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Combined embedded and surface-bonded piezoelectric transducers for monitoring of concrete structures

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ABSTRACT

Piezoelectric lead zirconate titanate (PZT) transducers are increasingly used for monitoring various engineering structures. PZT transducers are used for monitoring structures based on the electro-mechanical impedance (EMI) for a single PZT and the wave propagation technique for multiple PZTs. In concrete structures, the EMI sensing region is small due to high damping of the concrete. Using the wave propagation technique with high actuation voltage, a larger area can be monitored. The smart aggregates (embedded PZT transducers) can be employed using the wave transmission technique to monitor very large areas with a reasonably low actuation signal. The combination of smart aggregates (using the wave transmission technique) with surface bonded PZTs (using the wave propagation technique) can provide an effective method to study both the local and overall conditions of the structure. In this work, a concrete beam with the dimensions of $220 \times 40 \times 20$ cm was cast and nine PZT transducers were embedded or attached on the beam. The PZT readings were correlated with the damage on the structure. Combination of smart aggregates (using the wave transmission technique) with surface bonded PZTs (using the wave propagation technique) for SHM was studied. The results show that this combination provides an effective way to assess both the local and overall conditions of the structure.

1. Introduction

Due to increasing number of important infrastructures and the catastrophic consequence of failure, structural health monitoring (SHM) has attracted intensive research attention in the last two decades. In particular, the piezoelectric lead zirconate titanate (PZT) transducers based SHM techniques have been studied intensively for their potential applications in civil, mechanical and aerospace engineering [1–6].

PZT transducers are used for monitoring structures based on the electro-mechanical impedance (EMI) technique and the wave propagation technique, both relying on the elastic wave propagation in solids. In the EMI technique, one PZT transducer usually serves as both actuator and sensor, sending out the interrogating wave and receiving the reflected wave at the same time. Unlike steel structures for which large area can be monitored using the EMI technique [7], in concrete structures, the EMI sensing region is small due to the high damping of the concrete. With an impedance analyzer having interrogation voltage of 2 V, the sensing region is limited to 30–40 cm around the PZT [8,9]. A slightly larger area can be monitored using the surface wave propagation technique with multiple PZTs where the elastic wave is sent by one PZT (actuator) and received by one or more PZTs (sensors). Thus, the surface bonded PZTs based on either the EMI or wave propagation technique are not effective for monitoring a large area of or the entire concrete structure due to their small sensing range. On the other hand, the smart aggregates (embedded PZT transducers) using the wave transmission technique (based on electrical wave transmission) can be employed to monitor very large areas with a reasonably low actuation signal [10,11]. Elastic waves in solid materials are guided by the boundaries of the media in which they propagate and dissipate quickly due to the damping of the material, while electrical wave transmission relies on continuity of transmission medium between the sender and receiver for transmission of sinusoidal wave. Thus, the EMI and wave techniques based on elastic wave propagation are effective for local damage detection and the electrical wave transmission is suitable for assessing the overall condition of a structure. Here, the local damage means a crack in vicinity of a PZT transducer within its sensing range and the overall condition refers to the whole structural element or few connected structural elements.

In this work, a concrete beam with the dimensions of $220 \times 40 \times 20$ cm was cast and nine PZT transducers were embedded or attached on the beam. As the structures may undergo sudden over-loading due to natural disasters or accidental loading during their life time, it is important to evaluate the condition of the structure after

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overloading. Therefore, a cyclic loading scenario was designed in the experiment. The wave propagation and wave transmission results were correlated with the damage on the structure. Combination of smart aggregates (using the wave transmission technique) with surface bonded PZTs (using the wave propagation technique) for SHM was studied. The results show that this combination provides an effective way to assess both the local and overall conditions of the structure.

2. Experimental work

A total of nine PZT transducers with sizes of 20 × 20 × 0.5 mm developed by PI Ceramic Co. [12] were used in this experimental work. Four of them were fabricated as smart aggregates [10] and embedded inside the concrete during casting. Fig. 1 shows the production process for the smart aggregates. The PZTs were coated with a layer of waterproofing agent and were cast in mold with diameter of 50 mm and thickness of 30 mm.

