Effects of the bonding length on the reflected spectra and strain measurement of the surface bonded fiber Bragg grating sensor

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ABSTRACT

Surface bonded fiber Bragg grating (FBG) sensors have the limitation that signal characteristics are affected by the bonding layer. Previously conducted studies with regard to this limitation used different optical fiber sensors and load types during the experiments, and didn't consider the effects on the reflected spectra. Therefore, in this study, the effects of the bonding length on the reflected spectra and strain measurement of the surface bonded FBG sensor were experimentally investigated. From the experimentation results, sufficiently bonded FBG sensor showed stable reflected spectra and enough strain transfer rate. However, insufficiently bonded FBG sensor showed distorted reflected spectra with high multiple peak ratio due to internal strain gradients within the grating length of the FBG sensor. In addition, distorted reflected spectra made it difficult to calculate adequate peak and decreased the strain transfer rates. Therefore, it was found that effective bonding length need to be determined to get a stable reflected spectra and enough strain transfer rate from the surface bonded FBG sensors.

1. INTRODUCTION

Composite materials have design flexibility as well as high specific stiffness and high specific strength. Therefore, the use of the composite materials is being increased in many industrial fields. Characteristics of the composite materials are different from those of metal materials, so structure health monitoring (SHM) researches on composite structures are being carried out to guarantee the safety and reliability of the structure.

Since fiber Bragg grating (FBG) sensors have many advantages, it is being widely used in SHM research on composite structures. There are two ways to install the FBG sensor to a sensing point. One is to adhere the sensor to the surface of the structure and another is to embed the sensor into the composite material. Since the surface bonding method is relatively easy and convenient, it is preferred in many researches. However, surface bonded FBG sensors have certain limitation. The most critical limitation is that the signal characteristics are affected by the bonding layer. Therefore, many studies about the effects of the bonding layer on the optical fiber sensor have been conducted. Ansari et al. (1998) developed the analytical model for the strain transfer process between surrounding materials and the fiber core and conducted the experiments using the Michelson interferometer. Wan et al. (2006) showed the effects of the geometrical parameters on strain transfer rates using a FBG sensor and Her et al. (2006) showed the effects of protective coatings using a Mach-Zehnder interferometer. Previously conducted studies used different types of optical fiber sensor making absolute comparisons difficult. Since the FBG sensor use the reflected spectra to measure the change in physical quantity, it is necessary to confirm how the bonding length affects the reflection spectra and measured strain.

Therefore, in this study, the effects of the bonding length on the reflected spectra and strain measurement of the surface bonded FBG sensor were experimentally investigated to determine the effective bonding length of the FBG sensor.

2. FIBER BRAGG GRATING SENSORS

FBG sensors are composed of numerous Bragg gratings. Each Brag grating inscribed in optical fiber reflects the specific wavelength satisfying the Bragg condition. The Bragg condition is as shown below.

$$\lambda_B = 2n_e\Lambda \tag{1}$$

In Eq. (1), n_e is the effective refractive index of the grating, Λ is the grating period, and λ_B is the Bragg wavelength of the FBG sensor. The specific wavelength reflected from the Bragg grating is determined by the refractive index difference of the grating and the gap between gratings. Physical parameter changes near grating change the refractive index or gap. These changes lead to a wavelength shift of the reflected light in the grating. Since the reflected spectra of the FBG sensor is the superposition of the reflected light from each grating, non-uniform physical parameter change within grating length can cause the distortion of the reflected spectra.

3. EXPERIMENTAL METHOD

To investigate the bonding length effects on the strain measurement using FBG sensor, experiments were conducted. For the experiments, acrylate coated FBG sensors (FBG Korea, Inc.) which have 10mm grating length were used. FBG sensors were attached to the specimen by using epoxy adhesive (2 ton epoxy, Devcon.), and specimens were fabricated by using Al 6061-T6. In this process, the bonding length of the FBG sensor was 30mm for short bonding length and 70mm for short bonding. Electrical strain gages were attached beside the FBG sensor and the measured strains from this were used as a reference value. A low-speed FBG interrogator (SFI-700, Fiberpro Inc.) was used to measure the reflected spectra change of the FBG sensors. Bending loads were applied to the sensor attached specimen by increasing the tip displacement to lower direction. Bending loads were applied by 2000με at sensing point. Figure 1 shows the experimental set up.

