# Chapter 4
# Energy Dissipation Measurement Under Cyclic Torsional Loading Using Infrared Thermography

**Daiki Shiozawa, Motoki Yoshiike, and Takahide Sakagami**

**Abstract** In fatigue design, it is necessary to obtain the fatigue strength of the materials used; the conventional method of obtaining the fatigue strength by preparing an S-N curve requires the repeated application of stress to a large number of specimens in the order of 10∧7 cycles, which is enormously time-consuming and costly. A rapid fatigue limit estimation method based on dissipated energy measurements has attracted attention. This method can estimate fatigue limits in a shorter time and at a lower cost than conventional methods. Its applicability to fatigue limit estimation of materials under axial loading has been investigated. In this study, fatigue limit estimation based on dissipated energy measurements was carried out for SCM435 subjected to cyclic torsional loading to investigate whether the method can be applied to torsional loading as well. A compact torsional fatigue testing machine and a microscopic measurement system were constructed. Visible-infrared synchronous measurement was applied to correct the position of torsional deformation. Fatigue limit estimation based on the dissipated energy under torsional loading obtained by the developed fatigue testing machine and measurement system was found to be in good agreement with the fatigue limit obtained from the *S-N* curve.

**Keywords** Infrared thermography · Energy dissipation · Torsional fatigue

## Introduction

The dissipated energy is measured by infrared thermography, and the fatigue limit of the material can be estimated from the stress amplitude at which the dissipated energy increases rapidly [1–4]. Compared to conventional methods, this method can estimate the fatigue limit using a smaller number of test pieces and on the order of $10^4$ cyclic loadings, which is expected to reduce time and costs. Although this method has been widely applied to axial loads, there have been few cases of its application to torsional loads. In order to prevent fatigue failure of engines, turbines, motors, crankshafts, and other items that are subjected to torsional loads, it is necessary to design them taking into account the fatigue limit against torsion. Therefore, if this method could also be applied to torsional loads, it would be extremely beneficial for the industrial field. In this study, the dissipated energy of SCM435 under torsional fatigue loads was measured by infrared thermography camera and the fatigue limit was estimated based on the dissipated energy.

## Experimental Setup and Specimen

The geometry of the specimen used in this experiment is shown in Figure 1. The material is chromium molybdenum steel SCM435. Since infrared thermography camera cannot capture images of curved surfaces, a flat section with a width of 1 mm and a length of 4 mm was provided in the center of the specimen. A stir case like stress level test was performed on this specimen. In the stir-case like stress level test, a sinusoidal waveform with a stress ratio of $R$ = -1 and a frequency of $f$ = 5 Hz was applied to the specimen, and the shear stress amplitude was increased in a stepwise manner by 20 MPa each time the number of load cycles reached 1000 cycles. At each stress amplitude, the flat part of the specimen was measured using an infrared thermograph camera and a visible camera, respectively, at the time when the number of load cycles reached 300 and

Daiki Shiozawa · Motoki Yoshiike · Takahide Sakagami
Department of Mechanical EngineeringKobe University, Kobe, Japan
e-mail: shiozawa@mech.kobe-u.ac.jp; 248t368t@stu.kobe-u.ac.jp; sakagami@mech.kobe-u.ac.jp

 
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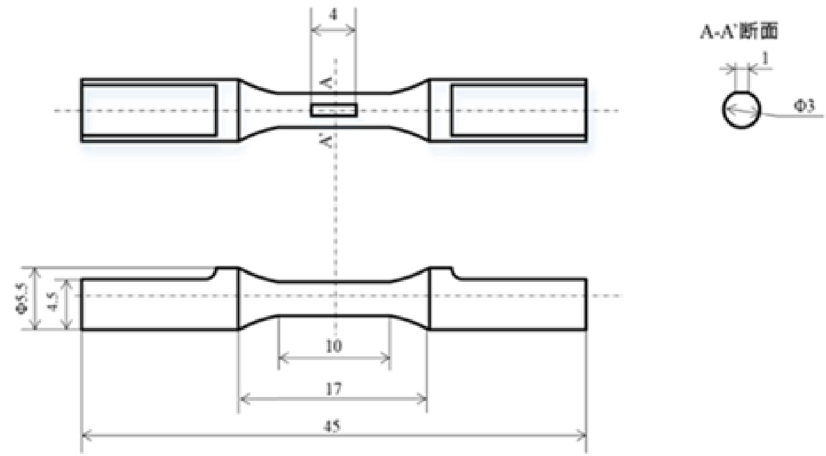


**Fig. 1** Geometry of specimen

600 cycles. A microscope lens was attached to the infrared thermography camera to perform magnified measurements of the flat part. The spatial resolution at this time was approximately 20 μm/pixel. The flame rate was 300Hz, and the shooting time was 10s, and the dissipated energy, which is 2nd frequency components of the load frequency, was measured. A position correction process was performed to infrared thermography images using visible images to remove apparent temperature fluctuations that occur when the observation point moves due to deformation or displacement of the specimen [5]. In the position correction process, digital image correlation is performed on the visible images to measure the displacement of the specimen.

