RELATIONSHIP BETWEEN DAMPING AND FATIGUE DAMAGE OF GFRP LAMINATES

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1. INTRODUCTION

Damping refers to the physical phenomenon that the energy in the oscillating system dissipates with time. It is affected by the materials, constraints and many other aspects of the structural system. Material damping represents energy dissipation due to factors such as material internal friction and hysteretic energy loss. The damping ratio of a material is the major parameter representing the its ability in vibration reduction.

In the previous studies, some researchers recommended damping ratio as the damage indicator of fatigue damage of FRP [1]. Thus, it is essential to reveal how the damping ratio of GFRP materials used in civil infrastructures will change with service life. This study investigated the relationship between damping ratio and fatigue damage of woven roving GFRP laminates. The damping ratio of GFRP materials with two fixed ends were measured before and during the fatigue loading test.

2. EXPERIMENTAL DETAILS

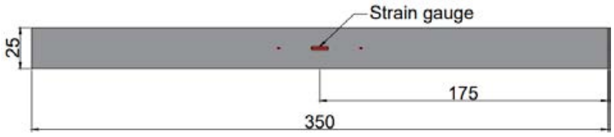
2.1 Experimental environment and specimen

The experiment was conducted at room temperature between 18°C and 20°C, and the laboratory humidity was between 54%RH and 60%RH. Regarding JIS K 7083 test standard, strip GFRP laminates with sizes of 350mm×25mm×5mm are used in this experiment as shown in Fig. 1. There are two specimens, numbered A1 and A2, respectively. The specimen was made by hand lay-up process, and the laminate structure was 10 layers of woven roving $(0/90)_{10}$. In general, aluminum tabs are glued to both ends of the specimen during fatigue loading. However, in this experiment, in order to reduce the influential factors during damping test, no aluminum sheet was attached to the specimens.

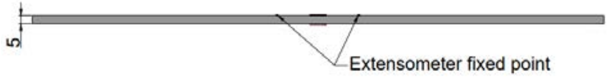
2.2 Static test and fatigue loading

During the fatigue test, the test piece was fixed to a Servo Pulser Loading Machine (maximum capacity 50 kN).

The applied load was a sinusoidal force during the loading process with a mean value of 11.67 kN and a span of 9.546 kN. The tensile fatigue loading process is shown in Fig. 2. After completing 0, 1, 4,000, and 10,000 cycles loading, the static test as well as impact test were performed to measure the elastic modulus and damping ratio of the specimen.



(a) top view



(b) side view

Fig.1 The size of the specimen

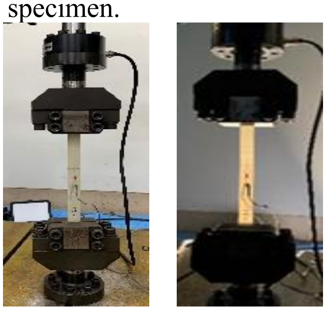
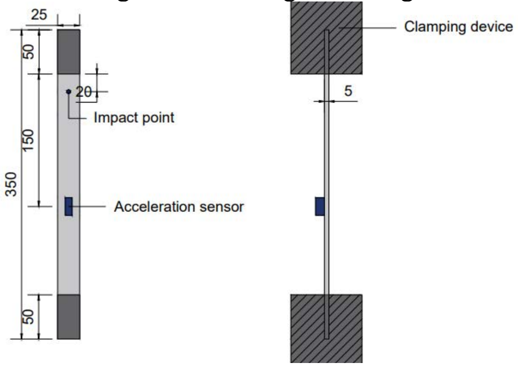


Fig.2 Tensile fatigue loading



(a)front view (b) side view

Fig.3 Device setup for impact experiment

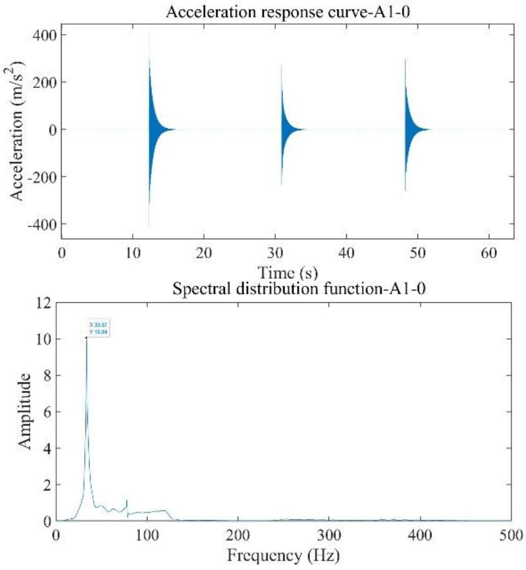


Fig.4 Examples of the response curve and spectral distribution function obtained from the impact test

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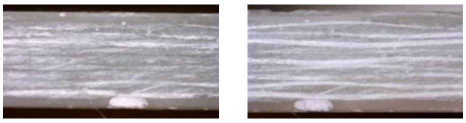

Fig.5 Digital micrograph of A1's middle part before the experiment (left) and after 12640 cycles (right)

Fig.6 Morphology of A1 specimen fracture

The static test was conducted under the loading speed of less than 1 mm/min, and the data were recorded by the data logger, which was used to draw stress-strain curves. The strain will mainly be measured by an extensometer, but strain gauges are used as well. Elastic modulus was from the stress-strain curve obtained from the statics test:

$$E = \frac{\sigma}{\varepsilon} \tag{1}$$

where σ and ε are stress and strain, respectively. In addition, digital microscopy was used to observe the changes in GFRP laminate fibers after each group of fatigue loading was completed.

