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Concrete beam crack detection using tapered polymer optical fiber sensors

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ABSTRACT

In this paper, a tapered polymer fiber sensor (TPFS) is employed to detect the crack of Concrete Beam (CB). The sensing principle for crack detection is simply described based on V-number theory. The experiments are carried out by cement mixture mixed with high reactive powder to form the CB, in which the TPFSs are embedded and surface glued. Thermocouples and strain gauges are also embedded to calibrate and determine the ambient temperature and applied strain, meanwhile, the Linear Variable Differential Transformer (LVDT) sensors are used to measure the deflection of the CBs. Four points loading test is applied for several samples to evaluate the sensors' ability for monitoring the beam deflection and crack. Experimental results also indicate that the TPFSs can be used for post-crack detection.

1. Introduction

Nowadays, in a Structural Health Monitoring (SHM) system, sensor techniques are playing an important role on monitoring not only the structural status, such as stress, displacement, acceleration, crack, but also influential environment parameters, for instance wind speed and temperature [1]. In the using of sensor techniques, conventionally, most of them are based on transmission of electric signal which issues many disadvantages, such as, the sensor heads are too big or not durable enough to measure interior properties when embedded it into a structure; the sensors are point sensing for only one parameter at one location and cannot be easily multiplexed; the transmission signal is easily perturbed by Electrical or Magnetic Interference (EMI). Compared with the conventional sensors, however, fiber optic sensors provide promising sensing in civil SHM system. Fiber optic sensors are easily embedded into the host specimen, are easily multiplexed and distributed, have long life cycle, and are EMI free, etc. [2]. Therefore, optical fiber based sensor system is one of the most frequently used techniques for modern SHM in concrete structures, such as, for steel reinforcement corrosion, temperature, vibration, strain and crack.

An assessment of cracks in a CB is crucial for the safety of concrete structures. The concrete structure degrades through the formation and propagation of cracks. The crack width beyond 0.2–0.4 mm may induce durability problems and corrosion of the steel reinforcement [3]. Crack width larger than 2 mm is a sign of damage and may require closing the facility immediately. Crack information is significant and can be used to adopt the appropriate rehabilitation method to fix the cracked structure and prevent any catastrophic failure [4]. Therefore, the way to get the crack information is becoming an indispensable approach to assess the health of a structure. In the past,

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many efforts have been made to detect the crack in a concrete structure, including, the processing of crack image [5], piezo-ceramic transducers [6], acoustic microscopy [7], and fiber based techniques [8–10]. The conventional crack detection technique is a point sensor that easily misses the crack because it detects the strain at a local point. To overcome this disadvantage, a distributed fiber sensor techniques, named Brillouin Optical Time Domain Reflectometry (BOTDR) was employed by Wu et al. [11] to study the crack in concrete structural. In their study, two basic optical fiber installation methods, overall bonding installation and point fixation installation were proposed and investigated experimentally for a reinforced concrete bending beam. The experimental results showed that the n-round superposition installation method could detect the total crack width effectively and correctly with a relatively local region [12]. FBG is one of the most popular methods for crack detection. An embedded FBG was used to monitor cracking deep within the concrete specimens [13]. By using the embedded FBG, the internal cracking can be assessed and the degree of cracking is determined between the bandwidth of the FBG sensors, the differential strain across the grating.

Besides, Polymer Optical Fiber (POF) based sensor techniques have been investigated to detection many parameters, i.e. refractive index [14], displacement [15], strain, crack, etc. Crack detection using POF has received much attention due to POF sensors' many advantages over glass based optical fiber sensor, including low cost, ease of termination and coupling, high resistance to fracture, high elastic module, etc. Kuang et al. [16] employed the POF to monitor the initial cracks, post-crack vertical deflections and failure cracks in concrete beam and steel reinforced concrete beams subjected to three or four-points flexural bending test. Experimental results have shown that the intensity of light decreased gradually until the cracks appeared at the peak loading, resulting in a dramatic drop in intensity of the POF sensor. By monitoring the intensity of the light, therefore, the deflection and crack propagation can be recognized. The sensor probe was fabricated by removing part of cladding and attaching it to scale-model concrete samples. Experimental results have shown that partially removing the fiber cladding induces the enhancement of sensor's strain sensitivity. Most recently, Zhao et al. employed the POFs as a sensor to detect the concrete crack. Of which, two types of POF with diameters of 0.25 mm and 0.5 mm were utilized and the POF sensor with diameter of 0.5 mm has higher crack detection sensitivity. Experimental results shown that the output light intensity of POF sensor is decreased gradually with the crack width propagation in between of 1 and 6 mm [17].

In this paper, the TPFSs are used to study the crack detection in CBs. The crack detection principle using TPFS is described by employing the V-number theory. Four points loading test is applied for several samples to evaluate their ability for monitoring the crack and beam deflection. For crack detection, the scale-model CBs and full scale reinforced CBs are used, in which the TPFSs are embedded. In addition, some TPFSs are mounted on the surface of the CBs in order to explore the sensor performance affected by the sensor installation approaches between the embedded sensors and surface mounted sensors. The LVDT sensors and strain gauges are employed to detect the deflection and strain of the CBs when the CBs are being load tested.

2. Sensing principle of TPFS

By reducing the diameter of an optical fiber through tapering process, the strain sensitivity can be enhanced significantly. This is mainly due to the effect of stress concentration (geometric discontinuities cause an object to experience a local increase in the intensity of a stress field). The tapered section may suffer more stress than that of standard fiber both sides, leading to improved strain sensitivity. Based on this principle, we have employed the TPFS as a strain sensor to detect the crack in the concrete beam. The configuration of an Embedded TPFS (ETPFS) for crack detection is shown in Fig. 1. For a loaded CB, the properties of ETPFS involve two separate parameters, namely, photo-elastic effect and mechanical effect. The photo-elastic effect induces the change of refractive index in fiber core and the deflection of TPFS considers as the effect of mechanical property. Accordingly, the theoretical analysis of crack detection principle is based on those two involved effects. A V-number theory is employed to analyze the crack detection principle of embedded TPFS. V-number is a parameter to describe the number of propagation modes guided by the optical fiber which is defined by [18],

$$V = \frac{2\pi r}{\lambda}\sqrt{n_{co}^2 - n_{aq}^2} \quad (1)$$

where r is the fiber radius, λ is the transmitted light wavelength, n_{co} is the refractive index of fiber core, and n_{aq} is the refractive index of surrounding medium.

As shown in Fig. 1, the number of transmission modes are determined by the tapered fiber radius r_0, the refractive index of fiber core $n_{co,}$ and the refractive index of cement paste n_{aq}. It is assumed that the refractive index change

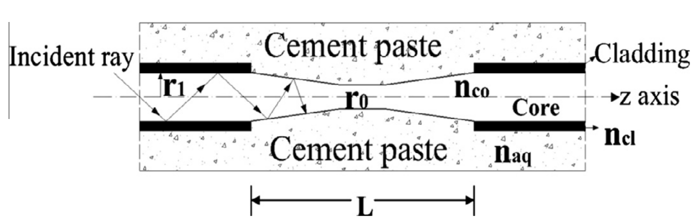

Fig. 1. Configuration of tapered polymer fiber for embedded into the CB.