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Measurements of Ultrasonic Surface Wave Velocities in Silicon Crystals and its Comparison with FE Analysis

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1. Introduction

Guided wave inspection is one of the numerous methods that we can utilize when trying to determine the characteristics of a certain object or material. Unlike many of the other methods that exist, this one in particular is a non-destructive method that leaves the object intact and available for further use. These advantages make guided wave inspection a favorable method amongst others when checking for cracks in very sensitive facilities like nuclear power plants.

For this research project, we used a variety of methods to measure the velocity of the Rayleigh wave which is a surface wave that forms when a longitudinal wave component parallel to the surface and a transverse wave component normal to the surface combine, resulting in an elliptical motion of the particles. The first being an experimental method that uses a large aperture line focused transducer, the second being an FEM simulation program and the last being a theoretical approach using Christoffel’s equation.

2. Experimental methods

2.1 Theoretical Background

Using Christoffel's Equation, we could roughly calculate the speed of the longitudinal and transverse waves for the materials in question. And assuming that the materials we used were isotropic we could approximate the speed of the Rayleigh surface wave by using the ratio of the longitudinal and transverse wave speeds.

2.2 Experiment

By using a handmade large aperture line focused transducer[1)] we could generate and send signals through certain media and receive any reflected or scattered ones. We then analyzed the signals by using an oscilloscope and could separate the signals that were reflected off of the plate in question and the signals that resulted from leaky surface acoustic waves by comparing the amplitude of the signal and the time it took for the signal to return.

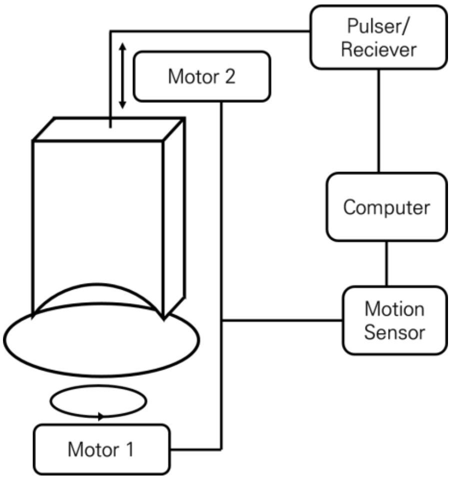

Fig. 1 Experiment setting

2.3 FEM Simulation

For this method, we used an FEM simulation program known as PzFlex that solves partial differential problems. By cutting up a simulated plate of similar size and composure as those of the ones used in the experiment in lines parallel to the x and y axes, we could produce meshes(small fragments of the plate). Then, by setting the frequency and the speed of the Rayleigh surface wave in the plate and by imbuing each of the meshes with a tensor value.

After the pre-processing part, we could move on to the analysis solver in which we implemented a force in a specific direction. Then, after being given a time limit and a specific timeskip, each of the individual meshes were used to detect changes in the plate.

3. Results and discussion

Fig. 2 is the graph of the time lapse amplitude based on the distance between the large aperture line focused transducer and the silicon plate. The graph shows the difference in the time between when the direct reflected wave and the leaky acoustic surface wave reach the transducer. **Fig. 3** was made by turning the silicon plate 360 degrees. From these results, we found the points

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that represent the leaky acoustic surface wa used it in **Fig. 6**.

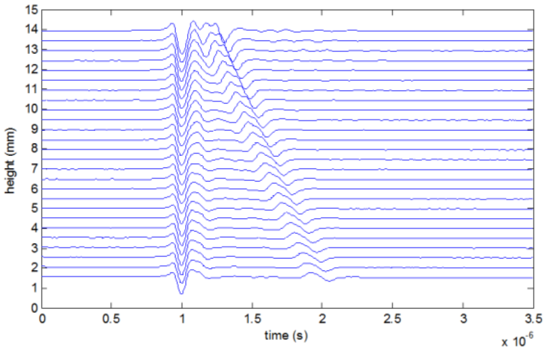


Fig. 2 Time Lapse Amplitude in Accordance to the Vertical Distance from the [100] Silicon Plate(z)

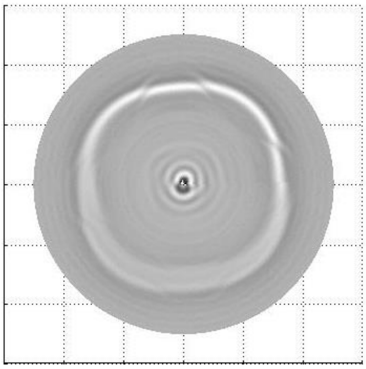
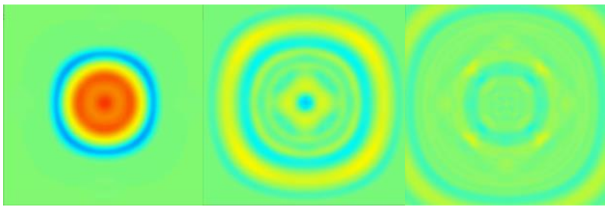


Fig. 3 Time Lapse for all Directions on a specified height for [100] Silicon



t = 1.996 μs t = 3.052 μs t = 3.991 μs

Fig. 4 FEM Simulation

In **Fig. 4**, we took several points in the plate to receive the wave form produced from the simulation. From comparing the time gap between peak points, we determined the velocity of Rayleigh wave.

For [100] silicon, we found that the data accumulated by the three methods were quite similar to one another. The + mark in **Fig. 6** represents the experimental values and the blue lines represent the theoretical values. As you can see, the circle shaped part of the theoretical values match up with the + mark, meaning that the two speeds are nearly the same for all directions. However, there seems to be another part that looks quite similar to that of a square in the theoretical values. This is the second velocity calculated by the second transverse wave velocity from Christoffel's equation.

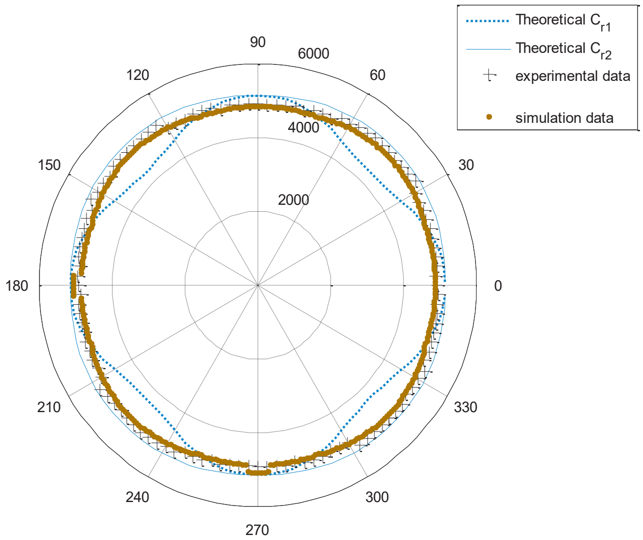


Fig. 6 Rayleigh wave's group velocities(m/s) in Si-100

4. Conclusions

From what we can see in the results, the theorized wave velocity, experimental velocity, and the simulated velocity are very similar in values. However, since we calculated the speed of the Rayleigh surface wave on Si-100 using a theory that was meant only for use in isotropic media, we will concentrate on finding a better method for approximating the speed of the leaky acoustic surface wave. Furthermore, for the remainder of our research project we will be focusing mainly on evaluating the data on Si-110, Si-111 and z-cut quartz using the FEM simulation program and the improvised theoretical velocities.

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