Composite Structures 160 (2017) 248–255

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Effect of sensing distance of aluminum-coated FBG sensors installed on a composite plate under a low-velocity impact

Sang-Woo Kim

Department of Mechanical Engineering, Hankyong National University, Anseong-si, Gyeonggi-do 17579, Republic of Korea
Institute of Machine Convergence Technology, Hankyong National University, Anseong-si, Gyeonggi-do 17579, Republic of Korea

ARTICLE INFO

Article history:
Received 5 September 2016
Revised 10 October 2016
Accepted 17 October 2016
Available online 17 October 2016

Keywords:
Metal coating
Memory effect
Carbon fiber reinforced polymer composite
Impact behavior
Damage mechanics

ABSTRACT

This study investigates the effect of sensing distance on multiplexed aluminum-coated (Al-coated) fiber Bragg grating (FBG) sensors when they are applied to a carbon fiber reinforced polymer (CFRP) composite plate. The study involved a low-velocity impact test and its finite element analysis for the plate. The findings indicated that all the results from the test and FEA were consistent with each other. Additionally, the results revealed that permanently induced residual strains of all three Al-coated FBG sensors were linearly related to the sensing distance measured from the impact point. The findings also suggested that the linear relationship between the residual strains and sensing distances was closely related to the linear correlation between the sensing position and the maximum strains experienced by the composite plate. This implied that the impact information experienced by the composite structure could be quantitatively evaluated if the correlations between the structural deformation and residual strains with respect to the sensing distance were constructed in advance. Therefore, the correlation between the residual strains and the sensing distance examined in this study can improve the integrity of the proposed damage evaluation methodology and can be utilized as guidelines for designing a metal-coated optical fiber sensor (MCOFS) based damage evaluation systems for actual applications.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Fiber reinforced polymer (FRP) composites exhibit excellent mechanical properties such as high specific stiffness, high strength, and fatigue and corrosion resistance. This has led to their widespread use in many fields [3–6], especially in aerospace engineering [7,8]. However, composite structures are susceptible to damage from external impact loadings. Low-velocity impacts can cause impact-induced damage such as fiber breakage, matrix cracking, fiber-matrix debonding, and delamination. These damages are sometimes referred to as "barely visible impact damages (BVID)" because they cannot be visually inspected.

In the author's previous studies [1,9,10], the author proposed a methodology using a metal-coated optical fiber sensor (MCOFS) to evaluate impact-induced damages of composite structures under low-velocity impacts and quasi-static indentation. Furthermore, Choi et al. [2] proposed aluminum (Al)-packaged Brillouin optical correlation domain analysis (BOCDA) sensors by using a similar approach. The BOCDA sensors were based on the Brillouin scattering effect [11–13], and it was demonstrated that Al-packaged OFS achieved a spatial resolution of 2 cm and could successfully produce residual strains of the sensors following the impact tests. These methodologies for damage evaluation and detection using MCOFS were based the "memory effects" of an elasto-plastic metal coated on the surface of optical fiber sensors. That is, the impact-induced damages could be assessed by measuring residual strain values since the maximum strains as well as the impact energy experienced by composite structures were correlated with the residual strain values [1,2,9,10,14]. This implied that the MCOFS could recall the information of the impact events that occurred in the past. This phenomenon is referred to as the "memory effects". The methodology using MCOFS could be applied to the composite structures during operating periods and especially during inoperative periods.

However, previous laboratory tests for the proposed methodology were primarily conducted by focusing on the feasibility of the methodology under limited conditions [1,2,9,10,14–16]. This study builds on the previous feasibility studies and investigates the effect of the sensing distance of multiplexed Al-coated FBG sensors from the impact point. The sensing distance can be an important factor when the sensors are in operation because the mechanical

E-mail address: swkim@hknu.ac.kr

http://dx.doi.org/10.1016/j.compstruct.2016.10.050
0263-8223/© 2016 Elsevier Ltd. All rights reserved.

behaviors and responses of MCOFS can significantly vary according to the distance between an impact point and a sensing position. Additionally, prior to actual usage, it should be verified that the structural vibration induced by the external impact does not significantly affect the residual strain producing characteristics of the sensors with respect to the sensing distance. This ensures that the sensors are able to recollect the past impact information experienced by composite structures.

Fig. 1 shows a prime example of an actual application of MCOFS for damage evaluation of a composite cylinder. As shown in Fig. 1(a), a distributed type of MCOFS was preferred for damage evaluation and detection because it covers a wide area range. Fig. 1(b) shows the actual application of an Al-packaged distributed sensor for the impact detection of a composite cylinder. However, the actual application of the MCOFS continues to be limited because the effect of the sensing distance on the residual strains is not well established. Thus, it is necessary to examine the sensing distance to understand how the residual strains induced by the metal coating should be varied with respect to the sensing distance prior to an actual application.

