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Investigation of acoustic emission source localization performance on the plate structure using piezoelectric fiber composites

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ABSTRACT

Due to its unique structure, piezoelectric fiber composites (PFCs) is receiving more and more interests in the field of structural health monitoring. In this paper, PFCs was fabricated and used as an acoustic emission sensor. The simulated signal was generated by a pencil lead break on an epoxy plate and the localization of source was measured based on acoustic emission technology. The results showed that PFCs exhibited an apparent directional sensitivity owing to its unique electric field and architectural heterogeneity, which was different from the conventional piezoelectric disc and 1–3 composite sensors. When the acoustic emission source was located along the fiber length, the PFC sensor could provide precise location information no matter how long the distance between the source and sensor was. The planar localization performance demonstrated that PFCs presented a higher accuracy in the direction normal to the fiber length than in other directions owing to the directivity of PFCs sensor's response. These special differences of PFCs could be validated by the sensitivity factors in various directions The high sensitivity ensured PFCs possessed a capability of reliable and precise localization that was comparable to a conventional PZT disc sensor.

1. Introduction

Structural health monitoring (SHM) is an emerging technique that is used to evaluate structures, detect deteriorations and ensure structural integrity and safety. Recently numerous researches have been conducted to investigate different types of devices and sensors in the SHM system to evaluate their performance and durability. Piezoelectric materials, especially PZT (lead zirconate titanate) is widely used in various situations [1,2]. However, the brittle nature of monolithic piezoceramic leads them to be vulnerable to accidental impact and hardly conform to curved structures. These drawbacks and the high mass density restrict their applications in many areas, particularly in curved or irregularly shaped and flexible or lightweight structures. Piezoelectric fiber composites (PFCs) sensor consists of unidirectionally aligned rectangular piezoelectric fibers sandwiched between two sheets of interdigitated electrode film, in which interdigitated electrode fingers were normal to the fiber length. This unique electrode configuration provides the electric field that exploits in-plane d_{33} piezoelectric effect instead of d_{31} piezoelectric effect used in traditional monolithic piezoceramics. The directional electric field provides PFCs sensor the ability to tailor the direction of actuation or sensing capability [3]. Except for increased sensitivity PFCs sensor exhibits a comparable durability, robustness to damage and flexibility to PVDF (polyvinylidene fluoride) sensor. Additionally the thin sheet construction also provides PFCs the potential to be embedded in a composite structure to build an integral SHM system [4,5].

In 2001, a study was first conducted to investigate the characteristics of PFCs sensors with ribbon fibers on panel structures [6]. The results verified PFCs sensors had the potential use in large structures for SHM while reducing the cost, complexity, number of channels of data acquisition and the weight of monitoring instrumentation. Barbezat et al. [7] confirmed that PFCs had an anisotropic sensitivity and revealed mounting methods had significant influences on the sensitivity. Eaton et al. [8] found a good agreement of acoustic emission (AE) trends recorded by both a PFCs sensor and a commercially available sensor on carbon fiber coupon specimens. Gonzalez Carrato et al. [9] presented a novel pattern recognition approach for a non-destructive test based on PFCs sensor applied in pipes. The application of PFCs for sensingdelamination in antisymmetric laminates was reported by Krishna [10], who confirmed that damage could be determined from the difference in the PFCs sensor responses. Castro et al. [11] carried out a study of assessing the feasibility of PFCs sensors to measure AE signals from partial discharges in power transformers filled with mineral oil, which indicated a good sensitivity of the PFCs sensors

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with the high correlation between the results obtained by the PFCs sensors and the conventional sensor.

In an SHM system, the damage localization could be achieved by identifying and diagnosing changes in the static and dynamic features of the structure. In Gómez Muñoz's work [12], the PFCs sensor showed a high accuracy to detect and locate a simulated AE source in a wind turbine blade. Lee et al. [13] utilized sixteen PFCs sensors to generate ultrasonic waves to visualize damage locations in a pipeline structure. Cui et al. [14,15] monitored and evaluated the growth, size and orientation of axial cracks in cylindrical structures using torsional wave generated by PFCs sensor. Pearson et al. [16] demonstrated that PFCs possessed a decreasing correlation of signals with increasing damage severity and a real possibility for identifying and sizing impact damage in composite structures. Matt et al. [17,18] proposed a satisfactory method for locating AE sources utilizing two rosettes made of six PFCs sensors in anisotropic or geometrically complex structures, in contrast to the conventional time-of-flight source location requiring information on wave velocity. Salamone et al. [19] conducted impact location tests in a high-velocity regime that showed satisfactory results on both isotropic aluminum panels and woven composite panels.

Though many researches had been conducted to investigate the damage detection performance of PFCs sensor, few studies have provided the detailed localization information and the limited information available was usually obtained from a system requiring a large number of PFCs sensors. The aim of the present work was to fabricate a PFCs sensor and study its sensing and localization performance using the AE technique compared with conventional AE sensors. Firstly, a comparison in sensitivity of PFCs sensor with conventional PZT disc and 1–3 piezoelectric composite sensors was carried out. Then the linear planar localization performance were investigated with only two and four PFCs sensors, respectively. Finally the different localization characteristics of PFCs in various directions were further evaluated.

