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Nonlinear Acoustic Characteristics for Micro-Crack Detection in a SA508 Gr. B Reactor Pressure Vessel Material

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1. Introduction

Early detection of micro-cracks is an important issue for the extension of structural life and increases of material reliability. Because of the detectability limit of current nondestructive evaluation methods, most of the cracks are detected after a half of the structural life has passed. Recently, the nonlinear acoustic effect is applied to characterize or diagnose the cracks and damages in materials.

Micro-scale damages can produce a nonlinear stress-strain relationship and this nonlinearity can be measured by increasing the dynamic strain i.e. excitation amplitude in a Resonant Ultrasound Spectroscopy (RUS) device. Nonlinear Resonant Ultrasound Spectroscopy (NRUS) has been applied for micro-damage assessment in the human bone [1]. The more damage, the larger the level of nonlinearity and it can be used for the diagnosis of micro-cracks [2]. On the contrary, undamaged or intact material shows essentially linear behavior in their resonance response.

This study conducted an investigation of a nonlinear RUS (NRUS) method for a diagnosis of micro-cracks. A shift of resonance frequency and a normalized resonance pattern as a function of driving voltage or strain reflect the nonlinearity.

2. Methods and Results

2.1 Experimental Method

A standard 1/2T-1Compact Tension (CT) specimen with a dimension of 63.5 mm× 61 mm× 12.72 mm was fabricated with SA508-Gr.3 material. In order to fabricate a natural close crack, a fatigue test was carried out with an Instron universal test machine. The number of cycles of each step are N = 1000, 5000, 10000, 20000, 40000, and 60000 cycles with 10 Hz for each respective load.

The nonlinear acoustic response at each fatigue step was measured by using a fully digitized ultrasonic resonance system. The system can control the power amplifier for the generation of the required ultrasound with a sweep function for signal processing of the received signal. In order to shield the specimen from vibration, temperature change, and even air flow, the cracked CT specimen was suspended with loops of synthetic fiber, such as dental floss inside a double-wall chamber. The temperature inside the chamber was monitored with a thermocouple with a dummy specimen, shown in Fig. 1. The temperature variation was kept within ±0.1^{0}C during data acquisition. The frequency vs. normalized amplitude was measured at different driving voltage levels.

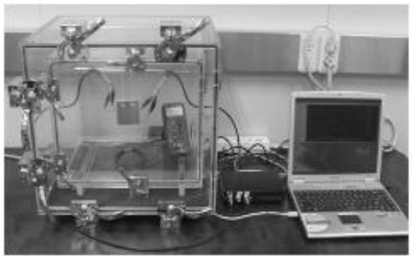


Fig. 1 Experimental setup and a chamber to maintain constant temperature and free of vibration.

2.2 Results and Discussion

The fatigue cracks were fabricated progressively at the different fatigue cycles. The relationship between the crack lengths and fatigue cycles were shown in Fig. 2, which can be consistent with Paris law [3]. An intact material shows no variation with the different driving voltage, which can show a linear elastic response, shown in previous study [3].

Fig. 3 shows a normalized resonance pattern of a cracked CT specimen with increasing excitation amplitude from 2 volt to 160 volt. At the very early stage of cracking, such as fatigue cycles of 1000 shown in Fig. 3(a), the normalized resonance pattern shows a small change as increasing excitation voltage. As the fatigue crack increases, a resonance frequency shift can be observed with an increase of excitation amplitudes, shown in Fig. 9(b) through (f). From the fatigue cycle of 5000, which corresponds to an estimated crack length of 0.1 mm, a meaningful frequency shift can be observed. The amount of frequency shift, however, does not increase proportionally as the number of fatigue cycles increases, in another words, crack length increases. This means that the nonlinear effect can be observable at the early stage of cracking, but not proportional to the crack length after the crack length reaches a critical size. Comparing the resonance patterns of the fatigue cycle of 2000 (crack length < 50 μ m) and fatigue cycle of 5000 (crack length ≈ 0.1 mm), it can be concluded the NRUS technique can be effective to detect very early stage of cracking.

