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Numerical simulation of the effects of cracks in solid on transmission characteristics of longitudinal and shear waves

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1. Introduction

Billets, the primary product of steel, may develop cavity defects during casting. Processing in this state causes cracking, which adversely affects the safety of the final product. Therefore, nondestructive inspection at the billet stage is essential. Ultrasonic testing is used to detect defects inside the billet. In recent years, studies have been conducted to detect internal defects using the transmission method[1)], which utilizes the propagation time of ultrasonic waves. When ultrasonic waves propagate in a solid and there is no defect in the propagation path, the first direct wave is received. On the other hand, if there is a defect in the propagation path, diffraction occurs near the defect and the propagation distance increases. Therefore, the apparent time-of-flight (TOF) increases. This is the basis for detecting the presence of defects. However, these studies were aimed at determining the presence or absence of defects and did not focus on estimating the defect shape[2)]. Knowing the direction of defects in addition to their presence would improve the manufacturing process.

In this paper, the effects of cracks in solids on the propagation characteristics of longitudinal and shear ultrasonic waves are investigated by numerical simulation.

2. Numerical simulation condition

Figure 1 shows the numerical simulation conditions. The Finite-Difference Time-Domain (FDTD) method was used in this simulation. The test billet was 100 x 100 (mm^2) steel with a density of 7700 kg/m^3, longitudinal wave velocity of 5950 m/s, and shear wave velocity of 3240 m/s. The mesh size was 0.1 mm, the mesh space was 1001 x 1001, and the time discrete width was 11.9 ns. The billet surface and defects were assumed to be free boundaries with zero stress. The transmitted signal was a 0.5 MHz sine burst wave with a Hann window. The crack was reproduced as an ellipse with a major axis of 2 mm and a minor axis of 0.1 mm. In this simulation, the position of the transmitter/receiver and the location of the crack were varied in two different patterns. Case 1 is the case where the 2 mm transmitter is placed in the upper center of the billet, the receiver is placed at all points in the lower part, and the crack is placed in the center of the billet. In case 2, the linear scanning method was used as the measurement method.[3)] 20 mm transmitter and

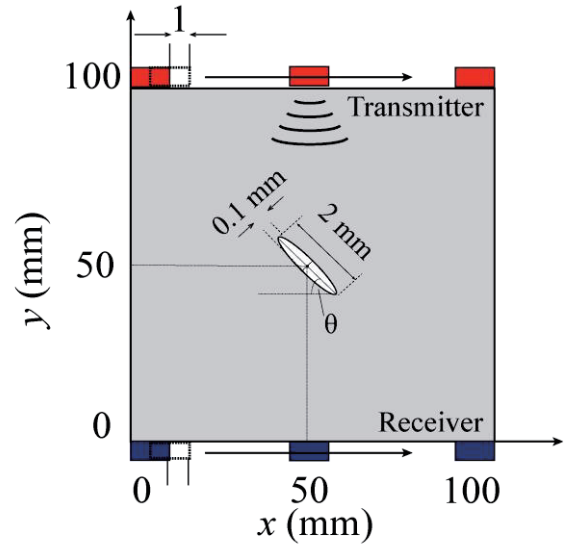

Fig. 1 Simulation condition

receiver was placed opposite each other at the top and bottom of the billet, each with a scanning interval of 1 mm, and 99 points were measured. [2)].

3.Simulation results

Figure 2(a) and Figure 2(b) show the simulation results for Case 1. Figure 2(a) shows the difference in the time variation of the horizontal particle velocity at a certain position when longitudinal ultrasonic waves are injected into both a crack with a crack at $\theta = 0$ deg and a billet without a crack. The horizontal axis is the receiving position and the vertical axis is the elapsed time. At x = 50mm, the bottom of the crack, no change in horizontal particle velocity is observed. This suggests that no mode conversion from longitudinal to shear waves has occurred. Therefore, the crack is considered to be parallel to the transmitter and receiver. Figure 2(b) shows the difference in the time variation of the horizontal particle velocity at a certain position when