2. Experimental procedures

2.1. Materials and procedures

Firstly, PZT-51 piezoceramic wafers with a thickness of 200 μm were cut from a piezoceramic block (Zibo Yuhai Electronic Ceramic Co. Ltd.). Then rectangular cross - sectional piezoceramic fiber sheet was obtained by further dicing the PZT-51 wafer. During this process, the width of fiber was set to be 250 μm and the gap between fibers was 100 μm. Interdigitated electrodes (Xufei Electronics Technology Co., Ltd.) and epoxy resin (Huntsman Corporation, China) were later used to assemble PFCs. And the interdigitated electrodes had an active area of 28 mm × 7 mm with an electrode finger width of 60 μm and neighbor-neighbor electrode finger distance of 800 μm. Two steps of curing were adopted in the assembly process. In the first step, one interdigitated electrode sheet and the fiber sheet adhered on an adhesive polymer film membrane were packaged with epoxy resin. It was necessary to ensure that the epoxy resin fully filled the gaps between the fibers. After 10 min curing at a pressure of 1.5 MPa and a temperature of 65 °C, the adhesive polymer film membrane was peeled off to form a partial assembly. In the second step, another interdigitated electrode sheet and the obtained partial assembly were packaged with epoxy resin again. The curing time of 45 min was adopted to ensure epoxy fully cured. During the whole assembly processes the application of pressure and temperature was used to ensure a direct and good contact between electrode fingers and fibers. Defects, i.e. epoxy voids should be avoided from causing an electric breakdown during poling and operation processes. Most importantly, a good alignment of the two interdigitated electrode sheets in PFCs must be guaranteed to yield the satisfactory performance. Finally, the polarization of PFCs was conducted at room temperature in methyl silicone oil with a constant DC voltage of 1.8 kV for 20 min. An illustration of the structure and an image of a typical PFC were shown in Fig. 1(a) and (b), respectively.

2.2. Characterization

Pencil lead break, namely the Hsu-Nielsen source, was used to generate a simulated AE source. During testing, the simulated AE sources were generated by a pencil lead with 0.5 mm diameter and 2H hardness. Then AE signals were acquired through the AE system (Physical Acoustic Corporation, USA) for data acquisition and analysis. The detection threshold of AE signal was set to be lower than 40 dB. Preamplifier gain and filter were set to be 38 dB. All signals are band-pass filtered between 20 and 400 kHz.

Experiments were conducted on an isotropic epoxy plate with dimensions of 500 mm length, 500 mm width and 5 mm thickness. Three experiments were carried out using different numbers of PFCs sensors in different configurations. In the first test, sensors including PFCs, 1–3 piezoelectric composite and piezoelectric disc were reversibly mounted on the center of the plate respectively, as schematically depicted in Fig. 1(c)(i). Petroleum jelly was used as the coupling agent. The simulated AE sources were measured each time at angular intervals of 22.5°. And the diameter of PZT disc was 20 mm and the thickness was 1 mm, 1–3 piezoelectric composite had dimensions of 20 mm length, 20 mm width and 10 mm thickness. The following two tests were set to investigate the linear and planar localization performances respectively. The configurations were depicted in Fig. 1(c)(ii) and (iii). Two or four PFCs were permanently mounted on the epoxy plate using a quick-setting adhesive. The purpose of a permanently mounted method was to acquire stronger and more stable signals to guarantee more precise localization results. In these two tests, several different source locations were adopted to study the localization performance. It was worth noting that all PFCs had its fibers aligned 0° in all experiments.

3. Results and discussion

An investigation into the sensitivity of different piezoelectric sensors was conducted and the values of signal amplitude and voltage were presented in Fig. 2. During the test, the AE source was located at a fixed distance of 60 mm from the center of the sensor. Clearly, differences in the sensitivity of these three sensors were apparent. At 0°, for example, the PZT disc sensor acquired the lowest signal amplitude and voltage of 55 dB and 510 mV. The sensitivity of 1–3 piezoelectric composite was better. Meanwhile, the PFCs sensor demonstrated the highest sensitivity with the largest signal amplitude and voltage of 74 dB and 1200 mV. This phenomenon could be attributed to the fact that as the signal propagated to the interface between the PZT disc sensor and epoxy plate, a large amount of energy was dissipated due to the huge mismatch of their acoustic impedances. The addition of epoxy with low acoustic impedance into the 1–3 piezoelectric composite and PFCs sensors could reduce their acoustic impedances to achieve a good match between the sensor and the epoxy plate. Thus it was beneficial for the effective propagation of signals and for improving sensitivities of sensors.

From this figure, it was evident that the AE source amplitude and voltage acquired by both the PZT disc and 1–3 piezoelectric composite were insensitive to the tested angle. It indicated that these two sensors had isotropic sensitivities and could receive signals from any direction. This characteristic of these two sensors could be attributed to the fact that the AE source propagation plane was