Available online at www.sciencedirect.com
ScienceDirect
Pacific Science Review 16 (2014) 8–18
www.elsevier.com/locate/pscr

Advances of strain transfer analysis of optical fibre sensors

Huaping Wang, Zhi Zhou*

School of Civil Engineering, Dalian University of Technology, China

Available online 16 September 2014

Abstract

The test precision optical fibre sensors are increasingly important due to the widespread application of optical fibre sensing technology in structural health monitoring. Strain transfer analysis, which can be used to determine the action mechanism and to improve the precision of these sensors, is therefore an important issue. The earliest research started in the 1990s, and many excellent achievements have been obtained based on traditional elastic theory and stress transfer analysis of composites. A variety of strain transfer deductions appear to describe the differences in the mechanical models, assumptions and boundaries. A comprehensive discussion and brief review of representative strain transfer analyses is conducted, and some problems that urgently need to be addressed are stated. In addition, the developing trends in this subject are mentioned. The work in this article provides valuable guidance for understanding the research advances in strain transfer analysis, which will ultimately serve for the strain transfer error modification of optical fibre sensing models.

Keywords: Strain transfer analysis; Optical fibre sensors; Structure health monitoring; Error modification

Introduction

Optical fibre is the most popular sensing element, due to its excellent long-term stability, durability, good geometrical shape-versatility, corrosion resistance, electromagnetic interference resistance, low cost and high precision. It has been widely applied in the aeronautics, energy, civil engineering, and nuclear environmental fields [1,2]. Because bare optical fibre is vulnerable to harsh environments, encapsulation technologies were developed to provide protection. Therefore, the test precision of packaged optical fibre sensors has become an important issue that is studied by many scientists. For strain sensors, high-precision detection is defined as the detected strain infinitely close to the true strain of the host material. However, a part of the strain of the host material is absorbed by the middle layer (usually composed of a protective layer and an adhesive layer) in the transfer process before being recognised by the fibre core.

The strain lost is called the strain transfer error and is influenced by the materials and encapsulation technology. The strain transfer analysis is developed to establish the quantitative strain relationship of host

* Corresponding author.
E-mail addresses: wanghuaping1128@sina.cn (H. Wang), zhouzhi@dlut.edu.cn (Z. Zhou).
Peer review under responsibility of Far Eastern Federal University, Kangnam University, Dalian University of Technology, Kokushikan University.

http://dx.doi.org/10.1016/j.pscr.2014.08.002

material and optical fiber. The different mechanical models, assumptions and boundaries used in the deduction leads to the birth of diversiform strain transfer theories. The immethical theory indicates immature applications, which cannot aid in the design of industrial sensors [3]. Therefore, a systematic strain transfer theory that has an intimate relationship with optical fibre sensing models is required.

The earliest research on strain transfer analysis started in the 1990s and used only elastic theory to analyse simplified mechanical models [4,5]. Improved strain transfer theory [6] was formed later based on the stress transfer mechanism of composites [7]. Since then, this field has grown because of the demands of practical engineering problems.

Based on these factors, advances in strain transfer analysis using optical fibre sensing models will be discussed in this article. A comprehensive discussion and brief review using representative strain transfer analysis will be conducted. Moreover, some problems that urgently need to be addressed will also be discussed, and the developing trends in this field will be mentioned.

Basic conception of strain transfer analysis

Bare optical fibres and fibre Bragg gratings are brittle and vulnerable to harsh environments. Therefore, encapsulation is required to protect them. As a consequence, a middle layer between the sensing element and the host material is created. Strain of host material firstly makes the middle layer deformed, and then arrives at fiber core. Some of the strain is dissipated by the middle layer, the magnitude of this dissipation is greatly influenced by the materials, packaging and bonded length. Strain transfer analysis that focuses on establishing the relationship of strains of optical fibre and host material in multi-layered models is introduced. The ratio of strain sensed by the optical fibre and the strain of host material is called the strain transfer coefficient.

Brief introduction of the existing theory

Strain transfer analysis, which reflects the action mechanism and improves test precision, has received considerable attention due to the extensive use of optical fibre sensors in various engineering fields. Initial research on discussing the relationship between the measured strain of embedded optical fibre and the real values started in 1991, which was limited by special hypotheses and sizes [4]. The strain transfer relationships for embedded optical fibre sensors were determined by simplifying the model as an infinite elastic body and considering it as equivalent plane strain problem. However, these assumptions were too ideal to use in practical cases [5]. In 1998, improved strain transfer theory was achieved for the first time by introducing the stress transfer analysis of composites [6,8,9]. The following research on the strain transfer analysis of different models was extracted from real engineering problems and conducted in succession. Several outstanding strain transfer deductions will be discussed in detail in the sections below.

The parameters $\sigma_m/\varepsilon_m/\tau_m$, $\sigma_f/\varepsilon_f/\tau_f$, $\sigma_p/\varepsilon_p/\tau_p$ and $\sigma_a/\varepsilon_a/\tau_a$ stand for the normal stress/strain/shear stresses of the host material, fibre core, protective layer and adhesive layer, respectively. The letters r_m, r_f, r_p and r_a indicate the radius, and the variables u_m, u_f, u_p and u_a indicate the displacement of the host material, fibre core, protective layer and adhesive layer, respectively; 2L is the bonded length.

Theory deduced by Farhad Ansari [6]

The three-layered mechanical model used in the deduction is shown in Fig. 1. The assumptions, boundaries and primary processes of the strain transfer theory based on typical elastic mechanics are as follows.

Assumptions

1) The bonded length L is supposed to be far greater than $(r - r_f^2)$, which produces $(r^2 - r_f^2)/L \approx 0$;
2) The displacement increments relationships between the host material, fibre core and protective layer obeys the summation $u_m = u_f + u_p$;
3) By ignoring the axial variation in the radial displacement, the simplified Hooke's law for shear strain is rewritten as $\gamma_p(r, x) = du/dr$;

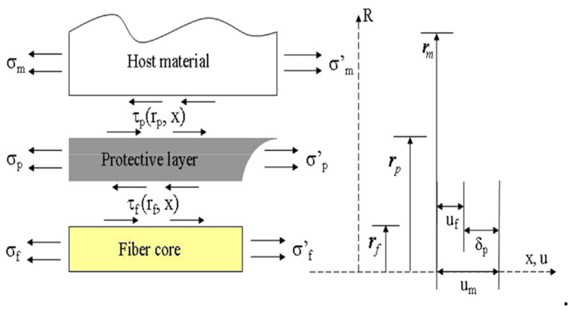

Fig. 1. The three-layered mechanical model.