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longitudinal ultrasonic waves are injected into both a crack with a crack at $\theta = 45$ deg and a billet without a crack. The horizontal axis is the receiving position and the vertical axis is the elapsed time. The change in horizontal particle velocity can be observed at x = 50mm, the bottom of the crack. Furthermore, it can be seen that symmetry is lost. This suggests that mode conversion to shear waves is occurring. On the other hand, when shear ultrasonic waves are injected, it is difficult to observe the change in particle velocity due to mode conversion, and the effect of transverse waves is smaller than that of longitudinal waves. Therefore, by injecting longitudinal waves directly above the crack in the solid and observing the mode-converted transverse wave component, the direction of the crack can be seen to be oriented.

Figure 3 shows the apparent change in propagation time when longitudinal ultrasonic waves are injected by scanning the transmitter and receiver, respectively, in Case 2. The horizontal axis is the position of the transmitter and receiver. In Figures 3(a) and 3(b), the cracks are located at (x,y) = (31,51) and (51,51), respectively. x = 0,100 mm is not considered due to possible surface wave effects. When ultrasonic waves propagate a path where a crack exists, the apparent TOF increases due to diffusion[4]. Therefore, it can be seen that the crack exists at the point where the propagation time is the longest.

4. Conclusion

In this paper, the effect of cracks in solids on the propagation characteristics of longitudinal and shear ultrasonic waves is evaluated by numerical simulations. In the case of an inclined crack, the asymmetry of the signal was confirmed by observing the mode conversion of the longitudinal ultrasonic wave incident on the crack. Further validation at different angles and positions of the crack is needed to estimate the directional characteristics of the crack in more detail.

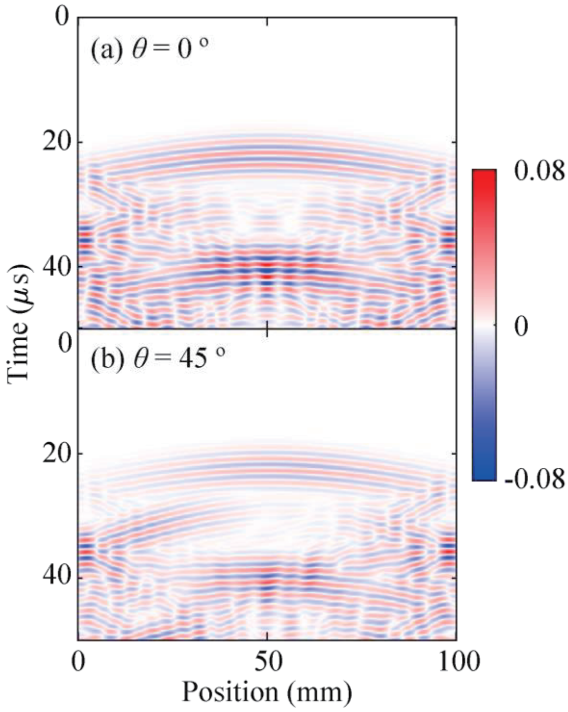

Fig.2 Differences in the distributions of horizontal vibrations between with and without crack. (a) $\theta = 0$ deg, (b) $\theta = 45$ deg.

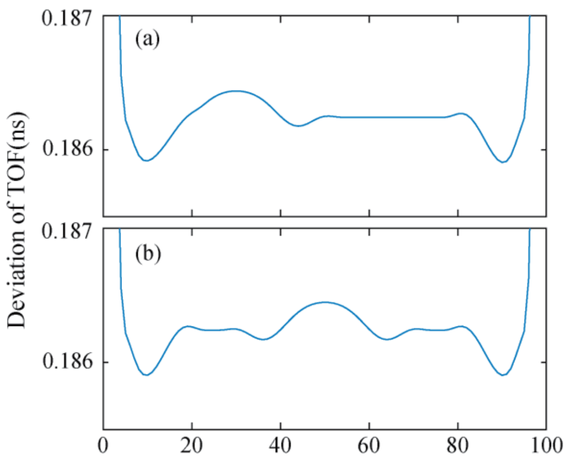

Fig.3 Deviation of apparent TOF

References

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