DEVELOPMENT OF A NON-CONTACTING STRESS MEASUREMENT SYSTEM DURING TENSILE TESTING USING THE ELECTROMAGNETIC ACOUSTIC TRANSDUCER FOR A LAMB WAVE

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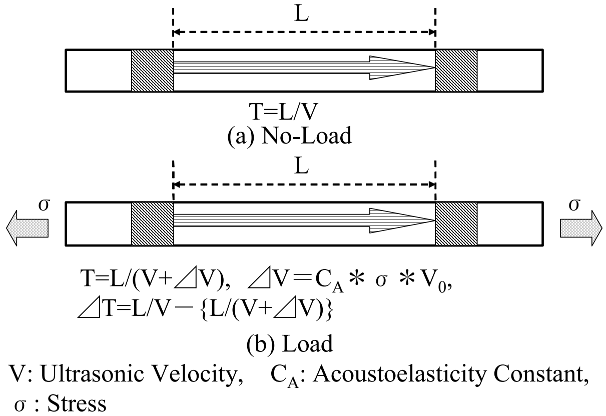
Abstract: In recent years, investigations into the changes in the microstructure during the processing of functional metal materials have been carried out by many researchers. Therefore, it is required that the change in the material characteristic during processing by a nondestructive evaluation method be evaluated. However, conventional technology has been restricted to a static material characteristic evaluation. For example, a strain gauge has the problem that it can influence the measurement conditions of the tensile test and can only evaluate the position at which the strain gauge is attached. We then tried to develop a non-contact stress measurement system for tensile testing using an EMAT with a Lamb wave. The EMAT measures the propagation time of a Lamb wave between the receiver and a transmitter during the tensile testing. The actual measurement system consists of 2 sets of EMATs. The interval between the transmitter and the receiver of the first set is 100mm and the interval between the lead lines of the meander sensor coil is 5mm. Another one is installed between the transmitter and the receiver of the former EMAT, and the interval between the transmitter and the receiver is 10mm, while the interval between the leads lines is 0.5mm, and can move in the direction of the load. The average stress of the entire piece can be measured by the former EMAT and the partial stress distribution can be measured by the latter one. In this presentation, the specifications of the measurement system and the evaluation results are reported.

Introduction: Conventionally, a destructive examination, like a tensile test or a bending test and a nondestructive examination using an ultrasonic wave method or electromagnetic wave have been carried out to develop several materials. In recent years, the steel material development producing a highly efficient process performance has been progressing. The evaluation of the internal organization change process at the time of processing has become very important for each research organization as a key technology for the evaluation of a set organization formation process and the valuation of the organization change process at the time of cooling and transformation. In connection with such a material development trend, the nondestructive evaluation technology in which a change of the material characterization in an in process can be followed at every moment is needed. However, a conventional nondestructive evaluation technology can only evaluate a material characterization with almost static states. We have therefore developed a system that can evaluate the stress distribution in a tensile specimen under a tensile test as the first step in place of the last purpose to evaluate the dynamic characterization of a steel material under processing examination.

Principle: Generally, the transit time of the ultrasonic wave which travels between the fixed distances is obtained by dividing the propagation distance by the ultrasonic wave velocity as shown in Fig.1 (a). However, when the compressive or tensile stress is applied to the material, the ultrasonic velocity changes slightly in proportion to the load stress and the propagation time also changes. It is generally called Acoustoelasticity law. Therefore, the load stress can be evaluated from the transit time change as shown in Fig.1 (b).

