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Advances of FRP-based smart components and structures

Yung William Sasy Chan*, Zhi Zhou

School of Civil Engineering, Dalian University of Technology, China

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Abstract

Fibre-Reinforced Polymer (FRP) composites have been widely used in civil engineering for the past two decades. This paper presents an overview of the smart components and structures based on FRP. The basic principles of intelligent structures made of FRP and Optical fibre sensors are introduced. Some significant up-to-date smart elements used as reinforcing and health monitoring structures are also described in detail. Moreover, certain applications of smart FRP systems in civil engineering are briefly mentioned. Smart bars based on FRP are found to be very useful and could replace conventional steel. In addition, FRP-OF-OFBG is one of the most advanced techniques for local and global monitoring. However, interface strain for externally reinforcing systems requires specific characteristics to overcome debonding effects. Finally, analysis of the problems of existing applications based on carbon fibre composites are highlighted, followed by a description of some possibilities of new designs of smart FRPs.
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Keywords: Fibre-reinforced polymer (FRP); Optical fibre; Smart sensor; Smart structure; Structural health monitoring

Introduction

In recent decades, smart structures and components have been developed as an interesting means to monitor civil engineering infrastructures [1,2]. Indeed, all structures and/or parts with an integration of sensors and/or actuators systems are classified as "Intelligent structures". These intelligent structures are able to perform self-structural health monitoring and/or provide an actuating response without human intervention. Moreover, the new and existing large infrastructure projects being built everywhere are suffering from different forms of deterioration. Thus, smart systems facilitate the performance of Structural Health Monitoring (SHM) tasks, ranging from the construction phase to the service phase [3].

Traditional methods using conventional sensors have been applied to detect the key parameters of structures in the past few decades. Many sensors (electrical strain gauge, accelerometer, etc.) have been installed for the integrity evaluation of bridges, dams, buildings, and so on [4,5]. However, these techniques present some limitations for widespread application, such as durability and high cost. Moreover, due to the new trends of smart materials, standard transducers have been replaced by intelligent sensors. Currently, most detectors are based on smart materials, such as piezoelectric materials, Shape Memory Alloys

* Corresponding author.
E-mail addresses: sasychanwill@yahoo.com (Y.W. Sasy Chan), zhouzhi@dlut.edu.cn (Z. Zhou).
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(SMAs), electro-magneto-rheological fluid, and fibre optics [6−8]. Hence, all smart structures to date are based on the properties of the smart materials used in the design. In other words, the performance of the sensors and the quality of the data depend on the advantages and disadvantages of the materials utilised.

The concept of an intelligent structure is based on safety and economic improvement concerns, weight and time savings, sensing, and auto-control. For these reasons, many attempts of actuating and/or sensing systems have been introduced by researchers. For example, a smart aggregate-based active-sensing system was introduced to evaluate the severity of damage to a concrete shear wall; using this system, the fragility of the PZT patch, when directly embedded into concrete, could be overcome [9]. Smart self-healing Reinforced Concrete (RC) beams comprised of superelastic SMA and containing fibre optic sensors for temporary repair cracks were demonstrated in [10]. The self-repair of fissures by embedding SMA wires into concrete was also developed, but thermal or electrical actuation is required as an activation [11]. Long-term monitoring of a concrete bridge by using many types of Fibre Optic (FO) sensors has been proposed in some reports in the literature. Fibre Bragg Grating (FBG) sensors bonded at the surface or integrated into concrete with stainless steel or epoxy resin encapsulation techniques were used in [12]. Moreover, proof ABS enclosures were used for the Tsing Ma Bridge to protect the FBG sensors from moisture and dust [13]. Nevertheless, these methods seem to be inconvenient for durable health monitoring due to the fragility of glass fibre, difficulties of sensor installation, and corrosion effects of certain materials.

Composites of fibre reinforced polymer (FRP), such as carbon fibre, have been used in aerospace for many decades for aircraft frame production. These composites possess good mechanical properties, such as high tensile stress, high young modulus in the fibre direction, lightweight, and so on [14]. The applications of composites in Civil Engineering began in the early 1980s for the rehabilitation and repair of damaged structures. These composites could also be used as reinforcing elements for new projects to replace conventional materials, such as steel bars [15]. Furthermore, these composites have been used to package Fibre Optic sensors with good strain sensitivity similar to the bare OFBG. Therefore, much research has been performed to produce smart components based on FRPs and Fibre Optic sensors. In spite of the efforts performed to date, further progress is still required for the successful implementation of smart components for damage detection, long-term monitoring, high accuracy measurements, and so on.

In this paper, the basic principles of smart components are presented in detail, followed by a brief description of some optical fibre sensors. In addition, some significant existing advances in smart FRP systems and their applications in civil engineering are individually described. Finally, a brief discussion of the challenges facing the current systems and proposals to address these challenges are established.

Basic principles

Smart components rely on: (1) the sensing principles of the optical fibre sensors used and (2) the properties of the FRP for the mechanical performances. Fig. 1 illustrates the basic principles of a smart system based on FRP and Optical Fibre sensors (OFS). A brief introduction of the commonly used fibre optic sensors and FRP materials are given below.

Fibre optic sensing

Optical fibre sensors are very promising tools for sensing due to their potential advantages, such as immunity to electromagnetic interference, high sensitivity, high corrosion resistance, being small in size, non-electrical sensor, and so on [16].

In addition, optical fibre sensors respond to a change in optical intensity, phase, frequency, polarization, wavelength, or mode when exposed to environmental effects [17]. Many types of optical fibre sensors have been reported in the literature, including Bragg Grating, distributed sensing (BOTDA, OTDR), Fabry-Perot Interferometry, Long gauge Grating, SOFO, and so on. Among them, Fibre Bragg grating

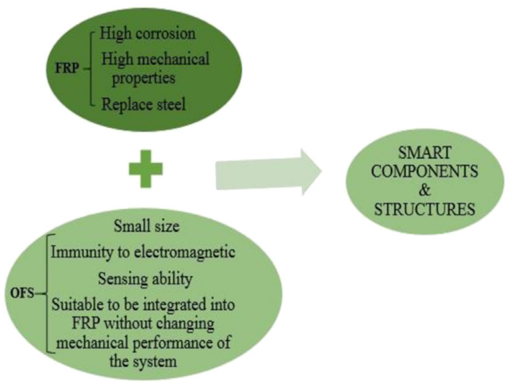

Fig. 1. Schematic process of the formation of smart components based on FRP and optical fibre sensors.

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