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Acoustical Defect Reconstruction in Square Billet
超音波による角ビレット内部の欠陥再構成

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1. Introduction

Square billet in continuous casting may have defects due to remaining inclusions and contraction stress during cooling. Defects detection is important for quality improvement of the billet because the defects depress endurance strength. Ultrasonic nondestructive testing has efficiency as defects detection.[1-2] To detect the defects, the pulse echo method is mainly used.[3] However, attenuated echo may not be received, for the grain size of billet is large. In addition, the treatment of elastic waves and mode conversions caused by defects is so complicated as to separate the echo.

We proposed an alternative method to detect the defects using time of flight (TOF) of longitudinal waves.[4] Apparent sound velocities are reconstructed using the TOFs measured by the transmission method. The defects are visualized as decrease of apparent sound velocities because the TOFs increase due to diffraction at the defects. This method could save on the attenuation of ultrasonic waves because the propagation path of transmission method was smaller than that of reflection method. In addition, the mode conversions and the waves other than longitudinal waves could be neglected because first waves received were longitudinal waves. In addition, the defects could be detected wherever they were located. However, the diameter of transducers was fixed to 2 mm, and we did not make a study on the influence of its size

In this paper, the effect by the size of transducers is evaluated with experiment and calculation of defects detection.

2. Principles

2.1 TOF Measurement of longitudinal waves

Figure 1 shows the delay of TOF of longitudinal waves by the diffraction. Figure 1(a) shows the direct wave. An incident wave is diffracted by the defect in Fig. 1(b). The first wave received is not a direct wave but a diffracted wave when the defect is located on the propagation path. The TOF is equal to the time measured from the starting time to the cross-correlation peak between the input and received signals.[5] The TOF of diffracted wave is longer than that of direct wave. We detect the defect to utilize the delay of TOF because it contains the information leading to the defect.

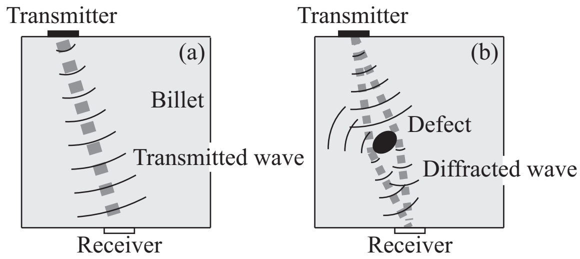

Fig. 1 Delay of TOF by the diffraction: (a) and (b) show the direct wave and the diffracted wave from the defect.

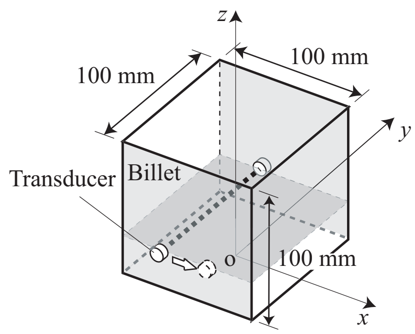

Fig. 2 Experimental system.

2.2 Defect reconstruction using the apparent sound velocity

The apparent sound velocity is reconstructed from the TOF of longitudinal waves. The apparent sound velocities of the defects part are lower than the surrounding area because the TOFs increase due to the diffraction at the defect. Therefore, the decrease of the apparent sound velocities makes it possible to detect the defects. Ultrasonic CT method is employed for the reconstruction.[6]

3. Experimental and calculation results

Figure 2 shows the experimental system. The billet is duralumin whose size is 100×100×100 mm^3. The sound velocity of the billet is about 6320 m/s. The origin is taken at the center of bottom face on the billet. Figure 3 shows the measurement area and the reconstructed images of the defects. Figure 3(a) shows the measurement area, which is the *x*–*y* plane

