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Effect of mode conversion on defect detection in billet from profile of time-of-flight using ultrasonic transmission method
モード変換が透過超音波伝搬時間プロファイルに基づく角鋼片内部欠陥検出に及ぼす影響

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1. Introduction

We have proposed defect detection and size estimation method in billet from profile of time-of-flight (TOF) using ultrasonic transmission method with linear scanning.[1)] In this method, defects are detected by deviation of TOF ($\Delta\tau$) of longitudinal wave caused by diffraction at defects. A measurement of a cross-section in a billet is performed by linear scanning as shown in **Fig. 1**, and defect detection is performed from profile of TOF, which is $\Delta\tau$ at each measurement point. To evaluate the validity of this method, wave-equation finite-difference time-domain (WE-FDTD) method for scalar wave field was employed for wave propagation simulation. In the simulation, only longitudinal waves were considered assuming that mode conversions and other than longitudinal waves could be neglected because the fastest waves in received signals are longitudinal waves. As a result, it was found that defect can be detected and defect size can be estimated by measured $\Delta\tau$ using the relationship between the defect size and $\Delta\tau$. However, the relationship should be prepared in advance of measurement and it is difficult to obtain the relationship by experiment because of difficulty of making various specimens. Although the results of simulations and experiments in our previous papers are roughly agree with each other, there are some errors in $\Delta\tau$.[2)] The errors make it difficult to estimate a defect size if the relationship between defect size and $\Delta\tau$ is obtained by the simulation. The errors are possibly caused by the assumption of longitudinal wave field. In actual situation, the existence of shear component caused by mode conversions on defect surface may not be able to be neglected.

In this paper, effect of mode conversion on proposed method is evaluated by elastic wave fields simulations.

2. Principle of defect detection

Figure 1 shows a schematic view of defect detection by the proposed method. An ultrasonic signal is projected to a billet and received at opposite side. If there is a defect on the ultrasonic propagation path, TOF deviates by $\Delta\tau$. The deviation $\Delta\tau$ is obtained by calculating the cross-correlation function between $m(t)$ and $r(t)$. $m(t)$ and $r(t)$ are measured at measurement plane and reference plane with no defects, respectively. Each cross section is measured by linear scanning of a transmitter-receiver pair, so that profile of TOF $\Delta\tau(x)$ is acquired. From this profile of TOF, defect detection and defect size estimation are performed.

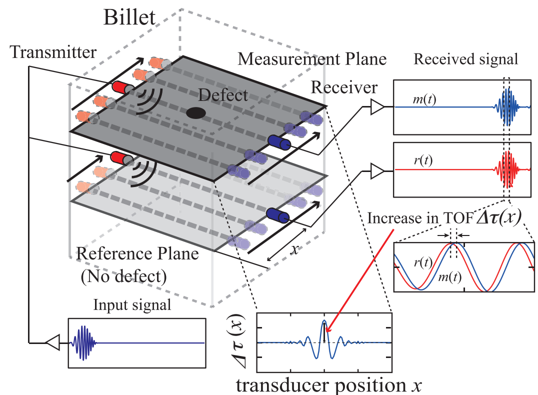

Fig. 1 Outline of defect detection by ultrasonic transmission method with linear scanning.[1)]

3. Numerical simulation

To evaluate the effect of mode conversion on proposed method, two simulation methods are employed and the results are compared. One is FDTD method for scalar wave and the other is for elastic wave fields, which contains shear wave component.[3)] **Figure 2** shows the simulation condition. Tested billet is assumed to be steel which has cross section of 100×100 (mm^2) with mesh size of 0.1 mm, density is 7700 kg/m^3, and the velocities of longitudinal and shear waves are 5950 and 3240 (m/s), respectively. The surface and defect of a billet was assumed to be a free boundary, in which stress is zero. This condition causes the coupling between longitudinal and shear components, and results in mode conversion of elastic waves at the defect. The time step of simulation was 1.12 ns. Input signal is two up-chirp signals, whose frequency is f = 0.5-1.5 and 1.0-3.0

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(MHz) in the durations, 10, 5 μs, respectively. The defect with a diameter of D exists at (x, y) as shown is Fig. 2. The transducers with 6 mm aperture were located at (X, 0) and (X, 100).

Figure 3(a), (b) show the TOF profiles when defect was located at (x, y) = (50, 50). These results suggest that the effects of mode conversion are observed on $\Delta\tau(x)$ even if defect or transducers are not near the surface of billet. This means that longitudinal waves are affected by mode conversion even though longitudinal waves are the fastest in the elastic waves and shear waves are separable in time domain. When shear component is considered, $\Delta\tau$ becomes larger than that from longitudinal wave only simulation. In previous experiments and simulations that consider only longitudinal wave of TOF measurement, apparent sound velocity in experiments is lower than that in simulations. This suggests that consideration of shear component may compensate this difference.