2.3 Impact test

Before the experiment and after the end of each group of loading, the specimens were subjected to impact tests. Experimental device settings are shown in Fig. 3, and the hitting was repeated three times in each experiment.

In the experiment, a GK-3100 impact hammer was used to hit the vertical specimen with two fixed ends. An acceleration sensor fixed to the middle point of the test piece was used to measure the acceleration response. The signal was recorded by DRA-107A with a sampling rate of 1,000Hz. Since the impact of the hammer on the test piece can be regarded as a Dirac function, the spectrum distribution function of the test specimen can be obtained by Fast Fourier transform of the response function directly (Fig.4). The damping was determined according to the half-power bandwidth method.

$$\zeta = \frac{f_b - f_a}{2f_n} \tag{2}$$

The amplitude of f_a and f_b is $\frac{1}{\sqrt{2}}$ times that of f_n.

3. EXPERIMENTAL RESULT AND DISCUSSION

Specimen A1 fractured after being subjected to 12,640 loading cycles. Its microscopic view of fracture morphology is shown in Fig. 5, and the macroscopic view is shown in Fig. 6. As the number of fatigue loading cycles increases, the lateral microscopic image of A1's middle part does not change significantly. Broken fiber and delamination occur after the fatigue test.

Fig. 7 shows the change of elastic modulus. The elastic modulus was measured using a strain gauge in preference. After gauge damage after 1,000 cycles, the extensometer data were used for calculation. The elastic modulus of the specimen showed a downward trend with the increase of loading cycles, which is consistent with previous studies[1].

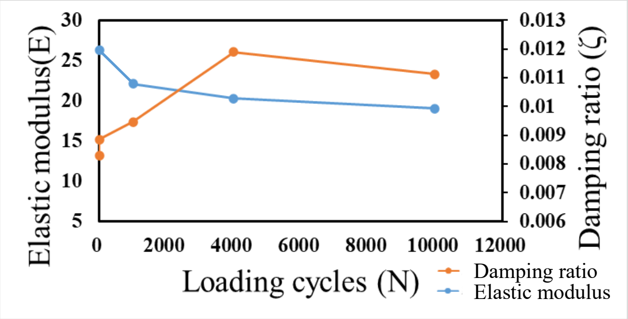

Fig.7 Variation trend of elastic modulus and damping ratio of A1

Table1 Experimental result

Loading times (N)	Natural frequency (f)		Damping ratio (ζ)		Damping growth rate (Δ)	Elastic modulus (E)
0	31.4	31.4	0.0084	0.0083	0.00%	26.27
	31.3		0.0082			
	31.4		0.0083			
1	33.5	33.5	0.0089	0.0088	6.82%	
	33.5		0.0088			
1,000	32.5	32.5	0.0094	0.0095	14.25%	22.10
	32.6		0.0098			
	32.4		0.0092			
4,000	29.8	29.8	0.0118	0.0119	43.72%	20.27
	29.8		0.0126			
	29.8		0.0113			
10,000	31.5	31.5	0.0110	0.0111	34.30%	19.01
	31.5		0.0111			
	31.5		0.0112			

The changes of natural frequency and damping ratio of A1 specimen obtained through impact test are shown in Table 1. As the number of loading cycles increases, the natural frequency is maintained at about 30 Hz. The damping ratio increased with the loading cycles. This may be caused by increased internal friction of the material.

4. CONCLUSION

This experiment measured the elastic modulus, vibration frequency and damping ratio of GFRP laminates with orthogonal fiber arrays under different numbers of cycles of tensile fatigue loading. The following conclusions can be drawn based on the study:

1) The elastic modulus of GFRP laminates decreases with the increase of tensile fatigue loading cycles. Before the fatigue failure occurs, the internal fibers may not change significantly before fatigue failure occurs.
2) For the GFRP beam with two fixed ends, the natural frequency of vibration does not change significantly with the increase in number of cycles. Since the frequency is expected to change with the decrease of elastic modulus, its reasons need to be discussed in future studies.
3) With the increase of fatigue damage, the damping of the laminate exhibits an apparent nonlinear increasing trend, and the maximum damping increases by more than 40% compared with that original specimen. Therefore, damping can be used in assessing GFRP damage processes, which appears to be more sensitive than stiffness.

REFERENCES

[1] Z. Zhang, G. Hartwig, Relation of damping and fatigue damage of unidirectional fiber composites, *International Journal of Fatigue*, Volume 24, Issue 7, 2002, pp. 713-718.