Optik 154 (2018) 441–452

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Full length article

Strain transferring mechanism analysis of the substrate-bonded FBG sensor

Wei Shen[a,b,*], Xiaoxing Wang[a], Lin Xu[a], Yingjiang Zhao[a]

[a] Key Laboratory of High Performance Ship Technology (Wuhan University of Technology), Ministry of Education, Wuhan 430063, China
[b] State Key Laboratory of Ocean Engineering, Shanghai Jiao Tong University, Shanghai 200240, China

ARTICLE INFO

Article history:
Received 28 July 2017
Accepted 20 October 2017

Keywords:
Fiber Bragg grating (FBG)
Strain transfer rate
Substrate material
Error analysis

ABSTRACT

One of the important application forms of Fiber Bragg grating (FBG) is to measure strain by pasting on the surface of structure. In order to improve the strength of surface-bonding FBG, packaging substrate in metal slice is designed and applied. On the basis of previous studies, an analytic model of the substrate-bonded FBG sensor is developed to predict the strain transfer rate. Moreover, the effects of substrate material and sizes on the strain transfer rate of substrate-bonded FBG are analyzed and compared. Finally, the theoretical analysis results are verified by experimental results. There is a good correspondence between the calculated values and experimental results.

1. Introduction

Civil engineering structures result in decreased resistance by the factors of material aging, natural disasters, accidental load during their service process. Once these structures failure, will cause serious disasters. The method of using structure health monitoring to assess the safety performance of structure, is becoming more and more important. The emergence of fiber Bragg grating sensor provides a favorable method for structural health monitoring. FBG sensor has gradually become the preferred sensor of high accuracy strain measurement, with the advantages of high measurement precision, good stability, short response time and distributed measurement, etc. In recent years, the technology of FBG sensors has been applied to the field of structural monitoring, infrastructure assessment, and some large industrial and civil engineering such as dams, bridges, large subway areas, ships and tunnels [1–4].

However, due to the shear resistance of the fiber grating is poor, it is easy to break. So the FBG sensor used in civil engineering structure must be encapsulated to protect. An optical fiber usually consists of three layers: fiber core, cladding, and coating. The diameters of the core and the cladding are 9 μm and 125 μm respectively, as shown in Fig. 1. The fiber core and the cladding have the same mechanical property with the material of silica glass. The coating outside the cladding is usually made of plastics to protect the fiber from damage or moisture absorption. In general, the diameter of coating layer is about 250 μm.

Embedment and the surface layout of FBG sensor are the main two ways in engineering application. According to the different arrangement, the strain transfer efficiency is different significantly. Therefore, it is crucial to obtain the relationship between the measured strain and the ture strain in the condition monitoring of FBG. Over the past decades, the strain transfer

* Corresponding author at: Key Laboratory of High Performance Ship Technology (Wuhan University of Technology), Ministry of Education, Wuhan 430063, China.
E-mail address: shenwei_abc@163.com (W. Shen).

https://doi.org/10.1016/j.ijleo.2017.10.097
0030-4026/

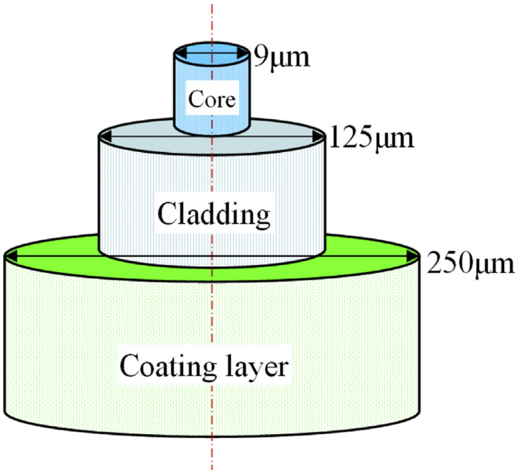

Fig. 1. The basic structure of fiber Bragg grating.

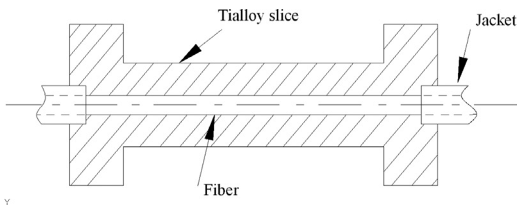

Fig. 2. Substrate encapsulated FBG sensor.

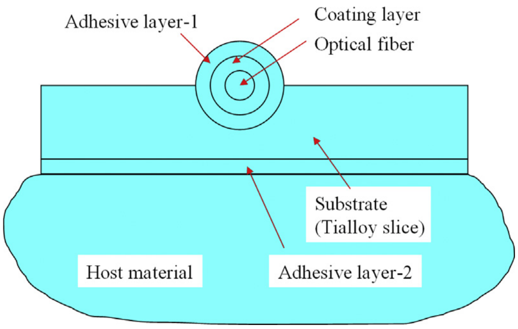

Fig. 3. The model of the substrate-bonded FBG sensor.

mechanism of embedded FBG has been researched thoroughly, due to the convenient arrangement of embedded FBG. Pak [5] analyzed the strain transfer of a coated optical fiber embedded in a host composite. Ansari and Yuan [6] obtained the distribution of the axial strain and interlaminar shear by assuming the centre strain of fiber is equal to the strain of the host material. Li et al. [7] considered the coating as an ideal elasto-plastic material and deduced the strain transfer coefficients under the conditions that the coating has elastic, elasto-plastic, and plastic deformation. Li et al. [8] developed an simple model to analyze the strain transfer rate of embedded FBG sensor under nonaxial stress.

One of the other important application forms of FBG is to measure strain by pasting on the surface of structure. Compared with the embedded FBG, the way of measuring stains with surface pasted FBG, has more important theoretical and practical significance. Wu et al. [9] established a multi-layer strain transfer model which included fiber core, substrate, adhesive layer and host material. Sun et al. [10] analyzed the main factors that influence strain transfer and put forward the method to increase the strain transfer rate of the surface pasted FBG. In the practical applications, in order to improve the strength of surface-bonding FBG, packaging substrate made of metal slice, e.g. Titanium alloy, was designed and applied. As shown in Fig. 2, the surface FBG sensor is pasted in the groove of substrate, and then pasted on the surface of the host material. There are optical fiber, coating layer, adhesive layer-1, substrate, adhesive layer-2 and the host material (see Fig. 3) in the whole model. The protective layer and adhesive layer result in inconsistency between the optical fiber strain and the structural strain, and the strain transfer error will be generated in the practical application. Therefore, this paper used the theoretical derivation