A reinforced concrete (RC) beam with dimensions of 220 × 40 × 20 cm was cast. The water/ cement ratio was 0.5 and concrete mix design was 500 kg/m^3 of ordinary Portland cement, 250 kg/m^3 of water, 700 kg/m^3 of coarse aggregate with maximum aggregate size of 25 mm and 800 kg/m^{3}of sand. The mix design for production of smart aggregates was the same as the beam; however, coarse aggregates were replaced by sand. The measured compressive strength of concrete was 40 MPa. The beam was designed as a single reinforced rectangular section under bending. Two #16 rebars with nominal area of 200 mm^2 were placed in the tension zone, and two #13 rebars were placed in the compression zone. Five strain gauges were attached to the tension rebars. Fig. 2 shows the installation of the strain gauges on the rebar. Fig. 3 shows the installation of the smart aggregates and the whole formwork. After demolding, five surface-bonded PZT transducers were installed on one side surface of the beam. Fig. 4 shows overall experimental setup and Fig. 5 shows the schematic presentation of the beam and the locations of various PZT transducers and strain gauges.

The beam was tested under two point loads. The two loading points were 70 cm apart. As shown in Fig. 5, the surface-bonded PZTs were attached at the center of the beam (PZT 3), aligned to two loading points (PZTs 2 and 4), and near the two ends of the beam (PZTs 1 and 5). The four smart aggregates were installed inside the beam, close to the tension rebars, at 20 cm and 80 cm from the center of the beam. The strain gauges were attached to the tension rebars (bottom of the beam) aligned with the surface-bonded PZTs. Five strain gauges were attached to the tension rebars aligned to the five surface-bonded PZTs. Strain gauge 3 was

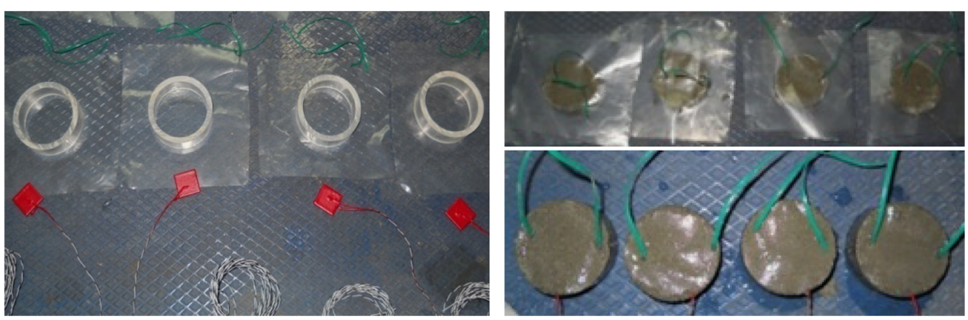

Fig. 1. Water-proof coated PZTs and the molds (Left). Smart aggregates during hydration and after demolding (Right).

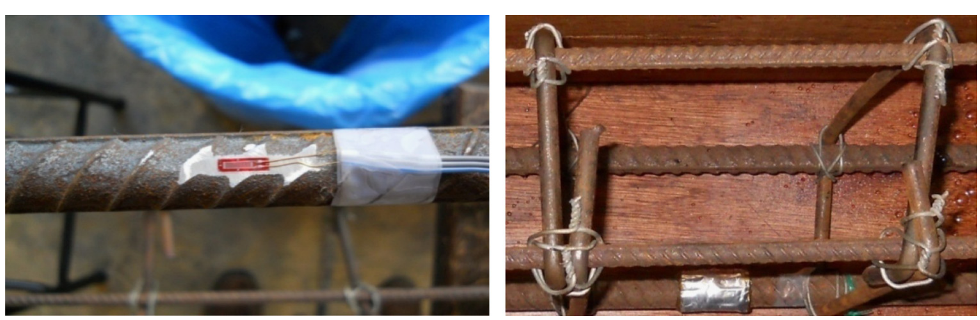

Fig. 2. Installation of strain gauge (Left) and strain gauge protection (Right).

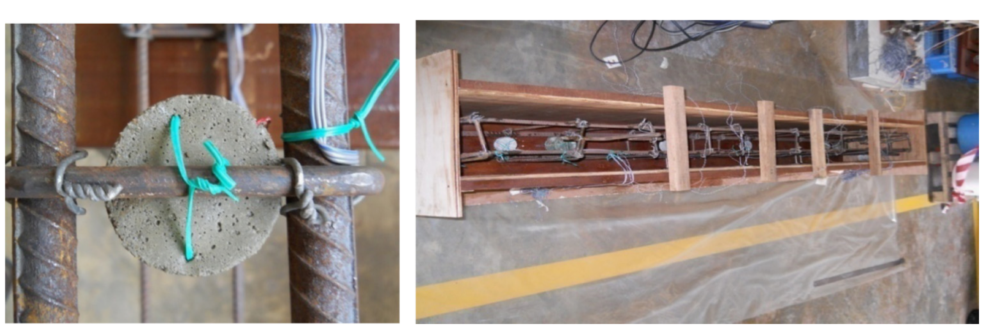

Fig. 3. Installation of smart aggregate (Left) and whole formwork (Right).