Development of the Novel Mixed Mode Ultrasonic Fatigue Test System based on Frequency Response Function and Dynamic Modal Analysis

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Abstract

In case it is important to characterizze the ultra-high fatigue behaviors of a metal, ultrasonic fatigue tests can be considered due to high test frequences. Moreover, it is quite important to understand the ultra-high fatigue life of metals under multi-axial stress status practically. This research demonstrates how to develop a novel mixed mode ultrasonic fatigue test system based on Frequency Response Function and Dynamics Modal Analysis, and the compatibility of the fatigue system is validated by experiments.

1. Introduction

So far, numerous fatigue testing techniques have been developed, such as the rotary bending test, servo hydraulic fatigue test and so on. However, due to the limited operating speed of testers, it is difficult to characterize the bahaviors of the ultra-high fatigue life range using any of the aforementioned conventional fatigue tests. Even at 3000 rpm, for example, it takes 8 months to barely reach the fatigue life at 109 cycles. Recently, for characterizing ultra-high fatigue behaviors, the ultrasonic fatigue testing machine operated at very high fatigue frequency has been developed and utilzed. The concept of ultrasonic vibrations to obtain very high cycle fatigue (VHCF) loading is appropriate, but the system must be properly built to resonate in the desired mode at a specific frequency. Although the analytical solution for the axial resonance of an hourglass-shaped specimen has been studied, the bending and torsional stress conditions have not been completely studied. In this study, a novel 20kHz resonant horn and specimen were designed to generate mixed mode stress, and an ultrasonic fatigue tests were performed to validate the compatibility of the newly designed system. Modal analysis is performed using the finite element approach to derive the natural frequency, and the frequency response function (FRF) of the newly designed ultrasonic fatigue test system is generated. Displacement and strain at the horn and specimen were measured to compare the results from numerical analysis. This paper focuses on the modeling of dynamics modal analysis and the optimization of mixed mode ultrasonic fatigue test system by comparing experimental results.

2. Results

The strian guage was fixed to the expected fracture site of the specimen, where is the polar point, in order to investigate various occurrences of resonance effect in actual fatigue tests. The dynamic modal analysis is performed as follows. First, the eigenvalue data from each component is imported to construct a modal body, which is then constrained by the suitable boundary condition and the amplitude generated by the real piezo vibrator. The schematics of dynamic modal analysis modeling are illustrated in Fig. 1 which shows that the numerical model can be validated by experiment so that the feasible horn and specimen can be properly designed.

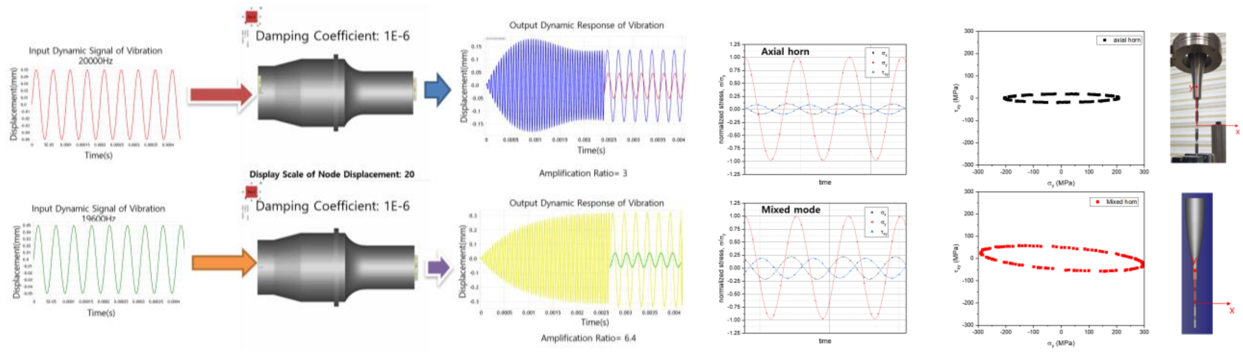
The assessment of newly designed systems is carried out based on the measured strain gauge data and the simulation results, and the following findings are reached:

1. The stress status of the mixed mode ultrasonic fatigue test system is identified by numerical simulations. In an ideal condition, shear stress is unlikely to arise, but the shear stress in the experimental results which may be caused by assembly tolerances.

2. The role of creating torsional vibration components is absent in both the novel and original horns. However, when resonance occurs at 20 kHz, the novel horn possesses a rather strong amplification capacity of torsional vibrations. The subsequent experiments require a torsional vibration generating unit or a waveform converter device.

3. The assembly preload of each component may affect the resonance frequency of the system, resulting in the variation of stresses at the intended testing frequency.

4. The resonance phenomena can be observed in case the system is subjected to torsional vibration with particular components, it is also identied from simulation results under same conditions. Interestingly, the simulation also effectively demonstrates the phase difference between axial and shear stress of the specimen in the experiment.



(a) (b)

Fig.1 – Dynamics Modal Analysis Model comparing with the experimental results.

It is well known that FRF are based on static analysis whereas dynamic modal analysis is based on dynamic analysis. Because modal analysis projects the dynamic model on the modal space for computation, the degree of freedom is considerably decreased resulting in a relatively quick simulation time. According to the comparison of the modal analysis and the experimental results, the experimental data such as phase and fatigue stress sequence acquired by employing the axial horn and the novel horn are reliable. To demonstrate that the novel horn has significant benefits to generate torsoinal vibration components from mixed mode ultrasonic fatigue tests, the components with waveform conversion functions have been developed for experiments. Using the newly developed mixed-mode ultrasonic fatigue tester in this study, it is possible to evaluate the variation in fatigue characteritics according to various stress ratios of axial and shear stresses. It is also expected that the technical limitations of generating mixed mode by the conventional ultrasonic fatigue tester can be overcome by utilizing the newly developed horn and specimen.

3. Conclusions

In this study, a new ultrasonic fatigue tester capable of generating various mixed mode stresses was developed overcoming technical issues of the existing ultrasonic fatigue tester, and its compatibility was validated by experimental results. FRF and dynamics modal analysis were adopted to design a new horn and specimen, and the the designed parts were modified by the comparison of simulation and experimental results. The mixed-mode ultrasonic fatigue tester developed in this study is expected to be utilized to quickly evaluate the ultra-high fatigue characteristics of metals required for the ultra-long-term fatigue life prediction of real parts under various stress ratios.