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Abstract

Fatigue Damage Evaluation of Epoxy Resin by Infrared Measurement †

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1. Introduction

Resin materials with high functionality and light weight are especially drawing the attention of the industrial field to realize carbon neutrality in recent years. However, resin materials are susceptible to degradation due to external factors such as heat, water, and ultraviolet (UV) radiation, depending on their usage environment. These degradations significantly affect the fatigue strength of the materials. To rapidly and quantitatively evaluate the decrease in fatigue strength of the materials caused by environmental degradation, this study proposes an evaluation method of fatigue damage by infrared measurement. Shiozawa, et al. [1,2] have proposed an estimation method of the fatigue limit of materials based on the change in dissipated energy using infrared thermography. The dissipated energy is the heat generation caused by plastic deformation in the material. In the case of metallic materials, it has been clarified that the second harmonic component included in actual temperature variations corresponds to dissipated energy of the materials. However, it remains unclear whether resin materials exhibit the same heat generation mechanism as metallic materials.

Therefore, this study aims to propose an infrared measurement to evaluate the effect of UV induced degradation on the fatigue strength of epoxy resin. By extracting the second harmonic component from actual temperature variations, similar to the approach used for metallic materials, we investigated whether evaluation of fatigue damage is feasible for epoxy resin itself and for UV degradation.

2. Experimental method

The material used in this study was a general-purpose epoxy resin, SikaBiresin® TD150. The specimens were fabricated into the shape of a dumbbell-shaped specimen according to JIS K6251 No.8. To clarify the effect of ultraviolet degradation of epoxy resin on fatigue strength, the specimens were irradiated with ultraviolet light using the weathering tester (Suga Test Instruments Co., Ltd., SX75-2D). The test conditions were the wavelength of the xenon lamp of 300 to 400 nm, the irradiance of 180 W/m^2, the black panel temperature of 63°C, the humidity of 50%, and the irradiation period of 2 months. Hereafter, specimens not irradiated with ultraviolet light are referred to as *Virgin* and those irradiated with ultraviolet light are referred to as *UV*.

Fatigue test was employed an electro-hydraulic servo pulser. Fatigue tests were conducted at room temperature with a stress ratio of 0.1 and a frequency of 3,5 Hz, and the number of unbroken test cycles was 2×10^6 cycles. Infrared measurement during fatigue tests of epoxy resins was conducted in a staircase stress amplitude increase test. In the staircase stress amplitude increase test, the stress amplitude is increased in a stair-

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case-like manner every N_{step}, and infrared measurements are conducted for each stress amplitude every $N_{measure}$ ($<N_{step}$) cycles. Fourier analysis is performed on the actual temperature variation of the material obtained from the infrared measurement, and the second harmonic components are extracted and plotted as representative values for each stress amplitude. In the case of metallic materials, the second harmonic components increase rapidly after a certain stress amplitude. The certain stress amplitude is used as the estimated fatigue limit. The estimated fatigue limit is roughly consistent with the actual fatigue limit of the materials. In this study, similar experiments were conducted with epoxy resin to evaluate fatigue damage. The staircase stress amplitude increase test was conducted by increasing the stress amplitude by 1 MPa until the specimen fractured. N_{step} and $N_{measure}$ of the staircase stress amplitude increase test are 1000 and 600 cycles, respectively. The conditions of fatigue test in the staircase stress amplitude increase test were stress ratio of 0.1 and frequency of 3Hz. Temperature variations at each stress amplitude in the staircase stress amplitude increase test were measured using an infrared thermography, Noxant NoxCam 640 HSi. The measurement conditions were a pixel count of 640pixel × 512pixel, a frame rate of 100Hz, and a shooting time of 10 seconds.

3. Results and discussion

Figure 1 shows the fatigue test results for *Virgin* and *UV*. The fatigue strength of the *UV* was lower than that of the *Virgin*. Figure 2 shows the second harmonic component of each stress amplitude for the *Virgin* and *UV* obtained in the staircase stress amplitude increase test. The second harmonic component was evaluated over a 10x10 pixel area centered on the fracture origin of the specimens. The second harmonic components of both *Virgin* and *UV* showed constant values up to a certain stress amplitude, after that the second harmonic components increased with increasing stress amplitude. This is similar to the tendency of change in dissipated energy of metallic materials. Therefore, it is inferred that temperature fluctuations due to fatigue damage in epoxy resin appear in the second harmonic component. The *UV* shows higher values after the stress amplitude that begins to increase. Therefore, it is suggested that the second harmonic component of epoxy resin also captures the effect of UV degradation on fatigue damage and the change in fatigue strength.

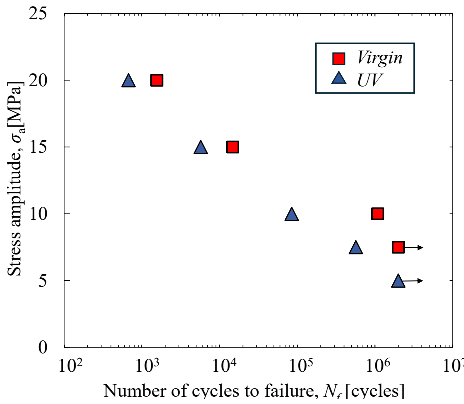

Figure 1. Results of fatigue test.

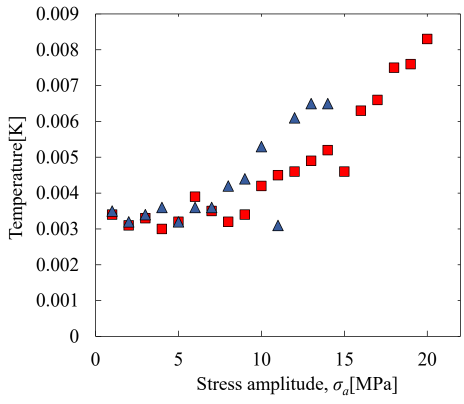

Figure 2. Relationship between stress amplitudeand the second harmonic component

4. Conclusions

Comparing the second harmonic components of the resin and UV materials, the UV material shows higher values after the stress amplitude at which the second harmonic component begins to increase. The effect of the degradation caused by UV irradiation on fatigue damage and the resulting changes in fatigue strength were captured by the second harmonic components.

It is suggested that there is a possibility that the fatigue damage of resin materials can be evaluated by the second harmonic component as well as that of metal materials.

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