This study focused on a type of MCOFS, namely a multiplexed Al-coated fiber Bragg grating (FBG) sensor, in order to examine the effect of sensing distance. The reason for using multiplexed FBG sensors instead of distributed sensors was because the sensing capability of the former significantly exceeded that of the latter. Furthermore, a commercial interrogator system for FBG sensors provides excellent measurement resolution. Low-velocity impact tests for a composite plate with three Al-coated FBG sensors were performed to investigate the effect of sensing distance. The behavior of the composite plate with respect to the impacts was validated with the numerical results calculated by a finite element analysis (FEA) based on a continuum damage mechanics (CDM) considering damage model. The study also involved examining structural responses and strain distributions of the composite plate. Finally, the effect of the sensing position on the residual strains induced by three multiplexed Al-coated FBG sensors was investigated, and the relationship between the residual strains and sensing position was examined.

2. Metal-coated FBG sensors

Metal-coated FBG sensors permanently deform under alternately strained and unstrained state due to elasto-plastic metal coating. However, normal FBG sensors do not produce residual strains because they behave in a linear elastic manner. The principle of metal-coated FBG sensors is based on the shift of reflected wavelength satisfying the Bragg condition as given by the following equation:

$$\lambda_{Bragg} = 2n_e\Lambda_{Bragg}, \quad (1)$$

where λ_{Bragg}, Λ_{Bragg}, and n_e denote Bragg wavelength, period of the Bragg grating, and effective refractive index, respectively.

Fig. 2 illustrates the principle of metal-coated FBG sensors.

Under constant temperature conditions, the residual strain of metal-coated FBG sensors is estimated by measuring the wavelength shift as given by the following equation in accordance with previous studies [9,10,15,16]:

$$\varepsilon_r = \frac{1}{1-P_e}\left(\frac{\lambda_r-\lambda_i}{\lambda_i}\right) = \frac{1}{1-P_e}\left(\frac{\Delta\lambda_r}{\lambda_i}\right), \quad (2)$$

where $\Delta\lambda_r$, λ_i, λ_r, and Pe (=0.22) denote wavelength shift, initial wavelength, final wavelength shifted by permanent residual strain, and photo-elastic constant of an optical fiber, respectively.

FBG sensors recoated with ultraviolet (UV) curable acrylate and with Bragg gratings of 10 mm were used. An aluminum-alloy 1235-O foil with a thickness of 18 μm was used to coat the sensors using a cyanoacrylate adhesive. The details of the fabrication process are described in a previous study [1].

3. Experiment

3.1. A composite plate

A carbon fiber reinforced polymer (CFRP) composite plate was fabricated using a unidirectional prepreg (CU125NS; Hankook Fiber Co.) consisting of carbon fiber and epoxy resin. The prepreg was layered according to a layup sequence of

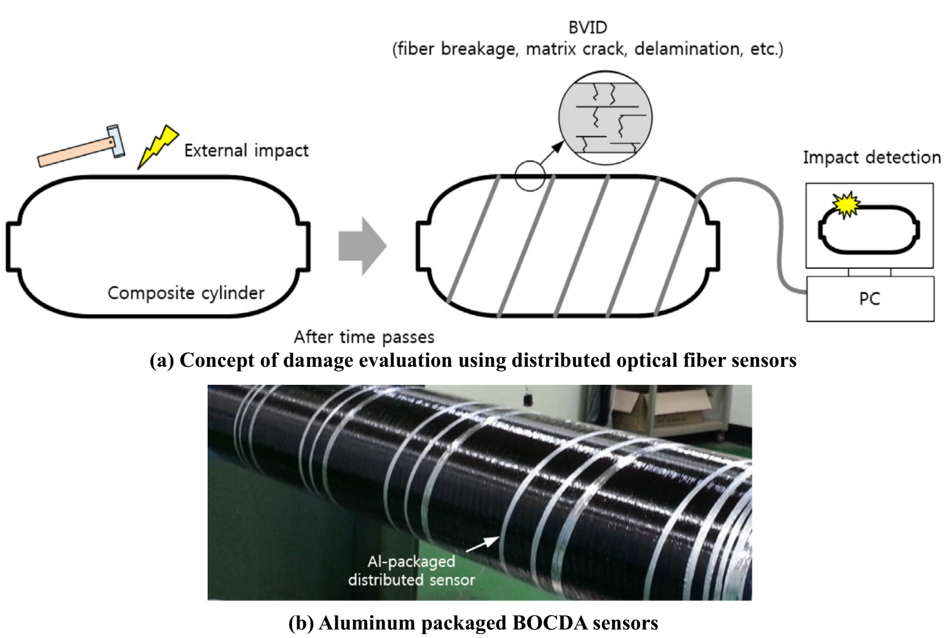

Fig. 1. Application of aluminum-coated optical fiber sensors.

Download English Version:

https://daneshyari.com/en/article/6479600

Download Persian Version:

https://daneshyari.com/article/6479600

Daneshyari.com