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Comparison of Longitudinal and Shear Waves in Detecting Defects in Metal by Transmission Method
透過法による金属内欠陥検出における縦波と横波の比較

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1. Introduction

Primary steel products such as billets may have internal defects during the casting process, which affect the quality of the final product. The non-destructive testing (NDT) using ultrasonic waves is one of the effective methods for detecting defects [1)]. In recent years, the ultrasonic transmission method, which uses transmitted waves to detect defects, has been investigated [2)] . The transmission method using the time-of-flight (ToF) of ultrasonic waves is used. When ultrasonic waves propagate the path where defects exist, the ToF increases due to the diffrection. The use of longitudinal ultrasonic waves have been investigated focusing on the fact that they have the highest velocity among ultrasonic waves propagating in steel.

On the other hand, in this paper, the use of shear ultrasonic waves is considered for NDT using transmission method. Different from the longitudinal wave, we can manipurate the direction of the shear wave, which has a potential to increase information of defects from multiple-direction signals. As a preliminary step, this study investigates the performance of NDT using shear ultrasonic waves in terms of the defect detection performance simulation.

2. Simulation Condition

Figure 1 shows the simulation condition. In this simulation, we use finite-difference-time-domain (FDTD) method. The testing billet is assumed to be a duralumin (A2017), whose density is 2,730 kg/m³, longitudinal wave velocity is 6,206 m/s, and shear wave velocity is 3,126 m/s. The size of the billet is 100×100 (mm²). The mesh size is 0.1 mm, the time step is 11.4 ns, and a circular defect with a diameter of d = 2 mm is placed of $(x, y) = (50, 50)$. The transmitter and receiver size is a = 10 mm. The linear scanning method is used as the measurement method [3)]. In the linear scanning method, the transmitters and receivers are placed face-to-fac. Scan interval width is Δl = 0.5 mm, and the number of measurement points is 201 points.

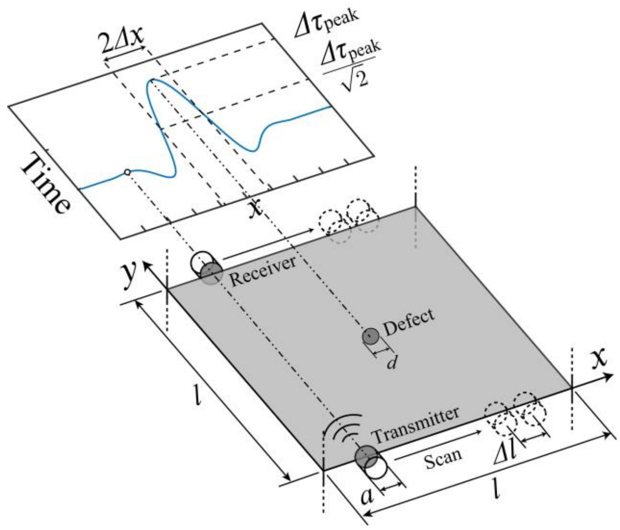

Fig. 1 Simulation Condition.

Since the minimum wavelength that can be calculated by the FDTD method is about 10 times of the mesh size [4)], the range of wavelengths of longitudinal and shear waves λ was set to be 1 to 10 mm, normalized to a range of 0.5 to 5 times longer than the defect size of d, the signal is a burst signal hang 5 or 10 waves with the Hann window. The direction of vibration of the shear wave is transmitted to in the x direction of the measurement plane.

In simulation, $\Delta\tau$ (the deviation of the ToF at the measurement point x) calculated from the equation (1) and (2).

$$R_{mr}(\tau) = \int_{-T}^{T} m(t) r(t-\tau) dt , \qquad (1)$$

$$\Delta\tau = \arg\max_{\tau}[R_{mr}(\tau)] - \arg\max_{\tau}[R_{rr}(\tau)] \quad , (2)$$

$m(t)$ is a received waveform at the measurement plane with defect, and $r(t)$ is a received waveform at the measurement plane with

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no defect. T is the each measurement time. $R_{mr}(\tau)$ is the cross-correlation function between $m(t)$ and $r(t)$, and $R_{rr}(\tau)$ is the cross-correlation function of $r(t)$. $\Delta\tau$ is calculated from the difference between the peak position of $R_{mr}(\tau)$ and that $R_{rr}(\tau)$.

In Fig.1 $\Delta\tau_{peak}$ is the value of $\Delta\tau$ at the measurement point with the defect. Furthermore, Δx is the distance from x_{defect} to x where $\Delta\tau$ becomes the value of $\Delta\tau_{peak}/\sqrt{2}$, which represents the half width at half maximum of $\Delta\tau$.