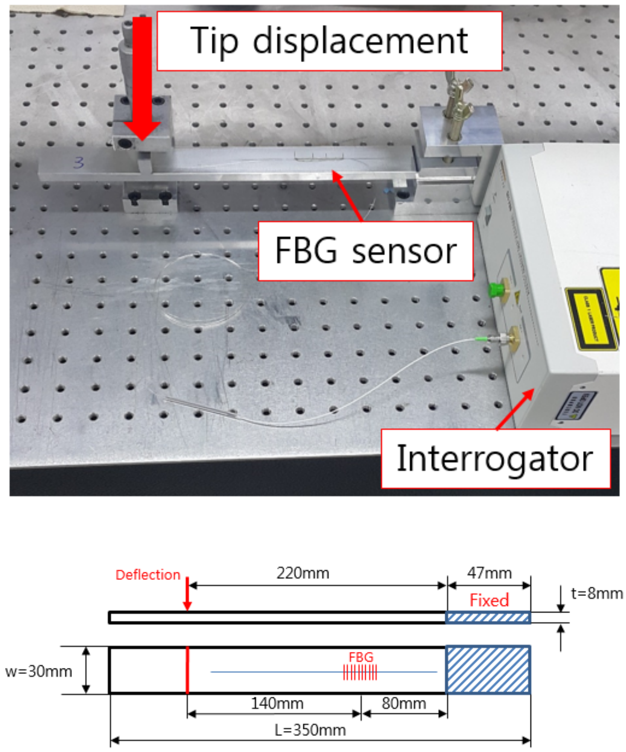


Figure 1. Experimental set up.

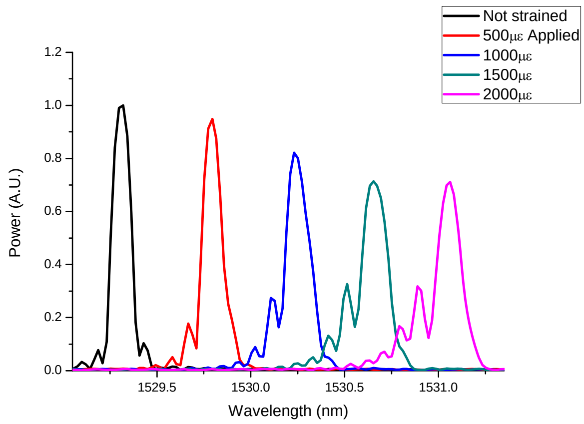
4. EXPERIMENTAL RESULTS

The effects of bonding length on the strain transfer rate of the FBG sensor was calculated by comparing the strain measured from the electrical strain gauges and the strain from the FBG sensors using Eq. (2), and the reflected spectra were investigated by comparing the peak amplitude of the main peak and multiple peaks using Eq. (3).

$$\mathit{Strain\ transfer\ rate} = \frac{\mathit{Strain\ measured\ by\ FBG\ sensor}}{\mathit{Strain\ measured\ by\ strain\ gauges}} \tag{2}$$

$$\mathit{Multiple\ peak\ rato} = \frac{\mathit{Multiple\ peak\ amplitude}}{\mathit{Main\ peak\ amplitude}} \tag{3}$$