When carrying out a nondestructive evaluation using an ultrasonic transducer, a sensor needs to be contacted to the measurement specimen through a coupling medium. Since the velocity change by Acoustoelasticity law is very minute as shown in Fig.2, the thickness change of a coupling medium will influence the transit time measurement as an error factor. Furthermore, as a tensile specimen pulls during the tensile test, the distance between the transmitter and the receiver fixed to the specimen increases. This phenomenon becomes a large error factor over the transit time measurement. Moreover, a conventional ultrasonic sensor directly influences the mechanical test results, because it would load the test specimen itself. We assumed that a non-contact sensor could solve these problems



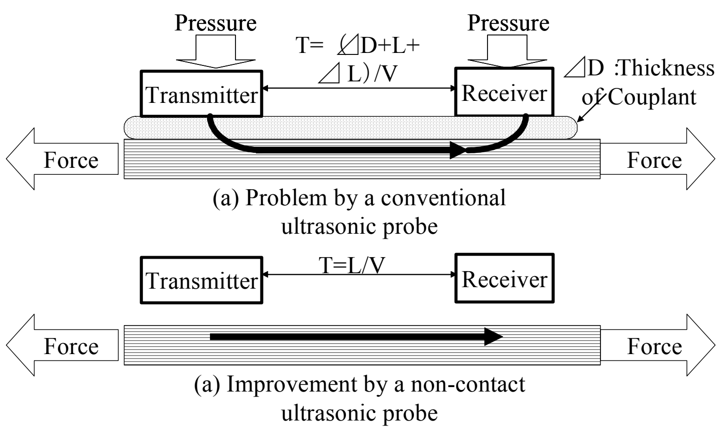


Fig.1 Principle of the measurement of the stress using ultrasonic wave

Fig.2 Feature of the developing system

Basic structure of the ultrasonic sensor: The basic structure of a transducer for the Lamb wave is shown in Fig.3. The transducer consists of an electromagnet and a pair of meandering sensor coils of which one is a transmitter and the other is a receiver. Although there are Lorenz force and a magnetostrictive effect for the drive force of an electromagnetic acoustic transducer (EMAT), we made the magnetostrictive type EMAT. The static magnetic field is applied to the specimen to become the largest change of the magnetostriction when the magnetic field changes. When the periodic dynamic magnetic field superimposes the static magnetic field, the largest change of the magnetostriction can be induced into the material. When the interval between the electrodes of the sensor coil is coincidence with the wavelength of the Lamb wave, it is converted into the Lamb wave. The velocity of the Lamb wave is calculated by the multiplied drive frequency and the wave length.

