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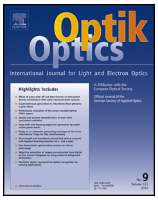

Original research article

Optical fiber sensor encapsulated by polyurethane

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ABSTRACT

Fiber Bragg gratings (FBGs) are ideally suited for monitoring strain in civil structures, aircrafts, ocean engineering due to their low cost, reliable and high accuracy. A new encapsulation technology for FBG using polyurethane is proposed to help the sensor withstand large displacement in hash environment. This paper aims to provide experimental packaging procedures, calibration and field tests of developed FBG sensors for strain measurement. The principles, basic chemical reaction processes and prepare procedures of polyurethane are demonstrated. Suitable protective encapsulation to the bare fiber by polyurethane ensures that there is no relative slip at the interface. The encapsulated FBG sensor has good linearity from the result of calibration test conducted on a universal testing machine. Further the sensor is embedded into the freezing soil to evaluate the performance in severe environment.

1. Introduction

When components of engineering system such as spacecraft, plane, civil, ocean equipment fail, human life is at risk. Structural health monitoring (SHM) is intended as a diagnostic unit, able to recognize the presence of an anomaly and to provide automated damage detection capabilities. First, the ability to quickly and accurately evaluate the condition of engineering structure under static/shock or cyclic loading, is critical to maintain the safety of human [1]. Another reason to pursue health monitoring system involves the reduction of operational and maintenance costs. However, in spite of exhaustive research efforts devoted to SHM, only a few have been fully validated for practical engineering structures. Accurate and reliable monitoring method is a perennial problem for complex system.

FBG is the best choice for long-term SHM for its small physical dimension, high accuracy, low cost and reliable durability. However, bare optical fiber is vulnerable in shear stress, and therefore, encapsulation is essential and require careful design before application [2–7]. This paper demonstrates with the aim to provide packaging plan to prepare FBG sensors. Compared with mechanical sensors, FBG sensors are light, flexible, immune to electro-magnetic interference (EMI), long-term stability, and can be easily multiplexed in a large-scale distributed strain monitoring network [8–13].

Polyurethane is a resilient, flexible and durable manufactured material that has been used in a wide range of items. It can be hard, squishy, protective, bouncy or sticky by design and fabrication [14,15]. The reliability and sensitivity of the optical fiber sensor can be designed by altering elastic modulus of polyurethane. By selecting different types of encapsulation method,

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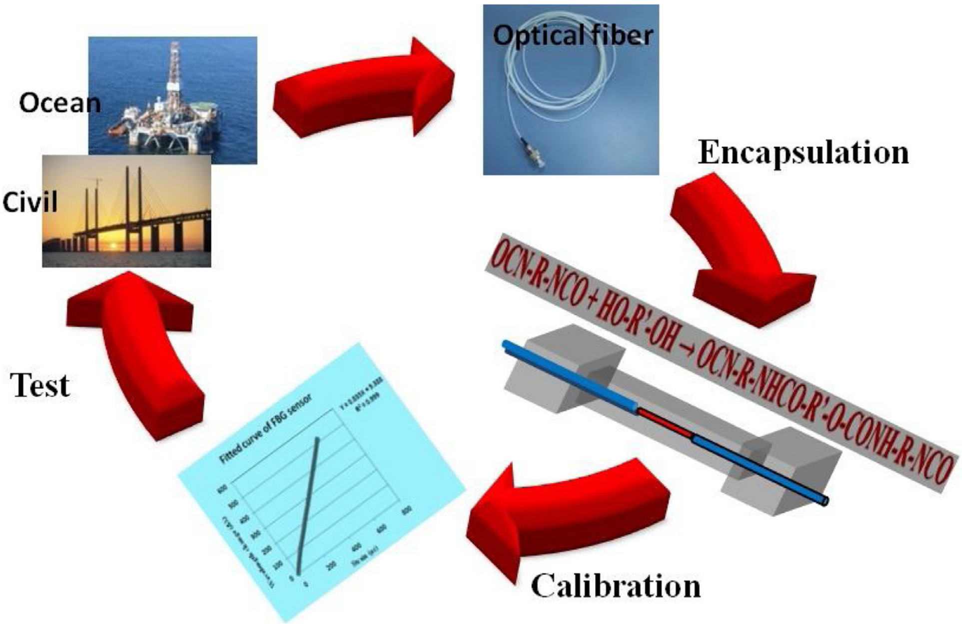

Fig. 1. FBG sensor. Schematic showing encapsulation (using polyurethane), calibration and tests of FBG sensor.

the properties of optical fiber will be improved, especially the shear stress. The FBG sensor with polyurethane encapsulated has potential be applied in SHM of hash environment such as spacecraft, significant civil and ocean engineering.

Currently, few references have been found related to using polyurethane as encapsulation of fiber sensor [16,17]. As shown in Fig. 1, the objective of this research is to provide detail packaging steps (Section 2) and calibration of the sensors (Section 3). Lab tests are carried out to evaluate the performance of the proposed sensors in dry, wet or frozen environment with different pressure, temperature (Section 4).

2. Detail encapsulation steps for FBG sensor

Basically, polyurethanes are produced by reacting an isocyanate containing two or more isocyanate groups per molecule (R—(N=C=O)n) with a polyol containing two or more hydroxyl groups per molecule (R'—(OH)n), which results into a polymer containing the urethane linkage (—RNHCOOR'—) with a characteristic crosslinking network. It is worth mentioning that, by selecting different types of isocyanates and polyols, elastic and rigid polymer can be achieved with flexible segment and crosslinking structure, respectively. The sensitivity of the optical fiber sensor can be designed by altering elastic modulus of polyurethane. Polyurethane is a kind of block polymer consisting of a hard segment and a soft segment which is connected by a carbamate bond. The soft segment is dispersed phase macromolecular diol, which occupies 80%–90% of the mass in polyurethane, and the molecular weight is generally in the range of 1000–2000. Maked Pu material is endowed with the characteristics of retraction and stretch by the soft segment. The hard segment is isocyanate and contains a variety of polar groups, which makes polyurethane a good resilience and strength. And there is a mass ratio of 10%–20% in Pu. The phenomenon of several adjacent hard segments to intermolecular forces together, tightly together into clusters or form "bound node" area, thus formed the discontinuous phase and scattered in the soft segment, is the micro phase separation. In terms of raw materials, the properties of polyurethane are determined by the properties and molecular weight of the components of the soft segment and the components of polyester or polyether. Changing the composition of the soft segment of a molecule can change the compatibility between the soft segment and the hard segment, thus changing the properties of the material and improving the elastic modulus of the material. Thus polyurethane's performance can be changed by controlling the structure of phase and degree of micro phase separately [18].

Choosing different isocyanates and polyols, as well as other additives and processing conditions brings a wide range of properties of polyurethanes, which makes FBG sensors have different encapsulation design.

Raw materials used in this study are prepolymer and MOCA with the mass ratio of 100:18. Basic chemical reaction processes are shown in Fig. 2.

The encapsulation steps are schematically shown in Fig. 3. We adopt prepolymer method to synthesize casting PU elastomer. At first step, prepolymer is heated to a temperature in vacuum drying oven of about 80 °C to eliminate bubble inside. By heating in the Electric jacket, the melted MOCA is mixed in hot polyurethane pre-polymers. The mixture is uniformly stirred for 1 min and put into vacuum drying oven again for 3 min.