Fatigue Evaluation and Rapid Fatigue Strength Determination of C-SMC Using Thermoelastic Temperature Variations

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Recently, carbon fiber sheet molding compound (C-SMC), which is a discontinuous carbon fiber-reinforced polymer composite produced via sheet molding compound methods, has attracted increasing interest in the automotive industry. Knowing the high-cycle fatigue strength of C-SMC is crucial for ensuring its long-term use; however, its determination requires time-consuming testing. Fatigue damage reportedly changes the load-sharing conditions between the fiber and resin in discontinuous carbon fiber-reinforced polymer composites[(1)]. Consequently, their stress state is also considered to change as fatigue damage progresses. The non-dimensional thermoelastic temperature amplitude, which is the amplitude of the thermoelastic temperature variation divided by the mean surface temperature, can be used to evaluate the stress state of materials under cyclic loading. Therefore, this amplitude can be a promising parameter for assessing the fatigue damage of C-SMC. In this study, a method for rapidly determining the high-cycle fatigue strength using the non-dimensional thermoelastic temperature amplitude is employed and applied to C-SMC. Moreover, the behavior of this amplitude is investigated under two stress levels to discuss the physical model of the employed method: one at which fatigue damage occurs and the other at which no fatigue damage is considered to occur.

In this study, two types of fatigue tests were performed on 13 test pieces of C-SMC (TP1–TP13). One was a step-load fatigue test, in which the stress amplitude was increased stepwise from 3.8 MPa to 45.8 MPa, with each step consisting of 1100 cycles, using one test piece. The other was a constant-amplitude fatigue test, in which the stress amplitude was maintained constant under two stress levels: one at which fatigue damage occurs and the other at which no fatigue damage is considered to occur. Figure 1 shows the experimental setup. As shown in Fig. 1, the test piece is subjected to a sinusoidal cyclic load with a load ratio of 0.1 and a frequency of 10 Hz using a fatigue test machine. The temperature distribution on the surface of the test piece under cyclic loading is captured using an infrared camera. The non-dimensional thermoelastic temperature amplitude is then calculated pixel-by-pixel from time-series temperature distribution images. In the step-load and constant-amplitude fatigue tests, the non-dimensional thermoelastic temperature amplitudes were measured at each step and at specific numbers of cycles, respectively. The actual high-cycle fatigue strength of the employed C-SMC is 36.3 MPa. Figure 2 shows the changes in the non-dimensional thermoelastic temperature amplitude with the stress amplitude (TP1–TP5). As shown in Fig. 2, the non-dimensional thermoelastic temperature amplitude exhibits approximately linear behavior from the beginning of the step-load fatigue test and then gradually becomes nonlinear around the actual high-cycle fatigue strength. Figure 3 shows the changes in the non-dimensional thermoelastic temperature amplitude with the number of cycles under two stress amplitudes: 45.8 MPa (TP6–TP10) and 3.8 MPa (TP11–TP13). As shown in Fig. 3, the non-dimensional thermoelastic temperature amplitude decreases with increasing number of cycles under the stress level at which fatigue damage occurs, whereas it remains constant under the stress level at which no fatigue damage is considered to occur. These findings suggest that the employed method can rapidly determine the stress level at which the load-sharing conditions between the fiber and resin in C-SMC begin to change due to fatigue damage.

(1) D. Shiozawa, T. Sakagami, Y. Nakamura, S. Nonaka, et al., doi:10.3390/s17122824.

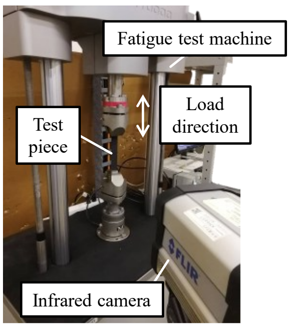

Fig. 1 Experimental setup.

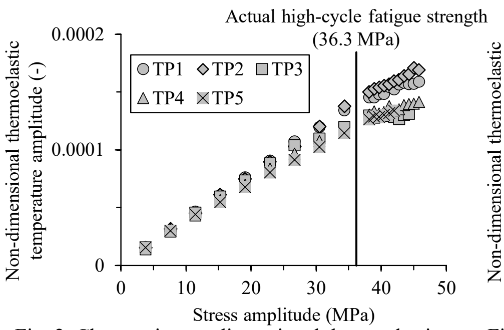

Fig. 2 Changes in non-dimensional thermoelastic temperature amplitude with stress amplitude.

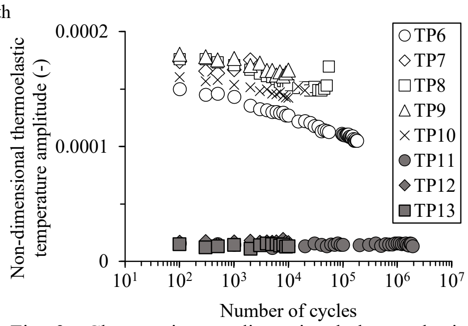

Fig. 3 Changes in non-dimensional thermoelastic temperature amplitude with number of cycles.

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