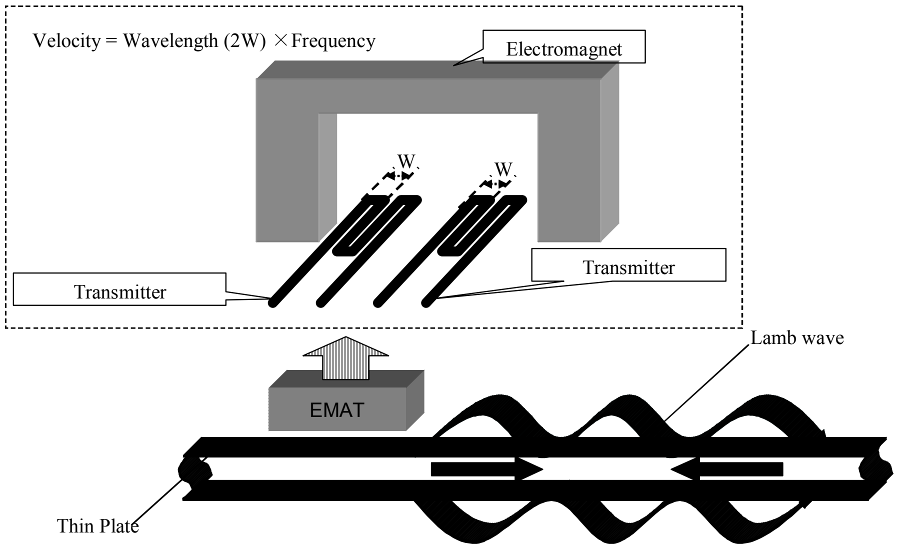


Fig.3 Basic structure of an EMAT for Lamb wave

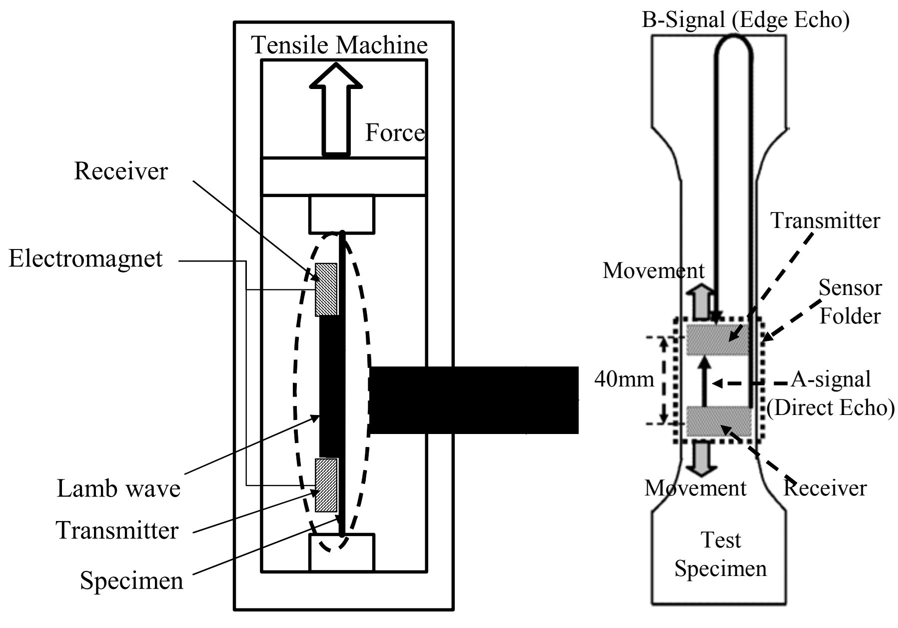
Stress Evaluation System: The outline of a trial measurement system is shown in Fig.4. Figure 4(a) shows the appearance of the entire experiment system. The system is composed of a portable type tensile machine, a tensile specimen and a sensor mounting system. The distance between the transmitter and the receiver is 30mm. Both sensors are arranged along the parallel to both poles of the electromagnet. The tensile machine can pull the tensile specimen to a maximum load 1000N. The transmitted signal to drive the EMAT is a 2 cycle burst type pulse with a drive frequency of 0.2MHz to 2MHz. The amplifier has the ability to amplify the signal with a frequency range from 2 KHz to 20MHz and the amplification magnitude is 60dB. The tensile specimen has a 0.25mm thickness, a 200mm maximum length and a 25mm width. As shown in Fig.4 (b), the direct ultrasonic wave (A-signal) arriving from the transmitter to the receiver and the reflected wave from the edge (B-signal) is observed. Although the propagation time evaluation of the A-signal was the main purpose, in order to see the influence of the elongation of the test piece, the B-signal was also evaluated. Equation (1) indicates the change of the transit time by A-signal. Equation (2) indicates the change of the transit time by the B-signal. Equation (3) indicates the elongation of L_2 in the tensile specimen

$$\Delta T_1 = \frac{L_1}{V_0} - \frac{L_1}{V_0 - \Delta V} \cong L_1 \times \Delta V = L_1 \times C_A \times V_0 \times \sigma \qquad (1)$$

$$\Delta T_2 = \frac{L_2}{V_0} - \frac{L_2 + \Delta L}{V_0 - \Delta V} \cong (L_2 + \Delta L) \times \Delta V = (L_2 + \Delta L) \times C_A \times V_0 \times \sigma \qquad (2)$$

$$L_2 = L_2 \times E \times \sigma \qquad (3)$$

L_1: Distance between the transmitter and the receiver
L_2: Distance between the transmitter, the edge and the receiver
ΔL: Elongation of L_2 in the tensile specimen
V_0: Velocity without the stress into the specimen
ΔV: Velocity change due to the stress
σ:Stress
E: Young elastic constant
C_A: Acoustoelasticity Constant



(a) Experimental System (b) Sensor System

Fig.4 Experimental system

Results: The interval between the leads of the meander sensor coil was changed from 10mm, which corresponds with the 250 KHz optimum drive frequency conditions, to 1.25mm, which corresponds with the 2MHz optimum drive frequency. We then tested if the A-signal was observable. The results are shown in Fig.5. As the interval becomes narrower, the dead zone becomes narrower. As a result, we could observe the A-signal using the sensor coil with a 1.25mm interval.

