傾斜利用 BOCDR を用いた CFRP 補強鋼材中の歪分布計測
Structural diagnosis of CFRP strengthened steel using slope-assisted BOCDR

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1. Introduction

Slope-assisted Brillouin optical correlation-domain reflectometry (SA-BOCDR) [1] is a recently developed structural health monitoring technique for measuring strain and temperature distributions along optical fibers. Its fundamental operations have been demonstrated with some unique features, such as a beyond-nominal-resolution effect [2] and measurement sensitivity dependencies on experimental conditions [3]. Also, loss-insensitive operation of SA-BOCDR was verified using a special single-mode fiber (SMF) [4]. However, the utility of SA-BOCDR using optical fibers embedded in actual structures has been proved yet, which is of crucial importance to its practical use.

In this work, as a first step to such practical applications, we present an example of SA-BOCDR-based structural diagnosis using composite structure comprising carbon fiber reinforced plastics (CFRP).

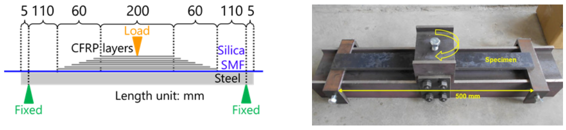
2. Fabrication of specimen

A specimen, which is a CFRP strengthened steel, was prepared using a so-called vacuum-assisted resin transfer molding (VaRTM) [5], which is known as an advanced fabricating process for composite materials. **Figure 1(a)** shows the structure of the specimen. A 1.4-m-long silica SMF with a Brillouin frequency shift of 10.85 GHz at room temperature (23 °C) was used as a sensing fiber. The SMF was embedded between a steel plate and CFRP strips. This structure was fabricated by placing the SMF before infusing liquid resin during the VaRTM process. The depth of the structure (both the steel plate and the CFRP strips) was 39 mm, and the thickness of the steel plate was 12 mm. The total thickness of the CFRP strips composed of 7 tapered layers (the length of each layer was different by 10 mm) was 3 mm.

3. Experiments

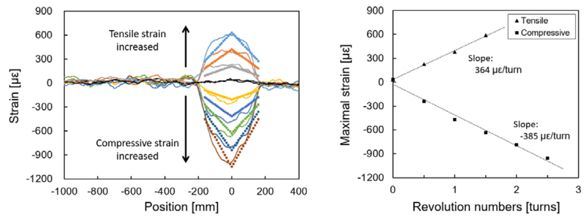
The experimental setup is basically the same as that of the Ref. [1]. Although the detailed experimental conditions are not given here due to the space limitation, the spectral power change at a fixed frequency ν_{B0} (= 10.83 GHz) of the Brillouin gain spectrum was observed. The modulation frequency and amplitude were set to 9.132–9.156 MHz and 1.52 GHz, respectively, corresponding to the measurement range of 11.3 m and the spatial resolution of 0.07 m. The room temperature was 23 °C.

First, we evaluated the magnitude of tensile and compressive strains applied to the sensing fiber. Using a three-point bending device shown in **Fig. 1(b)**, tensile and compressive strains were applied to the middle of the specimen by tightening the top screw (the specimen was upturned when tensile strains were applied). We measured the distributed tensile and compressive strains from 0 to 1.5 and from 0 to 2.5 turns (of the top screw), respectively, which theoretically correspond to the strains of 0 to 600 με and 0 to 1000 με. **Fig. 2(a)** shows the measured power-change distributions along the whole sensing fiber. The vertical axis was converted into strain using the known strain-dependence coefficient of the power-change of −1.59 dB/%. Note that the positive and negative signs mean tensile and compressive strains, respectively. The horizontal axis indicates the relative distance from the midpoint of the embedded section of the sensing fiber (positive values mean the distal points). With increasing applied tensile and compressive strains, the measured strains also increased moderately in accordance with the theoretical values. In **Fig. 2(b)**, the maximal strain obtained from each measured distribution in **Fig. 2(a)** is plotted as a function of revolution number of the top screw. Irrespective of tensile or compressive strain, the maximal strain increased almost linearly with increasing revolution number of the screw.



(a) (b)

Fig. 1. **(a)** Structure of the specimen. **(b)** Three-point bending device.



(a) (b)

Fig. 2. **(a)** Measured strain distributions. **(b)** Maximal tensile and compressive strains plotted in terms of the revolution numbers of the top screw.

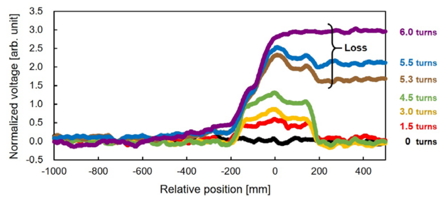


Fig. 3. Measured power-change distributions along the sensing fiber when the compressive strains were applied until the fiber was broken.

The slopes for tensile and compressive strains were calculated to be ~364 με/turn and ~385 με/turn, respectively, which moderately agree with the theoretical values (~400 με/turn).

Subsequently, we detected the breakage of the sensing fiber by applying larger compressive strains to the specimen. The top screw was tightened to 0, 1.5, 3.0, 4.5, 5.3, 5.5, and 6.0 turns. The measured distributions of power-change (output as voltage) are shown in **Fig. 3**. The vertical axis was defined to be positive when strain was compressive. When the revolution number was equal to or smaller than 4.5 turns, the power-changes were observed along the correct section. In this strain range, the power-change was almost proportion to the revolution number. However, when the revolution number was larger than 5.3 turns (~1060 με), the power-change showed drastic increase along the distal side from the midpoint of the specimen. This behavior implies that considerable optical loss was induced, possibly by fiber breakage. These results present an example case where SA-BOCDR has a capability of indirectly predicting the peeling of composite structure via fiber breakage detection.

We believe that, by presenting a promising example of composite structure diagnosis, this work will be an important basis for the future development of SA-BOCDR-based health monitoring systems for practical fields.

References

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