Spot markers were painted on the test specimen. The displacement information obtained here was reflected in the infrared image and position correction process was performed. In the constant stress amplitude test, a fatigue test was performed under loading conditions of $R$=-1 and $f$=5Hz using a specimen without a flat surface, and an *S-N* curve was obtained. The runout number of cycles at which no fracture occurred was set to $10^7$ cycles.

## Results

Figure 2 shows the *S-N* curve obtained from the constant stress amplitude test. It was found from Fig. 2 that the fatigue limit of this specimen $\tau_w$ was between 300 MPa and 320 MPa, since no fracture occurred at $\tau_a$= 300 MPa.

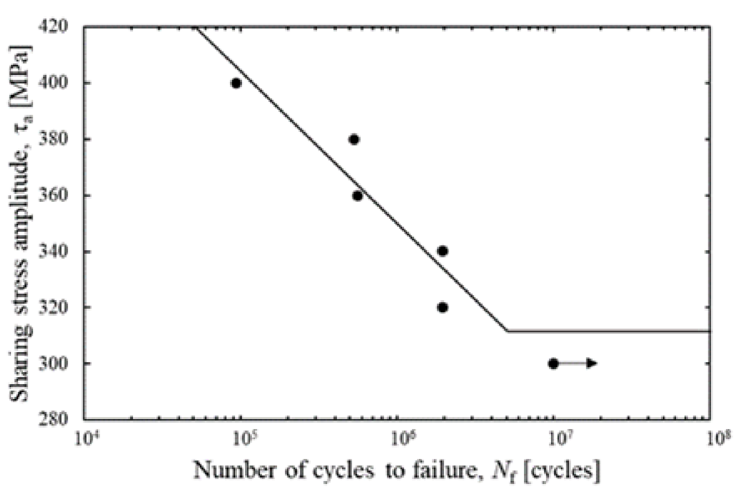


**Fig. 2** *S-N* curves

The change in dissipated energy in the stepwise stress increase test is shown in Fig. 3. In Fig. 3, the evaluation area is the flat area in the center of the parallel part of the specimen, and the average value of the data measured twice at each stress amplitude is used as the representative value. It was found from Fig. 3 that the dissipated energy remains constant at stress amplitudes smaller than 320 MPa, and it increases from $\tau_a$ =340MPa. For these measurement results, the data for each stress amplitude was divided into two groups, a low-temperature group and a high-temperature group, so that the residual in the linear approximation was minimized, and the boundary value of the grouping was used as the estimated fatigue limit. The estimated fatigue limit $\tau'_w$ in this experimental results was 330 MPa. The estimated fatigue limit $\tau'_w$ was close to the fatigue limit obtained from the *S-N* curve.

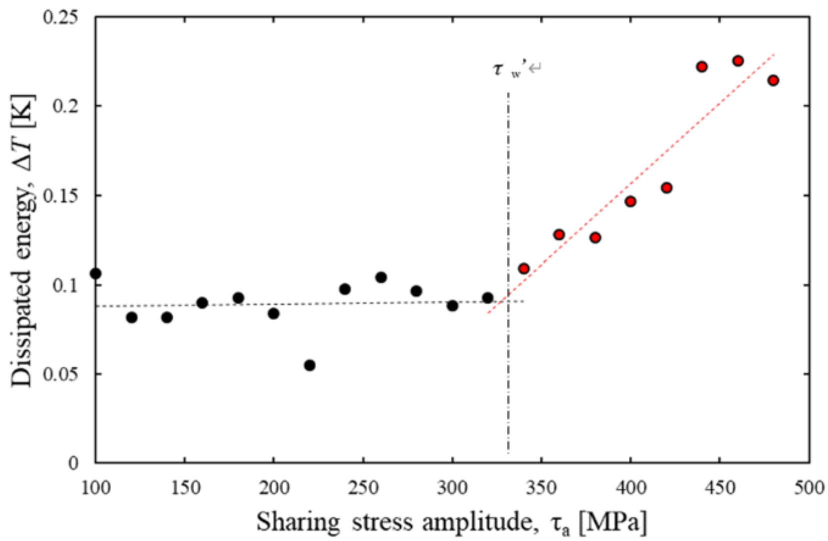


**Fig. 3** change in dissipated energy during the stir-case like stress level test.

## Conclusion

In this study, the fatigue limit of SCM435 was estimated based on dissipated energy measurements in torsional fatigue. It was found that the fatigue limit was between 300 and 320 MPa from the *S-N* curve obtained from a constant stress amplitude test. From a stir-case like stress level test, it was found that the dissipated energy showed a constant value below a certain stress amplitude, and then it rapidly increased. This estimated fatigue limit at which the dissipated energy rapidly increased was close to the actual fatigue limit.

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