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Analysis of Non-linearity of The Weld Region in Carbon Steel Using a High Power Ultrasonic Transducer

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1. Introduction

The nonlinear ultrasonic technique has been considered as a potential nondestructive evaluation method for assessing material degradation. One of the typical phenomena of nonlinear interaction is that the waveform of the incident fundamental ultrasonic wave is distorted during propagation in a material such that it generates higher-order harmonic frequency components, in which the amplitudes of the harmonic components are dependent on the elastic nonlinearity of the material [1-3].

This distorted waveform in the time domain shows the unique frequency modulation characteristics in the frequency domain. Quantified parameter of ultrasonic non-linearity or non-linearity parameter, β is defined as the ratio of the second harmonic components to the square of the fundamental frequency components of received signals. The β can be used to evaluate the microscopic degradations, damages and cracking of materials [4, 5].

Because the amplitude of second harmonic signal is relatively small, it requires a method to get a meaningful and reliable signal quality of second harmonics. A high power ultrasonic transducer with a single crystal $LiNbO_3$ and a high power ultrasonic generator are used to get higher amplitude of second harmonic signals. High voltage waveforms in the frequency range of few MHz were acquired and the correctness of waveforms was verified. In order to compare the non-linearity parameter, β of the weld region, intrinsic non-linear parameter, β_{int} from the base materials also acquired. We have developed a technique to acquire a higher harmonic signal with a high power ultrasonic system. The technique can be a potential tool to diagnose the early stage of cracking or micro-cracking in the welds.

2. Methods and Results

2.1 System set up

The nonlinear properties in the materials are caused by the nonlinear stress-strain characteristics due to higher harmonic components of the materials. It is explained that the ultrasonic wave passing through the material and distortion of the received signal occurs and harmonic components are generated in addition to the initial incident wave frequency of the traveling wave. The magnitude of the higher harmonic component signal thus obtained is relatively small, thus the power of the incident wave must be increased.

A gate amplifier is used to amplify the voltage across the entire system and transmit the traveling wave. A 50 ohm load and an attenuator are applied to avoid overloading the system (Fig. 1).

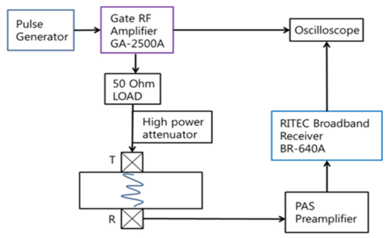

Fig 1. Schematic diagram of a high power ultrasonic pulser/receiver system.

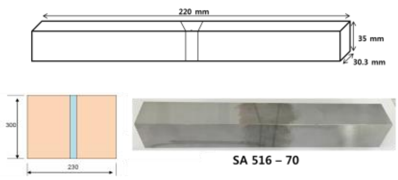

Fig 2. Dimensions of the welded specimen with base materials of SA 516.

The welded specimen with the base materials of SA 516 is shown in Fig. 2. In order to confirm the nonlinear characteristics of the weld and to compare the signal from the base material, the specimen was cut in half and the center was welded.

2.2 Single crystal $LiNbO_3$ transducer

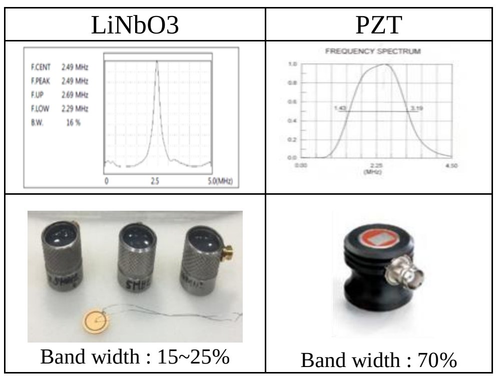

Fig 3. The bandwidth of conventional PZT transducer and single crystal $LiNbO_3$ transducer.

The second harmonic signals must be well distinguished in order to confirm the nonlinear characteristics of the material. However the magnitude of the signal in the case of the second harmonic signal is small, it is necessary to increase the excitation voltage. Conventional PZT transducers are designed to operate in the range up to ~400 V, and can be failed at a high voltage such as the range of 800~2,000 V. The non-linearity of the transducer itself is also manifested so that it is difficult to acquire a reliable data.

The single crystal, $LiNbO_3$ with a proper cut can be used for a high power ultrasonic transducer, because of stable operation at high voltages. We designed and fabricated a high power ultrasonic transducer with a single crystal $LiNbO_3$ (Fig. 3). The ultrasonic transducer shows bandwidth of 15~25% in the frequency domain. It can be compared to the bandwidth of 60~70% from the conventional PZT transducers.

2.3 Results

Figure 4 shows the signals in the frequency domain obtained from the weld region and base materials. The input voltages of 750 V and 1,000 V were applied to the conventional PZT transducers respectively. It can be seen that the second harmonics (signals around the frequency of 10 MHz) were appeared from the base materials, however, no meaningful second harmonics from the weld region.

It was difficult to measure the amplitude of second harmonics from weld region and the nonlinear parameter could not be determined.

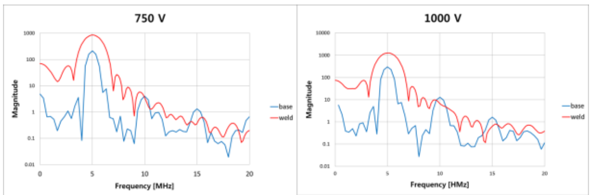

Fig 4. Comparison of the FFT signal from the base material and weld region using conventional PZT transducer.

Figure 5 shows the signals in the frequency domain obtained from the weld region and base materials. The input voltage of 770 V and 1,550 V were applied to the high power single crystal $LiNbO_3$ transducers respectively. It can be seen that the second harmonics (signals around the frequency of 10 MHz) were appeared from the base materials and weld region.

It was possible to measure the amplitude of second harmonics from weld region and the nonlinear parameter could be determined. It could be seen that the method of adjusting the transducer bandwidth advantageously performed the analysis of the frequency characteristics.

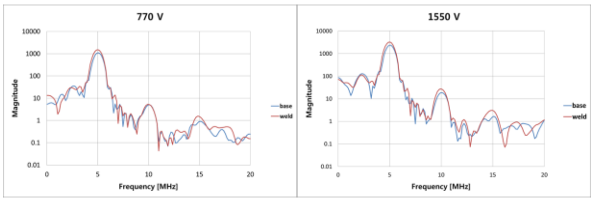

Fig 5. Comparison of the FFT signal from the base material and weld region using a high power ultrasonic transducer with the $LiNbO_3$ single crystal.

3. Conclusions

We have made a high power ultrasonic transducer using $LiNbO_3$ single crystal and compared ultrasonic nonlinear response with conventional PZT transducer. The second harmonic components in the frequency domain were clearly detected with the single crystal $LiNbO_3$ transducers, but not with the conventional PZT transducers. The frequency analysis method using the high power $LiNbO_3$ transducers could be a promising technique to distinguish the weld region from the base materials. The technique can be useful to diagnose the early stage of materials degradation and detection of the micro-crack or the closed cracks in the welds.

ACKNOWLEDGEMENTS

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