Assessment of thermal fatigue damage in square tubes using second harmonic generation of longitudinal waves

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This paper investigates the nonlinear guided waves in the square tube with material nonlinearity for the first time. The dispersion characteristics of guided waves in a square aluminum tube are analyzed using the semi-analytical finite element dispersion calculator (SAFEDC). According to the dispersion curves given by the SAFEDC, a mode pair, which approximately satisfies the phase velocity matching or synchronism condition, is selected as the wave mode for fundamental waves and second harmonics. The power flux transferring from the fundamental wave field to the secondary wave field is computed by COMSOL combining MATLAB. The non-zero power flux demonstrates the selected wave mode pair meets the internal resonance condition. Then, a three-dimensional (3D) finite element (FE) model is developed to simulate the second harmonic generation and propagation in the square tube. Based on the mode shape plotted by the SAFEDC, the fundamental waves are excited by applying the axial displacement excitation in the FE model. Using the phase reversal approach, the time domain waveform of the second harmonics induced by the propagation of fundamental waves is presented. The almost linearly increased nonlinear acoustic parameter versus propagation distance indicates the generated second harmonics are cumulative. Subsequently, the experiment is carried out to confirm the simulated results. Four shear piezoelectric transducers (PZTs) are bonded on the outer surface at the tube end to excite the fundamental waves, and one shear PZT is bonded on the outer surface of the tube to measure the generated guided waves. The experimental results are considerably consistent with the numerical ones. Furthermore, the generated second harmonics are employed to evaluate thermal fatigue damage in the square tube. The thermal fatigue damage is generated and cumulated by applying increased thermal cycles on the square tube. The nonlinear acoustic parameter grows with growing thermal cycles, which indicates the induced second harmonics are sensitive to thermal fatigue damage. This work provides practical applications for the detection and evaluation of early-stage damage in square tubes using the second harmonic generation technique.