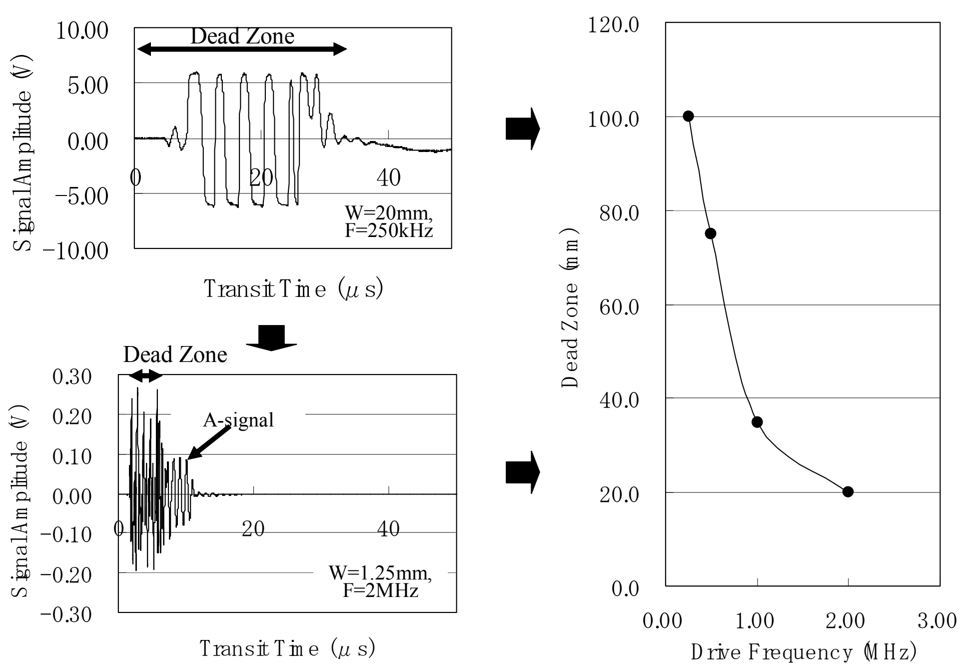
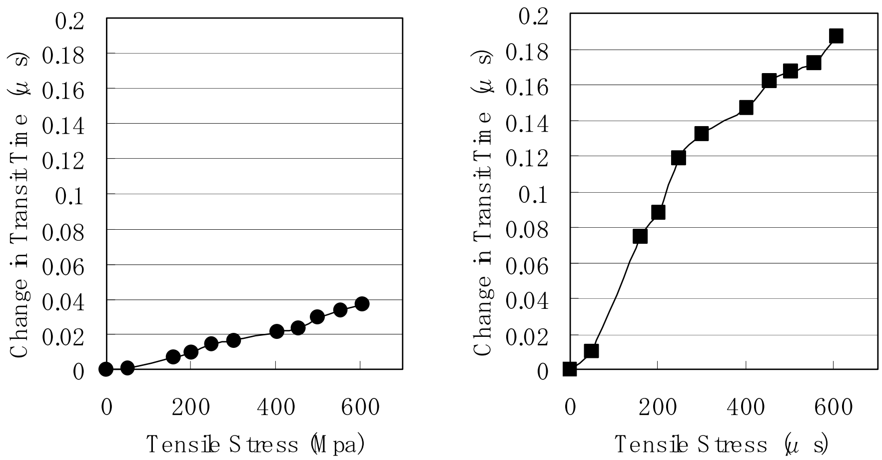


Fig.5 Experimental data

When the transmitter and the receiver were arranged in the center of the test specimen, the transit time change of A-signal and B-signal were shown in Fig.6. The elongation of the tensile specimen influences the transit time change by B-signal. Therefore, the transit time change by the B-signal is nearly 2 or 3 times larger than that by A-signal.