Figure 4(a) shows the relationship between the defect size D and TOF deviation $\Delta\tau$ when defect is center of a cross section (50, 50) when transducers position X = 50. The deviation $\Delta\tau$ by elastic wave model is larger than that by scalar model. Figure 4(b), (c) shows the $\Delta\tau$ when a defect was located at (x, 50) or (50, y) and transducers position X is x or 50, respectively. As shown in Fig. 4(b), deviation of $\Delta\tau$ in elastic wave simulation is smaller than that in scalar wave simulation when defect position x changes. In contrast to this tendency, deviation of $\Delta\tau$ in elastic simulation is large.

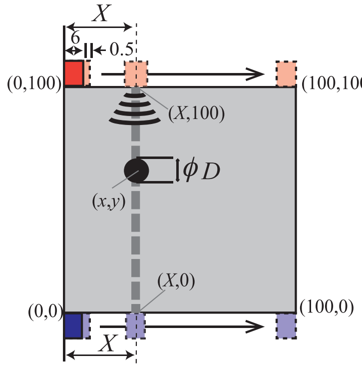

Fig. 2 Simulation condition

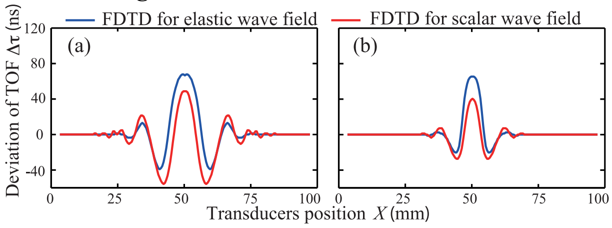

Fig. 3 TOF profiles at D = 5 and (x, y) = (50, 50): (a) f = 0.5-1.5 and (b) f = 1.0-3.0 MHz.

4. Conclusions

In this paper, the effect of mode conversion on proposed method is evaluated by elastic wave field simulation. TOF deviation increases when mode conversion is considered compare with considering only longitudinal waves. This will make simulations and defect size estimation more accurately.

References

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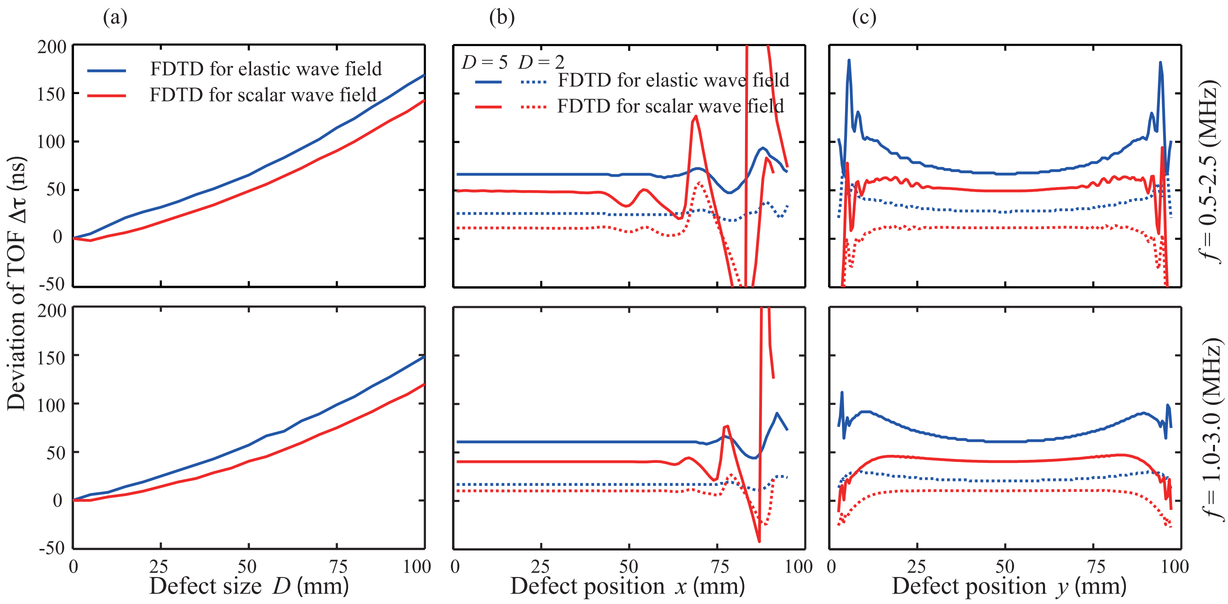

Fig. 4 Deviation of TOF when transducers position X = x and f = 0.5-1.5, 1.0-3.0 MHz: (a) (x, y) = (50, 50), (b) (x, y) = (x, 50) and D = 2,5 mm, and (c) (x, y) = (50, y) and D = 2.5 mm.