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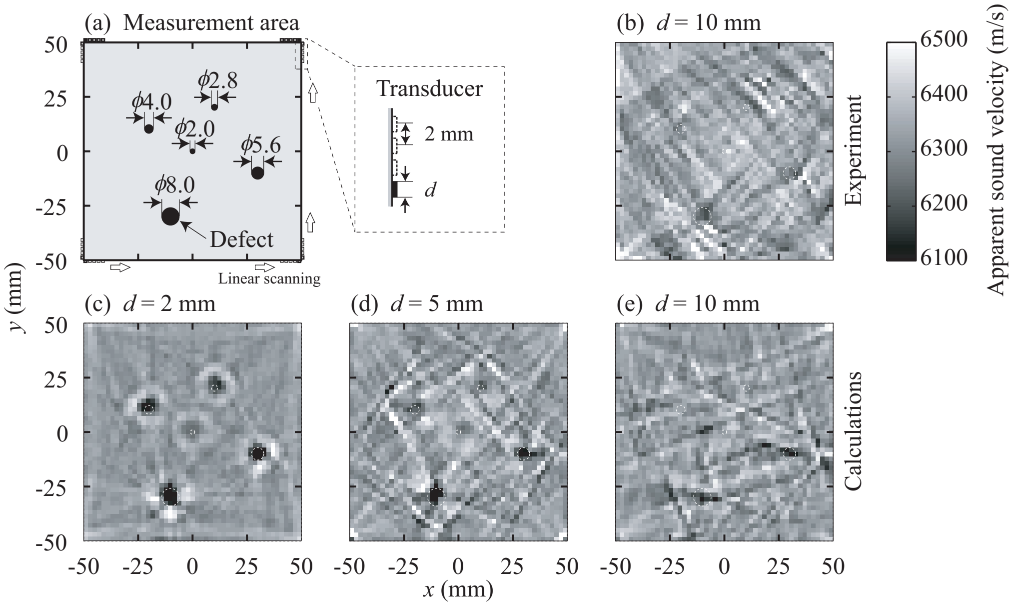

Fig. 3 Measurement area and reconstructed images of defects: (a) shows the measurement area which is the x–y plane at z = 70 mm; (b) shows the image for d = 10 mm from the experiment; (c)–(e) show the images for d = 2, 5, and 10 mm, respectively, from the calculations.

at z = 70 mm. The defects are located at (x, y) = (0, 0), (10, 20), (–20, 10), (30, –10), and (–10, –30) (mm). The diameters of defects are also 2.0, 2.8, 4.0, 5.6, and 8.0 mm, respectively. The transducers whose diameters are d mm are set on the billet, and scanned linearly at 2 mm steps. 50 measuring points are on a side. The number of TOF data measured is 15000, which is equal to the number subtracted combination number sharing side with transmitter and receiver from those of all transducers. The sampling frequency is 50 MHz. The input signals are chirp signals swept from 1 to 3 MHz for 5 μs. The conditions of the calculations are the same as the experiment, which is used as the reference. The calculation of the wave propagation uses the transmission-line matrix (TLM) method.[7)]

Figure 3(b) shows the image for d = 10 mm from the experiment. The gray scale indicates the apparent sound velocities. The defects could not be detected owing to the artifactual images, although the apparent sound velocities of defect whose diameter was 8.0 mm were slightly lower than that of surrounding. Figures 3(c)–3(e) show the images for d = 2, 5, and 10 mm, respectively, from the calculations. When d was 10 mm, the defect could not be detected as well as the experiment. The defects may be visible when d is less than 5 mm. In Fig. 3(d), the defects whose diameter was 2.0 mm could be detected although d was 5 mm. Therefore, the diffracted wave from the defect was received even though the transducers diameter was larger than the defects diameter. Comparing Fig. 3(c) and Fig. 3(d), the artifactual images have an effect on the defects detection as the transducers diameter is increased. We can think of two reasons. One is the directivity of transmitter, which gets wider as the diameter of transmitter gets smaller. The other is that received wave is integrated by the receiver diameter. The larger the receiver diameter, the larger the error of cross-correlation peak because we assume that waves are received at the center of receiver. Therefore, the diameter of transducer should be small, and the defect of 2.0 mm could be detected when transducers was less than 5 mm.

4. Conclusions

We studied the effect by transducer size with the experiment and calculation of defects detection. As a result, the transducers size affected the defects detection, and the proposed method could detect the defects of 2.0 mm when transducers size was less than 5 mm.

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