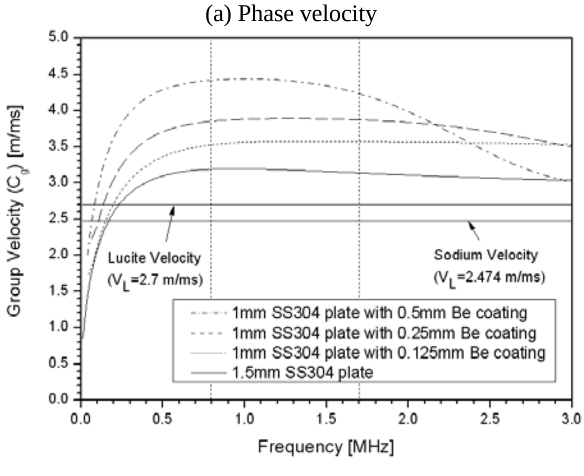
3. Ultrasonic Waveguide Sensor with a Layered-Structured Plate

For the performance enhancement of a 10 m long ultrasonic waveguide sensor in a sodium environment, the waveguide sensor formed of an SS304 stainless steel plate provided with beryllium (Be) coating layers is suggested. Figures 3 (a) and 3 (b) illustrate the dispersion curves of phase (C_{ph}) and group velocities (C_g) of the A_0-mode Lamb wave propagated through the waveguide provided with the Be coating layer. The beryllium (Be) is a material, in which the ultrasonic velocity is fastest among materials that exist in nature. The longitudinal wave velocities of the beryllium (Be) are 12.89 m/ms. The longitudinal wave velocity of the beryllium (Be) is twice as fast as the longitudinal velocity (5.79 m/ms) of an SS304 stainless steel plate.

The ultrasonic beam of a leaky longitudinal wave could be radiated through the radiation face of the waveguide sensor in a liquid sodium. The change range of the radiation beam angle of a leaky longitudinal wave is increased. Accordingly, the radiation beam steering function of the ultrasonic waveguide sensor device could be normally operated. The phase velocity of the A_0-mode Lamb wave propagated through the waveguide provided with the beryllium coating layer is faster than that of the longitudinal wave velocity (2.7 m/ms) of the Lucite wedge. Accordingly, it is possible to use the wedge made of a solid, which can be stably used for a long operation time under a high-temperature environment. Particularly, the waveguides provided with the beryllium coating layers have a characteristic in which the group velocity of the A_0-mode Lamb wave is very constant in the frequency range (0.8 to 1.7 MHz), thereby reducing the waveform distortion due to the long-distance propagation of more than 10 m [4].



(a) Phase velocity



(b) Group velocity

Fig. 3. Dispersion curves of the A_0-mode Lamb wave of Be-coated SS304 plates in ultrasonic waveguide sensor.

3. FEM Simulation

The common FEM program ANSYS and LS-Dyna are used in this numerical simulation. For simulation of the propagation and radiation of an A_0-mode Lamb wave in an ultrasonic waveguide sensor, a 1.5 mm thick and 400mm long SS304 plate double coated Be at both face, as show in Fig 4. The coating layer has 0.125mm or 0.25mm thick. The Solid164 element is used for the explicit pseudo 3-D modeling of solid structures. An excitation force in the xy-direction with the time dependence $F(t) = A\sin(2\pi \cdot t)$ for four periods (t<4/f) was applied to the excitation surface of wedge model.

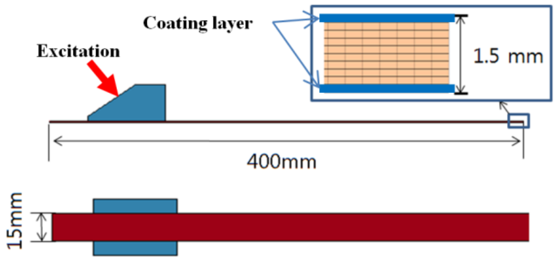


Fig. 4. The dimensions of simulation model.

A transient (time dependent) analysis was performed using a step size of 1/10f. The mesh sizes of the simulations were chosen to give a maximum element size of 0.05 mm and total element number was 1,348,000. Material parameters were chosen as appropriate for the SUS304 plate and Be as Table 1.

Table 1. Material parameters of waveguide sensor

Parameters / Material	Young's Modulus[GPa]	Density [kg/m^3]	Sound Velocity[m/s]
SUS304	210.0	7800	5189
Beryllium	309.18	1870	12858

4. Simulation results

Fig. 5 shows the numerical calculation results of the propagation of the A_0-mode Lamb wave in the SS304 plate at the various transient times in the case of the 1MHz frequency excitation.

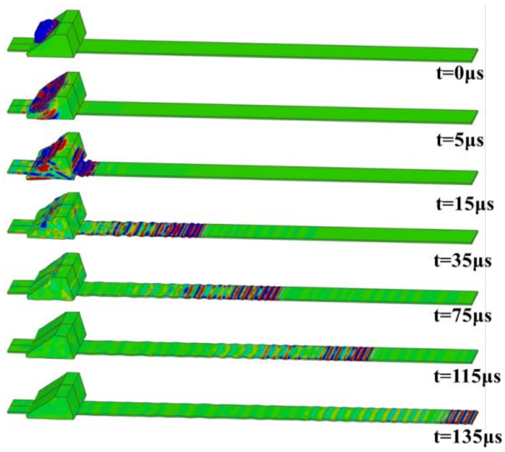


Fig. 5. Simulation results of the propagation and radiation of in the ultrasonic waveguide coatless sensor(SS304 1.5t).

Fig. 6 shows the wave propagation of coated plate sensor at 120 µsec. we can know the fastest propagation speed of the coated sensors. This simulation results show a good agreement with the previous study [4].

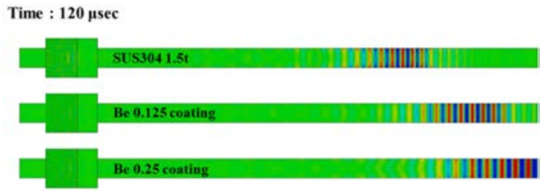
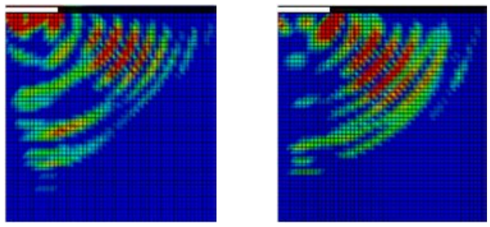


Fig. 6. Simulation results of the propagation and radiation of in the ultrasonic waveguide coated sensor at 120 µsec.

Fig. 7 shows the simulation results of the radiation in a coatless sensor and a coated sensor. The results are a vertical beam in an ultrasonic waveguide sensor submersed in water. The radiation angle of SS304 plate sensor(a) was about 60 degree and the radiation angle of the coated sensor(b) was about 40 degree. Based on this simulation results, we found out that the radiation angle of the coated sensor smaller than the radiation angle of coatless sensor.



(a) SS304 plate sensor (b) Coated sensor with Be

Fig. 7. Simulation results of radiation of a coatless sensor and coated sensor in an ultrasonic waveguide sensor submersed in water.

4. Conclusion

The radiation angle of vertical beam of ultrasonic waveguide sensors have been investigated by FEM simulation of the beam profile from the plate coating. Based on the results from this simulation, coated sensor with Be showed smaller radiation angle than coatless sensor. And this result shows the radiation angle of waveguide sensor changed by the coating.

In the future work, we will verify this simulation results with experiment and correlation between coating and dispersion.

ACKNOWLEDGEMENT

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