(a) A-signal (a) B-signal

Fig.6 change of transit time

Fig. 7 shows the converted results into the stress from the change of the transit time. The results by the A-signal nearly corresponded with the load stress, whose measurement accuracy was 27MHz of the standard deviation. In referenced to the B-signal, the converted stress value was 2 or 3 times' larger value than the real stress value. This result indicates that the influence of the contact type ultrasonic sensor is great and the stress could not be directly evaluated.

Fig.8 shows a change in the measured stress value at the conditions of the 300MPa and 500Mpa tensile stress, by moving the sensor along tensile direction. In the central part of the tensile piece, the measured value was almost identical. At the edge of the test piece, the measured stress value decreased. This result indicates that the sensor system could evaluate the stress distribution of the test piece.

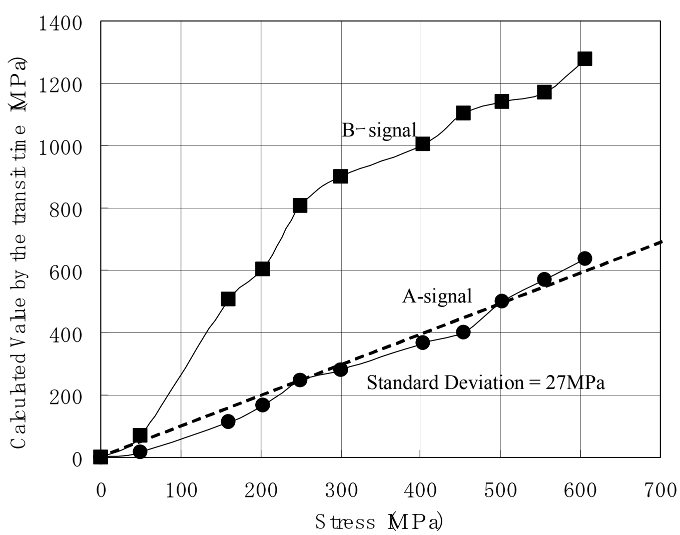


Fig.7 Stress measurement results at the center of the tensile specimen

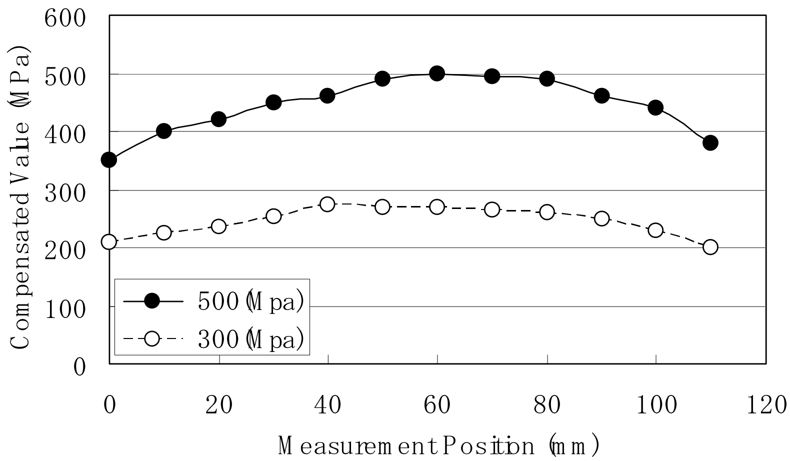


Fig.8 Stress measurement results along the tensile specimen

Conclusions: The stress evaluation system during tensile test using an EMAT was developed, the system, basically, could evaluate the stress distribution along the tensile direction of the tensile specimen. As a future improvement item, we must improve the measurement precision of the stress distribution and the position precision. Therefore, we would improve the transit time measurement method by the signal processing method and the EMAT with a frequency drive condition.

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