The amount of resonance frequency shift vs. applied strain at each fatigue stage is summarized in Fig. 4. As the applied strain increases, the resonance frequency shift increases. Also as the damage level increases, the slope depending upon the excitation voltage increases, which can be presumed to have higher nonlinearity in the larger crack.

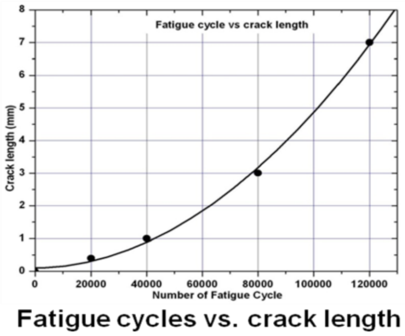
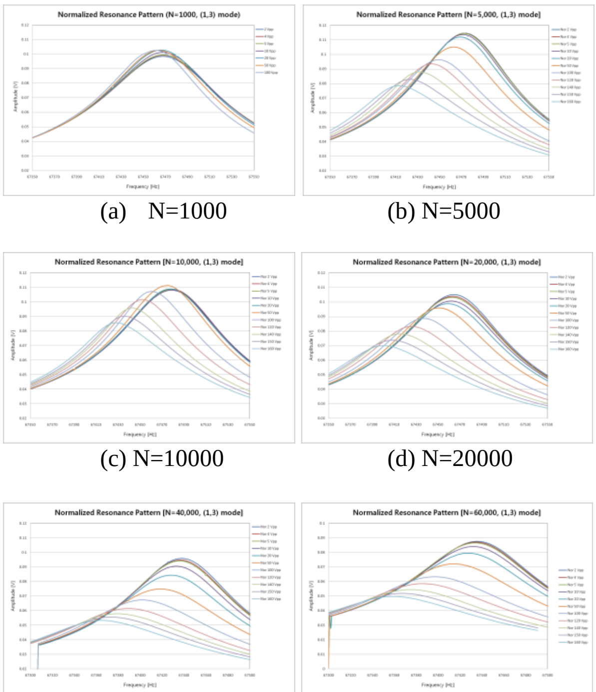


Fig. 2 Estimation of fatigue crack length at each stage of fatigue cycle.



(a) N=1000 (b) N=5000

(c) N=10000 (d) N=20000

(e) N=40000 (f) N=60000

Fig. 3 Normalized resonance pattern of CT specimen with a number of cycle (a) N = 1000, (b) N = 5000, (c) N = 10000, (d) N = 20000, (e) N=40000, and (f) N = 60000.

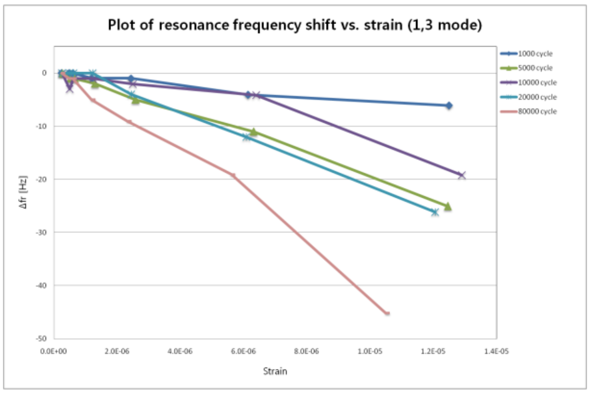


Fig. 4 Resonance frequency shift vs. applied strain for each fatigue steps.

3. Conclusions

In order for detection of an early stage of cracking or micro-damage, the A nonlinear parameter, resonance frequency shift of normalized resonance patterns were measured by the Nonlinear RUS technique. At the very early stage of cracking, such as crack length < 50 μ m, the normalized resonance pattern shows a small change as increasing excitation voltage.

A meaningful frequency shift can be observed at the stage of an estimated crack length of 0.1 mm. The amount of frequency shift, however, does not increase as the crack length increases. This means that the nonlinear phenomenon, i.e. the resonance frequency shift can be effective at the early stage of cracking.

These nonlinear parameters, resonance frequency shift and normalized amplitude can be a potential tool for the detection of micro-cracking or damage of a material.

Acknowledgement

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