(a) Reflected spectra of 30mm bonded FBG sensor



(b) Reflected spectra of 70mm bonded FBG sensor

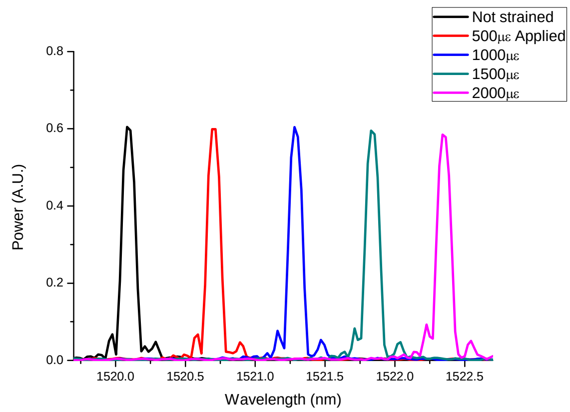


Figure 2. Reflected spectra of surface bonded FBG sensor

Table 1. Multiple peak ratio of reflected spectra (2000με)

Bonding length (mm)	Second peak ratio (%)	Third peak ratio (%)
30	44.65	24.55
70	18.32	3.94

Figure 2 shows the reflected spectra of the bonded FBG sensor. When the bonding length was short, the ratio of the multiple peaks increased. However, when the bonding length was sufficiently long, the ratio of the multiple peaks were stable even though there were strain gradients in the specimen by bending loads. The high multiple peak ratio in the reflected spectra means the strain gradient within the grating length. Therefore, it was found that insufficient bonding length generates and amplifies the strain gradients within the grating length of the FBG sensor.

Table 2. Strain transfer rate according to bonding lengths and peak calculation methods

Bonding length (mm)	Gaussian approximation (%)	Centroid (%)
30	72.64	70.48
70	97.00	96.57

Table 2 shows the strain transfer rate according to bonding lengths. The strain of the FBG sensor was calculated based on the approximated main peak in the reflected spectra. The peaks of the reflected spectra were calculated by using Gaussian polynomial fitting and reflectance centroid method. When the bonding length was short, the strain transfer rate based on Gaussian fitting was 72.64% and the reflectance centroid was 70.48%. When the bonding length was sufficiently long, strain transfer rate was higher than those of the shortly bonded FBG sensor and the peak difference between signal processing techniques was small.

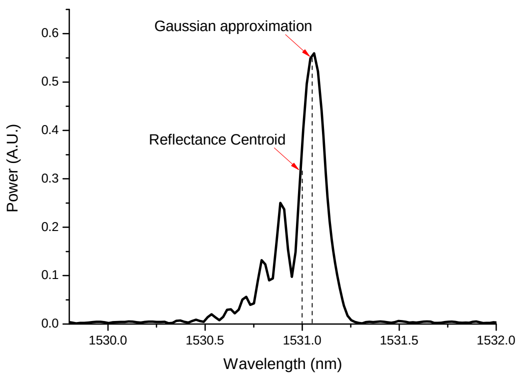


Figure 3. Peak calculation of the reflected spectra (30mm bonded FBG sensor)

Figure 3 shows the calculated peaks when the reflected spectra was distorted. Through this result, it was found that insufficient bonding length of surface bonded FBG sensor distorts the reflected spectra and the distorted reflected spectra makes it difficult to calculate the peak, hence the strain transfer rate is decreased.

5. CONCLUSION

In this study, the effects of bonding length on the reflected spectra and strain measurements of FBG sensors were experimentally investigated. When the bonding length of the surface bonded FBG sensor was not enough, reflected spectra was distorted by the internal strain gradients within the grating length of FBG sensor. The high multiple peak ratio in the distorted reflected spectra made it difficult to find the adequate main peak, so the strain transfer rate decreased according to peak calculation methods. However, when the FBG sensor was installed with a sufficient bonding length, the reflected spectra was stable and the strain was sufficiently transferred. Therefore, it was found that sufficient bonding length is needed to get stable reflected spectra and sufficient strain transfer.

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BIOGRAPHIES

Hyunseok Kwon was born in Korea in 1989. He received his MSc degree in Aerospace Engineering from KAIST, South Korea, in 2017. He is currently a PhD candidate in the Department of Aerospace Engineering at KAIST. His research interest is in the area of multifunctional composite structure & structural health monitoring of the composite structures using fiber optic sensors.

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