3. Simulation Result

Figure 2 shows the simulation results. Fig. 2(a) shows the value of $\Delta\tau$ for x_{defect} , $\Delta\tau_{peak}$. As with longitudinal and transverse waves, $\Delta\tau_{peak}$ increased as the wavelength became longer. Because the propagation speed of the shear wave is slower than that of the longitudinal wave, it takes longer time for the shear wave to arrive at the receiver for the same path difference so the shear waves $\Delta\tau_{peak}$ is higher than the longitudinal waves one.

Fig. 2(b) shows the value of Δx for each wavelength. Similar to (a), Δx increases as the wavelength becomes longer. However, the values of Δx for longitudinal and shear waves are not significantly different. This is because when the wavelength is the same, the directivity angle of the transmitter is same, so the reflection from the defect, the direct wave, and the diffraction by the defect will be the same.

Fig. 2(c) is a graph of the evaluation function of $\Delta\tau_{peak}/\Delta x$ newly created from the above two parameters. As shown in Fig. 2(a) and (b), the longer the wavelength, the higher the ToF, but the slower the change of ToF, and thus the lower the accuracy of detection. On the other hand, the shorter the wavelength, the lower the ToF and the weaker the sensitivity to noise. Therefore, the reason for creating this function was to find the best value of wavelength for defect detection between the two trade-off parameters. As a result, the evaluation values of longitudinal waves increased between 2.0 mm and 3.2 mm, or from 1.9 MHz to about 3.1 MHz in frequency, and shear waves increased between 1.4 mm and 2.4 mm, or from about 1.3 MHz to about 1.9 MHz in frequency.

4. Conclusion

In this study, we investigated the use of shear waves in comparing with longitudinal waves in transmission ultrasonic testing using ToF. The change in ToF, the width of the change, and their functions were compared for each wavelength, and

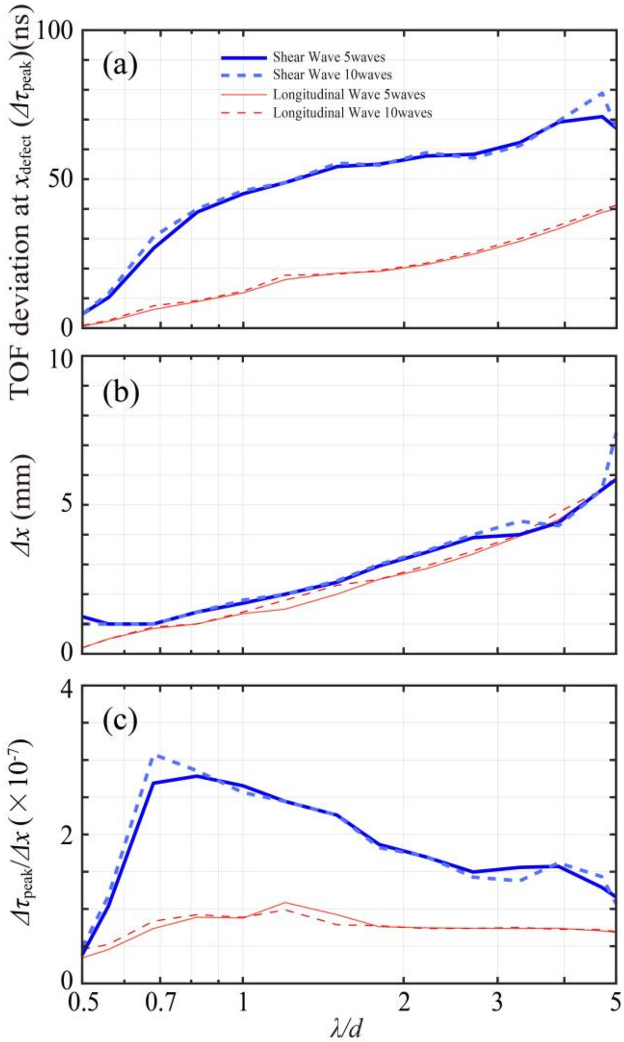

Fig. 2 Simulation result for each λ/d, (a) deviation value of ToF at x_{defect} ($\Delta\tau_{peak}$).(b) width of ToF Δx. (c) value of $\Delta\tau_{\mathrm{peak}}/\Delta x$.

the results showed that the shear wave is good to detect because the propagation time difference is larger, and the value of evaluation function of the parameter is higher than that of longitudinal. The subject of future research will be to investigate the change in ToF when we manipurate the direction of the shear wave. In this study, only the wavelength was considered. It is necessary to consider the opening diameter, the location of the defect, and the shape of the defect, which will be the subject of future research.

References

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